Environmental Engineering and Management Journal

April 2019, Vol. 18, No. 4, 789-795
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

CONTINUOUS INVASIVE MONITORING TECHNOLOGY FOR DETERMINATION OF AIR VELOCITY AT THE LEVEL OF MAIN VENTILATION STATION

Emeric Chiuzan*, George Artur Găman, Doru Cioclea, Cristian Tomescu, Ion Gherghe

National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroşani, 32-34 G-ral Vasile Milea Street, 332047 Petroşani, Hunedoara County, Romania

Abstract

Proper functioning of the main ventilation station depends on the mining network's degree of ventilation. Also, knowledge of changes in instantaneous aerodynamic parameters offers the possibility of taking operational measures necessary to maintain optimal health and safety in the underground. The objective of the present paper is to identify a new method of monitoring the aerodynamic parameters at the main ventilation station.

Key words: aerodynamic parameters, industrial ventilation, fans

Received: September, 2018; Revised final: January, 2019; Accepted: April, 2019; Published in final edited form: April, 2019

1. Introduction

The main objectives of the paper are represented by the analysis of aerodynamic parameters within mine workings belonging to the main ventilation station and by the possibility to directly establish the airflows by invasive means. The novelty consists in the development of a new invasive measuring method for obtaining the aerodynamic parameters of the main ventilation station, making of the continuous monitoring system for aerodynamic parameters, accurately establishing the functional parameters of main fans and development of an unconventional technology for measuring aerodynamic parameters.

The previous important research aimed at establishing the functional parameters at the main ventilation stations. At the same time important researches have been carried out regarding the modeling, solving and simulation of complex ventilation networks with the help of specialized programs (Hargreaves and Lowndes, 2007; Suvar et al., 2017; Wei, 2011; Wenyao et al., 2011).

2. Material and methods

2.1. Characteristics and operational parameters of fans

Characteristic curves of main ventilation fans are established by laboratory testing, plant tests and tests in exploitation conditions. Laboratory tests are performed on models and aim the determination of characteristic curves, as well as the study on the influence of various factors upon the performances of fans. Plant tests aim the establishment of characteristic curves for industrial fans, which differ from the characteristic curves obtained by recalculating the parameters of model fans based on similitude hypotheses (Băltărețu and Teodorescu, 1971; Matei and Moraru, 2000; Teodorescu et al., 1980).

Therefore, the performances of fans from main ventilation stations can be determined only by

* Author to whom all correspondence should be addressed: e-mail: emeric.chiuzan@insemex.ro; Phone: + 40 254541621; Fax: +40 254546277

establishing their characteristic curves in exploitation conditions (Chiuzan and Gherghe, 2012; Tomescu et al., 2017; Zhou et al., 2017).

For underground mines in our country, characteristic curves are determined for main ventilation fans with a nominal flow higher than 500 m^3/min at the moment when they are set into operation within the ventilation networks, as well as every two years (RSSM, 2007), after complete revisions.

These characteristic curves are as follows:

- the total pressure of the fan as a function of its Q performance;
- the power consuption of the fan as a function of its Q performance (Fig. 1);
- the efficiency of the fan as a function of its Q performance (Fig. 2).

By using these parameters, the useful power, efficiency of the ventilation installation and the energy consumption may be determined through calculations, for all working regimes to which the fan is subjected. For estimating the efficiency of main ventilation installations, measurement of the following parameters is required:

- fan performance, Q_v (m^3/min);
- fan total pressure measured at the operating point, h_v (Pa);
- mine flow, Q_m (m^3/min);
- mine total mine depression, h_m (Pa).

Based on these measurements the following parameter/s are determined:

- flow of air short-circuited with the surface, Q_{sc} (m^3/min) (Eq. 1):

$$Q_{sc} = Q_v - Q_m \text{ (m}^3\text{/min)} \quad (1)$$

- ventilation channel depression, h_c (Pa), (Eq. 2):

$$h_c = h_v - h_m \quad \text{(Pa)} \quad (2)$$

- aerodynamic resistance of the ventilation network, R_r (Ns^2/m^8), (Eq. 3):

$$R_r = \frac{h_v}{Q_v^2} \text{ (Ns}^2\text{/m}^8) \quad (3)$$

- aerodynamic resistance of the mine, R_m (Ns^2/m^8), (Eq. 4):

$$R_m = \frac{h_m}{Q_m^2} \text{ (Ns}^2\text{/m}^8) \quad (4)$$

- aerodynamic resistance of the ventilation channel, R_c (Ns^2/m^8), (Eq. 5):

$$R_c = \frac{h_c}{Q_v^2} \text{ (Ns}^2\text{/m}^8) \quad (5)$$

- equivalent orifice of the network, A_r (m^2), (Eq. 6):

$$A_r = \frac{1.2}{\sqrt{R_r}} \text{ (m}^2) \quad (6)$$

- equivalent orifice of the mine, A_m (m^2), (Eq. 7):

$$A_m = \frac{1.2}{\sqrt{R_m}} \text{ (m}^2) \quad (7)$$

- airpower, also known as a useful power can be written for incompressible flow, P_u (kw), (Eq. 8):

$$P_u = \frac{Q_v \cdot h}{1000} \text{ (kw)} \quad (8)$$

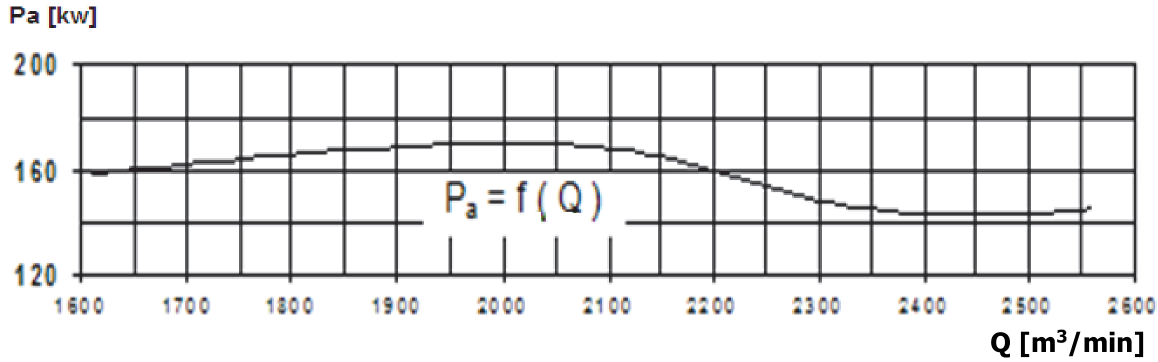

Fig. 1. Power curve

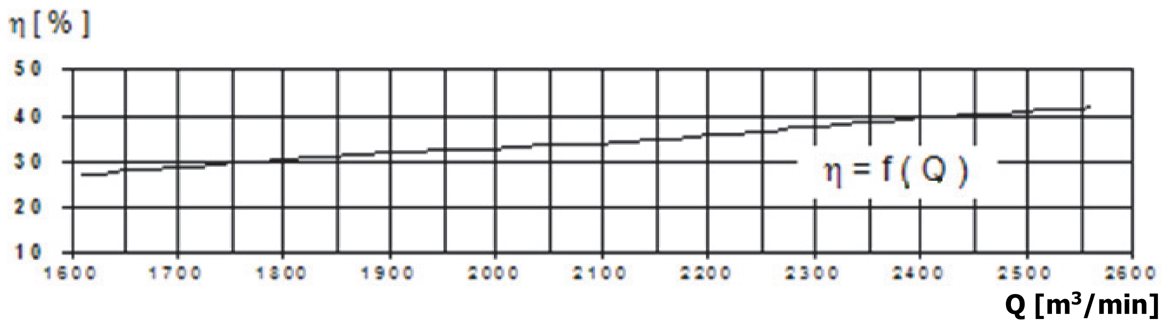

Fig. 2. Efficiency curve

- Total fan efficiency for incompressible flow, η (%), (Eq. 9):

$$\eta = \frac{P_u}{P_a} \cdot 100 \quad (\%) \tag{9}$$

where: P_a is the input power of the fan motor (kw).

- Percentage of air leakages by short-circuiting with the surface (P_{sc}, %), in relation with the mine flow, (Eq. 10):

$$P_{sc} = \frac{Q_v - Q_m}{Q_m} \cdot 100 \ (\%) \tag{10}$$

- The annual power consumption, E (kwh/an) of the main ventilation network (Eqs. 11, 12):

$$E = P_a \cdot 24 \cdot 365 \ \text{(kwh/an)} \tag{11}$$

- For main ventilation stations equipped with two fans which operate half year each other, alternatively (Eqs. 12, 13, 14):

$$E_1 = \frac{P_{a1} \cdot 24 \cdot 365}{2} \ \text{(kwh/an)} \tag{12}$$

$$E_2 = \frac{P_{a2} \cdot 24 \cdot 365}{2} \ \text{(kwh/an)} \tag{13}$$

$$E_t = E_1 + E_2 \ \text{(kwh/an)} \tag{14}$$

2.2. Analysis of the main ventilation station

Powerful fans, located on the surface within main ventilation stations, are used for circulating air within active mine workings, from fresh air input points towards the exhaust point of return-air (Cheng et al., 2010; Cheng and Yang, 2012; Cioclea et al., 2012, 2014).

Regardless of the location of main fan stations (underground vs. surface) the following measurements are performed:

- Air velocity in the ventilation chanel, V (m/s);
- Total pressure (depression) of the fan, h_V (Pa);
- Air velocity in the gallery output total mine, V (m/s);
- Total presure of main fan station pressure (depression), h_{st} (Pa);
- Electrical power absorbed by the electrical motor from the power supply network, N (kw);
- Air state parameters, namely:
  - air temperature, t (^{0}C);
  - relative humidity, φ (%);
  - barometric pressure, B (mm Hg);
  - specific weight of air, ρ (kg/m^3).

These parameters form the basis for determining the actual airflow circulated by the fan.

3. Results and discussion

3.1. Aerodynamic parameters of the main ventilation station

Aerodynamic parameters within the mine workings are the following:
- the pressure drop across the mine working, H (Pa);
- airflow, Q (m^3/min);
- aerodynamic resistance, R (Ns^2/m^8).

For measuring the aerodynamic parameters of the main ventilation station, direct measurements or indirect calculations are performed. In order to perform this, a complex of mine workings (Fig. 3) related to a main fan station is considered, with the following branches:

- 1-3, short-circuiting with the surface characterized by Q_{sc}, R_{sc}, H_{sc};
- 2-3, equivlent branch of the mine, which is characterised by Q_m, R_m, H_m;
- 3-6, ventilation channel characterized by Q_c, R_c, H_c;
- 5-6, locked passage into the ventilation channel characterized by Q_{sas}, R_{sas}, H_{sas};
- 4-6, ath of air flow towards fan no. 2 characterized by Q_{V2}, R_{V2}, H_{V2};
- 6-7, ath of air flow towards fan no. 1 characterized by Q_{V1}, R_{V1}, H_{V1}.

Air flows Q_{sc}, Q_m, Q_c, Q_{sas}, Q_{V2}, Q_{V1}, are determined by direct measurements with the anemometers over the branches 2-3, 3-6, 5-6, 4-6, and indirectly over branches 1-3 (Eq. 15) and 6-7 (Eq. 7) as follows:

$$Q_{1-3} = Q_{3-6} - Q_{2-3} \quad \text{(m}^3\text{/min)} \tag{15}$$

$$Q_{6-7} = Q_{3-6} + Q_{5-6} + Q_{4-6} \ \text{(m}^3\text{/min)} \tag{16}$$

The drop of pressures H_m, H_{sc}, H_c, H_{sas}, H_{V2}, H_{V1}, are determined by pressure measurements over all branches 1-3, 2-3, 3-6, 5-6, 4-6, 6-7. Measurement of pressure losses is done by the classic hose method

Aerodynamic resistances are determined by calculation (Gherghe, 2004; Patterson, 1992).

3.2. Determination of points for establishing fan performances curves

For obtaining different points required for drawing up the characteristic curves, the airflow circulated by the fan shall be modified by step by step increasing or decreasing the equivalent orifice of operation, as follows:

- Gradual obstruction of ventilation channel sections in case of centrifugal fans;
- Obstruction of the section for various operation regimes (different values of inclination angles of the rotor blades) or by changing the inclination angle of the blades from guide vanes the stator at the same angle, in case of axial fans provided with the ventilation channel.

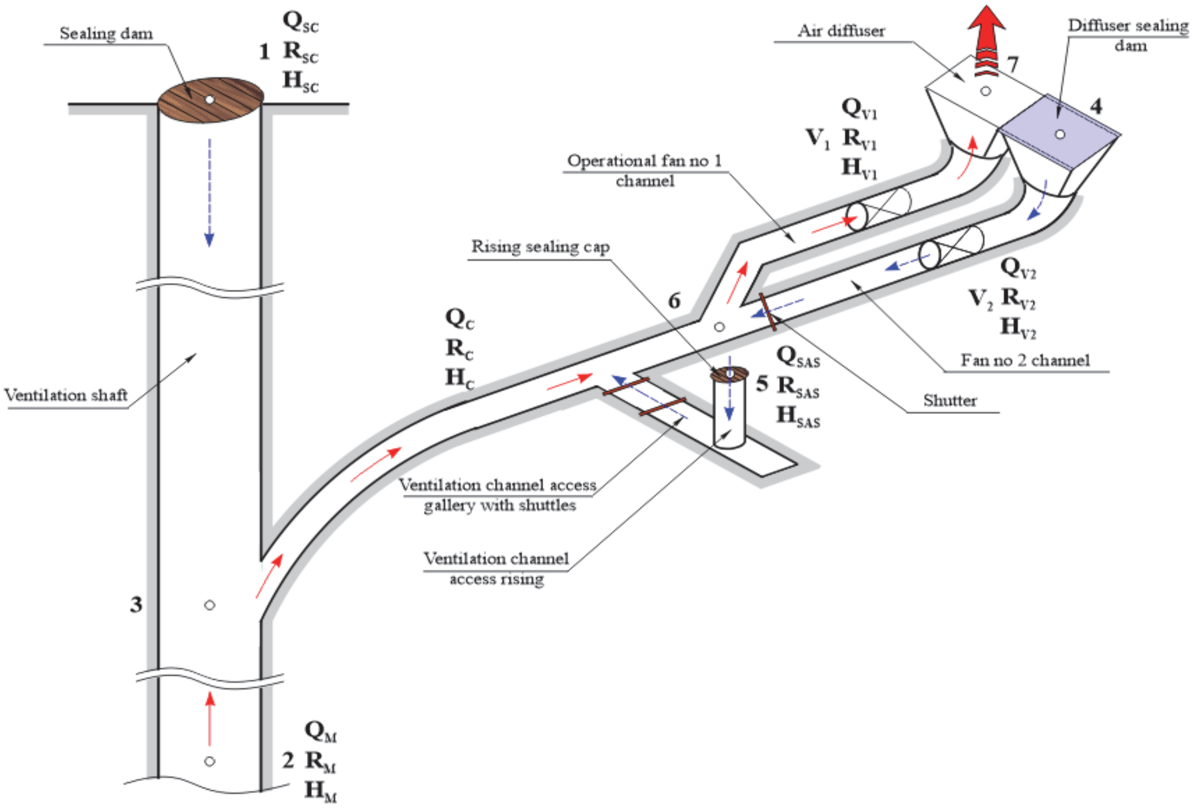

Fig. 3. Main ventilation station

3.3. Air flow determination

The air flow is determined by multiplying the cross-sectional area of the measurement station with the air current's velocity. The air velocity is determined using the anemometer or the Pitot-Prandtl tube. Measuring the air velocity with the anemometer is performed by uniform displacement in the measurement cross-section by point measurements, in subdivisions obtained by splitting the cross-sectional area. For the uniform displacement measurements, the rotation of air velocity meter, for which the velocity is established is given by the arithmetic mean of two measurements, which shall not differ one from the other with more than 3%.

In case of point measurements, the arithmetic means of average rotations measured the rotation of air velocity meter, in each point is taken into account (Oberholzer and Du Plessis, 2002; Şuvar et al., 2012, 2014). The average rotation provides the determination of air current using the anemometer's specific diagram. The velocity obtained is corrected depending on the section and on the measurement performance mean. Air flow is determined using the following equation (Eq. 17):

$$Q_d = S \cdot V \cdot K \text{ (m}^3\text{/s)} \quad (17)$$

where: S – area of the measurement station's cross-section, in m^2; V – average air velocity, in m/s; K – correction coefficient, depending on the cross-section $\left(K = \frac{S-0.4}{S}\right)$.

For determining the air velocity by dynamic measurements using the Pitot-Prandtl tube, the following equation is used (Eq. 18):

$$V = \sqrt{\frac{2\,h_d}{\rho}} \text{ (m/s)} \quad (18)$$

where: h_d – average velocity pressure, also known dynamic pressure, in Pa; ρ - air density, in kg/m^3.

The number of measurement points of the dynamic pressure is:

a) In the case of taken the measurements in circular shape of cross-section:

- 12 points located over two perpendicular diameters, for cross-sections with the diameter lower than 1.2 m and
- 24 points located on 4 diameters at 45^0, for cross-sections with the diameter higher or equal to 1.2 m.

Distances between the points and the circular wall are: 0.037 D; 0.135 D; 0.321 D; 0.679D; 0.865 D and 0.968 D respectively.

b) In case of rectangular cross-sections, the number of measurement points results from the ratio between the area of the measurement cross-section and the area of a subdivision (which has to be smaller than 0.05 m^2).

Airflow is determined by applying Eq. (19):

$$Q_d = S \cdot V \quad (m^3/s) \qquad (19)$$

Along with measurements performed for obtaining the characteristic curves of fans, measurements for the mine airflow within the mine working(s) for exhausting return air towards the ventilation channel are also performed.

3.4. Making of the continuous monitoring system for aerodynamic parameters

In order to have actual values of specific aerodynamic parameters from mining workings related to the main ventilation station, air flow and pressure measurements are performed. The system consists of:

- Four one-meter long straight segments (Fig. 4);
- One one-meter long T-segment;
- Four cross-shaped segments of 0.75 x 0.75m (Fig. 5);
- Pitot tubes numbered 1 to 13 (Fig. 6).

Two distributors each having twelve air-valves (Fig. 7). This extensible monitoring system is coupled with hoses connecting the Pitot tubes, the distributor and a pressure / depression measuring device. This invasive monitoring system was placed within Livezeni Mine, in the cross-cut gallery of Iscroni main line, the horizon 300, under the East Coal Pit air funnel. The mining work in which experimentation is carried out is similar to ventilation channel which belonging of a main ventilation station.Through repeated airflow measurements using the anemometer-classical method, the resulting average flow rate was 1500 m^3/min. The corrected flow rate allowing for the operator's surface was 1366 m^3/min.

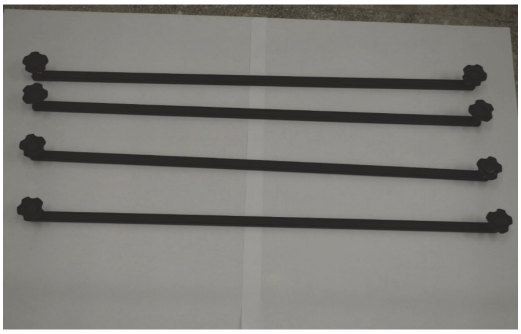

Fig. 4. Straight segments

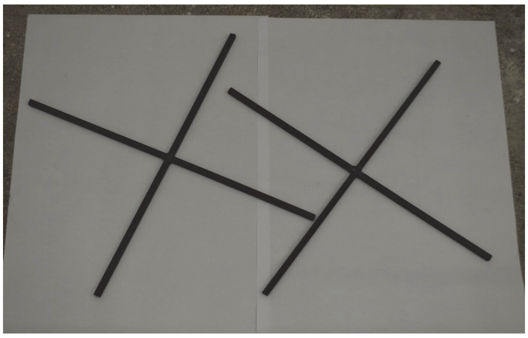

Fig. 5. Cross-shaped segments

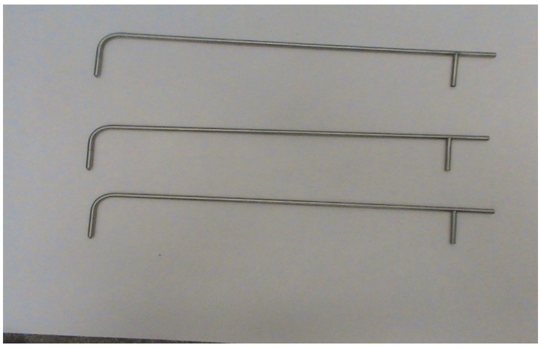

Fig. 6. Pitot tubes

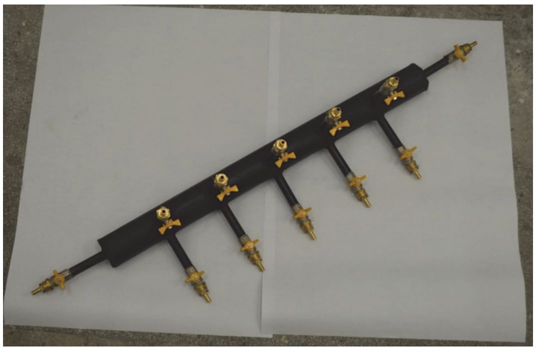

Fig. 7. Distributors with twelve valves

Table 1. Measuring results

Test no.	*Number of operating Pitot tubes*	*Pitot tubes positioning in the gallery*	*V (m/s)*	*Q (m^3/min)*
0	1	2	3	4
1.	All tubes operating	The entire gallery surface	3.6	1218
2.	3,4,10,5and 6	Tubes on the first brace	3	1015
3.	1,2,10,7 and 8	Tubes on the second brace	3	1015
4.	1,2,3,4,5,6,7 and 8	Tubes on the gallery's girth	3.2	1083
5.	9,10 and 11	Tubes in the center of the gallery	3.7	1252
6.	1,2,3 and 4	Tubes on the left wall of the gallery	2.7	914
7.	1,2,5 and 6	Tubes on the top of the gallery	3.3	1117
8.	5,6,7 and 8	Tubes on the right wall of the gallery	2.9	981
9.	3,4,7 and 8	Tubes on the gallery's hearth	2.3	778

The invasive monitoring system had 11 Pitot tubes (Fig. 8). The installations of Pitot Tubes numbered 1 to 11 (Table 1) is placed in the entire area of the gallery's cross-section. The area of the mine working was 5.64 m^2.The results obtained by applying new methods of measuring the average air velocity are more accurate than the direct anemometer measurement method. It is advisable to measure the average air velocity by the new method proposed in the mining works section near or in the ventilation channel.

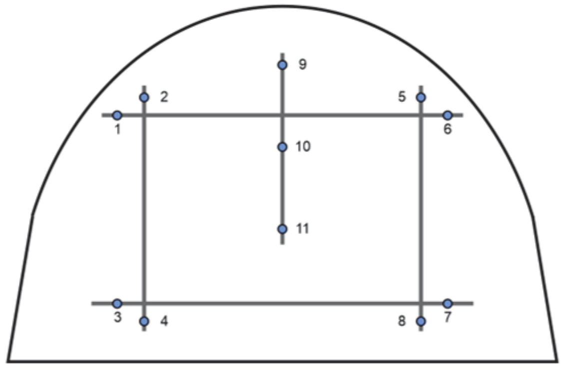

Fig. 8. System of Pitot Tubes in the cross-section of mine excavation

4. Conclusions

An invasive monitoring system for aerodynamic parameters pertain to a main ventilation station was achieved.

Conclusions drawn from the making of the invasive monitoring system for aerodynamic parameters pertain to main ventilation stations are as follows:

- The novelty consists in the development of a new invasive measuring method for obtaining the aerodynamic parameters of the main ventilation station, making of the continuous monitoring system for aerodynamic parameters, accurately establishing the functional parameters of main fans and development of an unconventional technology for measuring aerodynamic parameters
- During operation (depending on duration of operation, environmental conditions in which it operates and quality of maintenance) there may be changes in the aerodynamic characteristics of the fans leading to parameters different from those obtained at startup.
- The measurements showed the non-uniform flow of air in the mine working section.
- Different speeds were found on the mine working section, such as:

  - the highest speed was measured at the center of the section, being higher than the average speed measured;

  - on the two diagonals of the section the measured speeds were equal and lower than the average speed measured;

  - the speed measured on the section perimeter was lower than the average speed measured;

  - the speeds measured on the sides of the mine working section were lower than the average speed measured.
- The real air velocity in cross-sectional area of the mine gallery where the invasive measurement system for aerodynamic parameters was located, was the one with all 11 Pitot tubes operating.
- There is a difference unto the classic anemometer measurement. This difference results from the fact that:

  - an anemometer measurement is performed by a measurement person who, through the surface of his body, covers a certain area of the mine section area where the measurement is carried out;

  - no matter how uniform anemometer measurements would be on the measured unit surface, it cannot cover all the points on that surface.
- Given that the Pitot tubes were positioned in center of the surfaces, it follows that the result obtained by using the invasive monitoring system for aerodynamic parameters is the closest to the real value of speed, respectively airflow rate.

The comparison of measurements performed by anemometer and by the invasive monitoring system for aerodynamic parameters shows a difference of approximately 8%, which gives even greater credibility to values obtained by using the invasive monitoring system.

Acknowledgements

This paper was carried out through the Nucleu Program, implemented with the support of Romanian National Authority for Scientific Research, project no. PN-16-43-02-13.

References

Băltărețu R., Teodorescu C., (1971), *Ventilation and Occupational Safety in Mines* (in Romanian), Didactical and Pedagogical Publishing House, Bucharest, Romania.

Cheng J., Yang S., Lou Y., (2010), *Mathematical Models for Optimizing and Evaluating Mine Ventilation System*, Proc. of the 13th Unites States/North American Mine Ventilation Symposium, Hardcastle S., McKinnon D., (Eds.), Laurentian University, Sudbury, 278-285.

Cheng J., Yang S., (2012), Data mining applications in evaluating mine ventilation system, *Safety Science*, **50**, 918-922.

Chiuzan E., Gherghe I., (2012), *The characteristic curves of the fans at Uricani and Lupeni*, Research Report, National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX, Petrosani, Romania.

Cioclea D., Lupu C., Toth I., Gherghe I., Boantă C., Rădoi F., (2012), Fast network connections for ensuring decision operativity in mining ventilation, *Environmental Engineering and Management Journal*, **11**, 1225-1227.

Cioclea D., Toth I., Gherghe I., Tomescu C., Șuvar M.C., Păsculescu V.M., (2014), Analysis of transitory phenomena generated by underground explosions upon the ventilation networks, *Environmental Engineering and Management Journal*, **13**, 1401-1407.

Gherghe I., (2004), *Rationalization of Jiu Valley hard coal mines ventilation networks in terms of their restructuring, following the closure of inactive areas* (in Romanian), INSEMEX Research Study, Petroșani.

Hargreaves D.M., Lowndes I.S., (2007), The computational modelling of the ventilation flows within a rapid development drivage, *Tunneling and Underground Space Technology*, **22**, 150-160.

Matei I., Moraru R., (2000), *Environmental Engineering and Underground Ventilation* (in Romanian), Technical Publishing House, Bucharest, Romania.

Oberholzer J.W., Du Plessis J.J.L., (2002), *The Testing of the Strength of Ventilation Structures*, Proc. of the North American/Ninth US Mine Ventilation Symposium, Kingston, Canada, On line at: http://www.qrc.org.au/conference/_dbase_upl/2002_spk16_Ober holzer.pdf.

Patterson A.M., (1992), *The Mine Ventilation Practitioner's Data Book*, M.V.S. of South Africa.

RSSM, (2007), Health and Safety Regulations at Work, National Hard Coal Company Romania, On line at: https://issuu.com/valter_cojman/docs/rssm_-_cnh_-_2007

Suvar M.C., Cioclea D., Gherghe I., Păsculescu V.M., (2012), Advanced software for mine ventilation networks solving, *Environmental Engineering and Management Journal*, **11**, 1235-1239.

Suvar M.C., Lupu C., Arad V., Cioclea D., Păsculescu V.M., Mija N., (2014), Computerized simulation of mine ventilation networks for sustainable decision-making process, *Environmental Engineering and Management Journal*, **13**, 1441-1451.

Suvar M.C., Cioclea D., Arad V., Lupu C., Vlasin N.I., (2017), Method for improving the management of mine ventilation networks after an explosion, *Environmental Engineering and Management Journal*, **16**, 1373-1381.

Teodorescu C., Gontean Z., Neag I., (1980), *Mining Ventilation* (in Romanian), Technical Publishing House Bucharest, Romania.

Tomescu C., Prodan M., Vatavu N., Chiuzan E., (2017), Monitoring the work environment using thermal imaging cameras in order to prevent the self-ignition of coal, *Environmental Engineering and Management Journal*, **16**, 1389-1393.

Wei G., (2011), Optimization of mine ventilation system based on bionics algorithm, *Procedia Engineering*, **26**, 1614-1619.

Wenyao N., Baokuan L., Wenmei G., (2011), The research on integrated visual information management system of the mine ventilation and safety, *Procedia Engineering*, **26**, 2070- 2074.

Zhou L., Yuan L., Thomas R., Iannacchione A., (2017), Determination of velocity correction factors for real-time air velocity monitoring in underground mines, *International Journal of Coal Science & Technology*, **4**, 322–332.