Intelligent spraying installation for dust control in mine workings

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Abstract. Design solution of an intelligent spraying installation for dust control in mine workings, developed within the ROCD project is presented. Current solution for reduction of airborne dust in the underground mining industry is described. Design as well as principles of operation of new solution based on the adaptive operation, consisting in adaptation of spraying intensity to the measured dust concentration are discussed. In conclusions, the directions of further research project are pointed out.

1. Introduction
Current requirements regarding the application of dust control devices in hard coal mining industry are focused on the source of dust generation, i.e. when mining coal with the mining machines, during crushing and transferring the run-of-mine on the conveyor belts. Unfortunately, the local method of dust reduction does not eliminate completely the generated dust, contributing to its movement with the air stream of the mine, along the mine workings. This causes that the miners are exposed to the negative effect of dust [1, 2]. The presence of dust in mines, in addition to the explosion hazard, is also the cause of the development of pneumoconiosis, which is the most common occupational disease of miners in hard coal mines. Pneumoconiosis is manifested by chronic bronchitis and emphysema, and sometimes heart failure and hypertrophy, and the effects of dust on the workers' organ are visible only after a few or several years of work (Figure 1) [3].

![Number of cases of pneumoconiosis observed in the years 2013-2017 among the employees of active coal mines](image)

**Figure 1.** Number of cases of pneumoconiosis observed in the years 2013-2017 among the employees of active coal mines [3].
The suggested concept of an intelligent air-water device intended to prevent against propagation of fine dust particles, i.e. PM2.5 and PM10, to be used in potentially explosive atmospheres will be the response to the demand for dust reduction in roadways, where dust it is carried with air stream. Dust precipitation with use of water drops and its deposition on the floor will be the main task of the installation. The idea of effective dust elimination by the developed device will be based on the generation of a spraying stream of water drops with the diameter close to the size of dust particles, while maintaining a high ejection energy from the nozzle. The solution for producing water drops with diameters close to PM10 and PM2.5, will use the compressed air. Production of spraying streams with small water droplets is to increase the efficiency of dust particles elimination by combining them together, leading to their precipitation. The neutralization process (Figure 2) can take place as a result of combining several transportation mechanisms, the main ones are: inertial, hook and diffusion mechanisms, and in the case of electric potential differences – electrostatic mechanism [4].

![Figure 2](image)

**Figure 2.** Mechanisms of transporting the solid particles form gaseous phase to the water drop [4].

The mechanism of inertial deposition is based on the impact of a solid particle on the surface of a water drop, the hook mechanism - on its tangential contact, the diffusion mechanism - on the collision of a solid particle with a water drop in a result of random movements, regardless of the stream line, and the electrostatic mechanism - on attracting the opposite electrically charged particles of water and dust.

The spraying installation will be equipped with an intelligent control system which, basing on the information received from the dust sensor about actual dust concentration, will select an adequate intensity of the spraying stream, enabling the reduction of dust concentration below maximum allowable.

2. **Review of currently used solutions**

Operation of currently used dust control installation, especially in hard coal mines, installed in roadways is based on suction dust from these places [5] or using the water spraying devices [4].

The wet dust control devices are most commonly used to clean airstream from dust particles. Their use allows not only to capture dust particles, but also to neutralize their explosive properties. These devices use the spraying systems in which water is atomized in the air stream and the dust particles penetrate into the water droplets. Regardless of how the particles are mixed with water drops, a mixture of air with water drops and dust particles is swirled, while the drops, due to the centrifugal force, are directed towards the walls of the dust collector, where ribbed surfaces stop them and they flow to the water reservoir. The water circuit in the dust control device is schematically shown in Figure 3.
Figure 3. Schematic diagram and principles of operation of the wet dust collector [5].

Dust control by use of water spraying system is one of the most common and cheapest methods used in mines. The sprinkling technique consists in creating a barrier from water mist throughout the cross-section of the excavation, so that the dust is connected with the current of air, it merges with sprayed drops of water, creating moistened agglomerations of dust particles devoid of volatile properties. There are many concepts and design solutions for spraying devices, both domestic and foreign, which are used to reduce dust in pavement excavations. One of the first solutions to reduce dust with water and air, was developed in the 1960s. This solution was intended for use in Soviet hard coal mines (Figures 4 and 5) [6].

Figure 4. Roadway cross-section with the spraying system [6].

Figure 5. View of a roadway with the installed spraying installation [6].

The system consisted of several nozzles, to which air and water were supplied by means of ducts and was located on a roadway support. This installation was supplied with water and air coming from the pipelines available in the roadway, and the direction of the nozzles was opposite to the direction of the roadway ventilation. Unfortunately, this solution has never been used in underground conditions.

In 2010, a solution of the "mist system with net diaphragms", using air-water spraying system to reduce dust concentration in the roadway, developed by the Telesio Sp. z o.o., appeared in the Polish mines. The solution is also based on the use of water and compressed air to capture dust. The device is made of a spraying installation suspended in the roadway cross-section as well as of moving grids catching water drops combined with dust, in the form of a labyrinth, placed in area of the personnel
movement [7]. The spraying system consists of air-water nozzles, located on a frame consisting of pipes supplying water and air to them (Figure 6).

![Figure 6. Model of the spraying installation being a part of the mist system [7].](image)

High demand for compressed air is the solution disadvantage. This installation, with a flow of 9 dm³/min of water and a pressure of 0.6 MPa, needs about 5 m³/min of air, which is unobtainable in many mines and the need for such air volume raises many problems.

The solution developed in ITG KOMAG called CZP BRYZA (Figure 7) and FOG, where they were equipped with innovative mesh lattices that allow air flow while capturing wetted dust particles (Figure 8) [4, 8] was the answer to high consumption of compressed air in the spraying system. In turn, the air-water nozzles used there enable to achieve high efficiency of dust reduction, with low pressure of spraying media of 0.3-0.5 MPa and low water consumption of 3.0 dm³/min and compressed air of 0.75÷1.5 m³/min. This property results from the application of special solutions for spray nozzles in which, already inside, atomization of water takes place due to the use of much smaller amount of compressed air than in the case of a known, external atomization process of water, ultimately providing several times lower air flow.

![Figure 7. Model of the air-water roadway spraying device CZP BRYZA [4].](image)

![Figure 8. Innovative mesh lattices that allow air flow while capturing wetted dust particles [8].](image)

Air-water roadway spraying devices are solutions that significantly contribute to the improvement of safety and comfort of work and they improve the environmental working conditions in roadway workings. They cause a significant reduction in the risk of coal dust explosion. Low efficiency in reducing the PM10 dust, which is the most dangerous fraction for the human body is their important limitation. Underground tests of airborne dust concentration carried out within the project, in the case of using the currently used spraying devices, showed an effectiveness not exceeding 33% (Figure 9).
These solutions often cause problems with free passage of the personnel and are characterized by high water consumption resulting from their continuous work, which increase the cost of using such solutions and adversely affects the work comfort of miners. The newly developed concept of an intelligent spraying installation to be used in roadways, whose main task is to reduce airborne dust concentration is the answer to the above limitations. Such installation should ensure low water and air consumption and high efficiency of capturing even the smallest dust fractions.

3. Concept of intelligent spraying installation
The solution of intelligent spraying installation for controlling airborne dust concentration in mine underground workings was developed within the ROCD project. Adaptive spraying system consisting in adaptation of its output to the dust concentration measured by the EMIDUST dust meter is the solution advantage. The developed spraying installation will use water and compressed air to generate water drops of the size close to the size of PM10 dust.

The intelligent spraying installation (Figure 10) will have dozen or so spraying units installed on the roadway support circumference and they will be fed from the water and compressed air filtration-and-distribution units. Operation of the spraying units will be controlled by the controller, which will decide about spraying duration and intensity depending on PM10 and PM2.5 dust particles concentration measured by a dust meter to reduce airborne dust concentration below MAC.

**Figure 9.** Respirable dust reduction efficiency measured on 4 roadways equipped with currently used spraying devices.

**Figure 10.** 3D Model of the intelligent spraying installation.
Water and compressed air will be fed to the water (Figure 11) and compressed air (Figure 12) preparation units, where the media will purified and directed to the spraying units under the required pressure.

![Figure 11. Water preparation and distribution unit.](image1)

![Figure 12. Compressed air preparation and distribution unit.](image2)

Water in the water preparation and distribution unit will be divided into three stabilizing-and-supplying lines in which water pressure will be reduced to the set values (three different values $V_{r1}=0.1\text{MPa}$, $V_{r2}=0.2\text{MPa}$ and $V_{r3}=0.3\text{MPa}$). Water will flow through each spraying line after opening one of three controlled check valves, directing water stream to the hose supplying the spraying units. By analogy the compressed air in the preparation and distribution unit will be divided into three supplying lines in which air pressure will be reduced by the check valves to the set values (initial settings $V_{r1}=0.2\text{MPa}$, $V_{r2}=0.3\text{MPa}$ and $V_{r3}=0.4\text{MPa}$), and then air will be fed to the hoses supplying the spraying units through the controlled check valves (ZZS). Pressure in water and compressed air lines will be controlled by the pressure transducer.

The control of each ZZS controlled check valve is realized by double pre-control valves of Marco GmbH, installed on the distribution board (Figure 13) and it takes place in pairs (activation of one water ZZS check valve and activation of one compressed air ZZS check valve at the same time), so that water and compressed air are supplied to the spraying units.

![Figure 13. Double pre-control valves connected to the distribution board.](image3)

Electric equipment (Figure 14) of the intelligent spraying installation is responsible for proper operation of the spraying system. Intrinsically safe MDJ controller, responsible for collecting information from the EMIDUST EMAG optical dust meter and from the pressure transmitters of water and compressed air and then deciding about activation of double pre-control valves responsible for water flow to the spraying units, is the main subassembly of the electric equipment. The controller is powered from the ZIS intrinsically safe power feeder.
The intrinsically safe MDJ controller used in the electrical equipment consists of a steel enclosure in which the controller with a display and control buttons was installed. All modules, apart from the central module, are placed in standard plastic enclosures and mounted on a DIN rail fixed to the assembly board. The central module is equipped with a liquid crystal display installed on the enclosure door. Dust meter for the continuous measurement of the PM10 and PM2.5 dust concentrations is another component included in the electric equipment. The solution was developed as part of the project by ITI EMAG and is designed to provide information about the instantaneous concentration of dust sent to the intrinsically safe controller in the protected roadway. The dust meter uses the phenomenon of light scattering on dust particles. The measurement result is presented on the display and in the form of an analog voltage signal.

The spraying unit, generating the stream of water and compressed air is the last component of the intelligent spraying installation (Figure 15).

The spraying unit consists of a two-media nozzle, to which the connections of spraying media, i.e. water and compressed air, are mounted. The nozzle is mounted on a special articulating arm that allows adjusting the flow direction to the current needs for the roadway. The design of mountings makes them possible to adapt to various sizes of the roadway arch support frames, so the spraying...
nozzles can be placed in the mine workings of different cross-section shape. The advantage of the two-media nozzle is the wide fractional range of produced water drops, depending on the parameters of supplied water and compressed air. Such nozzles enable to operate in the range of low water pressure and compressed air pressure (0.05÷0.5 MPa), with low water consumption. The estimated minimum water consumption is 5 dm$^3$/h.

4. Principle of operation
The developed solution for the intelligent spraying system, after its installation in the roadway, has to measure PM10 and PM2.5 dust using the EMIDUST ITI EMAG dust meter. Basing on the signals from the dust meter, the pressure parameters for water and compressed air will be selected (one of the nine combinations of settings of water and compressed air parameters), enabling to obtain the highest dust control efficiency below MAC. The hydraulic-pneumatic-electric diagram is shown in Figure 16.

![Figure 16. The hydraulic-pneumatic-electric diagram of the intelligent spraying installation.](image_url)

Water and compressed air will be supplied to water and compressed air preparation and distribution unit from the pipelines. First they will be filtrated and then be distributed into three independent lines controlled by the ZZS check valves. Each water line will have different setting within the range 0.1÷0.3 MPa, and each compressed air line will have different setting within the range 0.2÷0.4 MPa. After getting information from the EMIDUST dust meter, the control unit will select parameters of water and compressed air, and then will open the water and compressed air valves (Figure 17).
Proper selection of pressures of water and compressed air supplied to the spraying units will enable the generation of drops with such fractional distributions reduce the identified dust concentration most effectively below MAC.

5. Conclusions
The intelligent spraying installation developed within the ROCD project is a response to the problem of airborne dust, especially the PM10 and PM2.5 fractions, occurring in underground hard coal mines. Its task is to eliminate the unfavourable parameters of spraying installations currently used for dust control, by applying the adaptive actions, consisting in adjusting the operational parameters and drops sizes to the dust concentration measured online. This will allow controlling the amount of water, adjusting it to the actual level of dust concentration. The installation consists of preparation and distribution units for water and compressed air. After passing them the media are distributed to each spraying line of individual settings of water and compressed air. The flow of media to each line of the spraying installation is realized by the controlled check valves. Water and compressed air of the set parameters are directed to the spraying units installed on the support arches, where water mist streams of the most favourable parameters will be generated, with drops size adequate to the measured dust concentration (Figure 18).
Design of the intelligent spraying installation, which will enable the construction of a prototype device will be based on the developed concept. Further stand tests aiming at determination of dust control efficiency depending on the generated water drops parameters [9], which will allow the development of the installation operation algorithm are planned.

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