Comparative Analysis of Selected Types of Crushing Forces in Terms of Dust Emission

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Abstract

Selected issues of dust pollution caused by industrial mineral processing operations, were presented in the paper. Two test series of rock material comminution in various crushers were carried out. Dust generation level during operation of each crusher was registered and analyzed from the scope of energy consumption of a device, its throughput and technological effectiveness, measured by achieved comminution degree index (S_x).

Results of the analysis show that the proposed indices can help in comparative analysis of effectiveness operation for machines with various capacity or energy consumption. The obtained results also show that the type of comminution forces determines to some extent the dust emission level.

Keywords: comminution, crushers, dust emission, raw materials

Introduction

Air pollutants can be divided into two main categories: gases and dusts. It is estimated that total annual emission of both types of pollutants in Poland exceeds 7 million Mg, and it may come from following sources:

- burning of fossil fuels in electricity generation,
- industrial processes
- agriculture
- waste treatment
- natural sources.

The dust emission, that include PM10 and PM2.5 particles, constitute about 2% of total air pollution. (EEA 2014; EEA 2018).

Main categories of sources for particulate matters emission shows Table 1. It can be seen from the Table that the highest share in dust emission is connected with energy consumption. Traffic road also affects the level of dust emission, especially in urban areas (Saramak 2019). Industrial processes cause approximately 5% of total dust generation.

Other sources claim that total industrial contribution of PM10 and PM2.5 concentration in the air in Europe exceeds 20% of the annual total concentrations of these particles (AIRUSE, 2016). It does not need to be in contradiction with data presented in Table 1, because mineral processing operations consumes significant amount of energy. For this reason some categories can be also withdrawn from the position Energy consumption, and placed in Industrial processes.

Mineral raw materials treatment processes are of a key-significance in the entire metal production value-chain, but they also affect an environment in negative manner through extensive dust particles and noise emissions. It applies especially to mechanical processing stage in technological circuit of ore processing, in particular to the size reduction operations (Gawenda 2013, Saramak 2012). Processes of comminution are also a very energy consuming ones, therefore especial attention for limitation of their negative impact on environment together with operational cost reduction, is being paid recently. In general, operations of crushing and grinding are of a high negative impact both on environment and humans, and due to their high energy consumption, they indirectly contribute to higher emission of carbon dioxide CO_2. Apart from energy, crushing and grinding device consume significant amount of steel and other metals and alloys due to high wear of working parts and grinding media. This is also of negative environmental impact due to emissions of additional amounts of CO_2 in production of steel and other metals required as spare parts for comminution devices. Increased dust emission into atmosphere is an effect of feed material breakage in working chamber of the device. Unlike the grinding mills, working chambers of selected crushers are not closed and isolated from atmosphere. Dry crushing and opened or semi-opened working chambers cause high level of dust emission into atmosphere, what influences deterioration the living conditions, especially for habitants in proximity of processing plants (Zawada 1998, Naziemiec and Gawenda 2006, Saramak et. al 2016, Saramak and Kleiv, 2013). Another drawback of crushing operation is an excessive noise emission. Apart from living conditions, the dust pollution may cause various diseases, connected to a major extent with respiratory and cardiovascular systems. This may be also related to higher level of stress, general feeling of discomfort, malaise or even sleep disorders (Report 2008, Library 2011).

The paper aims at analyzing the dust emissions characteristics of various crushers. Three types of crushers were analyzed both in laboratory and in plant conditions, and the dust generation during each operation was analyzed.

Material and methods

As it was mentioned the above, industrial processes have a significant impact on the level of dust, understood as Total Suspended Particles (TSP) emission. Among these, there are selected operations of feed material treatment in mining and

Tab. 1. Dust emission by sectors
Tab. 1. Emisja pyłów w różnych sektorach gospodarki

Source – sector	Percentage share [%]
Energy consumption	72
Road transport	17
Industrial processes	5
Waste treatment	5
Other types/sectors	1

Tab. 2. Typical amount of dust generation per the amount of the treated feed material for individual comminution stages (Report 2012)
Tab. 2. Przykładowe wielkości zapylenia na tonę przerabianej nadawy, emitowane na różnych stopniach rozdrabniania (Report 2012)

Crushing stage	TSP [g/Mg]	PM10 [g/Mg]
Primary crushing	200	20
Secondary crushing	600	40
Tertiary crushing	1400	80

Tab. 3. Laboratory research
Tab. 3. Badania laboratoryjne

Force type	TSP, [mg/m^3]		Q [Mg/h]	Esp [kWh/Mg]	S_{90}
	Mean	Std. dev.			
Impact	1.0	0.4	0.5	3.6	5.5
Shear	1.7	0.8	1.0	4.3	3.2
Compression	2.9	0.9	2.0	2.2	4.0

mineral processing sector, that involve the feed disintegration. The TSP term characterizes the entire dust pollutions from the given source (or sources), that are usually finer than 20 microns. Two ingredients of TSP are measured most commonly: PM10 – factions finer than 10 microns and PM2.5 – fractions finer than 2.5 microns. Both PM10 and PM2.5 have a negative impact on human's health. PM10 fractions affecting the trachea-bronchial section of respiratory system, while PM 2.5 are even more dangerous, because they are recognized as respirable fraction that participates in gas exchange process in human body.

Contemporary approach to management and effective reduction of dust emission in the mining plant includes determination the type of source, utilization of efficient measuring methods and application of best solutions in reduction of that dust emission (Lilic et. al 2018). During the crushing process the much more surface area of material is created. There are various estimations concerning the amount of dust generated per the mass of the processed feed material during the crushing process. These values depend on the crushing stage and crushing material properties. Average emission are given in Table 2.

It might be seen that depending on the crushing stage in a given technological circuit dust emission are diverse. It is also connected with crushing device capacities and technological performance measured through value of a comminution degree. Comparative analysis of direct emissions of dust for different crushers might not give the full view on the problem, because when two crushers operating with different capacities produce similar amount of dust, the one with higher capacity is more environmental friendly, due to lower unit emission. Therefore it can be helpful an introduction of following indices, that can help in assessment of environmental impact of individual crusher:

a) Index of dust emission per comminution degree (D_{Sx})

$$D_{-S_x} = \frac{Dust\ \ emision}{S_x}, [mg/m^3] \quad (1)$$

b) Index of dust emission per energy consumed (D_{Esp}):

$$D_{-Esp} = Dust\ \ emission * Esp, [\frac{mg}{m^3} * \frac{kWh}{Mg}] \quad (2)$$

where:
S_x – comminution degree (i.e. S_{50}, S_{80}, S_{90});
E_{sp} – specific energy consumption per Mg of processed material.

Investigative programme included two series of tests. The first one was conducted in a small scale at the laboratory of the Department of Mineral Processing, AGH, while the second one was carried out in a limestone processing plant. Crushers utilizing various crushing forces: impact, compression, and shear, were tested in laboratory. In order to maintain similar conditions of experiment, a limestone rock with a moderate comminution susceptibility – Bond index Wi =11,1 kWh/Mg – was used. The feed material moisture content in each test was below 1% and measuring device was located around 2 meters from the crusher. Each measurement was performed through several minutes during operation of individual crusher with the one-second automatic averaging. After individual measurement mean and standard deviation were calculated for each crusher.

Results of experiments

Characteristics of individual crushers along with obtained values of dust emission were presented in Tables 3 and 4. Table 3 summarizes results of laboratory tests, while in Table 4 plant-scale experiment results are presented.

Inspecting Table 2 it can be noticed that impact crushing force achieved the lowest average value of dust emission as well as standard deviation. The highest values, in turn, were registered for the compression. However the most favourable crusher operation in terms of specific energy consumption and was recorded for the compression force, while most intense comminution caused the impactor.

In plant-scale conditions (Table 4) the impactor also turned to be the most favorable device in terms of dust emission. For

Tab. 4. Pilot-scale experiments
Tab. 4. Testy przemysłowe

Force type	TSP, [mg/m3]		Q [Mg/h]	Esp [kWh/Mg]	S_{90}
	Mean	Std. dev.			
Impact	3.2	2.6	120	0.6	2.9
Shear	4.8	2.5	500	0.6	6.5
Compression	4.7	0.9	120	0.7	2.7

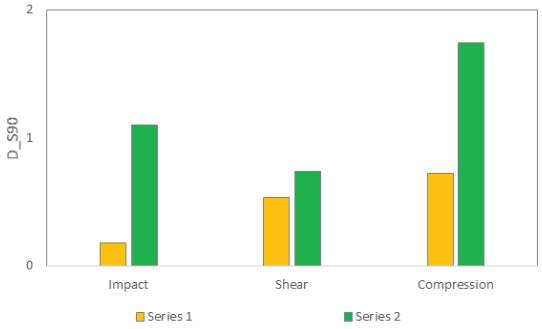

Fig. 1. Values of dust emissions per comminution degree for crushing devices in laboratory (series 1) and plant-scale (series 2) operation
Rys. 1. Wartości zapylenia w stosunku do uzyskanego stopnia rozdrobnienia w warunkach laboratoryjnych (seria 1) i przemysłowych (seria 2)

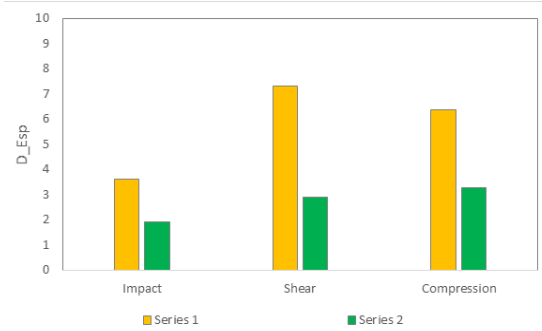

Fig. 2. Values of dust emissions per energy consumption for crushing devices in laboratory (series 1) and plant-scale (series 2) operation
Rys. 2. Wartości zapylenia w stosunku do energochłonności urządzeń w warunkach laboratoryjnych (seria 1) i przemysłowych (seria 2)

the jaw and roller crushers the mean values of dust emission were almost identical, however the roller crusher was characterized with the lowest standard deviation value.

In the next stage of analysis there were calculated the indices expressed by formulas (1) and (2). Results are presented in Figures 1 and 2.

The most favorable value of dust emission per an unit comminution degree in laboratory conditions was obtained for hammer crusher. It means that in terms of technological performance hammer crusher appeared to be most effective. In plant-scale condition, in turn, the jaw crusher appeared the most environmental friendly crushing device. Roller crusher/HPGR achieved the worst results. From technological point of view this crushing device is regarded as least effective for the given conditions.

Analysis of dust emission compared to energy consumption for individual crushers was presented in Fig. 2. The presented results show that the most favorable device appeared the hammer crusher/impactor, both in laboratory and in plant scale. Roller crusher was only insignificantly worse in laboratory scale, but appeared the less effective in plant conditions. Jaw crusher has achieved unfavorable results in laboratory scale, but average ones in plant operation.

Conclusions

The analysis presented in the paper concern an environmental footprint of selected comminution devices utilizing various types of crushing forces. Results of investigations show that it is not always possible to compare performance of individual crushers operating under various technological conditions, with various capacities and achieving different comminution degrees. The results of analysis showed that different types of crusher are capable to emit various amount of dust.

Results of investigative programmes showed that different crushers appeared to be more or less effective. From technological point of view (analysis of obtained comminution degree) the crusher utilizing an impact force has achieved the most favorable results, while for the compression force the dust emission was the least favorable. However in terms of economic/energetic aspects the compression force in terms of dust emission achieved results similar to crusher based on impact force.

A practical utilization of the main results obtained from the investigative programme can be done by creating suitable models of dust emission, based on statistical and mathematical models (Tumidajski et. al 2008, Siewior et. al 2011).

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Analiza porównawcza wybranych metod rozdrabniania pod kątem emisji pyłu

W artykule przedstawiono wybrane zagadnienia związane z zanieczyszczeniem pyłami w przeróbce surowców. Przeprowadzono dwie serie testów rozdrabniania surowca w różnych kruszarkach. Dla każdego testu rejestrowano poziom zapylenia a wyniki były analizowane pod kątem energochłonności, wydajności oraz efektywności technologicznej kruszarki, mierzonej uzyskanym wskaźnikiem stopnia rozdrobnienia (S_x).

Wyniki analizy wskazują, że zaproponowane wskaźniki oceny zapylenia mogą pomóc w ocenie porównawczej maszyn o różnej wydajności lub zużyciu energii. Uzyskane wyniki pokazują również, że rodzaj sił rozdrabniania w pewnym stopniu określa poziom emisji pyłu.

Słowa kluczowe: rozdrabniania, kruszarki, emisja zaplenia, surowce mineralne