Selection and Calculation of Air Cooling Solutions in Underground Coal Mines in Vietnam

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Abstrakt

Currently, Vietnamese underground mines have been exploited down to -500 m and, in the near future, they will be exploited deeper. The exploitation of coal of seams has an negative impact on a workers environment. The increase in the depth of coal seam exploitation causes is the increase of adverse microclimate factors such as temperature, moisture, heat radiation. According to the current Vietnamese laws, coal deposits can be mined in a condition when air temperature does not exceed 30oC, although this rule is not always observed, especially during summer. The article show how reducing the adverse impact of climate factors in the mines and calculating the parameters which reduce the temperature on an example in one of underground coal mines in Vietnam.

Keywords: *air temperature, air humidity, air cooling, thermal power of cooler*

1. Introduction

In underground mines, in addition to technical hazards resulting from technological processes, there are also natural threats related to the rock mass surrounding the excavation (water, gas, gas and rock burst, gas and dust explosions and climatic hazards). The air flow temperature is the main factor shaping the climate in headings. The prevailing microclimate determines the working conditions of mining crews in workplaces. Working in difficult climatic conditions, especially in hot environments, is often associated with acute ailments which are caused by disturbances of water-mineral balance with impaired thermoregulation of the body. It causes decreasing in such functions of the human body as the ability to perceive, concentrate, pay attention, perceptiveness and work efficiency [1, 2, 3]. Air parameters significantly reduce the efficiency of mineral extraction, which contributes to reduce in the economic efficiency of the underground mining plant.

Factors influencing the character of the air temperature in the excavation are: sources of moisture, depth of exploitation and related air compression in the air intake shafts and heat flow from the rock mass to the air. Moreover, an increase in air temperature causes the temperature oxidation of coal and additional technological heat sources (electromechanical devices) [4, 5]. Another factor affecting the deterioration of climatic conditions air humidity is often exceeding 85%.

The main methods of combating temperature threat in underground mines include the classic ventilation methods and artificial air cooling methods. In this article, the authors analyse a solution of reducing the adverse impact of climatic factors on the state of air in the heading of coal mines in Vietnam, involving an utilization of local cooling equipment.

2. Microclimate parameters in underground hard coal mines in Vietnam

Most of the underground mines of the Vietnam National Coal – Mineral Industries Holding Corporation Limited (VINACOMIN) had completed the mining of deposits over the sea level since 2019, such mines include Vang Danh, Thong Nhat, Nam Mau, Ha Lam, Khe Cham III, Khe Cham II-IV, Mao Khe and Nui Beo. The annual average production in these mines is around 1,500,000 Mg. Vietnamese underground mines are shallow mines which extract coal deposits up to 300 m below ground, e.g. Nui Beo, Ha Lam, Mao Khe, Khe Cham III. Deepest mines include Khe Cham II-IV, reaching to 500 m below ground. In these mines, the annual average production in the wall is output, and it is over 500,000 Mg, e.g. in the Ha Lam mine the wall 11-1-17 of coalbed 11 about 600,000 Mg is extracted, and the wall 7-2-1 of coalbed 7 about 1,200,000 Mg of coal per year.

In the next few years, VINACOMIN will accelerate the implementation of mechanization for mining from seams by longwall systems and spoil transport, such as the use of mechanized mining technology, longwall shearers will be used and the excavated belt transport system will be modernized. Mechanization will also be used to transport people and materials.

Vietnamese underground mines use a ventilation system based on main ventilation fans, the so-called central suction system.

Mining operations in Vietnam are governed by Regulation No. 03/2011/TT-BCT of the Ministry of Industry and Trade, according to which the air velocity in the wall and heading faces cannot be less than 0.25 m/s. In mines with methane hazard categories III and IV air current speed cannot be below 0.5 m/s (in faces with an 15° incline or coal deposits is thicker than 2 m as well as face headings with a length up to 100 m). Air velocity cannot exceed: 4 m/s in coal excavations, 8 m/s for tunnel headings, 10 m/s – for air crossings, 12 m/s in shafts and fore-shafts while transporting people and 15 m/s in air ducts [6]. Table 1 presents the volumetric air stream and its velocity in selected underground mines in Vietnam.

According with Vietnamese regulations (03/2011/TT-BCT), air temperature at the working site cannot exceed 30oC [6]. In the most cases in underground mines in Viet-

Tab. 1. Examples of air velocity and volum delivery in selected mines in Vietnam

Tab. 1. Temperatura i wilgotność powietrza w badanych wyrobiskach kopalń podziemnych w Wietnamie

No.	Heading name	Volum air stream [m^3/s]	Cross-sectional area of the heading [m^2]	Air velocity [m/s]
A	**Ha Lam mine**			
1	Wall -150 / -160, zone III, coalbed 11	6.9	5.2	1.33
2	Wall 10-2, zone III, coalbed 10	6.0	5.1	1.18
3	Wall CGH 7-3-1	24.0	10.4	2.31
B	**Vang Danh mine**			
1	Bottom road of wall CII-8-3, coalbed 8, Canh Ga zone	4.6	4.5	1.02
2	Air-heading of wall CII-8A-2, coalbed 8A, Canh Ga zone	5.4	4.8	1.13
3	Air-heading level +106, coalbed 6, Gieng Vang Danh zone	13.2	5.5	2.40
C	**Thong Nhat mine**			
1	Bottom road of wall KT7	6.7	4.8	1.40
2	Air-heading of wall KT8	11.0	8.5	1.29
3	Bottom road of wall KT9	11.2	6.6	1.70

Tab. 2. Air temperature and humidity in selected headings of underground mines in Vietnam

Tab. 2. Temperatura i wilgotność powietrza w wybranych wyrobiskach kopalń podziemnych w Wietnamie

No.	Heading name	Air parameters	
		Temperature [°C]	Relative humidity [%]
A	**Mao Khe mine**		
1	Air-heading, level -80, coalbed 8	29.0	83
2	Carrying heading, level -80 of wall I, coalbed 8, east	30.6	87
B	**Vang Danh mine**		
1	Carrying cross-heading, level -50 F11-F12, zone II - Gieng Canh Ga	28.9	88
2	Carrying heading, level +60 of wall CIII-8A-2 - Gieng Vang Danh	28.0	88
C	**Nam Mau mine**		
1	Air-heading of wall I-9-5	29.5	94
D	**Ha Lam mine**		
1	Wall CGH 7-3-1	33.5	93
1	Wall CGH 11-1-17	32.4	90
E	**Thong Nhat mine**		
1	Cross-heading, level +18	29.9	94
2	Carrying heading , level +8, PV4C	29.2	93
F	**Ha Long mine**		
1	Roadway -50 - V11B -CB Cam Thanh	28.6	88
2	Wall -20/+40 V11B -Cam Thanh	28.8	88
G	**Khe Cham mine**		
1	Carrying heading of wall 14.5.2.A, coalbed 14.5	28.5	75
2	Air-heading, level -152 of wall 14.5.3.1, coalbed 14.5	29.0	82
H	**Quang Hanh mine**		
1	Air-heading, level -200 of wall 7.13, coalbed 7 TT	29.0	92
2	Carrying heading level -50 of wall 7.1, coalbed 7 ĐN	28.5	90

nam, the air temperature is maintained at the level of the above standards. However, during summer, when the external air temperature exceeds 35°C, hot air is supplied to the working site through the ventilation system, resulting in air temperature higher than 30°C. Table 2 presents air temperature and relative humidity values in selected Vietnamese mines.

As it is shown in Table 2, air temperature above 30oC is found in several headings of the Ha Lam and Mao Khe mines, in which walls mechanized complexes of high electrical power were used, and which emit an additional heat stream to the flowing air.

3. Analysis and selection of solutions to reduce air temperature in underground hard coal mines in Vietnam

In order to improve climatic conditions in underground headings, mining companies mainly use traditional methods of headings ventilation, with air cooling methods being used in selected mines and operating areas. The traditional methods of improving climatic conditions in mines are such that do not require cooling equipment. The effective ventilation of headings may improve climatic conditions, taking into account some requirements as followings [7, 8, 9] :

- Limiting fresh air humidification in downcast shafts and headings, simplification of the ventilation network and, consequently, directing a broader stream of fresh air to walls and headings,
- Proper exposure and cutting of the deposit, shortening the air supply paths and spoil haulage,
- Selecting an optimum longwall ventilation system,
- Tight insulation of cave-in workings (limiting air flow through workings),
- Avoiding serial ventilation of longwall headings,
- Locating the spoil haulage from the longwall in the used air current,
- Proper design of heading length, especially of longwalls, to account for the ventilation system's efficiency

To improve climatic conditions, the methods mentioned above are also used to limit moisture evaporation from watercourses by covering them, resulting in a decrease of air humidity. These methods do not always bring the assumed effect of lowering the air temperature to the permissible values at the workplace of the mining crew due to restrictions introduced by safety regulations, e.g. the maximum airflow speed in excavations, the risk of gas and dust explosion. Therefore, it is necessary to use other methods including the use of cooling equipment.

Air conditioning equipment can operate in the indirect or direct system. These devices include an evaporator, which is an air cooler combined with a machinery assembly consisting of a water-cooled condenser, an expansion valve (Fig. 1

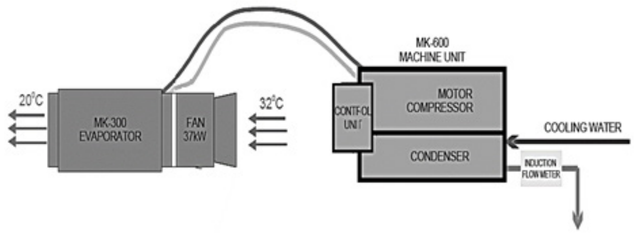

Fig. 1. Air cooler diagram

Rys. 1. Schemat chłodziarka powietrza

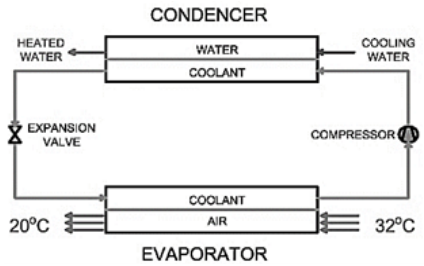

Fig. 2. Principle diagram of the operation of the air cooler

Rys. 2. Schemat zasadniczy działania chłodziarki powietrza

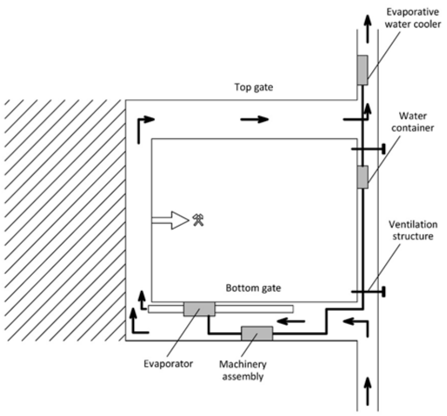

Fig. 3. Local air conditioning diagram

Rys. 3. System klimatyzacji lokalnej

and 2). The evaporator and the condenser are connected with elastic wires to the coolant circulation. Direct action chillers cool the air stream with an evaporator located directly in the cooled air stream, while heat is collected from the condenser in an open or closed system with the use of technological water (by the water from the fire-fighting system). In a closed system, the stream of heat received from the condenser is discharged via the water into the circulating air current in the evaporative water cooler. In the indirect operation system, the heat stream taken from the air in the excavation via water is directed to the evaporator and then it is collected by the water from the condenser. The correctness and efficiency of the air cooling process in the excavation ensure sufficient heat collection from the condenser.

Currently, there are three trends in the technology of air conditioning in mining headings used to reduce air temperature in workplaces: local, group or central air conditioning [10].

In hard coal mines, local air cooler with a capacity of up to about 350 kW is used primarily to cool the air in hollow excavations ventilated by ventilation pipes. Such devices are also used to cool the air in bottom gates.

In a group air-conditioning system, cooling aggregates with a cooling capacity of 1 to 3 MW can be used as individual or combined. Cooling aggregates, depending on the conditions in a given mine, are usually located near the downcast shafts, from which the cooled water is transported by insulated pipelines to the local air coolers. The main advantage of group air conditioning systems is the possibility of implementing many variants of the arrangement of air coolers. Group air conditioning systems are very often used in Polish underground mines in combination with local air coolers.

In central air-conditioning systems, the location of cooling aggregates together with their cooling system is possible on the surface or underground, or on the surface and underground (combined system). Central air conditioning systems use cooling aggregates that cool water, which is pumped into local water air coolers. The cooling capacity of such a system reaches up to 10 MW. In Poland, central air conditioning systems are used e.g. in KWK Pniówek, KWK Budryk and in the mines belonging to KGHM Polska Miedź S.A.

In hard coal mines in Vietnam, in order to actively reduce the air temperature, a local air-conditioning system should

Tab. 3. Air temperature in the CGH 7-3-1 wall at the Ha Lam mine in 2019.

Tab. 3. Temperatura powietrza w ścianie CGH 7-3-1 w kopalni Ha Lam w 2019 r.

Heading name		Months											
		1	2	3	4	5	6	7	8	9	10	11	12
Bottom gate CGH 7-3-1	°C	28.2	28.5	29.7	30.9	30.2	31.3	31.4	31.6	31.6	30.6	29.8	29.3
Wall CGH 7-3-1	°C	29.9	30.3	31.1	31.5	32.2	32.9	33.4	33.5	33.4	33.3	31.2	30.5
Top gate CGH 7-3-1	°C	30.5	30.9	31.3	32.0	33.7	33.4	34.7	34.5	34.4	33.8	32.5	30.9
Volumetric air stream	m^3/s	22.2	22.8	21.8	22.3	23.2	22.5	22.8	21.6	22.7	22.1	22.4	22.7
Surface temperature	°C	23.5	29.3	30.5	35.0	34.9	37.2	35.8	35.3	31.1	30.3	27.2	25.3

Tab. 3. Air temperature in the CGH 7-3-1 wall at the Ha Lam mine in 2019.

Tab. 3. Temperatura powietrza w ścianie CGH 7-3-1 w kopalni Ha Lam w 2019 r.

No.	Parameter	Symbol	Unit	Value
1	Cross-sectional area of the heading	A	m^2	11.2
2	Heading perimeter	B	m	13
3	Heading length	L	m	536
4	Dry-bulb temperature	t_s	°C	31.6
5	Wet-bulb temperature	t_w	°C	30.8
6	Relative humidity	φ_d	%	88
7	Air pressure	p	Pa	103,977
8	Average air speed across the heading cross-section	w_d	m/s	2.0

be used, which among the mine air-conditioning systems has the lowest investment costs. The scheme of such a system is shown in Figure 3.

4. Calculating of air temperature after using an air cooler for wall No. 7-3-1 in the Ha Lam mine

The CGH 7-3-1 wall is located on bed 7 in the Ha Lam mine in Vietnam. The wall was launched on October 20, 2018. The capacity of this wall is 1,200,000 Mg/year. The CGH 7-3-1 wall is at the deepest mine level of -265.8 m. The mining and transport devices used have high electrical power: longwall shearer – 600 kW, armoured face conveyor – 630 kW and 400 kW, belt conveyor in the bottom gate – 500 kW. During operation, the air temperature in the wall often exceeds 30°C, especially in summer (table 3 and figure 4). Traditional ventilation solutions were used to reduce climate risk and reduce air temperature, but they were still ineffective. Therefore, another solution was to apply the method of artificial air cooling, consisting in lowering the air temperature in the bottom road before it is led to the longwall.

In order to reduce the air temperature in the CGH 7-3-1 wall excavation, the TS-300 cooler from the Polish manufacturer Termospec Co. was used. The air cooler will be installed at the inlet of the bottom gate (536 m from the wall inlet). The direct action TS-300 cooler uses R407C refrigerant. The cooler consists of two separate units connected by flexible conduits. The first includes the refrigerant compressor, electric motor, condenser, expansion valve and control and monitoring system. The second unit is the refrigerator evaporator which is an air cooler. Directly in front of the evaporator is a lute fan, in this case WLE 803B forcing air flow through the cooler. Table 4 contains technical data and results of measurements of air parameters at the inlet to the heading.

Equations from (1) to (7) were used to determine the thermodynamic parameters of the cooled air.

Partial pressure of water vapour p_w:

$$p_w = \varphi \, p_{wn} \quad \text{(Pa)} \tag{1}$$

where:
p_{wn} – saturated vapour pressure, Pa
φ – relative humidity, -.

$$p_{wn} = 610.6 \times 10^{\frac{7.5 t_s}{(237.29 + t_s)}} \quad \text{(Pa)} \tag{2}$$

t_s – dry-bulb temperature, °C

Specific humidity of air, xd:

$$x_d = 0.622 \frac{p_w}{p - p_w} \quad \text{(kg/kg)} \tag{3}$$

where:
p – air pressure, Pa

Humid air density, ρ_d:

$$\rho_d = \frac{(1+x) p_{wn}}{462(0.622 + x) T} \quad (\text{kg/m}^3) \tag{4}$$

where:
T – air temperature in the duct, $T = t_s + 273.15$ (K);
t_s – dry-bulb temperature, °C

Mass flow rate of humid air $\dot{m}_d$.

$$\dot{m}_d = \dot{V} \rho_d \quad \text{(kg/s)} \tag{5}$$

where:
V – volumetric flow rate of air, m^3/s, V=Aw
A – cross-sectional area, m^2
w – air velocity in the heading, m/s.

Mass flow rate of dry air $\dot{m}_{sd}$.

$$\dot{m}_{sd} = \frac{\dot{m}_d}{1+x} \quad \text{(kg/s)} \tag{6}$$

Specific enthalpy of air h_d:

$$h_d = 1.005 t_s + x(1.926 t_s + 2500) \quad \text{(kJ/kg)} \tag{7}$$

Taking into account the calculated air parameters at the inlet to the refrigerator fan, at the inlet to the evaporator and the nominal thermal power of the TS-300 cooler, the air temperature at the outlet from the evaporator was determined. The air flow leaving the evaporator is a mixture of the part of the air that has been cooled to the maximum in the cooler,

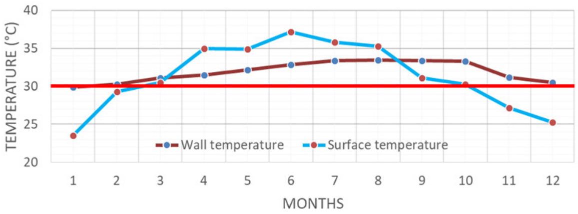

Fig. 4. Air temperature change diagram for wall CGH 7-3-1
Rys. 4. Wykres zmian temperatury powietrza w ścianie CGH 7-3-1

obtaining the temperature of the wall of the cooler and the part that has not completely cooled. Then, the cooled stream of air is mixed with the stream of air flowing in the heading (next to the air-conditioning machine). By indicating by tmk and xmk, respectively, the temperature and specific humidity of the air at the outlet of the evaporator, when it is saturated, on the basis of [11] you can write:

$$\begin{cases} x_{mk} = x_{\text{nmk}} = \dfrac{379.793\times10^{\frac{7.5t_{mk}}{t_3+237.29}}}{p-610.6\times10^{\frac{7.5t_{mk}}{t_3+237.29}}} \\ t_{mk} = \left\{\dfrac{1}{C_p+C_{\text{pw}}x_{mk}+C_{\text{ww}}\cdot[(1-b_f)x_c+b_f x_2-x_{mk}]}\right\}\cdot \\ \left\{(1-b_f)[C_p t_c + C_{\text{pw}} t_c x_c + r_p x_c] + b_f[C_p t_2 + C_{\text{pw}} t_2 x_2 + r_p x_2] - r_p x_{mk}\right\} \end{cases} \quad (8)$$

where:
b_f – TS-300 evaporator's bypass coefficient calculated from the formula – according to [12],

b_f=0.01364/60 Q_p-0.03507 (-) (9)

Q_p – volume air flow at the evaporator inlet, m^3/s
C_p – specific heat of dry air at constant pressure, kJ/(kg.K),
C_{pw} – specific heat of steam at constant pressure, kJ/(kg.K),
C_{ww} – specific heat of water, kJ/(kg.K),
r_p – latent heat of water evaporation, kJ/kg,
t_c – temperature of the conventional part of the cooled air at the evaporator outlet, °C
x_c – specific humidity of the contracted part of the cooled air at the evaporator outlet, kg of steam/kg of dry air,
t_2 – temperature of air at the evaporator inlet, $t_2 = t_s + \Delta t$, °C
Δt – increase of air temperature as a result of fan operation, °C. It can be determined from the dependence [13]:

$$\Delta t = \frac{\Delta_p}{\rho_d c_p 10\eta} \quad \text{(kg/s)} \quad (10)$$

x_2 – specific air humidity at the evaporator inlet equal to the specific air humidity xd at the fan inlet, kg/kg
η – fan efficiency,%. According to [13], it can be calculated for the WLE 803B fan from dependence:

$\eta=-6.4676Q_p^{2} + 75.427Q_p-162.32$ (11)

Δ_p – total pressure of the fan, Pa. Based on [13], the pressure of the lute fan is equal:

$\Delta_p=-456.43Q_p^{2}+ 4883.2Q_p-8875.4$ (12)

If the air mixture does not reach saturation at the evaporator outlet, where $(1-b_f)\,x_c+b_f\,x_2 \geq x_{nmk}$, its temperature and humidity can be determined by solving the system of equations (13):

$$\begin{cases} x_{mk} = (1-b_f)x_c + b_f x_2 \\ t_{mk} = \dfrac{1}{c_p+c_{\text{pw}}x_{mk}}\begin{Bmatrix}(1-b_f)[c_p t_c + c_{\text{pw}} t_c x_c + r_p x_c] + \\ +b_f[c_p t_2 + c_{\text{pw}} t_2 x_2 + r_p x_2] - r_p x_{mk}\end{Bmatrix} \end{cases} \quad (13)$$

The air temperature tc and the specific humidity xc (corresponding to the parameters of the cooler wall) are calculated from the equations (14) or (15) below. Equation (14) applies to the condition (16) that cools air with condensation of water vapor on the surface of a recuperative heat exchanger, which is the evaporator of a TS-300 cooler. For dry air cooling (x2 <xc), the system of equations (15) is solved [11]:

$$\begin{cases} x_c = x_{\text{nc}} = \dfrac{379.793\times10^{\frac{7.5t_c}{t_c+237.29}}}{b-610.6\times10^{\frac{7.5t_c}{t_c+237.29}}} \\ t_c = \dfrac{t_2(c_p+c_{\text{pw}}x_2)+r_p(x_2-x_c)-\frac{N}{(1-b_f)Q_m}}{c_p+c_{\text{pw}}x_c+c_w(x_2-x_c)} \end{cases} \quad (14)$$

$$\begin{cases} x_c = x_2 \\ t_c = t_2 - \dfrac{N}{(1-b_f)Q_m(c_p+c_{\text{pw}}x_2)} \end{cases} \quad (15)$$

$$x_2 \geq x_c \quad (16)$$

wherein:
Q_m – dry air mass flows in the evaporator:

$Q_m=(Q_p\,\rho_2)/(1+x_2)$ (kg/s) (17)

ρ_2 – air density at the evaporator inlet, kg/m^3
N – evaporator's thermal power of the TS-300 refrigerator, kW.

Mass stream of air flowing through the excavation (next to the air-conditioning machine) m_1:

$$\dot{m}_1 = (\dot{V} - \dot{V}_{mk})\rho_d \quad \text{(kg/s)} \quad (18)$$

where :
V_{mk}– air volume flow at the fan inlet, $V_{mk}=Q_p$, m^3/s

Mass stream of air flowing through the air conditioning machine m_{mk}, kg/s,

$$\dot{m}_{mk} = \dot{V}_{mk}\rho_d \quad \text{(kg/s)} \quad (19)$$

Specific enthalpy of air at the cooler outlet h_{mk}:

$h_{mk}=1.005t_{mk}+x(1.926t_{mk}+2500)$ (kJ/kg) (20)

Tab. 5. Results of calculations of the air temperature in the excavation after using the air-conditioning machine

Tab. 5. Wyniki obliczeń temperatury powietrza w wyrobisku po zastosowaniu maszyny klimatyzacyjnej

Parameter	Symbol	Unit	Value
Partial pressure of water vapour	p_{wd}	Pa	3,907
Specific humidity of air	x_d	kg/kg	0.024
Humid air density	ρ_d	kg/m³	1.17
Moist air mass stream	$\dot{m}_d$	kg/s	26.2
Dry air mass flow	$\dot{m}_{sd}$	kg/s	25.6
Specific enthalpy of air	h_d	kJ/kg	93.9
Temperature of air at the evaporator outlet	t_{mk}	°C	8.1
Specific air humidity at the evaporator outlet	x_{mk}	kg/kg	0.0065
The air volume flow at the evaporator inlet	V_{mk}	m³/s	7.08
Specific enthalpy of air at the evaporator outlet	h_{mk}	kJ/kg	24.62
Mass stream of air flowing through the air-conditioning machine	$\dot{m}_{mk}$	kg/s	8.29
Mass stream of air flowing through the excavation (next to the air-conditioning machine)	$\dot{m}_1$	kg/s	17.93
Specific air humidity after mixing air streams	x_m	kg/kg	0.019
Specific enthalpy of air after mixing air streams	h_m	kJ/kg	72.00
Dry-bulb temperature after mixed air stream	t_{sm}	°C	24.3
Partial pressure of water vapour in the exhaust air	p_{pwm}	Pa	3,030.8
Wet-bulb temperature after mixed air stream	t_{wm}	°C	24.2

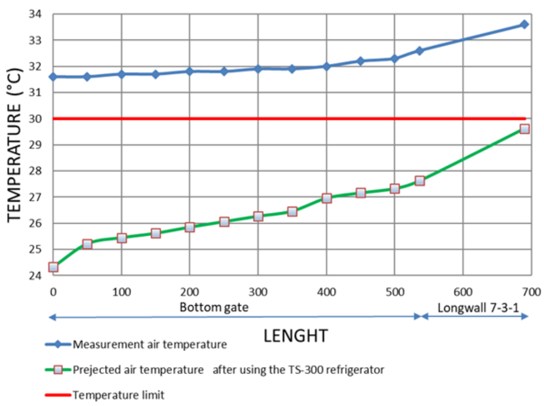

Fig. 5. The graph of air temperature changes before and after using the air conditioning machine in the bottom gate of the CGH 7-3-1 longwall

Rys. 5. Wykres zmian temperatury powietrza przed i po zastosowaniu maszyny klimatyzacyjnej w chodniku podścianowym i ściany CGH 7-3-1

Specific air humidity after mixing air streams in the excavation, x_m:

$$x_m = \frac{\dot{m}_d x_d + \dot{m}_{mk} x_{mk}}{\dot{m}_d + \dot{m}_{mk}} \quad \text{(kg/kg)} \tag{21}$$

Specific enthalpy of air after mixing air streams in the excavation h_{mk}:

$$h_m = \frac{\dot{m}_d h_d + \dot{m}_{mk} h_{mk}}{\dot{m}_d + \dot{m}_{mk}} \quad \text{(kJ/kg)} \tag{22}$$

Dry-bulb temperature mixed in the excavation, t_{sm}:

$$t_{sm} = \frac{h_m - 2500 x_m}{1.005 + 1.926 x_m} \quad \text{(°C)} \tag{23}$$

Partial pressure of water vapor in the air in the excavation p_{wnm}:

$$p_{wm} = \frac{p x_m}{0.622 + x_m} \quad \text{(Pa)} \tag{24}$$

Wet-bulb temperature (t_{wm}) of mixed air streams is determined by iterative methods on the basis of an equation:

$$p_{wm} = 610.6 \times 10^{\frac{7.5 t_{wm}}{237.29 + t_{wm}}} - 6.77 \times 10^{-4}(t_{sm} + t_{wm})p \quad \text{(Pa)} \tag{25}$$

The results of the calculations are presented in the table 5.

On the basis of the calculated temperature of air in the excavation behind the cooler, the authors carried out a forecast of the air temperature in bottom road of the CGH 7-3-1 wall using the J. Voss method [14]. The value of the projected temperature at the outlet of the wall CGH -7-3-1 is less than 30°C and is 29.6°C. Figure 5 presents a graph of changes in air temperature before and after using an air-conditioning machine in bottom road of the CGH 7-3-1 wall.

5. Summary

Ventilation in underground mines in Vietnam meets the requirements for the flow and air velocity in the underground excavation in accordance with the regulations of the Ministry of Industry and Trade. According to the regulation, the temperature at the workplace in the underground mine should not exceed 30°C. However, in summer, in Vietnam, the outside air temperature is high and is above 35°C, this causes an unfavorable increase in the air temperature in underground excavations.

To minimize the adverse effects of climatic conditions on production activities in underground coal mines, ventilation methods are used that are not always sufficient. In order to lower the air temperature at workplaces, the Vietnamese mines began to use air cooling methods using local, direct-acting air coolers.

In the CGH 7-3-1 wall of the Ha Lam mine, the air temperature in summer often exceeds the permissible value of 30°C. To lower the air temperature in the wall a direct-acting air cooler type TS-300 from Termospec Co. was used. According to calculations, the air temperature in the excavation was reduced to 24.3°C. Figure 5 shows a gradual increase in the air temperature in the excavation, but it does not exceed 30°C at the inlet to the longwall excavation. The use of the compressor system allowed to reduce the air temperature, which at the inlet to the wall reached 29.6°C and the same improve the climatic conditions in this excavation. The use of a second air cooler would allow a further reduction air temperature in the excavation.

Literatura – References

1. Świloń A, Skowrońska A. Wpływ warunków klimatycznych złoża rud miedzi na wypadkowość. Materiały V Konferencji „Wybieranie złóż na dużych głębokościach oraz w trudnych warunkach geotermicznych", Głębokie Złoże 2005, Jugowice, 14-17 czerwca 2005.
2. Roszczynialski W., Nawrat S., Szlązak J„ Tomczyk J. Bezpieczna kopalnia - prawo, zagrożenia, zarządzanie, Oficyna Wydawnicza TEXT, Kraków 1999.
3. Spioch F., Wpływ mikroklimatu w kopalniach na zdrowie, wydajność i bezpieczeństwo pracy górników, Chłodnictwo 8-9/1976.
4. Navarro Torres V.F.: Modeling the heat transfer in underground atmosphere – case study in Portugal and Peru. 10th Session of the International Bureau of Mining Thermophysics, "IBTM 2005", 14-18 February 2005, Gliwice, Poland.
5. Wacławik J.: Wpływ wilgotności na temperaturę skał. Archiwum Górnictwa. Tom XII, zeszyt 1, 1971.
6. Ministry of Industry and Trade of Vietnam: National technical regulation on safety in underground coal mining QCVN 01: 2011 / BCT (Issued together with Circular No. 03/2011 / TT-BCT of February 15, 2011) of the Minister of Industry and Trade). Bộ Công thương Việt Nam: Quy chuẩn kỹ thuật quốc gia về an toàn trong khai thác than hầm lò QCVN 01:2011/BCT (Ban hành kèm theo thông tư số 03/2011/TT-BCT ngày 15 tháng 02 năm 2011 của Bộ trưởng Bộ Công thương).
7. Łuczak R, Zwalczanie zagrożenia temperaturowego w wyrobiskach górniczych chłodziarkami powietrza bezpośredniego działania typoszeregu TS. Górnictwo i Geoinżynieria, Rok 34, Zeszyt 3/1, Kraków 2010.
8. Pawiński J., Roszkowski J., Strzemiński J. Przewietrzanie kopalń, Śląskie Wydawnictwo Techniczne, Katowice 1995.
9. Wacławik J. Wentylacja kopalń. Tom I i II, Wydawnictwo Uczelniane AGH, Kraków (2010).
10. Nowak B., Łuczak R., Życzkowski P. Prognoza temperatury i wilgotności powietrza na wylocie parownika chłodziarki bezpośredniego działania, Przegląd górniczy, ISSN 0033-216X, nr 4/2017.
11. Nowak B., Łuczak R., Życzkowski P. Temperatura i wilgotność powietrza ochłodzonego za pomocą chłodziarki sprężarkowej TS-300. Ciepłownictwo, Ogrzewnictwo, Wentylacja 47 (2016).
12. Łuska P. Prognoza parametrów powietrza schładzanego górniczą chłodziarką powietrza z ekologicznym czynnikiem chłodniczym, Rozprawa doktorska, Kraków 2003. Praca niepublikowana.
13. Explanatory statement about exploiting the longwall of CGH 7-3-1 in the coal seam 7 in the Ha Lam mine, Quang Ninh, 2018 (Công ty than Hà Lầm, Thuyết minh khai thác lò chợ CGH 7-3-1 vỉa 7, 2016) Document not public.
14. Wacławik J., Cygankiewicz J., Knechtel J.: Warunki klimatyczne w kopalniach głębokich. Biblioteka Szkoła Eksploatacji Podziemnej, Wydawnictwo IGSMiE PAN,Kraków 1998, ISBN-83-86286-64-4.

Dobór i obliczenia rozwiązań chłodzenia powietrza w podziemnych kopalniach węgla w Wietnamie

Obecnie wietnamskie kopalnie podziemne zostały wyeksploatowane do -500 m, w najbliższej przyszłości będą eksploatowane głębiej. Eksploatacja ma negatywny wpływ na środowisko. Działalność eksploatacji w wyrobiskach powoduje wzrost niekorzystnych czynników mikroklimatycznych, takich jak temperatura, wilgotność, promieniowanie cieplne. Zgodnie z obowiązującym wietnamskim prawem, złoża węgla mogą być eksploatowane w warunkach, gdy temperatura powietrza nie przekracza 30°C, chociaż nie zawsze jest to przestrzegane, zwłaszcza latem. W artykule przedstawiono rozwiązanie ograniczania niekorzystnego wpływu czynników klimatycznych w kopalniach oraz obliczenie parametrów obniżających temperaturę powietrza na przykładzie podziemnych kopalń węgla w Wietnamie.

Słowa kluczowe: *temperatura powietrza, wilgotność powietrza, chłodzenie powietrza, moc cieplna chłodnicy*