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Przyczynek do teorii wzbogacania grawitacyjnego

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Abstrakt

Wyniki modelowania doświadczalnie sprawdzonego probabilistycznego modelu rozkładu gęstości warstw w łożu osadzarki umożliwiają zastosowanie części tego modelu do obliczania wyników wzbogacania nieidealnego z lepszą dokładnością od aktualnie stosowanych metod związanych głównie z wykorzystaniem krzywych rozdziału. W tej pracy przedstawiono teoretyczne uzasadnienie nowej metody proponowanych obliczeń znacznie rozszerzających zastosowanie od lat powszechnie używanych sposobów obliczeń dla wzbogacania idealnego. Stosując krzywe Fuerstenaua do prezentacji wyników obliczeń stwierdzono, że te krzywe nie są α-nieczułe jak się je przedstawia w literaturze.

Słowa kluczowe: *wzbogacanie minerałów, modelowanie procesów wzbogacania, krzywe wzbogacania*

Wprowadzenie

Wszystkie krzywe wzbogacalności i wzbogacania stosowane w teorii wzbogacania idealnego są obrazem bilansu mas poszczególnych frakcji gęstościowych i zawartości składnika użytecznego w tych frakcjach. Rozróżnienie między krzywymi wzbogacalności i krzywymi wzbogacania jest dalej rozumiane jak w pracy (Budryk 1949). We wzbogacaniu idealnym obrazowanym krzywymi wzbogacalności gęstości frakcji nadawy pozostają stałe. We wzbogacaniu rzeczywistym zmianie ulegają także gęstości frakcji wirtualnej nadawy, spowodowane rozproszeniem cząstek nadawy rzeczywistej. Dla tego wzbogacania istotne są więc trzy zmienne: gęstość frakcji wirtualnej nadawy, udział tej frakcji nadawy w masie całej nadawy i udział składnika użytecznego (lub balastu jak w przypadki węgla) w jednostce masy frakcji. Tylko dla wzbogacania idealnego skład gęstościowy i popiołowy nadawy wirtualnej jest identyczny jak nadawy rzeczywistej.

W teorii wzbogacania grawitacyjnego zauważalna jest duża ilość stosowanych różnych teoretycznych krzywych wzbogacalności przy prawie całkowitym braku teoretycznych krzywych wzbogacania i używaniu zamiast nich krzywych rozdziału (Tromp 1937 i Terra 1938) dla obliczeń możliwych wyników wzbogacania rzeczywistego. Takie obliczenia mogą prowadzić do znacznych błędów, co pokazano w pracy (Glowiak 2022). Z dużymi błędami należy się także liczyć przy eksperymentalnych próbach wyznaczenia krzywych wzbogacania (Zapała 1988, Kowol 2010). Zastosowanie wirtualnych nadaw pozwala na obliczeniową ocenę nie wzbogacalności materiału, lecz wyników rzeczywistego wzbogacania przy wybraniu konkretnego rozproszenia jako miary jakości wzbogacania w rzeczywistym procesie.

Opis proponowanej metody.

Przedstawiony w pracy (Głowiak 2020) probabilistyczny model rozkładu gęstości warstw w łożu osadzarki pozwala względnie dokładnie obliczyć skład gęstościowy i zawartość popiołu w każdej warstwie jak powstaje w łożu osadzarki dla znanej charakterystyki nadawy i przyjętych dwu wskaźników określających rozproszenie w rzeczywistym procesie wzbogacania. Podane i udowodnione także w tej pracy twierdzenie o równoważności rzeczywistego wzbogacania i idealnego wzbogacania innej nadawy pozwala na przyjęcie jako udziału danej frakcji w innej nadawie nazwaną nadawą wirtualną udziału masy każdej warstwy w masie nadawy oraz gęstości i zawartości popiołu w powstałych warstwach jako gęstości frakcji i zawartości w nich popiołu dla tej wirtualnej nadawy. Fizycznym uzasadnieniem proponowanej możliwości jest rezultat podziału nieidealnie rozwarstwionej nadawy na dwie części dokonany idealnie i dający dokładnie taki sam wynik jak idealny podział idealnie rozwarstwionej innej nadawy, nazwanej nadawą wirtualną. Jako idealny podział rozwarstwionej nadawy jest rozumiany taki podział, gdy cała wyodrębniona warstwa zostanie skierowana do jednego produktu wzbogacania. Takie zdefiniowanie idealnego podziału jest wynikiem dyskretnego charakteru modelu używanego do obliczeń. Ważną zaletą proponowanej metody jest zachowanie bez żadnych zmian wszystkich znanych w teorii i praktyce sposobów obliczeń i także teoretycznego analizowania zjawisk zachodzących dla wzbogacania nieidealnego. Przeprowadzenie obliczeń w proponowanej metodzie wymaga znajomości zależności jakie zachodzą między parametrami określającymi nadawę rzeczywistą i wirtualną.

Zależności między parametrami nadawy rzeczywistej i wirtualnej

Wymagania te są spełnione przez poniższy opis przekształceń niezbędnych do obliczenia charakterystyki nadawy wirtualnej, której idealne wzbogacenie daje taki sam wynik jak wzbogacenie rzeczywistej nadawy zachodzące przy niezerowym rozproszeniu w procesie wzbogacania.

Opis ten zostanie przedstawiony z zachowaniem oznaczeń przyjętych w pracy (Głowiak2020) prezentującej probabilistyczny model dyskretnego rozkładu gęstości warstw w łożu osadzarki.

Celowe jest zapoznanie się z tą pracą, ponieważ zawiera ona szczegółową interpretację pojęć z rachunku prawdopodobieństwa zastosowanych dla wzbogacania grawitacyjnego,

która w niniejszej pracy nie będzie ponownie przedstawiana. Dla zachowania jasności i spójności wywodu niektóre istotne jej fragmenty zostaną jednak przytoczone.

Charakterystyka rzeczywistej nadawy podana jest w postaci czterech kolumnowych wektorów I , R_c, U, Λ przedstawiającej wyniki empirycznego pomiaru. Wektor I przyporządkowuje numery " i" kolejnym frakcjom gęstościowym nadawy od 1 do n, gdzie n jest liczbą frakcji nadawy uporządkowanych według rosnących gęstości. Wektor R_c zestawia średnie gęstości ρ_{ci} poszczególnych frakcji gęstościowych nadawy, wektor U określa udział masowy u_i i-tej frakcji wyrażony w % całości masy próbki nadawy, a element λ_{ci} wektora Λ podaje średnią zawartość popiołu w i-tej frakcji nadawy.

Wektor kolumnowy S zmiany rozproszenia frakcji gęstościowych nadawy umożliwia prowadzenie obliczeń dla różnych rozproszeń poszczególnych frakcji gęstościowych nadawy pozwalających na uzyskanie krzywych rozdziału o malejącym z gęstością nachyleniu obserwowanych w praktyce wzbogacania węgla kamiennego. Wektor ten obliczany jest z przyjętego średniego rozproszenia w procesie wzbogacania E i przyjętej funkcyjnej zależności tego rozproszenia od gęstości frakcji gęstościowej ρ_{ci} wzbogacanego materiału. Element s_i wektora S jest wartością rozproszenia prawdopodobnego frakcji nadawy o gęstości ρ_{ci}. W obliczeniach użyta jest liniowa zależność rozproszenia si od gęstości frakcji s_i nadawy w postaci si = E + Ep (ρi -ρ_0). W tej zależności E jest rozproszeniem dla frakcji o gęstości ρ_0, iloczyn pE jest zmianą rozproszenia na jednostkę gęstości frakcji nadawy, a ρ_0 jest gęstością tej wybranej frakcji nadawy, której rozproszenie wynosi E. Współczynnik p posiadający wymiar objętości właściwej i zmienny w zakresie 0-1 dla tych obliczeń może być przyjęty jako stały o wartości 0,6 na podstawie pracy (Głowiak 2022a). We wszystkich pokazanych wynikach obliczeń przyjęto wartość ρ_0=2,0 jako przybliżony środek zakresu zmienności frakcji gęstościowych nadawy.

Element ρ_{woj} wektora początkowych gęstości warstw R_{wo} pozwalający iteracyjnie obliczyć gęstości poszczególnych warstw ρ_{wj} jest obliczany z zależności $R_{wo} = R_c^T$, gdzie R_c^T jest transponowanym wektorem R_c, stąd $\rho_{woj} = \rho_{ci}$ dla każdego j = i. Konieczność prowadzenia obliczeń iteracyjnych wynika z zależności obliczanych prawdopodobieństw od różnicy gęstości cząstki i gęstości warstwy, która zmienia się po obliczeniu prawdopodobieństwa z powodu zmiany gęstości tej warstwy.

Gdy gęstości powstałych warstw są transponowanym wektorem gęstości frakcji nadawy zachodzi wzbogacanie doskonałe. W modelu wykorzystywanym w tych rozważaniach start obliczeń iteracyjnych następuje ze stanu idealnego rozwarstwienia.

Jest to rezultat wybrania łatwiejszej obliczeniowo wersji, ponieważ wynik wzbogacania nieidealnego powinien być taki sam dla startu obliczeń ze stanu idealnego wymieszania jak i ze stanu idealnego rozwarstwienia.

Element a_{ij} macierzy A modelu oznacza średnie prawdopodobieństwo trafienia cząstek i-tej frakcji gęstościowej nadawy rzeczywistej o gęstości ρ_{ci} do j-ej warstwy łoża osadzarki o gęstości ρ_{wj}. Dla dużej liczby cząstek jest to średnia masa cząstek o gęstości ρ_{ci} w j-ej warstwie łoża osadzarki o gęstości ρ_{wj}.

Zapis Φ(a,b,c) oznacza funkcję dystrybuanty rozkładu normalnego zmiennej losowej a, której wartość oczekiwana wynosi b i odchylenie standardowe tej zmiennej wynosi c.

Dyskretne wartości funkcji gęstości prawdopodobieństwa określające średnie prawdopodobieństwo trafienia i-tej cząstki do j-tej warstwy wyrażone przez wartości dystrybuanty dla skrajnych gęstości warstwy są następujące:

$$a_{i1} = u_i[\Phi(\rho_{wd} + \Delta_1^+, \rho_{c1}, 1{,}4826 s_i) - \Phi(\rho_d - \Delta_1^-, \rho_{c1}, 1{,}4826 s_i)]$$

dla $\rho_{w1}=\rho_{wd}$ j=1 i=1...n (warstwa najlżejsza) (1)

$$a_{in} = u_i[\Phi(\rho_{wg} + \Delta_n^+, \rho_{cn}, 1{,}4826 s_i) - \Phi(\rho_g - \Delta_n^-, \rho_{cn}, 1{,}4826 s_i)]$$

dla $\rho_{wn}=\rho_{wg}$ j=n i= 1...n (warstwa najcięższa) (2)

$$a_{ij} = u_i[\Phi(\rho_{wj} + \Delta_j^+, \rho_{ci}, 1{,}4826 s_i) - \Phi(\rho_{wj} - \Delta_j^-, \rho_{ci}, 1{,}4826 s_i)]$$

dla $\rho_{wd}<\rho_{wj}<\rho_{wg}$ j=2...n-1 i= 1...n (pozostałe warstwy) (3)

Dla rozkładu normalnego:

$$\Phi(\rho_{wj} + \Delta_j^+, \rho_{ci}, 1{,}4826 s_i) = \frac{1}{\sqrt{2\pi}\,1{,}4826 s_i} \int_{-\infty}^{\rho_{wj}+\Delta_j^+} \exp\left[-\frac{(x-\rho_{ci})^2}{2(1{,}4826 s_i)^2}\right] dx \quad (4)$$

$$\sigma_i = \frac{s_i}{0{,}6745} = 1{,}4825 s_i \quad (5)$$

Powyższe wzory wynikają wprost z definicji dystrybuanty rozkładu zmiennej losowej i są wybraną częścią zależności podanych w pracy (Gowiak 2020).

Ograniczenie na elementy macierzy a_{ij} wynikające z bilansu mas poszczególnych frakcji jest następujące:

$$\sum_{j=1}^{j=n} a_{ij} = u_i = b_i$$

dla każdego i z zakresu 1...n (6)

Dla macierzy A wielkością przyjętą do oceny prawdopodobieństwa jest masa cząstek nadawy.

Pozostałe oznaczenia w powyższych wzorach oznaczają:

$\rho_{wd} = \rho_{w1}$ – gęstość średnią najlżejszej warstwy czyli najlżejszej frakcji nadawy wirtualnej

$\rho_{wg} = \rho_{wn}$ – gęstość średnią najcięższej warstwy czyli najcięższej frakcji nadawy wirtualnej

$\rho_d = \rho_{wd} - 9\sigma$ – gęstość teoretyczne możliwej najlżejszej warstwy rozkładu normalnego o wariancji σ, do której prawdopodobieństwo trafienia jakiejkolwiek cząstki nadawy jest przyjęte jako zerowe.

$\rho_g = \rho_{wg} + 9\sigma$ – gęstość teoretyczne możliwej najcięższej warstwy rozkłdu normalnego o wariancji σ, do której prawdopodobieństwo trafienia jakiejkolwiek cząstki nadawy jest jest przyjęte jako zerowe.

Gęstości ρ_d i ρ_g są koniecznym ograniczeniem dla możliwości rozproszenia się bardzo małych ilości nadawy w nieistniejących warstwach, które to rozproszenie powoduje utratę bilansu masy danej frakcji nadawy.

W każdym kroku obliczeń iteracyjnych zmieniają się masy i średnie gęstości warstw, zatem muszą się także zmieniać graniczne gęstości tych warstw. Dla wykonania obliczenia tych zmian wprowadzony jest wektor przyrostów Δ^- ustalający dolną granicę zakresu gęstości j-tej warstwy. Element Δ^-j pomocniczego wektora wierszowego Δ^- określa zmianę gęstości j-tej warstwy przy przejściu od średniej gęstości tej warstwy do minimalnej granicznej gęstości tej warstwy. Minimalna gęstość j-tej warstwy jest jednocześnie maksymalną gęstością

poprzedniej warstwy j-1. Wartość tego elementu obliczana jest z zależności:

$$\Delta^{-}j = (\rho_j - \rho_{j-1})/2 \quad (7)$$

Analogiczny do wektora Δ^- wektor przyrostów Δ^+ ustala górną granicę zakresu gęstości j-tej warstwy. Wartość tego elementu obliczana jest z zależności:

$$\Delta^{+}_j = (\rho_j + 1 - \rho_j)/2 \quad (8)$$

Obliczenie charakterystyki nadawy wirtualnej wzbogacania idealnego

Charakterystyka nadawy wirtualnej musi być podana także w postaci analogicznych czterech kolumnowych wektorów I^w, U^w, R^{wc}, Λ^w oznaczonych dodatkowym górnym indeksem "w" przedstawiających wyniki obliczeń. Stosowany model podaje dane charakteryzujące warstwy w postaci wektorów wierszowych, więc dla utrzymania konwencji podawania danych nadawy wirtualnej jako wektorów kolumnowych konieczna będzie transponowanie wektorów uzyskanych z obliczeń w modelu.

Stąd $I^w = J^T$ gdzie i jest numerem frakcji nadawy wirtualnej, a j jest numerem warstwy łoża uzyskanym z obliczenia w modelu.

Wektor udziałów frakcji gęstościowych nadawy wirtualnej U^w jest transponowanym wektorem mas warstw Bw obliczonych w modelu. Wektor R^w_c zestawia średnie gęstości ρ^w_{ci} poszczególnych frakcji gęstościowych nadawy wirtualnej równe gęstościom powstałych warstw, wektor U^w określa udział masowy u^w_i frakcji nadawy wirtualnej wyrażony w % całości masy nadawy, a element λ^w_{ci} wektora Λ^w podaje średnią zawartość popiołu w i-tej frakcji nadawy wirtualnej.

Obliczenie udziału frakcji gęstościowej nadawy wirtualnej

Element b_j wektora wierszowego Bw modelu jest sumą elementów a_{ij} w j-tych kolumnach macierzy A. Jest to element rozkładu brzegowego określającego względną zawartości cząstek wzbogacanego materiału w poszczególnych warstwach odniesioną do masy wszystkich cząstek nadawy. Inaczej jest to udział masy cząstek zgromadzonych w jednej warstwie w całości nadawy, a tych rozważaniach oznacza udział u^w_i i-tej frakcji gęstościowej nadawy wirtualnej.

$$b_j = \sum_{i=1}^{i=n} a_{ij} \qquad \text{dla j =1 ..n} \quad (9)$$

Charakterystyki nadawy w przyjętej konwencji są przedstawiane jako wektory kolumnowe więc $U^w = Bw^T$. Zatem $u^w_i = b_j$ dla i=j.

Obliczenie objętości i gęstości frakcji gęstościowych warstw nadawy wirtualnej

Element h_{ij} macierzy H modelu określa objętość zajmowaną w łożu przez cząstki i-tej frakcji gęstościowej nadawy znajdujące się w j-tej warstwie. Ta macierz służy do obliczenia gęstości poszczególnych warstw ρ_j czyli gęstości ρ^w_i poszczególnych frakcji nadawy wirtualnej dla tych rozważań.

Elementy h_{ij} macierzy H są obliczane z zależności:

$$h_{ij} = \frac{a_{ij}}{\rho_i} \quad (10)$$

Suma tych elementów w j-tej warstwie daje objętość h_j wszystkich cząstek różnych gęstości znajdujących się w tej warstwie, Jest to rozkład brzegowy objętości poszczególnych warstw macierzy H.

$$h_j = \sum_{i=1}^{i=n} h_{ij} \qquad \text{dla j =1 ..n} \quad (11)$$

Gęstość ρ_{wj} tej warstwy w k-tym kroku obliczeń iteracyjnych jest ilorazem masy tej warstwy bj i jej objętości hj danej wzorem:

$$\rho_{wj} = \frac{b_j}{h_j} \qquad \text{dla j=1..n}$$

lub wzorem (12)

$$\rho_{wj} = \frac{\sum_{i=1}^{n} a_{ij}}{\sum_{i=1}^{n} h_{ij}} \qquad \text{dla j = 1...n dla bez-}$$

obliczeń z macierzy A i H (13)

Gęstości ρ_{wj} tworzą wierszowy wektor R_w.

Ta gęstość ρ_{wj} w tych rozważaniach jest obliczoną gęstością ρ^w_{ci} i-tej frakcji nadawy wirtualnej. Wektory R^w_c i R_w są związane zależnością:

$$R^w_c = R_w{}^T$$

Obliczenie mas i zawartości popiołu w warstwach łoża

Element pij macierzy P określa masę popiołu zawartą w cząstkach i-tej frakcji gęstościowej znajdującej się w j-tej warstwie. Jest to macierz modelu służąca do obliczenia zawartości popiołu w produktach wzbogacania, gdy dokonany jest podział rozwarstwionego materiału na wysokości j-tej warstwy, wykonany tak, że cała j-ta warstwa zostanie zaliczona do produktu lekkiego (górnego). Obliczenia zawartości popiołu w poszczególnych klasach gęstościowych produktów wzbogacania wykonywane są także na podstawie tej macierzy.

Elementy p_{ij} macierzy P są obliczane z zależności:

$$p_{ij} = a_{ij}\lambda_i \quad (14)$$

Masa popiołu p_j w j-tej warstwie jest określona wzorem:

$$p_j = \sum_{i=1}^{i=n} p_{ij} \qquad \text{dla j =1 ..n} \quad (15)$$

Średnia zawartość popiołu λ_j w j-tej warstwie jest ilorazem masy popiołu w warstwie i masy cząstek tej warstwy i wynosi:

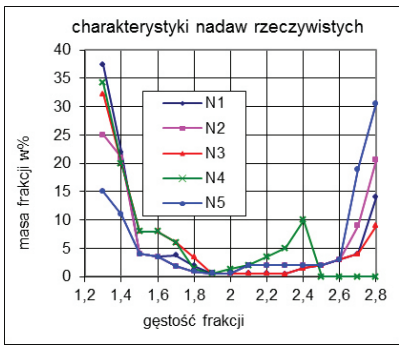
$$\lambda_j = \frac{p_j}{b_j} \qquad \text{dla j=1..n} \quad (16)$$

Zawartości popiołu λ_j w poszczególnych tworzą wierszowy wektor Λ_j, który po transpozycji staje się kolumnowym wektorem Λ^w zawartości popiołu we frakcjach gęstościowych nadawy wirtualnej:

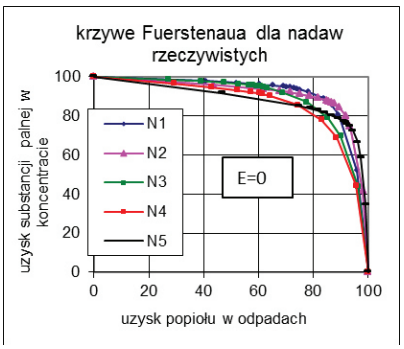
$$\Lambda_j{}^T = \Lambda^w \quad (17)$$

Opis iteracyjnych obliczeń w modelu

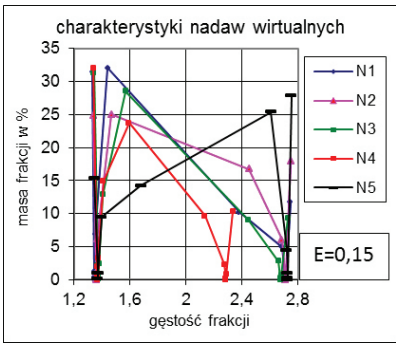
Model rozkładu gęstości warstw w łożu osadzarki wykorzystywany w części do obliczenia charakterystyki nadawy wirtualnej jest dyskretnym modelem iteracyjnym. Szczegółowe uzasadnie-



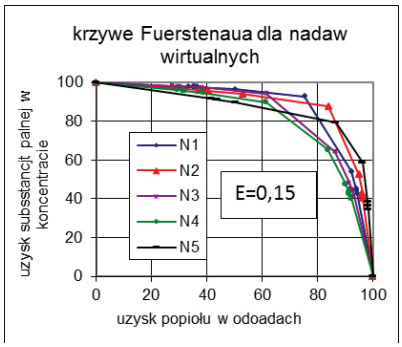
Rys. 1. Charakterystyki nadaw rzeczywistych
Fig. 1. Characteristics of real feeds



Rys. 2. Krzywe Fuerstenaua dla nadaw rzeczywistych
Fig. 2. Fuerstenau's curwes of real feeds



Rys. 3. Charakterystyki nadaw wirtualnych
Fig. 3. Characteristics of virtual real feeds



Rys. 4. Krzywe Fuerstenaua dla nadaw wirtualnych
Fig. 4. Fuerstenau's curwes of virtual feeds

nie dla wybranego sposobu prowadzenia obliczeń iteracyjnych podane jest w opisie wykorzystywanego modelu (Głowiak 2020).

Matematycznym kryterium zakończenia obliczeń jest przyjęcie przez wyrażenie K_{zk} wartości bliskiej zeru lub jego wzrostu w 3 kolejnych krokach, o ile wcześniej nie pojawi się warstwa o ujemnej gęstości.

$$K_{zk} = \sum_{j=1}^{j=n} m_{jk}(\rho_{jk} - \rho_{j(k-1)})^2 \qquad \text{k=1...m k=nr kroku iteracji} \qquad (18)$$

gdzie ρ_{jk} oznacza gęstość j-tej warstwy w k-tym kroku obliczeń iteracyjnych, a m_{jk} jest masą cząstek j-tej warstwy w k-tym kroku.

Przykłady charakterystyk częstości i krzywych Fuerstenaua obliczanych nadaw rzeczywistych i wirtualnych

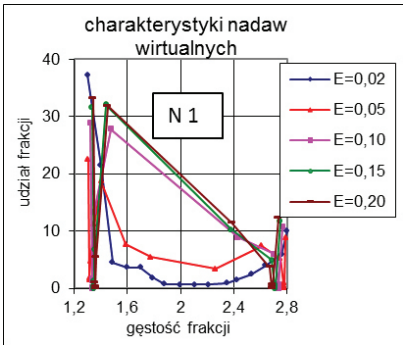
Podane niżej przykłady charakterystyk częstości nadaw wirtualnych są modyfikacją tak nazywanych w pracy (Stępiński 1964) zależności zawartości popiołu we frakcjach nadawy od udziału tej frakcji w całej masie nadawy. Modyfikacja polega na zastąpieniu zawartości popiołu w produkcie gęstością tego produktu i w dalszej części tej pracy jest tak nazywana do określenia zależności udziału frakcji gęstościowej nadawy od jej gęstości. To zastąpienie można także uzasadnić przebiegiem procesu wzbogacania, w którym produkty tego procesu różnicują się fizycznie głównie według gęstości cząstek, a nie według zawartości popiołu w nich. Charakterystyki częstości wybrano specjalnie, ponieważ ta forma pokazania zależności nie zawiera efektu uśredniania wyraźnie widocznego, gdy zmienną niezależną jest wychód skumulowany. Krzywa Fuerstenaua jest zdefiniowana zgodnie z pracą (Drzymała 2009) jako zależność uzysku substancji palnej i lotnej w koncentracie węglowym od uzysku popiołu w odpadach. Zastosowanie tej krzywej do porównania wyników obliczeń dla nadaw wirtualnych wynika z deklarowanej w tej pracy właściwości wyraźnych zmian w jej przebiegu w sytuacji, gdy zmiany te są wynikiem różnych sprawności procesu wzbogacania i małych zmian, gdy wynikają one tylko ze zmian składu densymetrycznego nasawy.

Przedstawiona w tej pracy metoda obliczeń wskazuje, że zmiany rozproszenia w procesie wzbogacania są równoważne zmianom charakterystyki nadawy, co wyraźnie zaprzecza deklarowanej w literaturze własnościom krzywej Fuerstenaua. Podane poniżej wyniki obliczeń pozwolą czytelnikowi na samodzielną ocenę możliwości przedstawianej metody obliczeń jak i zauważonych sprzeczności związanych z ideą istnienia krzywych α-nieczułych. Na rys. 1 przedstawiono charakterystyki częstości pięciu przykładowych nadaw dla wzbogacania węgla kamiennego, a na rys. 2 krzywe Fuerstenaua obliczone dla wzbogacania idealnego, to jest z rozproszeniem E=0 .

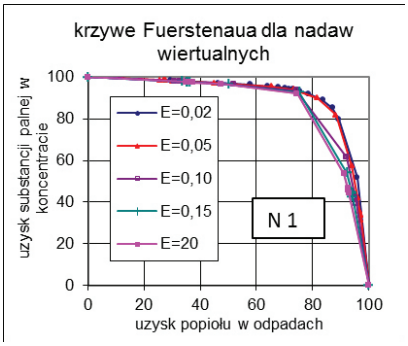
Pokazane na rys. 1 charakterystyki gęstościowe wszystkich porównywanych nadaw rzeczywistych są wyraźnie zróżnicowane pod względem składu densymetrycznego oraz także średniej zawartości popiołu i średniej gęstości.

Rys. 3 i 4 pokazują zmiany jakie zachodzą przy wzbogaceniu tych samych nadaw z rozproszeniem E=0,15.

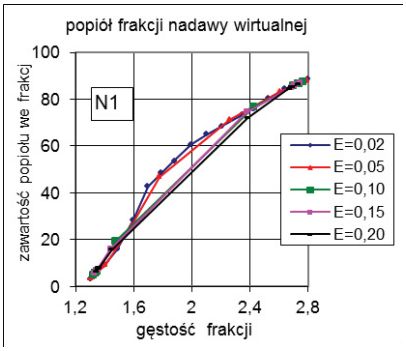
Przedstawione wykresy wyraźnie pokazują, że w obu przypadkach istnieją znaczące różnice między nadawami wirtualnymi (dla wzbogacania idealnego nadawa rzeczywista i wirtualna są tożsame). W tej sytuacji krzywe Fuerstenaua obliczone dla identycznego zróżnicowania nadaw rzeczywistych i przedstawione na rys. 2 i 4 powinny pokazać znaczne pogorszenie jakości wzbogacania dla przypadku jak na rys. 4 w stosunku do przypadku jak na rys. 2. Tymczasem w obydwu przypadkach wyraźnie widoczny jest bardzo podobny



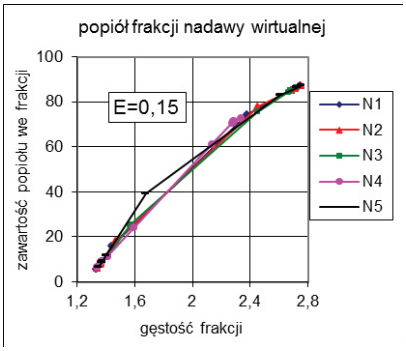
Rys. 5. Charakterystyki nadaw wirtualnych
Fig. 5. Characteristics of virtual real feeds



Rys. 6. Krzywe Fuerstenaua dla nadaw wirtualnych
Fig. 6. Fuerstenau's curwes of virtual feeds



Rys. 7. Popiół frakcji nadawy wirtualnej
Fig. 7. Virtual feed fraction ash



Rys. 8. Popiół frakcji nadawy wirtualnej
Fig. 8. Virtual feed fraction ash

charakter zmian tych krzywych. Ta sytuacja jest istotną przyczyną powstania wątpliwości co do α-nieczułości krzywych Fuerstenaua.

Wszystkie nadawy wirtualne pokazane na rys. 5 mają dokładnie takie same średnie zawartości popiołu i średnią gęstość cząstek tej nadawy, ponieważ są wynikiem różnego wzbogacania jednej nadawy rzeczywistej, więc ich współczynnik α jest taki sam. To pokazuje, że nazwa α-nieczułości nie wyraża dobrze sensu zjawiska jakie opisuje, ponieważ w tej sytuacji wszystkie krzywe Fuerstenaua z rys. 6 powinny być takie same.

Pokazane na rys. 6 krzywe Fuerstenaua zgodnie z ich deklarowaną właściwością pokazują zauważalny spadek jakości wzbogacania. Jednakże zmiany te są zbyt małe aby można było je odróżnić od zmian generowanych przez zmiany charakterystyki nadawy widoczne wyraźnie na rys 2. i 4. Jeżeli na rys. 2 naniesiono by krzywe z rys. 4 i 6. to wskazanie tych krzywych, które obrazują wzbogacane przy niskim rozproszeniu staje się trudne. Zatem w takiej sytuacji znika podstawowa zaleta krzywej α-nieczułej.

Rys. 7 i 8 pokazują zwykle niezauważany fakt, że zmiana rozproszenia także zmienia znacznie zależność między gęstością i zawartością popiołu nadawy wirtualnej, co jest całkowicie oczywiste przy zmianie charakterystyki nadawy.

Pokazane powyżej różnice między krzywymi Fuerstenaua są wynikiem obliczenia, a więc pozbawione są znacznych błędów pomiarowych jakie musza się pojawić przy eksperymentalnej próbie weryfikacji wyników podanych obliczeń. Wątpliwości odnośnie α-nieczułości krzywych Fuerstenaua wynikające z podanych wyżej wykresów powinny znaleźć także inne uzasadnienie wyjaśniające teoretycznie przyczyny zauważonych różnic. To uzasadnienie podane jest poniżej.

Teoretyczne uzasadnienie nieistnienia α-nieczułości krzywych Fuerstenaua

Istotnym powodem przypisywania α-nieczułości krzywym Fuerstenaua jest błędne zdefiniowanie wzbogacania idealnego, powodujące z kolei narzucenie niewłaściwych wymagań na stałość tzw. linii odniesienia (Drzymala 2009).

W tej pracy jako wzbogacanie idealne jest rozumiane wzbogacanie, w którym frakcje gęstościowe nadawy jak i te same frakcje możliwych do wyodrębnienia z produktów wzbogacania mają dokładne taką samą gęstość i sumaryczną masę. Dla wzbogacania w osadzarce oznacza to, że każda powstała warstwa zawiera cząstki tylko jednej frakcji gęstościowej nadawy. Takie rozumienie wzbogacania idealnego ma też uzasadnienie w krzywych wzbogacania pokazujących wszystkie możliwości podziału nadawy na produkty wzbogacania. W pracy (Drzymała 2009) jako wzbogacanie idealne jest rozumiane wzbogacanie tak jak wyżej podano uzupełnione o wymaganie, aby jeden z dwu produktów wzbogacania zawierał tylko minerał, którego uzyskanie jest celem prowadzonego procesu wzbogacania. To dodatkowe wymaganie, moim zdaniem całkowicie niepotrzebnie zawęża rozumienie wzbogacania idealnego wprowadzając dodatkowy warunek ustalający gęstość rozdziału i prowadzący do zmniejszenia liczby możliwych wyników takiego wzbogacania dla różnych nadaw. Jednocześnie dla przypadku wzbogacania węgla kamiennego pojawia się problem ze zdefiniowaniem jako minerału pojęcia "węgiel". Ponadto z rysunków podanych w pracy Drzymały wynika, że stałość tak wybranych linii odniesienia wymaga dodatkowego warunku, aby nadawa idealnego wzbogacania zawierała tylko dwie różne frakcje densymetryczne o zerowej i stuprocentowej zawartości popiołu dla przypadku

wzbogacania węgla. To wymaganie w całkowicie nieuzasadniony sposób ingeruje w skład nadawy dla tak rozumianego wzbogacania idealnego i powoduje, że linie odniesienia są wyznaczane tylko przez trzy punkty, co może być wyraźnym powodem do wyrażenia wątpliwości co do faktycznego istnienia takich linii. Tak przyjęte linie idealnego wzbogacania i idealnego mieszania trudno nazwać liniami, ponieważ każda z nich składa się tylko z dwu punktów, a ponadto jeden z tych dwóch punktów jest wspólny dla obydwu prostopadłych linii. Podobne zdefiniowanie linii odniesienia dla innych wymienionych w pracy Drzymały α-nieczułych krzywych jest istotnym powodem powątpiewania w istnienie α-nieczułości tych krzywych. Na zakończenie trzeba zauważyć, że sama idea istnienia krzywych α-nieczułych jest wewnętrznie niespójna. Ta niespójność wynika wprost z istnienia w każdym wzbogacaniu par nadaw: nadawy rzeczywistej wzbogacanej z rozproszeniem E≠0 i skojarzonej z nią nadawy wirtualnej wzbogacanej z rozproszeniem E=0 czyli idealnie. Te nadawy tworzące pary są zawsze różne z wyjątkiem idealnego wzbogacania nadawy rzeczywistej. Zatem dla każdej istniejącej krzywej wzbogacania wykazującej zmienność w funkcji zachodzących zmian rozproszenia musi istnieć także zmienność wynikająca ze zmian charakterystyki nadawy. Jest tak dlatego, że wszystkie możliwe nadawy wirtualne jednej nadawy rzeczywistej nie są takie same i mają zmienność wynikającą tylko ze zmienności charakterystyki, ponieważ rozproszenie dla ich wzbogacania jest jednakowe i zerowe.

Zależność wyników wzbogacania grawitacyjnego od jakości nadawy i sprawności wzbogacania jest powszechnie znana i akceptowana. Poszukiwanie takiej szczególnej formy podania graficznej zależności funkcji dwu zmiennych, aby wpływ jednej zmiennej był mało widoczny w mojej ocenie nie wnosi żadnej poznawczej wartości do zrozumienia zjawisk jakie ta funkcja opisuje i a-nieczułe krzywe wzbogacania są właśnie taką formą.

Wnioski

Przedstawiona metoda umożliwia obliczanie wyników wzbogacanie nieidealnego przy użyciu znanych metod stosowanych do obliczeń wzbogacania idealnego poprzez prostą zmianę charakterystyk nadawy.

Wyniki powyższych rozważań pozwalają na kwestionowanie α-nieczułości krzywych Fuerstenaua, a także innych krzywych α-nieczułych, do chwili przedstawienia dowodów na posiadanie przez nie rzeczywistej nieczułości na zamiany składu densymetrycznego i zawartości składnika użytecznego wzbogacanego materiału.

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Contribution to the Theory of Gravitational Enrichment

The results of modeling the experimentally proven probabilistic model of layer density distribution in the jig bed enable the use of part of this model to calculate the results enriched by the non-ideal with better accuracy than the currently used methods related mainly to the use of separation curves. This paper presents the theoretical justification of the new method of the proposed calculations, significantly extending the application of the commonly used calculations for ideal enrichment for many years. Using the Fuerstenau curves to present the results of the calculations made, it was found that these curves are not α-insensitive as they are presented in the literature.

Keywords: *mineral enrichment, modeling of enrichment processes, upgrading curves*

A Method of Optimal Design for the Base Network in Structural Deformation Monitoring at Song Hinh Hydroelectricity, Vietnam

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Abstract

The article mentions a method of optimal design for the base network in horizontal displacement monitoring at hydroelectric works, based on the average residual level of the measured values. When the target function is the weakest positional error, the obtained result after optimizing is the unique plan that no depends on the designers and their experience. Thus, this is helpful for the production units because they no need to have experts in designing the network. Experiment for the base network of deformation monitoring at Song Hinh hydroelectricity shows that 44%, 50% and 60% of the initial measurement can be reduced when the average residual level is chosen 0.5, 0.4 and 0.3, respectively. The weakest position error of the network after optimizing is 2.4 mm, 2.5 mm and 2.6 mm, respectively, all are smaller than requirement ±3.6mm. This method is mainly applied for the side-angle network that was measured by total station, without considering the optimal design network in the priority direction.

Keywords: *plane control network, optimal design, residual level, engineering surveying, positional error*

1. Introduce

The plane control network for serving construction, the base network in deformation monitoring for irrigation-hydroelectricity, underground works are always established at the area with difficult measuring condition. With the high accuracy requirement, this kind of network is designed as the dense triangle network so it is necessary to measure a lot of values. It takes much time and effort to measure so that the built network gains the requirement accuracy. Therefore, when the target function is chosen to be the weakest position error, optimal design for this kind of network is the efficiency solution because cutting down the measured values no affects the accuracy, additionally, brings economic efficiency to enterprises.

So far, problem of optimal design in geodesy has continuously been studied and further applied for satellite measurement networks (Alizadeh-Khameneh et al, 2016; Alizadeh-Khameneh, 2017). In the field of engineering surveying in Vietnam, the base network in horizontal displacement monitoring of hydropower works is measured periodic iteration, it is mainly an angle – side measuring triangle network that is established by high-precision electronic total station. The optimal design of the plane control based on the reliability of the network is called the type 1 design (Grafarend, E.W., 1974). The residual measuring level is an indicator of the reliability of the control network, the more the residual measurement values in the network are, the higher the efficiency of optimal design is and vice versa. This type of optimal design has been widely applied in China (Chen Yongqi et al, 1996; Li Deren, 2012; Zhang Zhenglu et al, 2008; Zhang Zhenglu, 2001). The optimal design according to the residual level of the measured values was researched in (Nguyen Quang Phuc, Hoang Thi Minh Huong, 2016, Zhang Zhenglu et al, 2008). Some recent studies on optimal design can be mentioned such as: optimizing deformation monitoring network according to basic edge correlations (Alizadeh-Khameneh, M.A., Sjöberg, L.E. & Jensen A.B.O., 2016), optimal design for the deformation monitoring network (Kutoglu, H.S. & Berber, M., 2015; Yetkin, M. & Inal, C., 2015); the basic concept on optimal design of the geodetic network (Amiri-Simkooei, A., Asgari, J., Zangeneh-Nejad, F. & Zaminpardaz, S., 2012), Optimal design according to cost, reliability and accuracy (M. Eshagh and R. Kiamehr, 2007). Optimization of deformation monitoring networks using finite element strain analysis (M. Amin Alizadeh-Khameneh, Mehdi Eshagh and Anna B.O. Jensen, 2018). The optimal design of the network according to two epoch (A Amiri Simkooei và nnk, 2012), Optimal design by the simulation method (Wojciech Pachelski, Paweł Postek, 2016), Optimisation of Lilla Edet Landslide GPS Monitoring Network (M.A. Alizadeh-Khameneh, M. Eshagh and L.E. Sjöberg, 2015). Almost studies optimized the network according to the basic problem and own proposal direction, no researches have mentioned the average residual level in the optimal design for the base network of structural horizontal displacement monitoring. Using the average residual measuring level as the indicator of reliability and the target function chosen to be position error not only determines the number of the measured values that can be omitted, but also ensures to gain requirement accuracy. Moreover, the design plan for each average residual measuring level is the unique for one network and the network is designed without depending on the experience of the designer. Therefore, this is the new approach that is different from the previous method.

2. The theoretical basis on optimal design

The problem about optimal design of a geodetic network that Grafarend, E.W. (Grafarend, E.W., 1974) proposed is shown in the general form as follows.:

$$\begin{cases} \min\limits_{X\in E^n} f(X) \\ g_i(X) \geq 0, i = 1,2,...m \\ h_j(X) = 0, j = 1,2,...,l \end{cases} \quad (1)$$

where, the first expression in formula (1) is called the target function, the second and third expressions are called the binding conditions. The nature of the optimal problem is to find the maximum or minimum value of the target function based on the binding conditionals to determine the optimal solution.

2.1. The redundant observations in the geodetic control network

Geodetic networks (such as survey network, construction network, deformation monitoring network) are only adjusted by the method of least squares when the network has redundant measured values. The redundant values in the geodetic network (indirect network or free network) are calculated as following (Tao Benzao, 2001):

- With the dependent network or the free network that has enough original data, then:

$$r=n-t \quad (2)$$

- With the free network

$$r=n-k+d \quad (3)$$

Where, n is total of the measured values in the network; t and k are the necessary values and the number of missing positioning components, d is missing number.

The average redundant measuring level is calculated according to the formula:

$$\bar{r} = \frac{r}{n} \quad (4)$$

2.2. The redundant measuring level of each observation

Assuming that the vector of measured values is L, vector of corrections is V, vector of parameters is X, approximation value is X_0, the adjusted value is $\hat{X}$, the weight matrix is P, then the error equation is determined as (Zhang Zhenglu, 2001):

$$V=A\hat{X}-L \quad (5)$$

In the generality adjustment problem, the adjusted values are calculated

$$\hat{X}=N^{+}A^{T}PL=Q_{XX}A^{T}PL \quad (6)$$

Where, N^{+} is the generality inverse matrix of the system of error equation; Q_{XX} is the covariance matrix of parameters.

With $N=A^{T}PA$. Replace in formula (5) the correction matrix is obtained:

$$V=(AQ_{XX}A^{T}P-E)L \quad (7)$$

Where E is the unit matrix.

According to the error propagation law, the covariance matrix of correction values is calculated as:

$$Q_W=P^{-1}-AQ_{XX}A^{T} \quad (8)$$

From that, gaining:

$$V=-Q_{VV}PL=-RL \quad (9)$$

with

$$R=Q_{VV}P \quad (10)$$

Matrix R is called the reliability matrix of the control network

Set:

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \quad (11)$$

In this matrix, the i[th] element on the diagonal of the matrix R is called the redundant level of the i[th] measured value, set:

$$r_i = r_{ii} \text{ và } r=\sum_{i=1}^{n} r_i \quad (12)$$

Where, r is the number of redundant observation in the network. When the weight matrix is the diagonal matrix (no correlation among the observations), then $0\leq r_i\leq 1$. The observations that have $r_i=0$ are the mandatory ones, The observations with $r_i=1$ are the redundant ones which no affect accuracy of the network even though these are no measured.

2.3. The feature of the redundant level of the observations

The internal reliability r_i of the observation l_i has the following features (Li Deren, 2012; Zhang Zhenglu et al, 2008):

(1) $0\leq r_i\leq 1$: the smaller r_i is the higher the importance of the observations. If $r_i=0$ the observation is unable to be omitted. The bigger r_i is, the lower the importance of the observations, if $r_i=1$ this observation has to be measured.

(2) In a network design plan, it is necessary to pay attention: In a certain grid design scheme include: graph, the number of observations, accuracy, sensitivity, the higher the precision of the observation is, the smaller the redundant measuring level r_i is; on the contrary, the lower the precision of the observation is, the bigger the redundant measuring level r_i is. Thus, the redundant level of the observations (the internal reliability) is contrary to its precision.

(3) In case of the measuring accuracy has been determined, in the network the more the measured values are, the bigger the redundant level of the observations.

(4) With the independent network, the redundant level of the observation no relates to the position of the benchmarks.

2.4. Relationship between the number of observations in the plane control network and the average redundant level of the observations

The number of observations are able to be determined through the average redundant level, from formula (4), shorten as follows

$$n = \frac{t}{1-\bar{r}} \quad (13)$$

In optimal design, depending on type of network, so that the observations have good effect, the average redundant level

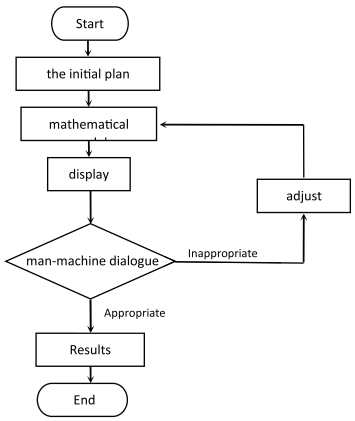

Fig. 1a. The optimal design with help of computers

Rys. 1a. Optymalizacja projektu ze wspomaganiem komputerowym

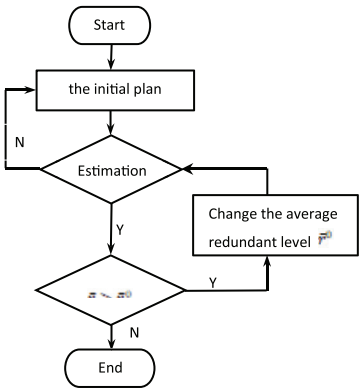

Fig. 1b. The optimal design according to the average redundant level of the measured values with the target function chosen to be the weakest position error in the network

Rys. 1b. Optymalizacja projektów odniesieniu do średniego poziomu redundancji mierzonych wartości z funkcją celu opartą o najmniejszy błąd pozycji w sieci pomiarowej

$\bar{r}$ is in the range of [0.3, 0.5] (Zhang Zhenglu, 2008). Symbolizing the average redundant level that belongs to the reliability range of [0.3, 0.5] as $\bar{r}^0$, the number of observations n^0 that is respective to the average redundant level is calculated as:

$$n^0 = \frac{t}{1-\bar{r}^0} \tag{14}$$

3. Solving the problem of optimal design of the geodetic control network

3.1. Solving the optimum problems with the help of computers

At present, the optimal design of the ground control network or the deformation monitoring network is mainly done with the help of computers, in fact, this is taking advantage of the calculation and judgment capabilities of computer in combination with the designer's practical experience. Computer helps to display design results at any time. Through man-machine dialogue, instantly adjusting the design plan (a. Add or remove some measurement values; b. Change the weight of the measurement values; c. Add or remove some control points in the network; d. Change the position of some points in the network; e. Change the original model of the network) until the designer satisfies with the proposed plan. Obviously, the end result of this design method is usually not a strictly optimal solution, but close to optimum. Moreover, the method has a simple mathematical model, convenient and flexible operation, the plan shows the reasonableness and feasibility of the design results. This design plan is implemented according to the process in Figure 1a.

3.2. Solving the optimum problems according to the average redundant level of the observations

Based on the theoretical research, the article proposes a process of the optimal design of the plane control network according to the average redundant level of the measured values, with the target function chosen to be the error of the weakest position in the network. The process is shown in Figure 1b and includes steps as follows:

1: The initial plan is that position of points and the network diagram must be designed on topographic maps and checked in the field. This plan should include all measurable values of the network.

2: Estimate the network according to the original design plan, with the limit error of the weakest position, and the accuracy of machines as required by the designer.

3: Comparison of the results (error of the weakest position with the input limit error), if the plan no gains requirement, it is necessary to redesign.

4: When the network has enough conditions for optimization, the average redundant level is chosen smaller, calculation for reducing the number of observations and the network is re-estimated whether it achieves the initial requirements.

Fig. 2. Hinh river hydroelectricity plants (https://triphunter.vn/places/phu-yen/items/ho-thuy-dien-song-hinh)
Rys. 2. Elektrownia wodna na rzece Hinh

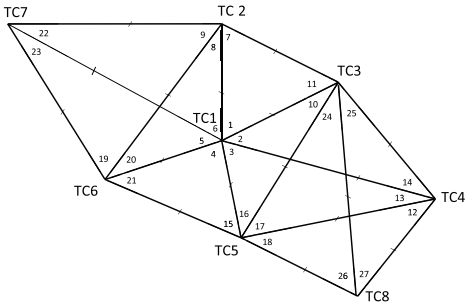

Fig. 3. The base network in horizontal displacement monitoring at Hinh river hydroelectricity
Rys. 3. Bazowa sieć kontrolno-pomiarowa dla badania przemieszczeń poziomych dla elektrowni

5: If the obtained accuracy of the network is better than the input requirement, then the average redundant level is adjusted much smaller and the network is re-estimated until gaining the requirements before stopping.

Comparing the optimal design method with the help of computers and the proposed method in the article, some comments are given as follows:

- The optimal design plan with the help of computers has generality characteristic, which can change many components of design plan. However, if the most optimal plan is chosen, this may be inappropriate to reality. Another disadvantage is without experience expert no gaining good results after optimum.
- The optimal design method according to the average redundant level of the observations with the target function chosen to be the error of the weakest position has narrower applicability. This method is done based on the network determined before on maps and fields. The average redundant level of the observations is chosen in the allowance range as [0.3, 0.5] to calculate the number of unnecessary observations that need to be omitted but still gaining the requirement accuracy. Moreover, this method no needs calculation experts but the final results are similar to the ones achieved from optimal design by computers

4. Experiment and discussion

4.1. Experimental area

The experiment of optimal design for the base network of the horizontal displacement monitoring was done at the Hinh river hydroelectric dam in Phu Yen province of Vietnam. This is a hydroelectric project with the earth-rock dam lied on the Hinh river in Ea Trol commune, Hinh river district. The hydroelectric dam is about 35 kilometres from Tuy Hoa city in the southwest. Hinh river hydroelectricity has a capacity of 70 MW including 2 units, annual electricity output of 370 million KWh, started in 1993 and completed in 2001. The normal rise water level in the reservoir is 209 m, dead water level is 196 m, total reservoir capacity is 357 million m^3. The elevation of the dam crest is 215 m, the highest flood discharge capacity is 6,952 m^3/s.

The plane base network is considered as the origin to monitor the horizontal displacement of the Hinh river hydroelectric dam. Figure 2 is the image of hydroelectric plant and dam, figure 3 is the diagram of the base control network for horizontal displacement monitoring at Hinh river hydroelectricity.

4.2. Data for research

The base network in horizontal displacement monitoring at Hinh river hydroelectricity includes 8 points, that are symboled from TC1 to TC8 (two points TC1 and TC7 were defined coordinates). According to Vietnam's regulations on the network of horizontal displacement monitoring of hydroelectric projects, the Hinh river hydroelectric dam is an earth-rock dam, so the accuracy of the monitoring point is ±5 mm (TCVN 9399-2012). The network of horizontal displacement monitoring usually consists of 2 levels, namely the base network and the monitoring network. Assuming the accuracy of the 2 network levels are respectively m_I and m_{II} the influence of the monitoring network system on the accuracy of the point P is determined as follows:

$$m_P^2 = m_I^2 + m_{II}^2 \tag{15}$$

K is called the accuracy declining coefficient between two network level, then

Tab. 1. The designed angles in the base network of the horizontal displacement monitoring at Hinh river hydroelectricity

Tab. 1. Projektowane do pomiaru kąty w sieci kontrolno-pomiarowej badania przemieszczeń poziomych dla hydroelektrowni na rzece Hinh

No	Angles			No	Angles			No	Angles		
	left	middle	right		left	middle	right		left	middle	right
1	TC2	TC1	TC3	10	TC5	TC3	TC1	19	TC7	TC6	TC2
2	TC3	TC1	TC4	11	TC1	TC3	TC2	20	TC2	TC6	TC1
3	TC4	TC1	TC5	12	TC8	TC4	TC5	21	TC1	TC6	TC5
4	TC5	TC1	TC6	13	TC5	TC4	TC1	22	TC2	TC7	TC1
5	TC6	TC1	TC7	14	TC1	TC4	TC3	23	TC1	TC7	TC6
6	TC7	TC1	TC2	15	TC6	TC5	TC1	24	TC4	TC3	TC8
7	TC3	TC2	TC1	16	TC1	TC5	TC3	25	TC8	TC3	TC5
8	TC1	TC2	TC6	17	TC3	TC5	TC4	26	TC5	TC8	TC3
9	TC6	TC2	TC7	18	TC4	TC5	TC8	27	TC3	TC8	TC4

Tab. 2. The designed sides in the base network of the horizontal displacement monitoring at Hinh river hydroelectricity

Tab. 2. Projektowane do pomiaru odległości w sieci kontrolno-pomiarowej badania przemieszczeń poziomych dla hydroelektrowni na rzece Hinh

No	Side		No	Side		No	Side	
	the first point	the end point		the first point	the end point		the first point	the end point
1	TC1	TC2	7	TC2	TC7	13	TC2	TC6
2	TC1	TC3	8	TC5	TC4	14	TC3	TC4
3	TC1	TC4	9	TC5	TC6	15	TC3	TC5
4	TC1	TC5	10	TC8	TC4	16	TC3	TC8
5	TC1	TC6	11	TC8	TC5			
6	TC2	TC3	12	TC6	TC7			

Tab. 3. The approximate coordinates of points

Tab. 3. Aproksymowane współrzędne punktów sieci kontrolno-pomiarowej

No	Name	Coordinate X (m)	Coordinate Y (m)	No	Name	Coordinate X (m)	Coordinate Y (m)
1	TC1	1429644.5460	277440.1230	5	TC5	1428937.2038	277222.4129
2	TC2	1430267.8209	277344.1670	6	TC6	1429502.2342	276873.8156
3	TC3	1430047.6716	277817.5782	7	TC7	1430561.2500	276420.7270
4	TC4	1429299.9189	277995.9955	8	TC8	1428889.8779	277877.6087

$$m_I = \frac{m_2}{K} \tag{16}$$

Formula (15) can be shown as

$$m_P^2 = \frac{m_{II}^2}{K} + m_{II}^2 \tag{17}$$

Calculated

$$m_{II} = \frac{m_P K}{\sqrt{1+K^2}} \text{ and } m_I = \frac{m_P}{\sqrt{1+K^2}} \tag{18}$$

Accuracy declining coefficient is usually chosen K=1-2, choosing K needs to comply the characteristic of network and accuracy of the observed equipment. In this example, formulas from (15) to (18) are used and K is chosen to be 2, calculating m_I= ±2.3 mm, m_{II}= ±4.5 mm. According to (TCVN 9399-2012), with the earth-rock dams, K should be chosen to be K=1, then m_I=m_{II}= ±3.6 mm. Because the network has high accuracy requirement, the initial intention of using equipment is electronic total station TC1700. According to specifications of machine, mean square error of angle measurement is 1.0", mean square error of side measurement is 1+1*ppm*. The initial plan includes total 43 observations, with 27 angle measured values, 16 side measured values, which are shown in Table 1 and Table 2.

4.3. Optimal design for networks

The base network in horizontal displacement monitoring for hydroelectric dam is the free network. With this characteristic, the network uses the average center point to be the coordinate origin, so it is hardly affected by error of the original data. Based on coordinates of TC1 and TC7, the approximate coordinates of other points in the network are calculated as Table 3.

Optimum for network according to the average redundant level of the measured values with the target function chosen to be the weakest position error is done the following steps:

a) Estimating the accuracy of the network by the algorithm of free adjustment with all measured values, the estimated results are shown in Table 4.

According to the estimated results, the point that has the weakest position error TC7, m_p=2.0(mm). From formula (3), the average redundant level of the measured value is calculated as 0.7, so the network is entirely optimal because the average redundant level is bigger than the range [0.3,0.5]

b) To determine the number of the omitted measuring values at each the redundant level in the range [0.3,0.5], as well as investigate the error of the weakest position, the network is designed in three plans that have the average redundant level, respectively $\bar{r}$=0.5; $\bar{r}$=0.4 và $\bar{r}$=0.3. The redundant levels of the measured values are shown in Table 5 and performed in figure 5.

The Figure 5 shows that the redundant level of almost the angle measuring values (from number 1 to number 27) is bigger than the redundant level of the side measuring values (from number 28 to number 43). So after optimum, the omitted measuring values are mainly angle values.

Tab. 4. Result of estimation for the initial design network

Tab. 4. Wyniki estymacji wstępnej dla projektowanej sieci kontrolno-pomiarowej

No	Name	X(m)	Y(m)	m_X(mm)	m_Y(mm)	m_P(mm)
1	TC1	1429644.546	277440.123	0.7	0.8	1.1
2	TC2	1430267.820	277344.168	1.0	0.8	1.3
3	TC3	1430047.671	277817.577	0.8	1.0	1.3
4	TC4	1429299.920	277995.994	0.8	0.9	1.2
5	TC5	1428937.206	277222.414	1.0	0.8	1.3
6	TC6	1429502.235	276873.817	0.9	1.1	1.4
7	TC7	1430561.250	276420.727	1.4	1.4	2.0
8	TC8	1428889.881	277877.607	1.0	1.1	1.4

Tab. 5. The redundant level of each measured value in the network

Tab. 5. Poziom redundancji dla kazdej mierzonej wartości w sieci kontrolno-pomiarowej

No	1	2	3	4	5	6	7	8	9	10	11	12
r	0.80	0.83	0.94	0.67	0.81	0.82	0.76	0.85	0.78	0.61	0.71	0.67
No	13	14	15	16	17	18	19	20	21	22	23	24
r	0.74	0.91	0.98	0.96	0.92	0.86	0.85	0.88	0.81	0.94	0.96	0.91
No	25	26	27	28	29	30	31	32	33	34	35	36
r	0.94	0.77	0.70	0.59	0.56	0.50	0.62	0.44	0.40	0.62	0.56	0.47
No	37	38	39	40	41	42	43					
r	0.36	0.40	0.65	0.54	0.59	0.71	0.63					

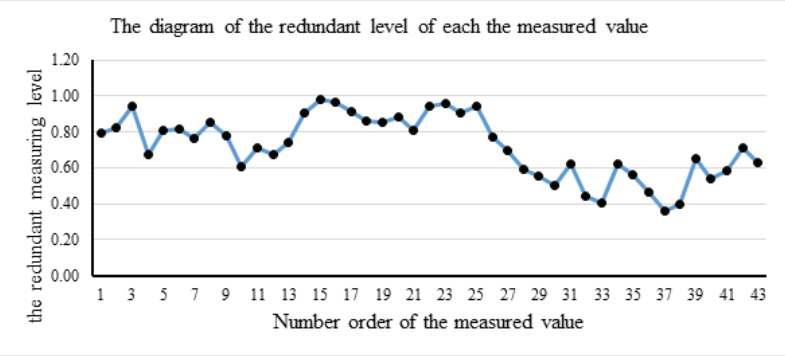

Fig. 5. The diagram of the redundant level of each the measured value

Rys. 5.Wykres poziomu redundancji dla każdej mierzonej wartości

c) The network optimum results with the binding condition as the weakest position error in three mentioned design plans are shown in the table 6.

The Table 6 shows that:

- The omitted measured values are usually the angle measuring values because these have large redundant level.
- Results of estimation in three plans with r̄=0.5, 0.4 and 0.3 are good, error of the weakest position is smaller than the initial target ±3.6 mm.
- All three plans can be used to measure in the field, but in our opinion, the second plan with r̄=0.4 should be chosen so that the network has good connection and no deviation in azimuth. In addition, the measured values in the field is also affected by many different sources of error, so the structure of network has to be tight.
- With this design plan, the initial network is omitted 23 the angle measuring values, the reality network only needs to observe 20 the measured values including 4 the angle measuring values (table 7), 16 the side measuring values as the initial design, the efficiency of the measuring volume reaches 53%. The shape of network after optimum is shown as Figure 6.

5. Discussion

Results of the experiment of the optimal design according to the average redundant measuring level with the target function chosen to be the weakest position error show that:

- The measuring values that are cut have the redundant level from high to low;
- When using this optimal design method, it is possible to calculate quickly the number of the omitted measuring values, the necessary values that are respective to the average redundant measuring level as formula (14);
- The number of the measured values before and after optimum that are respective to each the average redundant measuring level are different, the number of the omitted values at average is approximate 50% but the accuracy requirement of the weakest position is still ensured the same as the initial requirement.

6. Conclusion

- The base network in structural horizontal displacement monitoring should be optimized because this

Tab. 6. Table of comparing the number of the measured values and design efficiency before and after optimum

Tab. 6. Zestawienie porównywanej liczby wartości pomiarowych i projektowych współczynników efektywności przed i po optymalizacji

Plan	The average redundant measuring level	The number of angles	The number of sides	Total value	Mean square error of the weakest position TC7(mm)	The omitted measured values	Efficiency
initials $\bar{r}$	0.70	27	16	43	2.0		
optimum $\bar{r}^0$	0.5	8	16	24	2.4	19	44%
	0.4	4	16	20	2.5	23	53%
	0.3	2	15	17	2.6	26	60%

Tab. 7. The angular values after optimum with redundant measuring level

Tab. 7. Wartości kątów po optymalizacji z poziomem redundacji

No	Angle			redundant measuring level	No	Angle			redundant measuring level
	left point	middle point	right point			left point	middle point	right point	
4	TC5	TC1	TC6	0.673	12	TC8	TC4	TC5	0.674
10	TC5	TC3	TC1	0.610	27	TC3	TC8	TC4	0.697

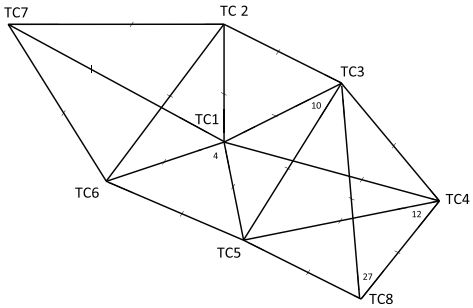

Fig. 6. The base network in horizontal displacement monitoring at Hinh river hydroelectricity after optimum with

Rys. 6 . Bazowa sieć kontrolno-pomiarowa do badania przemieszczeń poziomychdla elektrowni na rzece Hinh po optymalizacji na poziomie

kind of network is measured iteratively, has high accuracy requirement but usually uses the angle-side network.

- The average redundant measuring level is the important indicators in optimal design for network, the number of the measured values after optimizing are determined based on this indicator.
- Optimal design according to the average redundant level with the target function chosen to be the weakest position error achieves high efficiency, it is suitable for the network with a lot of the measured value and the angle-side network.
- This method only need to determine the average value from redundant measuring level of the measured values. The optimal result no depends on knowledge, experience of designer but still ensure tightness and consistence.
- This optimum method has no consider the priority direction in the design yet.

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Metoda optymalnego projektowania sieci bazowej w monitoringu deformacji konstrukcji w elektrowni wodnej Song Hinh, Wietnam

W artykule przedstawiono metodę optymalnego projektowania sieci bazowej w monitoringu przemieszczeń poziomych elektrowni wodnych na podstawie średniego poziomu rezydualnego zmierzonych wartości. Gdy funkcją docelową jest najsłabszy błąd pozycjonowania, uzyskany wynik po optymalizacji jest unikalnym planem, który nie zależy od projektantów i ich doświadczenia. Jest to więc pomocne dla jednostek produkcyjnych, ponieważ nie potrzebują one ekspertów do projektowania sieci. Eksperyment dla podstawowej sieci monitorowania deformacji w elektrowni wodnej Song Hinh pokazuje, że 44%, 50% i 60% początkowego pomiaru można zmniejszyć, gdy średni poziom pozostałości zostanie wybrany odpowiednio 0,5, 0,4 i 0,3. Najsłabszy błąd pozycji sieci po optymalizacji wynosi odpowiednio 2,4 mm, 2,5 mm i 2,6 mm, wszystkie są mniejsze niż wymagane ±3,6 mm. Metodę tę stosuje się głównie dla sieci kątów bocznych, które zostały zmierzone przez tachimetr, bez uwzględnienia optymalnej sieci projektowej w kierunku pierwszeństwa.

Słowa kluczowe: *pozioma sieć kontrolna, optymalizacja projektu, poziom residuum, pomiary inżynierskie, błąd pozycji*

Digital Transformation in Mining Sector in Vietnam

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Abstract

Digital transformation is one of the inevitable trends in today's world. Vietnam is one of the pioneer countries following this trend and has launched a national digital transformation program. Digital transformation has attracted great interest from both the community of scientists and managers in general and in the field of coal mining and other minerals. Currently, researchers have been focusing on issues, such as the theory of digital transformation in both state and the business sector, the relationships between digital transformation and the building of e-government or digital government, and between digital transformation and effective national administration. In this study, the method of document-based analysis (Desk review) was used to analyze and evaluate the current situation of digital transformation of the coal and mineral mining industry and identify achievements as well as limitations of the digital transformation process in the coal and mineral mining industry in Vietnam.

The study presents the following issues: (1) Some general issues about digital transformation, in which the concept of digital transformation is clarified; Meaning of digital transformation in the field of coal and mineral mining; Requirements for digital transformation in the field of coal-mineral mining. (2) The current status of digital transformation in coal-mineral mining in Vietnam, including applying advanced technologies in exploration and mining, and application of advanced technologies in mining and environmental protection.

Keywords: *digital transformation, coal-mineral industry, mechanization*

1. Introduction

1.1. Concepts of digital transformation

Digital transformation is a component of the fourth technology revolution. From the literature review, "Digital Transformation" is often seen as the process of changing from a traditional business model to a digital one by applying new technologies such as big data, the Internet of things (Internet of Things - IoT), cloud computing (Cloud) to change the way of operating, leadership, work process, and company culture.

In Vietnam, digital transformation is the integration of digital technology into the operations of businesses and organizations to change their ways of operation, and business models, and to provide value to customers. In other words, it is a change in operating methods, procedures, and culture, and based on digital platforms to achieve more effective goals(M.H.Nguyen, 2020).

Digital transformation enhances adaptability and focuses more on data collection, processing, analysis, and useful information to all levels of decision-making. This helps businesses become smart, creative, and quickly and effectively adapt to changes.

Vietnam is one of the few countries in the world that has a strategy and plan for digital transformation. On June 3, 2020, with the issuance of Decision 749/QD-TTg on approving the "National digital transformation program to 2025, with orientation to 2030", the Government of Vietnam confirmed that digital transformation is an inevitable process of the country in order to accelerate the modernization of the distribution system, to improve the competitiveness of enterprises, and promote the development of domestic and export markets. The government has made Vietnam's vision for the year 2030, in which Vietnam will become a digital, stable, and prosperous country. The country will pioneer employing new technologies and models and changing the government's operations fundamentally and comprehensively in management and administration, production, and business activities. In addition, this will make changes in people's lifestyles and work, and allow the development of a safe, humane, and widespread digital environment. The national digital transformation program comprises dual goals of developing a digital government, digital economy, and digital society and forming Vietnamese digital technology enterprises with global competitiveness (Government of Vietnam, 2020)).

Digital transformation in the field of coal and mineral mining is the integration and application of advanced digital technology platforms in all fields of mining, such as management, planning, exploration, transportation, processing and mineral enrichment, cooperation, calling for investment, sales, customer care,... Also, advanced technologies are applied in all stages of production and business chains of mining companies, in order to optimize operations, reduce costs, increase profits, distribute value chains, increase competitiveness, assure safety at work, and contribute to environmental protection and sustainable exploitation of mineral resources.

The focusing areas of digital transformation in enterprises are proposed as a model with the aim of clarifying the levels of digital transformation in enterprises, including (1) strategy, (2) business model, and (3) administration model.

1.2. Inevitable requirements for businesses on the need for digital transformation for the coal mining industry

Fig. 1. Digital transformation model in enterprises (Ernst & Young, Digital Transformation Guidelines)
Rys. 1. Model transformacji cyfrowej w przedsiębiorstwach (Ernst & Young, Digital Transformation Guidelines)

Currently, coal mines have been exploited more and more deeply due to the depletion of coal reserves. This leads to an increase in the cost of fuel which is seen as the driving force of the exploitation process and creates extra costs in transportation, ventilation, drainage, methane fire safety, etc. Besides, deep mining still needs to improve the efficiency of the work to ensure the safety of workers and equipment.

Another challenge is the lack of business capital and difficulty in raising investment capital. This is because mining enterprises often need large investment capital, a long time for having profits, and many costs incurred. Therefore, in order to operate effectively, mining companies need to prepare a large amount of capital to cover both short-term and long-term expenses, and counterpart funds. In order to achieve the level of coal mining output according to Decision No. 403/QD-TTg on "Planning coal industry development to the year 2020, with a vision to the year 2030", all coal mining companies will need a total investment of about 269,000 billion VND, with an average of 17934 billion VND per year (nangluongvietnam.vn.news/vn).

Moreover, other problems include inefficient management of investment capital, poor assessment methods for investment projects, scattered investments, and limitations in the development of business strategies and investment forecasts. These may cause a series of bad investment projects of VIANCOMIN in subsidiaries and affiliates in recent years, causing losses of trillions of dong, leading to a huge amount of debt up to more than 100,000 billion VND, with an interest of 12 billion VND every day (thuonghieucongluan.com.vn and kienthuc.net.vn).

From the safety perspective, the flight altitude needs to In recent years, labor productivity in the coal mining sector has gradually improved but is still quite low compared to the common level in some other countries in the region and in the world. According to the assessment of the Intergovernmental panel on climate change (IPCC), Vietnam is one of the five countries that will be most affected by climate change [3, 14]. Climate change makes the occurrence of natural disasters such as storms, floods, lightning, and landslides more frequent and serious, causes many difficulties in ensuring mine safety, reduces mining productivity, and significantly increases the cost of disaster prevention and recovery.

In addition, there are many other difficulties that Vietnamese coal mining companies are facing such as increasingly strict regulations of environmental protection, competition from cheap imported coal sources, instability of price and purchasing power of the coal consumption market, the decrease in the coal industry's attractiveness to labor.

To overcome the challenges posed to coal and mineral mining companies in Vietnam, it is necessary to have quick changes. The most important change might be the effective application of scientific and technical advances from the fourth industrial revolution (4.0) into each stage of the management, production, and business processes, and this is a mandatory requirement of the nature and survival of businesses. In a study, McKinsey predicted that digital transformation in the global mining industry will reduce costs by 17% in 2025. Therefore, it can be noted that digital transformation is no longer an idea or vision for the future, in fact, it is a compulsory activity for production and business enterprises in general. Vietnamese mining companies must urgently implement digital transformation to adapt to new changes in the 4th digital age.

In Vietnam, basically, the energy industry is divided into two groups: the material and fuel industry and the electricity industry. Furthermore, in the raw material and fuel extraction industry, there are two main industries: the coal mining industry and the oil extraction industry. Therefore, it can be said that the energy industry includes three main industries: the coal mining industry, the oil and gas extraction industry, and the electricity industry.

In the national digital transformation program, energy is one of eight priority areas for implementation. According to Decision No. 749 dated June 3, 2020, on approving the National Digital Transformation Program to 2025 and orientation to 2030 of the Prime Minister, "For digital transformation in the energy sector, priority is to be given to focusing on the power sector towards maximizing and automating networks for efficient power supply, connecting digital meters to improve speed and billing accuracy, identifying network problems faster, helping users save energy, and detecting losses of electrical power" Coal and mineral mining is one of the key resource extraction sectors of the country and is managed and exploited by Vinacomin. Therefore, digital transformation in

this field is extremely important, contributing to improving the production efficiency of enterprises and national economic potential.

Digital transformation brings many benefits to coal mining enterprises from management to research and business. Coal mining enterprises can optimize operating costs and increase labor efficiency; better reach and satisfy customers; leaders make timely and more accurate decisions when switching from the traditional model to the application model of modern technologies.

Practical experience shows that the successful formula of enterprise digital transformation is the combination of five pillars: (i) Digital business culture and strategy; (ii) Connect and optimize customer experience; (iii) Process optimization; (iv) Technology; (v) Data analysis and management.

2. Status of digital transformation in the coal-mineral sector in today's Vietnam

2.1. Applying advanced technologies in exploration and exploitation

a. Inevitable trend of mechanization in the exploration, exploitation, and processing of the coal- mineral industry

In order to grasp the trend and advantages of digital transformation, Vinacomin has promoted the application of IT and the application of computer software in some stages of the chain of coal production; For example, Vinacomin's geological data mining and management system allow the construction and integration of geological data into a geological data bank (N.C.Nguyen, 2022).

Typically, VINACOMIN has applied a coal flow monitoring system that provides information about coal volume and quality to its units in a complete and intuitive way. A geologic data bank helps to upgrade the document management and operational management system to standardize the management procedure of administrative documents. In addition, they integrate digital signatures and move forward to document interoperability throughout the group, subsidiaries, and affiliated units, and have many other information technology ideas. Deo Nai Coal Joint Stock Company – VINACOMIN has conducted 34 projects of computerization, automation, and application of information technology in production. In particular, it is worth noting that the company employs online recording and statistics software, Google Sheets. Uong Bi Coal Joint Stock Company – VINACOMIN has deployed a software environment for assigning daily tasks, instead of handwritten like before, which reduces the time to do this job from 60–120 minutes to about 10 minutes, integrating fingerprint and face recognition into the daily shift delivery process, ... (baoquangninh.com.vn)

In the context of the strong impacts of the 4.0 technology revolution on production and business as well as all activities of social life, the coal-mineral industry has also experienced great efforts in facilitating innovations through constantly applying modern technologies and implementing digital transformation in production, business, and coal-mineral exploitation. It is confirmed that mechanization is an inevitable trend of VINACOMIN.

- For open-pit mines

+ Completing the technical connection of mines that have the same mineral deposits (e.g. Deo Nai – Coc Sau; and Cao Son – Khe Cham II), developing and expanding existing open-pit mines in the direction of increasing the stripping ratio; maximizing the exploitation capacity in accordance with the planning on dumping, transportation, and drainage, protecting the landscape and environment, actively responding to climate change and extreme weather.

+ Basically, mechanization is undertaken at all stages of production; systematically applying heavy mechanized equipment to reduce costs, such as 130 metric ton dump trucks (Ha Tu mine), large-diameter drills (up to 269 mm), hydraulic excavators with 12 m3 for the volume of a bucket, the transportation system combining trucks and conveyor. For example, in Cao Son mine, the conveyor transports waste rock with a designed capacity of up to 20 million m3/year; Improving the quality of drilling–blasting activities to reduce the cost of rock removal for open-pit coal mines.

+ Researching on applying new technologies and using materials for road construction in order to utilize local materials and reduce costs of trucks' tires; studying and testing the automatic fuel distribution and monitoring system and investing in applying modern software to manage from design to operation and production monitoring.

- For exploiting crude coal tar:

Over the years, VINACOMIN has made efforts to implement digital transformation, constantly investing capital to purchase equipment, and applying modern technology in production and business, especially the group has been applying mechanized equipment in coal mining, therefore, the volume of crude coal tar has been increasing in recent years.

According to reports of Vinacomin, the production of crude coal tar in the period from 2017 to 2020 was presented as follows: The total output of crude coal tar exploited from 2017 to 2010 increased. Figure 2 shows that in 2017, the total mining output was 40,501 thousand tons, of which open-pit coal reached 14,804 thousand tons, underground coal was 24.884 thousand tons, and other methods were 812 tons. In 2018, the total number was 42,939 thousand tons, of which open-cast coal reached 16,281 thousand tons, underground coal was 25,854 thousand tons, and other methods were 803 tons. In 2019, the total number was 46,9675 thousand tons, of which open-pit coal reached 18,858 thousand tons, underground coal was 27,149 thousand tons, and other methods were 668 tons. 2019 is also a year with higher coal mining output than 20117, 2018, and 2020. In 2020, the total mining product is 44,894 thousand tons, of which open-pit coal reaches 17,194 thousand tons, underground coal is 27 thousand tons, 145 thousand tons, and the other method 555 tons. Total coal mining product in 2020 decreased by 1,781 thousand tons compared to 2019 but was still higher than those in 2017 and 2018. In 2020, there was a decrease in the coal mining rate due to the Covid-19 pandemic which has seriously affected all areas of social life, especially in production and business.

- For underground coal mine

In underground coal mining, the geological conditions of mines with many faults, the complex structure of the coal seam, and the thickness and slope angle of the seam are uneven, making it difficult to apply mechanization. Therefore, the rate of mechanized working tunnels (using continuous miners) only reached 13.4% in 2018, and 15% in 2019. The

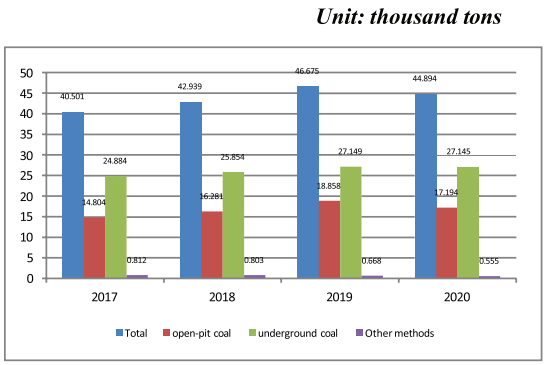

Fig. 2. The output of exploited crude coal tar in the 2017–2020 period. (Source: The reports of VINACOMIN and DONG BAC)
Rys. 2. Wydobycie wydobywanej surowej smoły węglowej w latach 2017-2020. (Źródło: raporty VINACOMIN i DONG BAC)

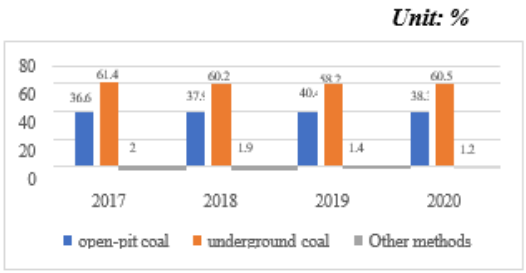

Fig. 3. Contribution rate of crude coal tar production by different exploitation methods (Source: The reports of VINACOMIN and DONG BAC)
Rys. 3. Wskaźnik udziału produkcji surowej smoły węglowej różnymi metodami eksploatacji (Źródło: Raporty VINACOMIN i DONG BAC)

increase in the rate of mechanization was due to the Ha Lam Coal Joint Stock Company where there were two mechanized working tunnels with a capacity of 1.8 million tons of coal per year. In these two tunnels, self- advancing hydraulic ceiling supports (including continuous miners, GK, GX, ZH frame/ chain rack, ZRY staging, XDY TLDD rack...)

Thanks to the effective application of mechanized equipment, coal production and productivity of units in VINACOMIN increased significantly, helping VINACOMIN to successfully achieve the objectives in production and business, and improve business conditions, working conditions, and ensure labor safety in coal mining.

Facing difficulties due to complex geological conditions, deep mining, high pressure, and the potential risk of gas explosions, VINACOMIN actively took the initiative of using technological solutions in production.

Typically, an automatic methane explosion (CH4) control system has been introduced into tunnels, helping VINACOMIN to master the assessment of methane content in coal seams. As a result, a series of centralized automatic methane monitoring systems have been put into operation in most underground mines and connected to the internet for remote monitoring.

+ Design and construction of underground coal mines with a high degree of mechanization, and modern and heavy equipment, including design and construction of mine shafts (Ha Lam, Nui Beo, Khe Cham II-IV, and Mao Khe).

+ Promote the application of systematic mining mechanization, especially the mechanized longwall working tunnels with a capacity of up to 1.2 million tons/year is applied at Ha Lam Coal Joint Stock Company; use light hydraulic ceiling supports, combined with frame rack and chain rack; maximize applications of modern ceiling supports in areas with suitable conditions, completely replacing wooden pillars and heading to replace single hydraulic cylinders; use ZRY and GM hydraulic ceiling supports in areas of medium thickness and steep seams to replace old technologies of coal mining; apply mechanization in most stages of transportation; promoting the application of mechanization to excavate tunnels with anchors in order to improve productivity and safety.

+ Improve the level of automation in monitoring and control of drainage pumping stations in working tunnels (applied in Ha Lam, and Vang Danh), conveyor transport (applied in many mines), power stations (applied in Ha Lam, and Nui Beo), emulsifying fluid supply stations (applied in Khe Cham, Thong Nhat), automatic ventilation systems (applied in Mao Khe, and Thong Nhat); apply energy saving solutions, to reduce labor, improve production and business efficiency.

- For coal screening and processing

+ Renovating and building new coal screening and processing plants with deep processing technology and modern equipment suitable to the characteristics of regional coal such as pressurized gas sedimentation machine, wheel suspension, multi-curved sieve sloping surface... double-sealed sludge treatment by pressing and drying system. Product quality after processing with a high recovery rate from 85–90%, waste rock Ak>80%, and loss of finished products in processing approaches 0%.

+ New investment has been made to improve the automation system of screening and processing stages, ensuring digitization, automation, and centralized control.

(i) For other mineral open-pit mines:

Open-pit mines such as bauxite Tan Rai, Nhan Co, Dong Sin Quyen, Dong Ta Phoi, have been applying heavy mining equipment and continuous transportation to reduce the cost

of production. Applying automatic equipment monitoring systems and researching and investing in applying software to manage from planning to production operation.

(ii) For other mineral underground mines:

+ Using new high-productivity mining and transportation equipment for underground mines such as lead-zinc mines in Thai Nguyen – Bac Kan region and making new investments in copper mines Vi Kem – Lao Cai, a tin mine southwest of Nui Phao.

+ Applying robotics in production inspection and administration; applying energy-saving solutions to reduce costs, and labor, and improve production and business efficiency.

(iii) For the field of mineral processing:

+ New investments in the mineral selection, refining, and processing factories in recent years have been researched and invested from the very beginning with advanced technology and equipment with high levels of mechanization, automation, and IT usage for different minerals and climatic conditions of each mining region.

+ During production operation, VINACOMIN has researched, improved, and innovated technologies at some stages to be more suitable to actual conditions, contributing to reducing costs, and improving production and business efficiency, typically as:

+ In the selection of copper, zinc, and iron ores: Researched, manufactured, and put into effective use the system of cell flotation equipment and researched to replace and use environmentally friendly flotation agents, therefore it helps to increase the net ore yield from 92.52% to 94.0% for iron, from 25.2% to 27.0% for copper, and from 91.8% to 92.7% for zinc Figure 4).

+ In alumina smelting: focusing on mixing, neutralizing materials, adjusting technologies, and regularly learning and applying solutions to optimize production such as: improving the process of feeding and draining the concentration system - adjusting the solution, changing the diameter of the pipes and plates of the separators at Lam Lam Aluminum Company Copper; Taking advantage of the second condensate of the condensation station for recycling, improving the filter system for the bottom flow pumps in the red mud washing area at Dak Nong Aluminum Company, thereby reducing the consumption of raw materials (coal, sedimentation aids), improving production efficiency.

- For the field of mechanical engineering

+ VINACOMIN's mechanical engineering has gradually developed in the direction of modernizing repairing mechanics, and developing mechanical engineering with focusing on promoting technology research, investing in equipment to increase mechanical engineering capacity, step by step mastering designs and technologies to manufacture imported equipment and spare parts. Using modern technological equipment in precision machining stages and gradually automating the production stages, including specialized equipment for the production of hydraulic cylinders; assembly of heavy trucks; manufacture of industrial alloy chains; rolling steel for tunnels, specially shaped steel, and making rollers.

+ The mechanical production division of VINACOMIN has researched and mastered the manufacturing technologies and produced a series of key mechanical products, such as the production of all kinds of hydraulic struts, supports, and soft rigs (CCTL), DW, XDY, GK, ZH, GN, GM 20/30...); conveyor belts used in the mining industry (BT, BT-VMC, BTC...); cable car winch (TCCN), excavator (VMC E500-1, ML 01-0.15, XD-0.32...), rake chute (SKAT), electric train (TDM, TD...), starting verbs, explosion-proof transformers, soft starters used in underground mines (KDP, TBKP, TBHDP, TKMP...), screening equipment (vibrating screens, feeders, beaters...), spare parts replacement equipment for repairing drilling machines, excavators, automobiles especially, VINACOMIN's mechanical engineering division has linked and cooperated with design and construction consultancy units in VINACOMIN to successfully carried out the EPC project for designing, manufacturing, construction and installation of coal screening plants, Tan Rai bauxite ore screening plant, Nhan Co bauxite ore screening plant, and Vang Danh 2 screening plant.

b. Achievements in mechanization in exploration, extraction, and processing of the coal-mineral industry

In 2015, VINACOMIN employed mechanized longwall working tunnels with a capacity of 600,000 tons/year at Ha Lam, Duong Huy, Khe Cham Coal Companies and mechanized longwall working tunnels for thin-seam coal mining with a capacity of 180,000 tons/year at Quang Hanh Coal Company. At the same time, the mechanization for the exploitation of slope seams with a combination of 2ANSH ceiling supports combined with planers and ZRY soft rigs at Mao Khe, Uong Bi, Hong Thai Coal mines initially improved the working conditions, achieved productivity, and ensured labor safety.

In 2016, the mining output by mechanization technologies of VINACOMIN reached about 1.42 million tons, accounting for 7% of underground mining output. This level of production has far exceeded previous years, nearly two times the production level in the year 2015.

In 2017, over 14,221 billion VND was invested in upgrading the mining system. All signals and operating parameters of each conveyor were transmitted to the control center. This project optimized the number of workers operating the conveyor lines, from 45 operators/day and night of production to 12 workers. With this system, the operator could monitor the entire operation of the conveyor lines, and remove metal mixed in coal. At the same time, they could identify each location at risk of incidents to coordinate with the organization to fix the problem as quickly as possible, ensuring safety in the production process (THINK TANK VINASA, 2019).

VINACOMIN used 96 hydraulic ceiling supports, cutting machines, scrapers, and conveyors for transporting coal. After more than one year of operation, the mechanized longwall working tunnels of Mong Duong Coal have exceeded the design capacity.

According to VINACOMIN's business result reports, in the first 9 months of 2017, the Group's coal production by mechanization reached 1.95 million tons, equal to 225% compared to the same period in 2016. The length of the tunnels is 8,113 m, with an increase of 22% from the plan and an increase of 79.3% compared to the same period in 2016 (THINK TANK VINASA, 2019).

In 2018, the group's coal output reached 36.95 million tons, exceeding 4% compared to the plan at the beginning of the year, and up 5% compared to that of 2017. Coal consumption reached 40.5 million tons, an increase of 4 million

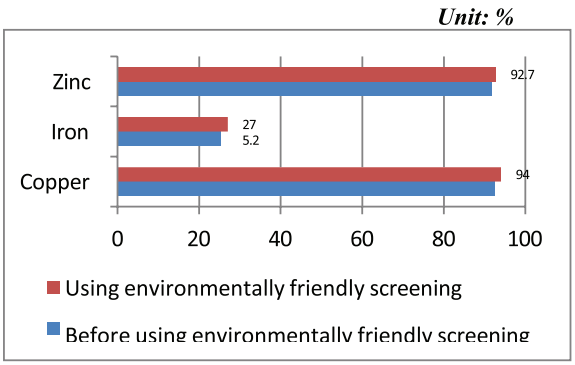

Fig. 4. Actual extraction rate of ore concentrates when effectively applying the cellular flotation system and using environmentally friendly screening (Source: The reports of VINACOMIN and DONG BAC)

Rys. 4. Rzeczywista wydajność wydobycia koncentratów rudy przy efektywnym zastosowaniu flotacji komórkowej i zastosowaniu przesiewania przyjaznego dla środowiska (Źródło: raporty VINACOMIN i DONG BAC)

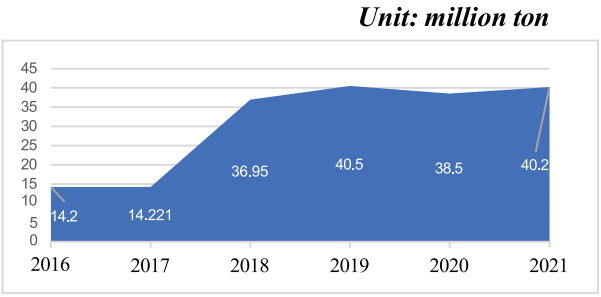

Fig. 5. Coal output in the 2016 -2020 period (Source: The reports of VINACOMIN and DONG BAC)

Rys. 5. Wydobycie węgla w latach 2016-2020 (Źródło: Raporty VINACOMIN i DONG BAC)

tons compared to the 2017 plan and increased by 5 million tons compared to that of 2017. Meanwhile, the electricity output produced by VINACOMIN reached 9.4 billion kWh (accounting for nearly 5% of the country's electricity output). VINACOMIN's revenue in 2018 reached VND 121,700 billion, up 13% compared to that of 2017. Its profit reached VND 4,000 billion, up 1,000 billion compared to that of 2017.

VINACOMIN has seven mechanized lines for coal slope seam exploitation in operation. Mining output by these lines grew significantly, from more than 720,000 tons in 2015 to more than 3 million tons in 2018 (accounted for 13.3% of the total coal underground production).

In 2019, VINACOMIN's production output reached 40.5 million tons of coal and consumption reached 44 million tons. This had been the highest output achieved by the Group since 2014. Domestic coal consumption reached 42.95 million tons, an increase of 8% compared to that of 2018. The coal supply for electricity production reached 36.06 million tons, an increase of 6.8 million tons. The Group's revenue in 2019 reached VND 131,500 billion, an increase of 9% compared to that of 2018.

VINACOMIN's coal output has reached 40.5 million tons, an increase of 9% compared to that of 2018 and about 6 times higher than that of 1995 (7 million tons). Since its establishment in 1995, after 25 years of development, VINACOMIN has exploited 700 million tons and consumed 715 million tons of coal. To achieve this output, VINACOMIN has excavated 5.2 thousand km of tunnels, 3 times the length of Vietnam, excavated 206 km/year on average, and excavated an average number of 3.4 billion m3 of soil and rock, with 128 million m3/year. Total coal revenue increased from VND 1.3 trillion in 1994 to VND 62.26 trillion in 2018; Labor productivity in terms of crude coal tar in 2018 reached 572 tons/person per year, an increase of 3.45 times compared to that of 1995.

VINACOMIN has strongly applied sciences and technologies in its production to increase labor productivity, and mining output, and save the country's mineral resources. For underground mines, VINACOMIN increasingly uses modern mining technologies, such as mechanized systems for coal mining and mine shafts with depths from 350 to 500 meters. The total output of coal extracted by mechanization from 2002 to the end of 2017 reached 12.75 million tons. In 2008, the rate of coal mining by mechanized systems only accounted for about 3% of the total coal production, but now it has increased to 15%. The length of tunnels in 2019 exceeded 40,000 meters, reaching over 18% of the total excavation length. Along with that, mechanization and automation are also promoted to apply to ventilation and control of mine gas and drainage in underground mines (ncif.gov.vn)

Currently, VINACOMIN has 10 out of 13 units investing in automation systems for the main conveyor line from tunnels to outside. Thanks to the application of automation and computerization in coal production and processing, VINACOMIN has saved more than 900 workers; average labor productivity reached 714 tons of coal/person in 2019, an increase of 12% compared to that of 2018. The economic profit thanks to the application of automation and computerization of the whole corporation is estimated at 260 billion VND/person.

In 2020, VINACOMIN produced 38.5 million tons of coal and consumed 42 million tons; excavating soil and rock was over 188 million m3, excavating nearly 255,000 m3 of tunnels. In 2021, planning to exploit 38.5 million tons of coal and consume 42 million tons. The production conditions of mines are getting deeper and deeper, production costs are increas-

ing day by day, affecting to implementation of economic and technical targets of VINACOMIN. However, VINACOMIN still sets the target of coal production and consumption not lower than 2020; to ensure an adequate supply of coal to the households that have signed commitments with the Group. Particularly, mechanized coal production reached 15.8% of total coal production.

In 2020, VINACOMIN operates two light mechanized tunnels for the first time. After more than a year of being put into use, these systems have proved the investment efficiency and opened up new prospects for the underground coal mining field, especially in the areas of thick and conditioned seams with complex geological conditions.

VINACOMIN used two mechanized equipment systems for testing in the VM-L(7)-1 longwall working tunnel at -250/-100 m level of seam 7 in Vu Mon zone of Mong Duong Coal Joint Stock Company and the I-11-5 longwall working tunnel at the -320/-295 m level, seam 11 of Khe Cham I zone of Ha Long Coal Company. According to the assessment of the Institute of Mining Science, up to 2020, after nearly one year of operation, these two systems had the advantage of small size and weight, allowing them to be transported across roads. The tunnel's smallest usable area was up to 8.5 m2. Its transportation and installation were more convenient. Ha Long Coal Company took only 18 days to complete the transportation and installation. For working tunnels in the Mong Duong coal mine, it took 25 days for installation (equivalent to 2/3 of the time for transporting and installing the medium and heavy complexes of mechanized systems applied in VINACOMIN's mines). The coal mining output of the two tunnels was about 300,000 tons/year. Labor productivity increased 1.5-2 times compared with that of old technologies (iemm.com.vn).

From October 2020 to now, the raw coal output of the light mechanized working tunnel has reached 247,000 tons, equal to 82% of the design capacity. Direct labor productivity is from 14 to approximately 29 tons/day/person, an average of 21.5 tons/day/person. Compared with the traditional tunnels with the same conditions in the company, the output of light mechanized working tunnels is more than 2 times higher, labor productivity increases by approximately 5 times, and costs are reduced from 5-18% (www.vinacomin.vn).

Figure 5 shows that in 2021, VINACOMIN exploited 40.2 million tons of coal, an increase of 7% compared to 2020. Consuming nearly 45 million tons, an increase of 6%; in which, domestic consumption reached nearly 43 million tons, an increase of 4%, and exported 1.7 million tons of coal, an increase of 192%. The total amount of coal in storage was 8.3 million tons. The Group also produced 1.43 million tons of alumina and consumed 1.45 million tons; exploiting 99.6 thousand tons of copper concentrate; producing 10.5 billion kWh of electricity, reaching 105% of the year plan. The average salary was 12.97 million VND/person/month (ncif.gov.vn).

In 2021, VINACOMIN applied automation and computerization in management to increase labor productivity and product quality, and reduce costs. Many important missions and tasks have been carried out on schedule, bringing high efficiency in production, and making an important contribution to fulfilling the 2021 targets of production and business, such as mechanized working tunnels of factory five exceeding the design capacity of 320,000/300.000 tons/year. Specifically, on December 18, 2021, the company's coal output reached 1,561,536 tons, exceeding 101%; in which, coal mined output reached 1,511,398 tons. Coal consumption output reached 1,554,598 tons, reaching 101% of the plan.

In the field of open-pit mining, new technologies have been applied in mining down below the self-flowing drainage level, applying equipment to loosen soil and rock by the method without blasting; drilling and blasting technology in flooded borehole conditions; technology using excavator equipment for combined transport. Or in the field of coal screening, advanced screening technologies have been applied to improve the quality of finished products, make full use of sieved coal and bad quality coal by the technology of spinning and self-generating suspensions. In particular, the coal industry has actively designed and manufactured technologies and equipment to avoid dependence on foreign countries and increase the localization rate. Notably, the successful manufacture of equipment and application of construction technologies for mine shafts in the Nui Beo underground coal mine have contributed to improving the technical capacity of the engineers, and workers in mastering issues from design, technological process, equipment manufacturing, and construction of deep mining works.

2.2. Applying advanced technologies in mining and environmental protection

With the trend that coal demand has been increasing, improving the quality of coal, taking advantage of resources, and protecting the environment are the factors that coal producers put as the top priority. The application of advanced technologies in coal mining and processing has brought initial results in environmental protection and sustainable development. VINACOMIN has cooperated with Viet An Environmental Engineering Joint Stock Company Group to apply many centralized wastewater monitoring systems (Mao Khe Coal Company – VINACOMIN; Mong Duong Coal Joint Stock Company – Vinacomin), emission monitoring station (Cao Ngan Thermal Power Company – Vinacomin: Lam Dong Aluminum Company Limited – VINACOMIN) in the whole VINACOMIN with a total of 37 wastewater monitoring stations, including: Monitoring system centralized wastewater provides information on the volume and quality of wastewater at the units in a complete and intuitive manner; the VINACOMIN wastewater data mining and management system - allows the construction and integration of mine wastewater data belonging to VINACOMIN into one data bank; upgrade the document management and operation management system to standardize the operating document management business process, integrate digital signatures and move towards document interoperability throughout the Group, including subsidiaries, affiliates, and subsidiaries. subordinate units, and many other information technology systems (H.M.Nong et al., 2022).

- For the coal mining industry:

+Waste collection and treatment: by the end of 2020, 43 mine wastewater treatment stations (excluding domestic wastewater treatment stations and other industrial wastewater treatment stations) have been built with a total capacity of over 50,000 m3/h, equivalent to more than 200 million m3/year. This ensured that mines have wastewater treatment sta-

tions meeting environmental standards. The group built and maintained an industrial hazardous waste treatment plant in Quang Ninh, annually treating over 3,600 tons of hazardous waste from its units, of which over 50% of products are treated. reused for production. Waste cinder blocks generated from coal sifting are dumped into planned waste dumps. Ordinary industrial solid waste and daily-life solid waste generated in production shall be collected and treated in accordance with regulations.

+ Rehabilitation and restoration of the environment:

Planting trees to improve and restore the environment is now over 1,500 ha. Some typical environmental rehabilitation and restoration areas have been completed, such as dumping sites: Nam Deo Nai, Nam Lo Phong, Chinh Bac Nui Beo, a part of Dong Cao Son, and Nam Khe Tam – Dong Khe Sim dumping site. Implement the plan of planting trees with high density to quickly green the mine waste dumps, shorten the greening time from 5-6 years ago to 2-3 years now, contributing to limiting soil leaching. stone, reduce dust emissions, and rapidly improve the general landscape environment, especially in Ha Long city. From 2016 to now, VINACOMIN has conducted more than 10 projects to build dykes and dams to prevent landslides and erosion, about 20 projects of environmental rehabilitation and restoration, and nearly 40 projects of renovation and dredging of drainage systems and sedimentation lakes. Funding for this work is deducted from the centralized Environmental Protection Fund, environmental protection expenses, and investment costs of the unit.

+ Dust prevention: Currently, transporting coal to ports and to power plants in Quang Ninh, Thai Nguyen, and Lang Son is basically done by conveyors and railways to prevent the spreading of dust, and contribute to the improvement of the urban environmental landscape. By the end of 2020, VINACOMIN has utilized over 80 high- pressure dust-extinguishing nebulizers (both mobile and fixed) for its mines. Using a 50 m3 mine road irrigation vehicle to improve the capacity and efficiency of dust suppression on mine routes. Other anti-dust solutions in production have been enhanced: making hard dust covers on wagons, building car and wagon washing stations, making dust nets for coal warehouses, and covering coal trucks and warehouses with tarpaulins piles investing in the additional capacity of dust suppression water trucks, anti-dust water supply systems on waste dumps.

+ Renovation of the landscape and environment: The landscape reclamation has been carried out at 4 concentrated warehouses and ports (KM6, Lang Khanh, Ben Can, Dien Cong) and 6 production sites, and the same for other production sites, new mines are built with green – clean – beautiful criteria (Nui Beo, Ha Lam, Thanh Cong, Giap Khau); Specialized coal transport routes are improved to ensure drainage, planting trees on both sides to prevent dust and noise, and improve the landscape environment.

+ Environmental pollution control: VINACOMIN cooperates with Quang Ninh province to install more than 50 automatic environmental monitoring systems for coal mine wastewater, and transmit data directly to the Department of Natural Resources and the Environment in accordance with the provisions of the Law on Environmental Protection. Continuing to carry out concentrated environmental monitoring for residential areas at risk of being affected outside the management boundary to control and detect pollution risks, and promptly direct the implementation of preventive measures. prevent. Carrying out periodical environmental monitoring at the member unit in accordance with the approved environmental impact assessment report.

+ Climate change response: Construction of many dams and dykes to prevent soil and rock at the bottom of dumping sites. Currently, the coal mine waste dumps have basically enough dykes as planned, preventing soil and rock from flowing, ensuring safety for production and population; Building nearly three dozen reservoirs upstream of streams for drainage, regularly dredging the system of rivers and streams to reduce sedimentation and prevent flooding. Relocating hundreds of households in dozens of areas at risk of dangerous landslides and floods due to the influence of VINACOMIN's mining areas under the Quang Ninh Provincial Master Migration Project to ensure people's safety. residence during the rainy season.

- According to the general assessment of VINACOMIN, environmental protection in mining has achieved the following results:

+ In 2010, all sources of environmental pollution were treated and controlled (water, soil, and air); By 2015, it was to basically improve the main environmental indicators in sensitive areas (urban areas, residential areas, tourist attractions, etc.), and all mines met environmental standards; Up to now, VINACOMIN has fully met environmental standards throughout the mining area.

+ VINACOMIN has done a good job in propagating, educating, and disseminating knowledge about environmental protection to all officers and employees, not only for units directly involved in production but also for consulting units.

+ Up to now, VINACOMIN has made efforts to complete more than a dozen large projects and hundreds of small and medium projects, such as wastewater treatment works, hazardous wastes, landfill rehabilitation, dredging of rivers and streams, etc. construction of embankments and dams, new construction of roads to avoid people's livelihood, relocation of seaports, coal mining plants, etc. shall be deducted from production costs, environmental funds, environmental concentration costs, and other expenses.

+ VINACOMIN has built a 5 to 10-year long-term plan and roadmap for the treatment, management, and reuse of mine wastewater, reclamation, and restoration of waste dumps, dust treatment, capacity building environmental management.

+ VINACOMIN has built an environmental database for the whole industry to store and look up data.

+ VINACOMIN has strictly observed and strictly controlled the implementation of processes and technical standards for safety and environment in coal exploration, mining, transportation, processing, and use. The investor has made an environmental impact assessment report and submitted it in accordance with current regulations before issuing the mining license and closing the mine under the guidance of the Ministry of Natural Resouces and Environment.

+ VINACOMIN has built 45 mine wastewater treatment stations with a capacity of more than 120 million m^3/year. This is to ensure that all underground wastewater is treated according to standards; moving many working sites and coal

production plants out of the centers, contributing to improving the landscape environment and urban development of the mining area. In mid-2019, VINACOMIN terminated the operation of the Nam Cau Trang Coal Screening Plant (nearly 33 hectares). VINACOMIN has invested 1,600 billion VND in the coal processing center and concentrated coal warehouse in the Hon Gai area; dredging the Lang Khanh port channel to serve the relocation of a new production location. In phase 1, VINACOMIN builds a screening station with a capacity of 2.5 million tons of coal/year; a system of raw coal storage with a capacity of 48,000 tons; a closed conveyor system transporting coal from Ha Lam and Hon Gai mines to the center. The successful relocation of Nam Cau Trang Coal Screening Plant helps VINACOMIN to completely handle the problem of dust and noise environment affecting the surrounding urban area and Ha Long Bay (vietcleanair.vn).

- About the mining and mineral processing industry:

In the past years, companies in the mining and mineral processing industry have planted trees to green the waste dumps and closed mines, prioritizing the dumping of waste to end each area to soon restore the environment, and protect the landscape.

They employed a system to treat mine wastewater and ore extraction wastewater without fully reusing it to ensure environmental standards; built a hydrometallurgical sludge treatment system for a zinc electrolytic plant; increased capacity and scale of waste storage and treatment works to ensure thorough collection and treatment in accordance with regulations; complete installation of an automatic environmental monitoring system for wastewater and emissions. Increase recycling and reuse of waste for production and supply to other businesses.

They also strengthened anti-dust work, planted a green belt to prevent dust, installed high-pressure dust- extinguishing foggers at primary ore depots, and rock waste dumps, used specialized road irrigation vehicles, and strengthened anti-dust solutions to increase dust suppression efficiency (installation of anti-dust nets, use of modern and advanced equipment to create less dust...). They regularly carried out industrial cleaning and preserved the landscape and environment of the factory to ensure the thorough prevention of dust and noise emissions affecting the area's environment.

They built a system of dikes and dams at the bottom of waste dumps, dams of reservoirs to settle upstream soil and rocks, and regularly dredging rivers and streams to reduce drainage. Other activities were done, including regularly inspecting and reinforcing tailing ore reservoir dams to ensure safety and prevent the risk of dam overflow; formulating and proactively implementing plans to prevent chemical leakage and natural disasters to ensure the safety of production, population, and environment.

VINACOMIN has installed an anti-dust system in coal mining. Because some areas of the company still are next to scattered and interspersed residential areas, it is compulsory to have the lowest level of environmental pollution. Therefore, coal mining companies have purchased modern equipment to increase mining productivity and reduce the amount of dust generated in the process of mining and screening and improve climatic and working conditions for workers.

Typically, Mao Khe Coal Company invested more than seven billion VND to install a dust-proof system for sieve house 56 and the route next to the tunnel's door. The company cooperates with the local government in dredging and clearing the Cau Lim stream, especially the section through the residential area of Mao Khe ward, to ensure irrigation and drainage. All underground wastewater during the mining process of the company is pumped to two industrial wastewater treatment plants with a capacity of 1,800 m3/hour, treated up to standards before being released into the environment, and a part is reused in production. Domestic wastewater is collected to two treatment stations with a capacity of 500 m3/day, ensuring that all wastewater meets standards before being discharged into the environment. Mao Khe Coal Company also signed a contract with Quang Ninh Center for Monitoring of Natural Resources and Environment to monitor the environment, quality of wastewater, and receiving water on a quarterly basis to promptly detect and correctly overcome the risks of pollution (www.vinacomin.vn).

Underground mines aim to build a model of green mines, modern mines, and high-yield mines, applying maximum mechanization to all stages of production lines. VINACOMIN also completes the model of "Coal production and trade", mixing between domestically produced coal and imported coal with an appropriate ratio. In particular, priority is given to spending more than 7,400 billion VND on key projects, such as exploiting coal seams below -150 m of Mao Khe mine (Mao Khe Underground Coal Company); the II-IV mining coal underground (Ha Long Underground Coal Company. These projects were to increase capacity, helping the companies soon achieve the goal of a modern coal mine, with high productivity and quality.

In addition, VINACOMIN will promote investment in applying sciences and technologies in labor, to increase labor productivity and product quality, reduce costs, and improve the working environment; implementing key projects on schedule, looking for new investment projects, resolutely not investing in fields outside the industry; continue to implement the VINACOMIN restructuring project for the period of 2017 - 2020 and prepare to develop the VINACOMIN restructuring project for the period of 2021 – 2025 (cmsc.gov.vn).

3. Conclusions

In general, digital transformation in the field of coal and mineral mining has made certain progress and is consistent with the trend of digital transformation in Vietnam today as well as in the world. Thanks to the world's 4.0 technology platform, Vietnamese coal mining enterprises have created many successes, such as converting from traditional mining to a smart mining model which in turn helps to improve productivity, labor efficiency, and safety. At the same time, digital transformation has helped the mining process to reduce negative impacts on the environment, and ensure sustainable development. However, although in comparison with other products and business enterprises, the level of digital transformation in the field of coal and mineral mining is still slow, with the achievements, digital transformation in coal and mineral mining enterprises will certainly have further development in the future.

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Transformacja cyfrowa w sektorze wydobywczym w Wietnamie

Cyfrowa transformacja to jeden z nieuniknionych trendów w dzisiejszym świecie. Wietnam jest jednym z pionierskich krajów podążających za tym trendem i uruchomił krajowy program transformacji cyfrowej. Transformacja cyfrowa cieszy się dużym zainteresowaniem zarówno środowiska naukowców, jak i menedżerów w ogóle oraz w obszarze górnictwa węgla kamiennego i innych kopalin. Obecnie badacze koncentrują się na takich zagadnieniach, jak teoria transformacji cyfrowej zarówno w państwie, jak iw sektorze biznesowym, związki między transformacją cyfrową a budową e-government lub cyfrowego rządu oraz między transformacją cyfrową a efektywną administracją państwową. W niniejszym opracowaniu metoda analizy dokumentów (Desk review) została wykorzystana do analizy i oceny aktualnej sytuacji transformacji cyfrowej górnictwa węgla kamiennego i kopalin oraz identyfikacji osiągnięć i ograniczeń procesu transformacji cyfrowej w górnictwie węglowym i mineralnym. przemysł wydobywczy minerałów w Wietnamie.

W opracowaniu przedstawiono następujące zagadnienia: (1) Niektóre ogólne zagadnienia dotyczące transformacji cyfrowej, w których doprecyzowano pojęcie transformacji cyfrowej; Znaczenie transformacji cyfrowej w obszarze górnictwa węglowego i mineralnego; Wymagania transformacji cyfrowej w obszarze górnictwa węglowo-mineralnego. (2) Aktualny stan transformacji cyfrowej w górnictwie węglowo-mineralnym w Wietnamie, w tym zastosowanie zaawansowanych technologii w eksploracji i wydobyciu oraz zastosowanie zaawansowanych technologii w górnictwie i ochronie środowiska.

Słowa kluczowe: *transformacja cyfrowa, przemysł węglowo-mineralny, mechanizacja*

Internal Communication Models Shaping Safe Behavior of Employees in the Raw Materials Sector During the Coronavirus Pandemic

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Abstract

The new threat, which the SARS-COV-2 virus turned out to be two years ago, meant that mining companies had to face this challenge. The rapidly deteriorating situation, the continuous increase in the number of coronavirus infections and the severe course of the disease contributed to the development of new rules and procedures in the operation of mining plants. They were to guarantee all employees, especially those working underground, a sense of peace and security, as well as ensuring the continuity of maintenance and operation of plants.

This "unique challenge" resulted in the companies developing best practices during the pandemic, which were based primarily on efficient and reliable internal communication shaping safe behavior of employees.

This publication presents the internal communication models developed and used by various mining companies, which shaped the safe behavior of employees in the raw materials sector during the coronavirus pandemic. The authors compared the introduced actions shaping safe behavior and the resulting models of internal communication during extraordinary work. A comparative analysis of the communication tools used in individual models was made on the example of selected companies from the raw materials sector.

Keywords: *safety, pandemic, motivation, communication, raw materials sector*

Introduction

The uncertain economic, political, as well as environmental and social conditions of the raw materials sector, including its ongoing transition from a traditional economy to a low-carbon economy due to the publication by the European Commission of the Communication on the European Green Deal, caused many difficulties and a crisis in the raw materials sector [1-8]. This unstable situation and the functioning of enterprises was aggravated by the emergence in March 2020 of the epidemic threat, which turned out to be COVID-19 [9, 10]. The specificity of this virus (causing acute respiratory disease) turned out to be very dangerous, especially due to the fact that it spread very quickly and remained on contaminated surfaces for a long time.

Mining plants are clusters of people who have contact with each other in many common places within the plant, which increased the risk of infection and made it impossible to fully comply with the spatial distance rules. Subsequent lockdowns only aggravated the problems related to work safety in the raw materials industry. The lack of a sense of security among miners and the awareness of the existing danger in the workplace [11-13] resulted in appropriate reactions and wide-ranging activities of mining companies in this regard [14].

Many industries, including Polish mining and hard coal mines, faced a "unique challenge" two years ago [15]. Ensuring safe work for miners and the entire mining plant is one of the important goals of the mining industry and is part of the implementation of the corporate social responsibility strategy [11, 16]. Therefore, the actions taken consisted in introducing a number of changes to ensure the safety of employees [10, 14]. The most important issue for the companies and plants was to maintain the continuity of production while protecting the health of the working crews. In order to maintain the mining potential and the infrastructure ensuring access to energy resources, the minimum shift workload was planned, the contacts of the work teams were limited as much as possible and a number of safety procedures were introduced.

State of epidemic threat in mining enterprises

The first stage of the pandemic in Poland caused a lot of disinformation, fear and panic. It was important to react fairly quickly in the sector and in individual mining companies or plants to ensure safe working conditions for employees and stop the virus from spreading. Work in mining enterprises is performed in various conditions and is associated with hazards typical of their activities [17, 18]. In such specific mining plants, on the one hand, creating a safe working environment by the employer is extremely important, on the other hand, it is related to work discipline and compliance with many procedures [11, 16]. Due to the new situation and the state of epidemic threat, the companies had to reorganize the current working conditions and create a new organizational model appropriate to the current needs. And the preventive actions implemented in companies and mining plants were mainly aimed at:

- overcoming a difficult epidemiological situation,
- minimizing the negative effects of the pandemic.

Both goals could be achieved by limiting the contacts of employees on the premises of the plant. It was difficult, however,

Fig. 1. The stages of actions taken to combat the coronavirus. Source: own study
Rys. 1. Etapy działań podejmowanych na rzecz walki z koronawirusem

because the plants had to continue to operate as before with the simultaneous reduction of the number of employees per shift (only the minimum number of employees per shift worked) [19].

The next steps of the actions taken, both at the national and sectoral level, are shown in Figure 1. In March 2020, a state of emergency related to the spread of SARS-CoV-2 was introduced in Poland. In the next step, the Chief Sanitary Inspector together with the Minister of State Assets prepared guidelines for the functioning of mines during an epidemic. Then, the Chief Sanitary Inspectorate (GIS) issued recommendations regarding the operation of industrial plants. The recommendations are divided into three areas: prevention (e.g. providing employees with personal protective equipment, sanitary and hygienic instructions), limitation (e.g. using distance barriers or reducing the number of work shifts, places for disinfection) and emergency procedures, which you can read more about, inter alia, in related studies [19, 20].

The President of the State Mining Authority appointed Crisis Management Teams in Underground Mining Facilities, whose task was to detail the guidelines for safety procedures. In turn, the Crisis Response Teams worked at the level of the mining companies themselves. They were appointed by the Presidents of the Management Board and worked on even more detailed recommendations ensuring the continuity of production and changing working conditions in order to ensure the safety and protection of employees.

In order for the introduced recommendations and procedures to be effective and constitute safety standards in the period of an epidemic threat, mining plants had to provide employees with all the necessary information on an ongoing basis. The factors influencing the effectiveness of the actions taken in the mining industry were primarily:

- reaction time,
- crisis management structures introduced,
- and the mobilization of the crew and mutual motivation.

Safe behavior motivating tools

The situation that mining faced was so difficult because the COVID-19 pandemic had a huge impact on society and the economy. The fear of the infection itself and the effects that could occur after infection with the virus made employees of mining enterprises feel threatened. The employers' task was to provide employees with safety and a sense of mental readiness for the work conditions. A. Gembalska-Kwiecień defines that a person's mental readiness to act in an emergency depends primarily on full information about what has happened or is happening [21]. As mentioned earlier, one of the factors influencing the effectiveness of the activities undertaken by mining enterprises was the mobilization of the workforce. It was based on efficient internal communication, based on broad access to information on the existing coronavirus threat. The sources and form of the information provided determine what is the scope of this knowledge of employees on a given topic, and the knowledge of employees, according to A. Gembalska-Kwiecień, is the most important element in formulating all kinds of preventive actions [21]. In the event of the SARS-CoV-2 virus threat, the task of mining enterprises was to provide employees with information on:

- the virus itself,
- the current pandemic situation,
- actions taken by the companies,
- guidelines, recommendations and procedures in the event of an employee becoming infected.

The form of transmitting the above information depended, on one hand, on effective communication with the staff, and on the other hand, on inspiring employees to behave properly [16]. The most difficult thing about communicating information to employees was that there was no possibility of face-to-face meetings. Mining companies had to use all the internal communication tools they had so far, but also to launch new ones in order to reach as many employees as possible. The main tools used in internal communication by mining companies are presented in Figure 2.

The most frequently used tools were radio broadcasts and health and safety displays located in common places such as staff rooms, equipment rooms or shafts, where miners spend time preparing to work. Posters were put up, brochures and leaflets were distributed with the most important information. In addition, electronic communication tools were used in the form of emails or texts with current information that employees received before each shift. Internal communication in this extraordinary situation was supplemented with specially created closed groups on social media, e.g. Facebook or a special hotline in some companies, where everyone could get information on questions bothering them, report a problem or even present proposals for anti-covid initiatives.

The changes in working conditions introduced by the companies as well as the rules and procedures to be followed in the event of infection with the virus made employees, fearing the infection and its consequences, feel the need to adapt

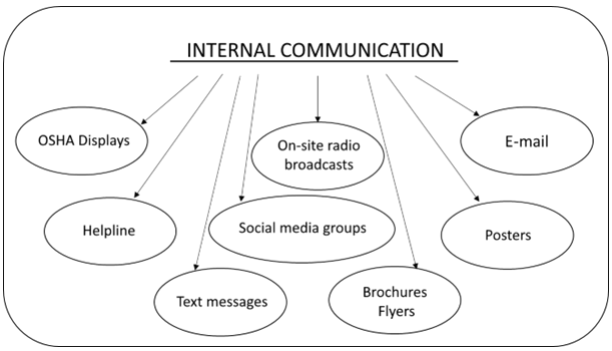

Fig. 2. Internal communication tools used by mining companies during the pandemic. Source: own study
Rys. 2. Narzędzia komunikacji wewnętrznej wykorzystywane przez spółki górnicze podczas pandemii

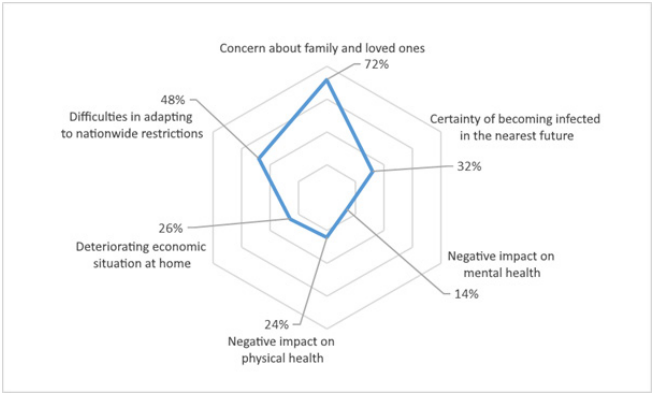

Fig. 3. Answers of the respondents to the question about what the pandemic caused in their lives. Source: own study based on: [22]
Rys. 3. Odpowiedzi respondentów na pytanie dotyczące na co miała wpływ pandemia

to changes and patterns of behavior. It is defined as the motivation to work safely. It is a specific state of the human psyche, which gives the belief that an attitude adjusting to the applicable methods will reduce the risk or eliminate it completely [21]. The research described by A. Lubosz may prove a strong motivation to work safely [22] which show adaptive behavior to the existing situation of workers working underground in mining plants in liquidation. The responses of the respondents show that the vast majority of people were "traumatized by the pandemic" [23]. When the miners were asked what the impact of the pandemic was in their case (Fig. 3), they all said that the pandemic caused significant changes in their lifestyle. Almost all of the respondents, i.e. 98%, followed the announced and implemented guidelines. This was mainly due to the fact that 72% of miners were afraid of infecting their family and loved ones, and 32% were certain that they would get infected with the virus soon. Almost half of the respondents (48%) had a problem with adapting to all restrictions and guidelines. The whole pandemic situation, the rapidly spreading virus, and all the lockdown restrictions introduced, resulted in:

- deterioration of the economic situation of miners (26%),
- deterioration of the miners' physical health (24%),
- deterioration of their mental health (14%).

Models of actions shaping safe behavior of miners – case study on selected examples

Information was an extremely important issue in shaping the proper, safe behavior of employees of mining enterprises during the coronavirus pandemic. The rapidly changing epidemic situation in the country meant that the guidelines, recommendations and procedures were implemented in a dynamic manner. It required a well-thought-out, broad information campaign among all mining crews. The actions of the emergency response teams used various forms of communication, creating the so-called educational and information campaigns on the SARS-CoV-2 virus. The aim of the campaigns was to reach as many employees as possible with the most important information. It was assumed that the high frequency and repetition of messages along with their content would positively affect responsible behavior and proper health habits of miners. The campaigns carried out used all possible information channels, but each company conducted the campaigns in its own way.

The conducted analysis of the available publications and studies made it possible to compare the activities carried out by mining companies that shape the safe behavior of miners during the pandemic and the communication tools used by them. The list of internal communication tools in selected mining companies is presented in Table 1.

Most of the analyzed companies used traditional forms and tools of communication, such as radio broadcasts or video screens. There were also created new channels, tools to reach as many employees as possible, the creation of which was dictated by the new situation in which the mining industry found itself.

Polska Grupa Górnicza SA

In order to support and facilitate the rapid flow of information between the Branches and the headquarters, PGG SA has developed a special internet application (Figure 4a). It in-

Tab. 1. Communication tools used by mining companies during the pandemic. Source: own study based on [16]

Tab. 1. Narzędzia komunikacji wykorzystywane przez spółki górnicze podczas pandemii

	Polska Grupa Górnicza SA	Węglokoks Sp. z o.o.	Spółka Restrukturyzacji Kopalń SA	ZGH „Bolesław" SA
Online portal	v	v	v	v
Radio broadcasts	v			
Printed materials (posters, brochures)	v	v	v	v
Emails	v	v	v	
Text messages	v	v		
Video screens, notice boards	v	v	v	v
Training videos	v			
Applications	v			
Online platform	v			

a) b)

Fig. 4. Web application created for the needs of the pandemic period (a) and Planet PGG – coronavirus knowledge base (b) [16]

Rys. 4. Aplikacja internetowa utworzona na potrzeby okresu pandemii (a) oraz Planeta PGG – baza wiedzy o koronawirusie (b)

a) b)

Fig. 5. Posters and messages informing about correct behavior (a, b) [24]

Rys. 5. Plakaty i komunikaty informujące o prawidłowych zachowaniach (a, b)

cludes, among others, reports containing lists of people suspected of being infected with SARS-CoV-2 or other covid-related events, templates of necessary documents, statistics, and even a discussion panel for users. Necessary information or reminders were sent to employees via e-mails or text messages. These information campaigns were aimed at:

- providing information on important decisions of the Management Board of the Company,
- informing about the details of mass screening actions,
- alerting employees to the risk of contamination both at work and outside,
- reminding about important preventative actions.

A knowledge base was added to the Company's website in the form of educational content for employees about the virus, e.g. Planet PGG (Figure 4b).

Employees could find information and educational content there, which included:

- current safety rules,
- current infection rates,
- health care information (night and holiday),
- recommendations for quarantine,
- epidemiological criteria during patient qualification,
- information on medical over-the-phone advice.

A very interesting idea and solution were the instructional videos on, for example, hand washing or COVID-19 quizzes, during which the employees (sometimes together with their family, children), learned about interesting things, expanding their knowledge about the virus. In addition, the Company used traditional methods of providing information, such as: posters, leaflets or announcements (Fig. 5), which were placed in generally accessible places along which the crews traveled (changing rooms, equipment rooms, passageways).

In addition, at the PGG SA IT and Telecommunications Department, a special telephone hotline was set up and launched for employees, where they could obtain basic information about the epidemic and answer questions regarding, for example, the course of the disease, prevention, test results or personnel information.

Moreover, the Management Board of Polska Grupa Górnicza SA organized psychological support for employees during the pandemic. Psychologists were on duty 24 hours a day and conducted consultations helping employees (mainly miners) to cope with emotions and stress.

Węglokoks Sp. z o.o.

In the case of the next analyzed company, Węglokoks Sp. z o.o., messages related to prevention were communicated to employees through various channels. The most frequently used include:

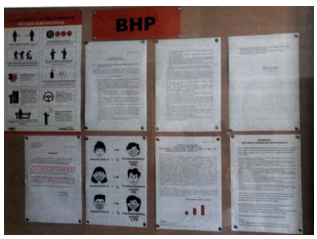

Fig. 6. A notice board with information and recommendations during the pandemic period [16]
Rys. 6. Tablica ogłoszeń z informacjami i zaleceniami podczas okresu pandemii

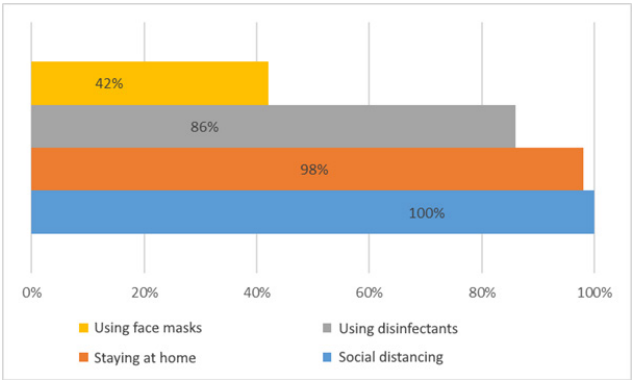

Fig. 7. Diagram of general measures to combat the coronavirus. Own study based on: [22]
Rys. 7. Schemat ogólnych działań na rzecz walki z koronawirusem

- printed materials in the form of posters and brochures,
- electronic media, i.e. the employee portal, e-mails, text messages, video screens.

The purpose of this form of providing employees with knowledge about the risk of the SARS-CoV-2 virus was mainly to disseminate and systematize the guidelines introduced in the company.

Spółka Restrukturyzacji Kopalń SA

A proper information policy was a priority for SRK SA. The services provided the crews with information about the current covid situation and current instructions on how to behave during the epidemic. The company used readily available means of communication, such as:

- direct communications,
- e-mails,
- company website,
- posters,
- notice boards.

The posters informed about the rules of conduct in the event of a risk of infection. The campaign of hanging posters was carried out in all Branches of the Company in generally accessible places. Employees could also learn how to avoid the spread of the virus, as well as what actions and steps to take in the event of suspicion of infection. Such tools were used by SRK SA to convey the appeal of the President of the Management Board regarding, in particular, the rules of behavior, as well as announcements, recommendations of ministries and sanitary inspection. In the event of a rising threat of quarantine, the frequency of repetition of this information became high and regular.

ZGH „Bolesław" SA

Also Zakłady Górniczo-Hutnicze "Bolesław" SA in Bukowno informed about the current situation and all preventive measures by putting up information posters. They were located in generally accessible places where the crew gather - at the entrance to the mine and steelworks, near the xerographs, and on all notice boards (Fig. 6). Moreover, the Orders of the President of the Management Board were placed in the GroupWise electronic system.

Discussions

The use of the discussed tools of internal communication had a large impact on motivating miners to act safely, causing them not so much as to adapt to safety standards [25], but also increase their mobilization and sense of community in the activities carried out. The aforementioned research by A. Lubosik also shows how three quarters of the surveyed miners complied with the restrictions introduced in the mining plants (Fig. 7). This shows how responsible the mining community, made up primarily of underground miners, is. Such action strengthens the organization, and mutual motivation (one looks at the other) strengthens the social bonds in the crew.

All respondents observed a safe distance to reduce the risk of falling ill. Slightly less, 98%, wanting to avoid contact with other employees, stayed at home, choosing to take out overdue off days. 42% of the respondents used masks, and 86% used and applied disinfectants. Thanks to the collective responsibility of the mining community and the presented behaviors, mining companies managed to limit the growth of infections in mines.

Conclusions

The activities of companies from the raw materials sector, thanks to the activities shaping safe behavior and the internal

communication models introduced during the extraordinary work period, ensured an appropriate level of safety for their employees, as well as the continuity of mining operations. The most important thing was to think over the prohibitions, orders, rules of conduct and pass them on to all employees of the plant. The comparison of the models of activities shaping safe behavior of miners shows that in this respect the communication was very good. Not only were traditional internal communication tools used (posters, notice boards, company websites), but also, due to the needs, the message was extended to include new, previously unused methods of communication (text messages, e-mails, applications, groups on social networks). Among the presented companies operating in the raw materials sector, PGG SA was very active and its internal communication model was the most developed.

It should be mentioned that the flow of information and communication in the case of mining plants is not easy due to the large number of people working on various shifts. For this reason, internal communication in plants was extremely important, because, on the one hand, it depended on the manner and form of its communication whether it would reach the vast majority of employees, and on the other, whether the employees would adapt to the current restrictions, rules and recommendations. The solutions introduced during the pandemic, and above all consistency in the activities carried out by the companies, have brought specific effects. Even when there was a gradual unfreezing of restrictions in the country, the level of risk for plants was determined as still high and most of the introduced internal restrictions and solutions protecting against COVID-19 have not ceased to be in force at that time. Thanks to such decisions, we can say from the point of time that the raw materials sector coped with the situation very well and this gives a good prospect for the future. It seems that after the experience gained, the industry will be better prepared for the occurrence of possible future crises, and the existing preparations for such a situation will then be put to the test.

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Modele komunikacji wewnętrznej kształtujące bezpieczne zachowania pracowników w branży energetycznej podczas pandemii koronawirusa

Nowe zagrożenie jakim okazał się dwa lata temu wirus SARS-COV-2 spowodował, że spółki górnicze musiały sprostać temu wyzwaniu. Pogarszająca się w dużym tempie sytuacja, ciągły wzrost liczby zakażeń koronawirusem i ciężki przebieg choroby wpłynęły na wypracowanie nowych zasad i procedur w funkcjonowaniu zakładów górniczych. Miały one zagwarantować wszystkim pracownikom, a szczególnie pracującym pod ziemią, poczucie spokoju i bezpieczeństwa, a także zapewnić ciągłość utrzymania i funkcjonowania zakładów. To „unikalne wyzwanie" spowodowało, że spółki wypracowały przez okres pandemii dobre praktyki, które opierały się przede wszystkim na sprawnej i niezawodnej komunikacji wewnętrznej kształtującej bezpieczne zachowania pracowników.

Niniejsza publikacja prezentuje wypracowane i stosowane przez różne spółki górnicze modele komunikacji wewnętrznej, które kształtowały bezpieczne zachowania pracowników w branży energetycznej podczas pandemii koronawirusa. Autorki dokonały porównania wprowadzonych działań kształtujących bezpieczne zachowania oraz powstałych modeli komunikacji wewnętrznej podczas nadzwyczajnego trybu pracy. Analizę porównawczą wykorzystywanych narzędzi komunikacji w poszczególnych modelach dokonano

Słowa kluczowe: *bezpieczeństwo, pandemia, motywacja, komunikacja, sektor surowcowy*

Application of Clustering Method in Different Geophysical Parameters for Researching Subsurface Environment

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Abstract

Safety of construction needs knowledge of physical parameters as stiffness or porosity of the subsurface environment. Combination of different geophysical methods such as electrical resistivity imaging and multichannel analysis of surface waves can provide distributions of resistivity and shear velocity which are responsible for the underground physical parameters. Their joint interpretation can solve individual problems of none-uniqueness of the solutions when expressing two inversion results to describe environment characteristics. In our work, the k-means clustering method can categorize the two parameters into specific zones that can help to interpret the geophysical data effectively. Our workflow consists of two stages in which two independent geophysical data are inverted and the k-means clustering is applied to the two results for achieving the specified groups. The collocated geophysical data are measured in District 9, Ho Chi Minh City, Vietnam. Matching with the geology drillhole information, the joint results generally present layered medium with the upper zone having smaller resistivity and shear velocity values and the bottom zone of stronger stiffness.

Keywords: *Electrical Resistivity Imaging, MASW, K-means Clustering*

Introduction

Colocation of different geophysical data is important in remedying non-uniqueness of solutions issue and improving accuracy of their interpretation (Le et al., 2019, Gallardo and Meju, 2004, Le et al., 2016a, Haber and Oldenburg, 1997, Moorkamp, 2017). Like minerals, hydrocarbon, ground water and hydrothermal sectors, civil construction have also applied multichannel analysis of surface wave (MASW) and electrical resistivity imaging (ERI) survey methods for validating stiffness of shallow underground environment (Mahajan et al., 2015).

ERI method can investigate electrical resistivity characteristics of a medium for tracking variation of stiffness of soil rock, existence of groundwater or distribution of geological formations (Telford et al., 1990, Sharma, 1995, Hamzah et al., 2007, Costall et al., 2018, Sikandar et al., 2010, Loke and Barker, 1995). Besides, MASW method can produce shear wave velocity model that can evaluate stability of soil rocks in civil engineering. The low velocity can respond to weak areas whereas the high one can guarantee the harder environment.

For interpreting the environment structures, geophysical joint/cooperative inversion is used for constraining each inverted geophysical (Gallardo and Meju, 2004, Gallardo and Meju, 2011, Le et al., 2016a, Le et al., 2019). Cross-gradient constraints or prior model constraints (Gallardo and Meju, 2004, Gallardo and Meju, 2011, Le et al., 2016a, Le et al., 2019) can utilize their individual geometry for solving problems of none-uniqueness of the solutions.

For enhancing data interpretation, our research purpose is to link two geophysical parameters through using defining each lithology setting after having independent inverted model. The two geophysical methods are electrical resistivity imaging and multichannel analysis of surface wave (Sauvin et al., 2011, Wisén and Christiansen, 2005, Cardarelli et al., 2014). The method for joining two geophysical models as resistivity and velocity is k-means clustering in which each lithological type can be represented of one or two k-means clusters (Le et al., 2016a, Le et al., 2019).

In our research, distribution of resistivity and shear velocity in a high-tech park, Ho Chi Minh City, Vietnam, is built for evaluating soil foundation structures. K-means clustering applied to the models can illustrate layers of clay and sands with different level of stiffness in terms of their inverted geophysical values.

Study area

Being the east gate of Ho Chi Minh City (HCMC), Thu Duc City plays a role as the newly emerging socioeconomic factor connecting Ho Chi Minh City with other southeast Provinces. Our geophysical survey including seismic and resistivity data was conducted in the One Hub project (Fig. 1), a high-tech park for examination of its soil foundation structures.

The subsurface geological materials of HCMC are divided into two main lithological units as Pleistocene and Holocene sediments (Le et al., 2020, Nguyen, 2016, Nguyen et al., 2022). The shallow geology information of the One Hub project area can consist of five layers: (i) the soil cover, (ii) dark gray silty clay, being plastic flow with depth from 1.5 to 5 meter, (iii) yellow or brown mixture of clay and sand being soft plastic, (iv) clay or sandy clay with gray-white, yellow brown, red-brown being plastic hard in the depth over 5 meter to over 20 meter, and (v) yellow sand, sand mixed with gravel (Nguyen et al., 2022).

The survey length for collocated measurement of the electrical resistivity imaging and MASW methods is 170 m. Three drill holes was setup for understanding lithology structures up to 30 m.

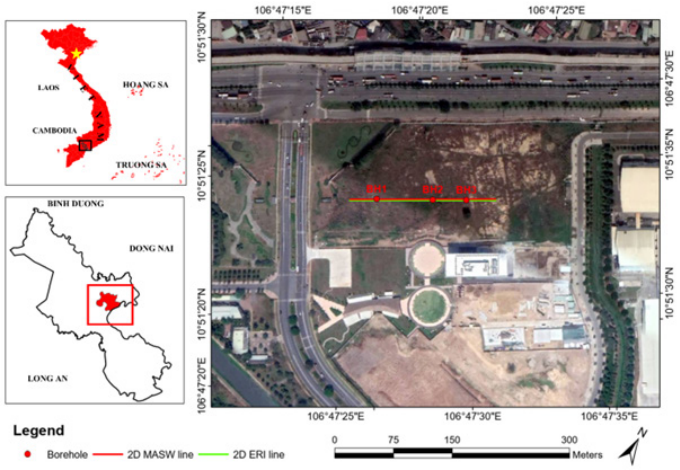

Fig. 1. Survey map and Vietnam map

Rys. 1. Mapa geodezyjna i mapa Wietnamu

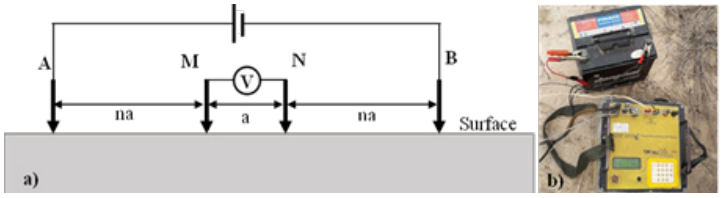

Fig. 2. a. Wenner-Schlumberger array with geometric factor K = πn(n+1)a; b. MiniSting R1 meter (AGI, 2022)

Rys. 2. a. Tablica Wennera-Schlumbergera z czynnikiem geometrycznym K = πn(n+1)a; b. Miernik MiniSting R1 (AGI, 2022)

Methodology

Our workflow focuses on three parts: (i) building electrically conductivity model from geoelectric method, (ii) setting up shear velocity model from the multichannel analysis of surface wave method, and (iii) clustering the two models for limited meaningful groups reflecting underground soils.

Electrical resistivity imaging: building electrically conductivity model

We would mainly use the geo-resistivity method to investigate the electrically conductivity of underground structures. The technique needs to collect the potential differences between two points on the ground with two or more additional electrodes after injecting an electric current into the ground through two electrodes (Loke and Barker, 1995, Loke, 1999). Ratio between the potential differences and the electric current is a measurement of the electrical resistance of the soil material known as apparent resistivity, (Loke and Barker, 1995, Loke, 1999) (Fig. 2). The 2D survey length is 170 m. Then, the data analysis process as inversion is applied to build the electrically resistivity model for delivering the answer to the project about soil stability and stiffness of the interest area.

The principle of the ERT is to solve the famous relation as known as Ohm law in calculating electrically conductivity distribution (Mufti, 1976, Akca, 2016, Telford et al., 1990, Ghanati et al., 2020):

$$\vec{J} = \sigma \vec{E} \tag{1}$$

The electric field and potential difference between two points on the ground can be related through the equation:

$$\vec{E} = -\nabla \Phi \tag{2}$$

Moreover, gradient of current density versus three axes (i.e., x, y, and z) has relationship with current as the equation below:

$$\nabla . J = \left(\frac{I}{\Delta V}\right) \delta(x - x_s)\delta(y - y_s)\delta(z - z_s) \tag{3}$$

where J electrically current density, σ electrically conductivity, E electric field, ΔV the volume. The Dirac delta function, δ(a), is shown as

$$\delta(a) = \begin{cases} 1 \; if \; a = 0 \\ 0 \; if \; a \neq 0 \end{cases}$$

Combination of the three equations (1), (2), and (3) can lead to the general equation (4):

$$-\nabla \bullet [\sigma(x,y,z))\nabla \Phi(x,y,z)] = \left(\frac{I}{\Delta V}\right) \delta(x - x_s)\delta(y - y_s)\delta(z - z_s) \tag{4}$$

Equation (4) which express the calculation of potential difference are dependent on conductivity model if the prior current is known play a crucial role as modeling stage in inversion procedure (Mufti, 1976, Akca, 2016).

Inversion is minimization of the objective function for building resistivity model after reducing difference between the real data and synthetic data (see Fig 3) (Meju, 1994).

In our research work, the source code Elris (Akca, 2016) is used for inverting the geoelectric data. Smooth constrain is used in minimizing the object function presented in the forming update model:

$$\Delta m_i = (J^T W_d^T W_d J + \lambda C)^{-1} (J^T W_d^T W_d \Delta d - \lambda C m_{i-1}) \tag{5}$$

Where Δm_i the model update showing variation of old and new values in a position, J the Jacobian matrix, λ the damping

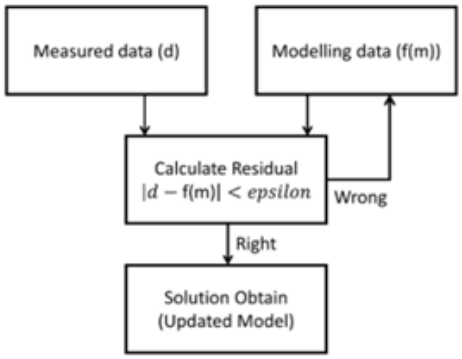

Fig. 3. Inversion procedure (Meju, 1994)
Rys. 3. Procedura inwersji (Meju, 1994)

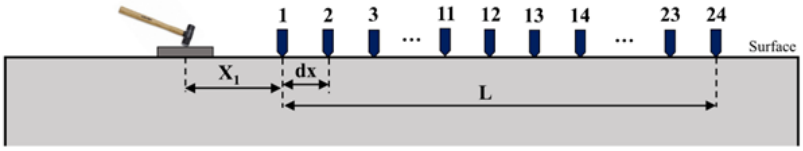

Fig. 4. MASW survey map with representation of active source (i.e., hammer) and 24 geophones
Rys. 4. Mapa pomiarowa MASW z przedstawieniem aktywnego źródła (tj. młota) i 24 geofonów

factor, Δd data discrepancy, i expressing the iteration number, W_d data weighting matrix relating to the standard deviation of data recordings, C the five-point finite difference Laplace (Mufti, 1976, Akca, 2016).

MASW theory

Raleigh waves as surface seismic wave are often seen as noises in conventional seismic methods as refraction or reflection. However, the surface waves are very useful in investigations of soil stiffness (Xia et al., 1999, Park et al., 2018). They are created from interaction of P and S waves at ground surface. The Raleigh equation (6) expresses their contributions as follows (Novotny, 1999):

$$\left(2-\frac{c^2}{V_S^2}\right)^2 = 4\left(1-\frac{c^2}{V_P^2}\right)^{\frac{1}{2}}\left(1-\frac{c^2}{V_S^2}\right)^{\frac{1}{2}} \quad (6)$$

where, c is Raleigh seismic wave velocity, Vs and Vp are shear and primary velocities, respectively.

The modelling function F (Xia et al., 1999, Schwab and Knopoff, 1972) is responsible for building the Raleigh waves dispersion curves in a layered earth model:

$$F(f, c, V_S, V_P, \rho, h) = 0 \quad (7)$$

where, c is known as the Raleigh velocity, f as frequency, V_S as shear velocity, V_P as compressional P wave velocity, ρ as density, and h as thickness.

In our paper, the active MASW mode was utilized by placing the multiple receivers (i.e., Seistronix RAS-24 geophones (Seistronix)) along a 2D survey line with single shots. For each shot, a seismograph is formed from vibrations measured by 24 geophones. Geophone spacing, sampling rate and record length were set at 1 m, 0.25 ms and 1 s, respectively (Fig. 4). The source offsets were sequentially set at 5 m to the left of the first geophone (Fig.4). A 9-kg sledgehammer was employed to knock on the metal plate to generate the seismic waves.

Inversion procedure: Dispersion curves are extracted from seismogram datasets measurement in the field. The curves expressing relation between phase Raleigh velocity versus frequency are input for the inversion procedure. Inversion approach is to build the shear velocity model in terms of reducing misfit of the synthetic and real data of phase Raleigh velocity. Minimization of the object function (equation 7) and shear wave velocity model can be conducted (Xia et al., 1999):

$$\Phi = \|J\Delta x - \Delta b\|W\|J\Delta x - \Delta b\| + \alpha\|\Delta x\|^2 \quad (8)$$

$$\Delta x = V(\Lambda^2 + \alpha I)^{-1}\Lambda U^T d \quad (9)$$

Where, x represents solution of shear wave velocity, b shows measured phase Raleigh velocity, J as Jacobian matrix expressing the first derivative function of Raleigh velocity versus shear velocity, and α is damping factor. Δb is the difference between the synthetic and real data of phase Raleigh velocity. W is the covariance matrix relating measured error and $W=L^T$ L. Δx is the difference of the initial model and updated model. Matrixes V and Λ are calculated from A=LJ and decomposition of $A=U\Lambda V^T$. d=Lb. I is the unit matrix.

For updating the shear velocity model from the measured MASW data, we have used the PS software (Park Seismic LLC, 2022) to investigate shallow underground structures. The MASW inversion procedure follows the scheme discussed in Fig. 3.

K-means approach

K-means, an effective clustering approach, is well-tested and easily executed in many geophysical research areas (Di Giuseppe et al., 2014, Le et al., 2016b, Zhao et al., 2015, Shen et al., 2005). In Lindsten et al. (2011)'s work, the idea for K-means clustering technique was first proposed by Hugo Steinhaus in 1957. Its main idea "minimises the sum, over all clusters, of the within-cluster sums of point-to-cluster-centroid distances" (MathWorks, 2014) and its equations are presented below (Lindsten et al., 2011, Le, 2017):

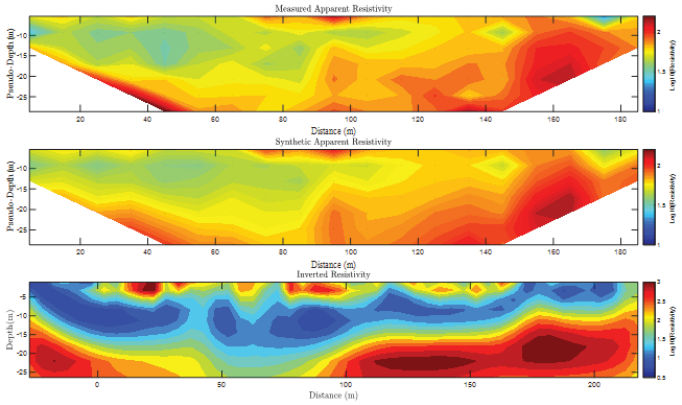

Fig. 5. Distribution of Resistivity for the survey area. The top image represents the measured apparent resistivity, the middle image shows the synthetic data and the below image is the inverted resistivity model after using Elris source (Akca, 2016)

Rys. 5. Rozkład rezystywności dla badanego obszaru. Górny obraz przedstawia zmierzoną rezystywność pozorną, środkowy obraz pokazuje dane syntetyczne, a poniższy obraz to odwrócony model rezystywności po użyciu źródła Elris (Akca, 2016)

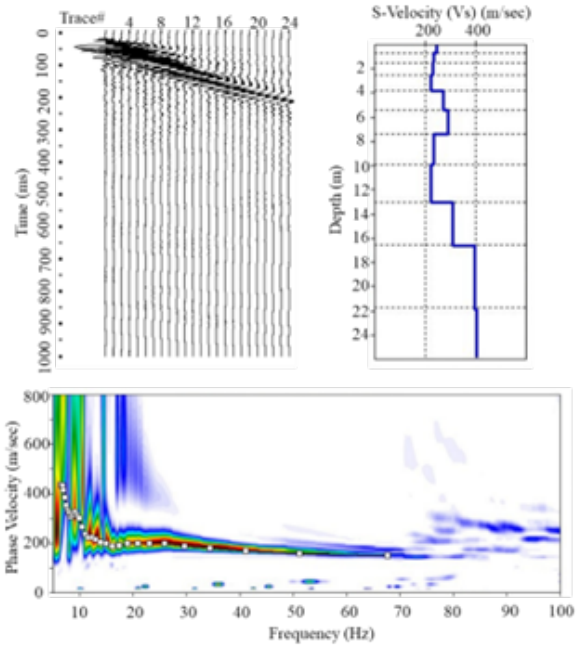

Fig. 6. Seismic data, dispersion curve (Raleigh phase velocity), and 1D VS profile extracted from the MASW inversion of BH1

Rys. 6. Dane sejsmiczne, krzywa dyspersji (prędkość fazowa Raleigha) i profil 1D VS wyodrębniony z inwersji MASW BH1

$$E = \sum_{i=1}^{k} \sum_{i=1}^{n_i} d(x_{ij}, m_i) \quad (10)$$

$$d(x_{ij}, m_i) = (x_{ij} - m_i)(x_{ij} - m_i)^T \quad (11)$$

where E, an objective function (Shen et al., 2005), is the sum of square-errors for all data observations, x_{ij} the jth observation in the ith cluster, m_i the center value or mean of the cluster I, n_i the total number of observations in each cluster i, and k the number of clusters (Lindsten et al., 2011).

Four steps in the k-means approach are listed below:

Step 1: K cluster centroids is initially chosen

Step 2: Allocate new observations belong to one cluster with the closest centroid.

Step 3: Updating the new values of the centroids from Step 2 or new centroid for each cluster is computed.

Step 4: Repeating the step 2 until the new centroids are not changed.

The way to choose the optimal cluster of k-means algorithm can follows some mathematical criterion (Davies and Bouldin, 1979) or lithology information extracted from drill holes (Le et al., 2016a, Le et al., 2019).

Results and discussion

We have collected the geophysical data as MASW data and geoelectric data. Their collocated profile length is 170 meters. Noise filters for each data are applied prior running inversion. The inverted results are input for clustering procedure.

ERI result

The 2D ERI data was collected by the MiniSting R1 meter manufactured by Advanced Geosciences Inc (AGI, 2022) and using a Wenner-Schlumberger configuration (Fig.2.) (Nguyen et al., 2022). The first sequence of spacing factor (n) is 1 with a minimum of electrode spacing is 10 m. The last sequence of a spacing factor equals 7 corresponding to the median depth of investigation about 28.5 m (Edwards, 1977).

The Elris code (Akca, 2016) follows the smoothness inversion style for producing the resistivity model. The starting mod-

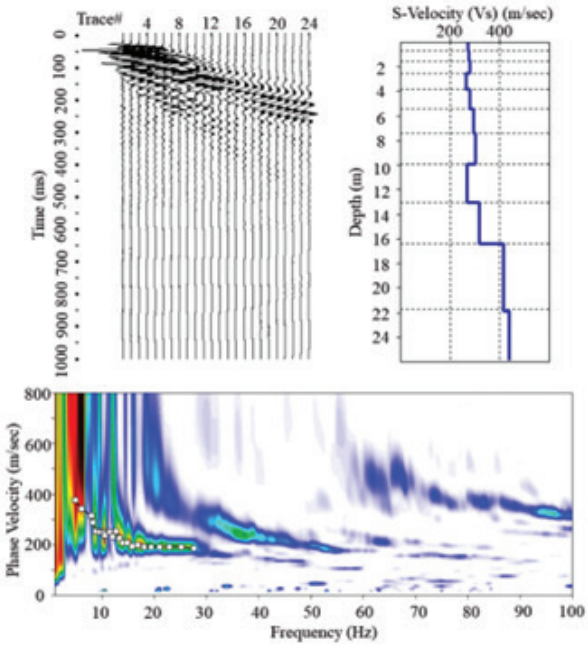

Fig. 7. Seismic data, dispersion curve (Raleigh phase velocity), and 1D VS profile extracted from the MASW inversion of BH2
Rys. 7. Dane sejsmiczne, krzywa dyspersji (prędkość fazowa Raleigha) i profil 1D VS wyodrębniony z inwersji MASW BH2

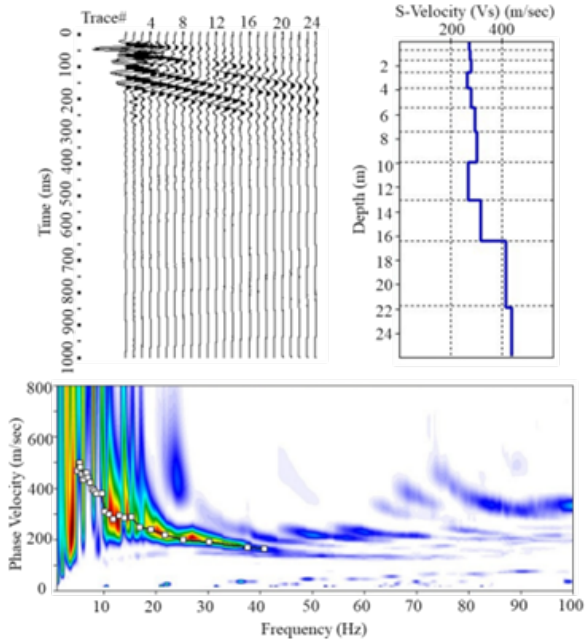

Fig. 8. Seismic data, dispersion curve (Raleigh phase velocity), and 1D VS profile extracted from the MASW inversion of BH3
Rys. 8. Dane sejsmiczne, krzywa dyspersji (prędkość fazowa Raleigha) i profil 1D VS wyodrębniony z inwersji MASW BH3

el is the homogenous model with the constant value extracted from the background resistivity as 66 Ω.m. After 19 iterations, data difference between real and synthetic data is 14.53%.

The resistivity model presents three distinct layers with the maximum depth as 25 m. The first layer can be interpreted as the cover with about 100 Ω.m, the second layer is responsible for the most conductive one, and the third layer is the most resistive (Fig. 5).

MASW result

The analysis of the MASW-method data is conducted as three steps (See Figs. 6, 7, and 8):

The seismic records were loaded into the PS software (Park Seismic LLC, 2022) to display and transform the raw data to phase velocity-frequency spectrum to get the dispersion images. In this study, the frequency and phase velocity were set in the range of 0 -100 Hz and 1-800 m/s, respectively.

Manual process for picking the peaks values from the dispersion image is to generate the dispersion curve. This dispersion curve is the real data for MASW inversion approach in building shear velocity model.

The shear wave velocity (Vs) distribution was calculated from an iterative inversion process (Xia et al., 1999). In inversion scheme, the nonlinear least square technique is needed

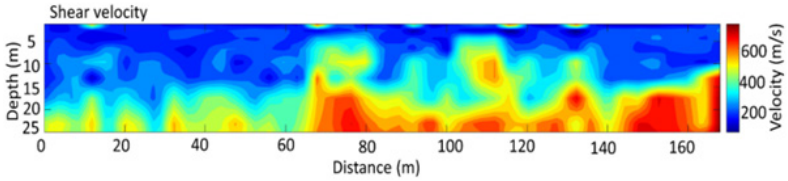

Fig. 9. MASW velocity model
Rys. 9. Model prędkości MASW

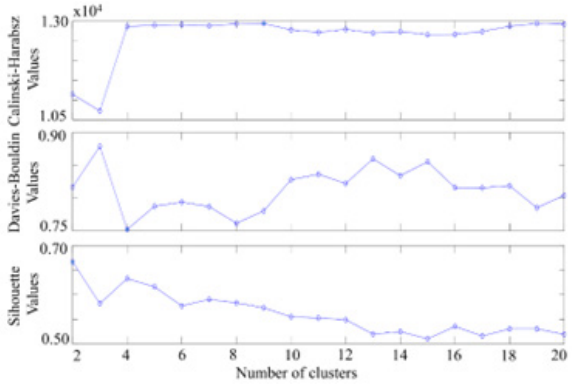

Fig. 10. Three criteria for choosing the optima numbers
Rys. 10. Trzy kryteria wyboru liczb optymalnych

to generate the 1D VS (shear wave velocity) profile in which misfit between real and synthetic data is reduced.

The 1D MASW inversion stops after 3 iterations. The match of the synthetic and real data is larger than 90%. The 1D model VS profile is divided into 11 layers from surface to the depth of 26 m (Figs. 6,7,8). Their thickness values increases versus depth (from 1 m to 6 m). The shear wave velocity ranges from 200–500 m/s.

The 2D shear velocity model (see Fig. 9) is formed from 43 1D-shear velocity curve extracted from the MASW inversion. It looks like the underground structures consists of two distinct zones as low and high shear velocity values. The low velocity zone starting from surface to 15 m depth can be divided into two sub layers while the high velocity zone is believed to correlate with zone of the high stiffness.

Clustering of ERI and MASW result

Our purpose of using k-means clustering algorithms is to figure out compatibility between our inverted geophysical results (i.e., resistivity and velocity models) with lithology information extracted from the three drill holes (BH1, BH2, and BH3).

For testing k-means clustering with these two datasets as resistivity and velocity, we have run all 19 choices with number of k-means cluster groups ranging from 2 to 20. Then, we also use three criteria for choosing the optima numbers (Fig. 10). The criteria Calinski-Harabsz, Davies-Bouldin (Davies and Bouldin, 1979), and Sihouette (Matlab, 2019) prefer the number of clusters as 9, 4, and 2, respectively.

For further interpretation about geology structures, we have plotted the input of k-means algorithm and its clustering results in Fig. 11. We also added one result processed from the cluster 7. The cluster 7 is got from number of geology sediments in three drill holes BH1, BH2, and BH3. The results from indexes 7 and 9 looks similar with structures of the geophysical data (resistivity and velocity models).

The great compatibility between lithology and 7-clustered image can prove that the validity of velocity and resistivity models (Fig. 12). Boundaries of different sediment layers are greatly matched with ones of lithology structures.

In Fig. 13, cross-plot between of two geophysical models as resistivity and velocity presents roughly three trends. One is a line parallel to the y axis (log10 of Resistivity), the other reflects the middle value of tangent angle and the one is smallest angle. It looks like there is existence of the most conductive layer with velocity varying from medium to maximum (Fig. 11).

Conclusion

Combination of the two geophysical models can enhance knowledge of the soil rock foundation which is useful for safety of construction. The interest environment are k-means analyzed with different clustering indexes. The seven clusters are chosen for processing. In the results, there only six lithology within the specified depth 25 m. Interestingly, one important conductive but average to largest velocity values exist and below 20 m, one layer of being highly resistive and maximum velocity is the most stiffness. The collocated geophysical data are measured in District 9, Ho Chi Minh City, Vietnam. The results reflect high stability of the soil where layers of clay and sands with strong stiffness are homogenous.

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Conflicts of Interest: The authors declare no conflict of interest.
Author Contribution: All authors contribute to data processing and writing the manuscript. CVAL mainly write the manuscript. NNKN processed MASW data, NVT and CVAL processed ERI data. CVAL processed clustering and lithology interpretation.

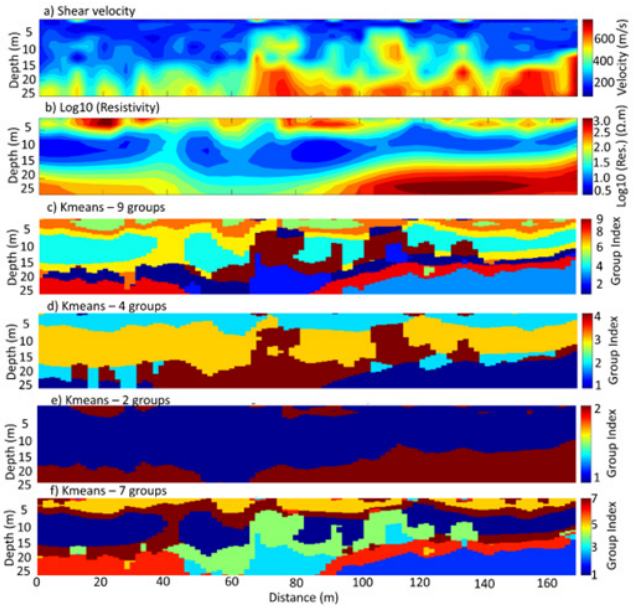

Fig. 11. Resistivity and Velocity and clustering results of different k-means

Rys. 11. Wyniki rezystywności i prędkości oraz grupowania różnych k-średnich

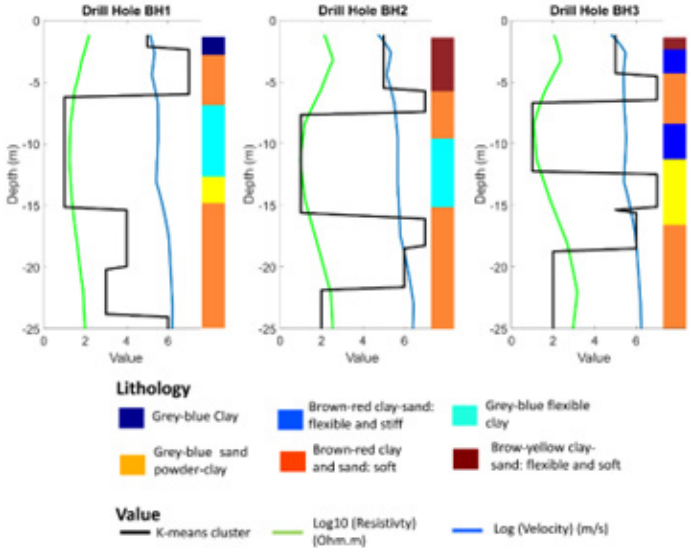

Fig. 12. Representation of Resistivity and Velocity, clustering results versus depth in the three drill holes, BH1, BH2, and BH3

Rys. 11. Wyniki rezystywności i prędkości oraz grupowania różnych k-średnich

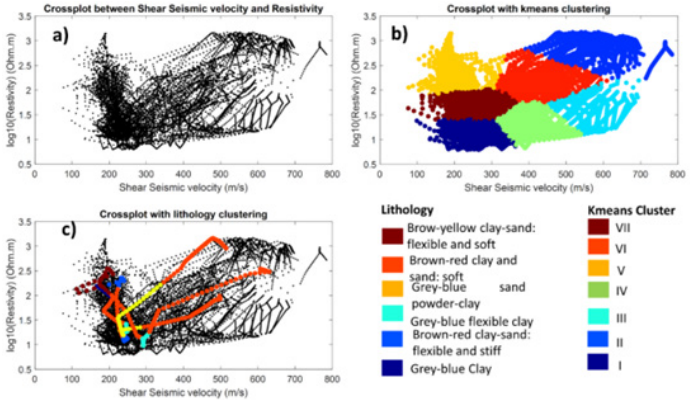

Fig. 13. Cross-plot of Resistivity and Velocity with and without overlaid information of k-means clusters which is extracted from 7-index and lithology information

Ryc. 13. Wykres krzyżowy rezystywności i prędkości z i bez nałożonych informacji o klastrach k-średnich, który jest wyodrębniony z 7-indeksów i informacji litologicznych

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Zastosowanie metody klastrowania w różnych parametrach geofizycznych do badania środowiska podpowierzchniowego

Bezpieczeństwo konstrukcji wymaga znajomości parametrów fizycznych, takich jak sztywność czy porowatość środowiska podpowierzchniowego. Połączenie różnych metod geofizycznych, takich jak obrazowanie rezystywności elektrycznej i wielokanałowa analiza fal powierzchniowych, może dostarczyć rozkłady rezystywności i prędkości ścinania, które są odpowiedzialne za parametry fizyczne podziemnych warstw. Ich wspólna interpretacja może rozwiązać indywidualne problemy niejednoznaczności rozwiązań przy wyrażaniu dwóch wyników inwersji do opisu cech środowiska. W naszej pracy metoda grupowania k-średnich może podzielić dwa parametry na określone strefy, co może pomóc w skutecznej interpretacji danych geofizycznych. Nasz przepływ pracy składa się z dwóch etapów, w których dwa niezależne dane geofizyczne są odwracane, a grupowanie k-średnich jest stosowane do dwóch wyników w celu uzyskania określonych grup. Zebrane dane geofizyczne są mierzone w Dystrykcie 9, Ho Chi Minh City, Wietnam. Dopasowując się do informacji uzyskanych z odwiertów geologicznych, wyniki połączeń ogólnie przedstawiają ośrodek warstwowy, w którym górna strefa ma mniejsze wartości rezystywności i prędkości ścinania, a dolna strefa ma większą sztywność.

Słowa kluczowe: *obrazowanie oporności elektrycznej, MASW, grupowanie K-średnich*

Wartość rynkowa górniczych spółek eksploracyjnych notowanych na AIM London

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Abstract

Projekty eksploracyjne to specyficzny rodzaj projektów, które w pierwszej fazie są bardzo czasochłonne. Wymagają one również dużej ilości nakładów inwestycyjnych, przez co tracą swoją atrakcyjność na parkietach giełdowych, w dużej mierze opartych na spekulacjach. Poszukiwanie inwestorów w tego typu środowisku wymaga precyzyjnie opisanej historii złoża - traktowanego jako projekt eksploracyjny. Charakterystyka rynków alternatywnych pokazuje, że istotną rolę w podejściu do wyceny spółek ma forma ich finansowania. Spółki junior mines, ze względu na swój innowacyjny charakter szukają różnych rodzajów finansowania, począwszy od pozyskiwania kapitału od spółek, wobec których są zależne a skończywszy na emisji akcji na rynkach alternatywnych – dotyczy to jednak największych spółek eksploracyjnych. Każdy ze wspomnianych elementów – źródła finansowania, ryzyko inwestycyjne, długi czas zwrotu – stanowi istotny wkład w ostateczną wycenę wartości rynkowej spółki. Dodatkowym, bardzo często najtrudniejszym elementem wyceny jest ekonomiczne oszacowanie wypracowanego w obszarze eksploracji know-how, które bardzo często stanowi o przewadze konkurencyjnej na rynku.

Słowa kluczowe: *wartość rynkowa, spółki górnicze, aim londyn, rynek alternatywny*

Wstęp

Spółki eksploracyjne stoją przed bardzo dużym wyzwaniem rynkowym, które w czasach pandemii dotyczy niemal wszystkich branż – gwałtowny wzrost cen surowców. Reakcja na wzrost cen wymaga inwestycji w nowoczesne technologie umożliwiające dostarczanie zaufanych oraz wysoce weryfikowalnych danych, które będą mogły usprawnić i uwierzytelnić procesy w ramach projektów eksploracyjnych. Zapotrzebowanie na różnego rodzaju surowce nieustannie wzrasta i bazując na prognozach długookresowych Christmanna, obejmujących najbliższe trzydzieści lat, zapotrzebowanie w dalszym ciągu będzie rosnąć (Christmann, 2018). W związku z tym spółki junior mines mogą liczyć na wysokie zainteresowanie potencjalnych inwestorów oraz korporacji górniczych, które będą chciały poszerzyć swoje portfolio projektowe, tym samym realizując strategię rozwoju o charakterze poziomym. Biorąc pod uwagę specyfikę procesu dokapitalizowania spółki o charakterze innowacyjnym, inwestorzy podchodzą do tego typu zagadnień jak do spółek typu start-up, chcąc generować możliwie największą ilość zysku w możliwie jak najszybszym okresie. Działają oni na największych rynkach giełdowych. Jednak specyfika spółek junior mines wymaga nieco więcej czasu i nakładów. Projekty eksploracyjne posiadają swój cykl życia, który w swoich pierwszych fazach jest wysoce kapitało i czasochłonny. Stąd też spółki junior mines notowane są na rynkach alternatywnych – rynkach, na których kapitalizacja oraz wielkość spółek z założenia jest niższa niż na głównych parkietach giełdowych. Do najważniejszych z punktu widzenia spółek eksploracyjnych rynków należą przede wszystkim londyński AIM London, australijski ASX oraz kanadyjski TSV-X. Niniejsza publikacja ma na celu przybliżyć spółki notowane na londyńskim parkiecie, porównując tym samym praktyki oraz zachowania giełdowe. Przeprowadzona została również analiza spółek eksploracyjnych pod kątem ich podstawowych wskaźników finansowych, niezbędnych do rozpoczęcia prac nad analizą możliwości wyceny spółek eksploracyjnych.

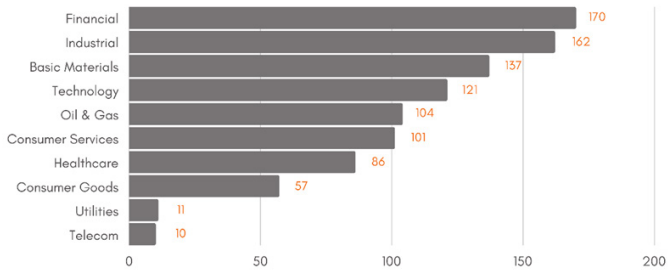
Aktualny stan wiedzy

Przeprowadzono analizę literaturową zagadnień dotyczących funkcjonowania spółek junior mines na giełdzie papierów wartościowych w kontekście możliwości zwiększenia wartości przedsiębiorstwa i budowania długotrwałego modelu opłacalności inwestycyjnej projektów eksploracyjnych. Podejście do budowania wartości uległo zmianie biorąc wzgląd na czynniki wymienione w literaturze (Wirth, Kubacki and Napierała, 2013): stworzenie karty strategicznej, definiowanie wartości zasobów niematerialnych, podejście do marketingu i jego wpływu na strategię oraz rozwój koncepcji społecznej odpowiedzialności biznesu, będącej odpowiedzią na wyzwania stojące przed przedsiębiorstwami.

Kluczowym z punktu widzenia zrozumienia problemu było w pierwszej kolejności zbadanie podstaw praktyk eksploracyjnych (Wellmer, Dalheimer and Wagner, 2008) oraz zapoznanie się ze stosowanymi w praktyce metodami wycen spółek (Damodaran, 2007).

Biorąc pod uwagę wspomniane czynniki zbadano również ogólną akceptowalność projektów górniczych (Bergeron, 2021). Analiza makro otoczenia ma znaczący wpływ na wycenę spółek eksploracyjnych oraz opowieść, którą muszą przedstawić potencjalnym inwestorom oraz akcjonariuszom (Damodaran, 2017). Problem pozyskiwania kapitału może dotyczyć przede wszystkim dwóch obszarów. Pierwszym z nich jest możliwość finansowania projektów eksploracyjnych (Eggert, 2010) oraz możliwości pozyskiwania kapitału przez spółki junior mines (Iddon, Hettihewa and Wright, 2013), które w większości korzystają z funduszy wewnętrznych spółek, które posiadają już kopalnie oraz środki na

Rys. 1. London Stock Exchange – struktura grupy giełdowej
Fig. 1. London Stock Exchange – exchange group structure



Rys. 2. Główne sektory rynku London AIM i liczba spółek w sektorze
Fig. 2. Main sectors of the London AIM market and number of companies in the sector

eksploracje kolejnych złóż. Dużym wyzwaniem dla spółek eksploracyjnych jest również uzyskanie finansowania zewnętrznego dłużnego. Powodem takiego stanu jest brak aktywów pod zabezpieczenie kredytu. Z tego powodu spółki muszą finansować się w sposób rynkowy, będąc aktywnym uczestnikiem obrotu akcjami. Podejmowane do tej pory próby wyceny spółek junior mines (Miranda, Brandão and Lazo Lazo, 2017) metodą opcji realnych dla charakterystyki przedsięwzięcia wydobywczego wskazują na niedokładności wyliczeń rzędu 25%, co ma istotny wpływ procesy decyzyjne firm eksploracyjnych. Podjęto również próby stworzenia modelu drzewa decyzyjnego dotyczącego podejmowania dalszych prac eksploracyjnych (Guj, 2008) opartego na badaniu ryzyka (współczynnika tolerancji ryzyka RT) oraz rozkładu prawdopodobieństwa wystąpienia zdarzeń w trakcie eksploracji.

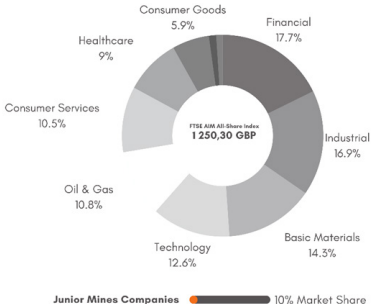
Cena akcji spółki musi również uwzględniać międzynarodowe standardy wyceny, przyjęte w różnych krajach. Literatura (Wirth, 2006) wskazuje na zastosowanie metod porównawczych oraz kosztowych w podejściu do wyceny spółek junior mines.

Charakterystyka spółek juniorskich wymaga elastycznego podejścia do zarządzania, tym samym dając możliwość do wypracowania nowych, bardziej dopasowanych metod zarządzania finansami oraz ryzykiem. Mimo wysokiego ryzyka działalności spółki chętnie debiutują na międzynarodowych parkietach, realizując tym samym politykę generowania wartości poprzez finansowanie obrotem akcjami. Do największych międzynarodowych parkietów należy między innymi londyński rynek alternatywny (z ang. Alternative Investment Market – AIM), którego charakterystykę przeanalizowano w kolejnym rozdziale.

Charakterystyka londyńskiej giełdy

Londyńska giełda alternatywna została założona dla małych i średnich przedsiębiorstw, które spełniając szereg kryteriów mogą rozpocząć poszukiwanie inwestorów oraz doradców. Rynek zrzesza firmy z dziesięciu różnych sektorów gospodarki o łącznej wartości ponad 100 bilionów funtów. Strukturę grupy giełdowej przedstawiono na rysunku 1.

Proces złożenia pierwszej publicznej oferty (z ang. Initial Public Offer – IPO) wymaga przejścia czterech głównych etapów. Pierwszy z nich to konsultacje z zespołem analityków London Stock Exchange, który analizuje nadchodzące plany inwestycyjne, tym samym przygotowując zarówno zalety oraz wady wejścia na rynek giełdowy. Okres ten trwa zazwyczaj od 3-6 miesięcy i charakteryzuje się dużą ilością nieformalnych spotkań oraz dyskusji, które mają ułatwić start. Drugi etap to czas przygotowania oraz planowania, trwający maksymalnie 12 miesięcy. Okres ten rozpoczyna się doborem doradców oraz w szczególności nominowanego doradcę (z ang. Nominated Adviser - NOMAD) – osobę, która związana jest zawodowo z bankiem inwestycyjnym. NOMAD ma za zadanie przeprowadzenie analizy typu due diligence, pod kątem zdolności finansowej wnioskodawcy. Po zatwierdzeniu i pozytywnej opinii prowadzone są oficjalne negocjacje nad umową z doradcą, firmą prawniczą, brokerem oraz firmą raportującą finanse. Przygotowywany jest również harmonogram oraz niezbędna dokumentacja, umożliwiająca weryfikacje oraz negocjacje pierwszego publicznego ofertowania. Trzeci etap trwa do dwóch miesięcy, gdzie finalizowane są dokumenty podpisywane przez brokerów, trwają spotkania z inwestorami oraz umieszczane są pierwsze ogłoszenia związane z pub-



Rys. 3. Procentowy udział rynku spółek junior mines wśród notowanych spółek
Fig. 3. Percentage market share of junior mines among listed companies

Tab. 1. Porównanie wymagań kwalifikowalności dla spółek junior mines, spółek major mines oraz standardowych spółek notowanych na London AIM
Tab. 1. Comparison of eligibility requirements for junior mines, major mines and standard companies listed on London AIM

Warunki kwalifikowalności	**Major mining companies (Premium Equity)**	**Junior mines companies (AIM)**	**Standard listed company (Standard Equity)**
Powołanie sponsora	Wymagane	Wykazanie nominowanego doradcy (NOMAD Rules)	Niewymagane
Sprawdzenie wiarygodności finansowej	Możliwe wyjątki dla spółek wydobywczych	Niewymagane	Niewymagane
Sprawdzenie wiarygodności aktywów	Szczegółowa kontrola większości posiadanych aktywów za okres 3 lat	Niewymagane	Niewymagane
Audyt danych historycznych	3 lata wstecz oraz audyty sprawozdań finansowych	3 lata wstecz (jeśli to możliwe), przeglądy okresowe nie później niż 9 miesięcy od daty ostatniego audytu	3 lata wstecz (jeśli to możliwe), przeglądy okresowe nie później niż 9 miesięcy od daty ostatniego audytu
Stosowanie ogólnie przyjętych standardów rachunkowości (GAAP)	IFRS, US GAAP, Australia lub Canadian IFRS, Chinese GAAP	US GAAP, IFRS, Japanese	US GAAP, IFRS, Japanese
Dystrybucja publiczna	Minimum 25% ze wszystkich akcji	Niewymagane	Minimum 25% ze wszystkich akcji
Zabezpieczenie kapitału pracującego	Wystarczający kapitał obrotowy na 12 miesięcy od daty ogłoszenia prospektu emisyjnego	Wystarczający kapitał obrotowy na 12 miesięcy od daty ogłoszenia prospektu emisyjnego	Niewymagane
Zabezpieczenie ciągłości kadry menadżerskiej oraz doświadczenie	Bez wymagań	Bez wymagań	Bez wymagań
Sprawozdawczość finansowa	Listy gwarancyjne, rozbudowane formy raportowania, procedury finansowe oraz przeglądy prognozy zysków oraz pro-forma	Listy gwarancyjne oraz udostepnienie przeglądu prognozy zysków	Listy gwarancyjne oraz udostepnienie przeglądu prognozy zysków
Cykliczność raportowania wymagań	Roczne sprawozdania finansowe Półroczne raporty finansowe Okresowe sprawozdania zarządcze	Roczne sprawozdania finansowe Półroczne raporty finansowe	Roczne sprawozdania finansowe Półroczne raporty finansowe Okresowe sprawozdania zarządcze
Kluczowe transakcje akceptowane wstępnie przez akcjonariuszy	W ramach ciągłych zobowiązań wymagana jest zgodna na znaczące nabycia (25%) oraz zbycia (5%) transakcji z podmiotami powiązanymi	W przypadku odwróconych przejęć	Niewymagane

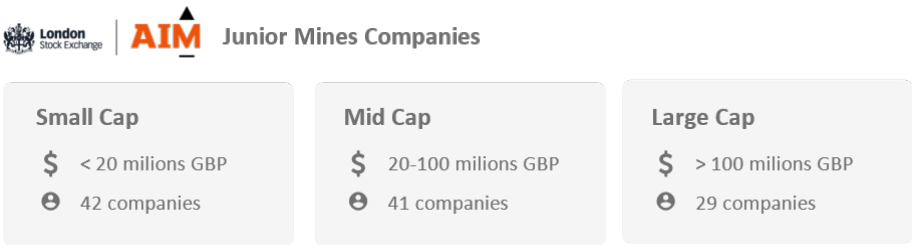
licznym ofertowaniem – co najmniej dziesięć dni od daty publikacji. W ciągu ostatnich dziesięciu dni wymagane jest ostateczne spotkanie oraz wysłanie wszystkich dokumentów do AIM. Cała procedura kończy się na pierwszej publicznej emisji oraz na przygotowaniu pierwszych rezultatów, badając tym samym efektywność spółki w przeciągu jej pierwszych stu dni. Skomplikowana procedura ma na celu weryfikacje spółek ubiegających się o publiczne ofertowanie. Jednocześnie jest ona uproszczona, w oparciu o wielkość znajdujących się na niej spółek. Różnorodność stanowi o atrakcyjności rynków alternatywnych, będących coraz ważniejszym ogniwem łańcucha giełdowego.

Główne sektory londyńskiej alternatywnej giełdy

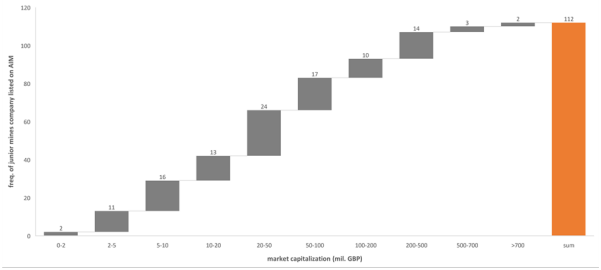
Wspomniana różnorodność dotyczy dziesięciu głównych segmentów rynku. Największym z nich jest rynek spółek finansowych oraz firm przemysłowych. Trzecim w kolejności jest rynek związany z eksploracją oraz górnictwem. Główne sektory rynku przedstawiono na rysunku 2.

Ponadto indeks sumy wartości rynkowej wszystkich spółek notowanych na AIM London wynosi 1250,30 GBP, z czego 14,3% należy do sektorów wydobywczych. Około 65% wszystkich spółek w sektorze Basic Materials stanowią spółki typu juniors, stanowiąc około 10% wartości całego rynku AIM.

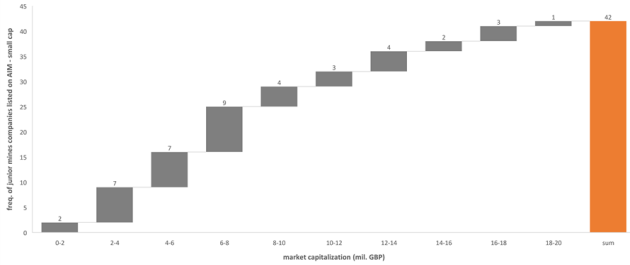
Zainteresowanie firm możliwością znalezienia potencjalnych inwestorów projektów eksploracyjnych wzrasta z każdym rokiem. Stąd wynika również potrzeba coraz dokładniejszej możliwości wyceny spółek ze wspomnianego sektora. Będąc w obrocie publicznym decyzje inwestycyjne podejmowane są wraz z doradcą, który bez niezbędnej wiedzy o projektach eksploracyjnych, może stanowić o dodatkowym



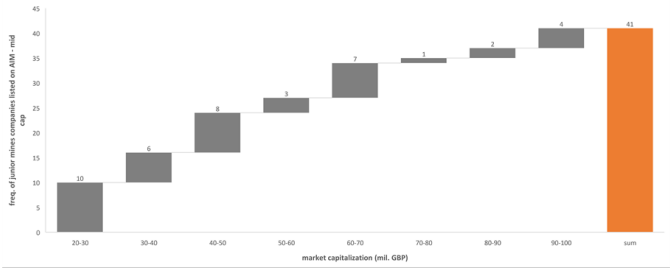
Rys. 4. Klasyfikacja spółek eksploracyjnych ze względu na wartość kapitalizacji rynkowej
Fig. 4. Classification of exploration companies by market capitalization value



Rys. 5. Częstość występowania spółek eksploracyjnych w wybranych przedziałach wartości kapitalizacji rynkowej dla całego rynku AIM London
Fig. 5. Frequency of exploration companies in selected market capitalization value ranges for the entire AIM London market



Rys. 6. Częstość występowania spółek eksploracyjnych w wybranych przedziałach kapitalizacji rynkowej dla segmentu o niskiej wartości do 20 mln GBP
Fig. 6. Frequency of exploration companies in selected market capitalization ranges for low-value segment up to £20 mln



Rys. 7. Częstość występowania spółek eksploracyjnych w wybranych przedziałach kapitalizacji rynkowej dla segmentu o średniej wartości od 20–100 mln GBP
Fig. 7. Frequency of exploration companies in selected market capitalization ranges for the segment with an average value from £20–100 mln

ryzku, które odbiłoby się na cenie oraz możliwościach inwestycyjnych spółki.

Porównanie wymagań dla spółek typu juniors ze standardowymi spółkami giełdowymi

W ramach działań na londyńskiej giełdzie wypracowano efektywne mechanizmy elastycznego zarządzania portfelami inwestycyjnymi. Zarządzanie poprzez weryfikacje wstępną umożliwia dokładną analizę spółki ubiegającej się o IPO. Tym samym spółka musi liczyć się ze spełnieniem kryteriów, zawartych w tabeli 1.

Poza wymienionymi w tabeli warunkami kwalifikowalności spółki górnicze, w szczególności badane spółki eksploracyjne, muszą spełnić specyficzne dla swojej branży warunki związane z przygotowaniem dokumentacji złoża, zgodnej ze standardami, w szczególności australijskimi, kanadyjskimi, amerykańskimi oraz południowo-afrykańskimi. Ponadto warunki te muszą zostać sprawdzone zarówno przez specjalistę z branży jak również przez nominowanego doradcę. W przypadku inwestycji dotyczących aktywów strategicznych, w kwocie powyżej dziesięciu tysięcy funtów, informacja ta musi zostać przekazana odpowiednim organom na szczeblu samorządowym lub innym organom regulacyjnym – ma to przede wszystkim związek z ryzykiem, jakim obarczone są badania eksploracyjne. Tym samym już na początku giełdowej drogi spółki górnicze – w szczególności spółki eksploracyjne – muszą zabezpieczyć swój kapitał obrotowy na dwanaście miesięcy od daty ogłoszenia prospektu emisyjnego.

Tab. 2. Porównanie parametrów wartości rynkowej dla dziesięciu spółek o najwyższej kapitalizacji w sektorze do 20 mln GBP
Tab. 2. Comparison of market value parameters for the ten companies with the highest capitalization in the sector up to £20 mln

Company name	Current price	Total Cash	Total Debt	Market Cap	Enterprise Value	Book Value
KEFI Gold and Copper	0,77	948 000	2 468 000	19 729 700	21 249 700	23 105 701
Capital Metals	9,60	1 199 612	-	16 553 952	15 354 340	2 069 244
Jangada Mines	6,30	5 004 000	-	16 291 927	11 287 927	6 982 254
Wishbone Gold	9,30	4 995 808	-	16 162 936	11 167 128	4 344 875
Thor Mining	0,70	783 000	10 000	14 023 940	13 250 940	16 027 360
Bluebird Merchant Ventures Limited	2,25	81 872	353 300	14 004 428	14 275 856	25 519 179
ECR Minerals	1,30	3 957 799	-	13 234 780	9 276 981	7 126 420
Panthera Resources	11,75	481 147	-	12 327 630	11 846 483	2 203 236
Goldplat	7,05	3 459 000	436 000	12 133 614	9 110 614	14 973 396
Galileo Resources	1,10	3 530 724	-	12 011 450	8 480 726	10 919 500

Tab. 3. Porównanie parametrów wartości rynkowej dla dziesięciu spółek o najwyższej kapitalizacji w sektorze od 20–100 mln GBP
Tab. 3. Comparison of market value parameters for the ten companies with the highest capitalization in the sector from £20–100 mln

Company name	Current price	Total Cash	Total Debt	Market Cap	Enterprise Value	Book Value
Altus Strategies	58,40	6 486 641	50 924	68 516 048	62 080 331	20 648 672
Tirupati Graphite	80,00	6 412 114	1 230 723	69 250 640	64 069 249	16 360 463
Gem Diamonds Limited	49,43	33 929 000	20 502 000	69 459 864	56 032 864	173 677 776
Savannah Resources	4,50	9 725 328	6 477	75 969 424	66 250 573	28 712 320
Bluejay Mining	8,73	5 246 915	20 896	86 000 648	80 774 629	33 077 171
Rainbow Rare Earths Limited	16,75	573 000	1 976 000	86 098 824	87 501 824	12 001 653
Shanta Gold Limited	8,64	24 839 000	5 389 000	90 517 248	71 067 248	167 721 595
Trident Royalties	36,05	8 107 000	-	90 698 912	82 591 912	81 264 216
Beowulf Mining	15,25	3 883 749	9 053	92 403 088	88 528 392	14 970 798
Ferro-Alloy Resources Limited	25,73	8 158 000	1 419 000	97 176 288	90 437 288	12 841 018

Determinanty wartości rynkowej oraz wartości księgowej

Ceny akcji oraz ich wartość są pochodnymi wielu decyzji rzutującymi również na wartość przedsiębiorstwa. W ujęciu rynkowym wartość uzależniona jest od trzech głównych czynników:

- Wartości kapitalizacji rynkowej – podstawowej miary wartości spółki notowanej na giełdzie. Zależy ona od ceny akcji oraz jej łącznej ilości. Wartość kapitalizacji rynkowej odzwierciedla wartość kapitału własnego – jednej z dwóch metod finansowania działalności.
- Wartości zadłużenia – sumy zobowiązań krótko i długoterminowych wobec wierzycieli – banków oraz innych instytucji.
- Wartości stanu gotówki – korekty dla wartości zadłużenia – najbardziej płynny czynnik, który obniża kwotę przedsiębiorstwa z racji możliwości najszybszego wykorzystania tych środków do spłaty zadłużenia.

Suma wartości kapitalizacji rynkowej oraz wartości zadłużenia pomniejszona o stan gotówki (lub ekwiwalentów w postaci zbywalnych papierów wartościowych) definiuje rynkową wartość.
Enterprise Value (EV)=Market Capitalization+Total Debt-Total Cash

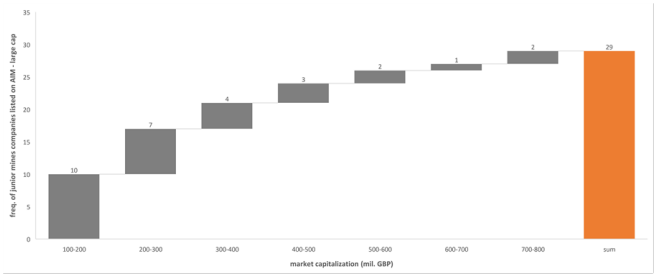
W ujęciu księgowym wartość definiowana jest jako różnica pomiędzy całkowitą wartością aktywów a całkowitą wartością zadłużenia. Wartość księgowa oparta jest na bilansie firmy – ustalana na podstawie pierwotnego kosztu zapłaconego za nabycie składnika aktywów, pomniejszona o amortyzację.
Book Value (BV)=Total Assets-Total Liabilities

Z punktu widzenia rynkowego różnica pomiędzy wartością księgową oraz wartością rynkową wskazuje na poziom przeszacowania lub niedoszacowania realnej wartości spółki. Różnica ta nazywana jest rynkową wartością dodaną (MVA).
Market Value Added (MVA)=Book Value-Enterprise Value

Nadwyżka wartości księgowej nad wartością rynkową (MVA > 0) może świadczyć o niedoszacowaniu wartości na rynku, sytuacja odwrotna (MVA< 0) mówi o przeszacowaniu wartości na rynku – tym samym o wysokim stopniu zaufania do wyników oraz planów spółki.

Klasyfikacja górniczych spółek eksploracyjnych ze względu na wartość kapitalizacji rynkowej

Wspomniane wymagania powodują, że spółki z dużą ostrożnością wchodzą na giełdę. Jednocześnie dzięki wysokim barierom wejścia, upatrują one szanse na pozyskanie finansowania na dalsze prace geologiczne.



Rys. 8. Częstość występowania spółek eksploracyjnych w wybranych przedziałach kapitalizacji rynkowej dla segmentu o wysokiej wartości – powyżej 100 mln GBP
Fig. 8. Frequency of exploration companies in selected market capitalization ranges for the high-value segment – above £100 mln

Tab. 4. Porównanie parametrów wartości rynkowej dla dziesięciu spółek o najwyższej kapitalizacji w sektorze powyżej 100 mln GBP
Tab. 4. Comparison of market value parameters for the ten companies with the highest capitalization in the sector above £100 mln

Company name	Current price	Total Cash	Total Debt	Market Cap	Enterprise Value	Book Value
Tharisa	125,89	92 355 000	36 850 000	366 206 496	310 701 496	444 427 087
Jubilee Metals Group	15,46	19 713 298	9 340 623	375 503 968	365 131 293	143 349 934
Central Asia Metals	231,21	50 743 000	61 688 000	406 996 832	417 941 832	392 540 228
Taseko Mines Limited	152,50	242 055 008	540 059 008	449 266 528	747 270 528	345 858 408
Kenmare Resources	477,78	56 543 000	130 873 000	453 518 336	527 848 336	813 101 852
SolGold	25,65	87 039 848	110 711 880	588 364 800	612 036 832	328 016 246
Atalaya Mining	426,00	140 927 008	57 663 000	588 885 376	505 621 368	459 081 756
Hochschild Mining	120,98	256 928 992	209 808 992	621 707 776	574 587 776	753 342 216
Eurasia Mining	24,99	16 067 991	550 591	713 104 640	697 587 240	22 828 481
Petropavlovsk	18,34	36 536 000	576 566 016	725 822 656	1 265 852 672	708 351 333

Tab. 5. Porównanie średnich parametrów wartości rynkowej dla sektorów przemysłowych (GBP)
Tab. 5. Comparison of average market value parameters for industrial sectors (GBP)

Industry	Current price	Total Cash	Total Debt	Market Cap	Enterprise Value	Book Value
Gold	52,80	20 185 499	59 580 411	97 145 396	136 540 308	109 207 065
Precious Metals & Mining	30,06	34 019 371	38 795 072	127 022 884	131 798 585	128 274 749
Industry Metals & Mining	41,78	18 478 133	20 578 835	99 831 533	101 932 234	77 270 258

Kapitalizacja rynkowa jako jeden z podstawowych parametrów ustalanych na rynku poprzez ceny akcji oraz ich ilość, odwzorowuje w najbardziej zbliżony sposób wahania rynkowe. Z tego powodu wskaźnik ten posłużył do zdeterminowania podziału, zaprezentowanego na rysunku 4.

Podział ten obejmuje trzy podstawowe grupy: spółki o niskiej kapitalizacji rynkowej której wartość nie przekracza 20 milionów funtów, spółki o średniej kapitalizacji, której wartość nie przekracza 100 milionów funtów oraz spółki o wysokim poziomie kapitalizacji, przekraczającym 100 milionów funtów. Zidentyfikowano łącznie 112 spółek eksploracyjnych oraz przypisano je do dziesięciu przedziałów kapitalizacji rynkowej co przedstawiono na rysunku 5.

Około 75% spółek mieści się w przedziale od 0 do 100 milionów funtów generując jedynie 20% całkowitej wartości kapitalizacji rynku junior mines. Zatem spółki z segmentu o wysokiej kapitalizacji (Large Cap) generują aż 80% wartości kapitalizacji rynkowej całego rynku spółek eksploracyjnych.

Spółki o niskiej wartości kapitalizacji rynkowej

Zidentyfikowano 42 spółki o kapitalizacji rynkowej poniżej 20 milionów funtów – gdzie 24 spółki mieszczą się w przedziale od 0 – 10 milionów funtów. Histogram z przedziałami wartości kapitalizacji zaprezentowano na rysunku 6.

Zbadano dziesięć największych pod względem kapitalizacji rynkowej spółek w tej kategorii i zestawiono je w tabeli 2.

Ceny akcji oscylują w przedziale od 0,70 – 11,75 GBP. Średni poziom gotówki wynosi 2 444 096 GBP. Zbadano również średnią wartość rynkową oraz księgową, które wynoszą kolejno: 12 530 070 GBP oraz 11 327 117 GBP.

Dla porównania, średnie wartości dla całego segmentu spółek o najniższej kapitalizacji rynkowej wynoszą:

- Średnia cena akcji: 8,01 GBP/share
- Średni poziom gotówki: 1 408 301 GBP
- Średnia wartość rynkowa: 7 352 644 GBP
- Średnia wartość księgowa: 7 559 892 GBP

Spółki o średniej wartości kapitalizacji rynkowej

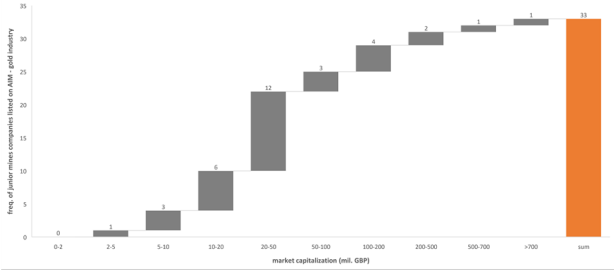
Zidentyfikowano 41 spółek o kapitalizacji rynkowej mieszczącej się w przedziale od 20 do 100 milionów funtów. Histogram z przedziałami wartości kapitalizacji zaprezentowano na rys. 7.

Zbadano dziesięć największych pod względem kapitalizacji rynkowej spółek w tej kategorii i zestawiono je w tabeli 3.

Ceny akcji oscylują w przedziale od 4,50–80 GBP. Średni poziom gotówki wynosi 10 736 075 GBP. Zbadano również średnią wartość rynkową oraz księgową, które wynoszą kolejno: 74 933 431 GBP oraz 56 127 568 GBP.

Dla porównania, średnie wartości dla całego segmentu spółek o średniej kapitalizacji rynkowej wynoszą:

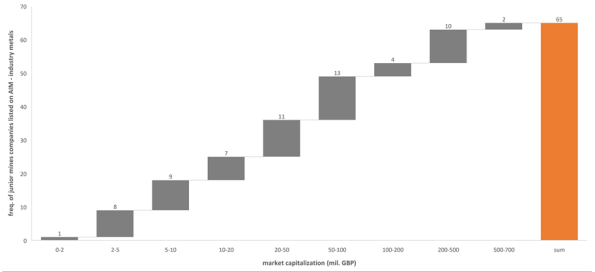
- Średnia cena akcji: 22,58 GBP/share
- Średni poziom gotówki: 8 480 788 GBP
- Średnia wartość rynkowa: 58 493 774 GBP
- Średnia wartość księgowa: 38 262 698 GBP



Rys. 9. Częstość występowania spółek eksploracyjnych w wybranych przedziałach wartości kapitalizacji rynkowej dla segmentu złota
Fig. 9. Frequency of exploration companies in selected market capitalization value ranges for the gold segment

Tab. 6. Porównanie parametrów wartości rynkowej dla dziesięciu spółek o najwyższej kapitalizacji w sektorze złota
Tab. 6. Comparison of market value parameters for the ten companies with the highest capitalization in the gold sector

Company name	Current price	Total Cash	Total Debt	Market Cap	Enterprise Value	Book Value
Shanta Gold Limited	8,64	24 839 000	5 389 000	90 517 248	71 067 248	167 721 595
AEX Gold Inc.	34,70	37 852 228	780 698	62 167 132	25 095 602	49 764 821
Anglo Asian Mining	105,90	36 640 000	2 061 000	121 141 128	86 562 128	123 772 144
Chaarat Gold Holdings Limited	19,12	24 608 000	52 553 000	131 798 336	159 743 336	83 418 848
Caledonia Mining Corporation	910,00	13 213 000	636 000	116 085 064	103 508 064	159 138 585
Pure Gold Mining Inc.	38,15	24 504 000	130 961 000	174 809 312	281 266 312	84 266 496
Pan African Resources	17,85	35 133 400	73 910 096	344 284 032	383 060 728	283 464 508
Resolute Mining Limited	18,75	75 702 000	324 987 008	207 108 752	456 393 760	632 551 881
Hochschild Mining	120,98	256 928 992	209 808 992	621 707 776	574 587 776	753 342 216
Petropavlovsk	18,34	36 536 000	576 566 016	725 822 656	1 265 852 672	708 351 333



Rys. 10. Częstość występowania spółek eksploracyjnych w wybranych przedziałach wartości kapitalizacji rynkowej dla segmentu górnictwa metali przemysłowych
Fig. 10. Frequency of exploration companies in selected market capitalization value ranges for the industrial metals mining segment

Tab. 7. Porównanie parametrów wartości rynkowej dla dziesięciu spółek o najwyższej kapitalizacji w sektorze górnictwa metali przemysłowych
Tab. 7. Comparison of market value parameters for the ten companies with the highest capitalization in the industrial metals mining sector

Company name	Current price	Total Cash	Total Debt	Market Cap	Enterprise Value	Book Value
Capital Limited	88,20	51 000 180	53 684 376	167 628 512	170 312 708	163 447 307
Griffin Mining Limited	89,90	25 143 000	43 000	156 383 744	131 283 744	245 969 531
Pensana	89,97	16 787 592	-	200 861 632	184 074 040	37 283 418
Horizonte Minerals	6,13	18 257 410	27 977 174	233 085 296	242 805 060	76 047 401
Bacanora Lithium	67,32	130 749 984	30 219 760	260 620 592	160 090 368	165 307 496
Adriatic Metals	135,00	20 836 984	11 690 161	359 198 560	350 051 737	59 600 350
Base Resources Limited	16,15	64 925 000	41 000	206 198 688	141 314 688	322 774 736
Jubilee Metals Group	15,46	19 713 298	9 340 623	375 503 968	365 131 293	143 349 934
Kenmare Resources	477,78	56 543 000	130 873 000	453 518 336	527 848 336	813 101 852
SolGold	25,65	87 039 848	110 711 880	588 364 800	612 036 832	328 016 246

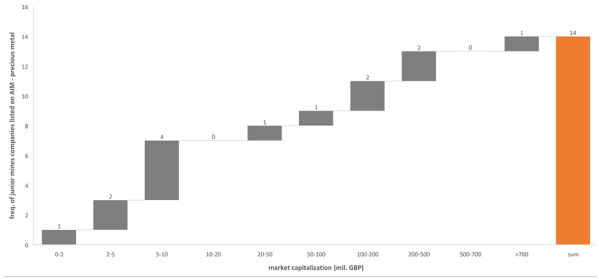
Spółki o wysokiej wartości kapitalizacji rynkowej

Zidentyfikowano 29 spółek o kapitalizacji rynkowej powyżej 100 milionów funtów. Histogram z przedziałami wartości kapitalizacji zaprezentowano na rysunku 8.

Zbadano dziesięć największych pod względem kapitalizacji rynkowej spółek w tej kategorii i zestawiono je w tabeli 4.

Ceny akcji oscylują w przedziale od 15,46–477,78 GBP. Średni poziom gotówki wynosi 99 890 915 GBP. Zbadano również średnią wartość rynkową oraz księgową, które wynoszą kolejno: 602 457 937 GBP oraz 441 089 754 GBP.

Dla porównania, średnie wartości dla całego segmentu spółek o wysokiej kapitalizacji rynkowej wynoszą:



Rys. 11. Częstość występowania spółek eksploracyjnych w wybranych przedziałach wartości kapitalizacji rynkowej dla segmentu górnictwa metali ziem rzadkich
Fig. 11. Frequency of exploration companies in selected market capitalization value ranges for the rare earth mining segment

Tab. 8. Porównanie parametrów wartości rynkowej dla pięciu spółek o najwyższej kapitalizacji w sektorze górnictwa metali ziem rzadkich
Tab. 8. Comparison of market value parameters for the five companies with the highest capitalization in the rare earth mining sector

Company name	Current price	Total Cash	Total Debt	Market Cap	Enterprise Value	Book Value
Petra Diamonds Limited	72,00	147 700 000	431 300 000	139 825 440	423 425 440	450 742 842
Sylvania Platinum Limited	90,67	106 135 432	283 607	247 504 576	141 652 751	244 321 568
Eurasia Mining	24,99	16 067 991	550 591	713 104 640	697 587 240	22 828 481
Gemfields Group Limited	15,25	67 305 000	42 634 000	181 159 328	156 488 328	432 441 224
Tharisa	125,89	92 355 000	36 850 000	366 206 496	310 701 496	444 427 087

- Średnia cena akcji: 124,72 GBP/share
- Średni poziom gotówki: 66 779 668 GBP
- Średnia wartość rynkowa: 354 122 407 GBP
- Średnia wartość księgowa: 294 343 460 GBP

Klasyfikacja górniczych spółek eksploracyjnych ze względu na sektor przemysłowy

Analizowane spółki sklasyfikowano również ze względu na eksplorowane surowce, badając tym samym wartość spółek w poszczególnych segmentach biznesowych. Na AIM London wyodrębnić można segmenty, sklasyfikowane w tabeli 5.

Sektor złota jest liderem, jeśli chodzi o spółki eksploracyjne. Średnia cena akcji wynosi 14 GBP, średni stan gotówki na poziomie 4 702 995 GBP a wartość rynkowa 38 398 920 GBP. Rynek ma zaufanie do danych dotyczących eksploracji złota generując nadwyżkę wartości rynkowej nad wartością księgową.

Spółki w sektorze eksploracji metali ziem rzadkich oraz metali szlachetnych warte są średnio 131 798 585 GBP, przy cenie 30,06 GBP/share. Natomiast spółki w sektorze eksploracji metali przemysłowych warte są średnio 101 932 234 GBP, przy cenie 41,78 GBP/share.

Sektor złota (Gold Sector)

Zidentyfikowano 33 spółki w sektorze spółek zajmujących się eksploracją złota. Histogram z przedziałami wartości kapitalizacji zaprezentowano na rysunku 9.

Zbadano dziesięć największych pod względem kapitalizacji rynkowej spółek w tej kategorii i zestawiono je w tabeli 6.

Ceny akcji oscylują w przedziale od 8,64–910 GBP. Średni poziom gotówki wynosi 56 595 662 GBP. Zbadano również średnią wartość rynkową oraz księgową, które wynoszą kolejno: 340 713 763 GBP oraz 304 579 243 GBP.

Dla porównania, średnie wartości dla całego segmentu spółek o wysokiej kapitalizacji rynkowej wynoszą:

- Średnia cena akcji: 52,80 GBP/share
- Średni poziom gotówki: 20 185 499 GBP
- Średnia wartość rynkowa: 136 540 308 GBP
- Średnia wartość księgowa: 109 207 065 GBP

Sektor górnictwa metali przemysłowych (Industry Mining Sector)

Zidentyfikowano 65 spółek w sektorze spółek zajmujących się eksploracją metali przemysłowych. Histogram z przedziałami wartości kapitalizacji zaprezentowano na rysunku 10.

Zbadano dziesięć największych pod względem kapitalizacji rynkowej spółek w tej kategorii i zestawiono je w tabeli 7.

Ceny akcji oscylują w przedziale od 6,13–477,78 GBP. Średni poziom gotówki wynosi 49 099 630 GBP. Zbadano również średnią wartość rynkową oraz księgową, które wynoszą kolejno: 288 494 881 GBP oraz 235 489 827 GBP.

Dla porównania, średnie wartości dla całego segmentu spółek o wysokiej kapitalizacji rynkowej wynoszą:

- Średnia cena akcji: 41,78 GBP/share
- Średni poziom gotówki: 18 478 133 GBP
- Średnia wartość rynkowa: 101 932 234 GBP
- Średnia wartość księgowa: 77 270 258 GBP

Sektor górnictwa kruszców drogocennych (Precious Mining Sector)

Zidentyfikowano 14 spółek w sektorze spółek zajmujących się eksploracją metali ziem rzadkich. Histogram z przedziałami wartości kapitalizacji zaprezentowano na rysunku 11.

Zbadano dziesięć największych pod względem kapitalizacji rynkowej spółek w tej kategorii i zestawiono je w tabeli 8.

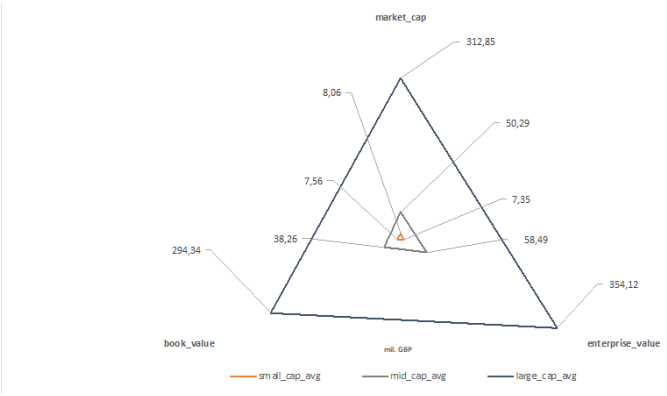
Ceny akcji oscylują w przedziale od 15,25–125,89 GBP. Średni poziom gotówki wynosi 85 912 685 GBP. Zbadano również średnią wartość rynkową oraz księgową, które wynoszą kolejno: 345 971 051 GBP oraz 318 952 240 GBP.

Dla porównania, średnie wartości dla całego segmentu spółek o wysokiej kapitalizacji rynkowej wynoszą:

- Średnia cena akcji: 30,06 GBP/share
- Średni poziom gotówki: 34 019 371 GBP
- Średnia wartość rynkowa: 131 798 585 GBP
- Średnia wartość księgowa: 128 274 749 GBP

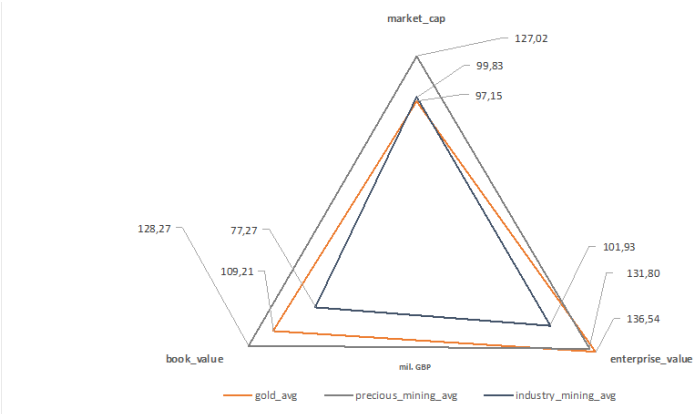
Podsumowanie i wnioski

Wartość spółek eksploracyjnych została przedstawiona dla dwóch różnych klasyfikacji: ze względu na wartość kap-



Rys. 12. Porównanie średnich wartości spółek należących do różnych przedziałów kapitalizacji w ujęciu wartości rynkowej, wartości księgowej oraz kapitalizacji rynkowej

Fig. 12. Comparison of average values of companies belonging to different capitalization brackets in terms of market value, book value and market capitalization



Rys. 13. Porównanie średnich wartości spółek należących do różnych segmentów przemysłowych w ujęciu wartości rynkowej, wartości księgowej oraz kapitalizacji rynkowej

Fig. 13. Comparison of average values of companies belonging to different industrial segments in terms of market value, book value and market capitalization

italizacji rynkowej oraz ze względu na eksplorowane zasoby.

Wyniki analizy spółek pod kątem kapitalizacji wyrażono na rysunku 12.

Spółki eksploracyjne sklasyfikowane w trzech grupach różnią się przede wszystkim skalą prowadzonej działalności. Spółki o niskiej kapitalizacji wyceniane są średnio 30–50 krotnie niżej niż spółki z grupy spółek o wysokiej kapitalizacji. Ponadto nachylenie wykresu w kierunku wartości rynkowej wskazuje na zaufanie inwestorów do spółek o średniej oraz dużej kapitalizacji. Spółki o niskim poziomie kapitalizacji wyceniane są praktycznie po cenie aktywów, czyli wartości księgowej.

Natomiast analiza spółek pod kątem eksplorowanych zasobów została wyrażona na rysunku 13.

Spółki eksploracyjne sklasyfikowane ze względu na eksplorowane złoże są zróżnicowane w umiarkowanym stopniu. Maksymalna różnica sięga rzędu 50 milionów funtów i jest to różnica pomiędzy spółkami z segmentu eksploracji złota oraz eksploracji metali przemysłowych. Również w tym przypadku wykres wyraźnie skierowany jest w stronę wartości rynkowej, zwłaszcza dla spółek eksplorujących złoto oraz kruszce przemysłowe w wyniku czego otrzymujemy rynkową wartość dodaną na ujemnym poziomie (MVA< 0). W przypadku sektora firm eksplorujących złoża metali ziem rzadkich oraz szlachetnych są to spółki, których wartość księgowa jest bardzo bliska wartości rynkowej. Ponadto spółki te generują największą wartość kapitalizacji na całym rynku.

Wartość spółek junior mines na rynku alternatywnym AIM London to opowieść, która posiada kilka najważniejszych wątków. Zostały połączone w trakcie przeprowadzonych badań. Pierwszym z nich jest proces pierwszej oferty publicznej IPO – proces wieloetapowy, który kosztuje spółki sporo czasu i wysiłku, jednocześnie umożliwiając pozyskiwanie kapitału na pierwsze, kosztowne etapy prac – wątek ten mówi nam o miejscu akcji. Drugi wątek rozpoczyna się już w trakcie działalności spółki, która realizując konkretne projekty eksploracyjne (projekty związane z eksploatacją złota, metali przemysłowych lub metali szlachetnych) zaczyna inwestować w konkretne pozycje zaliczane do bilansu, rachunku zysków i strat oraz przepływów pieniężnych – z tych dokumentów wynika wartość księgowa spółki – wątek ten stanowi podstawę postawionego problemu badawczego. Wątek trzeci jest uzupełnieniem wątku drugiego – mówi on o wartości spółki w ujęciu rynkowym, uwzględniającej codzienną dynamikę rynku oraz zadłużenie pomniejszone o najpłynniejsze elementy bilansowe – gotówkę oraz ekwiwalenty gotówki. W efekcie w wątku czwartym uzyskujemy informacje o rynkowej wartości dodanej – różnicy pomiędzy wartością księgową a wartością rynkową, która w kontekście dalszych badań może stanowić podstawę do ustalenia poziomu przeszacow-

ania lub niedoszacowania wartości spółek juniorskich. Cała historia o wartości spółek została podzielona na dwie ścieżki – historię o wartości kapitalizacji rynkowej oraz historię sektorów przemysłowych – umożliwiając w ostatnim etapie porównanie wartości księgowej oraz rynkowej – ukazując pełny obraz rynku spółek eksploracyjnych na londyńskim parkiecie.

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Market value of mining exploration companies listed on AIM London

Exploration projects are a specific type of projects that are very time-consuming in the first phase. They also require a large amount of investment outlays, which makes them less attractive on stock exchanges, which are largely based on speculation. Searching for investors in this type of environment requires a precisely described history of the deposit - treated as an exploration project. The characteristics of alternative markets show that the form of their financing plays an important role in the approach to the valuation of companies. Junior mines companies, due to their innovative nature, are looking for various types of financing, ranging from raising capital from subsidiaries to the issue of shares on alternative markets — however, this applies to the largest exploration companies. Each of the above-mentioned elements — sources of financing, investment risk, long payback period — is a significant contribution to the final valuation of the company's market value. An additional, very often the most difficult element of the valuation is the economic estimation of the know-how developed in the area of exploration, which very often determines a competitive advantage on the market.

Keywords: *market value, mining companies , AIM London, alterative market*

Assessment of the Stability State and the Risk of Landslides within Berbești Mining Basin (Romania) Post Closure

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Abstract

Berbești mining basin, located in the area of the Getic Subcarpathians, is part of the Central Heating Power Plant (CHPP) Govora, in fact representing the mining division, and has four open pits: Alunu, Olteț, Panga, and West Berbești.
Given that, at least in Europe, there is the issue of giving up energy production based on the burning of fossil fuels, especially coal, the four open pits will be in operation for a relatively short period of time, and one of the major problems related to the exploitation of lignite deposits is that of the post-closure stability of the lands in the influence area.
The research was conducted in such a way as to take into account in the stability analysis the factors and natural causes that predispose the lands in the Getic Subcarpathians to landslides, factors and anthropogenic causes (lignite mining) and the effect of their concomitant action.
These stability analyzes took into account different hypotheses related to the geometry of the final slopes and the influence of external factors. Also, a predictive analysis of the long-term stability of the lands (especially the final slopes of the open pits – as they were designed) was carried out, taking into account the behavior over time of the disturbed rocks. Based on the results obtained, after a series of statistical processing, a risk analysis was performed, using a methodology developed by a part of the research team.
It should be noted from the outset that the research focused on the West Berbești and Panga mining perimeters, as the lignite mining activity will be completed by the end of 2022 (at most).
However, taking into account the similar conditions (geology, morphology, tectonics, seismic zoning, weather and climatic conditions, applied exploitation methods), the research team considers that a significant part of the conclusions and recommendations contained in this study can be considered valid and for the rest of the active perimeters (Alunu and Olteț open pits).
In this context, the study ends with a series of conclusions on the stability of land in the Berbești mining basin (West Berbești and Panga perimeters) at the time of cessation of productive activities and recommendations that once put into practice will ensure long-term land stability.

Keywords: *Berbești mining basin, CHPP Govora, lignite, open pit, sliding risk, stability*

1. Introduction (short presentation of Berbești mining basin)

Berbești mining basin is geographically located in the Getic Plateau, along the parallel of 45º north latitude, at the confluence of Gorj and Vâlcea counties, being bounded on the west by the Gilort river, and on the east by the Bistrița river (Dican, 2011).

Berbești mining basin has a length of over 45 km and an inclined development of 2.5–5 km. The lignite deposit was divided into four mining perimeters: Gilort-Amaradia, Amaradia-Tărâia, Tărâia-Cernișoara, and Cernișoara-Bistrița. Within each mining perimeter, several mining fields have been outlined, these being the object of exploitation of some underground mines (closed at present) and open pits. Access to the mining perimeters can be done both by car and by rail (Fodor and Dican, 2013).

The geological formations present in the Berbești mining basin are made up of rocks belonging to the Pliocene and Quaternary, the Pliocene having the greatest development, being represented by: Pontian, Dacian, and Romanian (fig. 1).

The coal (productive) horizon is located in the Upper Dacian (Parscovian) and has a thickness that decreases, from south to north, from 150 to 60 m. Lithologically, it consists of a complex of sands, clays and marls, in which six layers of lignite numbered from I to VI are interspersed (fig. 1), found both in the drillings and in the outcrops from the northern part of the exploitation perimeters (Dican, 2014; Chiriță, 2019).

The transition from the Upper Dacian to the Romanian is delimited by the presence of a lumachelle level with a thick-

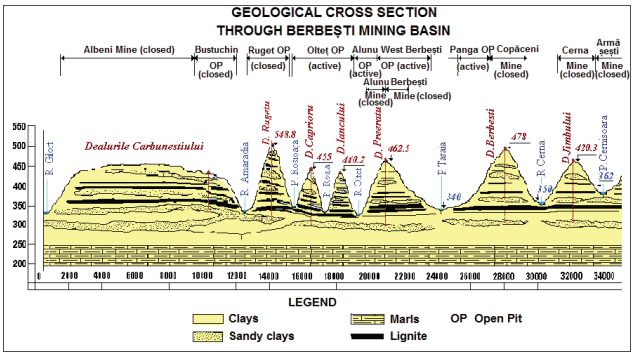


Fig. 1. Longitudinal geological section through the Berbeşti mining basin (Dican, 2014)
Rys. 1. Podłużny przekrój geologiczny przez zagłębie górnicze Berbeşti (Dican, 2014)

Tab. 1. Open pits and waste dumps within Berbeşti mining basin (Chiriţă, 2019)
Tab. 1. Odkrywki i hałdy odpadów w obrębie zagłębia górniczego Berbeşti (Chiriţă, 2019)

Open pit	Waste dump	Occupied surface [ha]		Stored volume [mil. m³]		Status
		2018	Designed	2018	Designed	
Alunu perimeter (2 open pits: Alunu and Olteţ)	Interior	198	490.5	47.5	210	Active
West Berbeşti	Interior	129	188	21.1	76.8	Active
Panga	Interior	99.5	171	53.5	95.5	Active

Tab. 2. Physico-mechanical properties of slope rocks
Tab. 2. Właściwości fizyko-mechaniczne skał zboczowych

Rock type	Volumetric weight, γ_v [daN/m³]	Cohesion, c [daN/cm²]	Internal friction angle, φ [°]
Yellow-brown clay	1843	0.31	10
Sandy marl	1933	0.45	21
Lignite	1187	1.10	26.5

ness of 1.5–2 m. The Romanian is represented by an alternation of gray, gray-green, or yellowish clayey sands, sometimes with reddish areas, of varied granulation, with torrential sedimentation and gray, green, or blackish clays, between which are interspersed 2–3 thin layers of lignite numbered VII, VIII, and IX (fig. 1) (Fodor and Dican, 2013).

After cessation of mining activity and the closure of the open pits, they become remaining gaps, thus changing the morphology of the region, and by the accumulation of rain and/or groundwater forms puddles, swamps, or open pit lakes that can increase the risk associated with land instability.

The waste dumps, generally positive forms of anthropogenic relief, are made up of heterogeneous rocks devoid of trophic substances necessary for plant growth and development and therefore cannot be considered soils. Due to their heterogeneity and relatively high degree of loosening are often prone to landslides.

Table 1 shows the centralized situation of the active open pits and waste dumps belonging to the Berbeşti mining basin.

Next, the open pits in which mining economic activities are currently carried out in the Berbeşti mining basin, respectively: Alunu, Olteţ, West Berbeşti and Panga, as well as the active waste dumps, are briefly presented.

1.1 Open pits

The Alunu, Olteţ, West Berbeşti, and Panga open pits are located in the western part of Vâlcea County. The currently mined lignite seams are no. I (with a maximum thickness of over 5 m), no. II and sporadically no. III (in Panga open pit). The operating method is "the method of transporting the overburden to the internal dump and partial transhipment", and the technology used is "the technology of excavation, transport and dumping in continuous flux" (***, 2021).

1.2 Interior waste dumps

They are located in the excavated area of the open pits, having the shape and dimensions of the foundation corresponding to the base of the open pit.

- Alunu interior waste dump – has the foundation in the form of a monocline with E-W direction and N-S inclination, between 3–5°, being made up of marly-clayey rocks with coal intercalations, the clayey rocks being represented by a gray to blackish greasy clay, plastic, with low compressibility (***, 2021);
- West Berbeşti interior waste dump - has a stable foundation consisting of gray marls with coal inclusions, with a general slope of 4–5° from north to south. Most of the first step of the dump was built by direct deposition of the waste rocks from the overburden (***, 2021);
- Panga interior waste dump - has a stable foundation consisting of gray marls with coal inclusions, with a general slope of 4–5° from east to west on half of the extension and an identical slope, of 4–5°, but inclined from west to east, on the other half. Most of the first step of the dump was built by direct deposition (transhipment) (***, 2021).

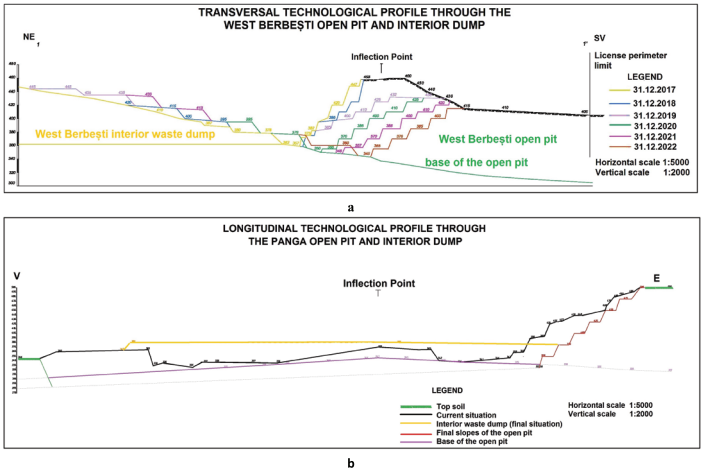


Fig. 2. Longitudinal sections through the open pits: a – Berbești West; b – Panga (***, 2021)
Rys. 2. Przekroje podłużne przez odkrywki: a – Berbești West; b – Panga (***, 2021)

2. Stability analysis of the designed slopes

2.1 Conditions for performing stability analyzes

As we have mentioned since the introduction, the stability analyzes for the designed situation at the end of the activity (end of 2022), refers to 2 open pits out of the four active in the Berbești mining basin (West Berbești and Panga). For the Alunu and Olteț open pits, it is expected that the lignite mining activity will continue until 2025 (at least).

In order to perform stability studies and determine the geometry of the steps that ensure the long-term stability of the slopes (post-closure), the following were completed:

- Study of documentation (***, 2019; ***, 2021) (description of the deposit, geotechnical drillings, situation plans, longitudinal and cross sections, stratigraphic columns);
- Sampling campaigns of overburden rocks and lignite from open pits slopes and dumps. Following the field trips some findings were made: geometric non-uniformity of the excavation fronts caused by the morphology of the terrain; phenomena of fragmentation and detachment of rocks from slopes in conditions of low humidity and tendencies of plastic flow of clay from the top of the step in conditions of saturation; local slides affecting the stability of the whole step, with variable magnitude depending on the structure of the massif and the hydrometeorological conditions; given the current geometry (December 2021) of the excavation fronts, the risk of massive landslides, involving large volumes of rocks and affecting the safety of equipment and personnel is relatively low; the difficulties in ensuring a relatively uniform geometry of the excavation fronts will be accentuated as they advance (taking into account the morphology of the terrain); it will be necessary to design appropriate operating technologies so that the geometry of the slopes will ensure their stability;
- Discussions with the representatives of CHPP Govora, regarding the working technologies, the projected works for the year 2022, problems of stability of the working slopes and of the lateral slopes encountered so far;
- The slopes of the open pits in the Berbești mining basin are essentially made up of clayey, marly, and sandy rocks and different combinations of them. Based on the sections from the documentation (***, 2021), and completed with field observations, the lithological sequence is as follows: a layer of yellow-brown clay, with a thickness between 5–15 m; a layer of sandy marl with a thickness between 3–4 m; layer no. II of lignite with a thickness between 2.6–5 m; an intercalation of sandy marl between the layers of lignite, with a thickness between 0.3–1.5 m; the no. I layer of lignite with a thickness between 2.3–3.2 m (maximum 5 m in Panga open pit, respectively 5.4 m in West Berbești open pit); a layer of sandy marl that represents the bed of the first layer of lignite;
- Carrying out laboratory tests on samples taken from the field and determining the physical and mechanical characteristics of the rocks;
- Collaboration with another specialized laboratory to confirm the results and expand the database for statistical processing;
- Analysis, comparison and statistical processing of data obtained in laboratories and those obtained from technical documentation.

Stability analyzes were performed using the Slide geotechnical software, in which the calculation sections were modeled.

2.2 Stability analysis results for the designed final slopes

Table 2 shows the physical-mechanical characteristics of the rocks in the structure of the analyzed steps (resulted from statistical processing) used in stability calculations.

The situation of the final slopes of the two open pits (West Berbești and Panga) and of the Berbești interior dump, as it was designed at the end of 2022, is presented in figure 2.

As can be seen from the two longitudinal sections, the final slopes designed for the two open pits have a uniform geometry (steps with a height of 10 or 15 m and slope angles of 63° and 41° for West Berbești open pit and steps with 25 m high and 54° slope angles for Panga open pit).

Interior waste dumps:

- In the case of the West Berbești dump – its steps, 6 in number, were designed with heights between 10 and

Tab. 3. Results of the stability analysis for the final slopes (designed)
Tab. 3. Wyniki analizy stateczności zboczy końcowych (projektowych)

Slope	Geometry		Rock type	F_{s1} (Fellenius)	F_{s2} (Bishop)	F_{s3} (Janbu)	F_{s4} (M-P)
	H (m)	α (°)					
T1 West Berbești	10	63	Yellow-brown clays	1.101	1.114	1.149	1.151
			Strata (6 m clay/4 m marl)	1.540	1.547	1.548	1.548
T2 West Berbești	15	41	Yellow-brown clays	1.073	1.103	1.081	1.100
			Strata (11 m clay/4 m marl)	1.351	1.377	1.356	1.375
T3 Panga	25	54	Yellow-brown clays	0.658	0.664	0.666	0.667
			Strata (21 m clay/4 m marl)	0.930	0.933	0.938	0.946

20 m, some of them having a maximum horizontal inclination of 5° towards the base of the open pit. It should be noted that, under the designed conditions, a remaining gap will result, located between the final steps of the interior dump and those of the open pit, with a variable depth, and which will most likely be filled with water;

- In the case of Panga interior dump, the designed situation at the end of the activity shows that it will be twinned with the final steps of the open pit. This will be done by pushing the dumped material with bulldozers, after withdrawing the mining equipment from the work fronts, towards the final steps of the open pit. In this way, the formation of a remnant gap is avoided and any problems related to its filling with water are prevented.

2.2.1. Stability analyzes for the final steps of the open pits

Given the designed situations at the end of the activity and those presented in the previous paragraph (related to the degree of knowledge of stratigraphy and the stratigraphic structure adopted in the stability analysis of working slopes), for the final slopes of the two open pits stability analyzes were performed for the following situations:

- slopes made entirely of yellow-brown clays;
- slopes composed partly of sandy marls (4 m) and partly of yellow-brown clays.

The heights considered for the final steps are 10, 15, and 25 m, according to the sections made on the designed situation plans, and the values of the physical-mechanical characteristics are those presented in table 2.

The results of these analyzes, performed by means of four procedures (Fellenius, Bishop simplified, Janbu simplified, and Morgenstern-Price) recommended by the literature (Hoek and Bray, 1981; Marinescu, 1988; Rotunjanu, 2005; Lazăr and Faur, 2015), are presented in table 3 and figure 3.

In the case of final slopes made exclusively of yellow-brown clays, even in conditions of lower slope angles, the minimum values determined for the stability factor (by Fellenius' procedure) indicate that the stability reserve is of 10% for slopes with a height of 10 m, respectively 7.3% for slopes with a height of 15 m and a sub-unit one for slopes with a height of 25 m (slopes below the equilibrium limit). In other words, we are dealing with either unstable slopes or close to the equilibrium limit, which is why, in order to ensure long-term stability, a resizing is required. This resizing is presented in Chapter 3.

For the steps excavated in both the clay and the marl layers, for the slopes with heights of 10 and 15 m, the values of the stability factor indicate stability reserves of 35 and 54%. These stability reserves can be considered as covering, but, as will be presented in the rest of the paper, when we talk about long-term stability, even these values cannot be considered sufficient.

In the case of slopes with a height of 25 m, the minimum value determined (by the Fellenius procedure) is subunit, ie the slopes are below the equilibrium limit (landslides can occur).

Another aspect is related to the position of the sliding surfaces in the case of slopes made of yellow-brown clays and sandy marls, with heights of 15 and 25 m. Thus in these situations, as can be seen in figure 3.d, the surfaces of minimum resistance materialize only through the layer of yellow-brown clay. This observation leads us to keep in mind that, depending on the angle of the slope, the height of the steps excavated in clays can not exceed 9-12 m, or if the designed height of the steps is maintained, it will be necessary to reduce the final slope angles.

2.2.2. Stability analyzes for the final steps of Berbești West interior dump

The stability analyzes were performed for each of the 6 steps designed in conditions of natural humidity of the stored rocks, and because it is very probable that a water accumulation will form in the remaining gap, this hypothesis was also taken into account. Basically, in this case, the first step of the dump becomes submerged and the material saturated.

The physical-mechanical characteristics of the dumped material were taken from a geotechnical study made available to the research team by the representatives of CHPP Govora (***, 2021) (table 4). This study aimed to determine the load-bearing capacity of the rocks in the base of the open pits, in the conditions of the expansion of the dump areas. In order to determine the effective pressure exerted by dumps, geotechnical drilling was performed through the dump's body and the average characteristics of the deposited heterogeneous mixture were determined.

In the case of the steps of the West Berbești interior dump, following the stability analyzes, it can be concluded that they have a sufficient stability reserve. Therefore, given the medium-term stability, all the steps analyzed can be considered stable, and in the case of the need to ensure long-term stability, ie Fs > 2, four of them (Tr1, Tr2, Tr3, and Tr5) require a resizing (Chapter 3).

In the conditions in which the first step is submerged, and in the body of the dump the pore pressure is manifested, a stability factor of 2,448 is obtained, superior to the one obtained under normal conditions (with the material at natural humidity and without the presence of water accumulation in the remaining gap).

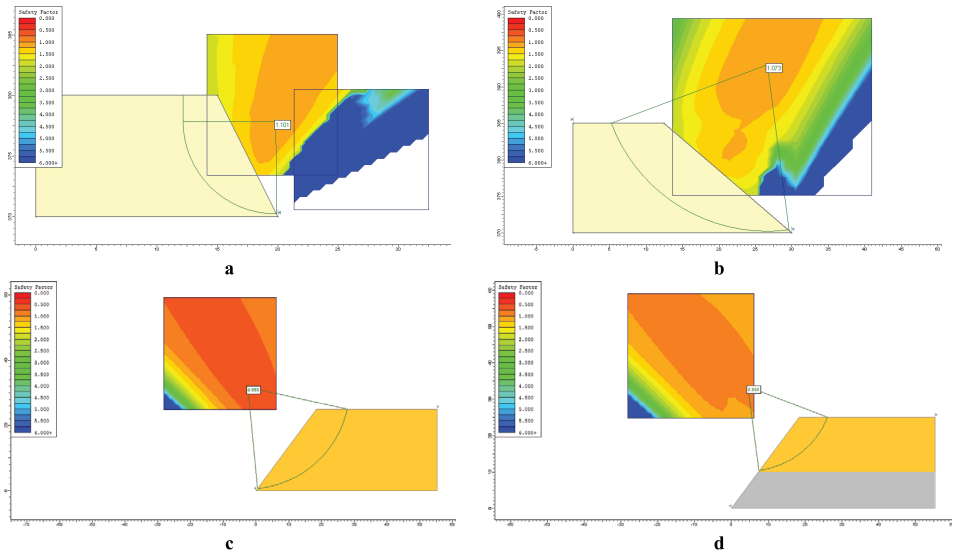


Fig. 3. Stability analyzes for slopes of: a – 10 m made of clays; b – 15 m made of clays; c – 25 m made of clays; d – 25 m made up of clays and sandy marls
Rys. 3. Analizy stateczności skarp: a – 10 m wykonanych z iłów; b – 15 m z gliny; c – 25 m z gliny; d – 25 m zbudowane z iłów i piaszczystych margli

This result is in accordance with the theory that, under the conditions of submerged slopes, the water exerts a hydrostatic pressure on the slope behaving like a supporting prism (Rotunjanu, 2005; Lazăr and Faur, 2015) and is sustained by the results of previous studies published by the research team in specialized journals (Lazăr et al., 2019; Apostu et al., 2021).

However, as previous studies (Lazăr et al., 2019; Apostu et al., 2021) have shown, during the filling of the remaining gap with water, especially if the flooding occurs exclusively by natural means, due to the relatively long time required to raise the water level, the rocks initially unsaturated in the dump are in contact with water for a longer period. These conditions allow the rapid saturation of the rocks and the increase of the hydrostatic level in the body of the dump (due to the capillary pores that allow the water to rise in the body of the dump), without being counteracted by the hydrostatic pressure exerted on the slopes by the water in the lake. Such a situation leads to an initial decrease in the stability factor, increasing the risk of negative geomechanical phenomena, such as landslides or liquefaction of the deposited material.

The period in which this decrease in the stability factor is observed is limited in time, and can be counteracted by accelerating the rate of filling the remaining gap with water. This acceleration can be achieved through adductions (Lazăr et al., 2019). The flooding process itself and the behavior of the dump during this period must be monitored, at least through observations, so that it can be intervened if there are signs of loss of stability (superficial landslides, plastic flows, abnormal settlements, tension cracks, etc.).

3. Determining the stable geometry of the slopes

The recommended value of the stability factor depends on the designed operating life of the slopes. In this regard, the following values are recommended (Rotunjanu, 2005):

- Fs = 1.1-1.2 - for short periods of existence, up to 1 year;
- Fs = 1.2-1.5 - for average periods of existence, up to 20 years;
- Fs = 1.5-2 - for long periods of existence, over 20 years;
- Fs = 3 - for very long periods of existence, of the order of centuries.

An important role in the formation and development of landslides is played by the rheological behavior of the rocks, materialized under two essential aspects: the slow flow (creep) of the lands in time, respectively their long-term resistance, which is reduced in time in close relation with deformation (Marinescu, 1988).

Slope slides can be defined as three-phase rheological processes (Todorescu, 1986):

- slow flow, characterized by successive local failures and the formation of the sliding surface, which can last as long as there is no movement in the slope;
- the actual slide, respectively a very large displacement in a very short time;
- stabilized slide, which is characterized by small displacements and local landslides.

In general, it is found that under the condition that only structural cohesion is considered to be maintained over time, taking into account Maslov's second criterion (Maslov, 1977; 1984) and the thixotropic behavior of clay rocks, the stability coefficient is reduced by about 25%.

Because the waste dumps are made up of loose rocks (at least immediately after cessation of mining activity) and store large volumes of waste rocks and their slides endanger all objectives in their influence area, to ensure long-term stability, we took into account a stability coefficient, also recommended by the literature (Rotunjanu, 2005), of 2. This is a covering value even in the conditions of the deterioration in time of the resistance characteristics.

For the final slopes of the open pits, where the rocks are close to the natural state of the massif, we considered that a value of 1.8 of the stability coefficient is sufficient.

In these conditions, to determine the stable geometry we used the grapho-analytical procedure of E. Hoek (Hoek and Bray, 1981) which proved its viability in many cases of stability analysis and design of the geometric elements of slopes.

Tab. 4. Physico-mechanical properties of rocks

Tab. 4. Fizyko-mechaniczne właściwości skał

Rock type	Volumetric weight, γ_v [daN/m^3]	Cohesion, c [daN/cm^2]	Internal friction angle, φ [°]
Mixture of dumped rocks	1827	0.21	21.6
Foundation (sandy marls)	1933	0.45	21

Tab. 5. Stability analyzes of dump steps

Tab. 5. Analizy stateczności stopni zrzutowych

Slope	Geometry		Rock type	F_{s1} (Fellenius)	F_{s2} (Bishop)	F_{s3} (Janbu)	F_{s4} (M-P)
	H (m)	α (°)					
Tr1	13.50	27	Mixture of dumped rocks	1.623	1.719	1.656	1.715
Tr2	15.00	45		1.294	1.375	1.311	1.373
Tr3	16.50	29		1.884	2.142	1.895	2.142
Tr4	16.00	28		2.413	2.772	2.413	2.772
Tr5	16.33	31		1.953	2.214	1.971	2.215
Tr6	10,00	18		2.311	2.588	2.385	2.586
Tr1 submerged	13.50	27		2.448	2.600	2.516	2.598

The hypothesis on which this procedure is based is that the landslide of the dump slopes occurs after a circular surface.

Starting from the factors influencing the stability of the slopes, Hoek graphically shows the correlations that exist between the functions "X" (of the slope angle, α) and "Y" (of the slope height, H), in correlation with the geotechnical characteristics of the rocks (γv, c, φ) and the slope safety or stability factor. The functions X and Y have the expressions (Hoek and Bray, 1981): $X = \alpha - 1{,}2 \cdot \varphi$; $Y = \gamma v \cdot H / c$.

To obtain a required value for the stability coefficient Fs = 2 for the steps of the interior dump and Fs = 1.8 for the final slopes of the open pits, the resizing procedure can follow either the determination of the angle of the slope for given heights or the determination of the maximum height of the slope for given slope angles.

In this regard, the geometric elements were determined to ensure a stability reserve appropriate to the situation in which the designed heights is maintained (achieved), with the help of the graph and calculation relations being determined the allowable slope angles.

For different heights H - of the slope and the geotechnical characteristics of the deposited rocks, the function Y is calculated, and from the points of intersection of its value with the curve of the stability coefficient Fs = 1.8, respectively 2, the value of the function X of the slope angle α is obtained on the abscissa axis, from which its size is determined.

The values of the physical and geotechnical characteristics considered in the calculations are those in tables 2 and 4, and for the slopes formed by the combination of clay + sandy marl, the weighted average values were calculated. The results obtained are shown in table 6.

Based on these data, it results that in the conditions of the designed heights of the final slopes of West Berbești Vest and Panga open pits, respectively of West Berbești interior dump, in order to ensure the imposed stability reserve, it is recommended in all cases to reduce the existing (initially designed) slope angles.

It can be seen that the lowest values of the calculated slope angle (necessary to ensure long-term stability), while maintaining the designed height of the steps, are those for the final steps of the open pits, excavated exclusively in clay, with h = 25 m (designed for Panga open pit) and with h = 15 m (part of the steps designed for West Berbești open pit).

A reduced value of the permissible slope angle (12.11°) under the imposed conditions is also obtained for slopes partially excavated in clay and sandy marl, also for slopes with a height of 25 m (designed for the Panga open pit).

In these conditions, it is recommended to adopt the solution with the division of the final steps of the open pits (those of 15 and 25 m excavated exclusively in clays and those of 25 m excavated in clays and sandy marls) in substeps, in which those excavated in clays do not exceed 10 m in hight. Such an approach would make it possible to achieve slope angles with values between 21.5° and 24°. These slope angles can be obtained by using for the final modeling of some classic excavators (power shovel).

For the final steps with a height of 10 m (part of the steps designed for the West Berbești open pit) a reduction of the slope angle from 63° to 24° is required, for the slopes excavated exclusively in clays, and from 41° to 33.28°, for slopes excavated in clay and sandy marls. The final modeling can also be done with the help of classic excavators.

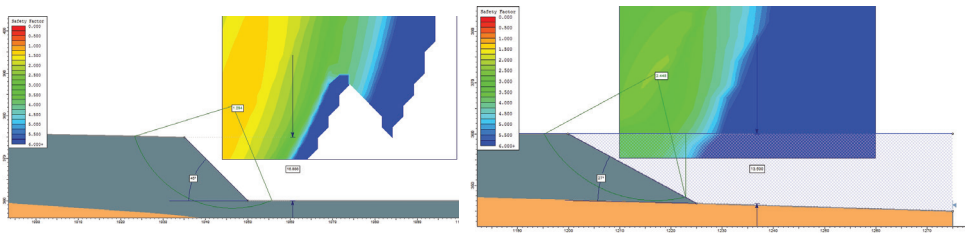
In the case of the steps of the interior dump, which require a resizing (Tr1-Tr3 and Tr5), the slope angles necessary to achieve long-term stability (while maintaining the designed heights) are between 20° and 23.42°. These angles can be achieved a little easier than in the case of the open pits steps, and bulldozers can be used for the final modeling. This backdrop operation with bulldozers is facilitated by the condition of the deposited material (loose condition), and can be performed in the most advantageous variant, ie by pushing the material from top to bottom.

It is mentioned that these slope angles are well below the value of the natural slope angle of the deposited rocks, α0 = 35° ÷ 37° (***, 2021).

4. Determination of the sliding risk for different assumptions

4.1 Working methodology

Sliding risk assessment analysis is required in particular in conditions of instability of the final slopes. The risk is defined as the product of the probability of landslides and the vulnerability of existing anthropogenic and natural objectives in the influence area of the landslide R = V x Pr (where: R – landslide risk; V – vulnerability – vulnerability of objec-



a b

Fig. 4. Stability analyzes for the West Berbești interior dump: a – Tr2 (Fs1 = 1,294); b – Tr1 in the conditions of flooding of the remaining gap (submerged) (Fs1 = 2,448)

Rys. 4. Analizy stateczności składowiska wewnętrznego West Berbești: a – Tr2 (Fs1 = 1,294); b – Tr1 w warunkach zalania pozostałej luki (zanurzony) (Fs1 = 2448)

Tab. 6. Results of slope angle resizing calculations

Tab . 6. Wyniki obliczeń zmiany wielkości kąta nachylenia

Slope	Height (designed), H, [m]	Slope angle (determined), α, [°]
Final slopes of open pits excavated exclusively in clays (Fs=1.8)		
T1	10	24
T2	15	17
T3	25	9
Final slopes of open pits excavated part in clays and part in sandy-marls (Fs=1.8)		
T1	10	33.28
T2	15	21.56
T3	25	12.11
Final slopes of West Berbești interior dump (Fs=2)		
Tr1	13.50	23.42
Tr2	15.00	20.92
Tr3	16.50	20.42
Tr5	16.33	20.02

tives in the area depending on the technical condition of the slopes; Pr – sliding probability) (Lazăr et al., 2015; Apostu et al., 2021).

In order to evaluate the risk of landslides in the different hypotheses considered in this study, we used a methodology developed by part of the members of the research team (Lazăr et al., 2015), verified in the completion of master and doctoral thesis, as well as in other scientific articles (Apostu et al., 2021).

Thus, within the methodology, in a first stage, a classification of rock massifs/deposits was elaborated according to the nature of the objectives located in the area of influence and the characteristics of the environment. Based on this, the vulnerability classes of the objectives in the area were established according to the technical condition of the in situ and waste dumps slopes (table 7).

According to the 2015 study (Lazăr et al., 2015), based on complex statistical processing, the probability of landslides was determined, after which a graph was constructed showing the dependence between the stability coefficient determined after the analyzes and the sliding probability (fig. 5).

In the present study, this graph was used to determine the probability of sliding, the stability coefficient being known for the situations analyzed in the previous chapter.

Based on existing models in the literature (US ACE, 1997; Gibson, 2011), the following scale has been established for defining the sliding probability:

- Pr = 1 for the range 0 ÷ 15% → very low sliding probability; the slope will almost certainly not slide;
- Pr = 2 for the range 15 ÷ 35% → reduced sliding probability; the slope is unlikely to slide;
- Pr = 3 for the interval 35 ÷ 65% → average sliding probability; whether or not the balance is lost is equally likely;
- Pr = 4 for the interval 65 ÷ 85% → high sliding probability; it is very likely that the slope will slide;
- Pr = 5 for the range > 85% → very high probability of sliding; the slope will almost certainly slide.

Following the scale for defining the sliding probability, each step (of the open pits and interior waste dump) was given the appropriate score. With the help of the calculation relationship, the risk of sliding is determined for the final slopes (initially designed and after resizing the slope angle) of the West Berbești and Panga open pits, respectively of the West Berbești interior dump.

Considering the 5 classes of vulnerability, respectively 5 classes of probability, for the evaluation of the sliding risk the following scale was established (Lazăr et al., 2015): R = 1 → very low sliding risk; R = 2 ÷ 4 → low risk of sliding; R = 5 ÷ 9 → average risk of sliding; R = 10 ÷ 15 → high risk of sliding; R = 16 ÷ 24 → very high risk of sliding; R = 25 → extreme sliding risk.

4.2 Slide risk assessment

The first stage to be completed involves the inclusion of natural and anthropogenic objectives in the influence area of the two open pits and the interior dump in one of the 5 categories contained in table 7.

For this classification, we used the satellite images presented in figure 6, supplemented with those found during field visits and details of the situation plans.

According to table 7 and figure 6, we classified open pits, as well as the interior dump (post-closure) in the vulnerability categories (table 8).

For the open pits slopes, taking into account the stability analyzes and field observations, it was considered that we are dealing with "rock masses that can enter in dangerous move-

Tab. 7. Vulnerability of rock masses/deposits according to the nature of the objectives in the area of influence [modified after (Lazăr et al., 2015)]

Tab. 7. Wrażliwość mas skalnych/złóż w zależności od charakteru celów w obszarze oddziaływania zmodyfikowana za [Lazăr et al., 2015]

Stability degree / - Nature of objectives in the influence area - Environmental characteristics	1. Massive/rock deposits with significant volume and active displacements	2. Massive/rock deposits which can enter into dangerous movements due to some factors	3. Massive/rock deposits with movements that can be limited by arrangements/ exploitation technology	4. Massive/rock deposits stabilized, landslides are not probable
1. – Households, social constructions - Forests, water courses/lakes, high value terrains	**V = 5** Very high vulnerability	**V = 5** Very high vulnerability	**V = 4** High vulnerability	**V = 3** Average vulnerability
2. – Industrial constructions and installations, high traffic routes, - Arable land, forests, water courses, productive land	**V =5** Very high vulnerability	**V = 4** High vulnerability	**V = 3** Average vulnerability	**V = 2** Reduced vulnerability
3. - Low traffic routes, reduced pedestrian access - Wooded pastures with varying degrees of consistency, limited water resources, low value land	**V = 4** High vulnerability	**V = 3** Average vulnerability	**V = 2** Reduced vulnerability	**V = 1** Very reduced vulnerability
4. - Areas without buildings, with sporadic access by people - Brownfield, unproductive lands, bushy pastures	**V = 3** Average vulnerability	**V = 2** Reduced vulnerability	**V = 1** Very reduced vulnerability	**V =1** Very reduced vulnerability

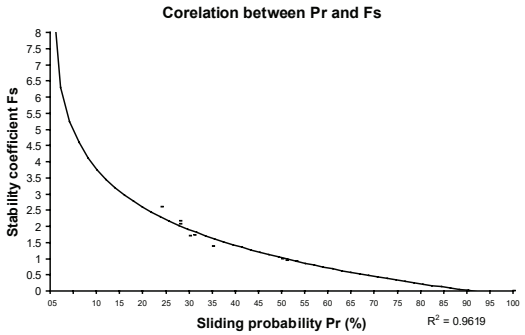


Fig. 5. Correlation between sliding probability (Pr) and stability coefficient (Fs) (Lazăr et al., 2015)

Rys. 5. Korelacja między prawdopodobieństwem poślizgu (Pr) a współczynnikiem stateczności (Fs) [Lazăr et al., 2015]

ments due to some factors", and for the interior dump with "moving rock deposits which can be limited by arrangements or by the technology of exploitation".

Based on the values obtained as a result of the inclusion in the vulnerability categories according to the nature of the objectives in the area of influence, an average value of the vulnerability was determined (table 8).

In the last step, based on those shown in Table 8, and taking into account the probability of sliding of the final slopes (determined from the stability analyzes presented in Chapter 2 and using the graph in figure 5), the risk of sliding was calculated, using the relation presented at the beginning of this chapter (table 9).

Framing the slopes in the risk classes and returning to the results of the stability analyzes, the following can be stated:

- for the final designed slopes of the two open pits, the calculated risk is 10.5, which corresponds to a high risk of sliding;
- for the slopes originally designed for the West Berbești interior dump:
- for the first two steps, the calculated risk is equal to 7.5, which corresponds to an average sliding risk;
- for the rest of the steps, the calculated risk is equal to 5, which also corresponds to an average risk of sliding.
- for the final slopes of the open pits, after the reduction of the slope angle, in the conditions of maintaining the designed heights and imposing a stability coefficient, the calculated risk decreases from 10.5 to 7. This reduction, passes the risk from high to average category;
- for steps Tr1 - Tr3 and Tr5, even after resizing the slope angle, under the conditions of a imposed stability coefficient of 2, the calculated value of the risk is 5, ie it implies an average risk of sliding;
- for the step Tr1 of the interior dump, in the conditions in which it is submerged and a possible landslide would produce a flood wave that would affect the downstream households, the calculated risk has a value of 8, ie an average risk.

Therefore, when we consider the displacement of a volume of water and its movement to the downstream areas where the individual households of the locals are located, although we fall into the same risk class (average), the calculated value increases to 8, compared to 5, provided if the slide would not have such an effect.

The general conclusion that emerges from the landslide risk assessment is that, even after the design of retrofit works (which aimed to reduce the slope angles, while maintaining the originally designed heights) the risk of landslide is medium. Only in the case of the final steps of the open pits was a lower risk class than the initial one, otherwise the classification in the category of the average risk of sliding is maintained.

a b

Fig. 6. The lands from the influence area of the open pits: a – West Berbești; b – Panga (***, 2022)
Rys. 6. Tereny z obszaru oddziaływania odkrywek: a – West Berbești; b – Panga (***, 2022)

Tab. 8. The nature of the objectives and the vulnerability of the land in the influence areas
Tab. 8. Charakter celów i wrażliwość gruntów na obszarach oddziaływania

Open pit/waste dump	Objectives in the influence area and environmental components				
	Natural objectives	Natural objectives (V1)	Anthropic objectives	Anthropic objectives (V2)	Average vulnerability: Vm = (V1+V2)/2
West Berbești open pit (post-closure)	Arable lands, forests, water curses, productive land	4	Roads with limited traffic or restricted movement of people	3	3.5
Panga open pit (post-closure)	Orchards, forests, water curses, productive land	4	Roads with limited traffic or restricted movement of people	3	3.5
West Berbești waste dump (at the end of 2022)	Brownfield, unproductive	1	Industrial constructions and installations, high traffic communication routes	4	2.5
* West Berbești waste dump (post-closure)	Arable lands, water curses, productive land	4	Households, social constructions	4	4
* We point out that, although the interior dump may slide into the remaining gap of the open pit (area of no value in terms of natural or anthropogenic objectives) and theoretically could not cause damage, the situation changes after the flood of the remaining gap. In this situation, a possible large landslide would dislodge an important volume of water that would move through the NE part of the perimeter, through the valley that separates the open pit from the West Berbești exterior dump. As individual households are located along this valley, the volume of water displaced would behave like a flood wave, being able to endanger not only goods but also the lives of the inhabitants of the area. For this reason, we considered the anthropic objectives in the area of influence as social housing and constructions, and the natural ones as arable, productive lands.					

Tab. 9. Determining the risk of landslides
Tab. 9. Określanie zagrożenia osuwiskami

Slope		Vulnerability V	Probability		Risk
			Pr [%]	Pr	
Final slopes, West Berbești open pit (initially designed)					
T1 (10 m)	Clay	3.5	47.5	3	10.5
	Clay +Marl		37	3	10.5
T2 (15 m)	Clay		48	3	10.5
	Clay +Marl		41	3	10.5
Final slopes, Panga open pit (initially designed)					
T3 (25 m)	Clay	3.5	61.5	3	10.5
	Clay +Marl		52.5	3	10.5
Final slopes, West Berbești interior dump (initially designed)					
Tr1	Natural state	2.5	35	3	7.5
Tr2	Natural state		42.5	3	7.5
Tr3	Natural state		30	2	5
Tr4	Natural state		22	2	5
Tr5	Natural state		29	2	5
Tr6	Natural state		23.5	2	5
Tr1 submerged	Saturated		21.5	2	5
Final slopes, West Berbești open pit (after resizing the slope angle)					
T1 (10 m)	Clay or Clay	3.5	32*	2	7
T2 (15 m)	Substeps	3.5	32*	2	7
Final slopes, Panga open pit (after resizing the slope angle)					
T3 (25 m)	Substeps	3.5	32*	2	7
Final slopes, West Berbești interior dump (after resizing the slope angle)					
Tr1 – Tr3, Tr5**	Natural state	2.5	28***	2	5
Tr1 submerged	Saturated	4****	21.5	2	8
* Value corresponding to an imposed stability coefficient Fs = 1,8; ** For the Tr4 and Tr6 steps no resizing was required, the stability coefficient for the initially designed situation being Fs > 2; *** Value corresponding to an imposed stability coefficient Fs = 2; **** In the event of a landslide-induced flood wave.					

5. Final conclusions and recommendations

☑ The stability analyzes performed for the designed situation at the end of the extractive activity in the two open pits (West Berbești and Panga) showed that the slopes excavated exclusively in clays are unstable or at equilibrium limit, while the slopes excavated in clays and marls have satisfactory reserves of stability for average period of existence (less than 20 years) for slopes of 10 and 15 m, and are unstable for slopes of 25 m.

☑ In order to ensure the conditions of long-term stability (over 20 years) it was necessary to perform some resizing calculations, in this sense being used the grapho-analytical procedure of Hoek.

☑ Through the resizing calculations for the final slopes of the open pits and the interior dump it was concluded that, in order to maintain the current designed heights and to ensure long-term stability, it is necessary to reduce the slope angles to values between 20 and 24° (except for an open pit slope, the 10 m slope made of clay and marl, where the slope angle can slightly exceed 33°).

☑ Under these conditions, it is necessary to restore the designed situation plans at the end of the activity, taking into account the elements of resizing the final slopes in order to ensure long-term stability.

☑ In the influence area of the open pits (post closure) arable lands, orchards, forested areas, and watercourses were identified. Only in the conditions in which we considered as possible a slide of the internal dump towards the remaining and flooded gap of the West Berbești Vest open pit, which in turn would generate a flood wave, were also identified individual households located in the extended area of influence.

☑ The lands in the influence area, taking into account the objectives in the area and the technical condition of the slopes, fall into vulnerability classes 1, 3 and 4 (or between 2.5 and 4 as an average value), and the sliding probability falls into classes 2 and 3.

☑ After performing the resizing calculations, the stability factor being imposed (1.8 for the final slopes of the open pits and minimum 2 for the final slopes of the interior dump), the probability of a landslide becomes 2 for all the analyzed slopes.

☑ After performing the resizing calculations, the final slopes of the open pits pass into a lower risk class, namely that of an average risks.

☑ For the final slopes of the interior dump the risk of sliding is average both for the situation initially designed and after the resizing of the slope angles.

☑ It is observed that in case of a landslide in the interior dump, capable of producing a flood wave, although the risk remains in the average category, the calculated value increases from 5 to 8.

☑ The fact that the calculated risks, both for the slopes of the two open pits and for the interior dump, after resizing do not fall into the low risk class (they remain in the average category), leads us to the conclusion that land stability depends to a large extent on the natural conditions (geology, hydrology, hydrogeology, tectonics, etc.) and natural factors (morpho-structural processes, seismicity, freeze-thaw cycles, etc.) characteristic of the region, the mining activity being able to start at an accelerated pace and aggravate the geomorphological processes specific to the investigated area.

☑ It is recommended the post-closure monitoring of the area, both by direct observations (in the field), by classical topographic measurements, but also by means of the latest technology such as: GPS, satellite observations, drone photogametry, LIDAR etc.

☑ Elaboration of intervention plans in case of signs preceding the triggering of landslides but also in case of occurrence of such phenomena.

☑ Regularly informing the inhabitants of the direct and extended influence areas about the situation regarding the stability/instability of the lands and the risks involved.

☑ Revegetation of the slopes as soon as possible, by grassing in a first phase, in order to reduce the amount of water coming from the precipitations that infiltrate in the final slopes (especially of the interior dump), in the conditions in which, as it was shown, this has an unfavorable influence on the physical-mechanical characteristics of the rocks and can favor the triggering of different types of landslides.

☑ Establishing the final destination of the lands released from technological tasks and carrying out the designed ecological rehabilitation works (afforestation, tree plantations, restoration of agricultural lands, etc.).

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Ocena stanu stabilności i ryzyka wystąpienia osuwisk w zagłębiu górniczym Berbești (Rumunia) po zamknięciu kopalni

Zagłębie Górnicze Berbești, położone na obszarze Podkarpacia Getyckiego, jest częścią Zagłębia Centralnego (EC) Govora, posiada cztery odkrywki: Alunu, Olteț, Panga i West Berbești. Biorąc pod uwagę, że w Europie istnieje koncepcja rezygnacji z produkcji energii w oparciu o spalanie paliw kopalnych, zwłaszcza węgla, relatywnie krótko funkcjonować będą cztery odkrywki. Jednym z głównych problemów związanych z eksploatacją złóż węgla brunatnego jest stabilność gruntów na obszarze górniczym po zamknięciu eksploatacji. Badania przeprowadzono w taki sposób, aby uwzględnić w analizie stateczności czynniki i przyczyny naturalne, tenedencje terenów Podkarpacia Getyckiego do osuwisk, czynników i przyczyn antropogenicznych (wydobycie węgla brunatnego) oraz skutków oddziaływań towarzyszących. Analizy stateczności uwzględniały różne hipotezy związane z geometrią zboczy i wpływem czynników zewnętrznych. Przeprowadzono także analizę predykcyjną długoterminowej stabilności gruntów (zwłaszcza końcowych zboczy odkrywek) z uwzględnieniem zachowania się gruntów w czasie. Na podstawie uzyskanych wyników, po wykonaniu serii analiz statystycznych przeprowadzono analizę ryzyka, wykorzystując metodologię opracowaną przez część zespołu badawczego. Na wstępie należy zaznaczyć, że badania koncentrowały się na obszarach wydobywczych West Berbești i Panga, ponieważ wydobycie węgla brunatnego zostanie zakończone do końca 2022 roku. Biorąc jednak pod uwagę podobne warunki (geologia, morfologia, tektonika, strefy sejsmiczne, warunki pogodowe i klimatyczne, zastosowanych metod eksploatacji), zespół badawczy uważa, że znaczna część zawartych wniosków i rekomendacji w tym badaniu można uznać za ważne i dla pozostałych obszarów czynnych (odkrywki Alunu i Olteț). W tym kontekście opracowanie kończy się szeregiem wniosków dotyczących stabilności gruntów w zagłębiu górniczym Berbești (zachodnie Berbești i obwód Panga) w momencie zaprzestania działalności produkcyjnej oraz zalecenia, które po wprowadzeniu w życie zapewnią długoterminową stabilność gruntów.

Słowa kluczowe: *zagłębie wydobywcze Berbești, elektrociepłownia Govora, węgiel brunatny, odkrywka, ryzyko, osuwiska, stateczność*

Studies and Research on the Recovery of Copper from Industrial Waste Solutions by the Cementation Method

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Abstract

*The paper brings original contributions in the particularly complex field of copper recovery from industrial wastewater. The purpose of this experimental research is to recover copper metal powder from wastewater with low copper ion content, by the method of cementation using a scrap iron electrode and to calculate the yield of copper cementation, influenced by the following parameters: initial concentrations of copper ions, pH values and contact time. Recipes were experimentally studied by the cementation method for the recovery of copper from industrially used solutions using iron waste, without consumption of other reagents or energy. Work recipes were designed and one chose three different concentrations: for each solution of prepared concentration: 0.5% $CuSO_4$, 1% $CuSO_4$ and 3% $CuSO_4$, and one performed laboratory experiments at two types of pH (natural pH obtained by dissolving $CuSO_4$*$5H_2O$ in water, pH=2 (adjustment with 0.1 M sulfuric acid solution). The optimal conditions for each recipe have been identified, based on the experimental data obtained from the monitoring of each experiment, to the WTW Multi 350i multiparameter and AAS ZEEnit 700 Analytik Jena spectrometer. The calculation of the yield of obtaining copper powder for each day of the experiment and for each recipe together, the other experimental data led us to the conclusion that the optimal variant for our study is: concentration of 0.5%, at an initial pH of 3.6 after 3 days of experiment and yield of 95.23%.*

Keywords: *recovery of copper; wastewater treatment; copper cementation method*

Introduction

Copper is one of the most valuable and widely used metals in the industry. It is an essential metal for organisms, but in excessive concentrations it can be very toxic for both humans and animals (Peña M.M., Lee J., Thiele D.J., 1999). Copper is a heavy metal found in large quantities in wastewater due to its various applications in industrial sectors, such as the manufacture of printed circuit boards, the metal finishing industry, galvanizing, electrolysis, painting, wood preservation, printing operations, etc. Copper can reach the environment from mines, farms, industrial installations through wastewater discharged into rivers, lakes, but also from natural sources, such as: volcanoes, degraded vegetation, forest fires (Mubarak A., 2006). Copper was the first metal used in undetermined amounts by man. The oldest craftsmen who worked with copper soon found that it is easy to form into sheets with a hammer and sheets in turn worked into other shapes that became more and more complex as their skill increased.

Through the project (https://umfcd.ro/cercetare...SARS-COV-2) PN-III-P2-2.1-SOL-2020-2-0208 Development of innovative solutions for the protection of personnel (exposed professionally) and the population against contamination with the virus SARS-CoV-2, studies of impregnation of cotton or medical equipment made of cotton fabric. Various impregnation recipes were used that allowed to obtain "in situ" the nanoparticles of copper and zinc oxides for the impregnation of cotton fabrics, in different concentrations and ratios. The stability of the impregnation of the nanoparticles was confirmed by chemical analysis and analysis by scanning tissues of the tissues after 1, 3 or 5 washes. It has proved to be a good enough stability and it is expected that even after 10 washes an amount of about 40–50% of the initially impregnated amount will still be fixed on the fabric. The washes involve a pH-neutral detergent for 30–50 minutes at a temperature of 30–40°C ((https://umfcd.ro/cercetare...SARS-COV-2) PN-III-P2-2.1-SOL-2020-2-0208).

Copper is present in normal human serum (the liquid part of the blood) at concentrations of 120 –140 μg/l. Signs of toxicity will be observed if the copper concentration increases significantly above this level. All copper compounds are potentially toxic. Thus, man can be exposed to copper by breathing air, drinking water, food he consumes, by skin contact with copper or its compounds (Solomon F., 2009).

The use of copper to kill algae, fungi and mollusks proves to be very toxic to aquatic organisms. In fact, copper is one of the most toxic metals to aquatic organisms and ecosystems. Copper recovery from wastewater is achieved by various methods, such as bioadsorption, ion exchange, membrane filtration, reverse osmosis, chemical precipitation, electrochemical processes, photocatalysis, cementation (Gunatilake S.K., 2015).

Each of these methods has its own advantages and disadvantages. Unfortunately, some of these methods are difficult to use widely or expensive to apply. The use of the cementation method for the recovery of copper from metallic wastewater can be considered as a relatively simple, inexpensive and environmentally friendly method. Contamination of metal-treated water is a serious problem for many industrial sectors.

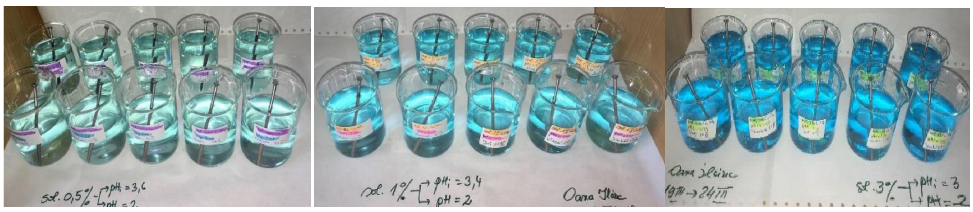

Fig. 1. Samples 3 solutions of different concentrations of $CuSO_4$ prepared for analysis
Rys. 1. Próbki 3 roztworów o różnych stężeniach $CuSO_4$ przygotowany do analizy

Tab. 1. Physico-chemical parameters of synthetic $CuSO_4$ solutions
Tab. 1. Parametry fizykochemiczne roztworu syntetycznego $CuSO_4$

$CuSO_4$ concentration	**pH initial**	**ORP (mV)**	**EC (µS/cm)**	**TDS (mg/l)**	**Salinity (‰)**
0.5%	3.6	+ 178.6	2480	1588	1.3
	2	+ 269	4570	2970.5	2.4
1%	3.4	+ 189.3	4250	2762.5	2.3
	2	+ 267.6	6190	4023.5	3.4
3%	3.0	+ 211.3	10290	6688.5	5.8
	2	+ 267.9	11910	7741.5	6.8

Tab. 2. Cu^{2+} values determined on the AAS ZEEnit 700 spectrometer
Tab. 2. Wartości Cu^{2+} wyznaczone na spektrometrze AAS ZEEnit 700

Time hours	*$CuSO_4$ 0.5% pH=2.0*	*$CuSO_4$ 0.5% pH=3.6*	*$CuSO_4$ 1% pH=2.0*	*$CuSO_4$ 1% pH=3.4*	*$CuSO_4$ 3% pH=2.0*	**$CuSO_4$ 3% pH=3.0**
0	2092.19	2092.19	4184.38	4184.38	12553.14	12553.14
24	628.66	627.33	3187.86	3177.44	4841.17	4601.41
48	488.31	487.35	626.92	623.33	4654.42	1749.41
72	182.26	140.15	483.41	481.71	1841.82	952.12
96	32.81	16.84	91.76	181.65	323.8	904.85
120	10.14	6.51	16.03	19.41	175.5	310.04

There are many different techniques used to treat wastewater to reduce metal content. A common technique involves raising the pH of the wastewater to an alkaline level to induce precipitation of the metal. Although this method reduces the metal content of wastewater, the resulting solid sludge will require additional treatment (Moscatello N., Swayambhu G., Jones G.H., Jiale Xu, Ning Dai, Pfeifer B.A., 2018).

Unlike organic contaminants, heavy metals are not biodegradable and tend to accumulate in living organisms and many of their ions are known to be toxic or carcinogenic (Fenglian Fu, Qi Wang, 2011). Copper has many practical uses in our society and is often found in coins, electric cables and pipes. However, too much copper can cause adverse health effects.

Materials and Methods

Cementation consists in the precipitation of metals from a solution of its salts by another electropositive metal (sacrificial metal) by spontaneous electrochemical reduction to its metallic state (Peng C., Liu Y., Bi J., Xu H., Ahmed A.S., 2011). The cementation method has several advantages, such as the recovery of metals in relatively pure metallic form, simple control requirements, low energy consumption and is generally a low cost process (Nassef E., El-Taweel Y.A., 2015). Cementation of copper on iron is done by a series of short-circuited electrochemical cells, in which electrons reduce the transfer of Cu2+ from the iron surface through the growing copper deposit. Copper ions are reduced from the surface of the copper deposit. Iron, which supplies electrons, is oxidized in the anodic places on its surface (EL-Ashtoukhy E.S.Z., Abdel A.M.H., 2013). However, it seems that cementing using an iron electrode is the simplest and most reasonable method for recovering copper. Therefore, it produces copper metallic sediments, which are suitable for metallurgical processes.

Eguipment used

Determination of physico-chemical parameters

Using the WTW Multi 350i multiparameter, the following physico-chemical parameters were measured:

- electrical conductivity (EC);
- total dissolved solids (TDS);
- salinity;
- pH;
- redox potential (ORP).

Before the analyzes were performed, the apparatus was calibrated using standard solutions for pH and conductivity.

Determination of heavy metals

Heavy metals were analyzed by flame atomic absorption spectrometry (AAS-F) using the AAS ZEEnit 700 Analytik Jena apparatus. The device allows the analysis of the following heavy metals: Ni, Cd, Cr, Pb, Zn, Cu, Fe, using the lamp specific to each metal. The detection limit of the method is between 0.01–0.08 mg/l, depending on the metal. Prior to analysis, the water samples were acidified to pH 2 (using 65% HNO_3) and filtered.

Cementation method-use of iron electrode

Procedure: studying the scientific information presented in the specialized articles, regarding the cementation method for the recovery of copper from used solutions, one observes the following:

- the mode of work is specific to a laboratory work (small amounts of used copper solutions 0.1–10 l, using continuous mixing and sometimes heating).
- the influence of the pH of the used copper solution on the recovery yield or efficiency (natural pH was

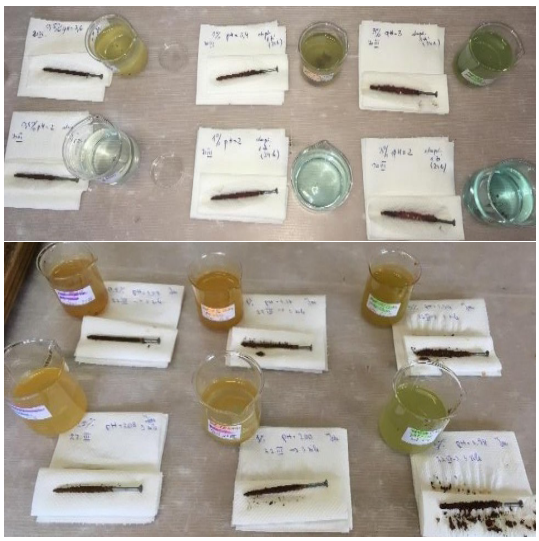

Fig. 2. Samples with the amount of copper deposited on the iron, from different days of the experiment
Rys. 2. Próbki z ilością miedzi osadzonej na żelazie w różnych dniach doświadczeń

Tab. 3. Yield values for the 3 solutions
Tab. 3. Wartości wydajności dla 3 roztworów

Concentration (%)	pH	Optime time (days)	$\eta_{optimal}$
0,5	3.6	3	95.23
	2	3	85.71
1	3.4	3	76.2
	2	4	97.62
3	3	3	86.83
	2	4	96.4

helped with 0.1 M H_2SO_4 solution up to pH 2).

- the working method designed for the experimental part simplifies the laboratory equipment (without agitation, without heating, with initial pH adjustment of $CuSO_4$ solutions prepared in the laboratory at a pH of 2, Fig. 1.) and one sought to identify the optimal conditions for copper deposition in a reasonable time.

One prepared 3 solutions of different concentrations of CuSO4 of 0.5%, 1%, 3% by dissolving the calculated amounts of CuSO4*5H2O for 250 ml volumetric flasks (stock solutions), (Table I) and the parameters were measured with multiparameter WTW Multi 350i.

One monitored day by day, the changes of previously measured parameters, with WTWMulti350i but also the amount of copper deposited (Fig. 2.), along with determining the daily concentration of copper ions remaining in solution at AAS ZEEnit 700 spectrometer, so one could calculate the efficiency and daily efficiency of experiments (Table 2).

Results

One started the experiment by preparing 3 solutions of different concentrations, of 0.5% CuSO4, 1%, 3% by dissolving the calculated amounts of $CuSO_4*5H_2O$ for 250 ml rated flasks. One monitored the changes in previously measured parameters with WTW Multi 350i but also the amount of copper deposited, along with determining the daily concentration of copper ions remaining in solution at the AAS ZEEnit 700 spectrometer, so one could calculate the daily efficiency and effectiveness of our experiments.

For each concentration solution prepared: 0.5% $CuSO_4$, 1% $CuSO_4$ and 3% $CuSO_4$ were performed laboratory experiments at 2 different pH:

a) the natural pH obtained by dissolving $CuSO_4$ in water;
b) pH=2 (adjustment with 0.1 M sulfuric acid solution).

The variation of salinity is observed, for the 3% pH 2 solution, which is fluctuating, reaching 6.8‰. The variation of the concentration of copper ions is observed, for the 3% solution (12553.14 mg / l) at pH 2, which is decreasing, reaching 175.5 mg/l. It is observed that after 4 days from the experiment, the concentration of copper ions reaches 323.8 mg/l, which gives us the possibility to identify an optimal time for the experiment (Fig. 3.).

The synthesis yield is defined as the ratio between the practical mass obtained by copper powder (dry) and the terrorist mass (Călțaru M., Bădicioiu M., 2007).

It is observed that after 4 days the copper recovery efficiency stabilizes at 96.4%. It should be noted that after the first day of the experiment (24h), the yield is almost 89% (Fig. 4). Which demonstrates the effectiveness of the iron waste used in the cementation method.

Table 3 shows yields over 95%, for all 3 optimal variants, but the time to obtain the optimal yield will differentiate the overall optimal variant, which one propose to be: concentration of 0.5%, at an initial pH of 3.6 after 3 days of experiment and yield of 95.23%.

Discussion

The resultated obtained for the variation of pH, EC, salinity, copper ion concentration and yield is the follow:

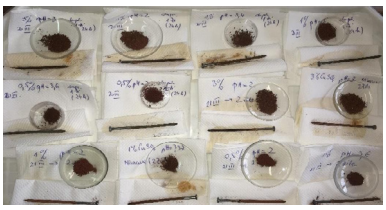

Fig. 3. Samples with the amount of copper deposited on the iron, from different days of the experiment
Rys. 3. Próbki z ilością miedzi osadzonej na żelazie z różnych dni doświadczenia

Fig. 4. The amount of copper powder obtained after one day of experiment
Rys. 4. Ilość proszku miedzi uzyskanego po jednym dniu doświadczenia

0.5 % copper sulphate solution of initial pH=3.6

The pH variation for the 5 days of the experiment is fluctuating, falling between 3.6–4.1 with an average of 3.88 (note that pH=4.1 is obtained after 4 days). The variation of the EC (μS/cm) for the 5 days of the experiment is increasing, ranging between 2480–2860 μS/cm, with an average of 2693.3 μS/cm (note that EC = 2860 μS/cm is obtained after 5 days). The variation of salinity (‰) for the 5 days of the experiment is increasing, ranging between 1.3–1.5‰, with an average of 1.4‰ (note that S=1.5‰ is obtained after 5 days). The variation of the copper ion concentration (mg/l) for the 5 days of the experiment is decreasing from 2092.19 mg/l to 6.51 mg/l (on the 5th day) which demonstrates that in these conditions the method cementation also helps us in solving the problem of the concentration of copper ions in the used industrial solution because after 5 days it reaches ovals below 10 mg/l (a decrease of about 322 times). The calculated synthesis yield is 95.23% after 3 days of experiment.

0.5 % copper sulfate solution at adjusted pH=2

The pH variation for the 5 days of the experiment is increasing, ranging between 2–3.8 with an average of 3.35 (note that pH=3.8 is obtained after 3 days). The variation of the EC (μS/cm) for the 5 days of the experiment is decreasing starting from 4570–2960 μS/cm, with an average of 3370 μS/cm (note that EC = 2960 μS/cm is obtained after 2 days). The variation of salinity (‰) for the 5 days of the experiment is decreasing, starting from 2.4–1.5 ‰, with an average of 1.7‰ (note that S = 1.5 ‰ is obtained after 2 days). The variation of the concentration of copper ions (mg/l) for the 5 days of the experiment is decreasing from 2092.19 mg/l to 10.14 mg/l (on the 5th day), which demonstrates that in these conditions the cementation method also helps us in solving the problem of the concentration of copper ions in the used industrial solution because after 5 days it reaches a value of about 10 mg/l (a decrease of about 209 times). The calculated synthesis yield is 85.71% after 3 days of experiment.

Analyzing the data obtained for the two pH at the 0.5% $CuSO_4$ solution, it is observed that the optimal conditions for cementation would be for the initial pH=3.6, because the yield is 95.23%, after 3 days of experiment.

1% copper sulphate solution at initial pH=3.4

The pH variation for the 5 days of the experiment is fluctuating, falling between 3.4–3.77 with an average of 3.61 (note that pH=3.77 is obtained after 3 days). The variation of the EC (μS/cm) for the 5 days of the experiment is increasing, ranging between 4250–5040 μS/cm, with an average of 4691 μS/cm (note that EC = 5040 μS/cm is obtained after 5 days). The variation of salinity (‰) for the 5 days of the experiment is increasing, falling between 2.3–2.7‰, with an average of 2.51‰ (note that S = 2.7‰ is obtained after 5 days). The variation of the concentration of copper ions (mg/l), for the 5 days of the experiment is decreasing from 4184.38 mg/l to 19.41 mg/l (on the 5th day) which proves that in these conditions the cementation method it also helps us in solving the problem of the concentration of copper ions in the used industrial solution because after 5 days it reaches a value below 20 mg/l (a decrease of about 215 times). The calculated synthesis yield is 76.2% after 3 days of experiment.

1% copper sulphate solution at adjusted pH=2

The pH variation for the 5 days of the experiment is increasing, ranging between 2–3.65 with an average of 3.12 (note that pH=3.65 is obtained after 5 days). The variation of the EC (μS/cm) for the 5 days of the experiment is decreasing starting from 6190–5480 μS/cm, with an average of 5383.3 μS/cm (note that EC = 5480 μS/cm is obtained after 5 days). The variation of salinity (‰) for the 5 days of the experiment is decreasing, starting from 3.5–3‰, with an average of 2.9‰ (note that S=3‰ is obtained after 5 days). The variation of the copper ion concentration (mg/l) for the 5 days of the experiment is decreasing from 4184.38 mg/l to 16.03 mg/l (in the 5th day) which proves that under these conditions the meth-

od cementation also helps us in solving the problem of the concentration of copper ions in the used industrial solution because after 5 days it reaches a value of about 16 mg/l (a decrease of about 261 times). The calculated synthesis yield is 97.62% after 4 days of experiment.

Analyzing the data obtained for the two pH at the 1% $CuSO_4$ solution, it is observed that the optimal conditions for cementation would be for adjusted pH=2, because the yield is 97.62%, after 4 days of experiment.

Solution 3% copper sulfate initial pH=3

The pH variation for the 5 days of the experiment is fluctuating ranging from 3–3.75 with an average of 3.42 (note that pH=3.75 is get after 2 days). The variation of the EC (μS/cm) for the 5 days of the experiment is fluctuating, falling between 10290–11980 μS/cm, with an average of 11418 μS/cm (note EC = 11980 μS/cm is obtained after 5 days). The variation of salinity (‰) for the 5 days of the experiment is increasing, falling between 5.8–6.9‰, with an average of 6.46‰ (note that S=6.9‰ is obtained after 3 days). The variation of the copper ion concentration (mg/l) for the 5 days of the experiment is decreasing from 12553.14 mg/l to 310.04 mg/l (on the 5th day) which demonstrates that under these conditions the method cementation also helps us in solving the problem of copper ion concentration in the industrialized solution because after 5 days it reaches a value of 310 mg/l (a decrease of about 40 times). The calculated synthesis yield is 86.83% after 3 days of experiment.

3% copper sulphate solution at adjusted pH=2

The pH variation for the 5 days of the experiment is increasing, falling between 2–3.43 with an average of 2.96 (note that pH=3.43 is obtained after 4 days). The variation of the EC (μS/cm) for the 5 days of the experiment is fluctuating starting from 11910–11960 μS/cm, with an average of 11421 μS/cm (note that EC = 11960 μS/cm is obtained after 5 days). The variation of salinity (‰) for the 5 days.

Conclusions

The cementation method can recover copper from industrial waste solutions. This study aimed to make a number of original contributions to the particularly complex field of recovery of copper from industrial wastewater by the method of cementation.

The best known reaction for obtaining copper in the laboratory is between iron and copper sulfate. This can be used to obtain copper by depositing it on the piece of metal iron inserted in the industrial water.

95.23% yield of obtaining copper powder indicates the optimal variant at the concentration of 0.5% with an initial pH of 3.6 after 3 days of experiment.

Experimentally it is possible to recover metallic copper powder from wastewater with low copper ion content, by the cementation method using a scrap iron electrode, without consuming other reagents or energy.

Acknowledgments

Faculty of Environmental Science and Engineering, Babes-Bolyai University, Cluj Napoca for the WTW Multi 350i multiparameter and AAS ZEEnit 700 Analytik Jena spectrometer. Faculty of Mining University of Petrosani for research in the Ecopedology Laboratory.

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Studia i badania nad odzyskiem miedzi z odpadów przemysłowych metodą cementacji

Artykuł przedstawia oryginalne badania związane z odzyskiwaniem miedzi ze ścieków przemysłowych. Celem badań eksperymentalnych jest odzyskiwanie sproszkowanej miedzi metalicznej ze ścieków o niskiej zawartości jonów miedzi metodą cementacji za pomocą złomowej elektrody żelaznej oraz do obliczenie wydajności cementacji miedzi, na którą wpływają następujące parametry: początkowe stężenia jonów miedzi, wartości pH i czas kontaktu.

Eksperymenty obejmowały odzysk miedzi z przemysłowych roztworów z wykorzystaniem odpadów żelaza metodą cementowania, bez zużycia innych odczynników lub energii.

Plan eksperymentu obejmował trzy różne stężenia $CuSO_4$: dla każdego roztworu o przygotowanym stężeniu: 0,5% $CuSO_4$, 1% $CuSO_4$ oraz 3% $CuSO_4$, przeprowadzono eksperymenty laboratoryjne dla dwu wartości odczynu pH (naturalne pH uzyskane przez rozpuszczenie $CuSO_4 * 5H_2O$ w wodzie, pH=2 (regulacja 0,1 M roztworem kwasu siarkowego).

Optymalne warunki dla każdej receptury zostały określone na podstawie danych eksperymentalnych. W badaniach wykorzystano spektrometry WTW Multi 350i i AAS ZEEnit 700 Spektrometr Analytik Jena. Przeprowadzono obliczenie wydajności pozyskania proszku miedziowego dla każdego dnia doświadczenia i dla każdej receptury. Dane eksperymentalne doprowadziły do wniosku, że optymalnym wariantem dla badania jest: stężenie 0,5%, przy początkowe pH 3,6 po 3 dniach doświadczenia i wydajność 95,23%.

Słowa kluczowe: *odzysk miedzi, oczyszczanie ścieków, metoda cementowania miedzi*

Responses of the Micro-Crustacean, *Daphnia magna*, across Five Generations Continuously Exposed to Di-2-Ethylhexyl Phthalate in Mekong River Water

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Abstract

Plastic pollution has been considered as an emerging environmental problem, and is among the ecological and human health concerns. Detrimental impacts of plastic pollution on living things are closely related to the plastic additives added onto the polymer during plastic manufacture. Di-2-ethylhexyl phthalate (DEHP) is one of the most common plasticizers and is usually found in water environment worldwide. Plastic additives can cause many negative effects on aquatic organisms such as fish and zooplankton. This study aimed to assess the chronic effects of DEHP on the life history traits of an ecotoxicological model micro-crustacean, Daphnia magna, across five generations (F0–F4). We used the natural water from Mekong River in Vietnam as the medium for the D. magna incubation in laboratory conditions. The concentrations of trace elements (e.g., metals and pesticides) in the natural water were under detection levels of equipment or very low which was sufficient for D. magna to grow well. The results showed that the body length was the main endpoint of the organisms inhibited by DEHP across all generations. DEHP adversely impacted the survival and fecundity of D. magna in the fourth generation (F3) only. The adverse effects of DEHP on body length of D. magna should be the consequence of the energy cost and allocation in the exposed organisms. The survival and reproduction responses of D. magna to DEHP across five generations could be explained by (i) the severe effects of the chemical on many individuals in the organism cohort, and (ii) toxin-tolerant development in the remaining exposed organisms. Although the trace elements in natural water from Mekong River were not toxic to D. magna at very low concentrations, together with DEHP they might enhance impacts on the organism. Besides, a multigenerational exposure to DEHP would reflect clearer impacts on the organism than a single exposure. Our results could be useful for extrapolation on the influence of plasticizers on freshwater zooplankton in nature.

Keywords: *chronic effects, Daphnia magna, energy cost, life traits, plastic additives*

1. Introduction

Plastic emission and pollution are among the most serious threats to aquatic environment and ecosystem globally (Miller et al. 2020; Azevedo-Santos et al. 2021). The di-2-ethylhexyl phthalate (DEHP) is one of the basic and common additives for more than 300 million tons of plastic products annually in the world (Wang et al. 2018; Chen et al. 2020). Globally, the compound DEHP was produced at more than 2 million tons (Rowdhwal and Chen 2018). In natural conditions (e.g., high temperature), DEHP can easily release out of the plastic surface and enter the surrounding environments (Wang et al. 2018). The existence of DEHP in the environment has been reported in many countries such as Finland, Denmark, Germany, Japan, China, Thailand, Poland, Sweden, and Italy (Wowkonowicz and Kijeriska 2017). The highest concentration of DEHP in river water reached 370 μg L-1 in China (Wang et al. 2018). Recently, DEHP has become an emerging pollutant. It is known as an endocrine disrupting chemical and considered as a carcinogenic compound to invertebrates (Wang et al. 2018). However, the impacts of DEHP on aquatic invertebrates are not fully understood.

Micro-crustaceans (e.g., *Daphnia magna*) are among the key animal groups in aquatic ecosystems having important position and function in aquatic food webs (Wetzel, 2001). *Daphnia magna* is the common representative of freshwater micro-crustaceans and is widely used as a model organism for testing the pollutant toxicity (US. EPA 2002; Lampert 2006; APHA 2012). The median lethal concentrations (LC50) of DEHP to *D. magna* were largely varied between 160 and 3,310 μg L-1 (Adams et al. 1995; Brown et al. 1998; Scanlan et al. 2015; Wang et al. 2018). The life history traits of *D. magna* chronically exposed to DEHP have been reported in many studies in which the DEHP concentration up to 500 μg L-1 did not impact survival of the organism (Brown and Thompson 1982; Knowles et al. 1987; Brown et al. 1998; Seyoum and Pradhan 2019; Le et al. 2019). Seyoum and Pradhan (2019) and Le et al. (2019) noted that DEHP enhanced the reproductive capacity of *D. magna*. The authors also found that the DEHP at 390 μg L-1 inhibited the growth of *D. magna*, but the inhibition was not showed at lower concentrations of the chemical.

Generally, all previous studies of the DEHP toxicity to *D. magna* were performed in artificial medium (e.g., ISO). However, the toxicity of DEHP in the artificial environment may not be the same as that in the natural water because of different chemical properties between them. Besides, the responses of *D. magna* to DEHP across multigenerational exposure are not yet fully understood (but see Le et al. 2019). Therefore, to fill the gap, in this study we assessed the effects of DEHP dissolved in natural water from Mekong River at the concentration of 500 μg L-1 on the life history traits of *D. magna* across five generations.

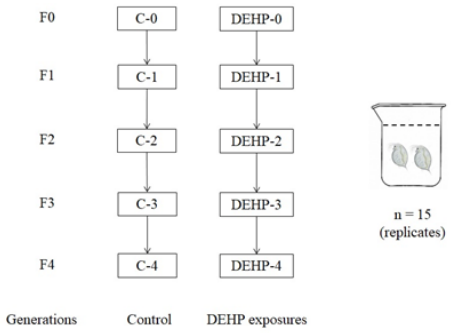

Fig. 1. Experimental setup for *D. magna* across five generations exposed to DEHP dissolved in Mekong River water
Rys. 1. Układ doświadczalny dla *D. magna* w pięciu pokoleniach poddanych działaniu DEHP rozpuszczonego w wodzie Mekongu

2. Materials and methods

2.1. Test organisms

The freshwater micro-crustacean *Daphnia magna* was purchased from Micro BioTest (Belgium) and has been maintained in ISO medium for many years. The organisms were fed with the green alga Scenedesmus sp. and YTC (US. EPA. 2002). The alga Scenedesmus sp. was cultured in a Z8 medium (Kotai 1972). The *D. magna* was raised under the temperature of 25 ± 1°C, the light intensity of less than 1000 Lux, and a photo regime of 14 h light: 10 h dark (APHA 2012).

2.2. Chemicals

The plastic additive Di-2-ethylhexyl phthalate (DEHP, Aldrich Sigma, purification 99.5%) was dissolved in acetone (Merck, Germany) at the concentration of 3292 mg L-1 referred as stock solution. The stock solution was kept at 4°C before the test implementation. The natural water used in this study was collected from Mekong River in Vietnam. The water was settled and then filtered through a GF/A filter (Advantech, Japan) before being used as a medium to culture *D. magna*. The chemical characterization of pesticides (all below 1 µg L-1) and trace metals (mostly below 1 µg L-1, and much far below the 48h-LC50 values to *D. magna*) confirmed that the natural water from Mekong River was suitable for cultivation of *D. magna* (Dao et al. accepted manuscript).

2.3. Experimental design

The chronic experiment was conducted according to APHA (2012) with minor adjustment. At the start of the experiment, nearly 40 mother *D. magna* were randomly selected and transferred into a one-liter glass beaker containing 800 mL of filtered river water. Sixty neonates (<24 hours old) from the second and third broods of the mother *D. magna* were randomly used for the chronic experiment. The experiment was performed over five generations of *D. magna* (Fig. 1). In more detail, at the first generation (called F0) of the experiment, two organisms were cultured together in a 50 mL glass beaker containing 40 mL of filtered river water. We conducted two treatments including the exposure to DEHP and the control. In the exposure, *D. magna* was raised in the natural water containing 500 µg DEHP L-1 while the organisms in the control were just incubated in the natural water without the addition of DEHP. There were 15 replicates in each treatment (n=15). Offspring from the second and third brood of F0 *D. magna* in control and DEHP exposure were used for the next generational experiment (hereafter we called F1) and continuously raised in the same medium as their mothers were (2 neonates per beaker, 15 replicates). This process repeated until the fifth generation (F4). The test concentration of 500 µg DEHP L-1 was chosen for the present study because the highest concentration of phthalates in surface water and landfill leachate could reach up to 370 µg L-1 and 460 µg L-1, respectively (Wowkonowicz and Kijeriska 2017; Wang et al. 2018).

The organisms in each treatment were fed daily with the mixture of green alga Scenedesmus sp. and YTC (US. EPA. 2002). The chronic test was performed in the laboratory conditions (as mentioned above) and lasted for 21 days for each generation (Adema 1978). We conducted this study with data within five generations of exposures because the Covid-19 quarantine was applied in the city before we could complete the experiment on the sixth generation. The test medium (filtered river water and food) in each treatment was totally renewed three times per week. During the time of the experiment, the life history traits including the survival, reproductive performance of *D. magna* were carefully checked and recorded daily. The dead mother *D. magna* and neonates released from each beaker were counted and discarded daily. By the end of the experiment, alive *D. magna* was fixed with Lugol solution (Sournia 1978) and its body length was measured from the head top to the base of tail spine of the *D. magna* on a microscope coupled with a digital camera. The pH and dissolved oxygen (DO) of the test medium were measured and their values ranged from 7.2–7.6 (for pH), and from 7.4–7.9 mg L-1 (for DO) which met the requirements for chronic experiments with *D. magna* according to APHA (2012).

2.3. Data treatment

Sigma Plot version 12.0 was used for data analyses. The Kruskal-Wallis test was utilized to calculate the statistically significant difference ($p < 0.05$) in body length, and accumulative offspring per beaker between control and DEHP exposure.

3. Results and discussion

3.1. The effects of DEHP on the survival of Daphnia magna

In the control, the survival of *D. magna* in all six generations was from 80–93% when the experiments terminated (Fig. 2) which meets the requirement of APHA (2012) for chronic treatments with micro-crustaceans. Similarly, the survival of *D. magna* in DEHP exposures was within the range of 80–100% except the survival of DEHP-exposed *D. magna* in F3 was 53% by the end of experiment.

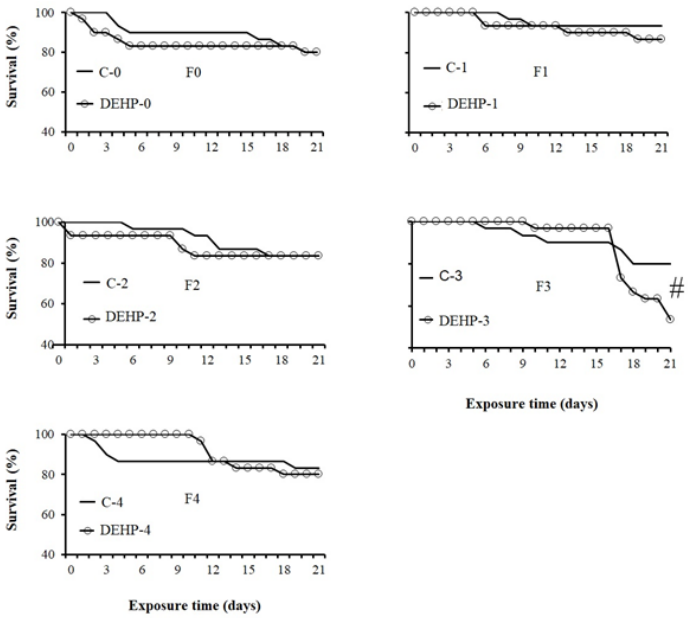

Fig. 2. The survival of *D. magna* in the control and DEHP exposure through five generations. The symbol (#) indicated the significant difference between control and DEHP exposure according to APHA (2012)

Rys. 2. Przeżywalność D. magna w próbce kontrolnej i poddanej ekspozycji na DEHP przez pięć pokoleń. Symbol (#) wskazywał na istotną różnicę między kontrolą a narażeniem na DEHP według APHA (2012)

In the first and second generational exposures (F0 and F1), the Daphnia's survival in present study is consistent with that in previous studies (Seyoum and Pradhan 2019; Le et al. 2019) in which *D. magna* was incubated in DEHP at the concentrations of 390–500 µg L-1. However, a significant decrease of *D. magna* survival (55%) in the third generation (F2) exposed to DEHP (500 µg L-1) was reported by Le et al. (2019). Therefore, the previous studies (Seyoum and Pradhan 2019; Le et al. 2019) and our study have a similar trend of effects reflecting the impact of DEHP on the *D. magna*'s survival was only profound in the later generations of exposure.

Biochemically, DEHP caused a significant reduction in the activities of catalase (CAT) and superoxide dismutase (SOD) enzymes, the antioxidant capacity and detoxifying activities in *D. magna* (Wang et al. 2018). DEHP can interfere the protein synthesis and fatty acid catabolism, consequently influence the normal functions of heart and hepatopancrea in *D. magna* (Scanlan et al. 2015; Ito et al. 2019). Hence, DEHP could indirectly affect the energy storage or cause the glycogen reduction in *D. magna* (Knowles et al. 1987). The compound DEHP could be accumulated and recalcitrant in aquatic organisms. Therefore, the DEHP-exposed *D. magna* would spend energy for biochemical adjustment and damage repair, consequently energy cost (Dao et al. 2018). The exposed organisms could withstand DEHP in the first generations by spending energy and material for survival (F0–F2; Fig. 2) and reproduction maintenance (F1, F2; Fig. 4). However, the *D. magna* could be impaired in a more generational exposure to DEHP (F3) consequently mortality increase (up to 47% of total exposed organisms).

The difference of the affected generations in the previous study (F2; Le et al. 2019) and ours (F3) could be related to the trade-off between survival and development in DEHP-exposed *D. magna*. The DEHP-exposed *D. magna* could face energy cost and material allocation to maintain its normal behaviors and fitness (e.g. survival and growth). Hence the slowdown its growth (see section 3.2) the DEHP-exposed *D. magna* could have a chance to conserve its survival rate similar to the control in F2 (Fig. 2).

Our study presented the initial evidence of *D. magna* continuously exposed to DEHP in natural river water over 5 generations. Interestingly, we found that *D. magna* was more likely to recover or even adapt in its survival to DEHP in the fifth generation (F4). Dao et al. (2018) studied the survival of a micro-crustacean Daphnia lumholtzi by exposed the organism to a cyanobacterial toxin, microcystin, across three generations and observed the tolerance of the organism in the first generation, the significant decrease of the organism in the second generation, and the acclimation of the organism in the third generation. The acclimation or recovery of microcystin-exposed mother *D. magna* was hypothesized with the formation of the genes for synthesis of detoxifying enzymes in its offspring, and thus improve the toxin tolerance in the daughters (Gustafsson et al. 2005). This helps to explain the acclimation of *D. magna* in F4 to the DEHP in present study. Further studies on the gene encoding for antioxidant enzyme and detoxification activities in *D. magna* exposed to DEHP are suggested to clarify.

3.2. The effects of DEHP on the growth of Daphnia magna

The average body length of *D. magna* in the control ranged between 3,000 and 3,610 µm. However, body length of *D. magna* in the DEHP exposure varied from 2,920–3,330 µm which was significant shorter than that in the control ($p < 0.05$; Fig. 3). Our results indicated that DEHP inhibited the growth of the organisms in all five generations.

Body size of *D. magna* is a very important endpoint of fitness because it is highly related to the time of first reproduction and clutch size of the organism (Ebert 1992). However, effects of phthalates on growth or body length of *D. magna*

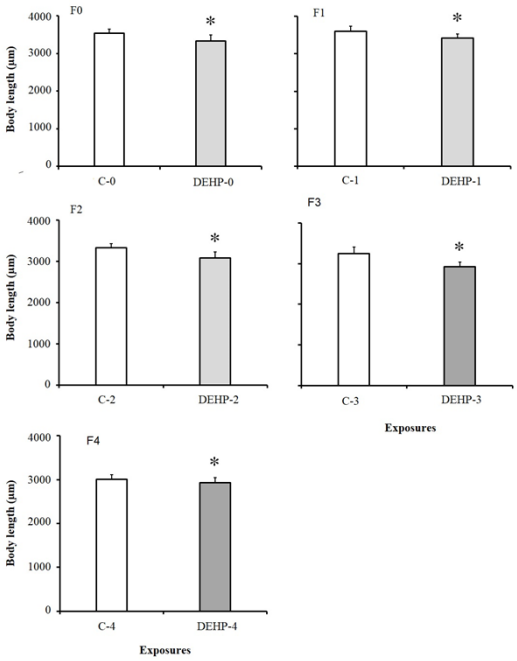

Fig. 3. The body length of *D. magna* in the control and DEHP exposure through five generations. The asterisk (*) indicated the significant difference between control and DEHP exposure by the Kruskal-Wallis test ($p < 0.05$)

Rys. 3. Długość ciała *D. magna* w próbce kontrolnej i w ekspozycji na DEHP przez pięć pokoleń. Gwiazdka (*) wskazuje istotną różnicę między próbką kontrolną a ekspozycją na DEHP w teście Kruskala-Wallisa ($p < 0,05$)

have not been studied (but see Seyoum and Pradhan 2019; Le et al. 2019). Our study firstly revealed the impact of DEHP on the growth of *D. magna* under a multigenerational exposure. The observation in present study was in line with the previous study for the F0 (Le et al. 2019). Seyoum and Pradhan (2019) also recorded a reduction of body length in *D. magna* exposed to DEHP at the concentration of 390 µg L-1 over 14 days. As mentioned above, DEHP could cause the material and energy allocation related to the fitness such as survival, growth, reproduction of *D. magna*. Generally, the DEHP-exposed *D. magna* in our study could maintain its survival at a normal rate during 21 days of incubation from F0 through F4, except F3 (Fig. 2). Therefore, DEHP-exposed organism had to face a trade-off that slowed down its growth consequently a shorter body length than the control *D. magna*.

3.3. The effects of DEHP on the reproduction of Daphnia magna

The reproduction of *D. magna* was calculated as the accumulative neonates released from each beaker in the control and the DEHP exposure during 21 days of treatment. The reproduction of *D. magna* of both control and exposure in F1, F2, and F4 was in a similar range. However, DEHP caused a significant reduction in fecundity of mother *D. magna* in the F0 ($p = 0.024$, Kruskal-Wallis test), and F3 ($p = 0.002$, Kruskal-Wallis test; Fig. 4).

Previous studies revealed that DEHP could enhance the reproduction of *D. magna* at the concentration of 390 µg L-1 (Seyoum and Pradhan 2019) or not inhibited this endpoint of the organism at the concentration of 500 µg L-1 (Le et al., 2019). On the contrary, we found a much lower reproduction in *D. magna* exposed to DEHP in the first generation (F0). Without a doubt – organisms in aquatic environments could be affected by not only a single pollutant but a mixture of pollutants as well. The natural water from Mekong River used in present study had some trace elements at low levels (Dao et al. accepted manuscript) which might have side effects on *D. magna* (Le et al. 2021). The combined effects of DEHP and trace elements in natural water could cause stronger toxic effects on micro-crustacean than the solely impact of DEHP on the organism in standard medium (Dao et al. accepted manuscript). In the second (F1) and third (F2) generations, DEHP-exposed *D. magna* showed signs of reproductive recovery (Fig. 4).

In our study, in the fourth generation (F3) *D. magna* were affected again and the total number of offspring born in DEHP exposure was significantly different from the control ($p < 0.002$). this should be the consequence of the high mortality of DEHP-exposed *D. magna* in F3 (Fig. 2). The much lower number of mother *D. magna* in F3 would lead to a lower number of accumulative neonates. On the other hand, the increase of DEHP-exposed *D. magna* survival in the fifth generation (F4; Fig. 2) resulted in the increase of accumulative neonates (Fig. 4).

The present study showed the effects of DEHP in natural water from Mekong River on *D. magna* across five generations. This could be useful for the extrapolation in situ and the prediction on potential impacts of plastic additives (e.g., DEHP) on freshwater zooplankton in Mekong River, the eleventh highest river loading plastic waste into the seas globally (Lebreton et al. 2017).

Conclusions

This is the first investigation assessing the toxicity of DEHP to *D. magna* incubated in natural water from Mekong River across five generations from the best of our knowledge. High mortality (47%) was found in the DEHP exposure in the fourth generation (F3). DEHP also caused a reduction in fe-

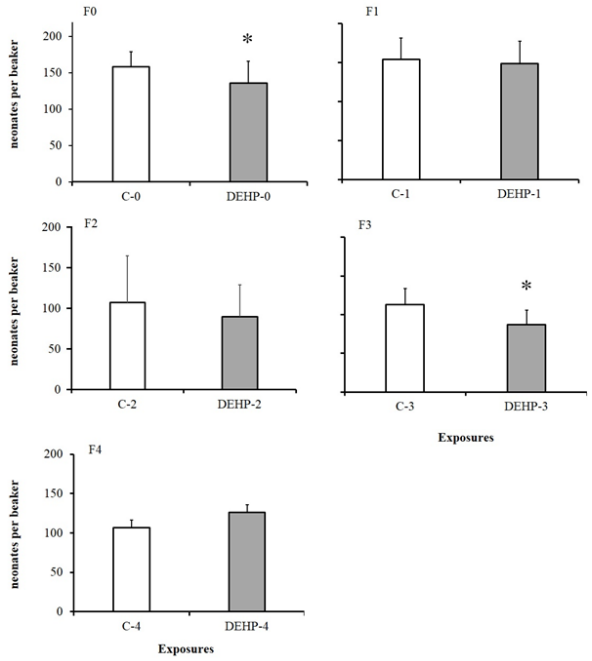

Fig. 4. The accumulative neonates from each culturing beaker in the control and DEHP exposure through five generations. The asterisk (*) indicated the significant difference between control and DEHP exposure by the Kruskal-Wallis test ($p < 0.05$)

Rys. 4. Skumulowana liczba nowych organizamów z każdej próbki hodowlanej w grupie kontrolnej i ekspozycji na DEHP przez pięć pokoleń. Gwiazdka (*) wskazuje istotną różnicę między próbką kontrolną a ekspozycją na DEHP w teście Kruskala-Wallisa ($p < 0,05$)

cundity of mother *D. magna* in F0 and F3. However, the body length of the animal in the DEHP exposure was significantly shorter than that of the control across five generations. The trade-off between the survival, growth and reproduction related to the material and energy allocation would be the root of the responses of *D. magna* to DEHP. The effects of DEHP in natural water from Mekong River are useful to extrapolate the toxicity of this chemical to micro-crustacean in situ, and the effects would become more severe uncomfortable environmental and biological conditions in nature.

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Reakcje mikroskorupiaków, Daphnia magna*, w ciągu pięciu pokoleń stale narażonych na działanie ftalanu di-2-etyloheksylu w wodzie rzeki Mekong*

Zanieczyszczenie tworzywami sztucznymi zostało uznane za narastające zagrożenie środowiskowe i jest jednym z problemów ekologicznych związanych ze zdrowiem człowieka. Szkodliwy wpływ zanieczyszczenia tworzywami sztucznymi na organizmy żywe jest ściśle związany z dodatkami tworzyw sztucznych dodawanymi do polimeru podczas produkcji tworzyw sztucznych. Ftalan di-2-etyloheksylu (DEHP) jest jednym z najpowszechniejszych plastyfikatorów i zwykle występuje w środowisku wodnym na całym świecie. Dodatki do tworzyw sztucznych mogą powodować wiele negatywnych skutków dla organizmów wodnych, takich jak ryby i zooplankton. Badania przedsatwione w artykule miały na celu ocenę ciągłego wpływu DEHP na cechy historii życia modelu ekotoksykologicznego mikroskorupiaka, Daphnia magna*, w ciągu pięciu pokoleń (F0–F4). Jako pożywkę do inkubacji* D. magna *w warunkach laboratoryjnych wykorzystano naturalną wodę z rzeki Mekong w Wietnamie. Stężenia pierwiastków śladowych (np. metali i pestycydów) w naturalnej wodzie były poniżej poziomu wykrywalności sprzętu lub bardzo niskie, co było wystarczające, aby* D. magna *dobrze się rozwijała. Wyniki pokazały, że długość ciała była głównym punktem oceny rozwoju organizmów hamowanego przez DEHP we wszystkich pokoleniach. DEHP negatywnie wpłynął na przeżywalność i płodność* D. magna *jedynie w czwartym pokoleniu (F3). Negatywny wpływ DEHP na długość ciała* D. magna *powinien być konsekwencją zużycia energii i jej alokacji w narażonych organizmach. Reakcje* D. magna *na przetrwanie i reprodukcję pod wpływem DEHP w ciągu pięciu pokoleń można wytłumaczyć (i) poważnym wpływem substancji chemicznej na wiele osobników w populacji organizmów oraz (ii) rozwojem tolerancji na toksyny u pozostałych narażonych organizmów. Chociaż pierwiastki śladowe w naturalnej wodzie z Mekongu nie były toksyczne dla* D. magna *w bardzo niskich stężeniach, to razem z DEHP mogą nasilać oddziaływanie na organizm. Poza tym wielopokoleniowe narażenie na DEHP odzwierciedlałoby wyraźniejszy wpływ na organizm niż jednorazowe narażenie. Przedstawione wyniki mogą być przydatne do ekstrapolacji wpływu plastyfikatorów na zooplankton słodkowodny w przyrodzie.*

Słowa kluczowe: *skutki chroniczne,* Daphnia magna*, zużycie energii, cechy życiowe, dodatki do tworzyw sztucznych*

Assessment of Heavy Metal Pollution in the Surface Water of the Doi-Cho Dem-Ben Luc Rivers, Vietnam

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Abstract

Heavy metals are a pressing concern in terms of their pollution in aquatic ecosystems because of their persistence, environmental toxicity, bioaccumulation. Aquatic environments receive heavy metals in untreated or inadequately treated wastewater from domestic, industrial, agricultural, and navigation sources. The Doi-Cho Dem-Ben Luc Rivers play the key roles of irrigation, navigation and ecological restoration. It is crucial to ascertain the pollution status, influencing factors, ecological risks, and possible sources of heavy metals in the surface water of the Doi-Cho Dem-Ben Luc Rivers. In this study, surface water from 7 sampling sites over was collected from the Doi-Cho Dem-Ben Luc Rivers, over 7 consecutive periods from April 2019 to October 2021. Each surface sample was analyzed for 9 heavy metals including Fe, Mn, Cr, Zn, Cu, Pb, Cd, Ni, As. The sampling technique and sample treatment were done based on the Standard Methods for the Examination of Water and Wastewater. The time and space variation of heavy metal concentrations were examined to test the analysis of variance (ANOVA) and correlation among all the parameters using R statistical software.

The results suggest a spatial homogeneity of heavy metals in the surface water the studied rivers. Among all nine examined heavy metals in the studied area, the concentrations of Fe (1.00 ÷ 5.06 mg/L) and Mn (0.14 ÷ 0.28 mg/L) are the highest, and the concentrations of Cr, Cd and As are the lowest that lower limit of detection. The results suggested that the mean concentrations of Fe and Mn were above the acceptable limits of the National technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT). While the concentrations of Fe, Mn, Zn, Cu, Pb, Ni do not meet the Water quality criteria for aquatic life (United State Environmental Protection Agency). Anthropogenic activities can be the main source of heavy metals in in the surface water of the Doi-Cho Dem-Ben Luc Rivers. Among the heavy metals, a significant positive correlation was observed between Fe, Mn, Zn and Ni (0.64 ÷ 0.87), whereas Cu exhibited a significant positive correlation with Ni (0.51). While Cu and Pb showed a not too strong correlation with Fe, Mn, Zn and Ni (0.25 ÷ 0.48). The distribution of heavy metals may also be influenced by properties of heavy metals and fluctuations in water flows. The results provide guidance for controlling heavry metal pollution and protectting water sources in the Doi-Cho Dem-Ben Luc Rivers.

Keywords: *heavy metal pollution, surface water, distribution, river, Doi-Cho Dem-Ben Luc, water quality protection*

1. Introduction

The Doi-Cho Dem-Ben Luc Rivers has a length of about 30 km with a width of from 30 to 70 m and a depth of 3 ÷ 7 m. It's one of an important inland waterway that connects HCMC with Long An Province (Mekong Delta). The Doi-Cho Dem-Ben Luc rivers play an important role in irrigation, transportation and ecological restoration. Among the inorganic pollutants of river water, heavy metals are gaining importance because of their non-biodegradable nature and often accumulate at tropical levels causing harmful biological effects [1]. Heavy metals are a pressing concern in terms of their pollution in aquatic ecosystems because of their persistence, environmental toxicity, bioaccumulation [2]. Anthropogenic activities like mining, ultimate disposal of treated and untreated waste effluents containing toxic metals as well as metal chelates [3] from different industries steel plants, battery industries, thermal power plants etc. and also the indiscriminate use of heavy metal containing fertilizers and pesticides in agriculture resulted in deterioration of water quality rendering serious environmental problems posing threat on human beings [4] and sustaining aquatic biodiversity [5, 6].

Sankar et al (2018) claimed that The concentrations of different metals, like Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Cooper (Cu), Zink (Zn), Lead (Pb), Cadmium (Cd), Mercury (Hg) and Arsenic (As) were highly increasing in coastal areas due to the discharge of agricultural and domestic wastes; intrusion of wastes from industries like metal plating; entry of organic and inorganic chemicals; leaching of metals from solid waste; and use of metal and metal components [7]. Heavy metal concentrations in water and fish from River Yamuna, at Allahabad were found that Pb and Cu were higher than the permissible limits of WHO, that gives an indication of hazardous risk to human health. Whereas Arsenic was detected lower than the permissible limit (Kumar et al., 2014). In Vietnam, the temperature, pH, dissolved oxygen (DO), conductivity, salinity, chlorophyll-a, phaeopigments, suspended particulate matter (SPM) concentrations, grain size distributions, nutrients, dissolved and particulate organic carbon and phosphorus, and trace metal(oid) (Cr, Ni, Cu, Zn, As, Cd, Pb, Hg, and MMHg) concentrations were measured at 17 sites along the Saigon River in water (filtered and suspended matter) and sediment. This research showed that the Saigon River remains moderately contaminated albeit the city was proved to be the major contributor of metal(oid)s [8].

The Doi-Cho Dem-Ben Luc Rivers receive heavy metals in untreated or inadequately treated wastewater from domestic, industrial, agricultural, and navigation sources. It is very important to monitor and evaluate the pollution status,

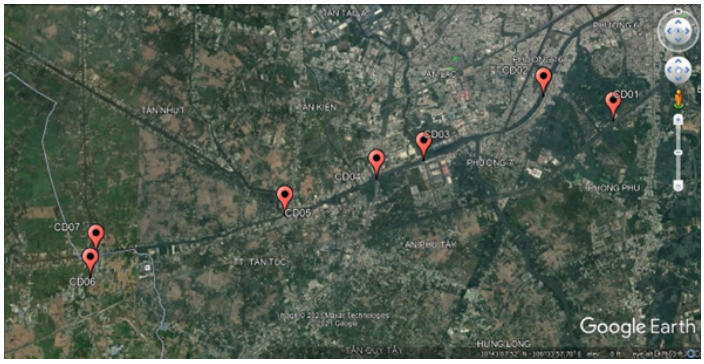

Fig. 1. Study area of heavy metal concentrations with 7 sampling sites (B1-B10)
Rys. 1. Obszar badań koncentracji metali ciężkich z 7 punktami poboru próbek (B1-B10)

Tab. 1. Coordinates and locations of the sampling sites in study area
Tab. 1. Współrzędne i położenie punktów poboru próbek na obszarze badań

Sites	Local Names	Longitude (N)	Latitude (S)
CD01	Ba Lon Creek flows into Doi Canal (near Residental Area 13C)	10°42'48.05"N	106°38'49.51"E
CD02	Doi Canal at 16 Ward, District 8 (near River Wharf)	10°43'06.17"N	106°37'57.22"E
CD03	Binh Dien River (near Binh Dien Market)	10°42'18.03"N	106°36'25.97"E
CD04	Binh Dien River (near Binh Dien Bridge)	10°42'04.67"N	106°35'50.39"E
CD05	Binh Dien River (near Cai Tam Bridge)	10°41'37.99"N	106°34'41.70"E
CD06	My Nhan Creek flow into Ben Luc River (near Tan Bua Ferry Station)	10°40'52.58"N	106°32'17.54"E
CD07	Ben Luc River (near Tan Bua Ferry Station)	10°41'09.70"N	106°32'21.22"E

influencing factors, ecological risks, and possible sources of heavy metals in the surface water of the Doi-Cho Dem-Ben Luc Rivers. This topic is crucial identify the levels of heavy metal pollution in the Doi-Cho Dem-Ben Luc Rivers. The results contribute to providing information and data for local authorities on heavy metal parameters as well as pollution levels of this system.

2. Materials and Methods

2.1. Study Area

Data from about 70 km^2 with length of 30 Km were used as a representative example for study areas. The water samples of heavy metal (Iron, Manganese, Chrome, Zinc, Copper, Lead, Cadmium, Nickel, and Arsenic) analysis at 7 sites were collected for 7 periods in April and October (2019, 2020); April, June and October (2021) (see Fig. 1; Tab. 1).

2.2. Sample Collection

The water samples for havey metal analyses in the field were collected according to the standards of TCVN 6663 – 1:2011 (ISO 5667 – 1:2006) Water quality – Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques; and, TCVN 6663 – 3:2008 (ISO 5667 – 3:2003) Water quality – Sampling – Part 3: Instructions for sample storage and handling [9, 10]. All samples were collected in 2.0 litre, clean polyethylene bottles, which were prewashed with 10% nitric acid and de-ionized water. Before sampling, the bottles were rinsed at least three times with water from the sampling site. Sample locations at each site were taken in the middle of the river with a depth layer of surface water of 30–40 cm [10-12]. All water samples were immediately brought to the laboratory.

2.3. Analytical Methods

The standard methods of heavy metal and their analytical methods were briefly presented in Tab. 2.

The samples were acidified with 2 mL concentrated Nitric acid to prevent precipitation of metals, reduce adsorption of the analytes onto the walls of containers and to avoid microbial activity, then water samples were stored at 2°C until the analyses. Surface water samples were filtered through milipor filtering unit using 0.45 µm Whatman filter paper. If the concentrations exceeding the calibration curve, the samples were appropriately diluted, and acid was added to measure samples. The samples for heavy metal analysis were measured in the Inductively Coupled Plasma Optimal Emission Spectrometer [13].

2.4. Data Analysis

The obtained data were subject to statistical analysis to test the analysis of variance (ANOVA) and correlation among all the parameters using R statistical software. The maps of the study area and sampling sites were applied using Google Earth.

3. Results and Discussions

3.1. Concentrations of heavy metals in river water

The concentrations of Fe, Mn, Cu, Ni, Zn, Pb, Cr, Cd and As in water surface at all seven different sites of seven periods in the Doi-Cho Dem-Ben Luc Rivers during 2019, 2020 and 2021 were detected and recorded in Tab. 3.

Tab. 3 showed that the mean concentrations of almost heavy metals were observed in decreasing order of Fe > Mn > Cu > Ni > Zn > Pb > Cr, Cd, As whereas the concentrations of heavy metals (Mn > Cu > Ni > Zn > Pb) were within the acceptable limits of the National technical regulation on surface

Tab. 2. Parameters and methods of water quality analysis

Tab. 2. Parametry jakości wody i metody oznacznia

No.	Parameters	Unit	Methods
1	Fe	mg/L	TCVN 6177:1996
2	Mn	mg/L	SMEWW 3111B:2017
3	Cr	mg/L	TCVN 6222:2008
4	Zn	mg/L	TCVN 6193:1996
5	Cu	mg/L	SMEWW 3111B:2017
6	Pb	mg/L	SMEWW 3111B:2017
7	Cd	mg/L	SMEWW 3111B:2017
8	Ni	mg/L	SMEWW 3111B:2017
9	As	mg/L	US EPA Method 2008

Tab. 3. Concentrations of heavy metals in the surface water of the study area. Notes: ND is non detect

Tab. 3. Zawartość metali ciężkich w wodach powierzchniowych na badanym terenie. Uwaga: ND nie wykryte

Parameters (mg/L)	Sampling Sites						
	CD01	CD02	CD03	CD04	CD05	CD06	CD07
Fe (mg l^{-1})							
Range	1.01÷1.16	2.38÷3.63	2.72÷5.04	1.65÷2.11	1.21÷2.85	1.05÷1.84	1.06÷2.04
Mean	1.06	3.25	3.59	1.91	1.78	1.36	1.68
Mn (mg l^{-1})							
Range	0.14÷0.19	0.24÷0.27	0.22÷0.28	0.16÷0.23	0.16÷0.22	0.16÷0.19	0.16÷0.18
Mean	0.16	0.25	0.24	0.20	0.19	0.17	0.17
Cu (mg l^{-1})							
Range	0.029÷00.34	0.057÷0.078	0.038÷0.081	0.032÷0.065	0.026÷0.070	0.051÷0.062	0.040÷0.058
Mean	0.031	0.062	0.053	0.045	0.047	0.056	0.049
Ni (mg l^{-1})							
Range	0.029÷0.037	0.043÷0.057	0.034÷0.053	0.031÷0.043	0.025÷0.038	0.026÷0.033	0.025÷0.030
Mean	0.033	0.049	0.44	0.037	0.031	0.029	0.028
Zn (mg l^{-1})							
Range	0.026÷0.034	0.048÷0.056	0.045÷0.068	0.030÷0.041	0.026÷0.030	0.026÷0.032	0.026÷0.034
Mean	0.029	0.052	0.054	0.036	0.028	0.030	0.029
Pb (mg l^{-1})							
Range	0.008÷0.010	0.010÷0.012	0.008÷0.012	0.008÷0.010	0.008÷0.010	0.008÷0.012	0.08÷0.010
Mean	0.009	0.011	0.011	0.009	0.010	0.010	0.010
Cr (mg l^{-1})	ND	ND	ND	ND	ND	ND	ND
Cd (mg l^{-1})	ND	ND	ND	ND	ND	ND	ND
As (mg l^{-1})	ND	ND	ND	ND	ND	ND	ND

water quality for QCVN 08-MT: 2015/BTNMT at the B1 Level (water quality for irrigation and drainage purposes or other uses with similar water quality requirements) [14]. Especially, the concentrations of heavy metals such as chromium, cadmium and arsenic have not been detected in water samples in this system. While the mean concentrations of iron (Fe) were above the permissible limits of the National technical regulation on surface water quality for QCVN 08-MT: 2015/BTNMT at the B1 Level. Moreover the mean concentrations of Fe, Mn, Cu, Ni, Zn and Pb were above concentration of the values than the permissible limits set by the water quality criteria for aquatic life [15].

3.2. Spatial in heavy metal concentrations of river water

The concentration of different metals in river water order as follow: Fe > Mn > Cu > Zn > Ni > Pb (Fig. 2). The results showed that heavy metals of iron and zinc had the highest concentrations in the sites CD2 and CD3. The next concentration indicated in the site CD4, and the lowest concentration in site CD1. The results showed that heavy metals of iron and zinc had the highest concentrations in the sites CD2 and CD3. The next concentration indicated in the site CD4, and the lowest concentration in site CD1 The results of concentrations of lead and nickel fluctuated similar to the concentrations of in manganese and copper. While the concentrations of chromium, cadmium and arsenic were the lowest that lowered the limit of detection (Fig. 2). These results were quite similar to the research of heavy metal pollution in the Lake Manzal, Egypt [16] that showed the concentration of different metals in water, plankton, and fish tissues followed the same order: Zn > Cu > Pb> Cd. The mean concentrations of metals in the water were as follow: Cu, 0.055; Zn, 0.311; Cd, 0.020; and Pb, 0.022 mg/L.

Among the six heavy metals identified above, the seasonal change was not significant. This needs to be further observed to provide a clear understanding of the characteristics of seasonal variations in heavy metal concentrations. While Tran et al. (2020) claimed that the total metal concentrations in the seawater of the Saigon – Dongnai Estuaries were higher during the rainy season than those during the dry season [17]. The increase of rainfall in the Saigon – Dongnai River Basin in the transition time mobilized both dissolved and particulate metals (Fe, Cr, Ni, and Pb) from the terrestrial environment to the aquatic environment [18]. Additionally, Raji et al. (2016) indicated that the concentrations of heavy metals that monitored at the Sokoto River in North-western Nigeria were generally higher in dry season than in the rainy season [19].

3.3. Correlation analysis

Pearson's correlation was performed on the combined data set of average values of the surface water of the studied area based on the significant levels (p=0.05). Correlation analysis was carried out for inter-metallic and intra-metallic association to understand the significance of association among the metals and the samples. The surface water exhibited a positive correlation between Fe-Mn (0.79), Fe-Zn (0.82), Fe-Cu (0.42), Fe-Pb (0.46), Fe-Ni (0.64); Mn-Zn (0.81), Mn-Cu (0.41), Mn-Pb (0.40), Mn-Ni (0.76); Zn-Cu (0.48), Zn-Pb (0.35), Zn-Ni

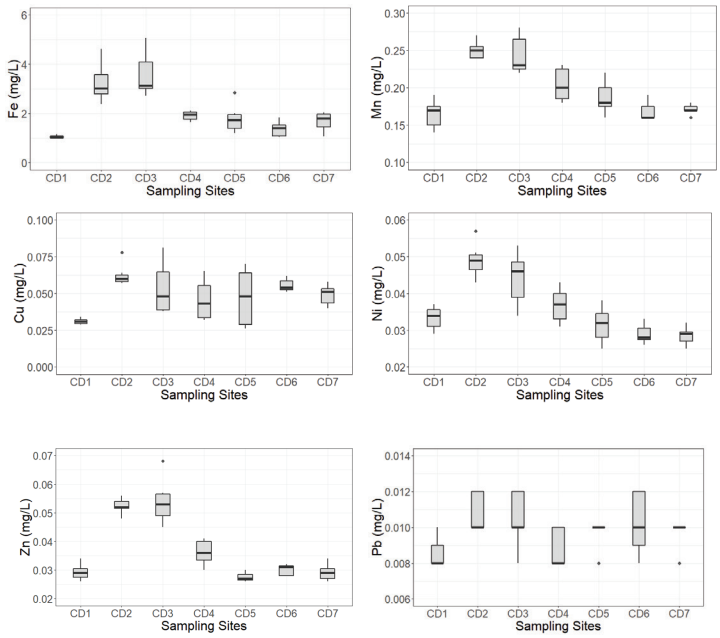

Fig. 2. Heavy metals measured in the 7 sampling sites at the study area
Rys. 2. Zmierzone zawartości metali ciężkich na badanym terenie

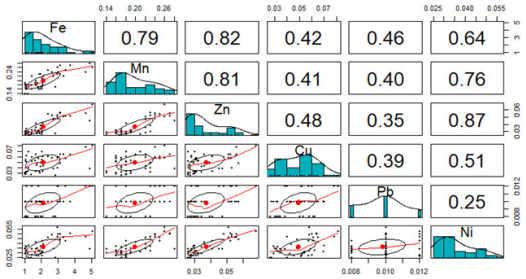

Fig. 3. Relationship among heavy metal concentrations in the study area
Rys. 3. Zależności pomiędzy zawartościami metali ciężkich w badanym terenie

(0.87); Cu-Pb (0.39), Cu-Ni (0.51); and Pb-Ni (0.25). (Fig. 3). This would help to understand the nature of these metals and their species speciation in the aquatic environment.

Among the nine heavy metals, there were six parameters evaluated results to calculate the correlation analysis with each other including Fe, Mn, Zn, Cu, Pb, and Ni (Figure 4). Among the heavy metals, a significant positive correlation was observed between Fe, Mn, Zn and Ni (0.64 ÷ 0.87), whereas Cu exhibited a significant positive correlation with Ni (0.51). While Cu and Pb showed a not too strong correlation with Fe, Mn, Zn and Ni (0.25 ÷ 0.48). This will help to understand the nature of these metals and their species speciation in the aquatic environment (Fig. 4). Similar to the study of Kar et al (2008), it may be concluded that the river water as such is not suitable for drinking purpose due to the inappropriate concentrations of Fe, Mn, Zn, Cu and Ni and it may not be suitable for irrigation due to the excess concentration of Fe and Mn [1]. There was a difference with the results of Strady et al., (2017), this study had not shown the correlation between Fe and As as well as Fe and Ni [8].

4. Conclusions

The results suggested a spatial homogeneity of heavy metals in the surface water the studied rivers. Among all nine examined heavy metals in the studied area, the concentrations of Fe (1.00 ÷ 5.06 mg/L) and Mn (0.14 ÷ 0.28 mg/L) were the highest, and the concentrations of Cr, Cd and As were the lowest that lowered the limit of detection. The results suggested that the mean concentrations of Fe and Mn were above the acceptable limits of the National technical regulation on surface water quality (QCVN 08-MT: 2015/BTNMT). While the concentrations of Fe, Mn, Zn, Cu, Pb, Ni did not meet the water quality criteria for aquatic life (United State Environmental Protection Agency)

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Although some heavy metals have been found to be beneficial to humans and creatures to a certain extent, it can be harmful beyond that. Therefore, the appropriate treatment measures needed be taken to remove heavy metal loads from industrial wastewater and renovate wastewater treatment plants as well as monitor water quality to improve river's water quality and save people's health protection. This helped to understand the nature of these metals and their species speciation in the aquatic environment.

5. Acknowledgement

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Ocena zanieczyszczenia metalami ciężkimi wód powierzchniowych rzek Doi-Cho Dem-Ben Luc w Wietnamie

Metale ciężkie stanowią palący problem zanieczyszczenia w ekosystemach wodnych ze względu na ich trwałość, toksyczność dla środowiska i bioakumulację. Środowiska wodne sa zasilane w metale ciężkie z nieoczyszczonych lub nieodpowiednio oczyszczonych ścieków ze źródeł domowych, przemysłowych, rolniczych i żeglugowych. Rzeki Doi-Cho Dem-Ben Luc odgrywają kluczową rolę w nawadnianiu terenów, transporcie odnym i odbudowie ekologicznej. Kluczowe znaczenie ma ustalenie stanu zanieczyszczenia, czynników wpływających, zagrożeń ekologicznych i możliwych źródeł metali ciężkich w wodach powierzchniowych rzek Doi-Cho Dem-Ben Luc. W artykule przedstawiono wyniki badania wód powierzchniowych, próbki pobrano z 7 punktów pomiarowych z rzek Doi-Cho Dem-Ben Luc przez 7 kolejnych okresów od kwietnia 2019 r. do października 2021 r. Każda próbka została przeanalizowana pod kątem zawartości 9 metali ciężkich: Fe, Mn, Cr , Zn, Cu, Pb, Cd, Ni, As. Metodyka pobierania próbek i obróbki próbek zostały opracowane w oparciu o Standardowe Metody Badania Wód i Ścieków. Zbadano zmienność w czasie i przestrzeni stężeń metali ciężkich, do analizyy wyników wykorzystano analizę wariancji (ANOVA) i korelacji między wszystkimi parametrami przy użyciu oprogramowania statystycznego. Wyniki sugerują przestrzenną jednorodność zawartości metali ciężkich w wodach powierzchniowych badanych rzek. Spośród wszystkich dziewięciu badanych metali ciężkich w badanym terenie najwyższe są stężenia Fe (1,00 ÷ 5,06 mg/L) i Mn (0,14 ÷ 0,28 mg/L), a najniższe Cr, Cd i As (wartości odpowiadające dolnej granicy wykrywalności). Wyniki wskazują, że średnie stężenia Fe i Mn były powyżej dopuszczalnych limitów, opisanych w krajowych normach dotyczących jakości wód powierzchniowych (QCVN 08-MT: 2015/BTNMT). Natomiast stężenia Fe, Mn, Zn, Cu, Pb, Ni nie spełniają kryteriów jakości wody dla organizmów wodnych (Agencja Ochrony Środowiska Stanów Zjednoczonych). Działalność antropogeniczna może być głównym źródłem metali ciężkich w wodach powierzchniowych rzek Doi-Cho Dem-Ben Luc. Wśród metali ciężkich zaobserwowano istotną dodatnią korelację między zawartością Fe, Mn, Zn i Ni (0,64 ÷ 0,87), natomiast Cu wykazywała istotną dodatnią korelację z Ni (0,51). Zawartości Cu i Pb wykazywały niezbyt silną korelację z Fe, Mn, Zn i Ni (0,25 ÷ 0,48). Na rozmieszczenie metali ciężkich mogą mieć również wpływ właściwości metali ciężkich oraz wahania przepływów wody. Wyniki dostarczają wskazówek dotyczących kontrolowania zanieczyszczenia metalami ciężkimi i ochrony źródeł wody w rzekach Doi-Cho Dem-Ben Luc.

Słowa kluczowe: *zanieczyszczenie metalami ciężkimi, wody powierzchniowe, dystrybucja, rzeka, Doi-Cho Dem-Ben Luc, ochrona jakości wody*

Survey and Assessment of the Safety of Laser Radiation Source Used in the Garment Industry

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Laser power source is a new energy source that is being widely used in industrial production. Therefore, the issue of safety in the use and operation of equipment using this energy source needs to be concerned. In this research, we conduct a survey on the use of laser energy-emitting devices and machines in the garment industry to ensure safety when using and measure the laser power of the devices. This equipment at the working positions of employees is then compared with ANSI laser safety standards to consider the safety of workers when operating these devices, so that timely solutions can be taken to ensure safety when working with equipment that emits laser energy. Because there is currently no safety standard for using lasers in Vietnam, through the process of surveying and measuring laser radiation, we found that these devices always have potential dangers that can cause damage to the environment. workers during work.
Therefore, to ensure the safety of workers when working with these devices, we have also compiled a set of safety manuals for using laser energy to supply factories to ensure safety. Workers when working with these devices. We have also compiled a draft of the standard for safe use of industrial lasers to submit to the authorities in Vietnam for the promulgation of Vietnamese standards on the safe use of industrial lasers. With the fabric laser machine, the laser radiation intensity is from 233.0 μW.cm^{-2} to 253.4 μW.cm^{-2} and the average value is 245.3 μW.cm^{-2}. Laser Flexi-Pro machine, the laser radiation intensity is from 173.5 μW.cm^{-2} to 196.0 μW.cm^{-2} and the average value is 187.3 μW.cm^{-2}. Laser Jeanologia-Twin HS Machine, the laser radiation intensity is from 255.8 μW.cm^{-2} to 279.2 μW.cm^{-2} and the average value is 270.7 μW.cm^{-2}. Laser Flexi-Denim machine, the laser radiation intensity is from 189.4 μW.cm^{-2} to 343.0 μW.cm^{-2} and the average value is 292.8 μW.cm^{-2}.

Keywords: *garment industry, laser radiation, laser safety, laser machines, safety standard*

1. Introduction to laser sources and the health hazards of laser radiation

Laser stands for Light Amplification by Stimulated Emission of Radiation, which outlines the main facts of laser light generation. In the most simplified sequence, an energy source excites atoms in an active medium (gas, solid, liquid) to emit a particular wavelength of light. The generated light is amplified by an optical feedback system that causes the light beam to bounce back and forth in the operating medium to increase phase coherence until the emitted light is a laser beam. [1]

The health hazards of using industrial laser sources as well as other hazards are: [1]

- Damage to eyes and skin
- Electrical hazards
- Chemical hazard
- Compressed air
- Air pollution
- Liquid freezing
- Danger of fire

Hazard classification of laser sources: in Vietnam, there is no standard to classify the level of hazard of laser sources, so in this study, the research team used the American national standard ANSI (American National Standards Institute) for laser hazard classification. The ANSI Z136.1-2007 standard classifies laser hazard levels as follows: [1] These calculations are used to determine a factor defined as the Accessible Emission Limit or AEL which is the mathematical product of the Maximum Permissible Exposure limit (MPE) given in the Standard and an area factor computed from the defined term called the Limiting Aperture (LA). That is: AEL = MPE x Area of LA.

Limiting Apertures are dependent on factors such as laser wavelength and are based on physical factors such as the fully dilated pupil size (7mm) and beam "hotspots" (1mm).

For most all exposures to the skin and IR exposures to the eye lasting greater 10 seconds, the involuntary movement of the eyes and the body as well as heat conduction will average an irradiance profile over an area of about 10 mm², even if the irradiated body part is kept intentionally still. This equates to a size of about 3.5 mm.

Especially in the near-infrared, radiation is penetrating relatively deep into skin and due to scattering, the irradiance profile is averaged over corresponding dimensions. For wavelengths larger than 0.1 mm, an aperture size of 11 mm is specified, as smaller apertures would lead to inaccurate measurements due to diffraction effects.

Each laser class is based on these AEL thresholds:

- Class 1 lasers or systems cannot emit accessible laser radiation in excess of the applicable Class 1 AEL for any exposure times within the maximum duration inherent in the design or intended use of the laser. Class 1 lasers are exempt from all beam-hazard control measures.
- Class 2 lasers are CW and repetitively pulsed lasers with wavelengths between 0.4 μm and 0.7 μm that can emit energy in excess of the Class 1 AEL, but do not exceed the Class 1 AEL for an emission duration

Tab. 1. Biological effects of laser radiation [1]

Tab. 1. Skutki biologiczne promieniowania laseowgo [1]

Spectral Domain (CIE range)	Eyes effects	Skin effects
Ultraviolet C (200-280 nm)	Photokaretitis	Erythema (sunburn) Skin cancer Accelerated skin aging
Ultraviolet B (280-315 nm)	Photokaretitis	Erythema (sunburn) Increased pigmentation
Ultraviolet A (315-400 nm)	Photochemical cataract	Pigmen darkening Skin burn
Visible light (400-780 nm)	Photochemical and thermal retinal injury	Pigmen darkening Photosenstive reactions Skin burn
Infrared A (780-1400 nm)	Cataract and retinal burn	Skin burn
Infrared B (1400-3.000 nm)	Corneal burn, aqueous flare, cataract	Skin burn
Infrared C (3.000-1.000.000 nm)	Corneal burn only	Skin burn

less than 0.25 seconds and have an average radiant power of 1mW or less.

- Class 3R lasers have an accessible output between 1 and 5 times the Class 1 AEL for wavelengths shorter than 0.4 μm or longer than 0.7 μm, or less than 5 times the Class 2 AEL for wavelengths between 0.4 μm and 0.7 μm.
- Class 3B lasers cannot emit an average radiant power greater than 0.5 Watts for an exposure time equal to or greater than 0.25 seconds or 0.125 Joules for an exposure time less than 0.25 seconds for wavelengths between 0.18 μm and 0.4 μm, or between 1.4 μm and 1 mm. In addition, lasers between 0.4 μm and 1.4 μm exceeding the Class 3a AEL cannot emit an average radiant power greater than 0.5 Watts for exposures equal to or greater than 0.25 seconds, or a radiant energy greater than 0.03 Joules per pulse.
- Class 4 lasers and laser systems exceed the Class 3b AEL.

2. Evaluation procedure of laser sources safety and laser radiation instrumentation

2.1. Evaluation procedure of laser sources safety

(1) Purpose:

In this topic, the purpose of evaluating the measured data is to see if it is within the allowable limits of the standard, to ensure the safety of workers who have been working near these laser sources.

(2) Determine the measurement location:

In this study, the measurement position is determined by the author's group at the positions of workers standing closest to the source of the laser, and for laser generators using shielding equipment, the position measurement is defined as measuring when shielded and measured when not shielded.

(3) Take measurements:

After determining the measurement location, the measurement is carried out and at each measurement location, it is necessary to have a number of repeat measurements to ensure the accuracy of the measurement results.

(4) Data processing:

After having the measurement results at each location with the number of repetitions, proceed to process the measured data by averaging at each location to get representative data for each measurement location.

(5) Comment and evaluate data:

From the processing data, comments and evaluations are made against the allowed standards and solutions are given accordingly.

2.2. Laser radiation instrumentation

Measurement of laser radiation is carried out using a meter: Handheld Laser Power& Energy Meter Ophir – Nova II. This measure machine functions are:

- Monitoring of laser beam size
- Accurate tracking of beam position to fractions of a mm
- Beam position and wander
- All the other features of standard power/energy meters

3. Research results

We have surveyed and measured a number of laser emitting devices at a number of garment factories with the following survey and measured results:

3.1. Laser safety assessment results of fabric laser machine

Through the survey, it was found that these cutters are cutting machines using CO_2 lasers with a laser power of 130W, wavelength of 0.6μm and labeled as hazardous by the manufacturer as group IV. Therefore, it is necessary to have personal protective equipment for workers when working with these machines.

On each laser cutting machine of this type, the factory has stickers on the process of using the machine as well as the safety measures that need to be applied. In this table, there are 4 main contents:

A. General provisions,

B. Points to be checked before operating the equipment,

C. Steps to start and operate the machine,

D. End of operations.

The measurement was carried out at 03 fabric laser machines at the factory, because during the working process, most of the workers operating at these machines removed the protection, so the measurement was done when the machine was covered. and without cover, with measurement results as shown in the following table.

With the fabric laser machine, the laser radiation intensity is from 233.0 $\mu W.cm^{-2}$ to 253.4 $\mu W.cm^{-2}$ and the average value is 245.3±4.8 $\mu W.cm^{-2}$. It was found that the measured results, if compared with the evaluation standards for maximum exposure limits (MPE) for eyes and skin, are lower than the allowable standards. However, it is very dangerous for workers to often remove the protective cover when working, we have advised the factory on this content to ensure the safety of workers when working with these devices.

Tab. 2. Maximum Permissible Exposure (MPE) for Point Source Ocular Exposure to a Laser Beam [1]
Tab. 2. Maksymalne dopuszczalne narażenie (MPE) dla punktowego źródła ekspozycji oka na wiązkę laserową [1]

Wavelength λ (μm)	Exposure Duration t (second-s)	Maximum Permissible Exposure (MPE)	
		J.cm^{-2}	W.cm^{-2}
Ultraviolet			
0,180 – 0,400	-	-	-
Thermal			
0,180 – 0,400	10^{-9} – 10	$0{,}56.t^{0,25}$	-
Photochemical			
0,180 – 0,302	10^{-9} – 3.10^{4}	3.10^{-3}	-
0,302 – 0,315	10^{-9} – 3.10^{4}	$10^{200(\lambda-0,295)}.10^{-4}$	-
0,315 – 0,400	10 – 3.10^{4}	1,0	-
Visible			
0,400 – 0,700	10^{-3} – 10^{-11}	$1{,}5.10^{-8}$	-
0,400 – 0,700	10^{-11} – 10^{-9}	$2{,}7.t^{0,75}$	-
0,400 – 0,700	10^{-9} – 18.10^{-6}	5.10^{-7}	-
0,400 – 0,700	18.10^{-6} – 10	$1{,}8.t^{0,75}.10^{-3}$	-
0,400 – 0,700	10 – 3. 10^{4}		10^{-3}
Thermal			
0,450 – 0,500	10 – T_1		10^{-3}
Photochemical			
0,400 – 0,450	10 – 100	10^{-2}	-
0,450 – 0,500	T_1 – 100	$C_B.10^{-2}$	-
0,400 – 0,500	100 – 3.10^{4}		$C_B.10^{-4}$
Near infrared			
0,700 – 1,050	10^{-13} – 10^{-11}	$1{,}5.C_A.10^{-8}$	-
0,700 – 1,050	10^{-11} – 10^{-9}	$2{,}7.C_A.t^{0,75}$	-
0,700 – 1,050	10^{-9} – 18.10^{-6}	$5{,}0.C_A.10^{-7}$	-
0,700 – 1,050	18.10^{-6} – 10	$1{,}8.C_A.t^{0,75}.10^{-3}$	-
0,700 – 1,050	10 – 3.10^{4}	-	$C_A.10^{-3}$
1,050 – 1,400	10^{-13} – 10^{-11}	$1{,}5.C_C.10^{-7}$	-
1,050 – 1,400	10^{-11} – 10^{-9}	$27{,}0.C_C.t^{0,75}$	-
1,050 – 1,400	10^{-9} – 50.10^{-6}	$5{,}0.C_C.10^{-6}$	-
1,050 – 1,400	50.10^{-6} – 10	$9{,}0.C_C.t^{0,75}.10^{-3}$	-
1,050 – 1,400	10 – 3.10^{4}	-	$5{,}0.C_C.10^{-3}$
Far infrared			
1,400 – 1,500	10^{-9} – 10^{-3}	0,1	-
1,400 – 1,500	10^{-3} – 10	$0{,}56.t^{0,25}$	-
1,400 – 1,500	10 – 3.10^{4}	-	0,1
1,500 – 1,800	10^{-9} – 10	1,0	-
1,500 – 1,800	10 – 3.10^{4}	-	0,1
1,800 – 2,600	10^{-9} – 10^{-3}	0,1	-
1,800 – 2,600	10^{-3} – 10	$0{,}56.t^{0,25}$	-
1,800 – 2,600	10 – 3.10^{4}	-	0,1
2,600 – 1000	10^{-9} – 10^{-7}	10^{-2}	-
2,600 – 1000	10^{-7} – 10	$0{,}56.t^{0,25}$	-
2,600 – 1000	10 – 3.10^{4}	-	0,1

Tab. 3. Maximum Permissible Exposure (MPE) for Extended Source Ocular Exposure [1]
Tab. 3. Maksymalne dopuszczalne narażenie (MPE) dla przedłużonej ekspozycji oka na źródło [1]

Wavelength λ (μm)	Exposure Duration t (second-s)	Maximum Permissible Exposure (MPE)	
		J.cm^{-2}	W.cm^{-2}
Visible			
0,400 – 0,700	10^{-3} – 10^{-11}	$1{,}5.C_E.10^{-8}$	-
0,400 – 0,700	10^{-11} – 10^{-9}	$2{,}7.C_E.t^{0,75}$	-
0,400 – 0,700	10^{-9} – 18.10^{-6}	$5{,}0.C_E.10^{-7}$	-
0,400 – 0,700	18.10^{-6} – 0,7	$1{,}8.C_E.t^{0,75}.10^{-3}$	-
Photochemical			
For α ≤ 11mrad			
0,400 – 0,600	0,7 – 100	$C_B.10^{-2}$	-
0,400 – 0,600	100 – 3.10^{4}	-	$C_B.10^{-4}$
For α > 11mrad			
0,400 – 0,600	0,7 – 10^{4}	$100.C_B.J.cm^{-2}.sr^{-1}$	-
0,400 – 0,600	10^{4} – 3.10^{4}	-	$C_B.10^{-2}W.cm^{-2}.sr^{-1}$
Thermal			
0,400 – 0,700	0,7 – T_2	$1{,}8.C_E.t^{0,75}.10^{-3}$	-
0,400 – 0,700	T_2 – 3.10^{4}	-	$1{,}8.C_E.T_2^{-0,25}.10^{-3}$
Near Infrared			
0,700 – 1,050	10^{-13} – 10^{-11}	$1{,}5.C_A.C_E.10^{-8}$	-
0,700 – 1,050	10^{-11} – 10^{-9}	$2{,}7.C_A.C_E.t^{0,75}$	-
0,700 – 1,050	10^{-9} – 18.10^{-6}	$5{,}0.C_A.C_E.10^{-7}$	-
0,700 – 1,050	18.10^{-6} – T_2	$1{,}8.C_A.C_E.t^{0,75}.10^{-3}$	-
0,700 – 1,050	T_2 – 3.10^{4}	-	$1{,}8.C_AC_E.T_2^{-0,25}.10^{-3}$
1,050 – 1,400	10^{-13} – 10^{-11}	$1{,}5.C_C.C_E.10^{-7}$	-
1,050 – 1,400	10^{-11} – 10^{-9}	$27{,}0.C_C.C_E.t^{0,75}$	-
1,050 – 1,400	10^{-9} – 50.10^{-6}	$5{,}0.C_C.C_E.10^{-6}$	-
1,050 – 1,400	50.10^{-6} – T_2	$9{,}0.C_C.C_E.t^{0,75}.10^{-3}$	-
1,050 – 1,400	T_2 – 3.10^{4}	-	$9.C_CC_E.T_2^{-0,25}.10^{-3}$

3.2. Laser safety assessment results of Laser Flexi-Pro machine

This is a device that uses a laser to burn on the surface of jeans to create the shapes required by the user, through the survey we found that these devices work very safely. because when operating, the entire process of laser emission is carefully covered, workers are not exposed at all, in some cases workers carelessly open or do not close the cover, the device cannot work. We have also conducted measurement of laser radiation when the machine is in operation at some locations where workers work around the machine with the following measurement results:

Laser Flexi-Pro machine, the laser radiation intensity is from 173.5 μW.cm^{-2} to 196.0 μW.cm^{-2} and the average value is 187.3±5.3 μW.cm^{-2}. Realizing that the measured results are in class 1 of laser sourse, it is a safe class for workers when working and operating these devices.

3.3. Laser safety assessment results of Laser Jeanologia-Twin HS Machine

Through the survey, we found that this device works quite safely and during the operation of the device, if someone enters the working area of the device, through the sensor system, the device will immediately stop working. However, when this equipment is operating without a cover, workers need to be careful not to intrude into the working area of the device to avoid the risk of accidents. We measure the intensity

Tab. 4. Maximum Permissible Exposure (MPE) for Skin Exposure to a Laser Beam [1]

Tab. 4. Maksymalne dopuszczalne narażenie (MPE) dla ekspozycji skóry na wiązkę laserową [1]

Wavelength λ (μm)	Exposure Duration t(s)	Maximum Permissible Exposure (MPE)	
		J.cm^{-2}	W.cm^{-2}
Ultraviolet			
Thermal			
0,180 – 0,400	10^{-9} – 10	$0,56.t^{0,25}$	-
Photochemical			
0,180 – 0,302	10^{-9} – 3.10^{4}	3.10^{-3}	-
0,302 – 0,315	10^{-9} – 3.10^{4}	$10^{200(\lambda-0,295)}.10^{-4}$	-
0,315 – 0,400	10 – 10^{3}	1	-
0,315 – 0,400	10^{3} – 3.10^{4}	-	10^{-3}
Visible and near Infrared			
0,400 – 1,400			
0,400 – 1,400	10^{-9} – 10^{-7}	$2C_A.10^{-2}$	-
0,400 – 1,400	10^{-7} – 10	$1,1.C_A.t^{0,25}$	-
	10 – 3.10^{4}	-	$0,2.C_A$
Far Infrared			
1,400 – 1,500	10^{-9} – 10^{-3}	0,1	-
1,400 – 1,500	10^{-3} – 10	$0,56.t^{0,25}$	-
1,400 – 1,500	10 – 3.10^{4}	-	0,1
1,500 – 1,800	10^{-9} – 10	1,0	-
1,500 – 1,800	10 – 3.10^{4}	-	0,1
1,800 – 2,600	10^{-9} – 10^{-3}	0,1	-
1,800 – 2,600	10^{-3} – 10	$0,56.t^{0,25}$	-
1,800 – 2,600	10 – 3.10^{4}	-	0,1
2,600 – 1000	10^{-9} – 10^{-7}	10^{-2}	-
2,600 – 1000	10^{-7} – 10	$0,56.t^{0,25}$	-
2,600 – 1000	10 – 3.10^{4}	-	0,1

Tab. 5. Parameters and Correction Factors [1]

Tab. 5. Parametry i współczynniki korekcyjne [1

Parameters/Correction Factors	Wavelength λ (μm)
$C_A=1,0$	0,400 – 0,700
$C_A=10^{2(\lambda-0,700)}$	0,700 – 1,050
$C_A=5,0$	1,050 – 1,400
$C_B=1,0$	0,400 – 0,450
$C_B=10^{20(\lambda-0,450)}$	0,450 – 0,600
$C_C=1,0$	1,050 – 1,150
$C_C=10^{18(\lambda-1,150)}$	1,150 – 1,200
$C_C=8,0$	1,200 – 1,400
$C_E=1,0$ $\alpha < \alpha_{min}$*	0,400 – 1,400
$C_E= \alpha / \alpha_{min}$ $\alpha_{min} \leq \alpha \leq \alpha_{max}$*	0,400 – 1,400
$C_E= \alpha^2 / \alpha_{max}.\alpha_{min}$ $\alpha > \alpha_{max}$*	0,400 – 1,400
$C_P= n^{-0,25}$**	0,180 – 1000
$T_1=10.10^{20(\lambda-0,450)}$***	0,450 – 0,500
$T_2=10.10^{(\alpha-1,5)/98,5}$****	0,400 – 1,400
* 0,400 ≤ λ ≤ 1,400 μm: α_{min} = 1,5 mrad, α_{max} = 100 mrad	
** Frequencies below 55 kHz (0.400 – 1.050 μm) and below 20 kHz (1.050 – 1.400 μm)	
*** T_1=10 s, λ=0,450 μm ; T_1=100 s, λ=0,500 μm	
**** T_2=10 s, α < 1,5 mrad ; T_2=100 s, α >100 mrad	

Tab. 6. Measurement results of Laser radiation intensity at fabric laser machines

Tab. 6. Wyniki pomiarów natężenia promieniowania laserowego na maszynach laserowych do cięcia tkanin

No.	Machines	Measuring position	Laser radiation intensity (μW.cm^{-2})	Average value	STD
1	Fabric laser machine 1	FLM 1.1.1	245.2	247.1	± 2.7
2	Fabric laser machine 1	FLM 1.1.2	250.2		
3	Fabric laser machine 1	FLM 1.1.3	245.9		
4	Fabric laser machine 1	FLM 1.2.1	234.1	233.9	± 0.8
5	Fabric laser machine 1	FLM 1.2.2	233.0		
6	Fabric laser machine 1	FLM 1.2.3	234.5		
7	Fabric laser machine 1	FLM 1.3.1	244.8	244.6	± 0.5
8	Fabric laser machine 1	FLM 1.3.2	244.0		
9	Fabric laser machine 1	FLM 1.3.3	245.0		
10	Fabric laser machine 2	FLM 2.1.1	252.4	251.9	± 0.8
11	Fabric laser machine 2	FLM 2.1.2	251.0		
12	Fabric laser machine 2	FLM 2.1.3	252.2		
13	Fabric laser machine 2	FLM 2.2.1	245.7	245.9	± 1.0
14	Fabric laser machine 2	FLM 2.2.2	245.0		
15	Fabric laser machine 2	FLM 2.2.3	247.0		
16	Fabric laser machine 2	FLM 2.3.1	244.8	244.7	± 0.4
17	Fabric laser machine 2	FLM 2.3.2	245.0		
18	Fabric laser machine 2	FLM 2.3.3	244.2		
19	Fabric laser machine 3	FLM 3.1.1	244.1	245.1	± 1.1
20	Fabric laser machine 3	FLM 3.1.2	245.0		
21	Fabric laser machine 3	FLM 3.1.3	246.2		
22	Fabric laser machine 3	FLM 3.2.1	246.2	245.8	± 1.4
23	Fabric laser machine 3	FLM 3.2.2	247.0		
24	Fabric laser machine 3	FLM 3.2.3	244.3		
25	Fabric laser machine 3	FLM 3.3.1	248.3	248.5	± 1.5
26	Fabric laser machine 3	FLM 3.3.2	250.1		
27	Fabric laser machine 3	FLM 3.3.3	247.2		
	Min		**233.0**		
	Max		**252.4**		
	Average			**245.3**	± **4.8**

Fig. 1. Handheld Laser Power and Energy Meter Ophir – Nova II
Rys. 1. Ręczny miernik mocy i energii lasera Ophir – Nova II

Fig. 2. Fabric laser machine
Rys. 2. Maszyna laserowa do cięcia tkanin

Fig. 3. Laser Flexi-Pro machine
Rys. 3. Maszyna Laser Flexi-Pro

of laser radiation at locations around the machine with the following results:

In general, Laser Jeanologia-Twin HS Machine use class 1 laser source, safe for employees to work, but businesses need to regularly check and maintain these devices to ensure that the sensors are always in good working condition. Prevent workers from entering the danger zone when the equipment is in operation to ensure the safety of workers. Laser Jeanologia-Twin HS Machine, the laser radiation intensity is from 255.8 μW.cm^{-2} to 279.2 μW.cm^{-2} and the average value is 270.7±7.2 μW.cm^{-2}.

3.4. Laser safety assessment results of Laser Flexi-Denim machine

We have conducted a survey of the use status of this equipment and found that these devices are very safe during use, with full instructions and danger warnings for workers when working with the equipment. suffer this. However, we also found that the workers working here did not comply with the safety regulations when operating this equipment, not closing the cover when operating this is very dangerous for workers because Workers may have an accident due to the laser beams reflecting outward or accidentally entering the hazardous area while working. At the same time, we have measured the intensity of laser radiation at locations around the machine where workers work with the following results:

Laser Flexi-Denim machine, the laser radiation intensity is from 189.4 μW.cm^{-2} to 343.0 μW.cm^{-2} and the average value is 292.8±41.3 μW.cm^{-2}. The measured results of laser sources comply with class 1 according to the standard of being safe for users. But during the survey, we found that workers in enterprises still have not a high sense of the laser dangerous. Safety regulations on laser sources when operating, working with equipment that emits laser radiation such as using personal protective equipment, is not complied.

3.5. Laser source safety manual

The safety manual for using laser sources was compiled by the research team into a system of safety solutions for each object with the following main contents:

- Management solutions
- Technical solutions
- About personal protective equipment
- Ensure radiation safety rules
- Training on OSH
- Taking care of employees' health
- General safety regulations for laser groups

3.6. Draft Vietnamese National standards for the safe use of industrial laser sources

Tab. 7. Measurement results of Laser radiation intensity at Laser Flexi-Pro machines
Tab. 7. Wyniki pomiarów natężenia promieniowania laserowego na maszynach Laser Flexi-Pro

No.	Machines	Measuring position	Laser radiation intensity (μW.cm^{-2})	Average value	STD
1	Laser Flexi-Pro machine 1	LFP 1.1.1	193.2	194.8	± 1.4
2	Laser Flexi-Pro machine 1	LFP 1.1.2	195.2		
3	Laser Flexi-Pro machine 1	LFP 1.1.3	196.0		
4	Laser Flexi-Pro machine 1	LFP 1.2.1	187.3	188.5	± 1.4
5	Laser Flexi-Pro machine 1	LFP 1.2.2	190.0		
6	Laser Flexi-Pro machine 1	LFP 1.2.3	188.2		
7	Laser Flexi-Pro machine 1	LFP 1.3.1	188.6	188.1	± 2.3
8	Laser Flexi-Pro machine 1	LFP 1.3.2	190.1		
9	Laser Flexi-Pro machine 1	LFP 1.3.3	185.5		
10	Laser Flexi-Pro machine 2	LFP 2.1.1	176.3	174.9	± 1.4
11	Laser Flexi-Pro machine 2	LFP 2.1.2	173.5		
12	Laser Flexi-Pro machine 2	LFP 2.1.3	175.0		
13	Laser Flexi-Pro machine 2	LFP 2.2.1	186.3	187.2	± 0.9
14	Laser Flexi-Pro machine 2	LFP 2.2.2	188.0		
15	Laser Flexi-Pro machine 2	LFP 2.2.3	187.2		
16	Laser Flexi-Pro machine 2	LFP 2.3.1	183.5	185.1	± 1.6
17	Laser Flexi-Pro machine 2	LFP 2.3.2	185.2		
18	Laser Flexi-Pro machine 2	LFP 2.3.3	186.6		
19	Laser Flexi-Pro machine 3	LFP 3.1.1	191.1	190.3	± 0.7
20	Laser Flexi-Pro machine 3	LFP 3.1.2	190.0		
21	Laser Flexi-Pro machine 3	LFP 3.1.3	189.9		
22	Laser Flexi-Pro machine 3	LFP 3.2.1	187.9	188.9	± 1.0
23	Laser Flexi-Pro machine 3	LFP 3.2.2	189.9		
24	Laser Flexi-Pro machine 3	LFP 3.2.3	188.8		
25	Laser Flexi-Pro machine 3	LFP 3.3.1	188.7	187.7	± 1.0
26	Laser Flexi-Pro machine 3	LFP 3.3.2	187.7		
27	Laser Flexi-Pro machine 3	LFP 3.3.3	186.7		
	Min		**173.5**		
	Max		**196.0**		
	Average			**187.3**	± **5.3**

Fig. 4. Laser Jeanologia-Twin HS Machine
Rys. 4. Laserowa maszyna Jeanologia-Twin HS

Fig. 5. Laser Flexi-Denim machine
Rys. 5. Laserowa maszyna Flexi-Denim

The research team has compiled a Draft Standard with 21 major contents and 6 attached appendices, arranged like the current standards of Vietnam. The main contents of the draft are as follows:

(1) Scope of application
(2) References
(3) Goals
(4) Terms and definitions
(5) Classification
(6) Harm of laser
(7) Causes of laser accidents
(8) Principle of measurement
(9) For Employers
(10) For employees

Tab. 8. Measurement results of Laser radiation intensity at Laser Jeanologia-Twin HS Machine
Tab. 8. Wyniki pomiarów natężenia promieniowania laserowego na Laser Jeanologia-Twin HS Machine

No.	Machines	Measuring position	Laser radiation intensity (μW.cm^{-2})	Average value	STD
1	Laser Jeanologia-Twin HS Machine 1	LJT 1.1.1	276.3	276.5	± 1.6
2	Laser Jeanologia-Twin HS Machine 1	LJT 1.1.2	275.0		
3	Laser Jeanologia-Twin HS Machine 1	LJT 1.1.3	278.1		
4	Laser Jeanologia-Twin HS Machine 1	LJT 1.2.1	278.9	278.3	± 0.5
5	Laser Jeanologia-Twin HS Machine 1	LJT 1.2.2	277.9		
6	Laser Jeanologia-Twin HS Machine 1	LJT 1.2.3	278.2		
7	Laser Jeanologia-Twin HS Machine 1	LJT 1.3.1	267.1	267.9	± 0.7
8	Laser Jeanologia-Twin HS Machine 1	LJT 1.3.2	268.0		
9	Laser Jeanologia-Twin HS Machine 1	LJT 1.3.3	268.5		
10	Laser Jeanologia-Twin HS Machine 2	LJT 2.1.1	255.8	256.2	± 0.5
11	Laser Jeanologia-Twin HS Machine 2	LJT 2.1.2	256.0		
12	Laser Jeanologia-Twin HS Machine 2	LJT 2.1.3	256.8		
13	Laser Jeanologia-Twin HS Machine 2	LJT 2.2.1	276.2	277.6	± 1.2
14	Laser Jeanologia-Twin HS Machine 2	LJT 2.2.2	278.0		
15	Laser Jeanologia-Twin HS Machine 2	LJT 2.2.3	278.5		
16	Laser Jeanologia-Twin HS Machine 2	LJT 2.3.1	265.7	266.3	± 0.8
17	Laser Jeanologia-Twin HS Machine 2	LJT 2.3.2	266.0		
18	Laser Jeanologia-Twin HS Machine 2	LJT 2.3.3	267.2		
19	Laser Jeanologia-Twin HS Machine 3	LJT 3.1.1	266.6	267.3	± 0.8
20	Laser Jeanologia-Twin HS Machine 3	LJT 3.1.2	267.0		
21	Laser Jeanologia-Twin HS Machine 3	LJT 3.1.3	268.2		
22	Laser Jeanologia-Twin HS Machine 3	LJT 3.2.1	267.3	268.6	± 1.1
23	Laser Jeanologia-Twin HS Machine 3	LFP 3.2.2	269.0		
24	Laser Jeanologia-Twin HS Machine 3	LJT 3.2.3	269.4		
25	Laser Jeanologia-Twin HS Machine 3	LJT 3.3.1	277.2	278.1	± 1.0
26	Laser Jeanologia-Twin HS Machine 3	LJT 3.3.2	278.0		
27	Laser Jeanologia-Twin HS Machine 3	LJT 3.3.3	279.2		
	Min		**255.8**		
	Max		**279.2**		
	Average			**270.7**	**7.2**

Tab. 9. Measurement results of Laser radiation intensity at Laser Flexi-Denim machine
Tab. 9. Wyniki pomiarów natężenia promieniowania laserowego na maszynie Laser Flexi-Denim

No.	Machines	Measuring position	Laser radiation intensity (μW.cm^{-2})	Average value	STD
1	Laser Flexi-Denim machine 1	LFD 1.1.1	302.3	301.2	± 1.2
2	Laser Flexi-Denim machine 1	LFD 1.1.2	300.0		
3	Laser Flexi-Denim machine 1	LFD 1.1.3	301.2		
4	Laser Flexi-Denim machine 1	LFD 1.2.1	278.1	279.0	± 1.0
5	Laser Flexi-Denim machine 1	LFD 1.2.2	280.0		
6	Laser Flexi-Denim machine 1	LFD 1.2.3	279.0		
7	Laser Flexi-Denim machine 1	LFD 1.3.1	189.4	190.5	± 1.4
8	Laser Flexi-Denim machine 1	LFD 1.3.2	190.0		
9	Laser Flexi-Denim machine 1	LFD 1.3.3	192.0		
10	Laser Flexi-Denim machine 2	LFD 2.1.1	298.9	299.3	± 0.6
11	Laser Flexi-Denim machine 2	LFD 2.1.2	300.0		
12	Laser Flexi-Denim machine 2	LFD 2.1.3	299.1		
13	Laser Flexi-Denim machine 2	LFD 2.2.1	288.7	289.9	± 1.2
14	Laser Flexi-Denim machine 2	LFD 2.2.2	290.0		
15	Laser Flexi-Denim machine 2	LFD 2.2.3	291.1		
16	Laser Flexi-Denim machine 2	LFD 2.3.1	301.3	300.1	± 1.1
17	Laser Flexi-Denim machine 2	LFD 2.3.2	300.0		
18	Laser Flexi-Denim machine 2	LFD 2.3.3	299.1		
19	Laser Flexi-Denim machine 3	LFD 3.1.1	331.7	330.2	± 1.4
20	Laser Flexi-Denim machine 3	LFD 3.1.2	329.0		
21	Laser Flexi-Denim machine 3	LFD 3.1.3	330.0		
22	Laser Flexi-Denim machine 3	LFD 3.2.1	341.4	342.1	± 0.8
23	Laser Flexi-Denim machine 3	LFP 3.2.2	342.0		
24	Laser Flexi-Denim machine 3	LFD 3.2.3	343.0		
25	Laser Flexi-Denim machine 3	LFD 3.3.1	303.4	303.1	± 1.0
26	Laser Flexi-Denim machine 3	LFD 3.3.2	304.0		
27	Laser Flexi-Denim machine 3	LFD 3.3.3	302.0		
	Min		**189.4**		
	Max		**343.0**		
	Average			**292.8**	± **41.3**

(11) Management solutions
(12) Occupational risk management of laser radiation exposure
(13) Signs and warnings
(14) Training and supervision
(15) Technical solutions
(16) Personal protective equipment
(17) Ensure radiation safety rules
(18) Taking care of employees' health
(19) Laser safety measures in case of equipment setup
(20) Laser safety measures in case of adding new components
(21) Laser safety measures in case of maintenance

4. Conclusion

We have conducted a survey of devices using laser energy in enterprises with the results as presented. From the survey and measurement results at enterprises, we also have basic data on the situation of using equipment with laser energy sources in garment enterprises in Vietnam. We have also developed documents on "Safety instructions for using laser sources" and developed "Draft standards for safe use of industrial lasers". These documents serve safety work in garment enterprises as well as industries using equipment that emits laser energy and in safety management in Vietnam.

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Badanie i ocena bezpieczeństwa źródła promieniowania laserowego stosowanego w przemyśle odzieżowym

Źródło zasilania lasera to nowe źródło energii, które jest szeroko stosowane w produkcji przemysłowej. Dlatego też należy zwrócić uwagę na kwestię bezpieczeństwa użytkowania i eksploatacji urządzeń wykorzystujących to źródło energii. W ramach przedstawionych badań przeprowadzono ankietę dotyczącą wykorzystania urządzeń i maszyn emitujących energię lasera w przemyśle odzieżowym w celu zapewnienia bezpieczeństwa podczas użytkowania oraz pomiaru mocy lasera urządzeń. Sprzęt wykorzystywany na stanowiskach pracy został porównany z normami bezpieczeństwa lasera ANSI. Uwzględniono bezpieczeństwo pracowników podczas obsługi tych urządzeń, tak aby można było na czas przyjąć rozwiązania w celu zapewnienia bezpieczeństwa podczas pracy ze sprzętem emitującym energię lasera. Ponieważ obecnie w Wietnamie nie ma norm bezpieczeństwa dotyczących korzystania z laserów, w procesie badania i pomiaru promieniowania laserowego stwierdzono, że urządzenia te zawsze stwarzają potencjalne zagrożenia, które mogą spowodować szkody w środowisku pracy. Dlatego, aby zapewnić bezpieczeństwo pracownikom podczas pracy z tymi urządzeniami, opracowano również zestaw instrukcji bezpieczeństwa dotyczących wykorzystania energii lasera do zasilania fabryk w celu zapewnienia bezpieczeństwa pracy. Opracowano również projekt normy dotyczącej bezpiecznego użytkowania laserów przemysłowych w celu przedłożenia stosownym władzom w Wietnamie w celu wdrożenia ogłoszenia wietnamskich norm dotyczących bezpiecznego użytkowania laserów przemysłowych. W maszynie z laserem tkaninowym intensywność promieniowania lasera wynosi od 233,0 $\mu W.cm^{-2}$ do 253,4 $\mu W.cm^{-2}$, a średnia wartość to 245,3 $\mu W.cm^{-2}$. Maszyna Laser Flexi-Pro charakteryzuje się intensywnością promieniowania lasera od 173,5 $\mu W.cm^{-2}$ do 196,0 $\mu W.cm^{-2}$, a średnia wartość to 187,3 $\mu W.cm^{-2}$. Laser Jeanologia-Twin HS Machine - intensywność promieniowania lasera wynosi od 255,8 $\mu W.cm^{-2}$ do 279,2 $\mu W.cm^{-2}$, a średnia wartość to 270,7 $\mu W.cm^{-2}$. Maszyna Laser Flexi-Denim - intensywność promieniowania lasera wynosi od 189,4 $\mu W.cm^{-2}$ do 343,0 $\mu W.cm^{-2}$, a średnia wartość to 292,8 $\mu W.cm^{-2}$.

Słowa kluczowe: *przemysł odzieżowy, promieniowanie laserowe, bezpieczeństwo laserowe, maszyny laserowe, norma bezpieczeństwa*

Aquatic Invertebrates and Their Correlation with Environmental Parameters in Coastal of Tien Giang Province, Mekong Delta in Vietnam

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The Tien Giang province is located in the tropical climate zone of the Mekong delta. The climate here is clearly divided into two main seasons, namely wet season and dry season and the average temperature is about 27°C. The coastline is 32 kilometers (20 mi) long with thousands of coastal warp, which is an advantage for aquatic breeding such as crab and sea-based economy development. Aquatic invertebrates are a diverse group of organisms that inhabit coastal area throughout the world, in regions spanning alpine, arid, Mediterranean, polar, temperate, and tropical climates. Estuarine coastal invertebrates include benthic, planktonic, and stygobitic taxa and range from widespread taxa to water quality assessment. Classified by size as either macroinvertebrates or smaller meiofauna, macroinvertebrates are more widely studied, although meiofauna can also be diverse and abundant in aquatic communities. The influence of environmental factors on the diversity of invertebrates was studied in the Tien Giang Coastal Area, Southern Vietnam. The study was done between March 2019 and September 2021, encompassing both dry and rainy seasons. Data from 10 sites were used as a representative example for the Tien Giang Coastal Area to conduct a qualitative study. To implement this evaluation, the analyses were based on MRC methods and classifications these improved by the scientific group. The biological and environmental variables were examined to test the analysis of variance (ANOVA) and the Pearson correlation among all the parameters using R statistical software. Significant or highly significant positive or negative correlations were assumed when the p-calculated value was < 0.05 or 0.01, respectively.

The results of the assessment showed that 32 species of zooplankton and 18 species of benthic macroinvertebrates were found in the study area. The density of zooplankton at each site ranged from 6 to 85 individuals/sample, while the density of benthic macroinvertebrates at each site fluctuated from 4 to 15 individuals/sample. The calculated values for the diversity index (H') of both zooplankton and benthic macroinvertebrates fluctuated at the average level (H' ≈ 1.00 ÷ 1.72). The results also show that several environmental variables, including total suspended solid, chemical oxygen demand, and ammonium were correlated with species richness and density of aquatic invertebrates. The obtained results will be useful for the monitoring of pollution status at the study area in particular the sensitivity of aquatic invertebrates to changes of environmental characteristics.

Keywords: *coastal area, aquatic invertebrates, physicochemical parameters, relationships, water quality assessment*

1. Introduction

Tien Giang Province is located in the left bank of Tien River and borders the East Sea. The part of Tien River which goes through the province is 103 km long (Tien Giang Portal, 2020). It has flat terrain with a slope below 1%, and the altitude varying from 0 m to 1.6 m in comparison with the sea level. The whole province area is in the lower section of Mekong River, and borders the East Sea to the East. Tien Giang is in the climate zone of Mekong Delta – the tropical monsoon climate zone whose temperature is high and stable all year round. It is clearly divided into two seasons: the rainy season is from May to November which is at the same time with Southwestern monsoon and the dry season is from December to April of the following year which is at the same time with Northeastern monsoon (Tien Giang Portal, 2020). Currently, the Tien Giang estuarine coastal waters has been received many different effluents from agricultural, aquaculture, industrial and domestic activities by human beings.

Bioindicators are organisms or biological processes which indicate altered environmental conditions and can be used to identify and/or quantify the impact of pollutants on the environment. The aquatic organisms and their associations can monitor for changes that may indicate the problem within their ecosystem. The changes can be chemical, physiological, behavioral and ecological health. Ecological health can be viewed in terms of ecosystems, in which structural and functional characteristics are maintained. It can be expanded to include many aspects of human health and well-being. Each organism within an ecosystem has the ability to report on the health of its environment (Manickvasagam et al, 2019). In Vietnam, the zooplankton and the benthic macroinvertebrates are good indicators of river health because of particularly useful for biomonitoring (Pham, 2014). This research provided the first information on the diversity of zooplankton and benthic macroinvertebrates of estuarine coastal waters in Tien Giang in terms of species diversity, abundance, and evenness. Especially, the relationships between aquatic invertebrates and physicochemical variables for the water quality evaluation also were checked. The findings of this study could be used to predict and foresee the potential effects as well as assist decision-making in future coastal development and impact mitigation plans in the Tien Giang costal area.

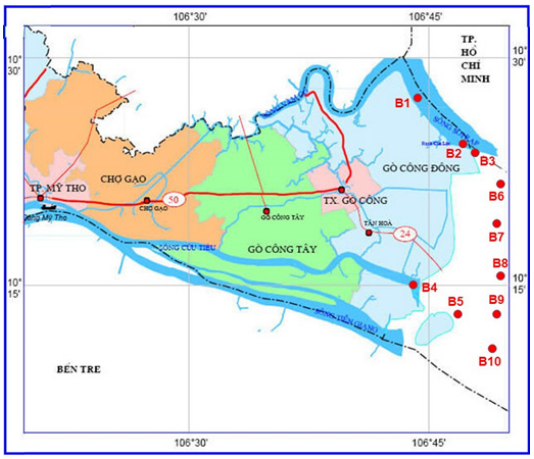


Fig. 1. Map of sample sites
Rys.1. Mapa obszaru opróbowania

Tab. 1. Coordinates and locations of the sampling sites
Tab.1. Koordynaty i lokalizacja miejsca pobierania próbek

Sites	Local Names	Describes	Longitude (N)	Latitude (S)
B1	Soai Rap River Mouth	Aquaculture, fishing activities	106° 46' 32,07"	10° 25' 47,50"
B2	Vam Lang Fishing Port	Trading, fishing activities	106° 47' 12,09"	10° 24' 30,00"
B3	Vam Lang Commune	Aquaculture, fishing activities	106^0 77′ 92,42″	10^0 26′ 78,83″
B4	Den Do Fishing Port	Aquaculture, fishing activities	106^0 74′ 93,73″	10^0 26′ 78,83″
B5	Phu Dong Commune	Aquaculture, fishing activities	106^0 75′ 52,95″	10^0 25′ 11,60″
B6	Kieng Phuoc Commune	Aquaculture, fishing activities	106° 47' 50,08"	10° 21' 43,50"
B7	Tan Dien Area	Fishing activities	106° 47' 29,06"	10° 20' 27,90"
B8	Tan Thanh Beach	Beach, aquaculture activities	106° 47' 26,08"	10° 17' 10,20"
B9	Tieu River Mouth	Fishing activities	106° 45' 31,05"	10° 15' 28,10"
B10	Phu Tan Area	Fishing activities	106° 48' 13,06"	10° 11' 10,50"

Tab. 2. Communities of zooplankton and benthic macroinvertebrates in coastal of Tien Giang Province during 2019 and 2021. Numbers in the table indicated the species number of each class of zooplankton and benthic macroinvertebrates
Tab. 2. Zbiorowiska zooplanktonu i makrobezkręgowców bentosowych na wybrzeżu prowincji Tien Giang w latach 2019 i 2021. Liczby w tabeli oznaczają numer gatunku każdej klasy zooplanktonu i makrobezkręgowców bentosowych

Zooplankton	No. species	%	Benthic macroinvertebrates	No. species	%
Hydrozoa	1	3.1	Polychaeta	9	50.0
Oligogchaeta	1	3.1	Gastropoda	2	11.1
Eurotatoria	1	3.1	Bivalvia	3	16.7
Hexanauplia	19	59.5	Ophiurodea	1	5.5
Malacostraca	4	12.5	Malacostraca	3	16.7
Chaetognatha	1	3.1			
Appendicularia	1	3.1			
Larva	4	12.5			
Total species	**32**	**100**	***Total species***	**18**	**100**

The objectives of this research were to: (1) Study on the relationships between aquatic invertebrates and physicochemical variables for the water quality assessment in the Tien Giang Coastal Area, Southern Vietnam; and, (2) Provide the basic ecological health information of this area for local managers in activities water resource control.

2. Meterials and Methods

2.1. Study Sites and Sample Collection

Data from over 100 km² estuarine coastal waters of Tien Giang Province were used as a representative example for study areas. The samples of qualitative and quantitative invertebrates (both zooplankton and benthic macroinvertebrates) at 10 sites were collected in 06 times in March and September from 2019 to 2021 (Fig. 1; Tab. 1).

2.2. Sample Collection

2.2.1. Water Quality

For water quality, the samples for environmental quality analysis in the field were collected according to the guideline of water monitoring (UNWP. – GEMS/Water, 1992; ALPHA, 2012). The samples were taken in March and September of 2019, 2020, and 2021. Sample locations at each site were taken in depth layer of surface water from 30–40 cm. The water samples were collected in 2-liter plastic bottles and kept at 2°C temperature (UNWP. – GEMS/Water, 1992; ALPHA, 2012).

2.2.2. Zooplankton

Samples were taken at least 1 m from potential contaminants such as debris and aquatic plants. Before sampling at each site, the equipment is washed to remove any organisms and other matter left from the previous site. 10 L of river water at a depth of 0–0.5 m was collected in a bucket. The 10 L of river water was filtered slowly through a plankton net (with a mesh size of 20 µm) to avoid any overflow from the net. Water was splashed on the outside of the net to wash down any zooplankton adhering to the inner parts of the net (MRC, 2010; APHA, 2012)

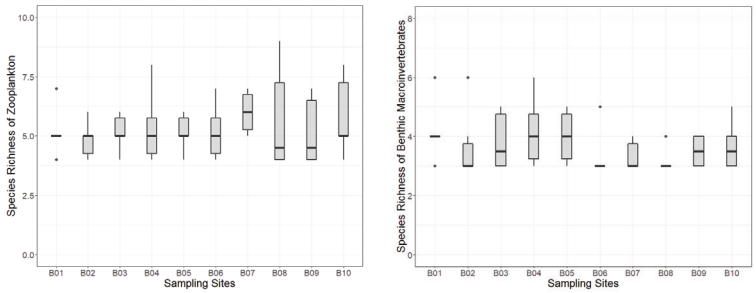
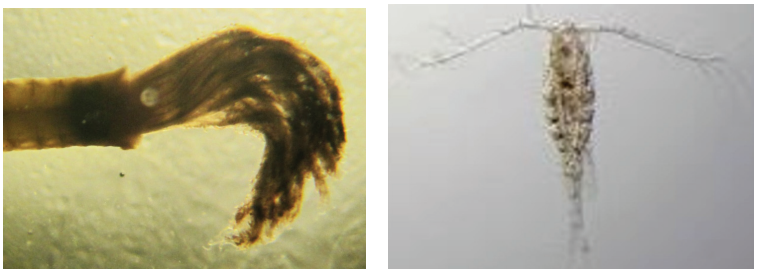
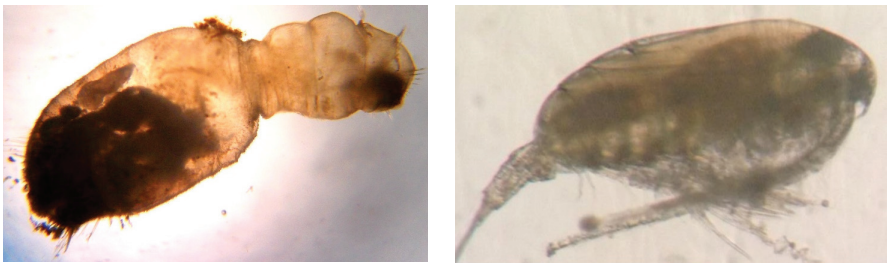


Fig. 2. Species richness of zooplankton and benthic macroinvertebrates in coastal of Tien Giang Province during 2019 and 2021
Rys. 2. Bogactwo gatunkowe zooplanktonu i makrobezkręgowców bentosowych na wybrzeżu prowincji Tien Giang w latach 2019 i 2021



Eudistylia polymorpha *Oithona similis*

Fig. 3. Species indicated for rich nutrient and organic pollution in coastal of Tien Giang Province
Rys. 3. Gatunki wskazane jako bogate w składniki odżywcze i zanieczyszczenia organiczne na wybrzeżu prowincji Tien Giang



Sternaspis scutata *Paracalanus aculeatus*

Fig. 4. Sensitive species with impacts of environmental pollution in coastal of Tien Giang Province
Rys. 4. Wrażliwe gatunki mające wpływ na zanieczyszczenie środowiska na wybrzeżu prowincji Tien Giang

When the water volume remaining in the net was only about 150 mL, the water (which contains the zooplankton sample) was transferred to a 250 mL plastic jar. The sample was immediately fixed in the field by adding ~75mL of 10% formaldehyde to achieve a final concentration of 4–5% formaldehyde. The sample jars were labelled with the site name, the site code, the sampling position, and the sampling date. These information were also noted in the field notebook, as was any information about the site that could be influencing the presence or abundance of different types of zooplankton (MRC, 2010; APHA, 2012).

2.2.3. Benthic Macroinvertebrates

Prior to sampling, all the equipment to be used was thoroughly cleaned to remove any material left from the previous sampling site. At each sampling location, a composite of four grabs was taken with a Petersen grab sampler, covering a total area of 0.1 m^2. If the sampler did not close properly because material such as wood, bamboo, large water-plants, or stones jammed its jaws, its contents were discarded and another grab was taken (MRC, 2010; Pham 2014; APHA, 2012).

The composite sample was washed through a sieve (0.3 mm) with care taken to be sure that macroinvertebrates did not escape. The contents of the sieve were then placed in jars and fixed with formaldehyde. Samples were sorted in the laboratory, because there was insufficient time at a site. The sample jar was labeled with the site location code, date, position within the river, and replicate number. The sampling location conditions, collector's name were recorded on a field sheet (MRC, 2010; Pham 2014; APHA, 2012).

2.3. Analytical Methods

2.3.1. Physical and Chemical Analysis

The aquatic environmental parameters (pH, total suspended solid – TSS, dissolve oxygen – DO, chemical oxygen demand – COD, amonium – NH_4^+, and chlorine – Cl^-) were analyzed according to standard methods (APHA, 2012).

2.3.2. Zooplankton and Benthic Macroinvertebrate Analysis

The identification of zooplankton and benthic macroinvertebrates were based on morphology based on morphology under a microscope (Olympus 41). Hydrozoa, Oligochaeta, Polychaeta, Gastropoda, Bivalvia, Ophiuroidea, and Crustacea, Chaetognatha, and Appendicularia were generally identified to species level. Insecta and Insecta larvae were classified only to genus level (MRC, 2010;

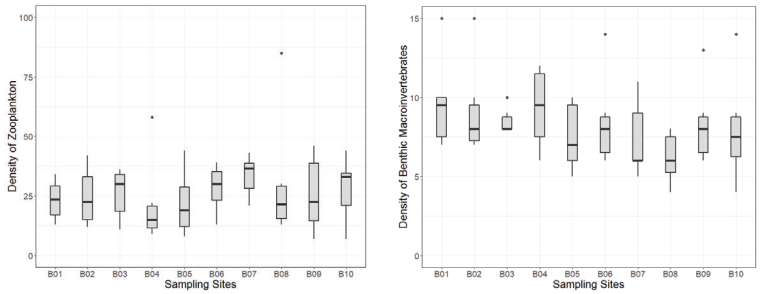


Fig. 3. Density of zooplankton and benthic macroinvertebrates in coastal of Tien Giang Province during 2019 and 2021
Rys. 3. Zagęszczenie zooplanktonu i makrobezkręgowców bentosowych na wybrzeżu prowincji Tien Giang w latach 2019 i 2021

Tab. 4. Values of biodiversity index (H') of zooplankton and benthic macroinvertebrates from Estuarine Coastal Waters in Tien Giang Province during 2019 and 2021. Notes: H' (Shannon-Wiener Diversity Index), and DS (Simpson Dominance Index)
Tab. 4. Wartości wskaźnika bioróżnorodności (H') zooplanktonu i makrobezkręgowców bentosowych z wód przybrzeżnych ujść rzek w prowincji Tien Giang w latach 2019 i 2021

Sites	Zooplankton	Benthic Macroinvertebrates	Ranking (Pham 2014)
B1	1.08 – 1.61	1.14 – 1.59	Low moderate pollution – High moderate pollution
B2	1.03 – 1.47	1.03 – 1.41	High moderate pollution
B3	1.00 – 1.52	1.04 – 1.47	Low moderate pollution – High moderate pollution
B4	1.00 – 1.52	1.03 – 1.68	Low moderate pollution – High moderate pollution
B5	1.16 – 1.52	1.01 – 1.47	Low moderate pollution – High moderate pollution
B6	1.02 – 1.54	1.01 – 1.49	Low moderate pollution – High moderate pollution
B7	1.07 – 1.61	1.01 – 1.33	High moderate pollution
B8	1.02 – 1.39	1.01 – 1.24	High moderate pollution
B9	1.03 – 1.72	1.01 – 1.32	High moderate pollution
B10	1.03 – 1.71	1.01 – 1.49	Low moderate pollution – High moderate pollution

SMEWW 10200G, 2017; SMEWW 10500, 2017; APHA, 2012). The results were recorded on data sheets and specimens are kept at the Ton Duc Thang University, Ho Chi Minh City, Vietnam.

The identification of zooplakton and benthic macroinvertebrates was based on morphology and taxonomic books such as Zooplankton (Fiji, 1993; Edmondson 1976); Microcrustacea (Edmondson, 1976; Dang et al., 1980; Dang & Ho, 2001; Karanoic, 2012); Polychaeta (Fauvel, 1953; Usakov, 1955; Day, 1967; Dejian & Raping, 1985); Oligochaeta (Dang et al., 1980; Sangpradub & Boonsoong, 2006 Thai 2007); Gastropoda (Brandt, 1974; Dillon, 2004; Sangpradub & Boonsoong, 2006; Dang & Ho, 2012); Bivalvia (Brandt, 1974; Dillon, 2004; Sangpradub & Boonsoong, 2006; Dang & Ho, 2012); Crustacea (Bouvier, 1925; Holthuis, 1950; Gurianova, 1951; Tiwari, 1963; Kensley & Schotte, 1989; Hayward & Raland, 1990; Sangpradub & Boonsoong, 2006; Dang & Ho, 2012).

2.4. Data Analysis

The following metrics of zooplakton and benthic macroinvetebrates at all sites sampled in March and September from 2019, 2020 and 2021 were calculated (i) taxonomic richness (i.e. number of taxa); (ii) abundance (i.e. numbers of individuals per site); and, (iii) the Shannon-Wiener Diversity Index (Mandaville, 2002; Stiling, 2002). The obtained data were subject to statistical analysis to test the analysis of variance (ANOVA) and the Pearson correlation among all the parameters using R statistical soflware. Significant or highly significant positive or negative correlations were assumed when the p-calculated value was < 0.05 or 0.01, respectively. The three metrics were tested for their potential as indicators of human impact by regressing values for two seasons of 2019, 2020 and 2021 (60 sampling events for 10 sites) against the water quality variables (pH, TSS, DO, COD, NH_4^+, and Cl^-).

3. Results and Discussions

3.1. Taxa Richness

During the six monitoring times, there were 32 species of zooplankton and 18 species of benthic macroinvertebrates in the studied area. Among the zooplankton, species number of hexanauplia was dominant in species composition with 19 species in total, gaining around 59.5% of total (Table 2). The Hexanauplia constituted comprised two groups: the Copepoda and the Tantulocarida. The Crustacea (especially Copepoda) had more abundant species than other phyla or classes (Modamed et al., 2004). While the species number of polychaeta was highest in the species composition of benthic macroinvertebrates with 9 species in total, accounting for 50.0% of the total (Tab. 2). The species richness of zooplankton and benthic macroinvertebrates recorded in Coastal of Tien Giang Province during 2019 and 2021 did not fluctuate much among the sampling sites (Fig. 2). Pham et al. (2021) also provide the information about more abundant species of Polychaeta than other classes.

The species of Paracalanus parvus and Acartia clausi (Hexanauplia) could be found in all sampling sites of zooplankton. In addition, the species of Acartia clausi, Oithona similis and nauplius copepods also occurred widely in the studied areas. For benthic macroinvertebrates, the polychaetas of Nereis (Ceratonereis) mirabilis and the bivalves of Aloidis sp. were the most species-rich groups and occurred in almost sites, while others appear in few sites.

Because of sampling in the coastal region (Pham & Le 2004; Pham et al. 2011), and these records were expressed clearly through the appearances of almost species of marine zooplankton and benthic macroinvertebrates. The species indicated for rich nutrient and organic pollution occurred in near urban and industrial areas sites, including the species of Nephthys polybranchia, Polydora sp., Eudistylia polymorpha, Scoloplos (Scoloplos) marsupialis, Goniada (Goniadopsis)

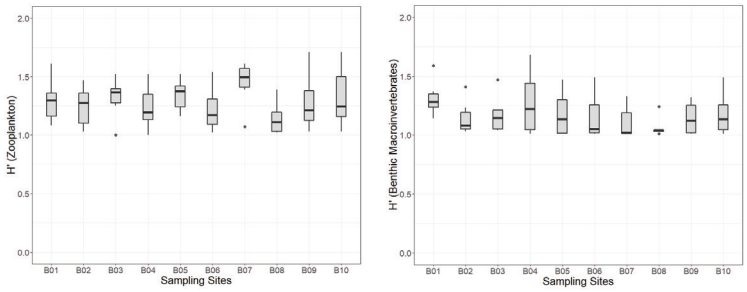


Fig. 4. Diversity index of zooplankton and benthic macroinvertebrates in coastal of Tien Giang Province during 2019 and 2021
Rys. 4. Wskaźnik różnorodności zooplanktonu i makrobezkręgowców bentosowych na wybrzeżu prowincji Tien Giang w latach 2019 i 2021

incerta, Terebellides stroemi (Polychaeta); Acartia clausi, Oithona similis (Microcrustacea) (Figure 3). While, the species of Nereis (Ceratonereis) mirabilis, Sternaspis scutata (Polychaeta); Paracalanus aculeatus, Acartia pacifica (Microcrustacea) were sensitive species with impacts of environmental pollution (Figure 4). Similar to the studies of recorded, this coastal area had a hard bottom beds, creating unfavorable conditions for the development of benthic macroinvertebrates (Pham and Le, 2004; Pham et al., 2011; Le et al., 2012; Pham et al. 2021). The studied results in the coastal of Tien Giang Province also provided information about the invertebrates richness in tropical sandy beaches along the Rio de Janeiro coast were related mainly to granulometric variables, decreasing in fine and very fine sediment (Fernanda et al. 2020).

Invertebrate assemblages responded to spatial and temporal variability with changes in their abundance and taxonomic richness. The analyses showed that local-scale factors (e.g. grain size) were the most important spatial determinants for the ordination of aquatic macroinvertebrates (Aurea et al. 2016). While Yildiz et al. (2010) determined the 4 most important environmental variables (elevation, water depth, dissolved oxygen, and temperature) affecting species distribution in general.

3.2. Density and Dominant Species

The density of zooplankton in each sites was highly variable, ranging from 9 to 85 individuals/sample. The dominant species in the monitoring area were Schmackeria speciosa, Oithona similis and nauplius copepods. Among the dominant species, nauplius copepods was dominant at most of the sampling sites. For the density of benthic macroinvertebrates in each site, it fluctuated from 4 to 15 individuals/sample. The dominant species in the study area were Nephthys polybranchia, Nereis (Ceratonereis) mirabilis, Scoloplos (Scoloplos) marsupialis, Aloidis sp. Among the dominant species, Aloidis sp. was dominant at most of the sampling sites.

The changes of density and dominant species at 07 sites expressed clearly the environmental characteristics of the study area with high suspended solid concentrations. Although the coastal in Tien Giang Province had good self-cleaning mechanisms which allow survival of these communities. However, the concentrations of TSS fluctuated from 73 (site B4) ÷ 115 mg/L (site B9) that effects on the density of both zooplankton and benthic macroinvertebrates. This findings for density and dominant species were discussed in the aquatic flora and fauna monitoring in coastal of the Tien Giang Province 2018 – 2021 (Pham et al. 2021).

3.3. Diversity Index

The values of zooplankton biodiversity index during the monitoring times in 2019 and 2021 ranged from 1.00 to 1.71; while the values of benthic macroinvertebrates fluctuated from 1.01 to 1.68 (Tab. 4). The H' values of zooplankton and benthic macroinvertebrates were not highly different between sampling sites (Tab. 4).

Generally, the bio-index values of zooplankton and benthic macroinvertebrates did not change much among the sampling sites. The bio-index analysis proved that the sustainability of aquatic flora in water column and bottom bed in the study area was not high. The water quality in coastal of Tien Giang Province fluctuated from low moderate pollution to high moderate pollution.

3.4 Relationships of Zooplankton and Benthic Macroinvertebrates with Physicochemical Variables

The results showed that the correlation between environmental and biological parameters was not high (Figure 5). While Joshi et al. (2007) concluded the level of species richness was found dependent on the abiotic factors like temperature, hardness, pH, dissolved oxygen, chloride. However, there were the significant positive correlations among the physicochemical variables, including TSS, COD, NH_4^+ (0.60 ÷ 0.79), whereas TSS exhibited a significant positive correlation with COD (0.79) and NH_4^+ (0.60). While COD showed a strong positive correlation with NH_4^+ (0.75) (Fig. 5). Additionally, there were the significant positive correlations between the species richness of zooplankton with the density and H' index (0.57 ÷ 0.59); the species richness of benthic macroinvertebrates with the density and H' index (0.62 ÷ 0.87). The monitoring results of zooplankton and benthic macroinvertebrates in coastal of the Tien Giang Province indicated that the climatic changes were the fundamental causes determining the processes leading to changes in zooplankton composition (in qualitative and quantitative terms), but anthropogenic factors may considerably influence and change the shape of these processes as Kovalev et al. (1998).

4. Conclusion

During the six monitoring times, we found 30 species of zooplankton and 18 species of benthic macroinvertebrates in the studied area. Among the zooplankton, species number of hexanauplia was dominant in species composition with 19 species in total, while the species number of polychaetas was highest in the species composition of benthic macroinvertebrates with 9 species in total.

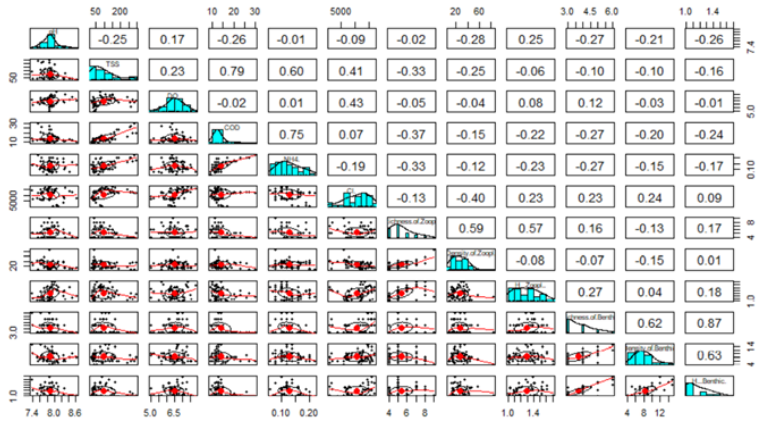


Fig. 5. Relationships between the metrics of physiochemical variables and aquatic invertebrates for sites sampled in coastal of Tien Giang Province during 2019 and 2021

Rys. 5. Zależności między metrykami zmiennych fizykochemicznych a bezkręgowcami wodnymi dla miejsc pobranych na wybrzeżu prowincji Tien Giang w latach 2019 i 2021

The density of zooplankton ranging from 6 to 85 individuals/sample. The dominant species in the monitoring area were Schamckeria speciosa, Oithona similis and nauplius copepods. The densities of benthic macroinvertebrates were fluctuated from 4 to 15 individuals/sample. The species of Nereis (Ceratonereis) mirabilis, Scoloplos (Scoloplos) marsupialis, Aloidis sp. were dominant.

Generally, the biodiversity of zooplankton and benthic macroinvertebrates was not high. The water quality in coastal of Tien Giang Province fluctuated from low moderate pollution to high moderate pollution.

The findings of this study could be used to orient the sustainable management of natural resources and evaluate the natural feed sources for aquaculture in Tien Giang and surrounding areas.

The results showed that the correlation between environmental and biological parameters was not high. However, there were the significant positive correlations among the physicochemical variables, including TSS, COD, NH_4^+ (0.60 ÷ 0.79). Additionally, there were the significant positive correlation between the species richness of zooplankton with the density and H' index (0.57 ÷ 0.59); the species richness of benthic macroinvertebrates with the density and H' index (0.62 ÷ 0.87).

The results confirmed the advantage of using benthic macroinvertebrates and their indices as useful tools for environmental monitoring and ecological health assessment. Therefore, monitoring programs should continue to control and maintain the environmental quality of the Tien Giang Coastal Area.

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Bezkręgowce wodne i ich korelacja z parametrami środowiska na wybrzeżu prowincji Tien Giang, delta Mekongu w Wietnamie

Prowincja Tien Giang położona jest w strefie klimatu zwrotnikowego delty Mekongu. Klimat jest tutaj wyraźnie podzielony na dwie główne pory roku, a mianowicie porę deszczową i porę suchą, a średnia temperatura wynosi około 27°C. Linia brzegowa ma 32 kilometry (20 mil) długości i bardzo urozmaiconą linię brzegową, co jest zaletą dla hodowli wodnych, takich jak kraby i rozwój gospodarki morskiej. Bezkręgowce wodne to zróżnicowana grupa organizmów zamieszkujących obszary przybrzeżne na całym świecie, w regionach obejmujących klimat alpejski, suchy, śródziemnomorski, polarny, umiarkowany i tropikalny. Bezkręgowce przybrzeżne ujść rzek obejmują taksony bentosowe, planktonowe i stygobitowe, od szeroko rozpowszechnionych taksonów do oceny jakości wody. Klasyfikowane według wielkości jako makrobezkręgowce lub mniejsza meiofauna, makrobezkręgowce są szerzej badane, chociaż meiofauna może być również różnorodna i obfita w społecznościach wodnych. Wpływ czynników środowiskowych na różnorodność bezkręgowców badano na obszarze przybrzeżnym Tien Giang w południowym Wietnamie. Badanie zostało przeprowadzone w okresie od marca 2019 do września 2021, obejmując zarówno porę suchą, jak i deszczową. Dane z 10 miejsc wykorzystano jako reprezentatywny przykład dla obszaru przybrzeżnego Tien Giang do przeprowadzenia badania jakościowego. Aby przeprowadzić tę ocenę, analizy oparto na metodach MRC i klasyfikacjach, które zostały udoskonalone przez grupę naukową realizującą badania. Badano zmienne biologiczne i środowiskowe w celu przetestowania analizy wariancji (ANOVA) i korelacji Pearsona R między wszystkimi parametrami przy użyciu oprogramowania statystycznego. Przyjęto znaczące lub bardzo istotne dodatnie lub ujemne korelacje, gdy obliczona wartość p wynosiła odpowiednio <0,05 lub 0,01. Wyniki oceny wykazały, że na badanym obszarze stwierdzono występowanie 32 gatunków zooplanktonu i 18 gatunków makrobezkręgowców bentosowych. Zagęszczenie zooplanktonu na każdym stanowisku wahało się od 6 do 85 osobników/próbę, podczas gdy zagęszczenie makrobezkręgowców bentosowych na każdym stanowisku wahało się od 4 do 15 osobników/próbę. Obliczone wartości wskaźnika różnorodności (H') zarówno zooplanktonu, jak i makrobezkręgowców bentosowych oscylowały na średnim poziomie (H' ≈ 1,00 ÷ 1,72). Wyniki pokazują również, że kilka zmiennych środowiskowych, w tym całkowita zawiesina, chemiczne zapotrzebowanie tlenu i amon, było skorelowanych z bogactwem gatunkowym i gęstością bezkręgowców wodnych. Uzyskane wyniki będą przydatne do monitorowania stanu zanieczyszczenia badanego obszaru, w szczególności wrażliwości bezkręgowców wodnych na zmiany cech środowiska.

Słowa kluczowe: *obszar przybrzeżny, bezkręgowce wodne, parametry fizykochemiczne, zależności, ocena jakości wody*

Marine Plastic Litter in Phu Quoc Marine Protected Area, Vietnam: Current Status and Mitigation Approaches

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Marine plastic pollution causes adverse effects on global environment and marine ecosystems, particularly in marine protected areas. However, little is known of the effects of marine plastic debris on marine ecosystem services, human wellbeing, society, and the economy. We selected Phu Quoc Marine Protected Area (Phu Quoc MPA) for gaining an insight into current marine plastic debris as a first step towards understanding its effects on the environment and biodiversity in the region. This study applied secondary data analysis, semi-structured interviews, field measurements, and the quadrate line transect method in pursuit of the objective of the study. The findings reveal that marine plastic debris disposed of in Phu Quoc MPA dominantly came from diverse sources including rivers, streams, canals, tourism service providers, and marine aquaculture development areas. The abundance of macroplastic on the beaches was approximately between 1.109 and 0.248 items/m² (equivalent to 0.082 ± 0.021 kg/m²). Most of the macroplastic were single-use plastics and accounted for more than 82%. The average size was approximately 14.932 ± 1.846 cm for items less than 30 cm. The remaining ones were HDPE plastic bags and plastic debris. The macroplastic and microplastic need to be stopped in order to encourage sustainable management of waste in the region.

Keywords: *macro-plastic, micro-plastic, marine protected area, Phu Quoc, Vietnam, policy recommendations, single-use plastics*

1. Introduction

Marine ecosystems provide a wealth of ecosystem services including food provision, carbon storage, waste detoxification, and cultural benefits (Worm et al., 2006; Liquete et al., 2013). Any threat to these services is highly likely to significantly impact human wellbeing (Naeem et al., 2016). Plastics, despite widespread use, cause environmental pollution, particularly in the marine ecosystem. Approximately 360 million metric tons of plastic were produced per year (PlasticsEurope, 2019). Of 9 million tons of plastic that ended up in the ocean annually, up to 12.7 million metric tons came from land-based sources in 2010 (Jambeck et al., 2015). Two-thirds of the global plastic waste came from polluted rivers in Asia (Lebreton et al., 2017). When entering the ocean, the plastic is normally chopped up into microplastics by marine vertebrates. Currently, about 15% of the world's sandy beaches are polluted with microplastics. Microplastics float at the water surface in the ocean and are eaten by plankton, fishes, and marine living things. Marine plastic debris will outnumber fishes by 2050 if no efforts are made to stop the disposal of plastic in the ocean (Jambeck et al., 2015). Previous studies showed that plastic disposal in the ocean poses negative impacts on marine life. However, little is known of the effects of marine plastic debris on marine ecosystem services, human wellbeing, society, and the economy. This knowledge is necessary, particularly in the context where plastic is increasingly consumed and there is a need for raising awareness, revising, and/or amending legislation and laws.

We selected Phu Quoc Marine Protected Area (Phu Quoc MPA), Kien Giang, Vietnam for understanding current marine plastic debris as a first step towards understanding its effects on the marine life because the island represents a good case study in this regard. Phu Quoc island becomes a popular destination locally and regionally thanks to its natural landscapes and biodiversity. The government at all levels invested a significant amount of capital in constructing infrastructure that serves tourism development in addition to service-oriented facilities such as hotels, resorts invested by private sector. This tourism development resulted in serious terrestrial and marine pollution. Plastic waste is a main cause of pollution in accordance with Phu Quoc City People's Committee (Phu Quoc PC) in 2020. Phu Quoc generated 190 tons of municipal solid waste (MSW) per day, 170 tons of which were daily collected by staff working for the Public Work Management Board. In addition, wastes were not properly treated and are still seen in terrestrial and aquatic ecosystems. In accordance with WWF in 2018, plastic waste accounted for 20% of total wastes (about 30 tons/day) that were generated in Phu Quoc on a daily basis. About one-third were uncollected and disposed into the natural environment. However, there is limited information on marine plastic debris in the Phu Quoc MPA. This study, therefore, aims to investigate status of marine plastic litter in the Phu Quoc MPA and its sources for better recommendations of mitigation approaches. In this study, secondary data analysis, semi-structured interviews, and field measurements were employed in pursuit of the objective of the study. The findings of this study would provide technical references for improving sustainable management of marine plastic debris in Phu Quoc and elsewhere in the wider region. The paper consists of four sections. Following Section 1 which

Tab. 1. Phu Quoc Marine Protect Area

Tab. 1. Morski obszar chroniony Phu Quoc

No.	Beach	Coordinates		Status
		Long	Lat	
1	Ham Ninh	104.066319	10.211247	Village, national park
2	Mui Da Bac	104.070835	10.215790	Village, national park
3	Mui Cay Sao	104.078815	10.241158	Village, national park
4	Bai Bon	104.077616	10.316513	Village, national park
5	Mui Da Chong	104.078453	10.356091	Village, national park
6	Bai Thom	104.075593	10.375675	Island, national park
7	Hon Mot	104.070808	10.383311	island, national park

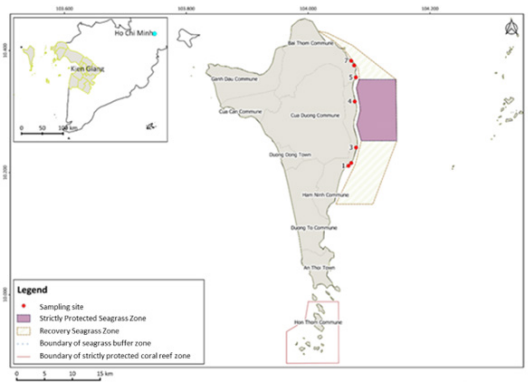

Fig. 1. The survey sites. The location of Phu Quoc in Kien Giang province and the Vietnamese Mekong Delta (on the left) and sampling sites in Phu Quoc island (on the right)

Rys. 1. Miejsca badań. Położenie Phu Quoc w prowincji Kien Giang i wietnamskiej delcie Mekongu (po lewej) oraz miejsca poboru próbek na wyspie Phu Quoc (po prawej)

Tab. 2. List of policies on marine plastic issues in Phu Quoc

Tab. 2. Lista zasad dotyczących postępowania z tworzywami sztucznymi w morzu w Phu Quoc

No.	Policy	Approved by	Year
1	Plan No. 231/KH-UBND dated 4 May 2020 of Phu Quoc City People's Committee launched the emulation movement for Phu Quoc Environment Day	PQ CPC	2020
2	Plan No. 274/KH-UBND dated 28 May 2020 of Phu Quoc District People's Committee to implement Phu Quoc Environment Day in June and respond to Environment Day (June 5), World Oceans Day (June 8), Vietnam Sea and Islands Week (June 1-8) in 2020	PQ CPC	2020
3	Decision No.45/QD-UBND dated 07 January 2020 of the Phu Quoc City People's Committee on establishing the Steering Committee for the implementation of the Action Plan on ocean plastic waste management in Phu Quoc City until 2025	PQ CPC	2020
4	Action plan No.545/KH-UBND dated 22 November 2019 of Phu Quoc District People's Committee on marine plastic waste management in Phu Quoc to 2025	PQ CPC	2019

is the Introduction, Section 2 describes methods used in this study. Section 3 and 4 present and discuss results against the literature. Section 5 presents a general conclusion.

2. Materials and methods

2.1 Site description

Phu Quoc MPA has two ecologically important areas, which are the coral reef zone and the seagrass beds. Phu Quoc MPA is ecologically and economically important because the MPA is key spawning and nursery area for many marine species and crucial fishing grounds locally and regionally. The MPA is home to many rare and endangered marine species such as Dugong, sea turtle, and dolphin. Previous studies show that the marine resources in Phu Quoc MPA were increasingly depleted due to rapid tourism growth.

Phu Quoc MPA contains seven sandy beaches, which are located in areas surrounding the strictly protected seagrass zone and recovery seagrass zone. Of the seven sandy beaches, five are sandy beaches located along the shoreline (Ham Ninh, Mui Da Bac, Mui Cay Sao, Bai Bon and Mui Da Chong). The two remaining ones are two islands (Bai Thom and Hon Mot). The survey sites are presented in Table 1 and Fig. 1.

2.2 Methods

The authors employed various methods in pursuit of the objective of the study. The methods included secondary data analysis, semi-structured interviews, field measurements, and the quadrate line transect method. Before undertaking field visits to Phu Quoc island, the authors collected reports and documents (secondary data analysis) related to marine plastic management and marine ecosystem in Vietnam and Phu Quoc island for adequately understanding current management of marine plastic waste in the region. The authors then contacted local authorities and staff working for Phu Quoc MPA for further data in relation to marine debris and the current waste management in Phu Quoc. The secondary data analysis provided a critical review of the current marine plastic debris and its management in Phu Quoc and assisted in developing open-ended questions which were subsequently used in semi-structured interviews with technical staff and local fishermen. The policies related to marine plastic litter reviewed collected were presented in Table 2.

This survey was organized from March to May 2021 with administrative support by local authorities and technical staff. During the field visits, the authors used the quadrate line

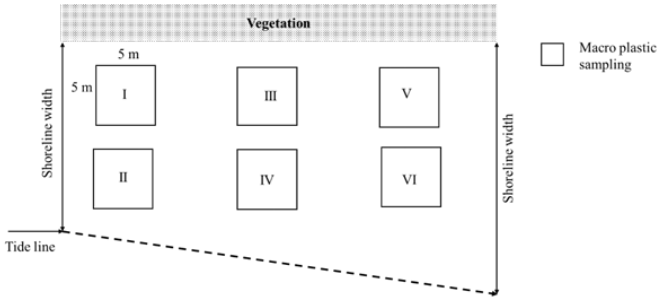

Fig. 2. Demonstration of random sampling methods for macro-plastic sampling
Rys. 2. Demonstracja metod losowego pobierania próbek makroplastiku

Tab. 3. Open-ended questions used in the semi-structured interviews
Tab. 3. Pytania otwarte użyte w wywiadach częściowo ustrukturyzowanych

Interviewees	Questions (English translation)
Local government officers and technical staff	1. What was the area look like in the past? 2. What was sources of marine plastic litter? 3. How did plastic waste enter the marine environment? 4. How was Phu Quoc MPA polluted? 5. How did the pollution affect the marine environment and biodiversity? 6. Who was involved in marine litter? 7. Who was involved in waste management in Phu Quoc? 8. How was marine plastic debris managed? 9. What needs to be done to improve the management of marine plastic debris?
Local fishermen	1. How did you dispose of your plastic waste? 2. What did you know about marine plastic pollution? 3. What was effects of marine plastic pollution on our environment and biodiverse? 4. How did you receive the information of marine plastic debris? 5. What should be done to prevent marine plastic litter?

Fig. 3. The marine plastic pollution at PQ MPA
Rys. 3. Zanieczyszczenie morza tworzywami sztucznymi w PQ MPA

transect method as suggested by de Carvalho and Baptista Neto (2016) for collecting marine plastics. Each quadrate is 5m × 5m. There were 19 samples collected at the seven beaches in this study from March to May 2021. At each beach, two to three quadrates (5mx5m) were randomly selected and recorded for classifying marine plastic debris (Fig. 2).

Plastic-related items were then collected, identified, and recorded using the techniques recommended by Lippiatt et al. (2013) (i.e. single-use plastic bags, single-use plastic cups, food packaging, plastic bottles, etc). The items were photographed and weighed using a portable electronic digital weighing scale to determine their relative composition (kg/m²). The concentration of macroplastic (number of items/m²) was calculated using the method recommended by Lippiatt et al. (2013).

$C = n/w*l$

c – concentration of debris items (number of debris items/m²).
n – number of macro debris items observed.
w – transect width (m); l – transect length (m).

This method resulted in determining (1) macroplastics on the beaches; (2) sources of plastics pollution, and (3) composition and concentration of macroplastics on the beaches. The average (± standard errors) number of marine plastic items collected per 25 m² was calculated for each beach. The average concentration of marine plastic litters obtained (± se) was also analyzed for each site.

In addition, the authors interviewed local authorities, technical staff, and local fishermen using open-ended questions for understanding local perspectives on marine plastic pollution. The interview guide questions for each group were presented in Table 3.

3. Results and discussion

3.1 Distribution of marine plastic debris

The beaches were contaminated with a huge amount of marine plastic debris which came from the ocean (see Fig. 3).

The study revealed that the concentration of macroplastic on the beaches was approximately 1.109 ± 0.248 items/m², with the highest concentration being 2.533 items/m²at Mui Da Bac and Bai Bon 1.6 items/m² respectively. Ham Ninh and Mui Da Chong shared macroplastic density which was between 1.080 and 1.093 item/m² respectively. Bai Thom and Mui Cay Sao beaches had the lowest level of macroplastic

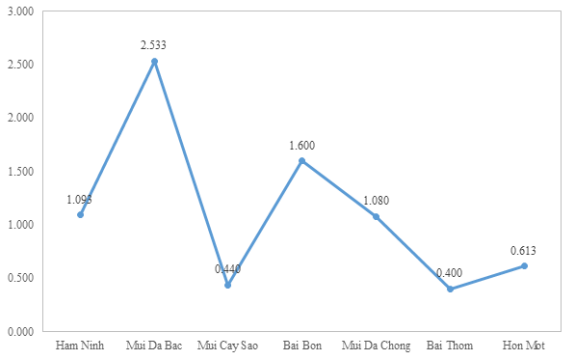

Fig. 4. The marcoplastic density at the beaches
Rys. 4. Gęstość markoplastików na plażach

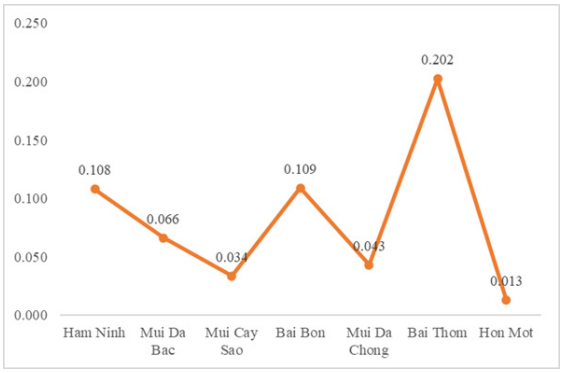

Fig. 5. Quantity of marcroplastic at study areas
Rys. 5. Ilość markroplastików na badanych obszarach

Tab. 4. Sources and types of plastic waste
Tab. 4. Zródła I typy odpadów plastikowych

No.	Category	Number of items	Possible sources	
			Land-based source	Ocean-based source
1	Single-use plastic bags	192	Tourist, terrestrial origin	Sea
2	Single-use plastic straws & spoons	41	Tourist, terrestrial origin	
3	Plastic fragments	39	Tourist, terrestrial origin	Sea
4	Styrofoam	38	Tourist, terrestrial origin	
5	Single-use plastic cups	34	Tourist, terrestrial origin	
6	Plastic packaging/containers and film	34	Tourist, terrestrial origin	
9	Ghost nets (partly)	20		Fisheries
7	Food packaging	19	Tourist, terrestrial origin	
8	Plastic bottles	18	Tourist, terrestrial origin	
10	Plastic bottle caps	17	Tourist, terrestrial origin	
11	Food containers	16	Tourist, terrestrial origin	
12	Others (Diapers, sanitary napkins…)	11	Terrestrial origin	
13	Plastic lighters	7	Tourist, terrestrial origin	
14	Ropes and lines (partly)	6		Fisheries
15	Fishhooks	5		Fisheries
16	Cotton swabs	4	Terrestrial origin	
17	Plastic sandals & shoes	4	Terrestrial origin	

density being 0.400 and 0.440 items/m² respectively. Hon Mot beach was about 0.613 items/m² (Fig. 4).

The results confirmed that the concentration of macroplastic was related to the human use of the beaches. Beaches near the residential area or villages had a higher level of marcroplastic concentration than those in the remote areas.

In comparison of quantity per square meter, Bai Thom beach had the highest quantity of marine plastic debris (about 0.202 kg/m²), followed by Bai Bon, and Ham Ninh beaches being 0.109 and 0.108 kg/m² respectively. The remaining beaches (Hon Mot, Mui Cay Sao, Mui Da Chong) were much lower with about 0.013, 0.034, and 0.043 kg/m² respectively (Fig. 5).

The analysis showed that macroplastic density was not related to the quantity. The beaches with the highest level of marcoplastic density were not those with the highest quantity of marcoplastic.

3.2 Sources, size, and types of microplastic

Of 505 macroplastic items collected, the majority were single-use plastics such as plastic bags (192 items), plastic straws and spoons (41 items), and plastic cups (34 items). Other single-use plastics such as Styrofoam, plastic bottles, food packaging and containers, and cotton swabs were also found on the beaches, which were 38, 19, 35, and 4 items respectively. The study showed that single-use plastic accounted for more than 82% of total debris collected. Other macroplastic included plastic fragments, PVC fishing float foams, ropes which accounted for about 18%. Most of the macroplastic came from tourists and

Fig. 6. Plastic waste from marine aquaculture activity
Rys. 6. Odpady z tworzyw sztucznych pochodzące z akwakultury morskiej

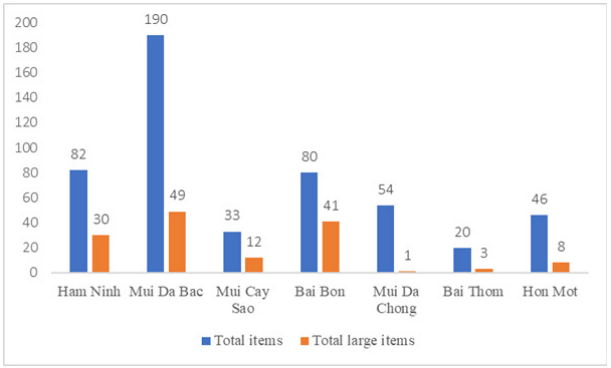

Fig. 7. The total macro-plastic items sampled at the study area
Rys. 7. Łączna liczba próbek makroplastiku pobranych na badanym obszarze

terrestrial sources such as streams, canals, or rivers. Plastic debris because of illegal dumping and uncontrolled littering was thrown into the current drainage system on the island under the influence of seasonal wind and rain. This debris eventually ended up in the ocean. Furthermore, the semi-structured interviews showed that there was no waste collection infrastructure and service available in place, forcing the local people to dispose of solid waste into the ocean (see Table 4).

Those living in areas near the sea or in remote areas with limited access to waste collection services tended to dispose of wastes in open environments. The wastes were then blown into the ocean by seasonal wind or rain. The other main source came from tourism activities. Up to date, 404 hotels, resorts, and hostels were operated with about 28,172 rooms. Despite dust bins available around restaurants located on islands, tourists occasionally dropped plastic bags or empty drinking bottles into the ocean. In camping sites, tourists did not collect their waste when they left the sites. The waste eventually ended up in the ocean. In addition, solid waste management, especially plastic waste was not adequately considered during the construction of hotels and resorts along the beaches, creating a significant pollution source. Farm operators did not have adequate knowledge of marine plastic waste management. Uncontrolled disposal of plastic products caused contributed to the beach pollution in addition to plastic fragments from their aquaculture and fishing such as plastic fragments from fishing gears (fishing nets, squid hook) (Fig. 6).

Plastic waste accumulated on the beaches also came from the ocean under the influence of seasonal tides, waves, and winds. The results showed that there were 144 large size items (more than 30 cm in length) which accounted for 28.5% of total waste collected. Mui Da Bac, Bai Bon, and Ham Ninh received the highest number of large items being 49, 41, and 30 items respectively (Fig. 7).

The size in length of large items ranged between 39.875± 4.286 cm (Hon Mot beach) and 60 ± 3.596 cm (Ham Ninh beach) (see Table 5). The average size was about 49.397 ± 3.971 cm. Mostly the large items were single-use plastic bags. For normal macroplastic items, their size ranged between 7.388 ± 1.173 cm (at Bai Thom) and 23.547 ± 6.223 cm (at Mui Da Chong). The average size of macroplastic items was about 14.932 ± 1.846 cm. They were plastic fragments, single-use plastics such as straws, spoons, cups, and plastic bottles and caps (Table 5).

In terms of material types, most macroplastic were HDPE (accounted for 34.85%), mostly used for single-use plastic bags and in plastic fragments. Other material types were PET/PE/PETE and PP being 27.92 and 23.17% respectively. They were the main materials that were used to produce single-use plastic products such as spoons, straws, cups, plastic bottles, and caps. The number of marcoplastic found in PS was about 10.30% (Table 6).

4. Discussion

4.1 Marine plastic debris and current waste management in Phu Quoc island

The study reveals that despite various policies and instructions on properly managing waste issued by Phu Quoc People Committee, plastic waste was still found with high density along small streams and canals. The waste also ended up in the ocean beyond control. The findings in entirely in accordance with recommendations provided by WWF in 2018. However, the study presented levels and quantity of marine plastic debris disposed on the beaches as well as pollution sources. To avoid this problem, waste collection infrastructure and service should be established particularly in populated areas, remote areas, along the canals, and streams. Besides, local awareness of the proper disposal of wastes should also

Tab. 5. Size distribution (in length) of macro-plastic at study areas

Tab. 5. Rozkład wielkości (pod względem długości) makroplastiku na badanych obszarach

No.	Beaches	Large items		Macroplastic items	
		Mean	SE	Mean	SE
1	Ham Ninh	60.000	3.596	14.731	0.990
2	Mui Da Bac	53.888	2.507	12.467	0.527
3	Mui Cay Sao	56.083	5.547	14.443	1.499
4	Bai Bon	46.034	2.092	17.638	1.311
5	Mui Da Chong	-	-	23.547	6.223
6	Bai Thom	40.500	5.795	7.388	1.173
7	Hon Mot	39.875	4.286	14.311	1.200

Tab. 6. Material types of Plastic waste. Note: HN – Ham Ninh, MDB – Mui Da Bac, MCS – Mui Cay Sao, BB – Bai Bon, MDC – Mui Da Chong, BT – Bai Thom, HM – Hon Mot

Tab. 6. Rodzaje skład materiałowy odpadów z tworzyw sztucznych

No.	Material type	Number of items								%
		HN	MDB	MCS	BB	MDC	BT	HM	Total	
1	PET/ PE/ PETE	38	45	12	26	10	4	6	141	27.92
2	HDPE	23	63	10	32	19	9	20	176	34.85
3	PVC	0	0	0	0	0	0	0	0	0.00
4	LDPE/ LLDPE	3	6	2	2	0	0	1	14	2.77
5	PP	17	50	3	12	15	5	15	117	23.17
6	PS	0	26	6	8	8	2	2	52	10.30
7	Other	1	0	0	0	2	0	2	5	0.99
Total										**100**

be improved. The residents should be involved in collecting waste along streams and canals and stop the disposal of waste into the marine environment. Law enforcement should also be strengthened along rivers and canal corridors. An additional collection of waste along the rivers and channels, dredging are needed to facilitate the flow in streams and rivers such as Ong Tri, Cua Lap canals, Cao stream, Ben Tram stream, Da Ban stream, Somaco canal, Cong Ban canal, Duong Dong 1 Secondary School canal, Sasco parking area, Xeo stream canal, Ba Phong bridge canal, Ba Keo bridge canal. Monitoring station systems should also be established in order to measure leakage of plastic waste at streams and canals. Finally, there is a need for raising local awareness and social behavior on waste separation at sources and discouraging the use of single-use plastic products on a daily activity basis.

4.2 The limitation of the study

The study presented the information in relation to marine plastic debris, quantity, and pollution sources. However, this study did not undertake an analysis in detail of how the waste has affected the biodiversity and environment in the region. If opportunities arise, marine environment and water quality should be tested and analyzed to understand pollution levels, as well as marine fauna and flora species, which should also be monitored to understand pollution effects on their lives.

5. Conclusion

In investigating the current marine plastic debris status in Phu Quoc MPA, we found that the beaches of Phu Quoc MPA were heavily polluted with marine plastic debris. The debris came from different sources. The distribution of microplastic was different from beach to beach. Most of the microplastic found were single-use plastic with the most common of plastic bags in HDPE. The current policies and instructions should be amended or revised together with strengthened law enforcement in order to deal with marine plastic pollution towards sustainable seagrass management and conservation.

6. Acknowledgments

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Odpady z tworzyw sztucznych w morskim obszarze chronionym Phu Quoc w Wietnamie: aktualny stan i metody łagodzenia skutków

Zanieczyszczenie morza tworzywami sztucznymi powoduje niekorzystne skutki dla globalnego środowiska i ekosystemów morskich, szczególnie w morskich obszarach chronionych. Jednak niewiele wiadomo na temat wpływu plastikowych odpadów morskich na funkcjonowanie ekosystemów morskich, dobrostan ludzi, społeczeństwo i gospodarkę. Wybraliśmy Morski Obszar Chroniony Phu Quoc (Phu Quoc MPA), aby uzyskać wgląd w aktualne morskie odpady plastikowe jako pierwszy krok w kierunku zrozumienia ich wpływu na środowisko i różnorodność biologiczną w regionie. W badaniu tym zastosowano analizę danych wtórnych, częściowo ustrukturyzowane wywiady, pomiary terenowe i metodę transektu linii kwadratowej w dążeniu określenie wpływu czynników.
Badania wykazują, że morskie odpady plastikowe usuwane w Phu Quoc MPA pochodziły z różnych źródeł, w tym z rzek, strumieni, kanałów, dostawców usług turystycznych i obszarów rozwoju akwakultury morskiej. Obfitość makroplastiku na plażach wynosiła w przybliżeniu od 1,109 do 0,248 sztuk/m2 (co odpowiada 0,082 ± 0,021 kg/m2). Większość makroplastiku to tworzywa sztuczne jednorazowego użytku, które stanowiły ponad 82%. Średni rozmiar wynosił około 14,932 ± 1,846 cm dla przedmiotów mniejszych niż 30 cm. Pozostałe to torby foliowe HDPE i odpady z tworzyw sztucznych. Należy powstrzymać wyrzucanie makroplastiku i mikroplastiku, aby zachęcić do zrównoważonego gospodarowania odpadami w regionie.

Słowa kluczowe: *makroplastik, mikroplastik, morski obszar chroniony Phu Quoc, Vietnam, zalecenia polityczne, tworzywa sztuczne jednorazowego użytku*

Surface Water Treatment Pilot using Micro Hydraulic Technology Combining Ozone and Activated Carbon

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The technological line proposed in the research process is a combination of Micro Hydraulic reaction technology combined with Ozone and activated carbon filtration. The processing line will be simulated by a test model with a capacity of 5 cubic meters per hour. Installation location at Nhi Thanh Water Supply Plant, Long An Province. The Pilot will operate in 9 different stages, in order to comprehensively evaluate the Pilot.
The results of water quality analysis after the operation showed that the DO index increased from 3ppm to 7ppm, the pH remained stable at 7, turbidity (NTU) after treatment is always very low and averages at 0.01 NTU, Permanganate index after treatment is lower than 2 mg/l, average iron content is 0.05 mg/l, average manganese content is lower than 0.2 mg/l. Most of the water quality indicators are within the allowable limits according to QCVN 01-1: 2018/BYT, National technical regulation on Domestic Water Quality. This result will be compared with the quality of clean water after treatment at the Nhi Thanh water supply plant. Thereby, we can see the advantages and disadvantages when comparing the two water treatment technologies.

Keywords: *water treatment, micro hydraulic, activated carbon filtration, oxidation tower, ozone*

Introduction

The Nhi Thanh Water Plant Project from Module I was built with a capacity of 30,000 cubic meters per day and came into operation in April 2020. Module I of the Plant has maximized the water supply capacity in a short time to serve the needs of people using clean water for daily life and production. However, the water use situation tends to increase very high and it is forecasted that the demand for water will exceed the capacity of the plant to meet. In a short time, it will increase to 60,000 cubic meters per day and will reach 120,000 cubic meters per day in the period 2025–2030.

Due to high consumption demand, it requires an early investment in Module II of Nhi Thanh Water Plant by an additional 30,000 cubic meters per day, for the total capacity of the plant to reach 60,000 cubic meters per day, when water quality is good and successful. For streets in need, it can reach 70-75,000 cubic meters per day. From the results of analysis and assessment of the quality of raw water, as well as the treatment efficiency and water supply capacity of Nhi Thanh – Module I, there are still many problems that are difficult to overcome. Therefore, there is a need for a new treatment technology line more suitable to the characteristics of the water supply, limiting the amount of chemicals used during operation and the treatment efficiency still meeting the requirements according to QCVN 01-1: 2018/BYT, National technical regulation on Domestic Water Quality.

The main goal of the testing process is to find the right specifications and use them as the baseline for: Evaluate the effectiveness of the oxygen tower in increasing dissolved oxygen and pH in raw water. Evaluate the processing capacity after the Flocculation/ Coagulation process in the Micro Hydraulic cluster. Evaluation of performance when combining Ozone technology with activated carbon, during treatment of Permanganate, Manganese, Ammonium, Iron, Color.

From the evaluation results, the testing process will get complete and accurate information, helping to make decisions and plan a more realistic and feasible test. At the same time, detecting possible problems with the system, thereby changing, giving timely adjustment directions, by the actual conditions and continually improving technology transmission lines to ensure quality the amount obtained after the treatment is the most optimal.

Experimental model operation process: In order to achieve accurate figures and specifications, the model will be operated in 2 phases.

Phase I: 10 different test cases.

Phase II: Period of bad raw water quality and low pH.

For Phase II of the test, since you already know the right specifications, only change the number of chemicals used during treatment.

Materials and Methods

Process water treatment technology of experimental model

Raw water will be directed from the raw water pipeline of Nhi Thanh Water Plant to the Oxygen Tower. Raw water is led down from the top of the tower. During the flow, water will be mixed with Pall Ring in the tower. At the same time, using a centrifugal fan to supply air directly inside, increase oxygen content in water, reduce CO_2, increase pH without using chemicals.

Tab. 1. Operation process of the experimental model – Phase I

Tab. 1. Proces eksploatacji w modelu eksperymentalnym – Faza I

Experiment	Time (day)	Water flow (m^3/h)		Application of experimental model operation				
		Q_1	Q_2	Centrifugal fan	Ozone (mg/l)	Chlorine for preliminary treatment (g/m^3)	PAC (g/m^3)	NaOH (g/m^3)
1	2	5	5	YES	< 0,4	NO	13,6	NO
2	2	5	5	NO	NO	NO	10,5	NO
3	6	5	5	YES	NO	NO	15,7	NO
4	3	5	5	YES	< 0,4	1	15,7	NO
5	5	5	5	YES	1 - 2	1,6	15,7	NO
6	2	5	5	YES	>2	1,9	15,7	NO
7	2	5	3,6	YES	>2	2	16,8	NO
8	2	5	2,5	YES	NO	2	16,8	NO
9	5	5	2,5	YES	2	2	13,6	NO
10	2	5	1,5	YES	NO	2	15,7	NO

Tab. 2. Operation process of the experimental model – Phase II

Tab. 2. Proces eksploatacji w modelu eksperymentalnym – Faza II

Experiment	Water flow (m^3/h)		Application of experimental model operation				
	Q_1	Q_2	Centrifugal fan	Ozone (mg/l)	Chlorine for preliminary treatment (g/m^3)	PAC (g/m^3)	NaOH (g/m^3)
17/6/2020	5	5	YES	> 2,3	1,3	15	NO
19/6/2020	5	5	YES	> 2,3	1,6	26	268
22/6/2020	5	5	YES	> 2,3	1,5	24,7	321
23/6/2020	5	5	YES	> 2,3	1,9	19	295
25/6/2020	5	5	YES	> 2,3	3	26,1	268
26/6/2020	5	5	YES	> 2,3	8,5	31,8	214
29/6/2020	5	5	YES	> 2,3	11,4	12,4	NO
02/07/2020	5	5	YES	> 2,3	14,7	17,5	NO
06/07/2020	5	5	YES	> 2,3	21,9	20,6	NO
07/07/2020	5	5	YES	> 2,3	21,4	14,2	NO

Notes:
Q1: Flow of raw water into the experimental model
Q2: Flow of water into the ozone mixing tower

Tab. 3. Symbols of sampling dates

Tab. 3. Oznaczenia próbek I daty pobierania próbek

No	Date	No	Date	No	Date
Day 1	March 2	Day 15	March 25	Day 29	June 19
Day 2	March 5	Day 16	March 26	Day 30	June 22
Day 3	March 6	Day 17	March 27	Day 31	June 23
Day 4	March 7	Day 18	March 30	Day 32	June 25
Day 5	March 10	Day 19	April 1	Day 33	June 26
Day 6	March 11	Day 20	April 6	Day 34	June 29
Day 7	March 12	Day 21	April 8	Day 35	July 2
Day 8	March 13	Day 22	April 9	Day 36	July 6
Day 9	March 16	Day 23	April 14	Day 37	July 7
Day 10	March 17	Day 24	April 15		
Day 11	March 18	Day 25	April 28		
Day 12	March 19	Day 26	April 29		
Day 13	March 23	Day 27	June 17		
Day 14	March 24	Day 28	June 18		

Raw water after going through the Oxygen Tower will automatically flow through the Micro Hydraulic treatment cluster. At the pipe position before entering Micro Hydraulic, the chlorine will be injected directly into the water to oxidize organic compounds after the pH has been raised, and at the same time, a quantity of PAC is added to support the flocculation process.

Water after filling with chlorine and PAC will flow through the Static mixer, which is designed with many small compartments inside when the water flows through it will create a turbulent flow, which will disturb and increase the optimization of the chemical.

After the flocculation has been dissolved in the water, the individual particles need to be bonded together. To create the flocculation reaction, it is necessary to add energy to the system (eg stir) according to the dfloc flocculation pattern and time T shown in Figure 1. The energy required to make the cotton is written by the formula:

The mixing of flocculant and flocculant is the most important in the surface water treatment line. If the floc does not precipitate well and the flakes are not large, the sedimentation and filtration are ineffective, the output water quality is poor and the system does not reach the design capacity and consumes a lot of chemicals. With innovative mixing and reaction technology combining lamel inclination technology and Leopold knitting filter plate, we will exploit the maximum capacity of the existing site and structure and the best water quality. The amount of chemicals used will also be much lower.

In each compartment, micro-hydraulic eddy currents of varying intensity flow through the deflector, the PAC will be more exposed, creating more flakes. The wiper plates are also designed in a variety of distances and sizes when the water flows, the right hydraulic source will not break the floc. Water continues to flow into the Lamela sedimentation compartment in the direction from below, large patches of cotton will sink, smaller and lighter cotton patches will emerge, but most of them will be retained in the lamen. Water continues to flow back up the serrated trough and is led into the 4 sand filter compartments of the treatment cluster.

Water after being treated in the Micro Hydraulic cluster will flow through the stainless-steel water tank and be pumped into the Ozone mixing tower.

The amount of ozone will be dissolved into the water through many steps such as Ozone mixer, static mixer, Ozone

$$G = \sqrt{\frac{P}{\mu V}}$$

G: gradient average speed (s-1)
P: Energy (Watt)
μ: Dynamic viscosity (Ns/m2)
V: Volume (m^3)

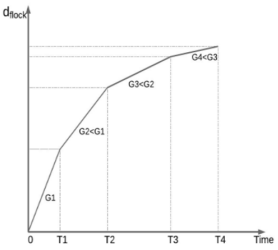
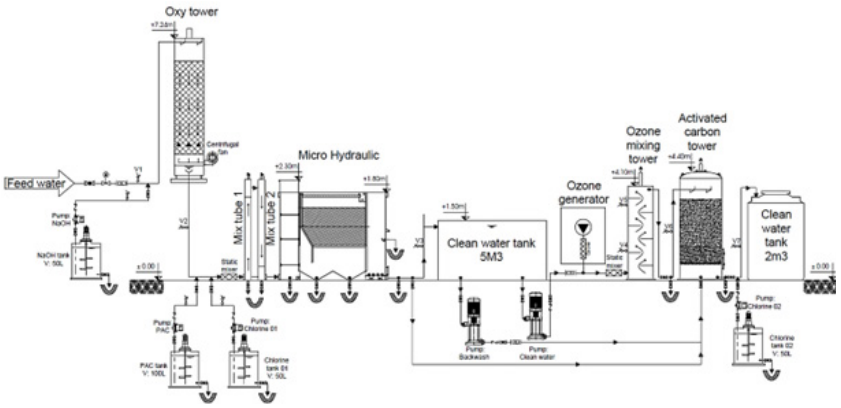


Fig. 1. The rate of floc residue generated over time
Rys. 1. Szybkość generowania pozostałości kłaczków w czasie



Note:
V_1: Sampling point raw water
V_2: Sampling point after crossing the oxygen tower
V_3: Sampling point after cross Micro Hydraulic processing cluster
V_4: Sampling point at ozone mixing tower (below)
V_5: Sampling point at ozone mixing tower (above)
V_6: Sampling point before entering the activated carbon filter tower
V_7: Sampling point clean water

Fig. 2. Descriptive scheme of the system
Rys. 2. Schemat opisowy systemu

mixing tower. Water will rise from bottom to top, in the process of rising water will have to continuously change the flow direction, because the tower is welded with many internal horizontal walls, optimizing the ability to handle O_3 in the water.

After passing the Ozone mixing tower, the water will be led to the activated carbon filter tower, where the water will flow from the top-down, going through the 2.7 m high activated carbon layer, then organic compounds are difficult to decompose and cannot be treated with Ozone will be adsorbed into the capillary pores of coal. The filtration process takes place 3 times a week, to ensure the coal layer is not washed away, the water flow used for the filtration process is 10 m3/h.

After the filtration process, the water will be disinfected with chlorine and led to a clean water tank.

RESULTS AND DISCUSSION

Metrics analyzed during operation include dissolved oxygen, pH, Turbidity, permanganate, Iron, manganese, and ammonium. The quality of the clean water sample will be compared with that of the Nhi Thanh water plant.

Dissolved oxygen index

Raw water has a very low dissolved oxygen content, ranging from 2 to 3 ppm on average. From the analysis results, it can be seen that the DO index in the clean water sample of the experimental model is higher than that of the clean water sample after the treatment process of the Nhi Thanh Water Plant. The reason for this difference is due to the technological transmission line of the experimental model using an oxygen tower combined with a centrifugal fan, forced air blowing, increasing the amount of dissolved oxygen in the water. Besides, using Ozone technology in the water treatment process also dissolves a large amount of oxygen into the water, increasing the DO index on average from 5-7 ppm. For the treatment system of the plant, after the filtration process, the dissolved oxygen content in the water also increased quite a lot, but the ability was still lower than the test model from 1.5 to 2.5 ppm.

pH index

Raw water has a relatively stable pH when it ranges from 6.6 to 6.8. However, in mid-June, the pH level had a big change and decreased to 4–4.2 (below the allowed limit according to QCVN 08-MT: 2015/BTNMT, column A2). After the treatment of the two systems, it can be seen that the clean water samples of the pH test model are almost equal to 7, and the stability is higher than the treatment system of Nhi Thanh Water Plant.

The pH in clean water samples of Nhi Thanh Water Plant meets the requirements of QCVN 01-1: 2018/BYT, but only fluctuates on average from 6.3 to 6.6. The reason is the chlorine filling process in many places in the system before being pumped into the water supply network.

Turbidity index

From the analysis results, it can be seen that turbidity in raw water sources has many relatively large fluctuations, and changes occur each day. The turbidity has a very low day of only 3 NTU but has a mutation time of more than 18 NTU. The fluctuation range was quite wide, averaging 6-14 NTU. In the early days of the experiment, the model handled the turbidity very well with Micro Hydraulic technology and activated carbon filter, but the turbidity was still much higher than Nhi Thanh Water Plant.

After many experiments, the system operates stably and the operating steps are more optimal. After the processing of the experimental model and the Nhi Thanh Water Plant, the turbidity in the raw water is processed almost entirely, when the results re-

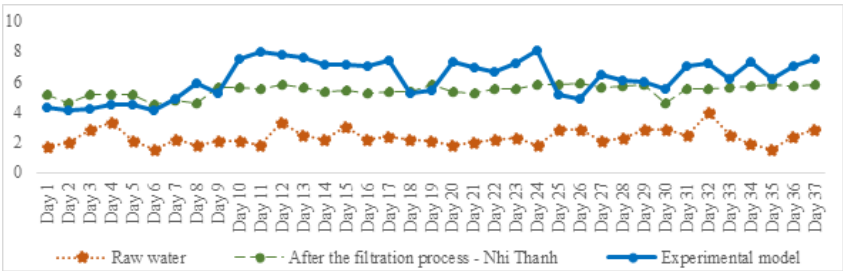


Fig. 3. Analysis results of dissolved oxygen index
Rys. 3. Wyniki analizy wskaźnika tlenu rozpuszczonego

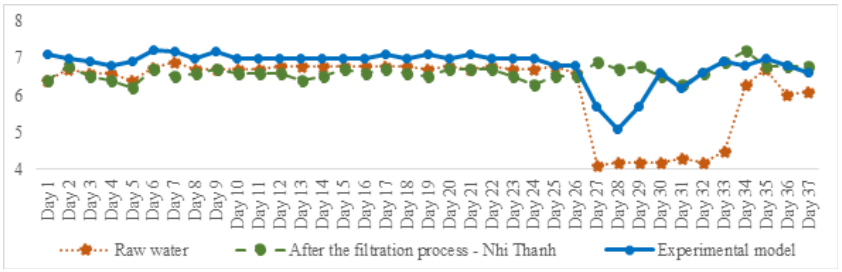


Fig. 4. Analysis results of pH index
Rys. 4. Wyniki oznaczenia wskaźnika pH

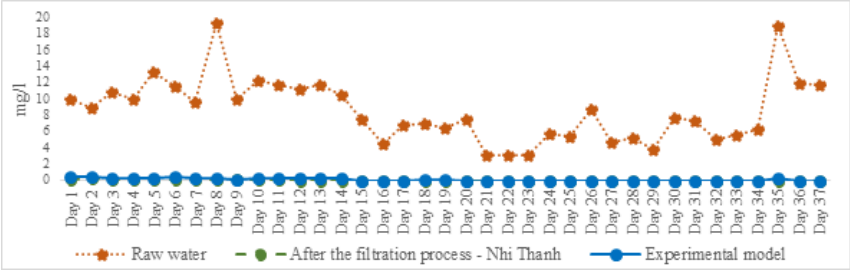


Fig. 5. Analysis results of turbidity index
Rys. 5. Wyniki analizy wskaźnika mętności

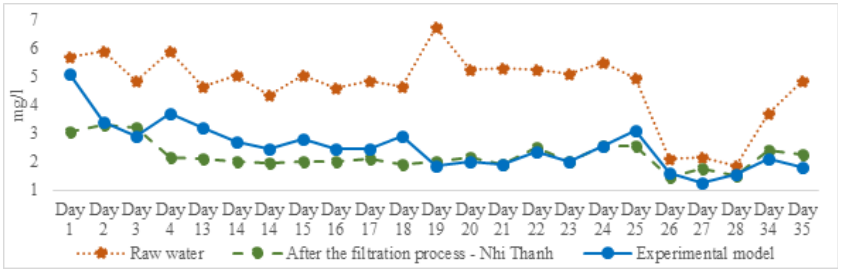


Fig. 6. Analysis results of permanganate index
Rys. 6. Wyniki analizy wskaźnika nadmanganianowego

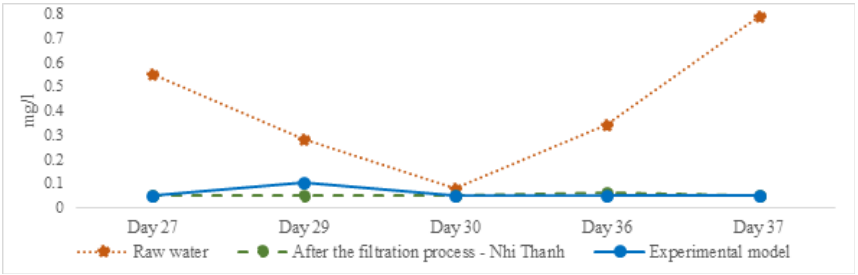


Fig. 7. Analysis results of iron index
Rys. 7. Wyniki analizy wskaźnika żelazowego

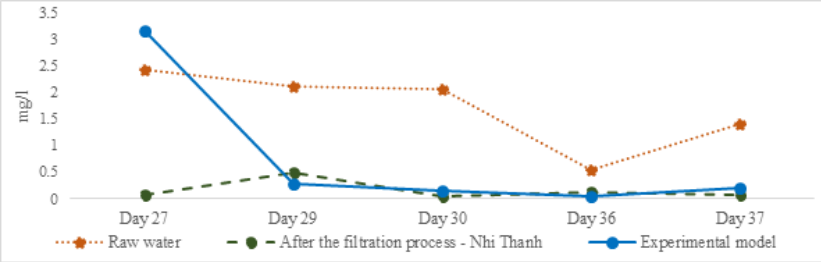


Fig. 8. Analysis results of manganese index
Rys. 7. Wyniki analizy wskaźnika manganowego

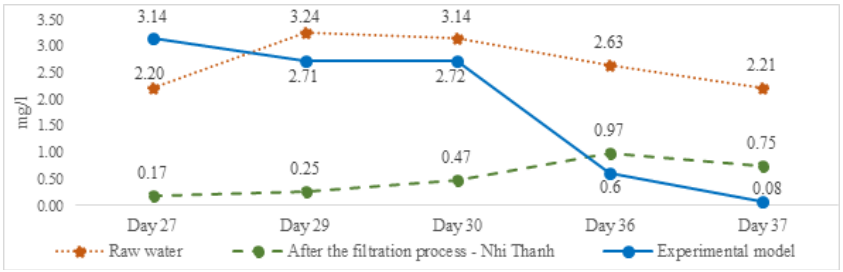


Fig. 9. Analysis results of amoni index
Rys. 9. Wyniki analizy wskaźnika amonowego

corded are mostly <0.01 NTU. Thereby we can conclude, the ability to handle turbidity of both technology lines is equally efficient.

Permanganate index

The post-treatment permanganate of both systems is ineffective. Most results are greater than 2 mg/l. But the analysis results of Nhi Thanh water samples from March 6 onwards showed that the maintenance performance was more stable, the difference compared to the threshold was not too large (difference 0.2–0.4 mg/l). The results of analyzing clean water samples in the experimental model, the results were not stable and the difference was quite clear between experiments. But from March 24, the permanganate index began to decline, especially from April 6 to 15, The analysis results of the permanganate index in clean water samples in the model, almost equivalent to the clean sample of Nhi Thanh Water Plant and lower than exceed the permitted threshold (QCVN 01-1: 2018/BYT).

In the phase II experiment, raw water had a permanganate index that was not too high, with a date almost equal to the threshold. So the processing capacity of both systems is very well achieved. The results of the permanganate index in two clean water samples of the two systems ranged from 1.5 to 1.8 mg/l.

Iron index

The iron content in raw water is relatively low and the difference between days is not too great. The lowest iron content was 0.08 mg/l on June 22, and highest on July 7 when the result was recorded at 0.79 mg/l. All analytical results reach limit values according to QCVN 08-MT: 2015/BTNMT, National technical regulations on surface water quality. Oxidation of Fe (II) to Fe (III) is precipitated and eliminated after Lamella deposition and OSF rapid filtration. The clean water sample after the Nhi Thanh Water Plant's filtration process was 0.05 mg /l. Satisfied QCVN 01-1: 2018/BYT. For the test model, a large amount of iron is oxidized at the oxygen tower. More than 50% of the iron content is processed in a Micro hydraulic assembly. The clean water sample after the activated carbon filtration process has an iron content of 0.05 mg/l. Satisfied QCVN 01-1: 2018/BYT.

Thereby, we can see that the iron content treatment efficiency of the two technological lines is the same, but the amount of chemicals consumed by Nhi Thanh Water Plant is much higher.

Manganese index

Manganese is one of the most concentrated ingredients in raw water. The results of Manganese content may be higher than 2 mg/l, 10 times higher than the permitted limit according to QCVN 08-MT: 2015/BTNMT, column A2. From the analysis results of 2 clean water samples, the treatment system of Nhi Thanh factory and the experimental model can be evaluated technically, the treatment capacity is equivalent and the treatment efficiency is acceptable. For the system of the Nhi Thanh Water Plant, the analytical result is much lower than 0.15 mg/l. However, on June 19, the manganese content exceeded the threshold 2 times according to QCVN 01-1: 2018/BYT, National technical regulation on Domestic Water Quality. The reason is that the ammonium content increases, the amount of chlorine in the system are insufficient, and the ability to handle manganese decreases. But the process of overcoming and processing from the Factory takes place very quickly, the manganese content decreases and is stable at less than 0.2 mg/l.

Model testing in the early days of phase II shows that the manganese content in the clean water sample is still very high, the ability to handle manganese is very poor. The reason is that the model has been suspended for a while after running the test in phase I (it takes time for the system to stabilize again). Besides, the absence of NaOH on June 17 was also the main cause of ineffective treatment performance, because during that time the pH in the water was very low, only ranging from 4-4.2, absolutely no. The flocculant and flocculent can be a great hin-

drance in the process of the system. On June 19, after adding NaOH into the system, the concentration of manganese analyzed in the clean water sample decreased sharply to only 0.27 mg/l, lower than the system of Nhi Thanh Water Plant.

Ammonium index

Ammonium is not only very difficult to treat ingredients in raw water but also fluctuates at a very high level from 2.2 to 3.2 mg/l. The analysis results show that the Ammonium content exceeded the limit from 7 to more than 10 times according to QCVN 08-MT: 2015/BTNMT, column A2.

Through the results presented in Figure 9, we can evaluate the ammonium processing capacity of the two technological lines.

The results showed that there are contradictions. For the treatment system of Nhi Thanh Water Plant, the analysis results of the clean water samples were very good on the 17th and 19th were below the limit. However, the results recorded in the following days tended to increase gradually, highest on July 6 when the Ammonium in clean water samples was at 0.97 mg/l (exceeded the limit of allowed folding 3 times).

The test model is gradually showing stability and very good handling of the system. Although in the first days of Phase II testing, the Ammonium treatment capacity is very low, with the right chemical increase and more and more stable operation, the Ammonium treatment efficiency is achieved post-processing is very high. Results were recorded on July 7 at 0.08 mg/l (3.75 times lower than the threshold).

Conclusions

Micro-hydraulic technology combining ozone and activated carbon filtration is technically feasible, the analysis results show that the parameters of DO, pH, turbidity, permanganate, color, iron, manganese, sulfate, and ammonium all change in a positive direction. Clean water samples meet QCVN 01-1: 2018 / BYT standards for the quality of clean water for domestic use. Although the first test results were not really as expected, the difference between the Nhi Thanh water treatment system and the experimental model was almost equal. In the tests, after the system gradually stabilizes and goes into orbit, combining calculation and choosing the right chemical charge rate, the processing efficiency of the experimental model increases very high. Besides, Ozone technology has not been applied much for the treatment of supply water with such a large volume of water in Vietnam, so it takes a longer time to study. The quality of activated carbon is very important in the treatment of mechanical pollutants.

When using ozone to treat water, it is necessary to ensure that ozone is aerated into the water for enough time necessary to create ozone dissolved water with enough concentration of sterilization and chemical decomposition. Avoid sniffing, direct inhalation of ozone gas often in the air because it will harm the respiratory tract due to ozone having strong oxidizing properties. Therefore, the ozone pipes must be regularly checked, maintained, and replaced if a leak is detected. Also, the risk of fire is a top priority when using Ozone technology in the treatment process.

For activated carbon filtration, additional tests are required with better-activated carbon and higher iodine content. Thereby, we can better evaluate the processing ability of the experimental model.

Acknowledgment

This document is based on work supported by Perfector Vietnam Joint Stock Company and the guidance of Ms. Nguyen Thi Mai Linh.

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Odpady z tworzyw sztucznych w morskim obszarze chronionym Phu Quoc w Wietnamie: aktualny stan i metody łagodzenia skutków

Zaproponowana w procesie badawczym linia technologiczna jest połączeniem technologii reakcji Micro Hydraulic połączonej z filtracją ozonem i węglem aktywnym. Linia technologiczna będzie symulowana przez model testowy o wydajności 5 metrów sześciennych na godzinę. Miejsce instalacji w zakładzie wodociągowym Nhi Thanh w prowincji Long An. Instalacja pilotażowa będzie działała w 9 różnych etapach. Wyniki analizy jakości wody po procesie wykazały, że wskaźnik DO wzrósł z 3 ppm do 7 ppm, pH utrzymywało się na stabilnym poziomie 7, mętność (NTU) po uzdatnianiu jest zawsze bardzo niska i średnio 0,01 NTU, wskaźnik nadmanganianowy po uzdatnianiu jest niższy niż 2 mg/l, średnia zawartość żelaza wynosi 0,05 mg/l, średnia zawartość manganu jest niższa niż 0,2 mg/l. Większość wskaźników jakości wody mieści się w dopuszczalnych granicach zgodnie z QCVN 01-1: 2018/BYT, krajowymi przepisami technicznymi dotyczącymi jakości wody użytkowej.

Wynik ten został porównany z jakością czystej wody po uzdatnieniu w wodociągu Nhi Thanh. W ten sposób pokazano zalety i wady dwóch technologii uzdatniania wody.

Słowa kluczowe: *uzdatnianie wody, mikrohydraulika, filtracja węglem aktywnym, wieża utleniająca, ozon*

Noise Reduction Solutions for Medicine Tablets Manufacturing – Specifically in the Sanofi Vietnam Joint Stock Company, HCMC

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Ho Chi Minh City is now considered one of the cities with a high proportion of industrial production, both in scales of operations and the level of technical and technological application, leading in the Southern region of Vietnam. Although the development of industrial manufacturing brings many economic and social values in this area, it also affects the quality of life and weakness the health of workers.

According to reports on occupational hygiene and health care for workers at enterprises, the current situation of working environment pollution, in which noise pollution at construction sites and manufactures remains many problems and no complete solution. Working noise is one of the commons harmful factors that often causes occupational deafness when workers are in contact for a long time. Noise often arises due to the characteristics of production technology, old and outdated machinery, and working equipment.

This article focuses on analyzing and evaluating the current situation noise of the medicine tablets manufacturing of Sanofi Vietnam Joint Stock Company in Ho Chi Minh City, that uses production equipment such as vibrating screen machines, tablet presses, and compressed air blowers. At the manufactory, they generate high noise level that exceeds the allowable standard according to the working time and can affect workers' hearing health. According to measurement data recorded at the position of workers standing at the tablet press, the highest noise measurement result is 90.4 dBA (Leq). Therefore, based on the process of analyzing and evaluating the cause of the noise, the authors proposed a solution to add a silencer made of brass (SL) which is suitable for an air outlet of the tablet press and equipped with an acoustic form on the wall to reduce the noise level of vibrating screen machine. And so, the result of the proposed solution is a noise at the locations to be treated has decreased compared to the original measurement level from 10dBA – 15 dBA, adapt to the standards enable and improving the working environmental quality, and prevent harmful factors causing occupational deafness for workers.

Keywords: *noise volume, silencer, occupational deafness, occupational health, Sanofi Vietnam Joint Stock Company in Ho Chi Minh City*

1. Introduction

Pharmaceutical manufacturing and medical devices are one of the industries focused on investment and development in Vietnam. Currently, besides the application of scientific and technological advances in production are the development of solutions to protect the safety and health of workers in the process of working. In the past, the production often focused on issues to ensure the quality of pharmaceuticals and medical equipment in accordance with the relevant requirements, such as machines and equipment, factory premises, materials should be appropriate, not affect the product. Therefore, if in working conditions there are dangerous and harmful factors that may adversely affect the employee, the employer will prioritize the settlement at the end of the priority order in the safety solution tower, such as the solution of administrative management, labor organization or equipped with personal protective equipment. Therefore, it is not possible to achieve the meaning of occupational safety and health work, which is worker-centered, the means and tools of labor must be suitable for workers, but especially this is a manufacturing industry with health care products and treatment of human diseases. [8]

Pharmaceutical production is characterized by means and tools of production must comply with strict hygiene standards to ensure product quality, so most factories set up automated or semi-automatic systems to be able to control and manage well. Therefore, it also limits the number of workers exposed to dangerous and harmful factors. However, through the process of surveying pharmaceutical factories and production facilities, the authors found that the outstanding problem of working conditions can adversely affect the health of workers but high noise from the production line of tablets and bottle stamping. Loud noises in production have been identified as the main cause of occupational deafness.

Occupational deafness is an occupational disease caused by frequent exposure to noise that exceeds the permissible limit for long periods of time at the place of manufacture, causing irreversible damage to the inner ear organ, which is a covered occupational disease in Vietnam.

Usually, the mechanism of occupational deafness due to noise progresses through 3 stages. The first is the auditory adaptation phase, which manifests it after a period of exposure to noise, the worker has the phenomenon of auditory adaptation to prevent the auditory organ from being damaged. At this stage the hearing threshold usually increases (10-15dBA) when exposed to noise. When you stop contact, the hearing threshold quickly returns to normal (after 2-3 minutes). This stage is difficult to detect; The second is the period of hearing fatigue, which manifests it through the employee's hearing threshold increases over the auditory adaptation stage (15-30dBA). The recovery time is slower (usually from 15 to 30 minutes), the auditory organ begins to reduce sensation with

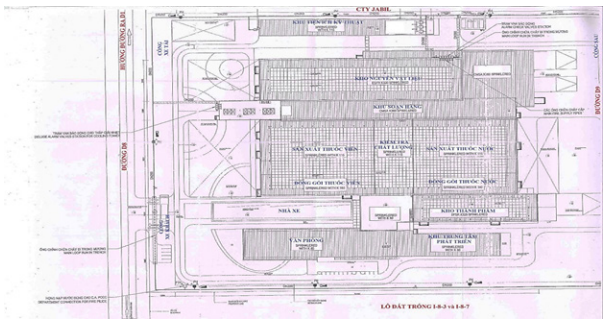


Fig. 1. Factory premises diagram
Rys. 1. Schemat pomieszczeń fabrycznych

Tab. 1. Results of noise measurement of locations exceeding allowable standards [2]
Tab. 1. Wyniki pomiarów hałasu w lokalizacjach przekraczających dopuszczalne normy [2]

Monitoring location	Leq	Sound pressure level in octave bands with center frequency (Hz) not exceeding (dB)							
		63	125	250	500	1000	2000	4000	8000
Ultilities									
Boiler (U-4)	**85.6**	53,1	66,3	74,2	78,4	79,6	**80.8**	**76.3**	68,5
Pure Water (U-15)	**86.8**	44,3	56,1	69,0	73,8	78,2	**83.4**	**81.0**	**75.2**
Pills/tablets									
Stamping (SP-36)	**90.0**	48,0	60,9	73,9	82,7	**85.1**	**84.4**	**81.2**	**76.6**
Stamping (SP-66)	**90.4**	52,5	69,7	78,2	81,1	**81.4**	**84.3**	**86.3**	**76.8**
Stamping (SP-37)	**85.7**	43,5	63,0	74,1	80,2	**81.2**	**78.9**	75,0	66,1
Stamping (SP-54)	**86.9**	58,0	64,4	73,1	79,5	**82.1**	**78.5**	**80.3**	**75.4**
Pills/tablets									
Blister packing (82)	**86.9**	52,4	61,6	69,4	76,3	77,4	**81.6**	**81.8**	**79.1**
Blister packing (102)	**87.5**	56,8	67,9	75,0	77,4	77,9	**82.0**	**82.3**	**79.0**
Packaging (SP-94)	**85.4**	55,5	64,5	71,8	76,1	76,0	**79.3**	**79.5**	**77.4**
Packaging (SP-98)	**85.3**	42,9	62,0	73,7	79,3	**80.8**	**78.1**	73,3	63,6
Solution									
Bottled Jasper 2000L (LC-23)	**90.3**	58,7	69,5	73,4	75,1	77,2	**79.0**	**84.5**	**83.2**
Solution									
Jasper Packing 2000L (LC-24)	**87.2**	40,0	49,9	60,3	69,1	74,0	**78.5**	**83.0**	**82.7**

sound (decreased hearing) especially the sounds at the frequency of 4000 Hz. If detected at this stage, it can interfere with the phenomenon of developing to the deaf stage. However, detection is often difficult; The third is the occupational deafness phase, manifested through workers who have had irreversible lesions in Corti organs and auditory nerves in the inner ear. Speaking out loud is also difficult to hear; patients with tinnitus regularly, difficulty talking; Reduce hearing at all frequencies. With such an effect on hearing, workers will be limited in the process of earning information, safety warning signals when working, possible incidents or occupational accidents. At the same time, it also affects the quality of life of the worker. [1]

In addition, when workers work regularly and prolonged in places with high noise levels, it also affects other organs, such as physically, workers feel full-body fatigue, headache, dizziness, bad eating, anemia, weight loss, high blood pressure, vestibules damage, balance disorders, movement; Psychologically, workers feel depressed, anxious, resentful, fearful, distracted thoughts and thoughts, insomnia, confusion, inaccuracy, easy conflict; Workers are also likely to have a vegetative neurological disorder manifested through increased heart rate, increased respiration, altered blood pressure; Changes in gastrointestinal movement, salivation, basic metabolism, decreased taste secretion, affecting the contraction of the stomach; Eyes reduce night vision, poor color difference, decreased adaptation. With the basis analyzed above, the team conducted a case study at a pharmaceutical factory with tablets and bottling lines to collect information and measurements of noise levels to analyze and determine the cause to find the most feasible solution to reduce noise levels. The purpose of the study is to both ensure pharmaceutical production requirements and protect workers' health.

2. Methods

2.1. Study area

Sanofi is a French multinational pharmaceutical company, has been present for more than 25 years in Vietnam and now has 3 manufacturing plants in our country with modern technology lines, large production scale, diverse products in many medical fields, also surveyed, Study the working environment conditions of factories in Vietnam to bring about root solutions to improve working conditions and ensure safety and health for workers. Sanofi Vietnam joint stock company holds the number one position in the market in Vietnam, leading in the categories of prescription, over the counter and vaccine pharmaceuticals. As a pharmaceutical company, the work of occupational safety and hygiene at the factory is always focused to ensure the quality of products and working environment for employees. Harmful factors in the working environment through periodic measurements are largely within the permissible limits of the prescribed standard. However, the problem that still exists here is the noise level when measured at the lines and equipment producing tablets, which have the potential to cause distraction, psycho physiological effects and adversely affect the hearing of workers when working regularly and prolonged in this position.

With a total area of 72.397,5 m2, Sanofi Vietnam factory located in District 9 Hi-Tech Park started production in 2015, there are 03 main production technology lines to serve the production of pharmaceuticals, cosmetics, and functional foods. The entire production processes of the project are arranged in

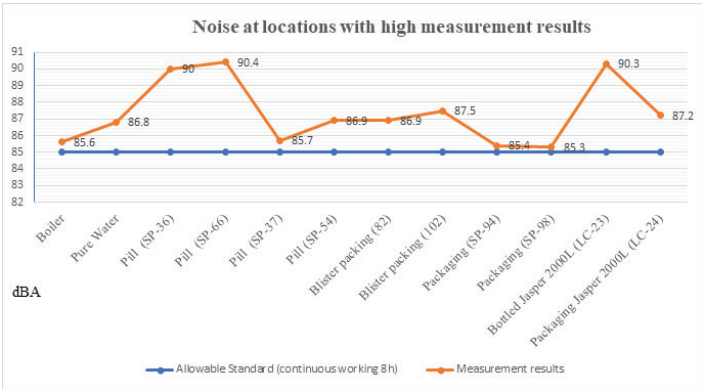
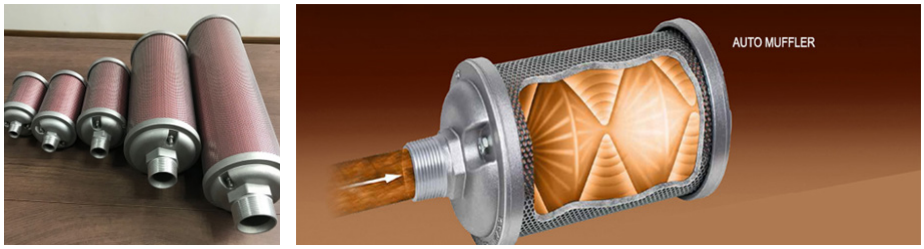


Fig. 2. Results of high noise levels after measurement

Rys. 2. Wyniki pomiarów poziomu hałasu w lokalizacjach o największym natężeniu hałasu



Img. 1. Example of silencers (sound-absorbers). Reference at https://3dtoancau.com/loc-tieu-am-xy-15-dung-cho-may-say-khi-hap-thu/

Zdj. 1. Przykład tłumików (pochłaniaczy dźwięku)

closed rooms, strictly controlled by high-tech technology, and corresponding to each room is a stage in the process. Therefore, the company's production stages are carried out, monitored, and controlled automatically, including dry product production technology (capsules, capsules, tablets, powder); technology for producing liquid/semi-solid products; high-tech production technology – granule medicine. [2]

The characteristics of the production line and equipment here are automatic so the noise generated during the production process is mainly from machines and equipment. Loud machines noise affects workers' health and can also hinder concentration and reduce employee productivity, ultimately having an impact on the company's bottom-right. Although at the factory still take some measures to improve noise such as earplugs, earplugs; Maintenance of machinery, but the efficiency is not high, the noise level is not reduced, so it still affects the health of workers.

The total number of employees in Sanofi is 404 people, including people working in occupational safety and hygiene are 03 people; The person doing medical work is 02 people; Female workers are 216; Labor working in heavy, toxic, and dangerous conditions (occupational conditions of type IV, V, VI) is 158 people; Working time at the factory 03 shifts, each shift 8 hours. When adjusting the product structure and adding new products, the working time is constant.

2.2. Data collection

Noise measurement principles are followed "Vietnam Standard 9799:2013 (ISO 9612:2009) Acoustics – Determination of occupational noise exposure – Engineering method" and "Method 1910.95 App G (OSHA – Monitoring noise levels)".

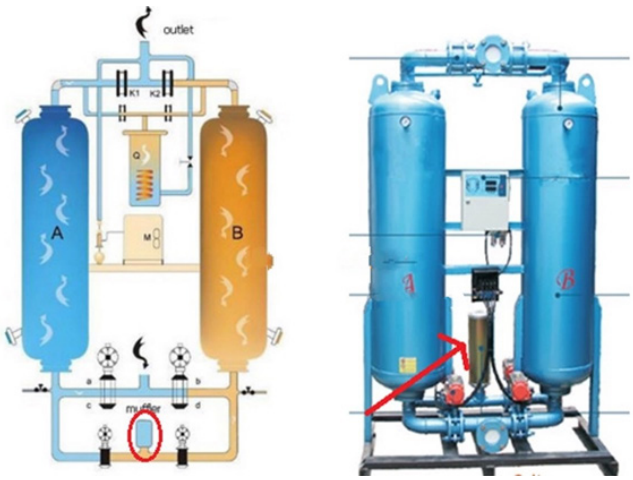
Noise monitoring time: The continuous measurement time of each measurement is 10 minutes, within 01 hours make a minimum of 03 measurements, after a take averages value of 03 measurements. The results are the average value of that hour measured.

For noises generated from production facilities affecting the outdoor environment, measurements must be conducted during working hours. [6], [7]

3. Results and Discussion

The results after the measurement were compared to NTR 24:2016/MOH collected 12 working positions with noise exceeding the standard and 59 working positions meeting the requirements of the standard, of which the positions of the stamping machine SP-36, SP-66 and LC-23 bottling machine had the highest noise levels. The HSE department at the plant must continue to improve and develop noise reduction measures in 12 work locations exceeding allowable standard, if the noise level exceeds the standard for a long time, it will affect the hearing health of employees and the compliance with the provisions of law.

Causes of noise in each substandard area, including in the utility area there is a boiler (U-4), when the boiler in the U-4 position operates the parts, the engine in the boiler moves leading to noise. Depending on the structure of each boiler, the level of noise generated varies. This mechanical noise is required to be generated when the boiler is operating and the noise of some nearby boilers with a measured noise of 85,6 dB exceeds the allowable standard of NTR 24:2016/MOH. Considered an area with high noise, when working nears this area, ear protections must be used. Frequency of contact of employees when starting the furnace, recording parameters; In purified water purifiers (U-15) there are water pumps with different capacities when the operation takes water through each stage to meet the water filtration process that will generate noise, which is the mechanical noise that must be generated when the pump is operating. In addition, the general



Img. 2. Simulation when installing sound absorber [9]
Rys. 2. Symulacja montażu pochłaniacza dźwięku [9]

noise of filters, machines operate when filtering water. With multiple sources of noise generated at the same time, the pure water production area (U-15) has a measured noise of 86,8 dB exceeding the NTR 24:2016/MOH requirement of 1,8 dB. Frequency of employee contact when recording waters quality parameters; In the tablet-stamping area (SP-36) for Panadol Extra tablets, the noise emitted is the obligatory mechanical noise that arises when the stamping unit moves up and down. After that, the tablet is put through the sieve machine to separate the dust of the pill, clean the tablet. Depending on the drug material, the amount of dust produced varies. The amount of drug dust generated must increase the capacity of the sieve, resulting in the greater the vibration of the sieve, resulting in a high noise intensity. In addition, there is general noise when machines and parts are operating at the same time. With many high-powered machines operating at the same time, the noise emitted by the stamping room (SP-36) is 90 dB exceeding the permissible standard of NTR 24:2016/MOH of 10 dB. The frequency of employee contact is continuous throughout the shift. The number of employees working in this stamping room are 02 people / 01 shift / 08 hours; The tablet stamping machine (SP-66), like the stamping room (SP-36), the pill product in this room is also Panadol Extra. The noise generated in the stamping machine is also from the up-and-down movement part of the stamping machine. The sieve machines in the SP-66 room have been built, the technology of the parts has been for a long time, so the noise is greater than in other stamping rooms. Panadol Extra produces more dust than other pills. Therefore, the sieve always increases the operating capacity to screen for dust clinging to the tablet leading to vibration and noise from the sieve machine. In addition, general noise comes from parts of the stamping machine and the sieve machine. The noise of the stamping room (SP-66) is 90,4 dBA, which is also the room with the highest noise at the factory. The frequency of exposure of employees to noise continuously throughout the shift, the number of employees working in the stamping room (SP-66) are 02 people / 01 shift / 08 hours.

The authors, after researching the specifics of production, technological processes, and existing conditions, have proposed a solution that is to install silencers (SL) for compressed air machines and equip additional sound-absorbing wall panels (acoustic form) in rooms where machines with measurement values greater than 85 dBA are located. Install silencers (sound-absorbers) for air compressors. Silencers are installed in Compressed air blowing dust from bottles (noise reached to 90,3 dBA).

Silencer should be made of copper or stainless steel, it has certain durability, long life and easy clean and can work in different environment with high pressure and temperature. [9]

Installing a muffler filter for an absorbent air dryer helps to reduce 85% of the noise emitted by the air compressor, making the working environment for more workers' health and fresher. Operating principle is the gas escapes, if discharged directly through the throat to the outside, the noise level will be high, but when it goes through the absorber filter, the air will be blocked through the filter layers and the sound will dissipate by an absorber and noise are reduced. Sound absorbers can be made from porous materials or resonant structures, and the main mechanisms for sound absorption are acoustic impedance matching on the absorbers' boundary and acoustic energy dissipation inside the absorbers. Porous absorbers are materials where sound propagation occurs in a network of interconnected pores so that viscous and thermal effects cause acoustic energy to be dissipated. Resonant absorbers have two common forms membrane/panel absorbers.

Calculating the noise reduction effect after installing the sound absorber in the air compressor according noise reduction rating (NRR = 85%). The measured noise is: (85%) x 90,3 = 76,6 dBA. This noise is in allowable standard (< 85 dBA). [3]

To increase the efficiency of noise reduction, other solutions can be used at the same time such as encourage your employees to wear earmuffs while working to help reduce the effect of the noise. Considering their low cost, you can even supply these earmuffs to workers. They should be worn just before the air compressor is activated. While this may be harder to pull off for industrial air compressors, it is still an option worth considering, depending on the layout of your workspace and if there are any provisions for the constructing of a soundproof air compressor enclosure. The inside of such a room or enclosure should be padded with convoluted foam boards to help absorb most of the noise. Sound blankets are typically made from quilted fiberglass, popularized through their use in recording studios. They can also be used to wrap around your industrial

air compressors to help further reduce noise levels. Alternatively, they can be wrapped around the outside of a soundproof room or enclosure for further affect. [5]

4. Conclusion

With the solution of installing sound absorber at the blown throat of the air compressor has significantly reduced the noise emitted during work. Depending on how the device emits noise, choose solutions to suit the actual situation of the business, the most important is to protect the hearing health of workers during long periods of exposure to high noise.

Excessive noise levels over a long time will damage the hearing. This may happen so gradually and painlessly that you may not notice the minor deterioration from one day to the next. Excessive noise in the workplace presents a risk of hearing damage and other health problems. So, we must propose some key solutions to reduce noise pollution as much as possible to protect occupational health for employees.

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Rozwiązania do redukcji hałasu w procesie produkcji tabletek medycznych na przykładzie wietnamskiej spółce akcyjnej Sanofi HCMC

Ho Chi Minh City jest obecnie uważane za jedno z miast o wysokim udziale produkcji przemysłowej, zarówno pod względem skali działalności, jak i poziomu technicznego i technologicznego, przodujące w południowym regionie Wietnamu. Chociaż rozwój przetwórstwa przemysłowego niesie ze sobą wiele dodatnich wartości ekonomicznych i społecznych w tym zakresie, to jednak wpływa również na jakość życia i osłabienie zdrowia pracowników. Według raportów z zakresu higieny pracy i ochrony zdrowia pracowników w przedsiębiorstwach, obecna sytuacja zanieczyszczenia środowiska pracy, w którym hałas na budowach i w zakładach produkcyjnych pozostaje problemem który nie ma pełnego rozwiązania. Hałas w miejscu pracy jest jednym z powszechnych szkodliwych czynników, które często powodują głuchotę zawodową. Hałas często powstaje z powodu charakterystyki technologii produkcji, starych i przestarzałych maszyn i urządzeń roboczych. Niniejszy artykuł skupia się na analizie i ocenie aktualnej sytuacji hałasu produkcji tabletek leczniczych w Sanofi Vietnam Joint Stock Company w Ho Chi Minh City, która wykorzystuje sprzęt produkcyjny, taki jak przesiewacze wibracyjne, tabletkarki i dmuchawy sprężonego powietrza. Fabryka generuje wysoki poziom hałasu, przekraczający dopuszczalne normy i mogące wpływać na zdrowie i słuch pracowników. Według danych pomiarowych zarejestrowanych na stanowiskach przy tabletkarce, najwyższy wynik pomiaru hałasu to 90,4 dB(A). Dlatego też, opierając się na procesie analizy i oceny przyczyny powstawania hałasu, autorzy zaproponowali rozwiązanie polegające na dodaniu tłumika wykonanego z mosiądzu (SL) odpowiedniego dla wylotu powietrza z tabletkarki i wyposażonego w wytłoczkę akustyczną na ściana, aby zmniejszyć poziom hałasu wibrującej maszyny przesiewającej. I tak, efektem proponowanego rozwiązania jest zmniejszenie hałasu w miejscach poddawanych zabiegowi w stosunku do pierwotnego poziomu pomiarowego z 10dB(A) - 15 dB(A), dostosowanie do norm jakości środowiska pracy oraz zapobieganie szkodliwym czynnikom powodującym głuchotę pracowników.

Słowa kluczowe: *natężenie hałasu, tłumik, głuchota zawodowa, higiena pracy, Sanofi Vietnam Joint Stock Company w Ho Chi Minh City*

Assessment of the Environmental Status of Household's Pig Farming System, at An Nhon, Binh Dinh Province, Vietnam

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The livestock industry has played an important role in Vietnam's economic development. In particular, pig farming is the bright spot of the industry, playing a role in ensuring food security across the country. Along with the rapid development of the livestock industry in general and pig farming in particular, environmental problems in livestock production are becoming more and more serious.

This study was carried out in Nhon Tan commune, An Nhon district, Binh Dinh province to initially assess the environmental status of pig production at household scale in the area. Nhon Tan commune is a mountainous commune, the terrain is mainly forest and low hills, is a purely agricultural commune, the labor structure is mainly agriculture, with little training, so the application of scientific and technological advances production technology has many limitations. In recent years, pig farming in the area has grown rapidly in both scale and value, contributing 51.97% of GDP, the commune's pig herd ranks first in An Nhon district and third in the world. Binh Dinh province (Economic office, Nhon Tan commune, 2020). The whole commune has 05 villages: Nam Tuong 1, Nam Tuong 2, Nam Tuong 3, Tho Tan Bac and Tho Tan Nam, pig raising is scatteredly distributed in all these 5 villages and most households still follow the form of individual husbandry so the scale is still small and scattered.

The investigation and data collection were done in the form of semi-structure interview directly. The survey sample was conducted to meet the data collection, including general information: (1) Number of households raising, number of pigs in the area; (2) livestock scale: less than 10 heads of pigs, from 10 to 50 heads of pigs, more than 50 heads of pigs; (3) time and experience in livestock production, (4) current state of the barn system, (5) livestock production and waste treatment; (6) technical information such as waste classification. By the end of December 2020, the total number of pig-raising households in the area remained 80 households (Economic Department, Nhon Tan commune, 2020), the research team had surveyed on a total of these 80 households. The results show that 59% of households have a number of pigs from 10 to 50 heads, mainly from 6 to 10 years of experience, accounting for 41%. The current status of the barns, 100% of the barn floor in the farms is cement, built 0.5-1m higher than the ground, the roof is 100% covered with corrugated iron, in some barns the roof has the phenomenon of falling down. The disease is clearly acute, rotten, affecting the hygiene of the barn and animal health, especially during the time when swine fever is still present and in the rainy season. In particular, in the process of raising, processing and storing animal feed, countless combinations of waste in solid, liquid and gaseous forms have been generated, 90% of farmers have not controlled and 51% of households have Waste treatment system (Biogas) has not been built to ensure environmental sanitation.

Keywords: *environmental status, household's pig farming, livestock industry, biogas, sustainable development*

Introduction

Vietnam in the last 5 years, pork production accounted for 76% of all meat production (Thu, 2019). Pork products are familiar and indispensable products for Vietnamese people, it has become the most popular food compared to other types of meat on the market such as beef, buffalo, chicken, shrimp, crabs. Along with the rapid development of the livestock industry in general and pig farming in particular, environmental problems are becoming more and more serious. The phenomenon of environmental pollution occurs not only in developed countries but also in developing countries including Vietnam.

An Nhon is a mountainous commune, in Binh Dinh province, Vietnam. The terrain is mainly forest and low hills. As a purely agricultural district, people are rarely trained in farming and livestock techniques, so the application of science and technology to improve production is still limited. In recent years, in An Nhon district, small-scale livestock production and pig farms have grown rapidly in both size and value, contributing approximately 52% of GDP (Binh Dinh, 2020). The pig herd of An Nhon district ranks third in Binh Dinh province. In An Nhon district, most pig raising models still follow the individual and traditional form. The development of livestock means that a lot of waste is released into the environment, which, if not properly managed and treated, will be a serious source of greenhouse gas emissions, with a great impact on climate change, threatening soil quality, surface water, groundwater and human health. Therefore, environmental problems in livestock production are becoming more and more serious. The current situation of livestock environment in Nhon Tan commune is a common feature of many villages in rural Vietnam, so it is necessary to quickly find management measures to make the most of waste resources and minimize waste environmental pollution. The study was carried out with two main objectives: (1) Assessment of the environmental status of household's pig farming system at An Nhon, Binh Dinh province. (2) Applying some available technology to improve the environmental status of household's pig farming in this area.

Fig. 1. Study area in Binh Dinh province
Rys. 1. Lokalizacja badanych gospodartw w prowincji Binh Dinh

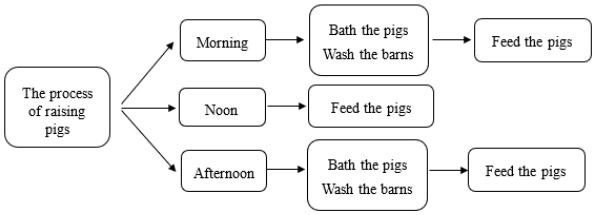
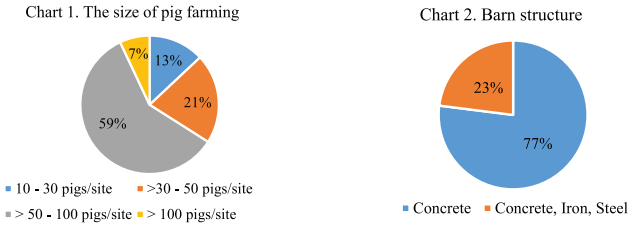


Fig. 2. The process of raising pigs
Rys. 2. Proces hodowli świń



Wykres 1. Wielkość farm świńskich
Wykres 2. Struktura obory

Materials and Methods

Study Area

In Vietnam, this study was conducted in Binh Dinh province, mainly focusing on An Nhon commune - the locality with the third largest pig raising scale in Binh Dinh province.

Sample Collection

The study applying the Slovin's method to determine the sample size in case the overall size is known.

With the lowercase n is the sample size, and the uppercase N is overall size, the total pig site in An Nhon district is 874 (Follow to Economic Department, Binh Dinh province, in first 6 months of 2020). So, we can calculate the sample size is 274 the pig sites.

$$\Rightarrow n = \frac{N}{1+N\times e^2} = \frac{874}{1+874\times 0.05^2} \approx 274\ (The\ pig\ sites)$$

With:
n: The sample size
N: Overall size (874 *The pig sites*)
e: Allowed error (choose e = 5%)

With this sample size, we investigated and collected data through using a semi-structured interview directly, it focuses on main groups question such as:

- The process of raising pigs
- The characteristics of pig farming in An Nhon
- Raw materials in livestock
- Application of mechanization in pig farming
- The waste and the status waste treatment from pig farm

Data Analysis

Statistical Package for the Social Sciences software (SPSS, version 18.0) was used for statistic and assessment. In this study, the results were selected and expressed as a percentage (%) or the chart depending on the in-tended use.

Results and Discussions

The process of raising pigs

Through the survey process, it shows that the pig raising process of the households in An Nhon district is similar. There is only variation in the time for pig shower, the barn washed and feed pigs. Most of the households bath their pigs

Fig. 3. Pig feed storage
Rys. 3. Magazyn paszy dla świń

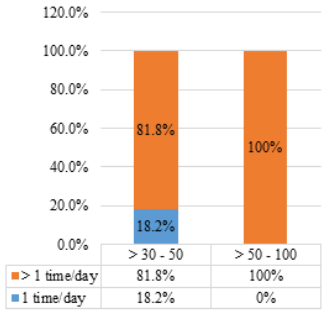


Chart 3. The ratio of washing barn
Wykres 3. Częstotliwość mycia stodoły

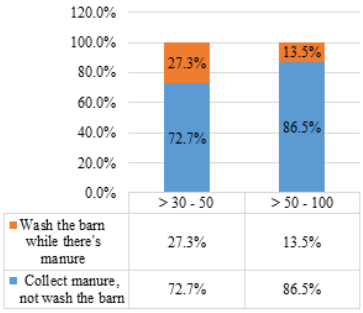


Chart 4. The ratio of manure removal
Wykres 4. Stopień odzysku gnojowicy

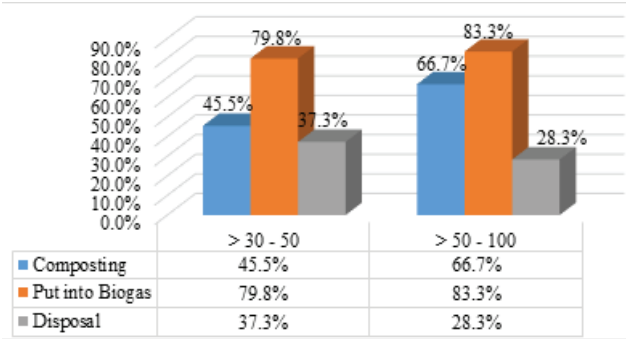


Chart 5. The method of pig manure treatment
Wykres 5. Metody postępowania z gnojowicą

twice per day (in the morning and in the afternoon), and they bath their pigs combine with washing the pens.

The flow of water for pig shower depends on the number of pigs. Wastewater from the process of bathing pigs and washing the barns will be piped down to the Biogas tank for treatment or disposal on the fields, into the near canals. Therefore, we can summary the process of raising pigs including 3 times: in the morning, at noon and in the afternoon.

The characteristics of pig farming in An Nhon

Survey Data Analysis shows that the size of pig farming focus on from over 50 to under 100 pigs per site with 59% and 21% is from over 30 to under 50 pigs per site in Pie chart 1. To explain for this, An Nhon is a mountainous district, most of the pig farms are still follow the form of individual and traditional method. Therefore, it will be limited in quantity.

With the barn structure in Pie chart 2, The barn is mainly built of concrete with 77%, and some households also combine concrete with iron and steel barns to separate the sow and pregnant pigs for convenient to care and clean.

Raw materials in livestock

Feed for pigs is bran mainly. In addition, some households also add pellets, probiotics, beer wort or something like that, into the food of pigs. Most of the livestock households use automatic feeders, so the loss and loss of feed is also limited significantly. Food of pigs is stored in a separate warehouse.

There are some famer households have not an area to build a warehouse, it is stored indoors their house or indoor the barn area. So, the food is not well preserved.

Food of pigs is stored in a separate warehouse. There are some famer households have not an area to build a warehouse, it is stored indoors their house or indoor the barn area. So, the food is not well preserved. This is the cause of reducing the quality of the feed affecting the growth of the pig.

The famers separate the sow and pregnant pigs for convenient to care and clean.

The waste and the status waste treatment from pig farm

Wastes from pig farming include: (1) Pig manure, (2) Pig urine, (3) Water to clean the barn, (4) Dead pig carcass, (5) Veterinary specimens, (6) Odor.

Fig. 4. The situation of waste disposal in household's pig farming system at An Nhon
Rys. 4. Składowanie odpadów na farmie świń w An Nhon

Fig. 5. The situation of waste disposal in household's pig farming system at An Nhon
Rys. 5. Składowanie odpadów na farmie świń w An Nhon

Fig. 6. The methods of waste anaerobic treatment
Rys. 6. Metoda anerobowej przeróbki odpadów

Tab. 1. The wastewater characteristics from pig farms
Tab. 1. Charakterystyka ścieków z farmy świń

Parameter	*Unit*	*Value*
pH	-	7-8
TSS	mg/l	1000
BOD5	mg/l	2014
COD	mg/l	3082
Total Nitrogen	mg/l	212
Total Phosphorus	mg/l	8
Coliform	MPN/100ml	107

Tab. 2. The quota for biogas generation from livestock waste

Tab. 2. Ilość biogazu generowanego z odpadów zwierzęcych

Kind of waste	*Kg VSS generate/ animal/day*	*% VSS decomposing*	*CC Biogas/mg/ VSS generate*	*m^3 Biogas/ animal/day*
Waste from cows	4,0 kg	30%	800 cc/mg	1 m^3
Waste from pigs	2,7 kg	50%	1.100 cc/mg	1,6 m^3
Waste from poultry	5,9 kg	60%	600 cc/mg	2,2 m^3

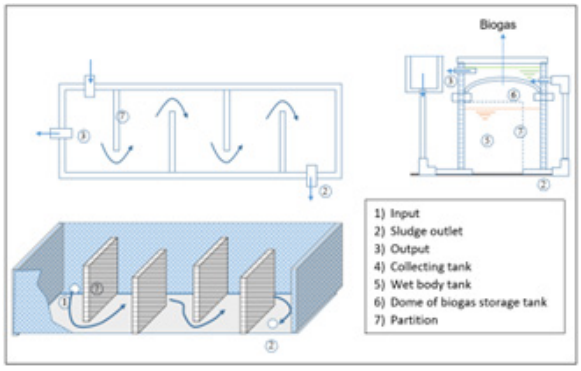


Fig. 7. The available technology

Rys. 7. Dostępna technologia W

In which, the most generated amount is pig manure, pig urine and water to clean the barn. Dead pig carcass and veterinary specimens only generate at the time when pigs are sick. For odor, with mountainous characteristics, the pig farming are sparse, so the odor doesn't have an effect significantly.

Chart 3 shows the ratio of washing barn with the scale from over 30 to under 50 and over 50 to under 50 for one time/day or more than 1 time/day. This figure explains the flow of water discharged in each pig bath, it also depends on the number of pigs. Chart 4, this chart illustrates the figures about the ratio of manure removal in 2 cases: the first, wash the barn while there's manure and the second, collect manure, not wash the barn. The method of pig manure treatment including: composting, put into Biogas and disposal. Each household's pig farming can apply more than one method, it showed at Chart 5. Besides that, the household's pig farming dispose the waste from pig farming around their land, into canals near their house or make wet fertilizer to plant the trees.

Another way, the household's make composting from pig manure.

Two popular ways of composting in An Nhon district are: Biogas bag and Biogas tank. Because the missing in transferring Biogas technology, the household's pig farming can't know how to calculate the scale of Biogas tank correctly. Therefore, the waste treatment from pig farms aren't effective. Besides that, they're only use Biogas tank to treat the waste. It's a an unoptimized design when lack of clarifier tank before and after the main Biogas tank.

This is the wastewater characteristics from pig farms, we can see the parameter TSS, BOD, COD. Among that, TSS, it's over 150 milligrams per liter. So, if move this flow into main Biogas tank, it's can't treatment completely.

Applying some available technology

From The quota for biogas generation from livestock waste, following The New Age International Publisher. We can see that waste from pig has 2,7 kg Volatile Solid (VSS) generate/animal/day. Accordingly, having 1100 CC biogas/mg/VSS generate. So, we can calculate the scale of Biogas tank correctly.

The design of clarifier tank before and after the Biogas tank. We can see the symbol number 1, this's input waste water, symbol 7 is partition, we have 4 partitions in here. Wastewater moves to the last partitions, under the last partitions, symbol 2 is the sludge outlet, behind the last partitions, here output wastewater treated….5 is wet body tank and 6 is dome of biogas storage tank.

Conclusions

Before the situation of African swine fever is still raging, the owners of pig raising households in Nhon Tan commune are very concerned about the increase in herd. Most households import piglets from reputable farms, having bought before in a small quantity, with the desire to continue with the profession and maintain the family economy. Before that, a cholera epidemic caused many livestock farms to close. Currently, the total number of pigs in the area is about 814, down 90.3% compared to the same period last year.

The source of feed for pigs is taken from eateries and restaurants and mixed with industrial bran. Therefore, the quality of diets for pigs cannot be guaranteed. Sanitary wastewater from the barn is discharged into the biogas tank and then to the receiving source without any other treatment. Therefore, the quality of wastewater discharged after biogas does not meet the required standards.

In general, pig raising in Nhon Tan commune applies outdated breeding technology, there is no investment in supporting models to help people both save water use, save effort, and save money. solve environmental problems. At the same time, the management of the government is not effective. Therefore, in order to limit environmental pollution caused by livestock production, it is necessary to perform well from planning the breeding area to building or renovating a reasonable system of stables, taking into account the increased demand for livestock. herd later. Attention should

Fig. 8. The Biogas technology
Rys. 8. Techologia produkcji biogazu

be paid to taking advantage of waste sources to use for other agricultural models, creating more economic for the family. Combining both the interests of the breeder and the problem of environmental protection.

Strengthening the management and state supervision of animal husbandry safety and environment for the purpose of synchronizing the environmental pollution control system.

Acknowledgement

The authors would like to express our thanks the Department of Economic and Department of Environment of Nhon Tan Commune, An Nhon District, Binh Dinh Province for human and the technical support for this study.

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Ocena stanu środowiska w zakładzie hodowli świni w gospodarstwie w Nhon, prowincja Binh Dinh, Wietnam

Przemysł hodowlany odegrał ważną rolę w rozwoju gospodarczym Wietnamu. W szczególności hodowla trzody chlewnej jest jasnym punktem branży, odgrywając rolę w zapewnieniu bezpieczeństwa żywnościowego w całym kraju. Wraz z szybkim rozwojem przemysłu hodowlanego, a w szczególności hodowli trzody chlewnej, problemy środowiskowe w produkcji zwierzęcej stają się coraz poważniejsze. Badanie to przeprowadzono w gminie Nhon Tan w dystrykcie An Nhon w prowincji Binh Dinh w celu wstępnej oceny stanu środowiskowego produkcji trzody chlewnej na skalę gospodarstw domowych na tym obszarze. Gmina Nhon Tan to gmina górzysta, teren to głównie lasy i niskie wzgórza, jest gminą czysto rolniczą, struktura pracy to głównie rolnictwo, poziom wykształcenia pracowników niewysoki, więc zastosowanie technologii produkcji postępu naukowego i technologicznego ma wiele ograniczeń. W ostatnich latach hodowla trzody chlewnej na tym obszarze gwałtownie wzrosła, zarówno pod względem skali, jak i wartości, generując 51,97% PKB, a pogłowie trzody chlewnej gminy zajmuje pierwsze miejsce w dystrykcie An Nhon i trzecie na świecie. Prowincja Binh Dinh (urząd gospodarczy, gmina Nhon Tan, 2020). Cała gmina ma 5 wiosek: Nam Tuong 1, Nam Tuong 2, Nam Tuong 3, Tho Tan Bac i Tho Tan Nam, hodowla trzody chlewnej jest rozproszona we wszystkich pięciu wioskach, a większość gospodarstw domowych nadal prowadzi indywidualną hodowlę, więc skala hodowli jest wciąż mała i rozproszona. Badanie i zbieranie danych przeprowadzono bezpośrednio w formie wywiadu częściowo ustrukturyzowanego. Próba badawcza w celu zebrania danychzostała wytypowana w celu uzyskania ogólnych informacji: (1) liczba gospodarstw hodujących, liczba trzody chlewnej na danym terenie; (2) liczba zwierząt gospodarskich: poniżej 10 sztuk, od 10 do 50 sztuk, powyżej 50 sztuk; (3) czas i doświadczenie w produkcji zwierzęcej, (4) aktualny stan systemu obory, (5) produkcja zwierzęca i utylizacja odpadów; (6) informacje techniczne, takie jak klasyfikacja odpadów. Do końca grudnia 2020 r. łączna liczba gospodarstw domowych zajmujących się hodowlą trzody chlewnej na tym obszarze wynosiła 80 (Departament Ekonomiczny, gmina Nhon Tan, 2020), zespół badawczy przeprowadził ankietę w sumie w tych 80 domach. Wyniki pokazują, że 59% gospodarstw posiada liczbę trzody chlewnej od 10 do 50 sztuk, głównie od 6 do 10 lat doświadczenia, co stanowi 41%. Stan obecny stodół, w 100%gospodarstw posadzka obory jest cementowa, zabudowana 0,5-1m wyżej od gruntu, dach w 100% pokryty blachą falistą, w niektórych oborach występuje zjawisko zapadania się dachu. Odory występujące mają charakter wyraźnie ostry, zgniły, wpływający na higienę obory i zdrowie zwierząt, szczególnie w okresie występowania pomoru świń oraz w porze deszczowej. W szczególności w procesie hodowli, przetwarzania i przechowywania paszy dla zwierząt powstały niezliczone kombinacje odpadów w postaci stałej, płynnej i gazowej, 90% rolników nie kontroluje, a 51% gospodarstw domowych posiada system przetwarzania odpadów (biogaz).

Słowa kluczowe: *stan środowiska, chów trzody chlewnej, przemysł hodowlany, biogaz, zrównoważony rozwój*

Raw Water Quality Assessment for Improvement Plan at Thu Duc Water Treatment Plant, Vietnam

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A conventional water treatment process is currently operated at Thu Duc Water Treatment Plant (TDWTP, Ho Chi Minh City, Vietnam) in which raw water is collected from Dong Nai River at Hoa An water intake and pumping station. The raw water quality is currently fluctuated due to the effects of run-off flows which has been increasing recently. This issue directly affects the operation and performance of existing treatment process at TDWTP since the current treatment are all based on traditional technologies and have been operating for a long time. This study is conducted to evaluate the quality of raw water collected at Hoa An intake station during the period of 2018–2020 with the aim to support the consideration of improvement and enhance the operation efficiency at TDWTP. The raw water quality is evaluated by investigating physico-chemical and biological parameters during the 36 months monitoring. This helps to produce a feasible and reliable results which may then can be used as a scientific database for the improvement plan at TDWTP. Results show that the changes of water quality during the investigated time is so complicated, and the concentration of most monitoring parameters is highly seasonal fluctuated. Specifically, the amounts of organic matters, microorganism, nitrogen compounds (NH_4^+, NO_2^-, NO_3^-) tend to increase strongly, which may be due to the urbanization and industrialization. The management of run-off flows on upstream of water intake and pumping station is also an important aspect which need to be considered to prevent the diffusion and spread of pollution. In addition, the effects of climate changes are the important reason which leads to the seasonal changes of flow and water quality. These issues cause a big challenge for TDWTP to maintain the treatment efficiency and overall performance. This study also proposes several management and technical solutions to address the changes of raw water quality in the future, which may be useful for TDWTP during their consideration to improve the treatment process.

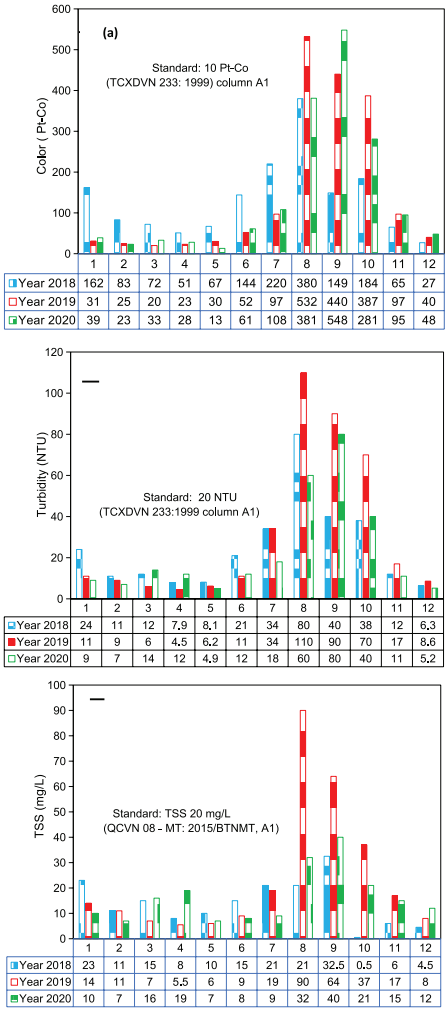
Keywords: *water intake, monitoring, run-off flow, organic matter, water treatment process, Thu Duc Water Treatment Plant, Vietnam*

1. Introduction

Thu Duc Water Treatment Plant (TDWTP) is the main water supply source of Ho Chi Minh City (HCMC, Vietnam). It is also the oldest and largest water plant, which belongs to Saigon Water Corporation (SAWACO) – the overall management agency of the HCMC water supply system. Since the inauguration in 1966 with the initial capacity of 450,000 m^3/day, TDWTP is now operated with the total capacity expanded to 750,000 m^3/day to supply clean water for urban districts of HCMC (SAWACO, 2018). A conventional water treatment process is currently operated at TDWTP, in which raw water is collected from the Dong Nai River, the upstream of Sai Gon River, at the water intake and pumping station located in Hoa An ward, Dong Nai province. The current treatment system just focuses on the removal of common pollutants, such as turbidity, colour, microorganisms by using traditional processes including coagulation-flocculation, sedimentation, rapid sand filtration, and disinfection, to produce clean water and satisfy the national standard (i.e., Standard No. QCVN 01-1:2018/MOH issued by The Ministry of Health in 2018 (MOH 2018)).

According to the periodic monitoring report conducted by SAWACO for the period of 2017–2018, the pollution of raw water at the intake stations is increasing due to the effects of run-off flows (SAWACO, 2018). This issue directly affects the operation and performance of existing treatment process at TDWTP. Specifically, surface water collected from Saigon and Dong Nai River is contaminated by organic matter, microorganisms, which causes low dissolved oxygen (DO) concentration. Furthermore, the residuals of antibiotics, fertilizer, pesticides are also found. The presence of these pollutants significantly influences the assurance of output water quality at TDWTP, because the current treatment processes are all designed and built based on traditional technologies and have been operating for a long time. Moreover, the increase of organic matter concentration in raw water sources leads to considerable risks of disinfection by-products (DBPs) formation during the chlorination at TDWTP. Thus, an assessment of raw water at Hoa An water intake and pumping station should be carried out.

This study is conducted to evaluate the quality of raw water collected at Hoa An intake station during the period of 2018–2020 with the aim to support SAWACO during their consideration to improve the operation efficiency at TDWTP. The raw water quality is evaluated by investigating physico-chemical and biological parameters during the 36 months monitoring. The results and findings obtained from this study can be used as a scientific basis for SAWACO and TDWTP in the control, assessment, and assurance of water quality before transfer to the distribution system. Furthermore, the topic can be applied to develop water quality indicators (WQC) and improve the management capacity at TDWTP. In addition, this study may help local authorities in forecasting the negative effects of the changes



	1	2	3	4	5	6	7	8	9	10	11	12
Year 2018	162	83	72	51	67	144	220	380	149	184	65	27
Year 2019	31	25	20	23	30	52	97	532	440	387	97	40
Year 2020	39	23	33	28	13	61	108	381	548	281	95	48

	1	2	3	4	5	6	7	8	9	10	11	12
Year 2018	24	11	12	7,9	8,1	21	34	80	40	38	12	6,3
Year 2019	11	9	6	4,5	6,2	11	34	110	90	70	17	8,6
Year 2020	9	7	14	12	4,9	12	18	60	80	40	11	5,2

	1	2	3	4	5	6	7	8	9	10	11	12
Year 2018	23	11	15	8	10	15	21	21	32,5	0,5	6	4,5
Year 2019	14	11	7	5,5	6	9	19	90	64	37	17	8
Year 2020	10	7	16	19	7	8	9	32	40	21	15	12

Fig. 1. The change of (a) colour, (b) turbidity, and (c) TSS (Total Suspended Solids) in raw water by time
Rys. 1. Zmiana (a) koloru, (b) zmętnienia i (c) TSS (suma cząstek zawieszonych) w wodzie surowej w czasie

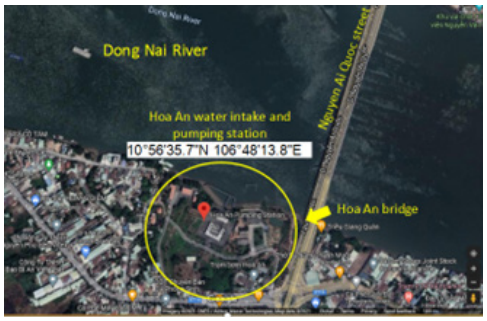


Fig. 1. Location of Hoa An Water intake and Pumping Station
Rys. 1. Lokalizacja ujęcia i przepompowni Hoa An

or fluctuation of raw water quality due to environmental pollution, which then arise awareness, behaviour, and specific activities to control waste discharge into raw water source areas.

2. Material and methods

2.1. Water samples collection

Raw water samples are collected from the Hoa An water intake and pumping station of TDWTP (10.94364, 106.80383) (Fig.1). During the raw water collection stage, composite sampling method is follow to obtain the representative water samples and the experimental water samples are produced from mixed samples. The sampling is taken at a specific time when the pumping station is operating at the average daily flow rate. Parameters, such as pH, DO are measured on-site by using water monitoring system (HACH, 85490 BASIC01).

Afterwards, all samples are preserved properly and transferred immediately to the research laboratory at Ton Duc Thang University (TDTU, Ho Chi Minh City, Vietnam). All samples before analysis are preserved according to the standard methods (APHA, 2005). The physical and chemical parameters are then analysed and measured under laboratory conditions. The properties of water samples are then characterized by physico-chemical parameters (i.e., colour, turbidity, TSS (Total Suspended Solids), N-based compounds, PO_4^{3-}, BOD, COD) and Coliforms.

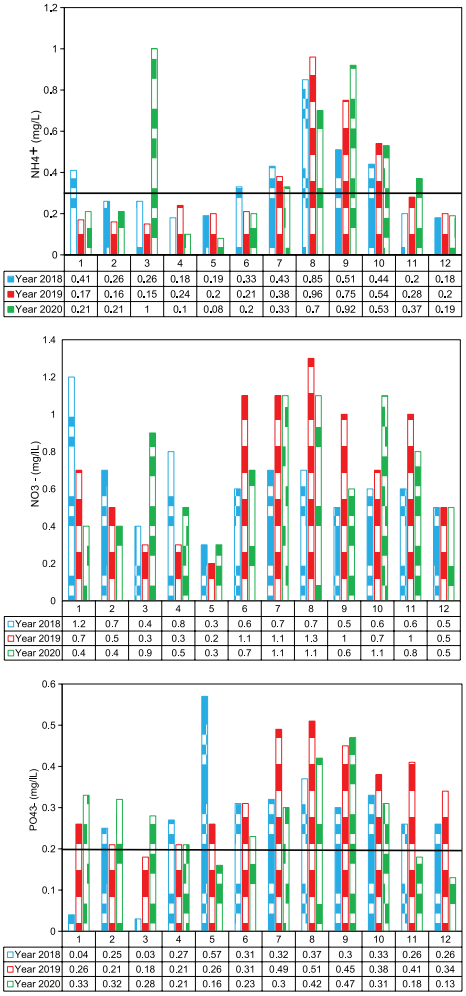


Fig. 1. The change of (a) colour, (b) turbidity, and (c) TSS (Total Suspended Solids) in raw water by time
Rys. 1. Zmiana (a) koloru, (b) zmętnienia i (c) TSS (suma cząstek zawieszonych) w wodzie surowej w czasie

2.2. Analytical methods

The physical and chemical parameters are analysed and measured under laboratory conditions and performed in triplicate. The results are obtained as the average values. Specifically, turbidity is measured by using a turbidity meter (Model: HACH 2100 Q). Colour, N-based compounds, PO_4^{3-} are analysed based on the standard methods (APHA, 2005) using UV-VIS Spectrophotometer (Model: Hach DR-6000, USA). TSS is measured by using Vacuum mini-pump (Model: N022AN18, Germany) and Laboratory furnace (Model: L15/11, Germany). Coliform is measured by 3M™ Petrifilm™ E. coli/Coliform Count Plate. BOD5 is measured by using Laboratory Research Grade Benchtop DO and BOD Meter (Model: Hanna HI5421-02). Soluble COD measurement was based on the Closed Reflux, Titrimetric method (APHA, 2005). All chemicals and reagents used during the analysis and measurement are analytical grade.

Previous monitoring data obtained from SAWACO and TDWTP is used as a database during the analysis and assessment of water quality. National technical regulation on surface water quality (i.e., QCVN 08:2008/BTNTMT, TCXDVN 233:1999 (MOC 1999)) issued by the Ministry of Natural Resources and Environment and Ministry of Construction (Vietnam) is also used as a reference to assess the water quality.

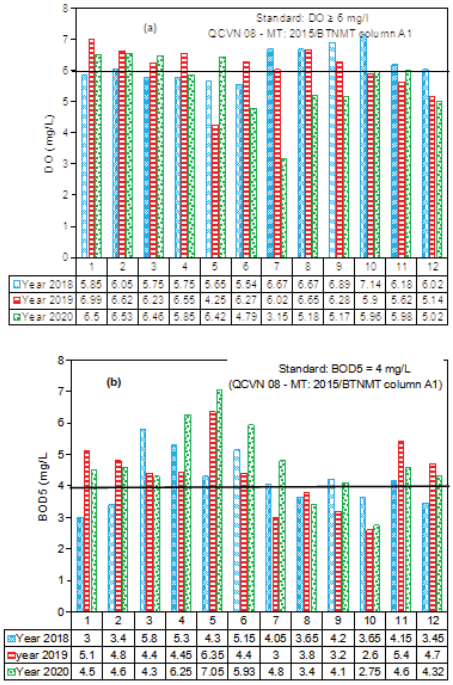
3. Results and Discussion

3.1. Assessment of water quality based on group of parameters

3.1.1. Colour, turbidity, and TSS

Physical parameters including colour, turbidity, and TSS in raw water were assessed simultaneously since they all reflect the transparency and aesthetics of water under visual observation. The variation of these parameter by time during the investigated period of 2018–2020 is shown in Fig. 1a, 1b, and 1c. Results showed that the colour, turbidity and TSS of raw water increased sharply in the rainy season months. In the southern region of Vietnam, the rainy season often occurs from July to October each year. Accordingly, the colour, turbidity, and TSS concentration as measured were 2–3 times higher than that regulated by national standard QCVN 08 – MT: 2015/BTNMT and TCXDVN 233:1999. In contrast, during the dry season months (i.e., from November to April), the value was so low and satisfied the standards. This can be explained that during the rainy season, the water quality is effected by run-off flow which normally brings silt and sediment, causing the colour, turbidity, and TSS in the raw water at the pumping station increase.

Fig. 1 also indicates that this issue occurs regularly every year since the same trend was found during 3 investigated years (2018–2020). Therefore, this helps the local authorities and TDWTP have a proper plan for management and operation of water treatment process. Specifically, the chemical used for co-



	1	2	3	4	5	6	7	8	9	10	11	12
Year 2018	5.85	6.05	5.75	5.75	5.65	5.54	6.67	6.67	6.89	7.14	6.18	6.02
Year 2019	6.99	6.62	6.23	6.55	4.25	6.27	6.02	6.65	6.28	5.9	5.62	5.14
Year 2020	6.5	6.53	6.46	5.85	6.42	4.79	3.15	5.18	5.17	5.96	5.98	5.02

	1	2	3	4	5	6	7	8	9	10	11	12
Year 2018	3	3.4	5.8	5.3	4.3	5.15	4.05	3.65	4.2	3.65	4.15	3.45
year 2019	5.1	4.8	4.4	4.45	6.35	4.4	3	3.8	3.2	2.6	5.4	4.7
Year 2020	4.5	4.6	4.3	6.25	7.05	5.93	4.8	3.4	4.1	2.75	4.6	4.32

Fig. 3. The change of (a) DO and (b) BOD5 concentration in raw water by time
Rys. 3. Zmiana zawartości (a) DO and (b) BOD5 w wodzie świeżej w czasie

agulation – flocculation during the rainy season should be higher than that used during the dry days. The frequency of backwashing in filtration tanks should also be increased to ensure the capacity of filter media and quality of water output during the rainy season. In addition, the sludge withdraw cycle from sedimentation tanks is also considered due to the high loading of suspended solid occurring in raw water.

3.1.2. N-based compounds and PO_4^{3-}

The change of N-based compounds and PO_4^{3-} concentration by time during the investigated period is presented in Fig.2.

As compared to physical parameters, similar trend was found in the case of NH_4^+ as the concentration exceeding the allowable level of the national standard occurred mostly in rainy months (i.e., from July to October). Due to the aerobic condition, NO_3^- compound was rapidly formed, however, the NO_3^- concentration was in the allowable range according to the QCVN 08 – MT : 2015/BTNMT (i.e., < 2 mg/L). In term of PO_4^{3-}, Fig.2 indicates the concern that needs the much attention since the PO_4^{3-} concentration was higher than the regulated level (i.e., 0.2 mg/L) in most of the monitoring months.

Surface run-off contamination due to domestic activities may be the reason to explain the pollution of NH_4^+ and PO_4^{3-}. This issue raises a concern considerably since the current water treatment process is not designed and operated for removal of N and P. Therefore, a surface water quality monitoring plan for nutrient contamination, especially at the area of raw water intake, should be done to forecast the possibility of pollution.

3.1.3. DO and BOD_5

Fig. 3a shows the changes of DO concentration at different monitoring time. As a result, the DO concentration in 2018 was relatively stable and indicate a good quality of surface water according to the national standard QCVN 08 - MT: 2015 / BTNMT (≥ 6 mg/l). Specifically, DO concentration was high in rainy days (from July to October), which may due to the increase of O_2 diffusion from the air. In 2019–2020, the DO concentration decreased, especially in July 2020, the DO concentration was 3.15 mg/L which was much lower as compared to the standard. The surface water pollution may be the reason since there are many industrial and production zones in this area, and the discharge into the river may affect water quality. In addition, wastewater from human activities and waterway traffic can be also the cause of pollution variables.

Monitoring data of BOD_5 (Fig. 3b) confirm the above statement since high BOD_5 concentration was mostly found when low DO concentration occurred (e.g., from April to July, 2020). High concentration of BOD_5 indicates organic contamination of water and the microorganisms consume more oxygen to degrade the organic matters. It was found that this pollution issue occurred regularly during the dry months which may cause negative impacts on water quality. Therefore further study should be carried out to find out the solution to mitigate the effects of water pollution during dry season which helps to reduce the fluctuation of raw water quality pumped to the TDWTP.

3.1.4. Coliform

In term of Coliform, results showed that this parameter were very high and exceeded QCVN 08 - MT: 2015/ BTNMT (column A1) many times during the period of 2018–2020. The reason came from active urine, domestic wastewater, and dead bodies floating in the river. Water sources heavily contaminated with Coliform need a priority treatment to ensure the health of public users. On the other hand, the current treatment of Coliform is now just based on chlorination - the common method used widely in most water treatment plants in Vietnam (MOC 2006). The more microbiological contamination, the more chlorine chemicals used during the disinfection. This lead to another concern which is related to the risk of disinfection by-products (DBP) formation

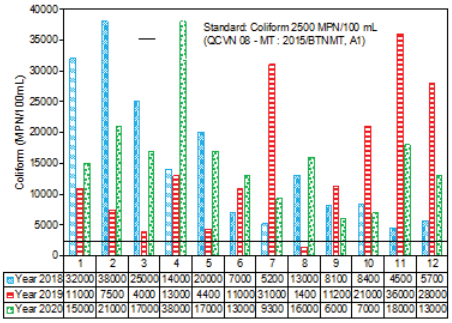


Fig. 3a. The change of Coliform in raw water by time
Rys. 3a. Zmiana miana Coli w wodzie surowej w czasie

Tab. 1. Water exploitation capacity toward 2025
Tab. 1. Możliwości eksploatacyjne wód do 2025 roku

No.	Water sources	Water exploitation capacity toward 2025 (m^3/day)
1	Dong Nai river	1,650,000
2	Tri An lake	1,000,000
3	Sai Gon river	600,000
4	Dau Tieng Lake	1,000,000
5	Groundwater	40,000
6	Small sources	7,000
Total		**4,298,000 m^3/day**

from the reaction of chlorine and organic matter existing in the raw water. Thus, the treatment system at the TDWTP should be upgraded to ensure good water quality to the consumers.

3.2. Issues of concern for water quality

During the 3-years of monitoring for water quality assessment at the TDWTP, some issues of concern for water quality was also recognized as following.

(i) The increase of surface water pollution was mostly due to inadequate control of discharge sources from industrial manufacturing, agricultural activities, and domestic wastes.

(ii) The water quality tends to deteriorate in which the occurrence and increase in concentration of organic matter, pathogen, NH_4^+, Mn^{2+} were considerable, especially in the case of Saigon River.

(iii) The flow fluctuated seasonally and was affected by climate change which led to the possibility of a sharp decrease in water level and saline intrusion at some times in the dry season.

(iv) The forecast results shows that by 2025, problems of organic pollution, saline intrusion and river water level fluctuations will have great impacts on exploitation, production and supply of clean water in Ho Chi Minh City. These are major challenges for Ho Chi Minh City's clean water supply system, requiring the preparation of technical solutions and strong resources to cope with these challenges.

3.3. Proposed solutions to TDWTP

3.3.1. Plan of mitigation of water pollution in Dong Nai river, orientation towards 2025

Since the water intake and pumping station is located in Dong Nai province, the raw water quality is thus partially controlled by Dong Nai government. At present, Dong Nai province has planned and carried out several projects to conserve the water quality, such as installation a surface water monitoring system, upgrading the urban water drainage and wastewater treatment systems, building an industrial park wastewater treatment station and effective control of discharge sources from industrial production.

Regarding the monitoring network, in the period of 2020–2025, Dong Nai will have more than 340 constructions, stations and locations for water monitoring in rivers, lakes, streams and canals. In which, there are 169 locations of flow quality monitoring and 127 groundwater monitoring stations in 9 districts and 2 cities. This will be an effective system to help the agencies control water quality parameters, and forecast risks promptly for further solutions.

In addition, Dong Nai province has invested in many domestic wastewater treatment works and drainage systems in several districts and cities, such as Bien Hoa and Long Khanh urban wastewater treatment plants. The drainage and flood control system are also carried out.

For industrial wastewater sources, in order to strengthen the inspection, monitoring and monitoring of the wastewater treatment situation, Dong Nai province has approved the investment project to install automatic wastewater monitoring system and surveillance camera since 2013. Up to now, 25/31 industrial parks have completed the installation and put into operation the automatic monitoring system and transmitted data directly to the Department of Natural Resources and Environment. It is expected that at the beginning of 2022, there will be 3 areas with automatic wastewater monitoring systems installed. In addition, manufacturers outside of industrial zones and clusters with large capacity of wastewater generation must also install automatic monitoring systems and transmit data to the Department of Natural Resources and Environment as the supervision.

3.3.2. Plan of alternatives raw water sources

In order to reduce the dependence on the current raw water sources as Dong Nai river, several expansion projects are proposed by SAWACO toward 2025. Specifically, there will be more water sources and intake stations with different exploitation capacity which is presented in Table 1.

3.3.3. Technical solutions for operation at TDWTP

Due to the fluctuations of water quality, proper changes in operation at TDWTP is essential to ensure the output water quality. Changes in chemicals used during the water treatment, for instance, is both feasible and economically option. Specifically in the flocculation stage, only PAC is currently employed for treatment. Therefore, alum as $Al_2(SO_4)_3$ and ferric chloride ($FeCl_3$) should also be studied to consider the effectiveness of treatment. In addition, in order to enhance the flocculation process, it is necessary to add polymeric compounds, such as polyacrylamide (PAM) to increase the settling rate. The use of flocculant will reduce the dose of coagulant, contributing to reducing chemical costs while ensuring treatment efficiency.

4. Conclusions

This study conducted the assessment of water quality in Dong Nai river at Hoa An pumping station in the period of 2018–2020. Results showed that the water quality fluctuated in a progressively worse direction, which is clearly demonstrated by the changes in concentration of color, turbidity, TSS, DO, BOD_5, N-based compunds, PO_4^{3-}, and Coliform. Due to the continuous development of urbanization in Ho Chi Minh City, leading to an increasing demand for domestic water of consumers, the water supply system needs to be gradually expanding and upgrading. Therefore, the management and monitoring of raw water quality should be tightened and more modern monitoring equipment should be applied. The results and finding obtained in this study may help local agencies and TDWTP to propose an appropriate and comprehensive plan to cope with the changes of raw water quality with the aim to ensure the clean water quality before pumping to the distribution system.

Acknowledgements

The authors would like to acknowledge the financial support from the funding of the International Foundation for Science (IFS) (Research Grant Agreement No. I2-W-6535-1) and the co-funding provided by the Organisation for the Prohibition of Chemical Weapons (OPCW) for this study.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Ocena jakości wody surowej na potrzeby planu poprawy w stacji uzdatniania wody Thu Duc w Wietnamie

Konwencjonalny proces uzdatniania wody jest obecnie prowadzony w zakładzie uzdatniania wody Thu Duc (TDWTP, miasto Ho Chi Minh, Wietnam), w którym surowa woda jest pobierana z rzeki Dong Nai i z przepompowni Hoa An. Jakość wody surowej podlega obecnie wahaniom ze względu na skutki spływów, które ostatnio nasilają się. Kwestia ta ma bezpośredni wpływ na funkcjonowanie i wydajność istniejących procesów oczyszczania w TDWTP, gdyż wszystkie obecne działające oczyszczalnie oparte są na tradycyjnych technologiach i działają od dłuższego czasu. Niniejsze badanie ma na celu ocenę jakości wody surowej pobieranej ze stacji poboru Hoa An w latach 2018–2020 w celu wsparcia rozważań nad poprawą i zwiększeniem efektywności działania TDWTP.

Jakość wody surowej oceniana jest poprzez badanie parametrów fizykochemicznych i biologicznych podczas 36-miesięcznego monitoringu. Pozwoliło to uzyskanie wiarygodnych wyników, które następnie mogą być wykorzystane jako naukowa baza danych dla planu modernizacji TDWTP. Wyniki pokazują, że zmiany jakości wody w badanym okresie są bardzo złożone, a stężenia większości parametrów monitoringu podlegają dużym wahaniom sezonowym. Szczególnie silnie wzrastają ilości materii organicznej, mikroorganizmów, związków azotu (NH_4^+, NO_2^-, NO_3^-), co może być spowodowane urbanizacją i uprzemysłowieniem. Ważnym aspektem, który należy wziąć pod uwagę, aby zapobiec rozprzestrzenianiu się zanieczyszczeń, jest również zarządzanie przepływami odpływowymi przed ujęciem wody i przepompownią. Ponadto skutki zmian klimatu są ważną przyczyną sezonowych zmian przepływu i jakości wody. Kwestie te stanowią duże wyzwanie dla TDWTP, aby utrzymać skuteczność oczyszczania i ogólną wydajność. W niniejszym opracowaniu zaproponowano również kilka rozwiązań w zakresie zarządzania i rozwiązań technicznych mających na celu zajęcie się zmianami jakości wody surowej w przyszłości, które mogą być przydatne dla TDWTP podczas rozważań nad poprawą procesu oczyszczania.

Słowa kluczowe: *pobór wody, monitoring, odpływ, materia organiczna, proces uzdatniania wody, zakład uzdatniania wody Thu Duc (miasto Ho Chi Minh, Wietnam)*

Determine the Scope of influence and Impact Due to Noise from Wind Turbines During the Operation of Wind Power Plant Project No. 3 – Soc Trang Province

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Facing climate change, global warming and the depletion of fossil resources such as coal, oil, etc., the development of clean energy sources has become a global trend. Clean energy sources are being exploited and strongly developed globally today, including: solar energy, wind energy, geothermal energy, ocean wave energy, geothermal energy, biomass energy . Vietnam is located in the tropical monsoon climate, with a coastline stretching over 3,000 km, so the potential for wind energy development in Vietnam is extremely large, attracting a lot of investment in wind power projects in Vietnam. current and future, including wind power plant project No. 3 – Soc Trang province. So far, we have only mentioned the benefits and clean, renewable aspects of wind power, but few have mentioned the environmental and human health impacts of wind power plants, especially noise during operation. The paper uses WindPro software 3.1.597 to determine the extent of influence caused by noise emitted by wind turbines during the operation of wind power plants, thereby assessing its impacts on people's health. local people living around the project area and propose remedial measures.

Keywords: *wind power, noise, environmental impact, wind power plant project No. 3 - Soc Trang province*

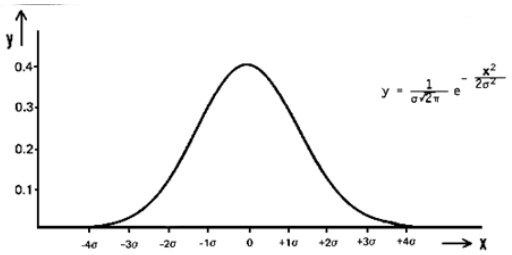
1. Introduction

Wind power plant No. 3 has installed capacity of 29.4MW, newly built in Soc Trang province and connected to the national power system by a new 110kV tranmisisonline. The construction area of the project is 10.22ha. The main items of the project include: substation 110kV, 7 turbines with 4.2MV capacity, connecting cables 5.8 km long.

2. Materials and Methods

2.1. Calculation method of noise circulation

Single noise: the noise is distributed according to the Gauss model.



Multi-noise: noise from multiple sources is calculated by the formula:

$$L_{\Sigma} = 10 \lg \sum_{i}^{n} 10^{0,1.Li}$$

Noise by distance

The noise level in the range r2> r1 will reduce the noise level in the range r1 by a value of ΔL (dB) according to the following formula:

$$\Delta L = 20 \lg \left(\frac{r_2}{r_1}\right)^{1+a} \quad (dB)$$

2.2. Software of the report

WinPro software has 2 main modules, as follows:

- The Decibel module is used to calculate noise from wind turbines;
- Shadow module is used to calculate flicker from wind turbine.

2.3. Model Input Document:

Altitude about +3.0 ~ + 0.0m.

In low-lying areas, there are shrimp ponds with an elevation of 0 ~ + 1.0m.

The study area has the dominant wind direction from West – Southwest, the average maximum wind speed from 1977 to 2011 is about 5.86 m/s.

Meteorological documents: from 1997 to 2018 of Vinh Phuoc Meteorological Station: Class II Meteorological Station, monitoring the elements of Surface Meteorology and Agricultural Meteorology according to the task targets assigned by the Southern Meteorological Station. annually (address: Vinh Phuoc, Vinh Chau town, Soc Trang province);

Meteorological data: from January 1, 2014 and ending on December 31, 2014 of the wind measuring column near the project site installed in Ward 2, Vinh Chau town - Soc Trang province. Geographic coordinates of the measuring column: 09019.243' N, 106001.997' E (WGS-84).

Topographic data is obtained online from Winpro software, with a resolution of 30m.

The data of sunshine hours are taken from the sun measuring station of Kota Bharu/Pengk Alan Chepa station of Malaysia, about 504km to the southwest of the study location, the average daily sunshine hours from 1975 to 1993.

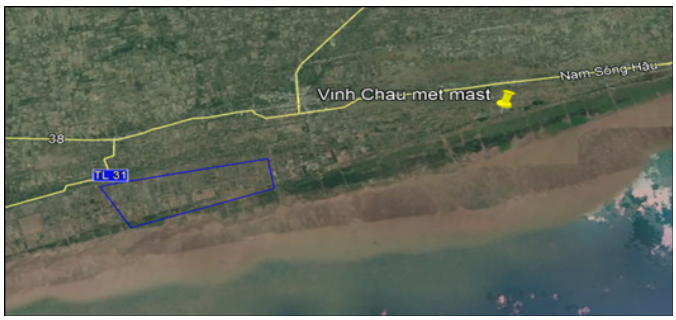


Fig. 1. Location of wind measuring tower
Rys. 1. Lokalizacja analizowanego wiatraka

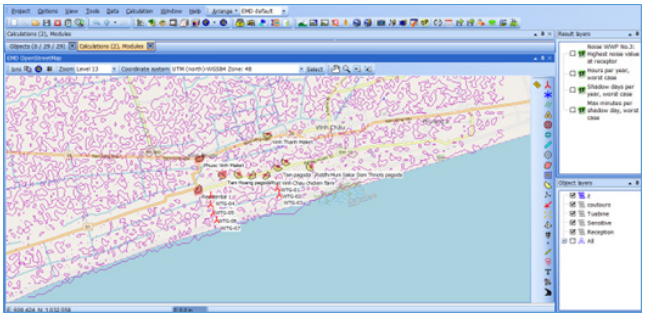


Fig. 2. Topographic map of the project area
Rys. 2. Mapa topograficzna lokalizacji analizowanej elektrowni

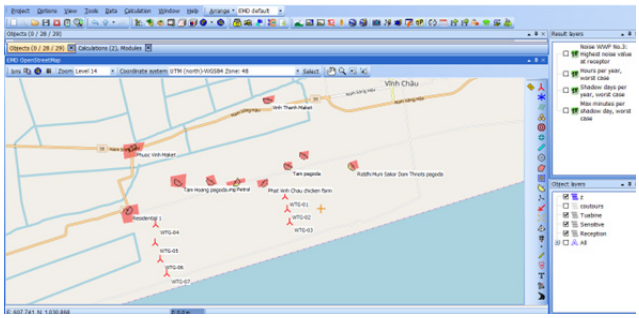


Fig. 3. Map of sensitive locations
Rys. 3. Mapa wrażliwych lokalizacji

Fig. 3. Map of sensitive locations
Rys. 3. Mapa wrażliwych lokalizacji

No.	Area	UTMCoordinates X,Y (m)	Altitude Z (m)	Influence height (m)	Noise level (dBA)
1	Phuoc Vinh market	X: 1029561 Y: 602447	0	4	32
2	Giong Me residential area	X: 1028054 Y: 602611	0	4	46,4
3	Tam Hoang pagoda	X: 1028758 Y: 603241	0	4	37,6
4	My Hung petrol station	X: 1028779 Y: 603985	0	4	35,3
5	Phat Vinh Chau Chicken Farm	X: 1028791 Y: 605192	0	4	44,3
6	Thien Thanh vegetarian fish sauce production facility	X: 1029327 Y: 605860	0	4	37,7
7	Tam pagoda	X: 1029101 Y: 605530	0	4	41,7
8	Riddhi Muni Sakor Dom Thnots pagoda	X: 1029114 Y: 606878	0	4	32,7
9	Vinh Thanh market	X: 1030449 Y: 605112	0	4	29,0
10	Residential area along roadHL31	X: 1028851 Y: 604730	0	4	38,2

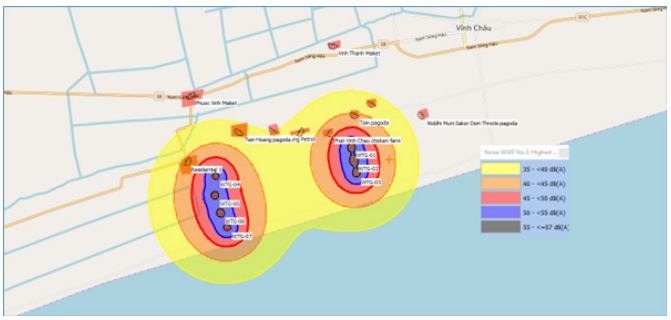


Fig. 4. Diagram of noise circulation as of Wind power plant No. 3 in operation

Rys. 4. Schemat rozprzestrzeniania się hałasu od momentu eksploatacji Elektrowni Wiatrowej nr 3

3. Results and Discussions

According to the noise calculation results, only Wind power plant No. 3 operates, the noise at the location of the turbines is from 55–57 dBA, and is about 35–40dBA at location about 2,000m from the wind turbines.

Compared to QCVN 26:2010/BTNMT – noise regulation, the noise from wind turbines all meet the standard. Compared with the noise assessed in the EIA report approved by the Soc Trang Provincial People's Committee in Decision No. 2125/QD-UBND dated August 1, 2019, the noise and flicker impact on the surroundings remain unchanged.

4. Conclusions

Compared to QCVN 26:2010/BTNMT – noise regulation, the noise from wind turbines all meet the standard. The noise impact on the project areas is small so that it's not affect to people healthy and ecosystem within project area.

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Określenie zakresu oddziaływania turbin i oddziaływania hałasu z turbin wiatrowych podczas eksploatacji elektrowni wiatrowej projekt nr 3 – prowincja Soc Trang

W obliczu zmian klimatu, globalnego ocieplenia i wyczerpywania się zasobów kopalnych, takich jak węgiel, ropa naftowa itp., rozwój czystych źródeł energii stał się światowym trendem. Czyste źródła energii są obecnie eksploatowane i silnie rozwijane na całym świecie, w tym: energia słoneczna, energia wiatru, energia geotermalna, energia fal oceanicznych, energia geotermalna, energia biomasy. Wietnam położony jest w tropikalnym klimacie monsunowym, z linią brzegową rozciągającą się na ponad 3000 km, więc potencjał rozwoju energetyki wiatrowej w Wietnamie jest niezwykle duży, co przyciąga wiele inwestycji w projekty wiatrowe w kraju. Przykładem omawianym a artykule jest elektrownia wiatrowa nr 3 – prowincja Soc Trang. Jak dotąd wspomnieliśmy tylko o korzyściach i czystych, odnawialnych aspektach energii wiatrowej, ale niewielu wspomniało o wpływie elektrowni wiatrowych na środowisko i zdrowie ludzi, a zwłaszcza emisji hałasu podczas pracy. W artykule wykorzystano oprogramowanie WindPro 3.1.597 do określenia stopnia oddziaływania hałasu emitowanego przez turbiny wiatrowe podczas pracy elektrowni wiatrowych, oceniając tym samym jego wpływ na zdrowie ludzi, lokalnych mieszkańców mieszkających w pobliżu obszaru objętego projektem i zaproponować środki zaradcze.

Słowa kluczowe: *energetyka wiatrowa, hałas, oddziaływanie na środowisko, wind power plant project No. 3 - Soc Trang province Vietnam-(miasto Ho Chi Minh, Wietnam)*

The Role of Slag from the Combustion of Solid Municipal Waste in Circular Economy

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Slag formed in the processes of thermal degradation of the municipal fraction is classified in accordance with applicable regulations as waste with code 19 01 12. It is estimated that as a result of the combustion of municipal fractions, about 0.25 Mg of slag per 1 Mg of incinerated waste is formed. From the perspective of the circular economy, it is necessary to seek new applications for this type of material in the industry. New business models, in particular the recovery of by-products, are a chance for their optimal use. This concept assumes that waste from one process is a product for another process. Action requires a new look at the market and the development of previously non-existent industrial symbioses. As a result of reintroducing slag into circulation, a reduction in natural resource consumption can be achieved, resulting in both economic and environmental savings. The objective of the article is a preliminary assessment of the physical and chemical properties of slag from municipal waste incineration plants as an additive to concrete. For the purposes of evaluating the use of slag in construction, the following scenarios were analyzed: slag as a substitute for aggregate, sand, and cement. The tests were carried out on slag obtained from three different installations operating in Poland. The article presents the oxide and elemental composition of slags, and the obtained results are related to the requirements for using granulated blast furnace slag as a type II additive to concrete. The analyzed slags are characterized by a low content of chlorine (Cl<0.5%), the total sulfur content was at the level of 0.7%. The organic carbon content (TOC) of the tested slags was below the level of quantification. The obtained results confirm that the use of slag as an alternative aggregate or raw material in concrete does not pose a threat to individual elements of the natural environment.

Keywords: *slag, raw material, recycling, concrete*

1. Introduction

Continuous economic development, consumerism and a growth of social status contribute to an increasing amount of generated waste. According to Eurostat data, 505 kg of municipal waste per capita was generated in Europe in 2020. In Poland it was 346 kg per capita [1]. According to the Waste Act of 14 December 2012 [2], every activity related to waste must comply with the appropriate hierarchy of waste management, according to which it is recommended to prevent formation of waste in the first place. Secondly, the waste must be prepared for reuse, then it must be recycled or subjected to other recycling processes, including energy recovery. Final element of the waste management hierarchy is its disposal. Management of mixed municipal waste can be carried out using various methods. One of them is thermal degradation in the installations designed for this purpose [3-4]. Indicated solution on the one hand contributes to the optimal management of the combustible fraction, but on the other hand contributes to the formation of significant amounts of secondary waste, such as: slag, fly ash, etc. [5-6]. According to the Regulation of the Minister of the Environment of 27 September 2001 on the waste catalog [7], slag derived from municipal waste incineration plants is classified as waste with the code 19 01 12 – incineration ash and slag other than those mentioned in 19 01 11. It is estimated that thermal degradation of municipal waste produces about 250-300 kg of slag per 1 Mg of incinerated waste [8-9]. From a circular economy perspective, new possibilities of using this type of material in industry must be sought. New business models are a chance for their optimal use. Emphasis should be put on the circular model developed under the international R2π project. It consists of 7 business models covering 3 phases i.e. production, use and end of life. One of the models in the phase of production is the recycling of by-products. Foregoing concept assumes that waste from one process can be a raw material for another industry. This requires a fresh look at the market and development of previously non-existent industrial symbiosis [10-11]. Repurposing of slag can lead to lower consumption of natural resources, which are shrinking due to intensive exploitation. Additionally, this will lead to economic and environmental savings [12, 13].

Modern concept consistent with the idea of the circular economy assumes the use of slag from incineration of municipal waste in broadly understood construction [12, 14, 15, 16, 17]. Various concepts of slag application in construction are analysed for example as a replacement for aggregate, sand or a partial replacement for cement. The problems of application of slag originating in incineration of municipal waste in Circular Economy is well recognized in many countries [5, 6, 18, 19]. It should be emphasized that despite the knowledge of the subject, there is no universal method of reusing this type of slag. In Poland, the issue of the optimal and safe use of slag from incineration of municipal waste is a new issue that requires analysis. Variable composition of municipal fractions related to seasonality and different levels of recycling translate into slag properties. Slags from incineration

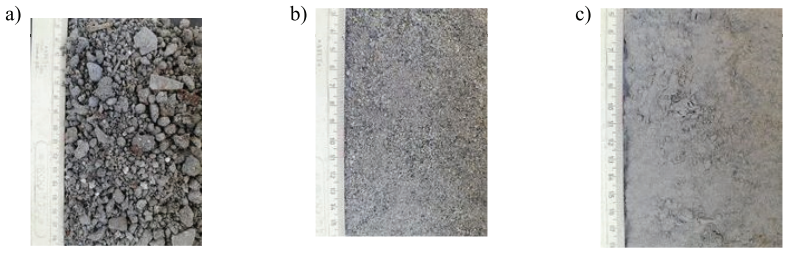

Fig. 1. Slag MSWI 1, a) granulated, b) sand fraction, c) cement fraction
Fig. 1. Żużel MSWI 1, a) granulowany, b) frakcja piaskowa, c) frakcja cementowa

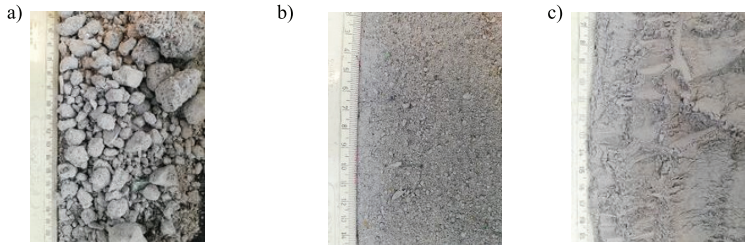

Fig. 2. Slag MSWI 2, a) granulated, b) sand fraction, c) cement fraction
Fig. 2. Żużel MSWI 2, a) granulowany, b) frakcja piaskowa, c) frakcja cementowa

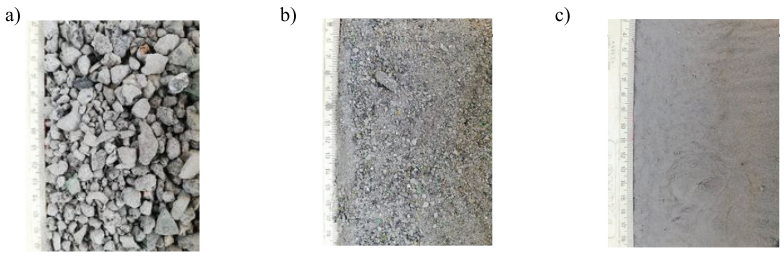

Fig. 3. Slag MSWI 3, a) granulated, b) sand fraction, c) cement fraction
Fig. 3. Żużel MSWI 3, a) granulowany, b) frakcja piaskowa, c) frakcja cementowa

of municipal waste require constant analyses, mainly regarding their chemical composition, on the basis of which it will be possible to make a decision regarding their potential use, for example for the production of concrete. The approach proposed in the article is pro-ecological, because waste is eliminated from the environment while maintaining a reserve of raw materials. The proposed solution is in line with the direction of climate neutrality and the circular economy.

The aim of the article is to initially assess the physical and chemical properties of slags from selected Municipal Waste Thermal Treatment Plants as an additive to concrete or alternative aggregate in road construction. Currently, there are no standards specifying the requirements for slag from incineration of municipal waste as a fully-fledged raw material for the construction industry. For the purposes of this article, the requirements for ground granulated blast furnace slag (GBFS), commonly used as a type II additive in the composition of concrete, were taken as a reference point for considerations.

2. Materials and Methodology

2.1 Materials

The material used in the research were slags, formed as by-products during thermal processing of mixed municipal waste. They mainly consisted of mineral (non-flammable) substances. According to the Catalog of Wastes [7], with the code 19 01 12 the slags are classified as bottom ash and slags other than those mentioned in 19 01 11). The analyzed slags came from three incineration plants. In order to facilitate their identification in the further part of the article, the following designations were adopted:

- Slag MSWI 1 – slag from a Municipal Waste Incineration Plant equipped with a sliding grate with an annual installation capacity of 220,000 Mg,
- Slag MSWI 2 – slag from a Municipal Waste Incineration Plant equipped with a sliding grate with an annual installation capacity of 210,000 Mg,
- Slag MSWI 3 – slag from a Municipal Waste Incineration Plant equipped with a reciprocating grate with an annual installation capacity of 94,000 Mg.

Slag MSWI 1 in the raw state did not exceed a fraction of 2 cm. It was characterized by a dark gray color. Numerous particles of glass and metals were visible. The slag was mechanically treated in order to obtain a fraction similar to sand and cement. Fig 1 shows slag MSWI 1 in the raw state and after the mechanical treatment.

Slag MSWI 2 in the raw state did not exceed the fraction of 3 cm. It was light-gray in color. Compared to the slag MSWI 1, slag MSWI 2 contained less glass and metal particles. In order to obtain a fraction similar to sand and cement, the slag was grinded. Figure 2 shows the slag MSWI 2 in the raw state and after the mechanical treatment.

Slag – MSWI 3 in the raw state, did not exceed the fraction of 1–2 cm. It was characterized by a gray color. It con-

Tab. 1. Basic technical properties of tested slags, expressed in % [*blq –values below the limit of quantification]

Tab. 1. Podstawowe właściwości techniczne badanych żużli, wyrażone w %

Properties	Symbol	Unit	Slag – MSWI 1	Slag – MSWI 2	Slag – MSWI 3	Standard requirement GBFS [26]
Moisture	M	%	1.19	0.70	4.84	≤ 1.0
Total carbon	C	%	1.44	2.26	1.88	-
Total organic carbon	TOC	%	blq	blq	blq	-
Sulfur	S	%	0.75	0.55	0.71	≤ 2.0
Chlorine	Cl	%	0.42	0.22	0.25	≤ 0.1

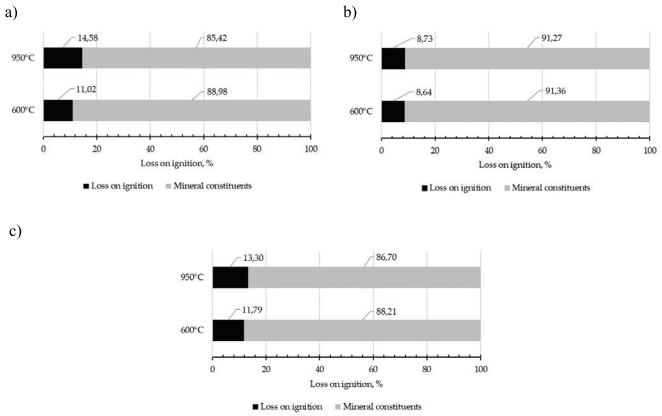

Fig. 4. Loss on ignition (LOI), a) slag – MSWI 1, b) slag – MSWI 2, c) slag – MSWI 3

Rys. 4. Strata przy zapaleniu (LOI), a) żużel – MSWI 1, b) żużel – MSWI 2, c) żużel – MSWI 3

Tab. 2. Content of oxides (%) in the tested materials

Tab. 2. Zawartość tlenków (%) w badanych materiałach

Properties	Symbol	Slag – MSWI 1	Slag – MSWI 2	Slag – MSWI 3	Standard requirement GBFS [26]
Silicon dioxide	SiO_2	50.50	57.90	54.50	37.63
Iron(III) oxide	Fe_2O_3	5.00	4.97	4.19	1.48
Aluminium oxide	Al_2O_3	11.30	10.80	6.53	6.84
Manganese(II,III) oxide	Mn_3O_4	0.11	0.12	0.13	-
Titanium dioxide	TiO_2	0.95	0.50	0.66	-
Calcium oxide	CaO	16.50	12.50	16.30	45.63
Magnesium oxide	MgO	1.77	1.73	1.80	5.33
Sulfur trioxide	SO_3	1.39	0.74	1.67	0.08
Phosphorus pentoxide	P_2O_5	1.12	0.74	0.99	-
Sodium oxide	Na_2O	4.16	6.61	5.62	0.55
Potassium oxide	K_2O	0.84	0.95	1.05	0.56
Barium oxide	BaO	0.14	0.14	0.12	-
Strontium oxide	SrO	0.04	0.06	0.06	-

Tab. 3. Properties of tested slags in relation to the standard requirements of PN-EN 197-1 [28]

Tab. 3. Właściwości badanych żużli w odniesieniu do wymagań normowych PN-EN 197-1 [28]

Requirements according to PN-EN 15167-2		Slag – MSWI 1	Slag – MSWI 2	Slag – MSWI 3	GBFS [28]
Glassy Phase	≥67,0%	-	-	-	
$CaO+MgO+SiO_2$	≥67%	68.77	72.13	72.60	89.00
$(CaO + MgO)/SiO_2$	≥ 1,0	0.36	0.25	0.33	1.18
CaO/SiO_2	1,3 ÷ 1,4	0.33	0.21	0.30	1.03
$(CaO+MgO)/(SiO_2+Al_2O_3)$	1,0 ÷ 1,3	0.30	0.21	0.30	0.98
$(CaO+1,4*MgO+0,56*Al_2O_3)/SiO_2$	≥1,65	0.50	0.36	0.41	1.36
$(CaO+MgO+Al_2O_3)/SiO_2$	≥1,0	0.58	0.43	0.45	1.21

Tab. 4. Heavy metal concentration, expressed in mg/kg

Tab. 4. Stężenie metali ciężkich, wyrażone w mg/kg

Properties	Symbol	Slag – MSWI 1	Slag – MSWI 2	Slag – MSWI 3
Zinc	Zn	2797.00	1621.00	2337.00
Copper	Cu	21608.00	1918.00	867.00
Lead	Pb	766.00	687.00	437.00
Nickel	Ni	73.60	81.00	211.00
Chrome	Cr	277.00	342.00	605.00
Cadmium	Cd	5.80	3.35	0.96
Arsenic	As	5.30	16.50	6.07
Vanadium	V	31.80	30.00	30.70
Thallium	Tl	<1.00	<1.00	-
Mercury	Hg	0.04	0.24	<0.01

tained significant amounts of glass and metals. The slag was mechanically treated in order to obtain a fraction similar to sand and cement. After grinding, no excessive dusting was observed, it was related to the higher humidity of the slag. Figure 3 shows the slag – MSWI 3 in the raw state and after mechanical treatment.

2.2 Methods

The first analytical step was to determine the total water content according to the PN-EN 15934: 2013 standard [20]. Then, the tested slags were mechanically ground using a ball mill in order to obtain an appropriate degree of homogenization for further analytics. The prepared samples were subjected to selected physicochemical analyzes. The determination of roasting losses was performed according to PN-EN 15935:2013-02 [21]. Then the slags were tested for the content of the following elements according to individual standards: carbon (C) - PN-EN 15407: 2011 [22], organic carbon (TOC) - PN-Z-15011-3: 2001 [23], sulfur (S) - PN-ISO 334: 1997 [24] and chlorine (CI) - PN-ISO 587: 2000 [25]. Optical emission spectrometry (ICP OES) was used to assess the oxide composition and heavy metal content in the dry mass of the samples.

3. Results and Discussion

Table 1 presents the basic physicochemical properties of the tested slags, which, in the absence of applicable requirements, have been referred to the requirements to be met by granulated blast furnace slag [26].

The total humidity of the tested slags (slag – MSWI 1 and slag – MSWI 3) was definitely higher than recommended in the norm (≤1.0%). Only slag – MSWI 2 meets the requirements. It is worth noting that increased humidity can affect pozzolanic activity. Undesirable components of a potential mineral additive include: too high content of sulfur compounds, chlorine and unburnt coal. The high content of unburned coal (C>5%) can increase water resistance and reduce the frost resistance of mortars or concrete with its participation. The content of chlorine, sulfur and organic carbon in the tested slags was below 1.0%.

Losses on ignition (LOI) for the tested slags are shown in Figure 4. LOIs were determined by heating the slag samples to a constant mass. A muffle furnace was used to heat the slag samples to a constant mass at two temperatures: 600°C and 950°C under an oxidizing atmosphere. In the case of slag – MSWI 1 and slag – MSWI 3, it was found that LOI at 600°C does not meet the criterion of allowing hazardous waste (LOI≤10%) to be disposed at a landfill. However, for slag – MSWI 2 this criterion was met [27]. The ignition losses for the tested slags were determined by roasting the samples at 950°C over an extended time of up to 1 hour. This parameter is important due to their use in construction. The permissible LOI limit for GBFS is ≤5% [28]. Slags with high ignition losses may cause concrete mixes to become less workable. In slag – MSWI 1 LOI was 14.58%, in the slag – MSWI 2 sample the value was 8.73%, and in the slag – MSWI 3 it was 13.30%.

Following the furnace slag testing, a chemical analysis was performed. Tables 2–4 present the results obtained from the analysis of the oxide composition and heavy metal content of MSWI slags. Table 2 shows the chemical composition of the tested slags and the ratio of individual oxides according to the requirements of the standard characterizing granular blast furnace slag (GBFS). The basic phase component of the studied MSWI was silica – SiO_2. High silica content (SiO_2 >50%) can result in high pozzolanic activity. The CaO content meets the requirements for ground granulated blast furnace slags.

Table 3 presents the properties of granular blast furnace slag in relation to the requirements of PN-EN 197-1 [28]. In accordance with the standard, construction slag should contain at least two-thirds of the sum of calcium oxide (CaO), magnesium oxide (MgO) and silicon oxide (SiO2). In the analyzed cases, the slag composition does not meet the required level. The mass ratio (CaO+MgO)/SiO_2 should be higher than 1.0%. The slags shows a lower value than required. Based on calculations, it can be concluded that the tested slags are not hydraulically active.

In the testing of heavy metal content in slags, most trace elements were found to be relatively high (Table 4). Tested slags from the incineration of municipal waste contain heavy metals in the following sequences:

- Slag MSWI 1 – Zn>Cu>Pb>Cr>Ni>V>Cd>As>Tl>Hg
- Slag MSWI 2 – Cu>Zn>Pb>Cr>Ni>V>As>Cd>Tl>Hg
- Slag MSWI 3 – Zn>Cu>Cr>Pb>Ni>V>As>Cd>Hg>Tl

Among the analyzed metals, the highest content for all tested samples was recorded for Cu in the range of 1867.0–21608.0 mg/kg and for Zn in the range of 1621.0–2797.0 mg/kg. The lowest value was recorded for mercury 0.01–0.24 mg/kg.

4. Conclusions

The slags that are generated from the incineration of municipal waste are not an easy raw material to use, but, if properly treated, they can be a good alternative to non-renewable natural resources. The obtained results give a chance for environmentally friendly use for slag from the incineration of municipal waste in construction, e.g. for the production of building materials or for roads. The issue under review may represent the best and cheapest long-term solution in line with the circular economy that could fill the market gap in the context of dwindling anthropogenic resources. During chemical tests, it has been shown that using slag from MSWI in concrete should not be harmful to the environment. However, it is important to note that the composition of the MSWI slag varies depending on the composition of the municipal waste stream sent to the incineration plant. It is necessary to conduct research on the variability of the chemical composition of the resulting slags thruought the year. In order to determine their optimal use in construction, a full set of data must be collected. The next research step will be to design concrete samples with different slag shares and test them under various environmental exposure classes according to PN EN 206. The search for mineral additives for concrete, as well as aggregate substitutes for the road industry is still a current and important topic.

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Rola żużla ze spalania odpadów komunalnych w gospodarce o obiegu zamkniętym

Żużel powstający w procesach degradacji termicznej odpadów komunalnych klasyfikuje się zgodnie z obowiązującymi przepisami jako odpad o kodzie 19 01 12. Szacuje się, że w wyniku spalania odpadów komunalnych powstaje około 0,25 Mg żużla na 1 Mg spalanych odpadów. Z perspektywy gospodarki o obiegu zamkniętym konieczne jest poszukiwanie dla tego materiału nowych zastosowań w przemyśle. Szansą na ich optymalne wykorzystanie są nowe modele biznesowe, w szczególności odzysk produktów ubocznych. Koncepcja ta zakłada, że odpad z jednego procesu jest produktem dla innego procesu. Działanie wymaga nowego spojrzenia na rynek i rozwój nieistniejących wcześniej symbioz przemysłowych. W wyniku ponownego wprowadzenia żużla do obiegu następuje redukcja zużycia zasobów naturalnych, co skutkuje oszczędnościami zarówno ekonomicznymi, jak i środowiskowymi. Celem artykułu jest wstępna ocena właściwości fizycznych i chemicznych żużla ze spalarni odpadów komunalnych jako dodatku do betonu. Na potrzeby oceny wykorzystania żużla w budownictwie przeanalizowano następujące scenariusze: żużel jako zamiennik do kruszywa, piasku i cementu. Badania przeprowadzono na żużlu pozyskanym z trzech różnych instalacji działające w Polsce. W artykule przedstawiono skład tlenkowy i pierwiastkowy żużli, a uzyskane wyniki odniesiono do wymagania dotyczące stosowania granulowanego żużla wielkopiecowego jako dodatku typu II do betonu. Analizowane żużle charakteryzują się niską zawartością chloru (Cl<0,5%), całkowita zawartość siarki kształtowała się na poziomie 0,7%. Zawartość węgla organicznego (TOC) w badanych żużlach był poniżej poziomu analitycznego. Uzyskane wyniki potwierdzają możliwość wykorzystania żużla jako alternatywnego kruszywa lub surowca do betonu. W wykorzystanie popiołów ze spalarni odpadów komunalnych do betonu nie stwarza zagrożenia dla środowiska naturalnego.

Słowa kluczowe: *żużel, surowiec, recykling, beton*

Simulating and Predicting Escape Routes for Ventilation Network of Duong Huy Coal Company using Ventsim DESIGN Software

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In underground coal mining, the ventilation task plays an important role because it ensures enough fresh air for workers and decrease negative effects of deleterious gases released from coal seam as well as blasting explosions. Furthermore, when coal mines go deeper, the ventilation task is more and more important. In order to guarantee good ventilation performance, we should apply a simulation software. In this article, we present the application of Ventsim DESIGN software for ventilation network of Duong Huy Coal company as well as prediction of escape routes in urgent cases. The simulation results demonstrate that the software offers good performance, stable operation as well as the suitable escape routes in urgent cases.

Keywords: *ventilation network, Ventsim DESIGN, escape routes, Duong Huy coal company, vinacomin*

1. Introduction

Ventsim DESIGN is the world's best-selling mine ventilation software, used and trusted by over 1500 mines, universities, consultants, government and research organizations. It is an underground mine ventilation simulation software package designed to model and simulate ventilation, airflows, pressures, heat, gases, financials, radon, fire and many other types of ventilation data from a model of tunnels and shafts [1, 2]. It includes two versions named Ventsim DESIGN Advanced and Ventsim DESIGN Premium. The first has some characteristics as follows:

- Compressible Flows: Compressible airflows effects at depth are modelled
- Thermodynamic environmental simulation:
  — Heating and Cooling – includes heat or refrigeration options in network analysis;
  — Rock Thermal Input – predicts heat and moisture emanated from rock strata;
  — Diesel Equipment – predicts heat and humidity generated by diesel equipment;
  — Natural ventilation – uses thermodynamics to simulate natural ventilation effects.
- Dynamic blasting: Blasting fume animated dynamic spread time and clearance time dispersion.
- Diesel Particulate Simulation: Utilizes diesel engine sources to estimate DPM levels throughout the mine.
- Dynamic Heat and Gas Distribution: Individual heat and gas time based simulation and spread through model with graphing.

While the later includes all features of Ventsim Advanced as well as Fire Simulation, VentLOG ventilation survey record software, LiveView remote data connection and display module AND the brand new Duct Calculator and has the following features [1]:

- All features of Ventsim Advanced
- Dynamic Heat and Gas programmable events: Heat, air or gas changes can be introduced at pre-programmed dynamic intervals.
- Radon Simulation: Predict worker exposure levels based on radon emission rates from different areas, and the length of time the gas is allowed to remain in the mine atmosphere based on your ventilation design.
- Escape Routes: Find the shortest path to a refuge bay or surface from any point in the mine.
- VentLOG: Software package to record survey data, export to plans and overlay on Ventsim models.
- LiveView to connect to external data and display and simulate real time data.
- Fire Simulation to predict fire heat, gases and flow direction
- Duct Calculator

Ventsim DESIGN is used in many scientific articles for simulating the ventilation network for tunnels as well as underground mines. The authors in [3] proposed to link real-time information generated by underground mine ventilation airflow monitoring sensors into a network simulation program to undertake network simulations and allow interpretation of key system data. Most mine ventilation engineers are involved in ventilation planning and design in some capacity. Ventilation modelling software used by a competent experienced ventilation engineer is extremely presented in [4]. The Redeemer Gold Mine is a sub-level caving gold operation located in Western Australia. The underground mining commenced in 1989 and followed a slightly subvertical ore body to the depth of approximately. The authors in [5] evaluated mine ventilation for Agnew Gold mine expansion using Ventsim. In Vietnam, there are several mine ventilation sim-

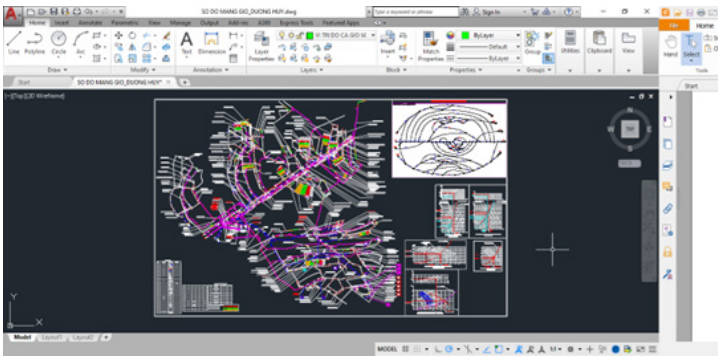


Fig. 1. The diagram of the mine ventilation network in AutoCAD
Rys. 1. Schemat sieci wentylacyjnej w programie AUTO CAD

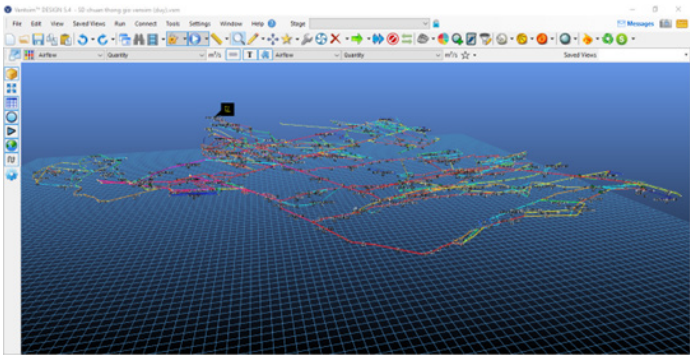


Fig. 2. The diagram of the mine ventilation network in Ventsim DESIGN
Rys. 2. Schemat sieci wentylacyjnej w programie Ventsim Design

ulation softwares as Ventsim, Kazemaru, VentGraph used for simulating underground Coal mine ventilation network [6]. Some Coal mines in Quang Ninh province begin using Ventsim DESIGN for simulating their mine ventilations. Duong Huy coal mine is one of those. In this article, we present the simulation results in using Ventsim DESIGN to simulate the ventilation network for this company.

The rest of the article is structured as follows: Section 2 describes the related works. The simulation of Duong Huy coal company's ventilation network and prediction of escape routes in urgent cases are presented in section 3. Section 4 offers some conclusions as well as the future work.

2. Related works

2.1. Steps of mine ventilation simulation in Ventsim DESIGN

In order to simulate the mine ventilation in Ventsim DESIGN, we execute as follows:

- Step 1: Draw the ventilation network in AutoCAD software, and then save it to .dxf/.dwg file
- Step 2: Import the AutoCAD file into Ventsim DESIGN
- Step 3: Import data for the ventilation in Ventsim DESIGN
- Step 4: Check for the validity of the ventilation as direction, the junction among airways. In order to do this, Fix flow for airways which we will install the fans equal to the total flows of whole mine
- Step 5: Simulate the ventilation
  — Remove the fixed flow at step 4
  — Install the fan at the airway
  — Run simulation of airflows
  — Check flows at airways which consume fresh air. If they do not ensure enough fresh air, we have to adjust the ventilation network as using local fan to increase flow, obstruct for reducing flow… Besides we also check the velocity of airways. If they exceed the threshold value, we have to decrease them.
- Step 6: Check the whole mine ventilation, focus on the flows, velocities, pressures, working mode of the fans.

2.2. Ventilation network characteristics of Duong Huy Coal mine

The ventilation network of Duong Huy coal mine is quite complicated and typical for underground coal mine in Vietnam. At present, the mine is exploring form level -100 to +38. The mine includes three mining areas called "Trung tam", "Nam", "Dong Bac". All the areas have 10 longwalls, 34 the prepared tunnel faces, where "Trung tam" area is exploiting seams 8, 10, 11; area "Nam" is mining seam 9 whereas area "Dong Bac" is exploiting seams 11, 12, 14. According to [7, 8], the total output of the mine in 2020 is 2,130,000 tons/year. The total length of digged tunnels is 22,730 m. For the ventilation task, the total flow of whole the mine (Qm) is manually counted according to the following equation [9]:

$$Q_m = 1.1 \times (k_{sl} \times \Sigma Q_{kt} + \Sigma Q_{cb} + \Sigma Q_{ht} + \Sigma Q_{rg});\ \mathrm{m^3/s} \qquad (1)$$

In which:
1.1: The coefficient refers to the uneven distribution of wind in wind currents.
k_{sl}: Coefficients to account for the increase in output of the longwall (normally $k_{sl} = 1.1$).
ΣQ_{rg}: Total leakage flow in mine, m^3/s.

Tab. 1. Quantity of fan used in simulation

Tab. 1. Ilość wentylatorów użytych w symulacji

Fan name	Role	Quantity
2K56No30	Main fan	2
2K56No24	Main fan	2
2K60-44-No16	Main fan	2
BD-II-4No12/2*45	Local fan	1
FBDCZ-II-4-No 12/2*45	Local fan	1
BD-II-6-No 12/2*30	Local fan	1
FBD6/2*15	Local fan	18
FBDY6/2*22	Local fan	2
FBDY6.3/2*30	Local fan	3
FBDY6.7/2*37	Local fan	2
JBT 52-2	Local fan	4
YBT 42-2	Local fan	5

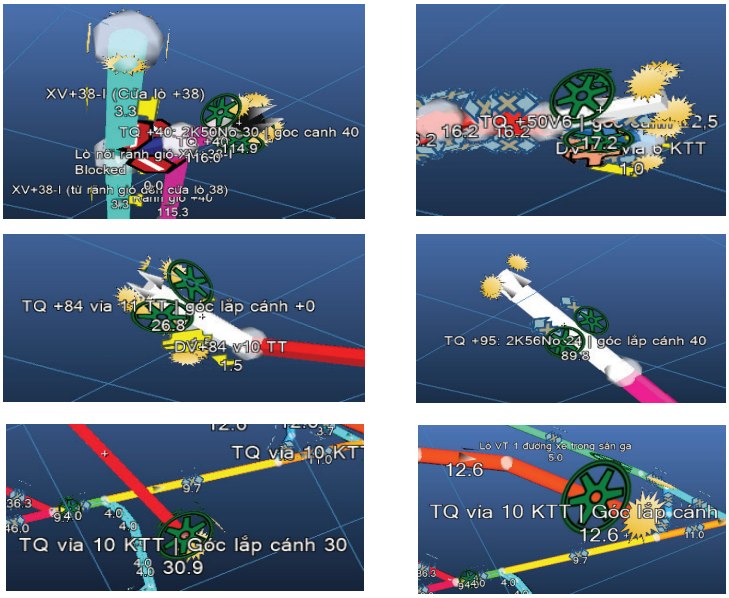


Fig. 3. The locations of 6 main fan stations in mine ventilation network

Rys. 3. Lokalizacja sześciu głównych stacji wentylatorowych w sieci wentylacyjnej

ΣQ_{lc}: Total flow required for the longwall face, m^3/s.

ΣQ_{cb}: Total flow needed for the roadway heading or heading, m^3/s.

ΣQ_{ht}: Total flow required for the stations, m^3/s.

The value of Qm is manually calculted equal to 304 m^3/s.

Total ventilation pressure of mine (hm) is counted using Equation (2) [9]:

$$h_m = \sum h_{ms} + \sum h_{cb},\ \text{mmH}_2\text{O} \tag{2}$$

where:

Σh_{ms}: The total hypotension is caused by the frictional resistance of the segments that follow each other in airflow, calculated from the beginning to the endpoint. The pressure of tunnel i (hms) is calculated according to formula (3).

$$h_{ms} = \alpha_i \frac{L_i \times P_i}{S_i^3} \times Q_i^2\ ;\ \text{mmH}_2\text{O} \tag{3}$$

In which:

α_i: The aerodynamic resistance coefficient in tunnel i on the airflow, kGS^2/m^4;

L_i, P_i, S_i: Length, circumference, the cross-section of the tunnel i;

Q_i: The amount of wind going through tunnel i, m^3/s.

Σh_{cb}: The total hypotension due to local resistance calculated by an airflow. In fact, it is often taken from 10 to 25% of Σh_{ms}.

The value of h_m is manually calculted equal to 1994.68 Pa.

The velocity of airflow at tunnel i (vi) is computed according to equation (4):

$$v_i = \frac{Q_i}{S_i};\ \text{m/s} \tag{4}$$

Where: Q_i, S_i are flow and area of tunnel i, respectively.

3. Simulating the ventilation network in Ventsim DESIGN

3.1. Simulation of the ventilation network

In order to simulate the mine ventilation of Duong Huy coal mine, we implement according to the steps in subsection 2.1. The diagram of the mine ventilation in AutoCAD is presented in Figure 1.

And then, we import this diagram into Ventsim DESIGN. Next, we put data for all the airways of the mine ventilation network. The mine ventilation diagram is shown in Figure 2.

When simulate the ventilation network of Duong Huy coal mine, we use several types of fans currently used in the mine shown in Table 1 [8].

The locations of 6 main fan stations are represented in Figure 3.

All the fans use exhaust ventilation method.

Summary of key simulation results of the mine ventilation network is shown in Figure 4. The mine ventilation network in-

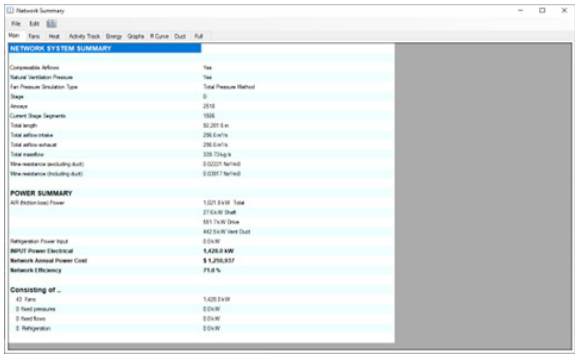
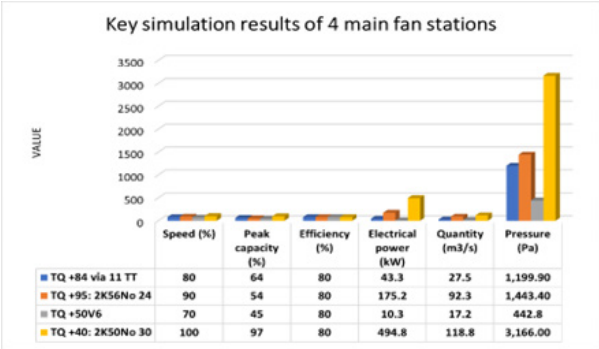


Fig. 4. Summary of main simulation results of mine ventilation network
Rys. 4. Podsumowanie wyników symulacji sieci wentylacyjnej



	Speed (%)	Peak capacity (%)	Efficiency (%)	Electrical power (kW)	Quantity (m3/s)	Pressure (Pa)
TQ +84 via 11 TT	80	64	80	43.3	27.5	1,199.90
TQ +95: 2K56No 24	90	54	80	175.2	92.3	1,443.40
TQ +50V6	70	45	80	10.3	17.2	442.8
TQ +40: 2K50No 30	100	97	80	494.8	118.8	3,166.00

Fig. 5. Simulation results of main fan station
Rys. 5. Wyniki symulacji stacji wentylatorów głównych

cludes 2518 airways, total length of 92,281.6 m, total airflow is 296.6 m^3/s; mine resistance (including duct) is 0.03917 Ns^2/m^8.

Figure 4 shows the main simulation results of 4 main fans used in the mine ventilation. Summary of the main factors is presented in Figure 4. The simulation results show that fan named "TQ +40: 2K50No30" has the best performance with the peak capacity is 97% while the remaining fans having this factor from 45 to 64 %. This means the TQ +50V6 has the worst performance with the peak capacity is 45%. These fans will be efficient used in the future when the mine is deploying the expansion of mining area. The mine will go deeper.

The calculation results of some important factors according to manual method and using Ventim DESIGN as shown in Table 2. It is clear that the difference between two methods is not significant. This means we can efficiently apply the software to simulation of the ventilation network of Duong Huy coal mine.

3.2. Prediction of the escape routes

This feaure is to offer the best/shorted path form the position of the breakdown (due to fire, tunnel collapse, water flooring, gas explosion, etc.) to the safe location (entrance/exit surface, refuge bay, etc.) with the shorted of moving time. According to [5], some urgent situations can be shown as:

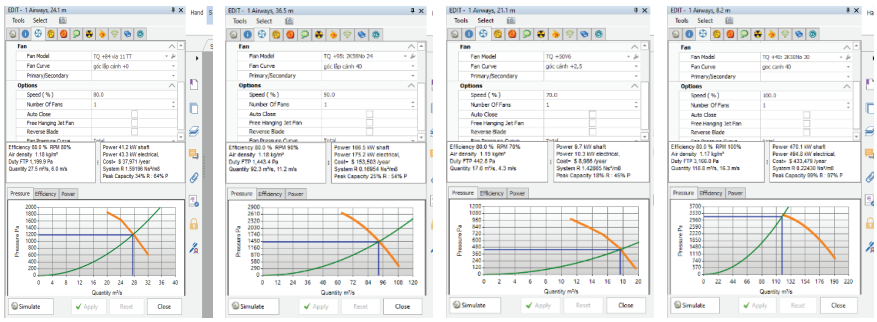
- Mine fires or explosions where some escape routes or parts thereof may be flushed with fire or pernicious gases;
- Blockage of an escape route through mine collapse or flooding;
- Some parts of a mine may not have planned or formed fully escape routes into all areas of the mine.

In Ventsim DESIGN, Dijkstra's algorithm [10] is developed to find out the safest and fastest path solutions. The mine ventilation is seen as a direction-oriented graph where node (junction) is the top of the graph, airway is the edge of the graph. The weighting of the connections between nodes needs be estimated. Relevant considerations for graph weighting include [5]:

- The speed and safety of escaping personnel include the walking slope or gradient of the path;
- Can the path can be driven, walked or climbed (with a ladderway)?
- The presence of blockages or non-route controls like inaccessible regulators or walls;
- The presence of smoke, gas, fire or impassable water within a pathway;
- What about if the roadway is entrance or return?
- The presence of mask stations or rescue bays in those roadways.

The speed and walk time of workers are computed according to Naismith's method [11, 12]. The method is based on a horizontal walking pace of 4.5 km/h with an inclined penalty of an extra hour travel per 1000 m vertical distance. Because of reduced visibility, a further walking speed penalty of 40% is recommended for travelling in adverse conditions such as smoke or gas. The speed (Sw) and walk time (Tw) of workers are counted according to Equations 5 and 6.

$$S_w = \frac{TD}{\frac{TD}{4.5}+H} \times (1-E)\,;\ \text{km/h} \tag{5}$$



a) *b)* *c)* *d)*

Fig. 6. Main simulation results of 4 of 6 main fans used in the mine ventilation. Names of fan stations: a) TQ +88 via 11TT; b) TQ +95: 2K56No 24; c) TQ +50V6; d) TQ +50 2K50No 30

Rys. 6. Główne wyniki symulacji dla 4 z 6 głównych wentylatorów Oznaczenia wentylatorów a) TQ +88 via 11TT; b) TQ +95: 2K56No 24; c) TQ +50V6; d) TQ +50 2K50No 30

Tab. 2. The calculation results of some important factors according to manual method and using Ventsim DESIGN software

Tab. 2. Wyniki obliczeń najważniejszych czynników metodą ręczną i z wykorzystaniem Ventsim DESIGN software

Method of calculation	Quantity of the mine (m^3/s)	Pressure of the mine (Pa)
Manual	304	1994.67
Ventsim DESIGN	296.6	1958.68
Difference	**±2.4%**	**±1.8%**

Tab. 3. Parameters used for simulating the escape routes in urgent cases

Tab. 3. Parametry wykorzystane w symulacji dróg ucieczki w warunkach niebezpiecznych

Scenario	Airway with breakdown	Positions of refuge bays	Number index of Entry/Exit branches
1	SSC cho N-8-1 V8 KN	DV+45 V7 Khu Nam; XV-100 Khu BI	509, 511, 596, 1126, 1275, 1280, 1306, 1310, 1312, 1358, 1359, 1388, 2061
2	TKD lap gia cho DB-11-3B V11 DB		

$$T_w = \frac{S_w}{L}; \text{h} \quad (6)$$

Where:
TD: Total distance (km);
L: Leng of pathway (km);
H: Vertical height up only (km);
E: Environmental penalty factor (0% = clear, 40% = smoke).

For this case study, we assume some positions which usually happen the breakdowns in practice. Then we use function of escape routes in the software for finding out the path to the safe location. In this simulation scenario, we suppose the breakdown positions as described in Table 3.

After simulation with the function of escape routes in the software, the simulation results of scenario 1 are indicated in Figure 8.

The selected path from the breakdown position (SSC cho N-8-1 V8 KN) to the surfaces is Exit Branch which has number index equal to 1306, with the total time is 59 minutes, including 40 minutes of walking time, and 19 minutes of climbing time. The total distance is 2,400.5 m. The total time of pathways to two refuge bays are 1 hour 21 minutes and 1 hour 25 minutes, consisting of time walking and time climbing. It's clear that, the selected path is the best pathway in this case. Figure 9 shows the selected path for the first scenario. The selected path is highlighted while the other airways hidden.

In the second scenario as shown in Figure 10, the selected path is the way to the Entry branch named "Ngam TG -100/+160" with 41 minutes of walking time only. The total distance is 2,073.9 m. The total time of pathways to two refuge bays "XV-100 khu BI" and "DV+45 V7 Khu Nam" are 14 minutes and 16 minutes walking time only, respectively. Hence, the best pathway in this scenario is the way to the refuge bay "DV+45 V7 Khu Nam". Figure 11 shows the selected path for the second scenario. The selected path is highlighted while the other airways hidden.

The simulation of urgent situations will show the best path to the safe location. This will protect the workers when having disasters. The simulation of urgent situations will show the best path to the safe location. This will protect the workers when having disasters.

4. Conclusion

In this article, we assess the performance of application of Ventsim DESGN software to the mine ventilation network of Duong Huy coal mine. The simulation results show that the software operates stably, exactly, lively. The mine ventilation network of Duong Huy Coal mine is quite complicated and typical for underground coal mines in Vietnam. So the successful development of the ventilation simulation will create many chances in applying the Ventsim DESIGN software to other underground Coal mines in Vietnam. In the future, we will study to simulate heat, contaminant, fire for the mine ventilation network of Duong Huy Coal mine.

Acknowledgements

We'd like to thank Vinacomin – Duong Huy Coal Company for providing documents and data of the ventilation net-

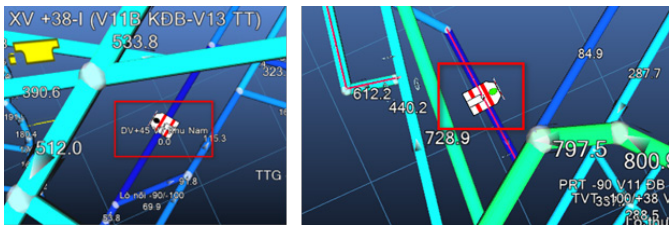


Fig. 7. Positions of the Refuge Bays
Rys. 7. Lokalizacja komór ucieczkowych

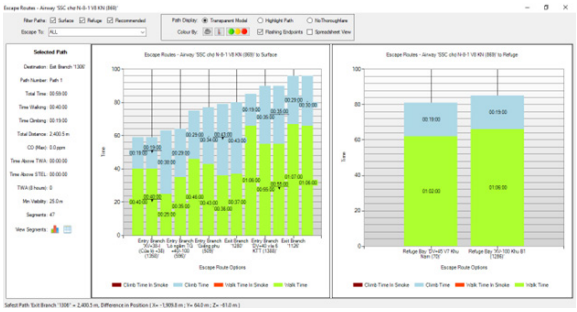


Fig. 8. Simulation result of the escape routes function for scenario 1
Rys. 8. Symulacja dróg ucieczkowych według scenariusza 1

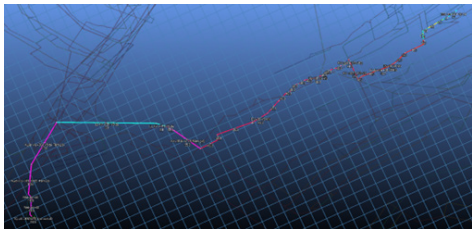


Fig. 9. The selected path is prominently displayed while the other remaining airways hidden in scenario 1
Rys. 9. Wybrana droga ucieczkowa jest wyraźnie widoczna, podczas gdy pozostałe drogi są opisane w scenariuszu 1

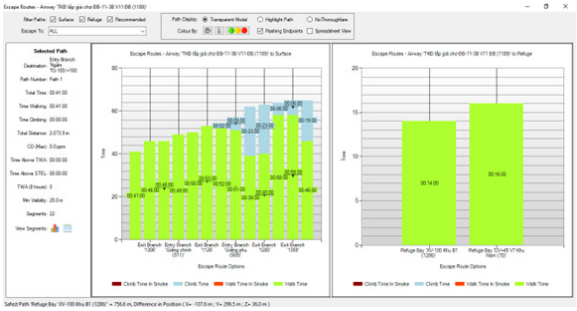


Fig. 10. Simulation result of the escape routes function for scenario 2
Rys. 10. Symulacja dróg ucieczkowych według scenariusza 2

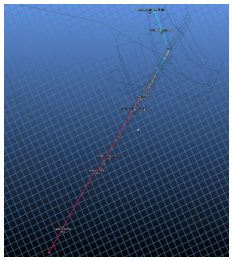


Fig. 11. The selected path is prominently displayed while the other remainning airways hidden in scenario 2
Rys. 11. Wybrana droga ucieczkowa jest wyraźnie widoczna, podczas gdy pozostałe drogi są opisane w scenariuszu 2

work as well as coordinated in using the Ventsim DESIGN software to simulate the whole ventilation network with realistic data of the mine.

Conflicts of Interest

The authors declare no conflict of interest.

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Symulacja i przewidywanie dróg ewakuacyjnych dla Sieci Wentylacyjnej Spółki Węglowej Duong Huy przy użyciu oprogramowania VENTSIM DESIGN

W podziemnym górnictwie węgla wentylacja odgrywa ważną rolę, ponieważ zapewnia wystarczającą ilość świeżego powietrza dla pracowników i zmniejsza negatywne skutki uwalniania się szkodliwych gazów z pokładów węgla oraz możliwość wystąpienia wybuchów. Ponadto, gdy eksploatacja sięga głębiej, zadanie wentylacji jest coraz ważniejsze. W celu zagwarantowania dobrej wydajności wentylacji do obliczeń sieci wentylacyjnej stosuje się oprogramowanie symulacyjne. W artykule przedstawiono zastosowanie oprogramowania Ventsim DESIGN dla obliczenia sieci wentylacyjnej kopalni Duong Huy oraz przewidywania dróg ewakuacyjnych w nagłych przypadkach.

Wyniki symulacji pokazują, że program dobrze wylicza wydajność sieci , warunki stabilnej pracy oraz odpowiednie drogi ewakuacyjne w nagłych przypadkach.

Słowa kluczowe: *sieć wentylacyjna, Ventsim DESIGN, drogi ewakuacyjne, spółka węglowa Duong Huy, Vinacomin*

The Role of Natural Succession in the Reclamation of Mining Waste Disposal Facilities

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Abstract

The mining industry is related with the production of waste, which are generated during the preperatory works, exploitation and processing of minerals. The type and quantity of generated waste result directly from the type of obtained mineral raw material (minerals), geological conditions of the deposit and the mining and processing technologies used. The changing approach to waste related to the circular economy model means that more and more waste is used economically. However, due to the different physicochemical properties of mining waste and the limited possibilities of its use, some waste is still deposited in mining waste landfills. Depending on the type of mining waste deposited, environmental and economic aspects, the landfill may be a source of raw materials (anthropogenic deposit) that may be exploited now or in the future. Some of this type of mining waste landfills are reclaimed and may be an important elements of the local landscape, as well as positively affect biodiversity through the development of specific natural habitats. The paper presents the concept of landfill reclamation of waste from hard coal mining, taking into account the importance of the phenomenon of natural succession in the formation of ecosystems in reclaimed landfills.

Keywords: *waste facility, mining waste landfills, anthropogenic deposit, circular economy, reclamation, biological tests*

1. Introduction

Getting mineral raw materials, inter alia: fossil fuels, metal ores, minerals used in chemical and building industry involves producing wastes. These are mainly mining wastes made in the processes of searching, identifying and mining of minerals from their deposits, as well as their processing. Most mining wastes are a result of the construction and maintenance of excavations, often called sterile rock. Processing wastes are wastes in a solid or silt-like form, which are formed after processing of minerals, i.e., getting useful components through mechanical, physical, biological, thermal or chemical processes. The kind and quantity of the produced mining wastes directly depend on the kind of the mineral, geological conditions of the deposit and the applied technologies of mining and processing. According to the catalogue of wastes, they belong to the first group of wastes [1, 2]. In Poland, the largest quantity of produced wastes is connected with the mining of coal, copper, zinc, lead, and aggregates. These are three kinds of wastes:

- wastes from the flotation enrichment of the ores of non-ferric metals, code 01 03 81, formed during the processing of the ores of copper, zinc and lead;
- wastes formed during panning and rinsing minerals, code 01 04 12. These are mainly wastes from the processing of coal and rock aggregates;
- wastes from mining minerals other than metal ores, code 01 01 02. These wastes arise during mining of coal and rock aggregates (so-called sterile rock).

Over the recent years, the mentioned above kinds of wastes were produced in the quantities 69.5 to 60.8 million tonnes per year, which was 54–56% of all the industrial wastes produced in Poland (table 1). From 37 to 41 per cent of wastes were recovered. In 2016, 40.5 million Mg of mining wastes were deposited in the waste facility (WF), while in 2020 it was 35.8 million Mg, which was 59% of the mass of the produced wastes.

In mining industry, depending on the kind of the mineral, specifics of the processing and the applied technologies, also other industrial wastes are produced, which can be deposited. In case of some hard coal mines, flotation is applied during the processing, and the remains from the enrichment of coal make the post-flotation wastes. These are wastes classified pod in code number 01 04 81 – other than the mentioned in 01 04 80 wastes from the flotation enrichment of coal. Another kind of wastes characteristic for underground mines are wastes made as a result of treating mine waters, which are sent to the decantation ponds on the surface. In the decantation ponds solid particles are sedimented and their code is 19 13 06 – sludges from groundwater remediation other than those mentioned in 19 13 05. Among the mentioned above wastes, characteristic for hard coal mining wastes of code numbers: 01 01 02, 01 04 12 and 19 13 16, and in some mines also code 01 04 81.

These wastes are characterised by various physical and chemical properties, which determine further processes of their management (e.g., chemical composition, granulometric composition, mechanic properties, the content of coal, humidity) [8-12]. The influence of wastes on the environment is also significant, e.g., through the presence of heavy metals, as well as leachability of salts, such as sulphates and chlorides in the amounts exceeding the highest acceptable levels. Thus, these wastes are used in various manners – in the building

Tab. 1. Production and management of mining wastes in Poland [3-7]

Tab. 1. Wytwarzanie i zagospodarowanie odpadów górniczych w Polsce [3-7]

Year	2016	2017	2018	2019	2020
	million tons				
Generated waste - total	128.3	113.8	115.3	114.1	109.5
Generated waste - Mining and quarrying	69.5	62.3	61.4	63.7	60.8
Waste recovery - Mining and quarrying	28.4	23.2	24.1	25.6	24.4
Landfilled waste - Mining and quarrying	40.5	38.0	36.9	37.5	35.8

Tab. 2. Production and management of wastes by the hard coal mines in Poland [3-7]

Tab. 2. Wytwarzanie i zagospodarowanie odpadów przez kopalnie węgla kamiennego w Polsce [3-7].

Year	Waste generated during the year [mln tonnes]				
	2016	2017	2018	2019	2020
Grand total	32.4	28.5	28.1	30.2	27.8
Recovered	25.0	20.9	21.2	22.7	21.4
Landfilled	7.4	7.1	6.8	7.2	6.3
Waste landfilled (accumulated) so far (as of the end of the year)	434.6	421.4	426.9	424.2	430.1

construction, road construction, energy industry, mining, land reclamation and agriculture [9-11, 13,14]. Nevertheless, due to large quantities of these wastes, lack of local customers, economical aspects, both in the past and nowadays, they are deposited or accumulated on the waste facility (WF), such as heaps or decantation ponds. According to recent data [7], in 2020 hard coal mining industry in Poland produced 27.8 million tonnes of wastes, among these 6.3 million tonnes were deposited, and by the end of 2020, 430.1 million tonnes of wastes were deposited on WF in total (table 2).

Such large quantities of wasted deposited on WF located near mines have direct and indirect impact on the environment. This impact is usually considered negative, nevertheless, with time, industry attempts to improve damage by reclamation of waste repositories, their liquidation by retrieving the wastes, or – what can be noticed in recent years – allowing the formation of new habitats through natural succession.

The article presents new trends, which can be observed in the approach to the management of WF which, depending on the kind of deposed wastes and estimated impact on the environment, can be treated as the reservoir minerals that can be obtained in the future. This can refer to e.g., wastes containing valuable components, which – due to previously applied technologies and economical aspects – were not retrieved in a satisfactory extent. Such objects can make anthropogenic deposits and their renewed mining gains increased interest. In case of WF where mining wastes of no environmental threat were deposed, it is possible to „leave the object to nature", after previous „technical reclamation od the object". In the repositories of this type, often due to natural succession valuable habitats are formed. At the same time these habitats are adjusted to local environmental conditions.

2. The Characteristics of Waste Facility

Disposal of mining wastes causes numerous changes in the environment, starting from the impact on fauna and flora, soil and water environment or visible changes on the surface of the terrain. For many years of the activities of mining industry anthropogenic forms of relief were made. There area, height and shape varied. This was mainly because of the properties of the deposited wastes and techniques of the disposal or the location of a specific landfill. Thus the existing repositories of mining wastes can be divided according to various criteria [15]: size and shape (terrace, table, ridge, dome and cone), situation referring to the ground (over-ground, underground, partially over-ground and underground and lateral), situation referring to the mining enterprise (near the mine, central, involving several mines), aquatic conditions (drainage, non-drainage) or the degree of vegetation cover (reclaimed, partially reclaimed, not reclaimed).

The legal status of the existing WF depends on many factors connected with the subject managing such an object and activities conducted in the area. Usually the subjects managing the waste repositories are mining enterprises, enterprises dealing e.g., with wastes recycling or the State Treasury. One can distinguish active WF, where mining wastes are still disposed, partially closed (disposal is conducted only in parts of the objects) and closed. Closing WF is usually a result of achieving its planned height, defined by the area, volume and height parameters. Another reason for the closure of WF can be the lack of the possibilities or the lack of the permission from the administration to increase its volume, as well as ceasing the activities of the mining enterprise. In the framework of the process of closing the object of mining wastes neutralisation, often an object is constructed. Such works are based on the construction project and the construction permit. Scarps are built and the crown of the object are built. Mining wastes are often use for this purpose. Once the construction works are finished, reclamation and area management are carried out in such a way that a proper state from utilitarian and ecological point of view is restored, especially soil quality, wildlife and flora, natural habitats, systems of fresh water and landscape [16].

3. Waste Facility as Antropogenic Deposits

The model of economy in UE, changing from linear into circular model, introduced changes, which also referred to mining wastes [17]. Mining industry in greater and greater degree will have to limit the amount of the produced wastes, and – if already produced – treating them as raw materials to produce products of various kind. Moreover, economic factors more and more often wastes disposed in WF and repositories (e.g., wastes from metallurgy, post-flotation wastes from metal ores or wastes from energy industry) are treated as anthropogenic deposits, where raw materials can be obtained.

The mining of such a deposit contributes to the regaining of the accumulated wastes, which make substitute for natural deposits, thus we save natural resources, as well as reclaim the previously occupied area, which then can be used in diverse ways. The kind of potential resources collected in an anthropogenic deposit, their amount and quality depends

on many factors connected with the source of wastes, the way of their disposal and the duration of time; these are the following: efficiency of the carried out previous methods of processing, the way of disposal (selective, not selective), kind and amount of deposited wastes, the age of the repository and physical and chemical changes in wastes, which took place inside the repository. Moreover, the mining of anthropogenic deposits also depends on other aspects, such as: profitability, new technologies of wastes processing to regain valuable raw materials, demand for the particular mineral, the impact on the environment of the liquidation of the repository, the role fulfilled by the object for the area or natural values. This the decision of the mining of the repository WF requires individual approach [18]. In case of the repositories of industrial wastes, usually retrieved minerals are metal ores, including valuable metals, rare-earth elements or critical raw materials, minerals used in chemical industry, scrap steel, cast iron and construction materials [19, 20]. The wastes deposited in WF by hard coal mines make potential source of energy and construction resources [21, 22]. According to the inventory [18], in Poland there are 259 objects, where hard coal mining wastes of different legal status in terms of the activities carried out are deposited (about 800 million tonnes). The estimated analysis contained in [21] indicates that in 1945–1989 120 million tonnes of coal silts were disposed in the objects like decantation ponds. The authors identified 59 objects where these wastes were disposed.

The exploitation of WF means taking wastes, usually with the use of excavators/loaders and processing them, depending on the kind of the retrieved wastes. The whole processing can take place in situ, in the facility located at WF or outside. In this case the product (waste) is transported in motor vehicles, railway or tape conveyors to the processing facility. Usually in the processing sieving, crushing and mincing are applied, as well as methods of gravity and flotation enrichment.

The obtained flammable fractions, depending on the calorific value and the size of grains, are used to produce energy for industry and households. The second significant raw materials are artificial aggregates – taken directly from the wastes repositories or being the remains after the processes of the recovery of the flammable fraction. Artificial aggregates make substitute for natural aggregates and they are usually used in construction industry, road construction and engineering. Regained wastes can make components of mineral fertilizers and stimulators of the development of plants [23].

As a result, old repositories, forming anthropogenic deposits are liquidated, the area can be reclaimed and brought back to agriculture or forestry use. It can also be used for economic purposes (the area for new service or production companies) and even converted to residential area.

4. Reclamation of the Waste Facilitis From Hard Coal Mines

Reclamation works can be carried out, provided that the legal status of the enterprise is regulated, including permit for wastes retrieval, permit to close the object of mining wastes neutralisation and, according to the legal regulations, so that they are safe for human health and life and did not have negative impact on the environment. Firstly, one should define the direction of reclamation, conduct the studies on geo-mechanic properties of the ground, water balance, as well as the range of land transformations. This is so-called preparatory reclamation, then a subsequent stage – basic reclamation – often called technical reclamation takes place [24].

In the framework basic reclamation, engineering works are done, including earth works connected with shaping the scarps and top of the repositories, earth works connected with reclamation cover, works regulating water balance and building access roads. Like in construction works, during reclamation, the mentioned above hard coal mining wastes are used in the amount connected with the technical way of reclamation. Due to the fact that the wastes of codes 01 01 02 and 01 04 12 are characterised by large size of grains and are often mixed with fine-grained wastes of code 01 04 81 to increase the isolation of the layer by fulfilling the inter-graine space (e.g., 10% participation). Earth works are connected with the shape of the top and scarps of the repositories, have also the purpose of securing the crown and scarps of the repositories from water and wind erosion. An example of earth works technology is distributing, levelling and compacting the wastes making the layer of thickness 1-1.5 m and density index Ismin = 0.95. After shaping the top and scarps of the waste repository, reclamation cover is made. Its thickness depends on planned plantations. If mining wastes are used, the participation of waste 01 04 81 increases e.g., to 20%, additionally, other wastes, such as concrete and brick debris (waste of code 17 01 07), soil and earth (waste of code 17 05 04), stabilised municipal sludges (waste of code 19 08 05) can be used.

Then, on the layer of reclamation cover, the earth layer of the thickness of e.g., 0.3 m is put, with the use of wastes from coal burning (e.g., slag, ash and dust from the boilers – waste of code 01 01 01), as well as soil and earth coming from construction works, renovation and demolishing of constructions and road infrastructure (waste of code 17 05 04), earth from digging (rocks from deepening – code of waste 17 05 06) or soil and earth coming from gardening (waste of code 20 02 02). After these measures biological reclamation is conducted.

Biological reclamation, also known as detail reclamation, is the third phase of the reclamation process. Biological stage of reclamation is a key stage. Its purpose is regeneration of biological activity of soil. Biological reclamation is a set of engineering and agrotechnical measures, a significant role is played by biological processes taking place in the upper layer of the ground, reshaping biocoenotic structure on degraded soils. The purpose of this stage of reclamation ma is first of all the protection from erosion, biological protection of the top and slopes and initiating and stimulation of soil-forming processes. Vegetation cover formed in the reclaimed area fulfils many functions, inter alia, causes the limitation of dust, increases the retention, which also limits leaching inside the profile, also fulfils the phyto-melioration function, sanitation, and remediation function (bioremediation and phytoremediation). Additionally, the vegetation cover forms microclimate and fulfils the protection function for the adjacent areas [25- 28].

The selection of the direction of biological reclamation is determined by many conditions. Firstly, the direction of reclamation must comply with the plan of the spatial management of a given area, as well as habitat conditions. Formal and legal, technical, hydrogeological, cultural conditions are important, as well as the kind and accessibility of infrastructure, the degree of urbanization of a given area and ecological factors [29, 30]. Natural succession in the reclaimed area must be considered [31].

Fig. 1. Spontaneous vegetation with the black locust (Robinia pseudoacacia) in a fine coal landfill
Rys. 1. Spontaniczna wegetacja z udziałem szarańczy czarnej (Robinia pseudoacacia) na składowisku węgla drobnego

Fig. 2 Spontaneous succession in the area of closed hard coal mines
Rys. 2. Sukcesja spontaniczna na terenie nieczynnych kopalń węgla kamiennego

The efficiency of biological reclamation depends on the properties of the reclaimed grounds. The reclamation measures are influenced by the pH, the amount of accessible nutrients, the content of humus, which significantly influence the sorption complex and retention properties, as well as the granulometric composition of the ground. Thus the condition of the revival of biological activity of soil is providing optima conditions for the development of plants and soil microorganisms, which also allow spontaneous succession of the adapted organisms.

Over years various concepts of biological reclamation in the degraded areas have been formed. The concept by Skawina considered the role of pioneer plants introduced in the reclaimed area. The role of pioneer plants was the initiation of soil-making process and activation of biological processes. Pioneer plants could be commercially used, nevertheless their basic function of the stimulation of soil-making processes before the final (permanent) species are introduced. To initiate soil-making processes and the enrichment of soil in nitrogen, Fabaceae (Papilionaceae, leguminous plants) are used. Due to the symbiosis with Rhizobium bacteria the Fabaceae can use atmospheric nitrogen and do not require mineral fertilizers. The species of pioneer plants also produce large amount of surface biomass and have strongly developed and draining root system. Often, apart from leguminous plants, various grass species are introduces, acting against erosion (the timothy (Phleum pratense), red fescue (Festuca rubra), orchard grass (Dactylis glomerata) In the area reclaimed in the forest direction the function of pioneer plants fulfil the species of trees and shrubs, such as: the black alder (Alnus nigra), grey alder (Alnus incana), silver birch (Betula verrucosa), Scotch pine (Pinus sylvestris) and various species and varieties of willow (Salix sp.). Non-native species with the features of pioneer plants were also introduced, but these were invasive species posing threat to native biodiversity, such as: the black locust (Robinia pseudoacacia), Siberian peashrub (Caragana arborescens) [Fig.1]. Other model of biological reclamation (Polish Academy of Science model) assumed intensive mineral fertilization in the first years of the reclamation, putting in doubt the significance of the organic substance. Direct introduction of final species was recommended, and then intensive mineral fertilization of plantation took place, which posed a significant risk of the eutrophication of water streams and water bodies. In practice often final species were replaced by various species of herbaceous plants, which spontaneously entered nitrogen-rich soils and overgrew the plantations. [32].

5. Natural Succession in the Degraded Areas

Devastated and degraded post-industrial areas include (among others): repositories of solid wastes from mining, metallurgy, energy industry, chemical and municipal wastes, decantation lagoons and the areas of soils strongly transformed by chemical substances. Depending on the degree and kind of degradation, technical formation of such a deposit, local climatic conditions, water and ground conditions and the properties of earth material, spontaneous development of vegetation is common. Spontaneously entering plant species usually come from the adjacent areas. In case of deposits rich in nutrients the biomass of a given plant species exceeds the biomass of the same plant species growing in normal conditions. Similarly, the content of macro and micro components in the biomass of these plants varies significantly. Plant communities on waste repositories and degraded grounds are communities of a high degree of hemeroby, characterised by high specialisation and pioneer character. The most common species belong to poly-hemerobes and meta-hemerobes [33]. Often plants growing in the degraded areas, especially in several decades old waste repositories, characterised by large content of heavy metals and low content of nutrients and unfavourable water conditions form defensive mechanisms, protecting them from environmental factors. Plants growing in such extreme conditions make quite rich phytocoenoses, which Wierzbicka called heap populations. Plant species of heap populations often morphologically vary from plants of

Fig. 3. Yellow iris (Iris pseudoacorus) position near the fine dust yard
Rys. 3. Stanowisko irysa żółtego (Iris pseudoacorus) w pobliżu placu drobnego pyłu

the same species, growing in natural conditions can also higher tolerance to heavy metals [33-36].

Due to the differentiation of post-industrial habitats, in terms of relief, hydrological conditions, content of various factors, including toxic elements and granulometric composition of the ground, the areas of this type have very differentiated ecological niches, possible to be populated by various species, and due this they have high potential of ecological remediation [37] [Fig.2].

Observed in the repositories mining wastes, often characterised by theoretically unfavourable conditions for vegetation (e.g., salinity, high temperature), after several years, dense vegetation cover is found. Through natural succession, these apparently hostile formations are colonised by plants of high adaptation abilities. The formed habitats are valuable objects of studies referring to the succession of adaptation mechanisms to unfavourable environmental conditions. Mining leads to the formation of ecological niches, which are often populated by valuable species, protected by law or regionally threatened. On the heaps of the gangue, covered with vegetation as a result of spontaneous succession nearly 600 species of vascular plants were identified, including several species protected by law. Most species are connected with ruderal and segetal habitats [38] [Fig.3]. Scientific studies carried out on the repositories of mining wastes, which underwent spontaneous succession, show much higher so-called biotic novelty index compared to forests grown in natural habitats. Observations are promising in the context of the reclamation and revitalisation of this type of objects, however, a factor which works against such solutions is the time of the formation of such ecosystems through the spontaneous succession place [39].

6. Conclusions

The amount of the produced mining wastes is significant, taking into account the production of industrial wastes in Poland, as well as produced only in hard coal mines. More than half of these wastes end on the repositories. Depositing wastes is connected with high environmental nuisance, due to the landscape degradation, threat to the quality of surface and ground waters and air quality. Repositories of mining wastes used to be left without reclamation. They used to be treated as indispensable disfiguring element of landscape in the mining areas. Nowadays, according to the law, every repository, after the end of use must be remediated. The mentioned above old not cultivated repositories are overgrown with vegetation. Even in the areas of spontaneous succession where the conditions were and still are very unfavourable, vegetation appeared as a result of natural succession. This way very interesting and ecologically valuable ecosystems appeared quite often. The example can be Hałda Storczykowa in the commune of Złoty Stok where the wastes from arsenic ores were deposited. This heap is now an ecological utility due to the rich flora, including calamine grasslands and the early spring orchis (Orchis mascula). Overgrown with vegetation old heaps now make recreational areas for local residents. They can be managed of left as „wild" areas. More and more often educational paths are made there, the purpose of which, apart from recreation is getting the visitors familiar with the history of this area and drawing their attention to local nature.

Due to changing economic conditions and developing technological possibilities of retrieving useful minerals from wastes, often old repositories are treated as anthropogenic deposit and mined. This also refers to the heaps of hard coal mining. Nowadays, during energy crisis and expected shortage of fuels in Europe and their growing prices, the recovery of coal from wastes deposited on heaps was included in the governmental programme of the reclamation of post-mining areas, in the framework of which a pilot installation for coal recovery was made. Unfortunately, during the exploitation of the mining wastes repositories valuable ecosystems, which were formed on them are lost. However, one should remember that the mining of such an anthropogenic deposit allows obtaining the lacking minerals, preserving natural deposits and ecosystems in the areas where these deposits occur. Making decision a waste repository should be mined, one must take into account both economic and ecological conditions.

Newly formed repositories are filled with post-mining wastes which cannot be used now. These repositories are reclaimed. There are many methods of technical and biological reclamation, depending on the conditions in the repository and its destination. Thus, depending on architectural, environmental and social conditions, regarding the well-being of the residents and cultural factors, two ways of procedures should be taken. Some objects should be reclaimed in a specific direction, so that the area can be used again, but some objects can be left for the formation of new habitats, due to natural processes taking place in the natural environment, even the environment with a strong anthropogenic pressure (Kantor-Pietraga et al. 2021; Pu et al. 2017; Chen et al. 2019). In the repositories formed now, valuable ecosystems will be formed with time. New technologies, allowing economically profitable recovery of minerals from wastes can appear. This way a difficult decision if the new habitats should be preserved or the mining should start will have to be taken.

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Rola sukcesji naturalnej w procesie rekultywacji obiektów unieszkodliwiania odpadów wydobywczych

Działalność przemysłu wydobywczego wiąże się z wytwarzaniem odpadów, powstających głównie w trakcie prac udostępniających, eksploatacji jak i przeróbki kopalin. Rodzaj jak i ilość wytwarzanych odpadów wynikają wprost z rodzaju pozyskiwanego surowca mineralnego (kopaliny), z występujących warunków geologicznych złoża oraz stosowanych technologii górniczych i przeróbczych. Zmieniające się podejście do odpadów związane z modelem gospodarki o obiegu zamkniętym powodują, że w coraz większym zakresie odpady są gospodarczo wykorzystywane. Niemniej jednak ze względu na właściwości fizykochemiczne odpadów wydobywczych i ograniczone możliwości ich wykorzystania, powodują, że niektóre odpady są nadal składowane na obiektach unieszkodliwiania odpadów wydobywczych (OUOW). W zależności od rodzaju składowanych odpadów wydobywczych, aspektów środowiskowych i ekonomicznych OUOW stanowić mogą źródło surowców (złoże antropogeniczne), które obecnie lub w przyszłości będą mogły być eksploatowane. Część tego typu obiektów jest rekultywowana i może stanowić cenny element lokalnego krajobrazu, a także korzystnie wpłynąć na różnorodność biologiczną, poprzez wykształcanie się specyficznych siedlisk przyrodniczych. W artykule przedstawiona została koncepcja rekultywacji OUOW z górnictwa węgla kamiennego, uwzględniająca znaczenie zjawiska sukcesji naturalnej w kształtowaniu się ekosystemów na rekultywowanych obiektach.

Słowa kluczowe: *obiekt unieszkodliwiania odpadów, składowiska odpadów wydobywczych, złoże antropogeniczne, gospodarka obiegu zamkniętego, rekultywacja, badania biologiczne*

Technological Reliability of Recycling Anthropogenic Minerals from the Landfills in the Move Towards Green Energy

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The subject of this paper is electromagnetic activation technology for fly ash, which allows for the transformation of the troublesome energy waste into a valuable market product. The move towards green energy, apart from decarbonisation and reduction of carbon dioxide emissions, is facing additional challenges, i.e. disposal and use of accumulated solid waste, which, due to its specific composition, may soon be considered hazardous. Therefore, it is important to recycle them for sale as a market product. Such opportunities are offered by the technology referred to above, which allows for the use of the above-mentioned anthropogenic minerals in concrete products. As demonstrated in the tests presented in the article, the use of activated fly ash does not deteriorate the resilience of concretes, bringing benefits in the form of avoiding emissions of CO_2 which is the result of limiting the use of cement and reducing emissions and transport costs. The liquidation of landfills also fits perfectly with the key points of the circular economy, at the same time implementing the philosophy of priority for secondary ones. High-efficiency and quick operation of furnace waste landfills has multi-threaded ecological effects, which include emission reductions, protection of natural resources and, finally, restoration and reclamation of devastated areas. The second group includes economic benefits, which will also be the result of many overlapping market effects.

Keywords: *fly ash, electromechanical activation, concrete, move towards green energy*

1. Introduction

The move towards green energy in Europe, including Poland, poses many new challenges, both in terms of the transformation to zero-emission energy, but also in terms of ordering the environment after coal energy. It must be implemented in accordance with sustainable development, keeping up with economic progress and, finally, ensuring an increase in the security of raw materials for both Poland and entire Europe. The reliability of the proposed solutions will be a key element that would not be possible without responsible and effective management of natural and anthropogenic minerals. The shift into circular economy model from the linear one is a necessity, and the existing "take-produce-consume-discard" attitudes should be a thing of the past and should be replaced with the philosophy of "use natural only if there are no secondary ones". The type of waste that still poses a big problem but can also be a chance to implement circular economy, is the constantly produced and collected fly ash from the energy industry. Exploitation of ash accumulated in landfills (25 million Mg) [1, 2] and transforming it into valuable market products should also be one of the goals of the proposed transformation. The move towards green energy should lead to ordering the natural environment with effective and reliable use of accumulated waste in the economy.

It is estimated that approx. 20.7 million tonnes of combustion waste, referred to as combustion by-products, are generated in Poland annually of which:

- approx. 11.8 million Mg – combustion by-product in the form of hard coal,
- approx. 8.9 million Mg – combustion by-product in the form of lignite. [3]

The recycling of combustion by-products in our country in recent years has been at the level of approx. 55–57%, but it is mainly using raw material.[4] In 2018, the document "Circular material use rate" was presented, and describing the methodology of waste circulation in the economy. Combustion waste is assigned to a category and it was included under the number W124. This document presents the methodology of the newly developed CMU indicator. This indicator represents the amount of material reintroduced into the economy, measured as a share of the total material consumption. First, we decided to exclude power recycling and landfilling, so that the CMU only covers material recycling. It is thus clear that the only way is to transfer waste to the economy. Another reason are the changes in the European legislation that force the necessity to revise the national waste catalogue again. As for the literal adoption of the list of the European waste catalogue into Polish legislation, not all waste generated in the systems will be included. In such circumstances, it will be necessary to prove that the above-mentioned waste is recognized as non-hazardous waste. Properties that may classify combustion waste as hazardous waste may result from the content of free calcium oxide CaO or Ca (OH)2 – substances which have been classified as dangerous substances according to Regulation (EC) No 1272/2008 due to proven specific target organ toxicity, skin irritation or serious eye damage. The waste will be considered hazardous if it contains at least one substance in a concentration above the limit value, classified in at least one of the hazard classes. Therefore, the technologies for transforming waste into a safe market product are needed. The use of combustion by-products in the economy

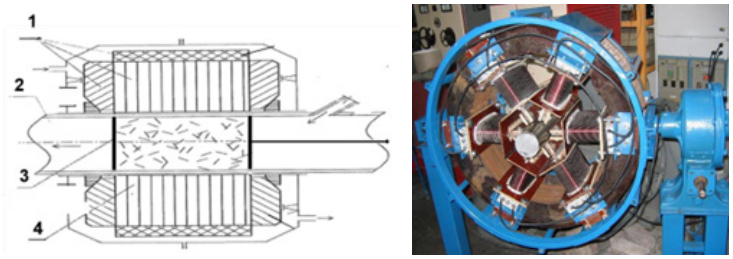

Fig. 1. Simplified diagram of an electromagnetic mill (left) Description: 1 - three-phase inductor, 2 - cylindrical working chamber, 3 - ferromagnetic grinding elements, 4 - inductor pole windings and a physical model of the inductor (on the right) [5,6,7]

Rys. 1. Uproszczony schemat budowy młyna elektromagnetycznego (po lewej) Opis: 1 –wzbudnik trójfazowy. 2 – cylindryczna komora robocza. 3 – ferromagnetyczne elementy mielące. 4 – uzwojenia biegunów wzbudnika oraz model fizyczny wzbudnika (po prawej) [5,6,7]

Tab. 1. Physical and chemical properties of silica fly ash selected for further research

Tab. 1. Właściwości fizyko-chemiczne krzemionkowego popiołu lotnego wytypowanego do dalszych badań

Properties	**Research result**	**Requirements according to PN-EN 450-1: 2009 standard**
Loss on ignition [% mass]	2.62	≤ 5.0 (cat. A) 2 ÷ 7.0 (cat. B) 4 ÷ 9.0 (cat. C)
Chloride(Cl^-) [% mass]	<0.01	≤ 0.10
Sulfuric anhydride as SO_3 [% mass]	0.34	≤ 3.0
CaO_{free} [% mass]	0.05	≤ 2.5
CaO_{react} [% mass]	3.60	≤ 10.0
$SiO_{2\ react}$ [% mass]	40.78	≥ 25.0
SiO_2 [% mass]	53.28	-
Al_2O_3 [% mass]	25.60	-
Fe_2O_3 [% mass]	6.36	-
$SiO_2 + Al_2O_3 + Fe_2O_3$ [% mass]	85.25	≥ 70.0
MgO [% mass]	2.67	≤ 4.0
Soluble phosphates as P_2O_5 [% mass]	0.0017	≤ 0.01
Na_2O [% mass]	1.054	-
K_2O [% mass]	3.088	-
Alkali as Na_2O_{eq} [% mass]	3.085	≤ 5.0
Specific density [kg/m^3]	2170	-
Blaine specific surface [cm^2/g]	3790	-
Fineness (sieve residue 0.045 mm in wet sieving)	34.35	cat. N ≤ 40 cat. S ≤ 12

has another extremely positive ecological aspect, namely it contributes to the reduction of total carbon dioxide emissions. The use of u combustion by-products as replacements for cements in construction materials will reduce emissions from the thermal treatment of components intended for the production of cement. Thus, the turn to green energy also results in problems with the disposal of waste from long-term production of coal energy. Safe and reliable technologies are needed to turn waste into marketable products, and the benefits of these solutions are multifaceted, from saving deposits of natural resources that we replace by combustion by-products to lower carbon dioxide emissions from cement production. Documentation prepared for the purposes of the registration process of combustion by-products in previous years, carried out at the EU agency ECHA, in accordance with the REACH regulation, proved that there are full grounds to consider that combustion by-products and gypsum from flue-gas desulfurization systems should not be classified as hazardous substances according to CLP Regulation No. 1272/2008 (EU) of the European Parliament and the European Commission of 16 December 2008 on classification, labelling and packaging of substances and mixtures. The hazard analysis and PBT/vPvB assessment showed that the combustion by-products and gypsum from flue-gas desulfurization systems do not meet the criteria for being classified as a hazardous substance (in accordance with Directive 67/548/EEC and 1272/2008/EC and do not pose a threat to humans or the environment. Therefore, there are all grounds to apply innovative high-efficiency technologies of transforming waste into utility products. [5,6,7]

2. Electromagnetic activation technology

In order for the material (fly ash) to become a full-value product, e.g. a cement substitute, it must meet a number of properties that are required from such materials, and at the same time be safe for the environment. The improvement of these properties can be achieved by applying, for example, mechanical or electromagnetic activation; by grinding, impact operations, temperature treatment or water treatment. You can combine all these methods with the use of an activator, i.e. an electromagnetic mill. The principle of operation of the electromagnetic mill is to generate a rotating electromagnetic field inside the grinding chamber. Due to magnetic induction, the grinding elements polarize, becoming magnetic dipoles, thanks to which they are attracted with a certain force by this field. As the magnetic induction increases inside the chamber, the chaotic, intense movement of fine ferromagnetic grinding elements is induced. Small size, proper shape and maintaining the appropriate proportions of dimensions allow to quickly achieve high accelerations and a maximum speed of approx. 3000 rpm (50Hz) [8]. The electromagnetic activator installation consists of two basic elements: a working chamber with grinding rods, i.e. magnetic steel rods and an electromagnetic field inducer (stator with salient pole windings). The working chamber is made as a closed non-ferromagnetic tube in which grinding media, excited by the field, move along with the activated material. Inside the working area, the activated material is processed: mechanically – by hitting it with high frequency and speed; thermally – by heating the grinding media under the influence of magnetic induction and mutual collisions,

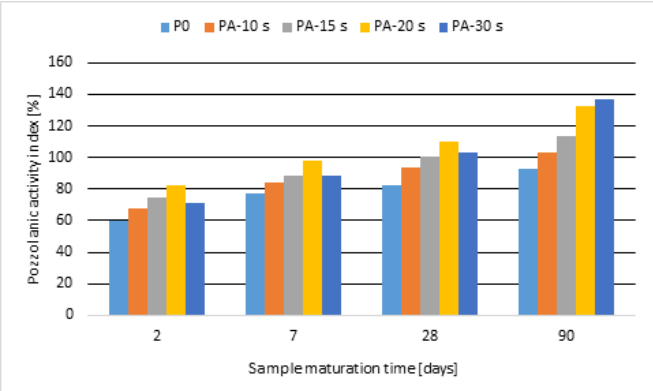

Fig. 2. Index of pozzolanic activity of reference ash (P0) and its modification (PA) after 10; 15; 20 and 30 sec. of mechanical activation

Rys. 2. Wskaźnik aktywności pucolanowej popiołu odniesienia (P0) oraz jego modyfikacji (PA) po 10; 15; 20 i 30 sek. mechanicznej aktywacji

as well as by the influence of the electromagnetic field. The scheme of the construction of the electromagnetic activator and the view of the field inductor are demonstrated in Fig. 1.

Basic technical parameters of the device and the set operating parameters during activation:

- magnetic induction in the central axis of the working chamber zone approx. 0.095T,
- dimensions of the working chamber 80 mm x 140 mm (the volume of the working chamber is about 0.71 dm^3),
- grinding media – steel bars with a diameter of 1 mm and a length of 10 mm,
- degree of filling the volume of the working chamber with grinding media – 10%,
- degree of filling the working chamber volume with feed (fly ash) – 60%,
- fly ash feed weight – 498 g,
- ratio of grinding media mass to feed mass – 0.24.
- activation time: 10 s, 15 s, 20 s, 30 s.

3. Methodology and research material

The primary objective of the research was to carry out electromagnetic activation on fly ash and cement samples, and then to produce concrete with activated fly ash and a reference material based on classic cement formulas. In the next stage, the samples were subject to tests, which are carried out as standard for classic concretes, in order to confirm their usefulness in the economy. The main parameter subject to tests was the durability test, which is decisive when to comes to the possibility of using concretes. These tests were carried out for all produced materials: for activated fly ash and for reference samples. In addition, a number of other studies were performed to describe the effects of the activation process on the end product. Finally, the optimum of activation was found based on the time criterion and increase in specific surface area and reduction of water demand. The subject of the research was silica fly ash subjected to mechanical activation in an electromagnetic mill and reference ash (not activated), which was then used as an additive replacing some Portland cement. The physicochemical properties of the activated ash are presented in Tab. 1.

For comparative tests and for preparing mixtures, CEM I 42.5 R Portland cement was used with a specific surface according to Blaine – 4000 cm^2/g, the content of C3A – 8.78% and Na_2Oeq – 0.87% of the total weight, CEN standard sand according to PN-EN 196-1:2005 standard, tested reference ash and its modifications after the mechanical activation process during the following times: 10; 15; 20 and 30 s. The specific surface area of the reference ash determined by the Blaine method was 3790 cm^2/g, and after its mechanical activation in time 10; 15; 20 and 30 s respectively: 4920; 5490; 6200; 6940 cm^2/g. Standard mortars with a w/s ratio of 0.5 and a binder/sand weight ratio of 1:3 were prepared for the tests. The composition of the mortars for the tested beams is presented below:

- reference mortar (model): 450 g of cement, 1350 g of standard sand, 225 cm^3 water
- mortar after replacing 25% of the cement mass with fly ash: 337.5 g of cement, 112.5 g of ash, 1350 g of standard sand, 225 cm^3 water.

The index of pozzolanic activity of the reference ash and its modification after the mechanical activation process was determined according to the PN-EN 450-1:2009 standard [9]. This indicator is expressed as a percentage ratio of the compressive strength of 40×40×160 mm bars made with a mixture of 75% reference cement and 25% of fly ash, to the strength of standard mortar bars of the same age made with 100% reference cement. The bars in the moulds were stored for 24 hours in humid air, and then, after demoulding, they were stored in water until the resilience tests were carried out.

The samples were subjected to compressive strength tests of 2; 7; 28 and 90 days of maturation in water according to PN-EN 196-1:2005 [10].

The water demand of the reference ash and its modification after the mechanical activation process was determined according to the procedure included in Annex B to the PN-EN-450-1:2009 standard [9].

Studies of the morphology and the texture of fly ash samples and its modifications were carried out using an ISM (IEOL) scanning electron microscope equipped with an energy dispersion spectrometer (EDX), which allowed to determine the chemical composition of selected grains of materials.

4. Results and discussion

The main components of the tested fly ash (Tab. 1.), converted into oxides, are: SiO_2, Al_2O_3, CaO, SO_3, Fe_2O_3, MgO, N_2O and K.$_2$O. They come from the decomposition of clay

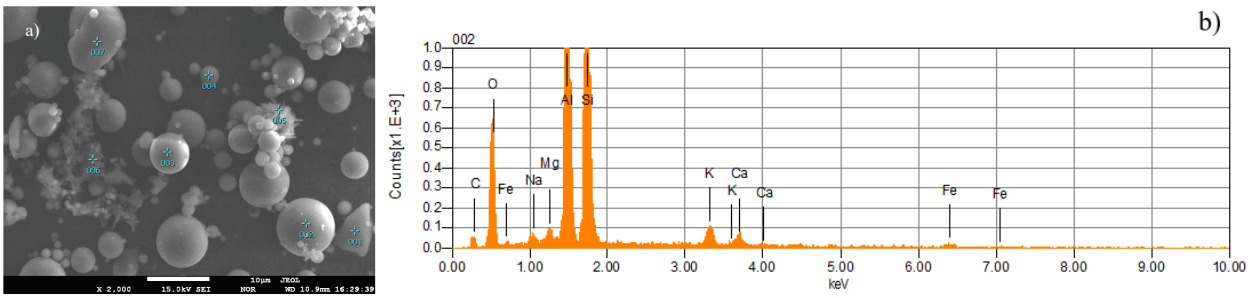

Fig. 3. SEM micrograph and EDS spectrum of reference ash

Rys. 3. Mikrofotografia SEM oraz widmo EDS popiołu odniesienia

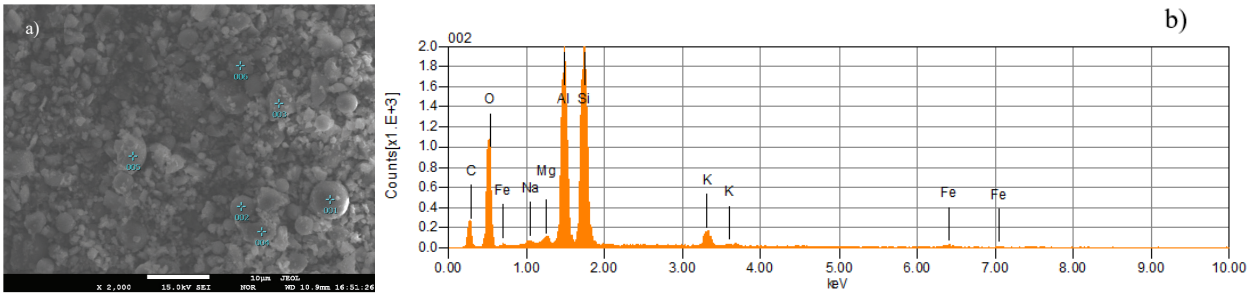

Fig. 4. SEM micrograph and EDS spectrum of ash after activation

Rys. 4. Mikrofotografia SEM oraz widmo EDS popiołu po aktywacji

minerals, pyrite and calcite, which are the inorganic components of coal. The basic chemical composition of this ash is typical for siliceous ashes from coal combustion in pulverized coal boilers without desulphurization. The analysis of the data contained in Tab. 1 shows that the tested silica fly ash meets all the requirements of the PN-EN 450-1:2009 [9] standard, which allows the ash to be used in concrete technology. The relatively low result of the loss on ignition (2.6%) qualifies this ash into category A, and the fineness (34.35%) to category N.

Fig. 2 shows the results of the pozzolanic activity of the reference ash and its modifications after mechanical activation, after 2; 7; 28 and 90 days of hardening.

The value of the pozzolanic activated ash index was higher than in the case of the reference ash, regardless of the ash activation time and the maturation time of the mortars. The dynamics of changes in the value of the pozzolanic index was constant for most of the activated ashes, with the exception of the ash activated within 30 s. The ash pozzolanic activity index increased with the increase of activation time (specific surface area) until the optimum for ash was reached after 20s of activation (approx. 6200 cm2/ g). For which, if compared with the reference ash, there was a significant increase in the pozzolanic activity index, which after 2; 7; 28 and 90 days of hardening the mortar reached the following values: 83%, 98%, 110% and 132%. On the other hand, increasing the activation time to 30 s (6940 cm^2/ g) caused the reduction of pozzolanic activity in the first stages of hardening of the mortar. Compared to the reference ash, the pozzolanic activity index, 2 each; 7; 28 and 90 days of hardening the mortar reached the following values: 71%, 88%, 103% and 137%.

Photographic documentation of SEM tests of reference ash (Fig. 3a) indicates high heterogeneity of the grain size within the range of 0 ÷ 170 μm. In the analysed sample of reference ash (Fig. 3a), both single grains and their agglomerates with irregular topography are observed.

In this ash the following morphological types of grains are represented in varying proportions: massive spherical; porous spherical and irregular rounded, irregularly sharp-edged, spongy, sharp-edged massive. Bulky, spherical and irregularly rounded spherical grains are made of glaze (amorphous or containing also slightly crystalline mullite). The chemical composition of the glaze (Fig. 3b) is essentially: Si, Al and K. Some of the grains also contain Fe, which indicates the presence of ferrous phase overgrowths. Fig. 3a shows that the grain composition of the ash is dominated by massive spherical grains with diameters of 1 ÷ 10 μm. The surface of most of these grains is clean, fine (less than 1 μm) crusts or sulphate phase inclusions are less often visible on it. Irregular, sharp-edged and spongy grains are generally found in the ash fraction thicker than 40 μm and are considered as non-melted clay mineral aggregates [11]. The coarse fractions also include massive, sharp-edged quartz grains and skeletal grains that are fragments of unburned carbon in a porous interior with fine spherical enamel grains. The porous, spherical and irregularly rounded grains are hollow (cenospheres) or may be filled with finer spherical grains (plenospheres). The authors of the study [11] believe that porous grains are formed from a viscous alloy with a high proportion of the gas phase, and massive grains – from a liquid alloy. Bulky and porous spherical grains occur essentially individually and form aggregate clusters composed of grains of various sizes (Fig. 3a).

The photographic documentation of the SEM tests of ash after mechanical activation indicates significant differences in the surface texture of the activated ash in comparison with the reference ash (Fig. 3a). Based on a comparative analysis of the photomicrographs from the SEM test of the reference ash (Fig. 3a) and after the modification of the ash (Fig. 4a), it was found that as a result of its mechanical activation, a significant development of its surface occurred, mainly due

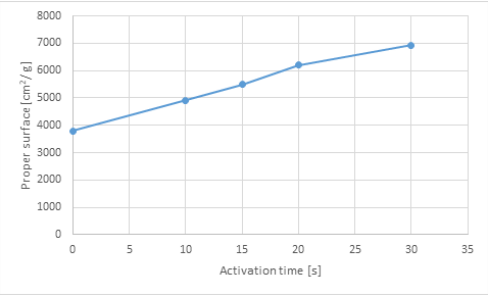

Fig. 5. The effect of activation time on the ash specific surface
Rys. 5. Wpływ czasu aktywacji na powierzchnię właściwą popiołu

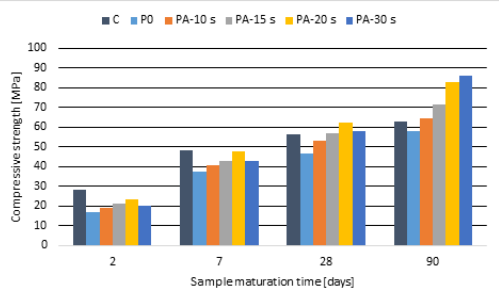

Fig. 6. Compressive strength of mortars: cement C; cement-ash with reference ash (P0); cement-ash with ash activated in 10 s (PA-10), 15 s (PA-15), 20 s (PA-20), 30 s (PA-30)
Rys. 6. Wytrzymałość na ściskanie zapraw: cementowej C; cementowo–popiołowej z popiołem odniesienia (P0); cementowo–popiołowych z popiołem aktywowanym w czasie 10 s (PA-10). 15 s (PA-15). 20 s (PA-20). 30 s (PA-30)

to the grinding of coarse grains, i.e. porous, spherical and irregularly rounded grains with empty interiors (cenospheres) as well as filled with fine (approx. 1 μm) with spherical grains (plenosphere). Dense aggregates of aggregate grains were also disagglomerated.

However, no significant fragmentation of the fine fraction (1÷10 μm) of the massive spherical grains was found, but only the cleaning of their surface of crusts and sulphate phase inclusions. From the analysis of the photomicrograph after mechanical activation (Fig. 4a) it transpires that the most susceptible to destruction are microspheres with empty interiors and small spherical grains inside. This is evidenced by numerous, relatively large, compared to massive spherical grains, fragments of crushed spherical shells of these grains. This is due to their significantly lower compressive strength compared to spherical massive grains, because the thickness of the walls of cenospheres and plenospheres does not exceed 10% and their diameters. Moreover, the fractures of such microspheres reveal the presence of numerous previously closed pores in their walls, which also reduce the mechanical strength of these grains. The deagglomeration of dense clusters of spherical grains and the opening of closed spaces inside the grains containing numerous smaller grains increases the proportion of the activated ash fine fraction of spherical massive grains, which are essentially the amorphous phase of the enamel rich in Si, Al, K. The key element determining the success of the application of fly ash is the increase of the surface area correct after electromagnetic activation. Its increase during activation is shown in Fig. 5.

Along with the extension of the activation time, a systematic increase in the specific surface area can be observed. It is caused by at least two reasons. Firstly, through grain cleaning, which opens the internal pores, and by the fragmentation resulting from the interaction of grinding media and grains with each other. The increase is practically linear and with 30 seconds of activation the value of the specific surface area is in fact doubled. Compressive strength tests performed are shown in Fig. 6. It was found that the compressive strength of mortars with reference ash was lower than in the case of mortars with activated ash, regardless of its activation time or the maturation time of the mortars.

Mortars with an addition of activated fly ash reached the resilience comparable to the resilience of the cement mortar without additives after 28 days of maturation. The analyses carried out demonstrate that the compressive strength of standard mortars with the addition of activated ash gradually increases with the increase of its activation time (an increase in the specific surface area).

As with the poozzolanic activity, until the optimum for ash is reached after 20s of activation (approx. 6200 cm^2/g). A further increase of the specific surface results in the reduction of mortar strength in the initial stages of hardening of the mortar.

This effect can be explained by the fact that in the range of ash activation times (up to 20 s), by the number of small spherical particles with an increased content of the amorphous phase (increased pozzolanic reactivity), released as a result of crushing plenospheres coatings, increases significantly. This is also confirmed by the fact that up to a certain level (activation time 20 s), as the specific surface of the activated ash increases, its water demand gradually decreases (Fig. 7) from the level of 96.9% to 88.9% (i.e. by 8.25%), and then for the 30 s activation time this factor increases again.

This can be explained by an increase in the amount of irregularly shaped particles (excessive grinding), which require more water particles to form a shell around the grain. It is also

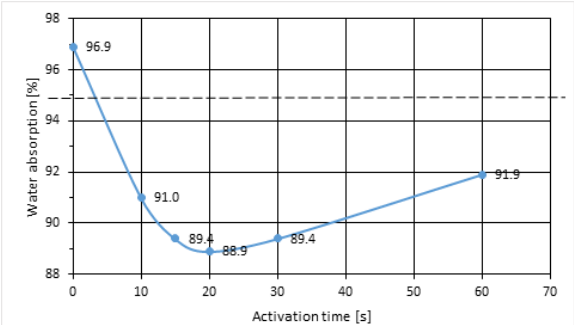

Fig. 7. Changes in fly ash demand depending on the time of its activation

Rys. 7. Zmiany wodożądności popiołu lotnego w zależności od czasu jego aktywacji

worth noting that all the obtained water demand results are much lower than the standard requirements. The tendency to reduce the water demand of ashes in the initial period of their mechanical activation and subsequent growth was also found in other publications [12].

Based on the above results, it can be concluded that the optimum fly ash activation time is 20 s, after exceeding this time, the demand for water increases, and the pozzolanic activity and compressive strength index decreased or slightly increased in the last stage of maturation.

The results of experimental studies have demonstrated that there is a relationship between the pozzolanic activity of ashes and the degree of their fragmentation. An increase in pozzolanic activity was found to reach the value of the Blaine specific surface area of 6200 cm^2/g, followed by its gradual reduction due to the progressive increase in the water demand of the activated ash due to an increase in porosity. A gradual increase in the proper surface area of the modified fly ash improves its pozzolanic properties by increasing the ability to react with $Ca(OH)_2$ and reducing water demand. It also positively influences the quick increase of the early strength, increases the strength parameters of the finished products, while reducing the water demand and improving the liquefaction of the mixture. Replacing 25% of cement with it in the mortar only slightly reduces the early strength, while in the further maturation period, the strength increases exceed the results obtained for pure cement.

5. Summary

The research carried out with the use of waste fly ash and electromagnetic activation technology indicates that there is a possibility of obtaining a valuable product from fly ash, which today is a kind of ecological and financial problem for the energy sector. The Green Deal provides for a gradual decarbonisation of the energy sector and the transition to renewable energy sources. On the other hand, apart from the elements strictly related to energy conversion and emissions, which are commonly discussed, there is also the issue of solid waste. In order to be effective, green transformation must be comprehensive, safe and reliable, so today it is necessary to indicate technologies that can turn troublesome waste into a market product. The presented electromagnetic activation technology shows the potential possibilities of treated waste. It indicates that the green transformation can also be an opportunity to protect valuable raw materials by using secondary anthropogenic minerals already extracted, which pose a problem, with an additional positive effect of avoided CO_2 emissions in cement production. A comprehensive approach to the issue of the Green Deal governance will create a safe system of transformation and will select reliable technologies for the exploitation of anthropogenic resources. Fly ash is a valuable material that, after appropriate treatment, can be used locally in road construction, which will again result in the protection of natural deposits and the avoided emissions from transporting aggregates from longer distances. The old slogan "grey to gold" is still valid and how eloquent it sounds in the new version, namely "grey to green".

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Niezawodność technologiczna odzysku minerałów antropogenicznych ze składowisk w zielonym zwrocie energetycznym

Przedmiotem artykułu jest technologia aktywacji elektromagnetycznej dla popiołów lotnych, pozwalająca kłopotliwe odpady energetyczne przekształcić w wartościowy produkt rynkowy. Przed zielonym zwrotem energetycznym poza samą dekarbonizacją i redukcją emisji ditlenku węgla stoją wyzwania dodatkowe, utylizacji i wykorzystania nagromadzonych odpadów stałych. które ze względu na swój specyficzny skład w niedługim czasie mogą być uznane za niebezpieczne. Dlatego też ważne jest aby zawracać je do gospodarki w postaci produktu rynkowego. Takie szanse daje opisana technologia, która pozwala na stosowanie z powodzeniem ww. minerałów antropogenicznych w wyrobach betonowych. Jak wykazały przedstawione w artkule badania, zastosowanie aktywowanych popiołów lotnych nie pogarsza właściwości wytrzymałościowych betonów, przynosząc korzyści w postaci uniknięte emisji CO_2 wynikającej z ograniczenia stosowania cementu oraz redukcji emisji i kosztów transportowych. Likwidacja składowisk wpisuje się również doskonale w założenia gospodarki obiegu zamkniętego realizując jednocześnie filozofię pierwszeństwa dla wtórnych. Wysokosprawna i szybka eksploatacja składowisk odpadów paleniskowych przynosi wielowątkowe skutki ekologiczne, na które składają się redukcje emisji, ochrona zasobów naturalnych i wreszcie przywracanie i rekultywacja terenów zdewastowanych. Drugą grupa, są korzyści ekonomiczne, które również będą wypadkową nakładających się na siebie wielu efektów rynkowych.

Słowa kluczowe: *popiół lotny, aktywacja elektromechaniczna, beton. zielony zwrot energetyczny*

Fuels from Waste in the Circular Economy as an Element of Multi-Sector Synergy

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The paper presents the current status of managing the combustible part of the waste (code 191210) as components for the production of alternative fuels. In 2017, about 2.3 million tons of fuels from waste were produced, while only about 1.3 million tons were recycled for energy, of which 97% in the cement industry. Oversupply on the alternative fuels market forces their producers to be more flexible in adapting their products to the growing requirements of customers. The article presents the results of tests of components for the production of alternative fuel used in the cement industry. An alternative fuel, not subjected to the comminution process, was used for the tests, which made it possible to segregate and name its individual fractions. A series of analyses were performed for the selected samples to determine their physicochemical parameters. The last element of the research was to create, based on the analyses and using the available components, fuel mixtures that meet the requirements for fuels of this type so that they meet the imposed standards, and at the same time are attractive for customers from the cement industry. The analysis of the obtained results made it possible to create optimum fuel mixtures with parameters that meet the requirements for this type of fuel. The mixtures obtained are a compromise between high-calorific products with a low chlorine content, the mass fraction of which was limited to such an extent that they could be used as a whole, and ingredients with an increased chlorine content, even a small amount of which exceeded the assumed content of this element.

Keywords: *alternative fuels, SRF, cement industry*

1. Introduction

Recycling of waste is one of the main objectives of circular economy, whose hypotheses are currently introduced in the European Union countries.[1] One of the possibilities of reusing the combustible part of waste is energy recycling. The production of alternative fuels is an opportunity to use this part of waste plastics for energy purposes, which is not recycled as a result of various factors. In Poland, every year, the process of reuse is subject to increasing amounts of waste classified as non-hazardous with the code 191210. The European Union has introduced uniform conditions for its member states for the classification of solid fuels from waste (under the name of Solid Recovered Fuels – SRF) and a research methodology for determining the quality of these fuels. [2,3] Standardizing this type of fuels will strengthen their presence on the market of energy carriers, as well as extend the scope of their current application in other energy-intensive industries. In Poland, the main recipients of alternative fuels are cement plants, which, due to the specificity of their production process, are particularly predisposed to use this type of fuel. On the other hand, in some EU countries, fuels produced from waste are increasingly more often used in industrial applications. The areas of application of waste fuels, apart from the cement industry, also include professional power engineering and heating, which seems to be justified both for economic and environmental reasons [4-9].

2. Production and use of alternative fuels in Poland

The production of alternative fuels, apart from material recycling, is one of the basic elements of the rational waste management system, in line with the assumptions of the circular economy. In Poland, the producers of this type of fuel are specialized companies processing the waste into high-energy fuels that meet additional quality requirements set by individual recipients. Another producer is the Regional Municipal Waste Processing Installations (Polish: RIPOK), mainly producing alternative fuels with lower quality parameters. Analysing the data contained in the reports regarding particular provinces, it can be noted that in 2015–2017 the amount of alternative fuels produced fluctuated slightly at the level of approx. 0.24 million Mg to reach the level of 2.36 million Mg in 2017. During this period, the number of systems for processing waste code with 19 12 10 ranged from 166 to 200. [10-11]

Table 1 presents the amounts of the produced and used alternative fuels in individual provinces, according to the data for 2017.

At that time, the energy use of alternative fuels ranged from 1.15 million Mg in 2015 to 1.32 million Mg in 2017, maintaining a slight upward trend. The data provided shows that the stream of produced alternative fuels is almost twice as high as the amount that is processed for energy production purposes. When analysing the data contained in Table 1, we can also notice a large dispersion both on the market of producers and recipients of alternative fuels. These factors increase competition on the alternative fuels market, and thus force their producers to be more flexible in adapting their products to the growing requirements of customers. Among the recipients of alternative fuels in Poland, the dominating one is the cement industry, which in 2017 processed 97% of the stream of all thermally transformed alternative fuels. The thermal energy recovered from combustion accounted for approx. 47% of the total energy used in the clinker combustion process. In the coming years, the cement industry is planning to increase the share of alternative fuels – the expected de-

Tab. 1. Amounts of produced and used alternative fuels in Poland

Tab. 1. Ilości wytwarzanych i wykorzystywanych paliw alternatywnych w Polsce

Voivodship	Number of generating installations	Quantity of alternative fuels produced	Quantity of alternative fuels used
	[pcs]	[Mg]	[Mg]
Silesian	28	384 736	51 764
Greater Poland	25	173 164	0
Masovia	22	643 156	38 658
Lublin	18	248 576	275 670
Lesser Poland	18	88 571	0
Kuyavia-Pomerania	13	209 880	161 937
Świętokrzyskie	8	94 298	461 228
Lodzkie	6	56 026	8 585
Opole	5	46 616	323 999
Subcarpathia	5	34 369	0
Warmia-Masuria	5	134 885	0
West Pomerania	5	145 640	1 942
Lower Silesia	3	73 828	0
Pomerania	3	14 121	0
Lubusz	2	15 137	0
Podlaskie	0	0	0

Tab. 2. Requirements set by cement plants for alternative fuel

Tab. 2. Wymagania stawiane przez cementownie dla paliwa alternatywnego

Parameter	Cement plant 1	Cement plant 2	Cement plant 3
Calorific value, MJ/kg	>20	≤18	18-22
Moisture content, %	<10 (10-15)	≥15	≥15
Ash content, %	<15 (15-20)	≤20	-
Sulphur content, %	≥0.5	≥0.5	≥0.5
Chlorine content, %	≥0.5	≥0.8	≥0.6
Granulation, mm	<40	<40	<25 (torch), 35 (cold end of the kiln)

mand is approx. 1.85 million Mg of fuel per annum. [12] The fuel used in the cement industry should be characterized primarily by a high calorific value, low chlorine and sulphur content, and homogeneous structure. This is important because it greatly influences the process, emissions and the final product. Controlling the combustion process itself and the quality of the fuel has a significant impact on obtaining clinker and cement that will meet the applicable standards. Apart from the physicochemical properties that are the basis for the use of alternative fuel, the fuel suitability is determined by such factors as granulation, not exceeding 30 mm and the absence of undesirable impurities. [13] Table 2 presents examples of the quality requirements for alternative fuels used in the cement industry.

3. Research methodology

The test was performed with the use of alternative fuel produced in accordance with the R12 recovery procedure. The research included a physical and chemical analysis as well as the content of chlorine in post-utilization materials with a polymer matrix. The analysis of the content of sulphur and elemental carbon was carried out with the use of the LECO SC 144 DR analyser. Combustion heat analysis was performed using the IKA C 2000 calorimeter. Qualitative analysis was performed with the Spectroscan V sequence spectrometer via synchronized rotation of the crystal around its axis and the detector in a circle, with continuous registration of the counter readings. A semi-quantitative analysis was also performed. The method allows to estimate the content of a given element with an error of up to 20%. In each spectral series (K, L or M) certain lines have dominant intensities and they have been chosen as the best indicators of the presence of a given element. The ash content analysis was performed according to the PN-EN 15403:2011 standard, and the moisture content according to the PN-EN 15414-3:2011 standard.

4. Research results

In order to produce a suitable reusable fuel, an analysis of the individual components had to be performed. An alternative fuel that has not yet been subjected to the comminution process was used for the tests, which made it possible to segregate and name its individual fractions. From the weight of 20 kg of the primary sample, 13 types of waste were selected, and the percentages of individual materials in the total weight of the sample were determined. Selected types of waste along with the assigned sample numbers are presented in Table 3.

The material for testing was prepared according to the applicable standards: for laboratory samples according to PN-EN 15443:2011, and for analytical samples according to PN-EN 15413: 2011. For the samples thus prepared, a series of analyses were performed to determine their physicochemical parameters, their results are presented in Table 4

The analysis of individual parameters shows a large discrepancy in the results for individual components included in the base sample. Due to the material diversity of which they were made and the form in which they appear (smooth elements, sponges, plastics), the waste groups obtained in the selection process are characterized by a large discrepancy in terms of moisture content. The highest humidity, from 20% to 30%, was characteristic for samples containing materials showing increased absorbency: synthetic fabrics (No. 4, No. 9), sponge (No. 7), artificial bristles (No. 8). On the other side of the scale, we have materials with closed structures that do not absorb water, mainly various types of rubber (No. 2, No. 5, No. 10, No. 11), for which the moisture content ranged from 1.3% to 2.9%.

Analysing the results of ash content in individual groups of selected waste, we see that in half of the cases this value does not exceed 15%. The exception here are four samples (No. 4, No. 7, No. 8, No. 9) also characterized by increased humidity, in which the ash content ranged from almost 38% to over 44%. Such an increased ash content seems to be related to the con-

Tab. 3. Results of analyzes of alternative fuels components

Tab. 3. Wyniki analiz komponentów paliw alternatywnych

Number	Name	Number	Name
1	conduit for carrying power cables	**8**	car seat covers
2	bicycle handles	**9**	synthetic fabrics 2
3	tires	**10**	rubber mounting elements
4	synthetic fabrics 1	**11**	pram tires
5	rubber covers for car pedals	**12**	plastic
6	rubber lagging	**13**	inner tubes , seals
7	sponge filling of car seats		

Tab. 4. Results of analyzes of alternative fuels components

Tab. 4. Wyniki analiz komponentów paliw alternatywnych

Name	Sulfur	Carbon	Moisture	Ash	Calorific value	Chlorine
	[%]	[%]	[%]	[%]	[kJ/kg]	[%]
1	0.160	14.42	11.3	20.5	26075	0.04
2	0.087	15.92	1.7	13.5	24033	5.30
3	0.328	21.86	8.1	13.0	33112	0.04
4	0.742	34.68	29.9	32.7	12695	0.01
5	0.488	37.84	2.9	9.7	33321	10.60
6	0.305	29.6	6.5	34.3	21862	> 0.04
7	0.053	26.69	29.9	18.0	19390	0.14
8	0.570	21.70	24.2	27.0	21800	0.00
9	0.035	33.42	20.3	32.7	13127	0.00
10	0.702	36.52	1.5	27.9	21432	1.68
11	0.032	23.89	1.3	4.3	41006	> 0.04
12	1.979	19.75	7.9	0.5	42663	> 0.04
13	0.116	20.64	7.7	14.5	23847	> 0.04

Tab. 5. Parameters of produced alternative fuels

Tab. 5. Parametry wytworzonych paliw alternatywnych

Name	Sulfur	Carbon	Moisture	Ash	Calorific value	Chlorine
	[%]	[%]	[%]	[%]	[kJ/kg]	[%]
Mix 1	0.57	33.00	6.70	13.90	27352	0.91
Mix 2	0.42	30.86	12.08	18.74	26091	0.82
Mix 3	0.49	28.21	9.41	16.59	26253	0.52
Mix 4	0.41	24.97	12.46	17.61	25632	0.03
Mix 5	0.43	31.99	18.38	20.12	25889	0.38

tamination of wet waste with mineral parts stuck to it, creating an additional undesirable ballast.

In the analysed groups of components, the calorific value ranged from approximately 13 MJ/kg for synthetic materials (No. 4 and No. 9) to over 42 MJ/kg for pram tires (No. 11) and plastics (No. 13). These discrepancies result from the variety of plastics from which the waste from individual selected groups is made. For four of them (No. 4, No. 7, No. 8, No. 9), the ballast contained in the samples also has a significant impact on the calorific value. In the increased form, the moisture content ranges from over 20% to almost 30% and the ash content significantly different from the other groups, ranging from about 28% to about 34%.

The last element of the research was to create fuel mixtures that meet the requirements for this type of fuel based on the analyses and the use of available components, so that they meet the imposed standards, and at the same time are attractive to customers from the cement industry.

It was assumed that such fuels should have the following parameters:

- calorific value above 25,000 kJ/kg
- chlorine content below 1.0%
- sulphur content below 0.5%
- ash content below 20%

The analysis of the results presented in Table 4 allowed for the selection of component blends so that the alternative fuels produced on their basis met the adopted assumptions. As a result of further work, 5 different fuel blends were produced from selected fractions, which, according to the assumptions, should meet the above-mentioned quality criteria. Samples were prepared from the prepared mixtures and then subjected to a set of analyses in the same scope as for individual components.

When analysing the results of the analyses of the fuel mixtures presented in Table 5 below, it can be observed that they meet the hypotheses adopted at the beginning of their formation. Only in the mixture 5 a slight excess of the assumed ash content was noted.

The mixtures are a compromise between high-calorific products with a low chlorine content, the mass fraction of which was limited to such an extent that they could be used as a whole, and ingredients with an increased chlorine content, even a small amount of which exceeded the assumed content of this element. For example, such a mixture should include a relatively small amount of rubber elements: tires, tubes, gaskets, which due to the high calorific value would be ideal for creating such fuels. Considerable amount of car recycling waste, such as synthetic fabrics, limited only by the increased ash content. And also very limited quantities of the following: car pedal covers or rubber installation elements containing large amounts of chlorine. Correctly composed mixtures of semi-finished products allow for the production of high-quality alternative fuel using the entire range of semi-finished products included in the primary sample

5. Conclusion

The changes taking place in the alternative fuels market in the recent years indicate that the phenomenon of oversupply

will continue in the coming years. Such a situation on the market forces the producers to be more flexible in adapting their products to the growing requirements of customers. The presented research results allow to conclude that by optimizing the selection of components, it is possible to produce alternative fuels, the use of which seems to be justified both for economic and ecological reasons. For this purpose, it would be necessary to conduct research on individual components used in the production of alternative fuels and to monitor the received waste used for their production on an ongoing basis. This will allow for the production of high-quality alternative fuels with a guarantee of repeatability of parameters, which will translate into an increase in their competitiveness on the market of this type of fuel. And also, with appropriate legislative support, it may translate into the extension of their use as part of a fuel stream in the energy and heating sectors, simultaneously reducing the oversupply, minimizing pathologies related to their storage and being more fully in line with the assumptions of the circular economy.

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Optymalizacja parametrów paliw alternatywnych dla przemysłu cementowego

W pracy przedstawiono aktualny stan zagospodarowania palnej części odpadów o kodzie 191210 jako komponentów do produkcji paliw alternatywnych. W roku 2017 wyprodukowano około 2,3 mln tony paliw pochodzących z odpadów, natomiast odzyskowi energetycznemu poddano tylko około 1,3 miliona ton z czego 97% w przemyśle cementowym. Nadpodaż na rynku paliw alternatywnych wymusza na ich producentach większą elastyczność w dostosowaniu swoich produktów do rosnących wymagań odbiorców. W artykule przedstawiono wyniki badań komponentów do wytwarzania paliwa alternatywnego wykorzystywanego w przemyśle cementowym. Do badań zostało wykorzystane paliwo alternatywne nie poddane jeszcze procesowi rozdrabniania, co umożliwiło wysegregowanie i nazwanie poszczególnych frakcji wchodzących w jego skład. Dla tak przygotowanych próbek wykonano szereg analiz mających określić ich parametry fizykochemiczne. Ostatnim elementem badań było wytworzenie na bazie wykonanych analiz oraz przy wykorzystaniu dostępnych komponentów mieszanek paliwowych odpowiadających wymaganiom stawianym paliwom tego typu tak by spełniały narzucone normy, a jednocześnie były atrakcyjne dla odbiorców z przemysłu cementowego. Analiza otrzymanych wyników pozwoliła na stworzenie optymalnych mieszanek paliwowych, o parametrach spełniających wymagania stawiane tego typu paliwom. Otrzymane mieszanki są kompromisem pomiędzy wysoko kalorycznymi produktami o niskiej zawartości chloru, których udział masowy ograniczono do takiego stopnia by wykorzystać je w całości, a składnikami o podwyższonej zawartości chloru, których nawet nie wielka ilość powodowała przekroczenie założonej zawartości tego pierwiastka.

Słowa kluczowe: *paliwa alternatywne, SRF, przemysł cementowy*

An Innovative Series of Types of Flameproof Lithium-ion Batteries of the SBS-4Lion Type for Powering Battery Locomotives in Underground Mines and Surface Shunting Locomotives with Stored Energy of 105 kWh and 150 kWh

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Battery and diesel locomotives are used in horizontal transport in Polish underground mining plants. At the moment, diesel locomotives have proved to be economically expensive: high diesel fuel consumption, low durability of drive engines and pollution of the workings atmosphere.
Battery locomotives have become more economical and ecological again. Based on the above, the PHPU Izol-Plast Sp. z o. o. company implemented a project co-financed by the EU, developing and implementing a physically innovative solution for a series of battery batteries in lithium-ion technology with a capacity of 105kWh and 150kWh.

Keywords: *flameproof batteries, Li-ion battery*

Introduction

In underground mining plants, battery and diesel locomotives are used for horizontal transport. In recent years, diesel locomotives have been introduced for transport, which at the moment turned out to be a fiasco for several reasons: high diesel fuel consumption, low durability of engines and air pollution in mine workings. At the moment, from the economic and ecological point of view, battery locomotives are more efficient.

Based on the above, the company PHPU Izol-Plast Sp. z o. o. carried out an EU-funded project by developing and physically implementing the design of the SBS-4Lion type battery series mentioned in the title of the article, with an energy capacity of 105 kWh and 150 kWh.

1. Purpose and construction of the SBS-4Lion battery

The SBS-4Lion batteries are made of cells made in the LiFePO4 technology, they are designed to power the Lea-BM12 and ELA-44-1/2/3 battery locomotives. They can also be used to power other machines in underground mines as well as shunting locomotives on the surface.

The battery housing is flameproof in the form of a cuboid divided into chambers. The chambers are divided by 4 rows of through pipes for passive cooling of the battery cells. Cells with a capacity of 1000 Ah were installed in the chambers for the 150 kWh battery, and cells with a capacity of 700 Ah for the 105 kWh battery.

In one of the chambers, a battery controller is built in, supervising the operation of the battery during charging and during its operation.

The CONTROLLER performs the following functions:

- prevents overcharging and deep discharge of cells;
- during charging, it supervises the even charging of the cells;
- controls the cell temperature;
- measures battery voltage and charge/discharge current in real time;
- cuts off the battery charging power supply or its operation in emergency states and in cases intended by the battery operator through external control buttons;
- intrinsically safe circuit supervising battery charging ensures proper connection of battery plugs to battery and charging rectifier sockets, as well as interrupts charging in case of violation of the disconnector of connection sockets or a particular plug.

To connect the battery with the charging rectifier and the locomotive, a special plug socket of the OGB-500 type was designed, equipped with a current disconnector and a set of contacts operating in an intrinsically safe circuit supervising the charging process from the rectifier.

The plug of the connection socket is compatible with the plugs previously used on Lea- BM12 and ELA-44/1/2/3 locomotives.

In order to adapt the locomotive to work with the SBS-4Li-on type battery, equipped with OGB-500 sockets, the protective fuses from the BPS-350 fuse must be replaced with the BPS-350/II in the plugs of the A+ and B- sockets.

ge 150 V

2. OPB-500 rectifier

For charging the SBS-4Lion type battery, there is a dedicated charger manufactured by PHPU Izol-Plast Sp. z o. o. OPB-500 flameproof rectifier with passive and forced cooling of the flameproof housing.

The rectifier must be powered from the IT network 3x500 V from a mine circuit breaker, on the surface from a 3x400 V manual switch with 100 A protection .

Rectifier parameters:

- supply voltage – 3x500 V or 3x400 V;
- power – 50 kW;

Tab. 1. Li-ion battery specifications

Tab. 1. Specyfikacja akumulatora Li-ion

	Battery 105 kWh	Battery 150 kWh
Cell type	WB-LYP700AhA	WB-LYP1000AhC(A)
Capacity	700 Ah	1000 Ah
Maximum charging current	300 A	
Minimum temperature of the cell during charging	0ºC	
Nominal cell voltage	3,2 V	
Maximum cell voltage	3,8 V	
Maximum battery voltage	150 V	
The number of cells in a battery connected in series	47	
Level of security	IP 54	
Dimensions of the battery (length x width x height)	2590 x 1070 x 860 mm	
Weight (without cells)	1740 kg	
Weight (with cells, depending on the type of cells)	2900 lub 3860 kg	
Ambient temperature	- 10ºC ≤ Tamb. ≤ + 40ºC	

– charging current max – 350 A;
– mass – 550 kg;
– noise level – 50 db;
– passive cooling + forced coolant (Borygo).

3. Battery charging

The SBS-4Lion type battery will be charged from the OPB-500 type rectifier dedicated by the manufacturer.

The battery can be charged on a locomotive in any excavation with wheeled transport classified as a, b, c methane explosion hazard and A and B coal dust explosion hazard.

The SBS-4Lion battery charging station should be equipped with:

– flameproof mine switch powered from 500 V IT network and 100 A current;
– OPB-500 flameproof rectifier;
– hoist on a rail transverse to the excavation axis with a lifting capacity of 6t, powered by electricity or compressed air;
– position for putting the batteries away during the inspection and service of the locomotive chassis;
– connected SUPO network to the circuit breaker and rectifier;
– while charging the SBS-4Lion type battery, the battery casing must be grounded to the SUPO mine network, on the surface the OPB-500 rectifier should be protected against the influence of weather conditions - mainly precipitation and in a shaded place.

To inspect the locomotive chassis, you can install a gate with a 6-ton load-bearing rail and install an electric hoist with such a lifting capacity that it is possible to remove the battery from the locomotive. The concept of such a station is shown in Fig. 2. The concept of charging stations in underground mining operations is shown in Fig. 1.

4. Battery usage

SBS-4Lion batteries are maintenance-free. The battery cells are completely sealed, they do not have any filler plugs or discharge valves during operation and charging, no gases are emitted from the cells.

Batteries in service should be periodically checked for proper tightening of inter-cell connectors. The inspection should preferably be carried out by a specialist company, e.g. every 6 months. The entire operation of the battery during operation and charging is supervised by a CONTROLLER built in a flameproof housing.

5. Economic and ecological effects

The use in the battery locomotives listed in point 1 will give mining plants the following effects:

– will allow for almost maintenance-free operation of the battery, due to the fact that the cells in li-ion technology are completely maintenance-free. No electrolytes or demineralized water are added to the cells. Cells do not emit any gases;
– will allow only 1 li-ion battery to be used for each locomotive. No reserve is needed.

During operation, the battery can be recharged at any time during short breaks, e.g. between shifts;
– electric motors are simple in construction with a long service life, especially when it comes to the ELA-44 locomotive where the most reliable 3-phase asynchronous motors have been used;
– it will make it possible to resign from servicing the battery charging station, which, due to the harmful atmosphere, works in a shorter time;
– in the construction of new mining levels, it will make it possible to resign from the need to build very expensive battery storage rooms;
– will reduce the cost of battery repairs, because li-ion batteries have at least 5 times higher permissible number of cycles.

6. Second life of li-ion batteries

As mentioned above, li-ion batteries have about 5 times more cycles than classic batteries with electrolyte or gel.

Li-ion batteries after 10 years of operation still retain 70% of their capacity. Therefore, the cells of a worn-out battery can get a so-called second life. They can be used to build energy storage facilities, e.g. in widely understood photovoltaic installations, where they can be used for another 10 years.

7. Disposal of li-ion cells

Used li-ion battery cells can also be recycled.

Manufacturer of li-ion batteries for the mining industry PHPU Izol-Plast Sp. z o. o. can accept used cells for recycling because it knows companies in the country that deal with this, but at this stage it has not yet selected a specific recipient. During utilization, 80% of the materials used for production

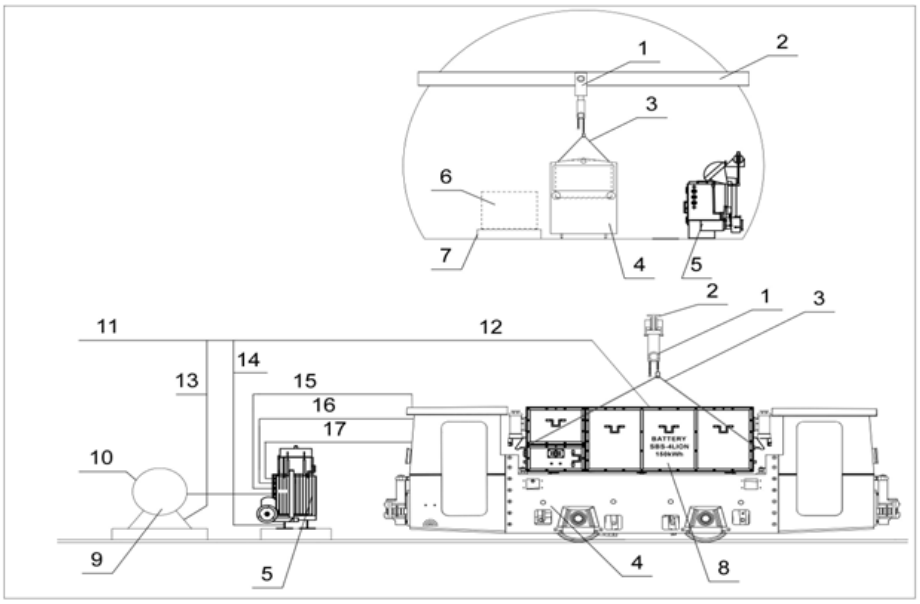

Fig. 1. Stand for fast battery charging on a locomotive in any excavation of an underground mining plant (concept); 1 – self-propelled 6-ton chain hoist type SWŁ-6; 2 – running rail – l-beam 300 mm; 3 – 4-hook rope sling; 4 – electric battery locomotive type ELA-44/3; 5 – OPB-500 rectifier; 6 – SBS-4Lion battery during inspection of the locomotive; 7 – place for batteries -3x1 field – concrete; 8 – battery SBS-4Lion; 9- mine curcuit breaker – 100A; 10 – 500V IT grid; 11 – SUPO grid; 12 – SBS-4Lion battery ground clamp; 13 – mine curcuit breaker ground terminal; 14 – ground clamp of the OPB-500; 15 – instrinsically safe curcuit control cable; 16 – high-current cable B-; 17 – high-current cable A+ [lenght of high-current cables is about 7.5m]

Rys. 1. Stanowisko szybkiego ładowania baterii na lokomotywie na dowolnym przekopie (koncepcja); 1 – samojezdny wciągnik łańcuchowy 6-cio tonowy typu SWŁ-6; 2 – szyna jezdna - dwuteownik 300 mm; 3 – zawiesie linowe 4-rozaczepowe; 4 – elektryczna lokomotywa akumulatorowa typu ELA-44/3; 5 – prostownik OPB-500; 6 – bateria SBS-4Lion podczas przeglądu lokomotywy; 7 – miejsce na baterię – pole 3x1 m –beton; 8 – bateria SBS-4Lion; 9- wyłącznik kopalniany – 100A; 10 – sieć IT 500V; 11 – sieć SUPO; 12 –zacisk uziemienia baterii typu SBS-4Lion; 13 – zacisk uziemienia wyłącznika kopalnianego; 14 – zacisk uziemienia prostownika OPB-500; 15 – kabel sterujący obwodu iskrobezpiecznego; 16 – przewód wysoko-prądowy B-; 17 – przewód wysoko-prądowy A+ [długość przewodów wysoko-prądowych około 7.5]

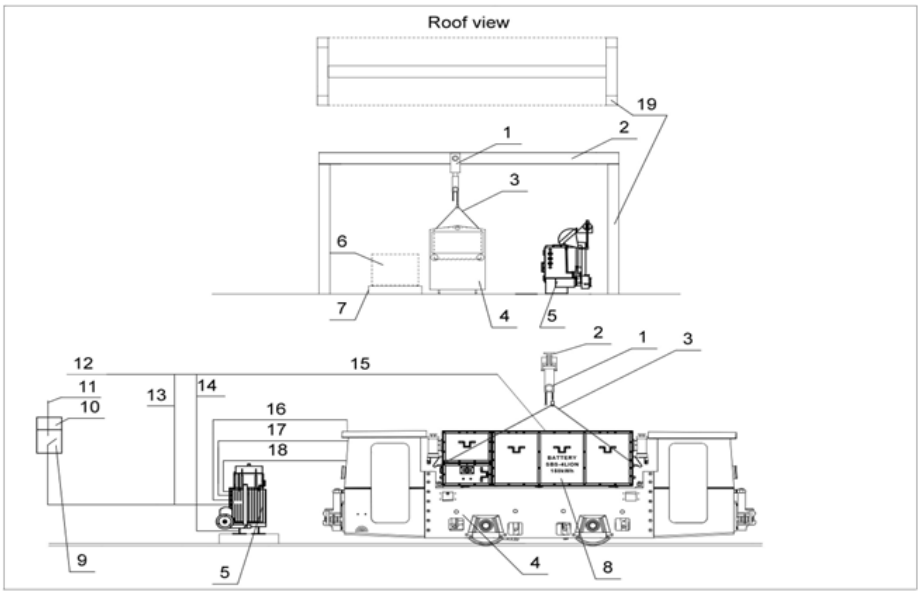

Fig. 2. Quick charging station on the ground (concept); 1 – self-propelled 6-ton chain hoist type SWŁ-6; 2 – running rail – l-beam 300 mm; 3 – 4-hook rope sling; 4 – electric battery locomotive type ELA-44/3; 5 – OPB-500 rectifier; 6 – SBS-4Lion battery during inspection of the locomotive; 7 – place for batteries -3x1 field – concrete; 8 – battery SBS-4Lion; 9 – manual switch; 10 – 3x100A fuse; 11 – 500V IT grid; 12 – SUPO grid; 13 – mine curcuit breaker ground terminal; 14 – ground clamp of the OPB-500; 15 – SBS-4Lion battery ground clamp; 16 – instrinsically safe curcuit control cable; 17 – high-current cable B-; 18 – high- current cable A+ [lenght of high-current cables is about 7.5m]; 19 – pole.w329

Rys. 2 Stanowisko szybkiego ładowania na powierzchni(koncepcja); 1 – samojezdny wciągnik łańcuchowy 6-cio tonowy typu SWŁ-6; 2 – szyna jezdna - dwuteownik 300 mm; 3 – zawiesie linowe 4-ro zaczepowe; 4 – elektryczna lokomotywa akumulatorowa typu ELA-44/3; 5 – prostownik OPB-500; 6 – bateria SBS-4Lion podczas przeglądu lokomotywy; 7 – miejsce na baterię – pole 3x1 m – beton; 8 bateria SBS-4Lion; 9 – wyłącznik ręczny; 10 – bezpiecznik 3x100A; 11 – sieć IT 500V; 12 – sieć SUPO; 13 - zacisk uziemienia wyłącznika kopalnianego; 14 – zacisk uziemienia prostownika OPB-500; 15 – zacisk uziemienia baterii typuSBS-4Lion; 16 – kabel sterujący obwodu iskrobezpiecznego; 17 – przewód wysoko-prądowy B-; 18 – przewód wysoko-prądowy A+ [długość przewodów wysoko-prądowych około 7.5m]; 19 – słup

are recycled, mainly cobalt, nickel and lithium. These metals currently have high prices on world markets due to the demand for them for the ever-increasing production of li-ion batteries.

8. Summary of the project

PHPU Izol-Plast Sp. z o. o. during the development and implementation of the production of a series of li-ion batteries in flameproof housings, it has acquired the technology of building any type of batteries that can be used in other industries, transport, and in widely understood energy storage installations. Accordingly, interested parties are encouraged to cooperate.

Acknowledgement

The tests of individual elements of the entire project were carried out in the "Laborex" laboratory of the OBAC – Gliwice company, and functional tests in the company PHPU Izol-Plast Sp. z o. o. For the development of the BPS-500 fuses, cooperation with Dr. Eng. Antoni Przygrodzki from the Faculty of Electrical Engineering of the Silesian University of Technology.

The research was carried out as part of the project co-financed from European Funds: "Conducting research and development works to develop an innovative product – a series of types of flameproof Li-Ion batteries for powering locomotives in underground mines with stored energy of 105 kWh and 150 kWh".

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Innowacyjna seria ognioszczelnych akumulatorów litowo-jonowych typu SBS-4Lion do zasilania lokomotyw bateryjnych w kopalniach podziemnych oraz powierzchniowych lokomotyw manewrowych o zmagazynowanej energii 105 kWh i 150 kWh

Lokomotywy akumulatorowe i spalinowe są wykorzystywane w transporcie poziomym w polskich podziemnych zakładach górniczych. W chwili obecnej lokomotywy spalinowe okazały się drogie ekonomicznie: duże zużycie oleju napędowego, mała trwałość silników napędowych oraz zanieczyszczenie środowiska pracy. Lokomotywy akumulatorowe znów stały się bardziej ekonomiczne i ekologiczne. W oparciu o powyższe firma P.H.P.U.Izol-Plast sp. z o o zrealizowała projekt dofinansowany ze środków UE, opracowując i wdrażając nowatorskie fizycznie rozwiązanie dla serii akumulatorów akumulatorowych w technologii litowo-jonowej o pojemności 105kWh i 150kWh

Artykuł powstał w ramach projektu dofinansowanego z Funduszy Europejskich:
Przeprowadzenie prac badawczo-rozwojowych w celu opracowania innowacyjnego produktu – typoszeregu ognioszczelnych baterii Li-Ion do zasilania lokomotyw w podziemnych zakładach górniczych o zmagazynowanej energii 105 kWh i 150 kWh.
Badania poszczególnych elementów całości projektów były prowadzone w laboratorium „Laborex" firmy OBAC – Gliwice a funkcjonalne w firmie PHPU „Izol-Plast" Sp. z o.o.
Dla opracowania bezpieczników BPS-500 współpracowano z dr inż. Antonim Przygrodzkim z Wydziału Elektrycznego Politechniki Śląskiej.

Słowa kluczowe: *ognioszczelne baterie litowo-jonowe ognioodporne, akumulator litowo-jonowy*

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