# Installation optimization of air-and-water sprinklers at belt conveyor transfer points in the aspect of ventilation air dust reduction efficiency

***Dariusz Prostański*[1] *and* *Marta Vargová*[2]**

*Dust content in the air is one of the big hazards experienced in hard coal mines. In the result of mining of seams and driving road-headings coal and stone dust is generated. Coal dust has explosive properties, and in a certain accumulation and at certain conditions, it can cause a disaster whereas stone dust has a harmful impact on a human respiratory system and may cause pneumoconiosis. Both kinds of dust are present in the mine air simultaneously but in different proportions and concentrations. Design solutions and a principle of operation of Bryza-1200 transfer point sprinklers are described in the paper. An application of these sprinklers in coal mines, in different configurations and development of this solution over a period of a recent few years, is presented. Test results are given and an analysis of dust reduction in the aspect of positioning the components of Bryza-1200 sprinkler, in relation to the conveyor transfer point, is described. A shape of the transfer point, its speed, the direction of ventilation air flow, dimensions of the working and a position of the conveyor transfer point in relation to the working axis have an impact on the installation.*

***Keywords:*** *dust, spraying system, prediction, optimization, neural networks*

## Introduction

Apart from basic sources of dust generation in mines, there are many secondary sources, among others dust is generated by a movement of personnel as well as transfer points of belt and scraper conveyors. Dust control equipment or spraying devices are used for a reduction of dust. Dust control equipment (Prostański and Jedziniak, 2013) stores sucked in dust in a wet or dry form. Spraying devices neutralize harmful and dangerous dust combining dust particles with water drops, eliminating volatility of dust (Kwiecień and Szponder, 1989; Shirey, 1985; Prostański, 2013).

The efficiency of a spraying installation, which can vary from a dozen or so up to nearly 100% depends on a selection of design parameters (location, type, and a number of nozzles) and a selection of supply parameters.

An improvement of dust reduction efficiency is usually achieved by increasing supply pressure which is connected with an increased water flow intensity (Kwiecień and Szponder, 1989; Shirey 1985).

A reduction of nozzle outlet hole diameters causes a decrease in water flow intensity; however, then nozzles are subject to stacking and a loss of permeability. Another way, preferred by the KOMAG Institute (Bałaga and Jaszczuk, 2016; Karowiec, 1984; Prostański, 2013, Fabian, 2015) and more and more commonly used, are air-and-water spraying installations in which compressed air is applied for an improvement of the stream spraying quality. These installations, in general, have a better dust reduction efficiency, a significantly smaller water flow intensity and they generate small droplets of median from a dozen or so to tens micrometers.

The KOMAG Institute, as a leader in developing and implementing air-and-water spraying devices, has contributed significantly to their dissemination in mines, which always led to an improvement of safety and work comfort (Prostański, 2018, Černecký et al., 2015).

One of basic solutions of air-and-water spraying installation is Bryza-1200 sprinkler which has been applied in nearly a hundred systems, reducing dust concentration in the area of belt and scraper conveyors transfer points (Prostański, 2013).

## Bryza-1200 sprinkler

Bryza-1200 sprinkler (Fig. 1) is a device supplied with water and compressed air, which may be delivered from standard mine media, i.e., from the fire extinguishing pipeline and from the compressed air pipeline (Prostański, 2013). Supply pressure of air and water in the installation varies from 0.3 to 0.5 MPa, at the water flow intensity - from 0.5 to 2 $dm^3$/min. The amount of the water flow, irrespective of the pressure, is established with flow controllers, thus eliminating a need of using pressure controllers. The whole installation usually consists of five nozzles, and it is sufficient for a dust reduction on the transfer point even by 90%. Standard construction of Bryza-1200 sprinklers includes a frame with installed nozzles and chains for its suspension as

[1] *Prostański Dariusz,* KOMAG Institute of Mining Technology, Gliwice, Poland, dprostanski@komag.eu
[2] *Marta Vargová,* Faculty of Mechanical Engineering, TU Košice, Department of Safety and Quality Production, Letná 9, 042 00 Košice, Slovakia

well as a box of media preparation, in which there are cut-off valves, filters, and flow controllers. The components are connected with flexible hoses. In the case of water pressure exceeding 1 MPa, a reduction valve is applied. Bryza-1200 sprinkler is additionally equipped with drain grid, to which the wet dust adheres. Such a simple construction of the installation ensures its failure-free operation and easy maintenance. During an observation of the sprinkler operation and in the result of suggestions made by its users, a few alternative solutions of Bryza-1200 sprinkler and its additional equipment, have been developed.

To automatize an operation of Bryza-1200 sprinkler, a few additional solutions have been offered. One of them consists in an installation of feed height sensor, located over the conveyor belt, indicating a presence of coal on the belt and causing a start of spraying nozzles through an electrovalve and a return valve controlled with pressure, coupled with it. Another solution, enabling to automatize an operation of Bryza-1200 sprinkler is an application of non-electric roller water divider, designed at the KOMAG Institute. A divider roller is set in rotary motion with a belt, it opens a water valve, causing a flow of water stream which supplies the nozzles with water and compressed air. Its flow is possible due to the use of a return valve controlled by air. Another solution, which has not been implemented yet, is a combination of Bryza-1200 sprinkler application with the dust sensor located over the conveyor. After exceeding the given value of dust concentration in the air, the dust sensor causes a start of the electrovalve opening a flow of water and indirectly a flow of compressed air. An element improving a spraying efficiency is a feeder of dust wetting agent. This agent, batched to the water, reduces its surface tension, facilitating adhesion of dust to water drops. The feeder, designed at KOMAG is a non-electric device, supplied with a stream of spraying water. The spraying installation is also equipped with return valves controlled with pressure. Their series of types have been designed for operational pressures of spraying installations. All these solutions have been designed to suit the best operation of Bryza-1200 sprinkler to local userô conditions, taking into consideration the accessibility of supply media and dust concentration.


*Fig. 1. Bryza-1200 transfer point sprinkler.*

## Measurement results of dust reduction efficiency

Each time the first implementations of Bryza-1200 sprinkler have been connected with instructions for users within optimal use of the spraying installation and measurements of dust concentration reduction efficiency. In the majority of cases tests of total dust and respirable dust have been carried out (ProstaŒski, 2013). An assessment of desired positions of spraying systems in relation to the stream of running coal and a position of drain grid has been impeded by existing installation conditions, a shape of transfer point, a position of conveyors (angular, parallel) and a transportation direction of material in relation to the direction of the air stream. In the result of tests different results of dust reduction efficiency have been obtained, but usually, they exceeded 70%. It has also been observed that apart from certain exceptions, air-and-water spraying devices reach a higher efficiency of dust reduction for respirable dust than for total dust (Fig. 2). Probably it is caused by a degree of stream spraying to the diameter size of drops similar to the size of dust particles.

The taken measurements have shown that if the sprinkler is carried away, the dust concentration and reduced dust concentration as well as dust reduction efficiency decrease (Fig. 2).

Another reason for an impact on the results of dust concentration reduction is an installation of drain grid, which improves a sprinkler operational efficiency (Fig. 3). This phenomenon can be seen, in particular, for respirable dust (ProstaŒski, 2018; ProstaŒski, 2013). In general an efficiency of a spraying installation increases when the water flow intensity increases in the scope from 0.5 to 2.0 $dm^3$/min (in a few cases 10 $dm^3$/min). It can be concluded that if the air velocity increases, the spraying water flow intensity should be increased, keeping the right relationship between water flow intensity and air velocity. In accordance with the run-of-mine transportation direction with the direction of ventilation does not have a significant impact on dust reduction while using Bryza-1200 sprinkler. Other factors, such as geometric relationships of the spraying installation, i.e., the height of sprinkler attachment and drain grid over the conveyor and a difference of height of cooperating belts affect the dust reduction efficiency. Obtaining an optimal spraying efficiency is not a simple issue, and each time it requires an individual approach. Type of coal and use of agent reducing water surface tension and a location of the conveyor in relation to the working axis also have an impact on the dust reduction efficiency. However, these last parameters have not been recorded.

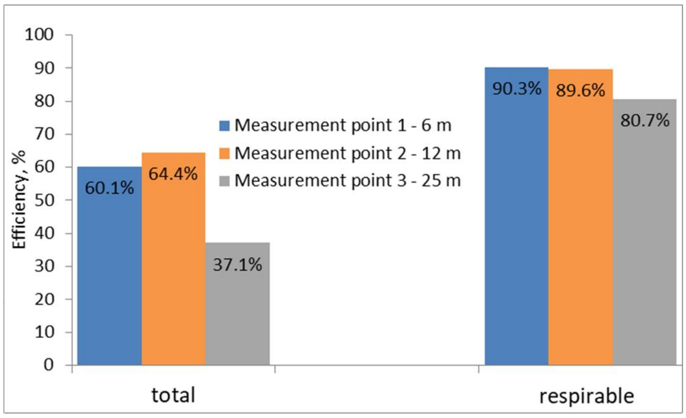


*Fig. 2. Dust reduction efficiency in different measurement points.*

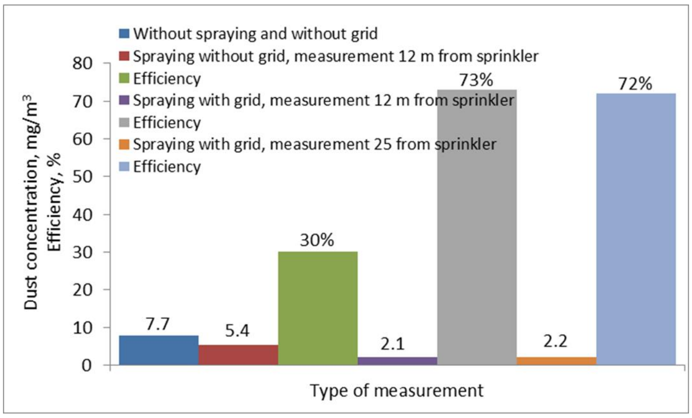


*Fig. 3. The efficiency of total dust reduction: measurement without grid 12 m from the sprinkler; with grid 12 m from the sprinkler; with grid 25 m from the sprinkler.*

## Analysis of test results of Bryza-1200 sprinklers used in coal mines

As can be seen from the conducted analysis (Fig. 4 and 5), it is difficult to select individual parameters of optimal positioning of air-and-water spraying installation unmistakably.

The conducted measurements indicate an increase in dust reduction efficiency explicitly while using Bryza-1200 sprinklers when a concentration of respirable dust increases. Similar, although less apparent trends can be observed in the case of total dust reduction efficiency. From Fig. 4a it can be concluded that at smaller distances of drain grid from sprinkler a reduction of respirable dust efficiency can be seen. This trend is less observable in the case of total dust (Fig. 4b). It is probably connected with smaller volatility of bigger dust grains. Lack of drain grid also affects a reduction of sprinkler efficiency. In the paper, for a presentation of results, in the case when it lacks the drain grid, it has been assumed that it is installed in the distance of 30 m from the sprinkler, in other words outside the furthest measurement point. As can be seen, when it lacks the drain grid one of the lowest results of dust reduction efficiency are experienced (Fig. 4).

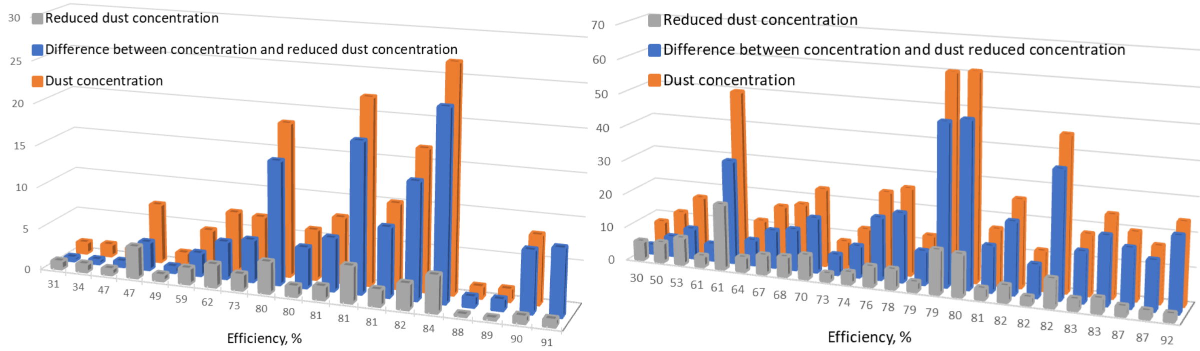


*Fig. 4. Impact of dust concentration level on the efficiency of its reduction: a) for respirable dust, b) for total dust*

A presentation of results, as regards total dust, is not unmistakable. It is affected by a repeatedly bigger weight of dust and significantly smaller distance of the settlement place from the dust raising place. However, only for about 4 % of results a dust reduction efficiency below 50 % and for about 30 % of results the efficiency lower than 70 % have been achieved. However, 40 % of results have had the efficiency exceeding 80 %. Such a high dust concentration reduction of respirable dust has been obtained for 58 % of measurements.

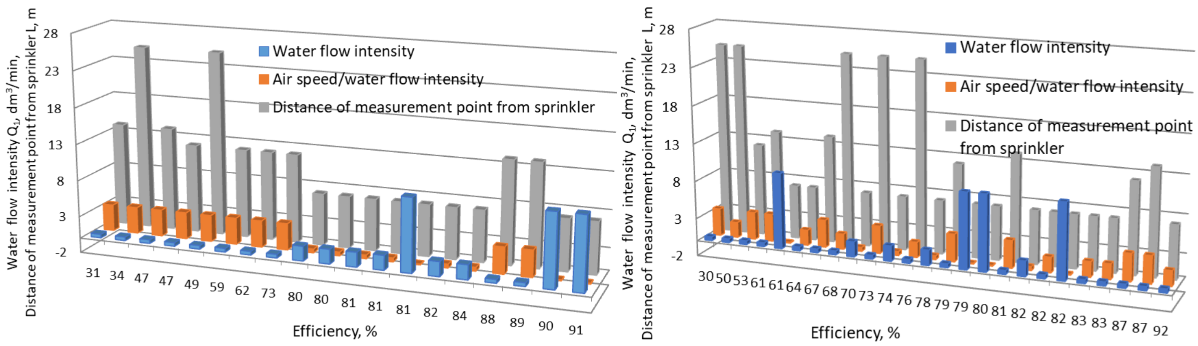


*Fig. 5. Impact of selected parameters on dust reduction efficiency: a) for respirable dust, b) for total dust.*

It should be borne in mind that the tests have been conducted in different configurations of the transfer point position, at the differentiated operational intensity and different types of coal, whose parameters have not been taken into consideration in this analysis. In the result of such an approach the obtained relationships should be treated as a generalization of the issue, and the results of the analysis show approximate values.

However, the conducted measurements show the usability of Bryza-1200 air-and-water sprinkler for a reduction of dust on conveyor transfer points. The high efficiency of dust reduction is achieved at a small water flow intensity, which has no negative impact on work conditions of the staff operating transfer points and it does not cause softening of the floor in the area of a transfer point.

## Possibilities of selecting parameters of spraying installation

The tested solutions have shown unmistakably that not only mining conditions in the working but also design features and supply parameters of spraying equipment have an impact on dust reduction efficiency. It is mainly seen in the case of reducing respirable dust. A correct selection of the type and configuration of the spraying device, adjusted to the transfer point in the roadway working, is not simple and explicit.

A selection of spraying devices is made, basing on the experience of producers and users, and often it may not be optimal.

A difficulty in assessing the impact of individual parameters on a dust reduction efficiency causes a need for searching tools for general and criterial optimization of spraying installation application method in given conditions.

It should also assume satisfactory thresholds of achieved efficiency which will enable convenient use of sprinklers in given application conditions, without a necessity of meeting all the given parameters, resulting from an optimization process.

An application of conventional models (Branny, 2008; Colinet et al., 2010; Changchi, Zhizong, and Dewen, 1996; Karowiec, 1984; Konduri, McPherson and Topuz, 1997; KwiecieŒand Szponder, 1989; Lange, 1996) of coal dust displacement and settlement and its combination with water drops, using mathematical function for a description, enables an exact description of the phenomenon but it is not practical to a big extent for a selection of spraying installation parameters. Statistical models (for example, multi-dimensional linear) (Colinet et al., 2010), which give a possibility of imaging a dust reduction process and a selection of application parameters of spraying installations to given operational conditions, are more practical. However, these models are complicated as regards their generation, and they require some appropriate theoretical knowledge (Jasiulek, Stankiewicz and WoszczyŒski, 2016; Latos and Stankiewicz, 2015; Stankiewicz, Jasiulek, Rogala-Rojek and Bartoszek, 2013).

Use of artificial neural networks seems to be a simple method of constructing a model describing a phenomenon of dust reduction using a spraying installation. This method is used successfully in many branches of science and industry for imaging processes and their control (Shirey, 1985; ProstaŒski, 2018; ProstaŒski, 2013).

Use of neural network consists of its training on a certain data set to foresee output data with it later on. It is essential that the network gets an ability to foresee exclusively on the base of delivered data. However, it is not supplied with any formulae or relationships between the input data and foreseen results. A right selection of the network type and structure is also of importance. An advantage of neural networks is a possibility of searching models for processes or phenomena, whose structure or operational principles have not to be recognized and described yet and only their quantities, which affect the phenomenon under testing and its result, are known. Thus this tool can be used successfully for modeling a dust reduction efficiency while using air-and-water spraying system.

Construction of a neural model requires a determination of network input parameters and its reply. Input and output quantities are measurement data and parameters obtained from conducted measurements on real objects.

It is best to apply classical classification models, for example, multi-layer perceptron trained with the use of a reverse propagation of errors (Jonak, ProstaŒski and Szkudlarek, 2003) for a description of this kind of phenomena. While constructing a model, it should also be determined which of the variables will be the network replies. The network reply enables a correct selection of spraying installation parameters in the aspect of dust reduction efficiency.

The tests of spraying equipment, conducted in mines, indicated an impact of the environment on spraying efficiency. Such parameters are among others:

- air flow velocity (m/s),
- the quantity of feed on the conveyor (Mg/h),
- the quantity of dust generated by the transfer point and its environment,
- coal moisture content (%),
- accordance of air flow direction with the conveyor movement direction (+/-),
- location of transfer point in relation to the working axis,
- the height of transfer point (mm),
- the difference in conveyor belts levels on transfer point (mm),
- run-of-mine transportation velocity (m/s),
- total dust concentration in the mine air (mg/m$^3$),
- the concentration of respirable dust in the mine air (mg/m$^3$).

Achieved efficiencies will also be input data of the network:

- reduction efficiency of total dust in the mine air (%),
- reduction efficiency of respirable dust in the mine air (%).

Above given quantities may be input parameters for a neural model. Other parameters, describing a specificity of a spraying system installation, are among others:

- spraying water flow intensity (dm$^3$/min),
- air pressure (MPa),
- water pressure (MPa),
- number of spraying nozzles (pieces),
- the height of sprinkler suspension (mm),
- type of nozzles.

These and other parameters can be network replies, in other words, quantities which can be affected. In relation to the number of measurements and degree of individual parametersô impact on a reply, a suitable number of layers in a neural model should be accepted, sufficient for getting a reply with the proper correlation coefficient, where a model will react properly on changes of these parameters. Another important feature of a neural model is an acceptable time of learning and getting a reply.

Reliability of a correct model selection and of getting replies close to these, which are obtained in real conditions, gives a testing set, on which a quality of the network adaptation to independent sets of measurement data is checked. To obtain reliability of a correct model operation, the network is checked on the third, independent validating set. A correlation coefficient which equals 1 proves a stiff adaptation of the network to the relationships under analysis, and it will render impossible to get correct network replies, for example, out of the scope of the data under consideration (ProstaŒski, 2002).

A model with a number of neurons in the input layer equal to the number of input data and the number of neurons in the output layer, equal to the desired number of network replies, seems to be most obvious. Intermediate layers, aimed at improving the efficiency of the network operation, should be included in the structure of such a network. Obviously, in the case of a smaller experience of a creator or lack of recognition of a phenomenon under description, intermediate layers should be selected experimentally, obtaining in each following modeling, a network of acceptable learning speed and a satisfactory quality of reply. However, assuming that this phenomenon is tested, using this method for the first time, it is correct to assume one reply of a network, i.e., one output neuron. In this way, it is possible to construct a few networks, each time expecting a different reply. Some of the output data, which can be affected in a smaller degree, can be placed in an input layer, for example, water flow intensity or water and compressed air pressure.

### Effects of modeling using an artificial neural network

Initial tests of measurement data sets with use of artificial neural networks have shown that a set, concerning respirable dust, is much more foreseeable than the total dust. A possibility of conducting an introductory analysis easily and quickly can give at once a reply as regards correctness of conducted considerations, confirming or not suppositions in the scope of an impact of individual factors on dust reduction efficiency.

An assessment analysis of the impact of a drain grid on a dust reduction efficiency has been conducted as the first one. An automatic network architect has generated 10 network models, where the best model is shown in Fig. 6. Basing on this model an average error 3.6, a standard deviation 2.6 and a correlation coefficient 0.13 have been determined. These quantities disqualify the network as regards its correctness and cannot be accepted at a selection of a drain grid location.

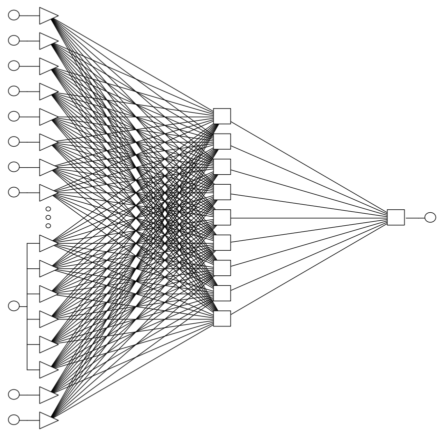

*Fig. 6. Model of a neural network for searching an optimal position of drain grid in the case of total dust measurements.*

Basing on collected data, it has been possible to present an impact of drain grid position (*d*) on dust reduction efficiency (*s*) in relation to dust concentration, a difference between dust concentration and reduced dust concentration (***φ****s*) and a distance of the sprinkler from the measurement place (l) ï Fig. 7. From the conducted analysis it can be concluded that the bigger distance of drain grid (*d*) and the smaller dust concentration (*a*), the bigger dust reduction efficiency (Fig. 7a). The situation looks different in the case when the difference between total dust concentration and reduced dust concentration decreases, then an increase in dust reduction efficiency is achieved at a smaller distance of the drain grid from the sprinkler (Fig. 7b). An increase of dust reduction efficiency is achieved at the biggest distance of the grid and possibly small distance of taking measurements of dust concentration from the sprinkler (Fig. 7c). It should be borne in mind that the presented relationships show the relationships between individual parameters in the context of relations determined by the neural network.

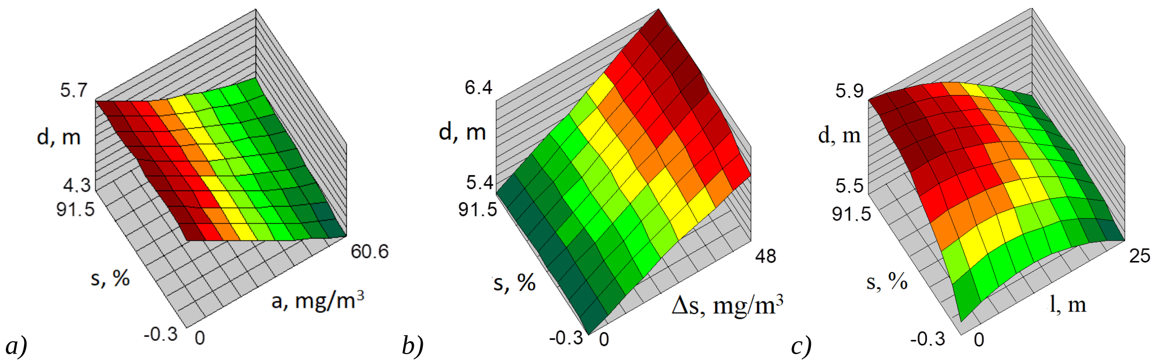


*Fig. 7. Impact of drain grid distance from the sprinkler on reduction efficiency of total dust in relation to a) dust concentration (a); b) difference between dust concentration (φs); c) distance from sprinkler to concentration measurement place (1).*

A significantly better quality of the network has been achieved for an efficiency assessment in the context of total dust measurement concentration. The best structure, among 10 suggested networks, is presented in Fig. 8. In the case of this network, an average learning error has been about 2, at an average standard deviation of about 5 and a correlation coefficient of about 0.7. Obviously, these parameters also disqualify this model. However, it is much more reliable than the previous one.

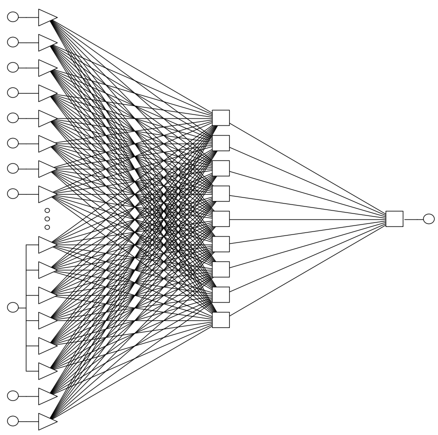

*Fig. 8. Model of the neural network at searching for optimal placement of total dust concentration measurement.*

Testing an impact of measurement place (1) of dust concentration (*a*) on dust reduction efficiency (*s*) in relation to dust concentration (*s*), a difference in dust concentration and reduced dust concentration (**φs**) and the distance of drain grid suspension from a sprinkler is presented in Fig. 9. In this case the bigger distance of the measurement place from the sprinkler (1), the higher efficiency of decreasing total dust quantities (Fig. 9a). A similar trend can also be observed at a decreasing difference between dust concentration and reduced dust concentration (Fig. 9b). Different relationships occur in the case of an impact of distances between measurement places and a sprinkler on dust concentration in $d/v_1$, which have an insignificant impact on dust reduction efficiency (Fig. 9c).

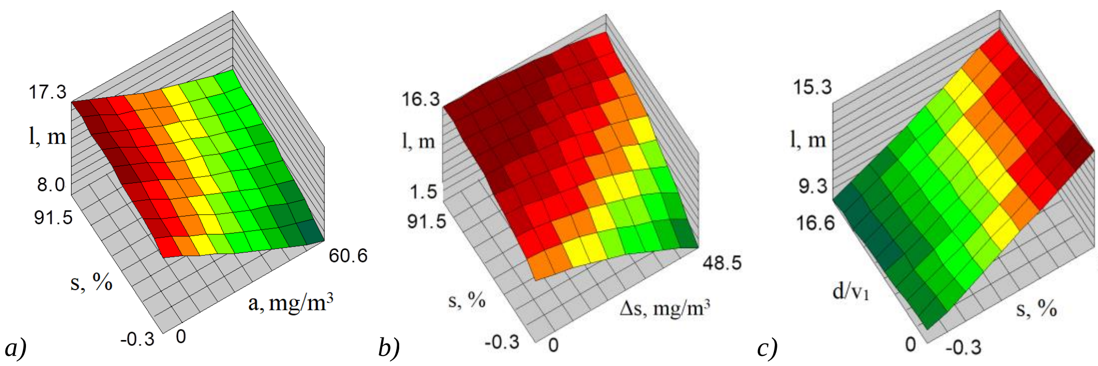


*Fig. 9. Impact of measurement distance from the sprinkler on a reduction of total dust concentration in relation to a) dust concentration (a); b) difference between concentration and reduced dust concentration (φs); c) air velocity and the distance of drain grid from the sprinkler (d/v1).*

A better quality network has been obtained at an assessment efficiency of respirable dust reduction in relation to the distance of drain grid suspension. The best network, among 10 selected ones, is shown in Fig. 10. In the case of this network, an average learning error has been about 2 and a standard deviation ï about 3 and a correlation coefficient has been about 0.99. These results of network learning are significantly better. It also concerns imaging relationships accompanying a reduction efficiency assessment of respirable dust, although also, in this case, they may be regarded as insufficient ones.

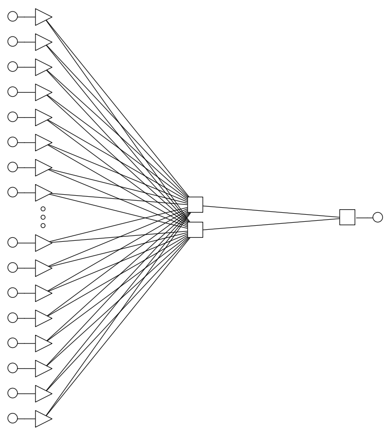

*Fig. 10. Model of the neural network at searching the optimal suspension place of drain grid for respirable dust fraction.*

The distance of drain grid suspension in relation to the parameters *s*, *φs*, *a*, *d* is shown in Fig. 11. In all the three cases, these relationships are shown by inclined planes. When the distance of the grid suspension from the sprinkler increases, the reduction efficiency of respirable dust increases and it also increases when the dust concentration decreases (Fig. 11a). The efficiency of dust reduction also increases proportionally to an increase of the distance of the drain grid from the sprinkler and an increase of the difference between dust concentration and reduced dust concentration (Fig. 11 b). An increase of reduction efficiency of respirable dust is also observed at the simultaneous increase of the drain grid suspension distance and the distance of measurement place (Fig. 11 c).

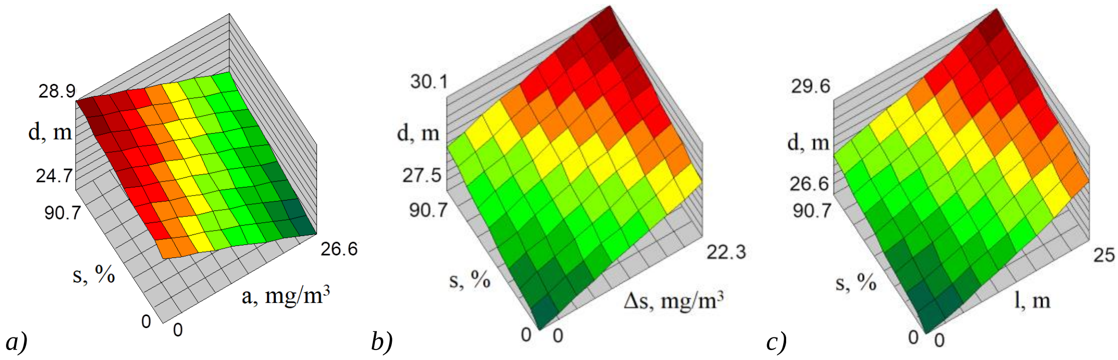


*Fig. 11. Impact of the distance between drain grid from the sprinkler on reduction efficiency of respirable dust in relation to a) dust concentration (s); b) difference between dust concentration and reduced dust concentration (φs); c) distance of taking concentration measurement.*

Even better results of learning have been obtained for a reduction efficiency assessment in the case of respirable dust in relation to the distance of dust concentration measurements (Fig. 12). An average error has been 0.6, standard deviation - 2.7 and correlation coefficient - 0.98.

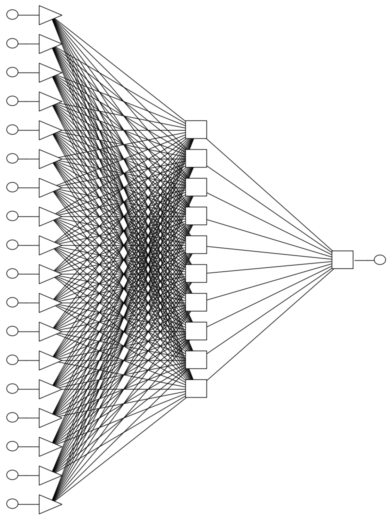

*Fig. 12. Model of the neural network of searching optimal measurement place of respirable dust concentration.*

In the case of testing a distance impact of concentration measurement on reduction efficiency of respirable dust in relation to *a*, $\boldsymbol{\varphi}s$, $d/v_1$, bent, regular surfaces (Fig. 13) of these relationships have been obtained. A location of measurement place has a small impact (Fig. 13a) on an efficiency assessment of dust reduction in relation to respirable dust concentration. This relationship looks different in the case of different $\boldsymbol{\varphi}s$ quantities, where the biggest efficiency is achieved for the furthest measurement places and the biggest $\boldsymbol{\varphi}s$ (Fig. 13 b). There is no essential impact of 1 and $d/v_1$ on dust reduction efficiency. Then an efficiency increase depends exclusively on an increase of $d/v_1$ (Fig. 13 c).

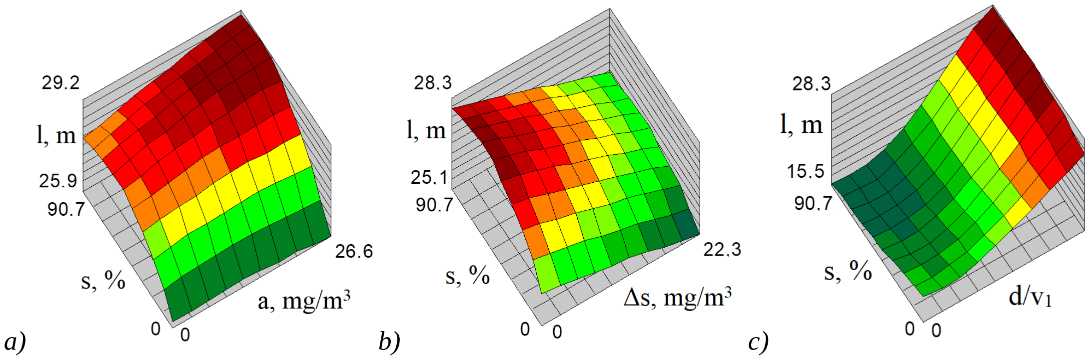


*Fig. 13. Impact of measurement place on reduction efficiency of respirable dust in relation to a) dust concentration (s); b) difference between dust concentration and reduced dust concentration ($\boldsymbol{\varphi}s$); c) air velocity and the distance of drain grid from sprinkler (d/v1).*

## Summary

The tests of reduction efficiency of air-borne dust, using air-and-water Bryza-1200 sprinkler, conducted in mines, have shown a high efficiency of this installation, however basing on these tests it is difficult to assess a real impact of individual parameters of a spraying installation on the efficiency. It is also difficult to assess the impact of the weight of these parameters at different mining conditions. The presented relationships of an impact of individual parameters on dust reduction efficiency reveal many diversities, in particular in the case of total dust. Having at disposal, a relatively small number of measurements and incomplete data as regards conducted measurements, an application of a simple and effective tool, such as neural networks for presenting an impact of individual parameters on dust reduction efficiency and trials of imaging relationships among all the available quantities, is suggested. Due to this fact, the use of neural network seems to the most appropriate and the simplest approach to the phenomenon. Basing on the obtained test results, preliminary models of neural network have enabled to image a phenomenon of air-borne dust with different, not always satisfactory quality. The main objective of this experiment has not been to get the best reply, but to show that getting it is possible in a simple way, without a deep understanding of relationships among individual parameters. Initial tests of spraying installations with the use of neural networks, conducted at the KOMAG Institute have indicated the right

direction of research work despite a relatively small population of learning and validating sets. In the learning process, as regards an efficiency assessment of respirable dust, a correct image of spraying parameters has been achieved. Within a simulation framework a network of multi-layer perceptron type, consisting of a dozen or so neurons in the input layer, ten neurons in the hidden layer and one output neuron, imaging an optimal measurement place of dust concentration, has been suggested. This network has been selected as the best one from 720 tested models of the network. It has been approved by the Statistica-Neural Networks Software as effective and correct, and its average learning error has been 0.6, standard deviation - 2.7 and correlation coefficient - 0.98.

## References


Bağaga, D. and Jaszczuk, M. (2016) Wpğyw parametrów strumienia zraszajŃcego na redukcjň zapylenia generowanego przez kombajn Ŝcianowy [Impact of spraying stream parameters on a reduction of dust generated by a longwall shearer]. Prace Naukowe - Monografie KOMAG. *Instytut Techniki Górniczej KOMAG nr 47.*

Branny, M. (2008) Numerical simulation of ventilation of blind drifts with a force-exhaust overlap system in the condition of methan and dust hazards. *Archives of Mining Sciences vol. 53.*

Colinet F. et al. (2010) Best Practices for Dust Control in Coal Mining. *Pittsburgh.*

Ųernecký J., Valentová K., Pivarļiová E., Boģek P. (2015). Ionization Impact on the Air Cleaning Efficiency in the Interior. *Measurement Science Review, Volume 15, Issue 4, 1 August 2015, Pages 156-166*

Changchi, Y., Zhizong, C. and Dewen, L. (1996) Prace naukowe i badania nad zwalczaniem zapylenia za pomocŃ wentylacji w zmechanizowanych przodkach chodnikowych chiŒskich kopalŒ wňgla [Scientific projects and tests on dust control with use of ventilation in mechanized roadway faces in Chinese coal-mines]. Miňdzynarodowa Konferencja Naukowo Techniczna U. S. Departament of Energy i KOMAG: ĂZwalczanie zagroŮeŒ pyğowych w przemyŜle górniczym na Ŝwiecieò. *Szczyrk.*

Fabian, M., Boslai, R., Iģol, P., Janeková, J., Fabianová, J., Fedorko, G., Boģek, P. (2015). Use of parametric 3D modelling - tying parameter values to spreadsheets at designing molds for plastic injection. *Manufacturing Technology, Volume 15, Issue 1, 2015, Pages 24-31*

Hamilton, R. J. and French, A. G. (1974) Research and development in dust control in coal mines. *Minerals and the Environment. London.*

Jonak, J. (1998) Teoretyczne podstawy urabiania skağ stoŮkowymi noŮami obrotowymi [Theoretical grounds of cutting rock with rotary, conic cutting picks]. *Wydawnictwa Uczelniane Politechniki Lubelskiej. Lublin.*

Jonak, J., ProstaŒski, D. and Szkudlarek, Z. (2003) Analiza moŮliwoŜci wykorzystania sieci neuronowych w badaniach stanu obrotowych noŮy stoŮkowych [Analysis of possibilities of using neural netowrks in testing a condition of rotary, conic cutting picks]. *Mechanizacja i Automatyzacja Górnictwa nr 10.*

Jasiulek, D., Stankiewicz, K. and WoszczyŒski, M. (2016) Intelligent self-powered sensors in the state-of-the-art control systems of mining machines. *Archives of Mining Sciences vol. 61(4).*

Karowiec, K. (1984) Zwalczanie zapylenia za pomocŃ wyrzutu strumienia powietrza nasyconego mgğŃ wodnŃ na Ťródğo pyğu [Dust control with outburst of air stream, saturated with water mist, on dust source]. Maszyny Górnicze. *UrzŃdzenia OdpylajŃce nr 5.*

Konduri, I.M., McPherson, M.J. and Topuz E. (1997) Experimental and Numerical Modelling of Jet Fans for Auxiliary Ventilation in Mines. Proceedings of the 6th International Mine Ventilation Congress. Pittsburg.

KwiecieŒ, Z. and Szponder, T. (1989) Ocena efektywnoŜci dysz stosowanych do zwalczania zapylenia powietrza [Efficiency assessment of nozzles used for air-borne dust control]. *WiadomoŜci Górnicze nr 8-9.*

Lange, U. (1996) ObniŮenie frakcji wdychanej pyğu poprzez zastosowanie Ŝrodka zwilŮajŃcego zawierajŃcego olejki z owoców cytrusowych wyciskane na zimno [Reduction of respirable dust using a wetting agent containing coldly squeezed out oils from citrus fruit]. Miňdzynarodowa Konferencja Naukowo Techniczna U. S. Departament of Energy i KOMAG: ĂZwalczanie zagroŮeŒ pyğowych w przemyŜle górniczym na Ŝwiecieò. *Szczyrk.*

Latos, M. and Stankiewicz, K. (2015) Studies on the effectiveness of noise protection for an enclosed industrial area using global active noise reduction systems *Journal of Low Frequency Noise Vibration and Active Control.*

Praca zbiorowa. Red. Shirey, G. A. (1985) Dust control handbook for longwall mining operation. *Wyd. Bureau of Mines United States Department of the Interior.*

ProstaŒski, D. (2018) Development of research work in the air-water spraying area for reduction of methane and coal dust explosion hazard as well as for dust control in the Polish mining industry. IOP Conference Series: *Materials Science and Engineering vol. 427 no. 1. IOP Publishing.*

ProstaŒski, D. (2013) Use of air-and-water spraying systems for improving dust control in mines. *Journal of Sustainable Mining vol. 12.2.*

ProstaŒski, D. (2012). Dust Control with Use of Air-Water Spraying System. *Archives of Mining Sciences vol. 57(4).*

ProstaŒski, D. (2002) Wybrane problemy identyfikacji procesu skrawania skağ z uŨyciem sztucznej sieci neuronowej [Selected issues of identification of rock cutting process using an artifical neural network]. *Maszyny Górnicze nr 20(1).*

ProstaŒski, D. and Jedziniak, M. (2013) Rozwój systemów zwalczania zagroŨeŒpyğowych [Development of dust hazard control systems]. *Maszyny Górnicze nr 2*.

Stankiewicz, K., Jasiulek, D., Rogala-Rojek, J. and Bartoszek, S. (2013) Selected, state-of-the art mechatronic systems in polish underground mining industry. ISARC 2013 - 30th International Symposium on Automation and Robotics in Construction and Mining, Held in Conjunction with the 23rd World Mining Congress.