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AUXILLIARY VENTILATION SYSTEMS IMPROVEMENT FOR OPTIMAL SAFETY CONDITIONS PROVISION IN UNDERGROUND ENVIRONMENTS

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Abstract: *The main objective of the research summarized in this article is based on a new methodological approach regarding the exhaustive analysis of auxiliary/partial ventilation systems in order to optimize their operation with a decisive and pro-active role in terms of ensuring safety and health at work. The intended result consists in the identification of the specific constructive elements of industrial ventilation installations for the efficiency of their operation. It was also aimed at identifying and establishing the necessary mathematical tools in order to establish the optimal flow regime, the geometric and aerodynamic characteristics specific to the mono or multifilar ventilation piping, as well as the establishment of the optimal operating characteristics specific to the fan-motor aggregates, including regarding the geometric shape and the specific aerodynamic characteristics, through the developed case study*.

Keywords: *auxiliary ventilation system, airflow, pressure drop, axial fan, underground environment, optimal configuration*

1. Introduction

The identification of effective methods and means for the prevention of work accidents and occupational diseases fits perfectly into the concept of work quality, work safety and health and is included in the current national programs [1]. The starting point in improving work to prevent occupational accidents and occupational diseases in an industrial structure is the assessment of the risks in the respective component system/subsystems [2]. Risk assessment involves the recognition/identification of all the risk factors in the analyzed structure and the quantification of the relevant proportions based on the combination of two parameters: the severity and the frequency of the maximum possible consequence on humans. Within the Council Directives no. 89/391/EEC states the obligation to assess existing risks in workplaces in order to stimulate workers' safety and health measures [3]. It is also specified that strategies for identifying risks and combating them must be based on the consultation and participation of employers, managers, workers and/or their representatives. In the spirit of Law no. 319/2006, which transposes Council Directive no. 89/391/EEC the managers of the economic agents, through the fixed obligations and responsibilities, are the only ones responsible for the health and safety of the employees [4].

The fundamental concept of this law places the employer at the center of the activity of preventing risks and ensuring the health and safety of his employees. Likewise, the prevention of occupational risks must be a constant activity among employees and all persons engaged in the work process. The safety and health documentation highlights the fact that, in the event of an accident or an occupational illness to which employees are exposed, during the exercise of work, the employer must order the assessment of the risks of occupational injury and illness for all workplaces, ensure an improvement in the level of employee protection and be integrated in all the unit's activities [5].

It also highlights that workplaces and equipment should be safely designed, operated and maintained. All risks must be dealt with in the following order of priority [6]:

- to be eliminated;
- to be controlled at the source;

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• to be reduced to a minimum by various means (the development of safe work technologies);
• to the extent that it persists, the use of individual protective equipment should be provided.

Risks are present in all economic and industrial activities that manifest themselves both through economic losses, malfunctions of installations, equipment and the occurrence of minor or major accidents, with particularly serious consequences, resulting in deaths and injuries, pollution of the environment [7]. The assessment of risk levels stimulates the co-interest of economic operators to improve their working and environmental conditions, i.e. to take measures to move from high risk levels to lower, acceptable levels [8].

The need to identify the risks encountered at industrial level, and in particular the risk of explosion, connected to a significant extent with the effectiveness of the operation of industrial/mining ventilation systems, is a pressing necessity for the following reasons [9]:

- some of the most important risks are the risks of explosion, intoxication and asphyxiation [10];
- within the continuous operation of the economic objectives related to the industrial branches, substances are used or appear in the form of gases, mists, dusts or powders that can create potentially explosive, toxic or asphyxiating atmospheres [11];
- to avoid the risks of explosion, intoxication and asphyxiation, it is necessary to eliminate accident situations that can lead to the loss of human lives, material losses, respectively the closure of some industrial objectives [12];
- avoiding or reducing the risk of explosions, poisoning and asphyxiation by providing adequate ventilation as a pro-active measure is a priority [13];
- the main measure to prevent the phenomena of explosion, intoxication and asphyxiation is represented by the achievement of optimal ventilation at the level of closed or semi-closed premises [14];
- the issue regarding the risk of explosion, poisoning or asphyxiation within industrial premises must be addressed both through the lens of creating an optimal ventilation system and through the lens of monitoring the atmospheres of industrial premises [15];
- the hazard and risk of explosion, intoxication and asphyxiation present in industrial premises under certain conditions, in accidental situations, in case of non-compliance with certain security measures and procedures, in the case of technical malfunctions or human errors and the exposure of workers during the processes of work represents an extremely strong motivation for identifying new means and ways to optimize ventilation systems [16].

All these aspects support the importance and opportunity of scientific research dedicated to the analysis of fan types, piping systems as well as the optimization of industrial/mining ventilation installations [17], [18], [19].

The research results of this article, which essentially represent a case study regarding the optimal design of a partial ventilation installation intended to ensure the quantitative and – implicitly – qualitative parameters of a work in progress, can be directly used by all specialists/decision-makers in in the field of ventilation and respectively in the field of Health and Safety at Work within industrial units and especially by those responsible for ensuring the optimal functioning of ventilation systems.

2. Methodology: dimensioning elements of auxiliary mining ventilation systems

2.1. Dimensioning the required air flow at the working front for mining opening and preparation works ventilated with auxiliary aeration installations

The following criteria apply when determining the air flow rate for mining operations ventilated by auxiliary systems [20], [21], [22]:

For diluting the gases resulting from the blasting operation:

- *Exhaust ventilation*:

$$Q_{fp} = \frac{c}{t} \cdot \sqrt{A \cdot S \cdot L_1} \qquad (m^3/min) \qquad (1)$$

where
c = 18.2 for salt mines;
c = 25.7 for ore mines;
c = 23.5 for coal mines;

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t – 15 - 30 minutes, ventilation time;

A - the amount of explosives planned to be used in a blasting (kg);

L_1 - the dispersion length of the gases after the blasting operation, (m);

$L_1 = 2.4A+10$, (m);

S - free section of the mine working, (m^2).

In the case of mine workings with a section greater than 16 m^2, the length L_1 is calculated with the relationship:

$$L_1 = \frac{7{,}8 \cdot q \cdot \sqrt{S}}{\rho \cdot \eta} \quad \text{(m)} \tag{2}$$

where:

q - specific explosive consumption, (kg/m^3);

ρ - volumetric weight of rocks, (t/m^3);

η - hole breakage coefficient (0,8 - 0,9).

- *Forced ventilation*:

$$Q_{fp} = \frac{c}{t}\sqrt[3]{A \cdot S^2 \cdot L_{cr}^2} \quad \text{(m}^3\text{/min)} \tag{3}$$

where:

c = 7 – salt mines;

c = 9 – ore mines;

c = 8.5 – coal mines.

L_{cr} - the critical length, i.e. the portion of the work along which the gases are diluted to the permissible limit (m);

$$L_{cr} = \frac{500 \cdot A}{S} \cdot K \quad \text{(m)} \tag{4}$$

K - turbulent diffusion coefficient, table 1;

A - the planned amount of explosives (kg);

S - the free section of the mine working (m^2).

If the value of the critical length L_{cr} is greater than the work length L, the length L will be entered in the air flow calculation relationship. Both in the case of exhaust system and in the case of forced ventilation system, when using quantities of explosive greater than 25 Kg, the ventilation time can be increased, provided that the adopted value is specified in the blasting order.

Table 1. Turbulent diffusion coefficient

Duct diameter d (mm)	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
K	0.64	0.60	0.53	0.48	0.45	0.39	0.34

By the number of Diesel locomotives

$$Q_{fp} = n \times q \ \text{(m}^3\text{/min)}$$

where:

n - the total power of machinery driven by internal combustion engines, simultaneously operating on the route of the mining working (hp)

q - the air rate required for exhaust gas dilution;

q - 6 m^3/min and horse power (hp) when the CO content in the exhaust pipe is between 0.08 and 0.12%;

q - 4 m^3/min and horse power (hp) when the CO content in the exhaust pipe is 0.06 and 0.08%;

q - 3 m^3/min and horse power (hp) when the CO content in the exhaust pipe is less than 0.06%.

In the case of the use of auto transportation, with the engines off during parking, the air flow will be calculated using the relationship below:

$$Q_{fp} = (n_1 q_1 + n_1' q_1' + n_1'' q_1'') \times K \quad \text{(m}^3\text{/min)} \tag{5}$$

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where:

n_1 - the total power of machines operated with Diesel engines simultaneously on the work route, which contain in the exhaust pipe a maximum of 0.06% vol. CO (hp);

n_1' - the total power of machines operated with Diesel engines simultaneously on the work route, which contain in the exhaust pipe between 0.06 ÷ 0.08 vol. CO (hp);

n_1'' - the total power of machines operated with Diesel engines simultaneously on the work route, which contain in the exhaust pipe between 0.08 ÷ 0.12 vol. CO (hp);

q_1 - 3 m^3/min for each hp when the CO content in the exhaust pipe does not exceed 0.06% vol.;

q_1' - 4 m^3/min for each hp when the CO content in the exhaust pipe is between 0.06% ÷ 0.08% vol.;

q_2'' - 6 m^3/min for each CP when the CO content in the exhaust pipe is between 0.08% ÷ 0.12% vol.;

$K = \frac{T_{ef}}{T_c}$ - the ratio of the actual machine operating time in the mine working (during a round trip) to the total time of a round trip.

T_{ef} - the actual operating time of the machine underground (s)

T_c - the total duration of a round trip (s).

The total duration of a round trip (s) is determined as follows:

$$T_c = t_g + t_p + t_i + t_d \quad \text{(s)} \tag{6}$$

where:

t_g - the duration of the journey of the empty machine (without load) on the gallery, (s);

t_p - the duration of the journey of the loaded (full) machine on the gallery, (s);

t_i - the loading time of the machine from the work front, (s);

t_d - the time of unloading the machine on the surface (s)

$$T_{ef} = t_p + t_g \quad \text{(s)} \tag{7}$$

By absolute gas flow

$$Q_{fp} = \frac{q_a \cdot 100}{C - C_0} \quad (\text{m}^3/\text{min}) \tag{8}$$

where:

q_a - the absolute flow rate of gas (methane or carbon dioxide) specific to the mine working in execution;

C - the gas concentration, admitted in the air exhaust stream from the mine working, (%);

C_0 - gas concentration in the intake air stream of the mine working, (%),

After minimum airspeed

$$Q_{fp} = 60 \cdot K \cdot S \cdot V_{min} \quad (\text{m}^3/\text{min}) \tag{9}$$

where:

V_{min} – 0.2 m/s - minimum air circulation speed;

S - the free section of the mine working (m^2);

K - coefficient that takes into account the size of the air circulation speed in the section of the mine working, figure 1.

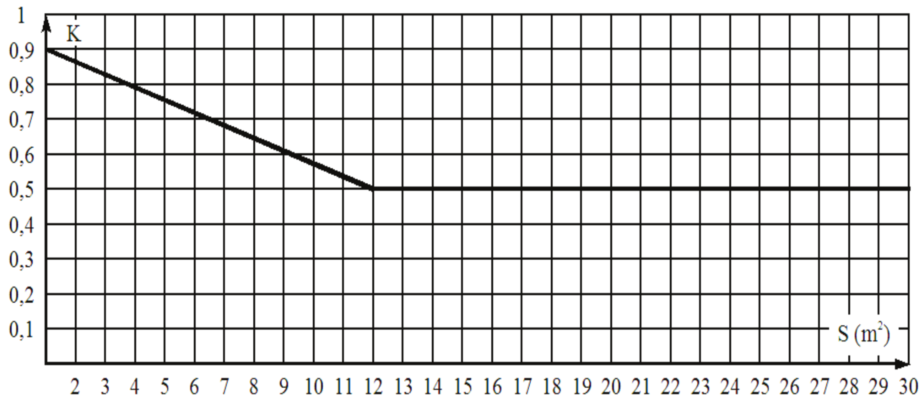

Fig. 1. The coefficient that takes into account the size of the air circulation speed

The air flow that is planned in the working front Qfp will be the highest resulting according to one of the calculation criteria mentioned above [23], [24], [25].

2.2. Auxiliary ventilation systems

Partial ventilation facilities are inherent in all mine opening and preparation in the execution stage. For this reason, in the present paper, both the defining elements for ensuring the safety and health of the personnel working underground are treated, taking into account the variety of deposit conditions, as well as the functional particularities of partial aeration installations.

Similar to the attributions of general ventilation, carried out through the main ventilation facilities, auxilliary ventilation, regardless of the nature of the useful mineral substance that is extracted, aims to ensure the safety and comfort conditions of the personnel in the opening and preparation mining works during their execution phase [26], [27].

Also outside of this type of work, auxilliary ventilation installations are appropriate for all mining works with the purpose of prospecting and geological exploitation [28].

From the point of view of the structure and the various conditions of use, the partial ventilation installations are essentially different from the main ventilation installations, being characterized by the following particularities [29]:

- the range of variation of the aerodynamic resistance at which an auxiliary ventilation installation must operate is extremely large (from R = 0 in the initial phase of the mining work, to R_{max} corresponding to the final length of the mine working), in a range of relatively short time;
- the continuous and significant change of the functional parameters (air flow, pressure) in relation to the progress of the mine working;
- the installation is carried out gradually and the correctness of the execution along the entire length directly influences the efficiency of the ventilation;
- the possibility of reusing both the fans and the column of ducts.

The auxilliary ventilation that ensures the circulation of air from the entrance to the mine working to the working front, through the columns of ducts on which one or more fans are located, is carried out by the following systems: exhaust, forced and combined.

The exhaust ventilation system

The exhaust ventilation system consists in aspirating the return/polluted air through the column of ducts, while the supply of fresh air is made along the route of the mine working in the excavation phase, or of the chamber-type face in operation (figure 2, with: L = 2 - 6 m in mines without methane emissions; L = 2 m in mines with methane emissions for works executed in the coal seam; L = 4 m, in mines with methane emissions for works executed in the surrounding rocks) [30].

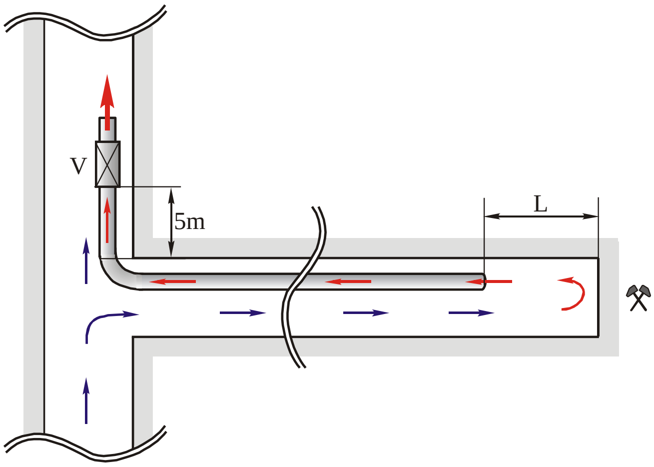

Fig. 2. Exhaust ventilation system

The ***advantages*** of the system consist in:

- the evacuation of gases from blasting, as well as silicone dust is done through the column of ducts;
- the air flows required to dilute the gases resulting from the blasting do not depend on the length of the mine working or the chamber-type face;

- allows the faster evacuation, compared to the forced system, of the gases resulting from the blasting operation in the case of long works.

The ***disadvantages*** of the exhaust ventilation system are:

- the evacuation of explosive gases and airborne dust is done through a column of ducts, respectively over the electric motor of the fan(s), without the possibility of permanently knowing the concentrations of these gases and dusts;
- an increased degree of difficulty in the liquidation operation of methane accumulations;
- the gases released from the coal seam along the route of the mine working, as well as those resulting from the operation of internal combustion engines, are transported to the working front;
- requires the permanent maintenance of the column of ducts near the front (2-4 m) as a result of the low range of action of the suction currents;
- mandatory use in the case of flexible ducts, only of those provided with stiffening elements.

The forced ventilation system

The forced ventilation system consists in circulating fresh air through the column of ducts and exhausting the polluted air along the route of the mine working in the excavation, or of the chamber-type face in operation (fig. 3) [31].

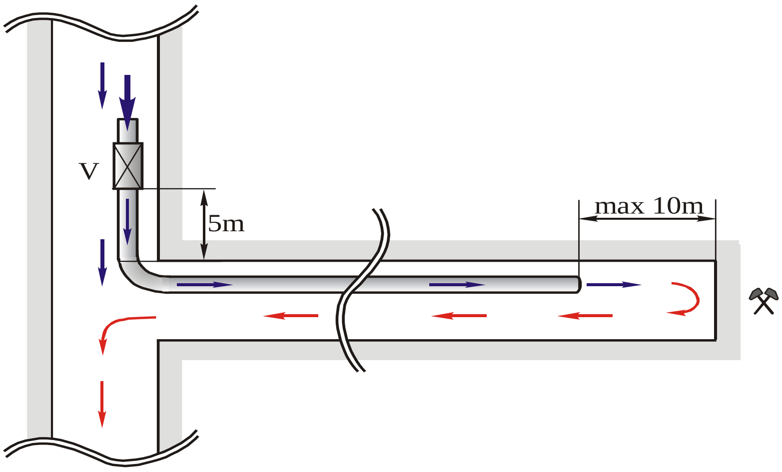

Fig. 3. Forced ventilation system

The ***advantages*** of this ventilation system are:

- the fan and, respectively, its motor are permanently traversed by currents of fresh air;
- the fresh air circulated in the work front is not contaminated by the gases released from the walls of the mining works or the chamber-type face and respectively by the gases resulting from the operation of internal combustion engines;
- air losses due to leaks in the pipe column amplify the dilution process of toxic and explosive gases from the mining route;
- the work front and the space in its vicinity are traversed by swirling air currents, with a long range (up to 10 m), a fact that ensures their effective ventilation;
- the fan achieves superior functional parameters in the case of discharge load compared to its operation with suction load;
- allows the use of flexible tubes without stiffening rings;
- ensures simplicity in the liquidation operation of a methane accumulation.

The ***disadvantages*** of the forced ventilation system are:

- the evacuation of toxic and explosive gases is carried out along the route of the mine working or the chamber-type face;
- requires higher air flows than the exhaust system, for diluting the blasting gases;
- in all conditions, diverters are needed at the discharge end of the tube column, to direct the air jet;
- the presence of several fans on the ventilation column can lead to an increase in the air temperature.

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Combined ventilation systems

The combined ventilation systems (figures 4 and 5), which is made with two partial ventilation installations, combines the advantages of exhaust and forced systems, thus reducing some of the disadvantages of each system [32].

However, the combined ventilation system also has the following disadvantages:

– requires the use of two auxiliary ventilation installations;
– implies the obligation of permanent correlation of the air flows related to the two installations.

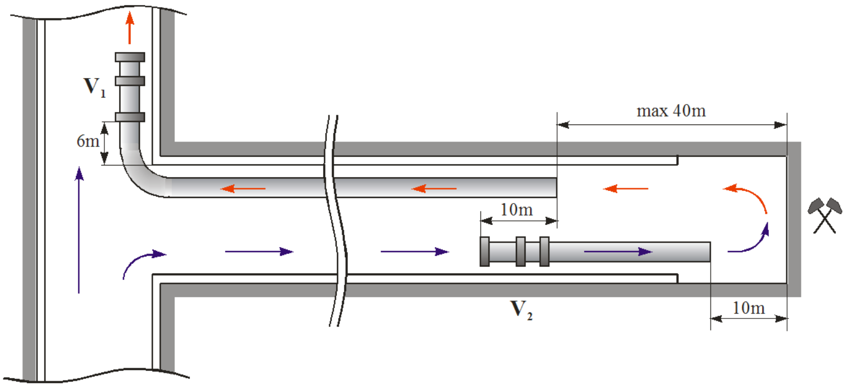

Fig. 4. Schematic of the auxiliary combined ventilation installation I (exhaust - forced variant)

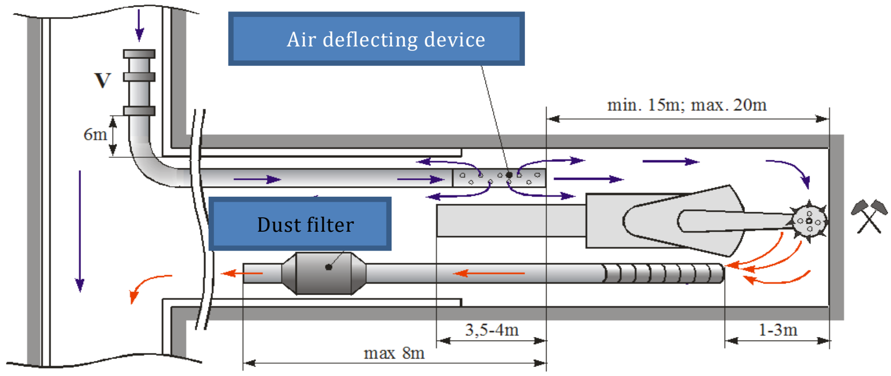

Fig. 5. Schematic of the auxiliary combined ventilation installation II (forced-exhaust variant)

According to the advantages and disadvantages of each system, as well as the particularities of mines in terms of safety, the ventilation systems described are recommended to be used as follows:

- the exhaust ventilation system (figure 2) applicable to all mines, it is particularly indicated for long mine workings where cutting is done with explosives, which require relatively small air flows (Q_r < 300 m^3/min)
- the forced ventilation system (figure 3) applicable to all mines, is especially indicated for mines with methane emissions and can be used regardless of the inclination of the mine workings with the obligation to control methane both at the workplace and on the route of the mine working;
- the combined ventilation system I (figure 4) composed of the main exhaust column and the secondary forced column, is applicable to all mines, and is particularly indicated in long mining works with methane emanations, or with high temperatures, works, in which cutting is done with the help of explosives;
- the combined ventilation system II (figure 5) composed of a main forced column and a secondary exhaust column equipped with dedusters, is applicable to all mines and is mandatory for mining works with mechanized cutting.

2.3. Characteristics of auxiliary ventilation installations

In an auxiliary ventilation installation, as the length of the column increases, both the air flow and the pressure drop change. The range of variation of the air flow achieved at the working front depends on both the aerodynamic coefficients related to the ventilation columns and the functional parameters of the fans [32].

The aerodynamic coefficients related to the ventilation columns

The coefficients that define, from an aerodynamic point of view, the ventilation columns are:

- the aerodynamic resistance of the column, R_c ;
- the air losses characteristic of the columns, K_c .

The diameter of the ventilation column

The indicative diameter of the ducts in the composition of a column is determined with the help of the relationship:

$$d = \sqrt{0{,}1 \times Q_{fp}} \quad \text{(m)} \qquad (10)$$

where: Q_{fp} - air flow at the working front, (m^3/s).

The value of the diameter resulting from the calculation is checked with the recommended values for different sections of the work according to table 2.

Table 2. Ducting diameter value for different sections of mining works

Mine working section, (m)	6	8	10	12	14	16
Recommended duct diameter, (m)	0.5	0.6	0.8	0.8	1.0	1.2

Aerodynamic resistance

The aerodynamic resistance of an air column, R_c, is the resistance that the ducting opposes to the flow of air. The value of the aerodynamic resistance varies both in relation to the geometric parameters of the column (diameter, length, changes of direction) and to the degree of sealing of the column [33], [34].

Aerodynamic resistance is the physical quantity that determines the characteristic pressure loss for a certain flow of air circulated over a given length [35]. The total aerodynamic resistance of a column of ducts, R_c, depends on the value of the unit aerodynamic resistance, R_0, on the length of the column L, and on the equivalent lengths expressing the changes of direction – bends and reductions of section, as well as on the amount of air losses. If the ventilation column were continuous, without joints and without air loss, i.e. perfectly sealed, which is impossible to achieve in practice, the total aerodynamic resistance R_c would be higher and would be determined by the linear dependence between the unit aerodynamic resistance R_0 , length L and fan parameters h_v and Q_v [36].

The calculation relation of total resistance R_c is:

$$R_c' = h_v / Q_v^2 = R_0 \times L \qquad (daPa \times s^2 / m^6) \qquad (11)$$

The unit aerodynamic resistance R_0' of the perfectly sealed column can be determined with one of the relations below:

$$R_0 = h_v / Q_v^2 \cdot L, \qquad (daPa \times s^2 / m^7) \qquad (12)$$

or

$$R_0 = 6{,}48 \cdot \alpha / d^5 \qquad (daPa \times s^2 / m^7) \qquad (13)$$

where:

α - the resistance coefficient due to air friction against the walls of the ventilation column, N s^2/m^4;

d – ventilation column's diameter, (m).

The unit aerodynamic resistance R_0, characteristic of non-tight columns, is chosen based on the data presented in table 3, specific to metal and flexible columns corresponding to different tube diameters and respectively different stages of wear.

Table 3. Unit aerodynamic resistance values, R_0

Ducting diameter (mm)	**Unit aerodynamic resistance R_0 [(daPa × s^2 / m^6) / m]**			
	Coloane metalice			Coloane flexibile α = 0.00126
	Noi α = 0.00030	Uzură medie α =0.00033	Uzură pronunțată α = 0.00040	
400	0.1870	0.2600	0.2700	0.800
500	0.0620	0.0700	0.0830	0.260
600	0.0250	0.0300	0.0330	0.120
800	0.0060	0.0080	0.0082	0.025
1000	0.0019	0.0020	0.0026	0.008
1200	0.0007	0.0008	0.0010	0.003

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The unit aerodynamic resistance R_0, characteristic of non-tight columns, is determined based on measurements, with the relation:

$$R_0 = (h_1 - h_2) / Q_m^2 \cdot L \qquad (daPa \times s^2 / m^7) \qquad (14)$$

where:

h_1 - represents the pressure or pressure drop measured at a point in the column, towards the fan, daPa;

h_2 - represents the pressure or pressure drop measured at a point in the column, towards the working front, daPa;

Q_m - the average air flow circulated in the ventilation column between the two measurement points, m^3/s;

L – column length between measurement points, m.

The average air flow Q_m is determined with the relation:

$$Q_m = (2Q_1 + 3Q_2) / 5 \qquad (m^3/s) \qquad (15)$$

where:

Q_1 and Q_2 represents airflows measured at the same points as pressures/depressions h_1 and h_2, m^3/s.

If the measurements are performed at the level of the entire aeration column, equipped with a single fan, $h_1 = h_v$ (h_v – the pressure developed by the fan) and $h_2 = 0$ (the pressure at the end from the working front), the resistance calculation relations unitary and total aerodynamics become:

$$R_0 = h_V / L \times Q_m^2 \qquad (daPa\ s^2 / m^7) \qquad (16)$$

and

$$R_c = R_0 \times L \qquad (daPa\ s^2 / m^6) \qquad (17)$$

Considering the role of air losses in the modification of aerodynamic resistance, it is indicated that whenever possible, when designing auxiliary ventilation installations, the values of unit aerodynamic resistances R_0, obtained from measurements carried out under the specific conditions of each work, should be adopted. In the case of changes in direction, which require the use of bends, the values of the lengths in column 1 which are equivalent to the local resistances and which must be added to the effective lengths of the columns are shown in table 4.

Table 4. Values of column lengths "l"

Angle of deflection (degrees)	**Equivalent length l (m) for different column diameters:**			
	1,000 mm	800 mm	600 mm	500 mm
120	27	23	16	13
90	16	14	10	8
60	8	7	5	4
45	5	4	3	3
30	3	2	1.5	1.5

Air losses through leaks in the ventilation columns

Air leaks occur at the joints of the ducts that make up the metal ventilation columns or at seams or solders in the case of flexible tubes. The term *air loss* refers to the difference between the air flow developed by the fan and the air flow achievable in the working front. Function of the type of ventilation, exhaust or forced, air losses are either air flows drawn along the column or air flows out of the column along the entire path of the mining operation.

In auxiliary ventilation, the air losses related to ventilation columns are generally expressed in terms of "*unitary loss coefficient*", K_0, which is defined by the air flow expressed in m^3/s lost through leaks per meter of column, at a given pressure and is determined with the relation.

$$K_0 = \frac{3(Q_1 - Q_2)(h_1 - h_2)}{2L\left(h_1^{3/2} - h_2^{3/2}\right)} \qquad (m^3/s\ /m \text{ at pressure } h_1 - h_2) \qquad (18)$$

The quantities Q_1, Q_2, h_1 and h_2 have the same meanings as in the case of the previous relationships. If at the end of the column from the front, the pressure is zero, i.e. $h_2 = 0$, we obtain:

$$K_0 = \frac{3(Q_1 - Q_2)}{2L\sqrt{h_1}} \qquad (m^3/s/m \text{ at pressure } h_1) \qquad (19)$$

Estimating air losses at a uniformly applied pressure is extremely difficult to achieve, because the pressure inside the ventilation columns varies continuously, for which a calculation algorithm was developed that eliminates this inconvenience [37].

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Thus, by combining the calculation relationships specific to the parameters R_0 and K_0, the dependence relationship between the ratio of air flows Q_1 and Q_2 and the aerodynamic coefficients related to the ventilation columns was obtained, eliminating in this way the influence of the pressure in the column:

$$Q_R = \frac{Q_1}{Q_2} = \frac{6K_0L(R_0L)^{1/2} + 15}{15 - 4K_0L(R\ L)^{1/2}} \tag{20}$$

where:

K_0 L = K_c - represents the air loss coefficient specific to the ventilation column, m^3/s for one daPa;

R_0 L = R_c - represents the aerodynamic drag of the column, daPa × s^2/m^6

Q_R - ratio of air flows Q_1 (developed by the fan) and Q_2 (achieved at the work front).

For the value of $Q_R < 5$ (that is, at least one fifth of the flow developed by the fan circulates at the working front), the product K_c has a value lower than 3.6. In this domain, the regression equation (correlation coefficient 0.99) is of the form:

$$Q_R = 1{,}02 + 0{,}585K_c\sqrt{R_c} + 0{,}15\,K_c^2\,R_c \tag{21}$$

Based on the presented relationship, the nomogram shown in fig. 6 which offers the possibility of operatively determining either the aerodynamic coefficients specific to an existing ventilation column, or the elements necessary for the design of a new installation.

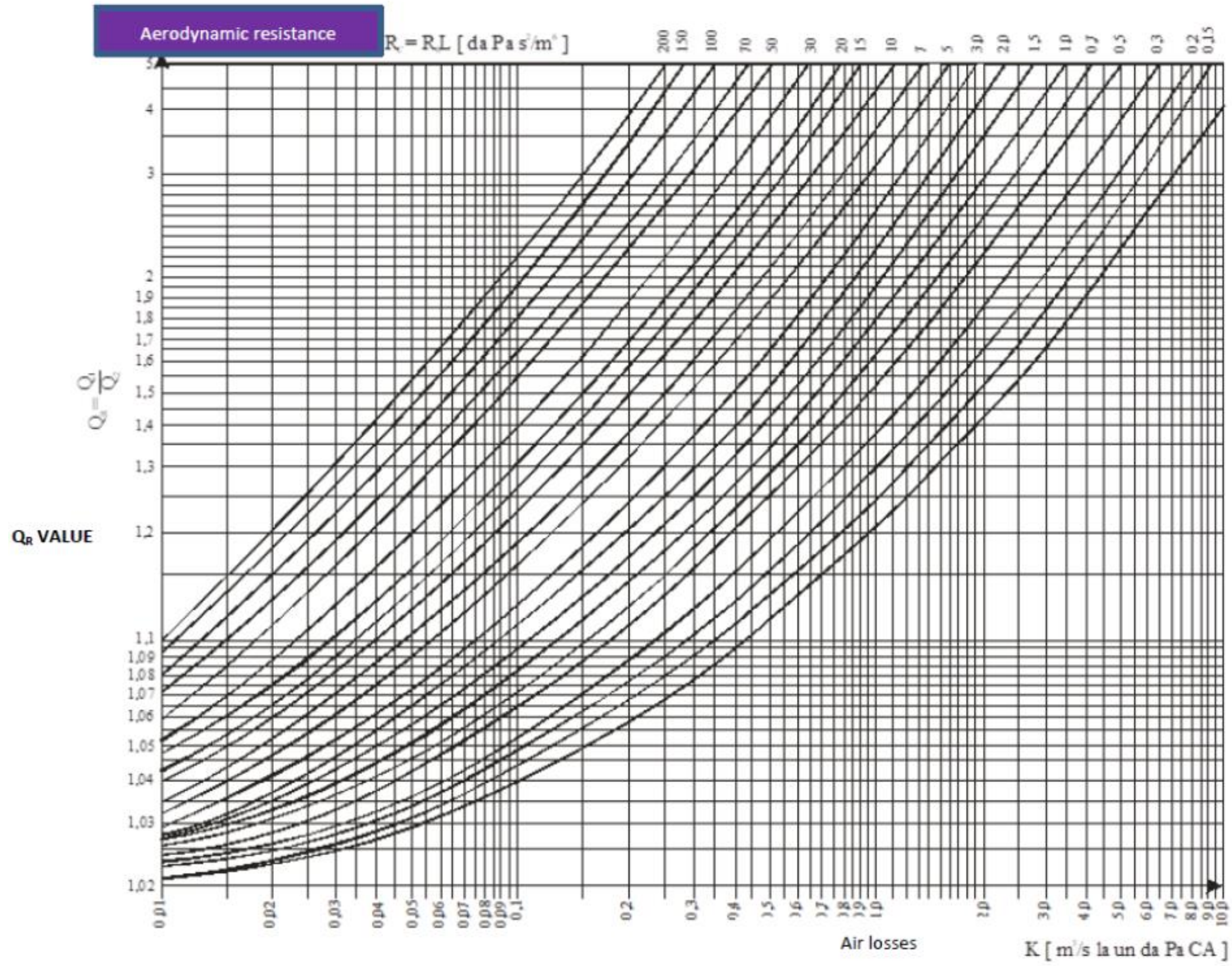

Fig. 6. Graphic method of determining the aerodynamic coefficients specific to an aeration column

The average values of the unit coefficient of air losses K_0 depending on the degree of sealing of the ventilation columns and their diameter are chosen based on the data presented in table 5.

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Table 5. Values of the K_0 coefficient

Duct diameter (mm)	The unit coefficient of air losses K_0, expressed in $m^3/s/m$, at one daPa		
	Very good	Good	Weak
500	0.00010	0.0005	0.0020
600	0.00012	0.0006	0.0024
800	0.00016	0.0008	0.0032
1000	0.00020	0.0010	0.0040
1200	0.00024	0.0012	0.0048

The values shown in table 5 are given as a guide and should not be considered as standard values. For this reason, the values obtained from the measurements are always indicated for consideration.

3. Case study: dimensioning a high length auxiliary ventilation system

3.1. The ventilation system of the "Castel amonte" front adduction

The ventilation of the main adduction gallery Surduc - Nehoiașu, front "Castel amonte" is carried out in an exhaust system by means of an auxiliary ventilation installation, consisting of a column of metal tubes with ϕ = 900 mm, two pneumatic fans placed in cascade and a centrifugal fan placed on the surface [38].

To seal the aeration column, consisting of metal tubes, flat rubber gaskets are used, the tubes being joined with flanges and screws. The length of the aeration column is 3,160 m, and the length of the gallery is 3,157 m. The fans located on the column are of the VP 500 type (no. 2 and no. 3). The centrifugal fan located on the surface is of type V 496/5 with the following nominal parameters:

- flow rate: - minimum: 17,100 m^3/h (285 m^3/min)
  - maximum: 111,600 m^3/h (1,860 m^3/min)
- pressure drop: - minimum: 150 mm CA (1,472 Pa)
  - maximum: 370 mm CA (3,630 Pa)
- rotation speed: 970 rot/min
- power: 110 kW

The fan drive motor has a power of 132 kW and a speed of 1000 rpm. The 2 VP 500 fans were placed on the column of tubes like this:

- fan no. 2 at 2,779 m from the mouth of the gallery;
- fan no. 3 at 3,112 m in front of the mouth of the gallery.

The axial fans used are type VP 500 with pneumatic drive, having the following characteristics:

- flow rate: - minimum: 3,600 m^3/h (60 m^3/min)
  - maximum: 18,000 m^3/h (300 m^3/min)
- pressure drop - minimum: 75 mm CA (736 Pa)
  - maximum: 230 mm CA (2,256 Pa)
- compressed air consumption: 5.7 Nm^3/min

It is mentioned that along a length of about 40 m from fan no. 3 at the working front for ventilation, a column of flexible tubes is used, each tube having a length of 5m with a diameter of 500 mm, instead of the metal column, to protect it when the operation of blasting the rock from the working front is carried out.

The main adduction Surduc - Nehoiaşu belonged to the A.H.E. branch. Surduc – Siriu, being an underground mine working (gallery) whose length will be 16,429 m. The excavation of this gallery is carried out from several points, respectively: the Bâsca Mare area, the Titilău area, the Pruncea area, the Trestia area and the Castel area. From these areas, access windows (connecting galleries) were constructed up to the adduction alignment from which, upstream and downstream, main adduction galleries are executed. The digging technology of this gallery is the one by the perforating-blasting process, and the perforation of the working front is carried out with individual perforating at a free section of 17.34 m^2. After concreting, this gallery will have a section of 12.56 m^2.

Temporary support is carried out with metal girders and definitive support works have been carried out on most of the sections. The transport of the material resulting from the operation of blasting the working front is carried out with VSA 9 wagons of 9 m^3, pulled by diesel locomotives type LDM of 45 HP. The required air flow at the work front, calculated according to the partial ventilation project drawn up by S.C. Hidroconstruction S.A. Bucharest - Siriu Branch, was 216 m^3/min., result according to the criterion "*Dilution of exhaust gases during the operation of machines driven by Diesel engines*", by using two axial fans VE 1200 and the centrifugal fan V496/5.

As a result of an incident resulting in large releases of methane from the work front and near it, the electric fans were replaced with pneumatic fans type VP 500, maintaining the centrifugal fan on the surface, and the *Partial Ventilation Project* was not updated for the new existing concrete conditions. In these conditions, the required air flow at the work front is the one presented in the next section, and the ventilation solutions are presented later.

3.2. Establishing the required air flow rate underground

The main sources of atmospheric pollution in underground mining are the gases emanating from the deposit (methane), the gases resulting from the operation of machinery driven by Diesel engines (exhaust) and those resulting from blasting operations. Since the ventilation of the main intake Surduc - Nehoiaşu, front Castel amonte is carried out in an exhaust system by means of an auxiliary ventilation installation, consisting of a column of metal tubes with ϕ = 900 mm, two pneumatic fans placed in cascade and a centrifugal fan placed on the surface, the calculation of the air flow was made according to the following criteria, using the relationships presented and explained in section 2.1:

By the amount of explosives:

$$Q_{fp} = \frac{C}{t}\sqrt{A \cdot S \cdot L_1} = \frac{25{,}7}{30}\sqrt{21{,}2 \cdot 17{,}34 \cdot 22} = 76 \text{ m}^3/\text{min.}$$

where:

C – 25.7;

t = 30 min;

A = 21,2 kg

$$L_1 = \frac{7{,}8 \cdot q \cdot \sqrt{S}}{\rho \cdot \eta} = \frac{7{,}8 \cdot 1{,}2 \cdot \sqrt{17{,}32}}{2{,}0 \cdot 0{,}9} = 22 \text{ m}$$

where:

S = 17,34 m^2;

q = 1,2 Kg/m^3;

η = 0,0-0,9.

By absolute gas flow

$$Q_{fp} = \frac{q_a \cdot 100}{C - C_0} = \frac{0{,}8 \cdot 100}{1 - 0{,}36} = 125 \text{ m}^3/\text{min}$$

where:

q_a= 0,8 m^3/min.

C =1 %;

C_0 = 0.36%; value determined through measurements.

$$Q_{fp} = \frac{0{,}8 \cdot 100}{1 - 0{,}36} = 125 \text{ (m}^3/\text{min)}$$

After minimum air speed

$$Q_{fp} = 60 \cdot K \cdot S \cdot V_{min} = 60 \cdot 17{,}34 \cdot 0{,}32 \cdot 0{,}2 = 67 \text{ m}^3/\text{min}$$

where:

K = 0,32;

S = 17,34;

V_{min} = 0,2 m/s.

By the number of Diesel locomotives

Considering the fact that two Diesel LDM 45 HP locomotives are operating in this mine working, one of which is for the transport of the excavated material and the other for the transport of the explosive, two values of the air norm are adopted, namely:

- q_1 = 3 m^3/min for the locomotive transporting explosives;
- q_1' = 4 m^3/min for the locomotive that transports the excavated material from the front.

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For exhaust gas dilution, the required air flow is determined with the relation:

$$Q_{fp} = (n_1 \cdot q_1 + n_1' \cdot q_1' + n_1'' \cdot q_1'') \cdot K = [(3x45) + (4x45)] \times 0,75 = 236\ m^3/min$$

where:

$$K = \frac{T_{ef}}{T_c} = \frac{3801}{5041} = 0,75$$

The total duration of a round trip (s) is determined as follows:

$$T_c = t_g + t_p + t_i + t_d = 1871 + 325 + 1930 + 915 = 5041\ s$$

where:

t_g - empty machine travel time (without load) on gallery (s);
t_p - duration of the travel of the loaded (full) machine on the gallery (s);
t_i - loading time of the machine from the work front (s);
t_d - unloading time of the machine on the surface (s).

$$T_{ef} = t_p + t_g\ (s)$$

After the timings performed, they were obtained:

– t_g = 1,871 s
– t_i = 325 s
– t_p = 1,930 s
– t_d = 915 s
T_{ef} = 3,801 s

$$K = \frac{T_{ef}}{T_c} = \frac{3801}{5041} = 0,75$$

The air flow that is planned for the working front (Q fp) will be the flow with the maximum value, resulting from one of the criteria mentioned above, i.e. the air flow "*According to the number of locomotives*" is adopted, i.e. $Q_{fp} = 236\ m^3/min$

3.3. Ventilation solutions for the main adduction gallery in front of Castel amonte

It is known that in order to avoid air recirculation in the case of applying aspiration ventilation, the condition must be met that there is depression in the column along its entire length compared to the atmosphere in the gallery [39].

In order to achieve depression in the column and, respectively, to exclude air recirculation, the following conditions must be met:

- calculating the length of each fan and the distance between them;
- achieving and maintaining the uniformity of the specific parameters of the aeration columns (K_0 and R_o).

The calculation took into account:

- characteristic pressure curve of the fan - $H_v = f(Q)$;
- required (planned) air flow at the work front – Q_{fp};
- diameter of the aeration column – ϕ;
- unitary aerodynamic resistance of the aeration column – R_0
- the unit coefficient of air losses through leaks - K_0

These calculations being arduous and long-lasting, nomograms were drawn up for efficiency. The values of the aerodynamic parameters specific to the ventilation columns (R_0 and K_0), taken into account for the preparation of the nomograms, were determined based on the measurements performed, and are presented below:

- for the exhaust metal column sections, the unit aerodynamic resistance R_0 has the value of 0.0030405 kμ/m;
- for the forced column sections, the unit aerodynamic resistance R_0 has the value of 0.003035 kμ/m;
- the average unit aerodynamic resistance R_0 of the metal column with a diameter of 900 mm has the value of 0.003038 kμ/m;
- the degree of sealing of the exhaust ventilation column with a diameter of 900 mm, expressed by the unit coefficient of air losses due to leaks K_0, recorded values between $3.383 \times 10^{-4}\ m^3/s/m$ at 1 mm H_2O and $3.269x10^{-4}\ m^3/s/m$ at 1 mm H_2O with an average value of $3.326 \times 10^{-4}\ m^3/s/m$ at 1 mm H_2O.

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Cascade placement of fans on the ventilation column

When establishing the ventilation solutions, the following elements were taken into account:

- the required air flow at the front, resulting from the operation of locomotives driven by Diesel engines, in the conditions where the concentration of CO in the exhaust gases does not exceed 0.08% vol;
- the aerodynamic parameters of the existing ventilation column with a diameter of 900 mm.

The following calculation relations were used to draw up the nomograms:

$$Q_v = Q_{fp}\,(1{,}02 + 0{,}585\,K_c\sqrt{R_c} + 0{,}15\,K_c^2\,R_c) \quad [m^3/s]$$
$$h_v = R_c \times Q_m^2 \quad [mm\ H_2O]$$
$$Q_m = (2\,Q_v + 3Q_{fp})\,/\,5 \quad [m^3/s]$$
$$R_c = R_0 \times L \quad [k\mu]$$
$$K_c = K_0 \times L \quad [m^3/s\ at\ 1\ mm\ H_2O]$$

where:

Q_v = air flow at the fan, [m^3/s]
Q_{fp} = air flow at the working face, [m^3/s]
Q_m = average air flow rate circulated in the metal tube column, [m^3/s]
L = length of the ventilation column, [m]
h_v = pressure drop at the fan, [mm H_2O]
R_0 = unit aerodynamic resistance of the ventilation column [kμ/m]
R_c = total aerodynamic resistance of the ventilation column [kμ]
K_0 = coefficient of air losses through leaks [m^3/s/m at 1 mm H_2O]
K_c = total air loss coefficient of the ventilation column [m^3/s at 1 mm H_2O]

The nomograms were drawn up taking into account the means of the existing equipment for the realization of auxiliary ventilation (ventilation columns made of metal tubes with ϕ 900 mm, sealed with flat rubber gaskets, the joining of the tubes being made with flanges and screws, respectively centrifugal fan V 496/5). Additionally, nomograms were made for fans type VE ϕ 700 – 11 kW, VE ϕ 800 – 30 Kw and Korfmann fans type dESN 9-300-30 Kw and dESN 9-370-37 Kw respectively

In fig. 7÷9 are shown the nomograms for a value of the unit aerodynamic resistance R_0 = 0.003038 kμ/m and the unit air loss coefficient through leaks, $K_0 = 3.3326 \times 10^{-4}$ m^3/s/m at 1 mm H_2O (average value resulting from measurements). The nomograms for a value of the unit aerodynamic resistance R_0 = 0.003038 kμ/m (average value resulting from the measurements) and the unit coefficient of air losses through leaks, $K_0 = 1.8\times10^{-4}$ m^3 /s/m at 1 mm H_2O (very good sealing degree), for the column with diameter ϕ = 900 mm, were also drawn, but but due to space constraints, they are not represented in the article.

From the analysis of the nomograms presented in figures 7 ÷ 9, the following aspects mainly result:

- For the current situation, columns with diameter ϕ = 900 mm, R_0 = 0.003038 kμ/m and $K_0 = 3.326 \times10^{-4}$ m^3/s/m at 1 mm H_2O:
  - under the conditions of using the V 496/5 centrifugal fan, the required air flow at the working front (236 m^3/min) cannot be achieved for the final length of the mine working of 3500 m or 3160 m (the current length of the ventilation column);
  - under the conditions of using the fans VE ϕ 700 – 11 kW and VE ϕ 800 – 30 kW, the required air flow cannot be achieved at the work front.
- For the column with the diameter ϕ = 900 mm, R_0 = 0,003038 kμ/m and $K_0 = 1{,}8 \times10^{-4}$ m^3/s/m at 1 mm H_2O:
  - under the conditions of using ventilation columns with ϕ = 900 mm for the 4 types of fans presented, the required air flow at the working front (236 m^3/min) cannot be achieved for a ducting column length of 3500 m, of to the centrifugal fan V 496/5. The maximum length of the ventilation column that will transport this flow to the working front is 3160 m.
  - under the conditions of using the VE ϕ 800 – 30 kW fan, respectively the dESN 9-300-30 Kw and dESN 9-370-37 Kw fans, the required air flow at the work front (236 m^3/min) can be achieved by the three types of fans with their cascading arrangement, thus:
    - ✓ with 3 fans VE 800-30 kW, at the total length of the column of 3720 m;
    - ✓ with 2 dESN 9-300-30 Kw fans, on a total column length of 3600 m;
    - ✓ with 2 fans dESN 9-370-37 Kw, on a total length of the column of 3750 m;
    - ✓ with 3 dESN 9-300-30 Kw fans, on a total column length of 4200 m;

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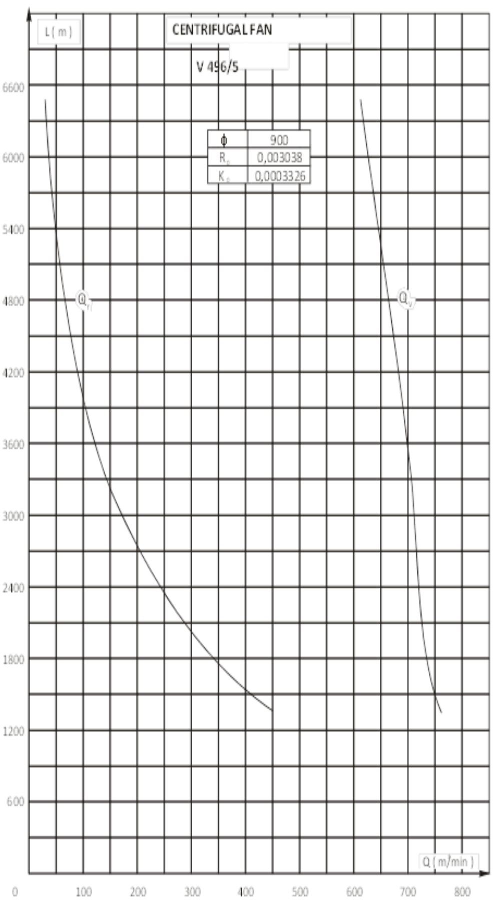

Fig. 7. Nomogram for centrifugal fan type V 496/5

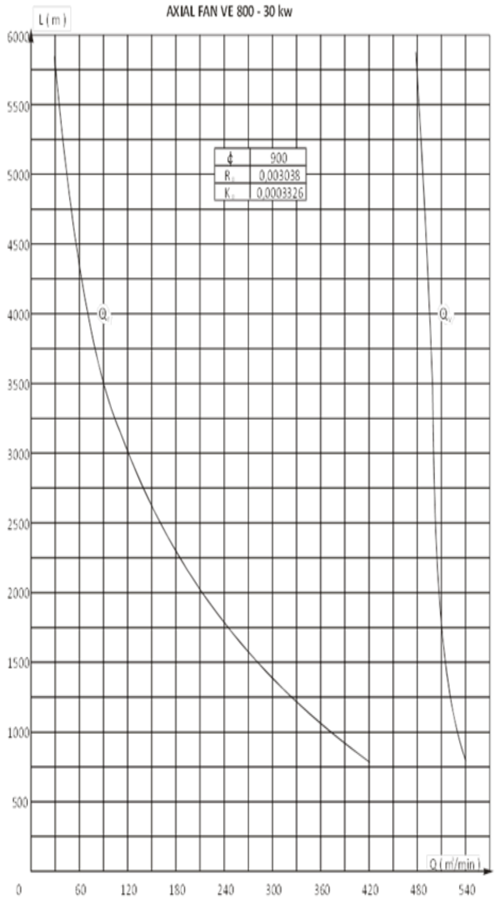

Fig 8. Nomogram for axial fan type VE 800-30 Kw

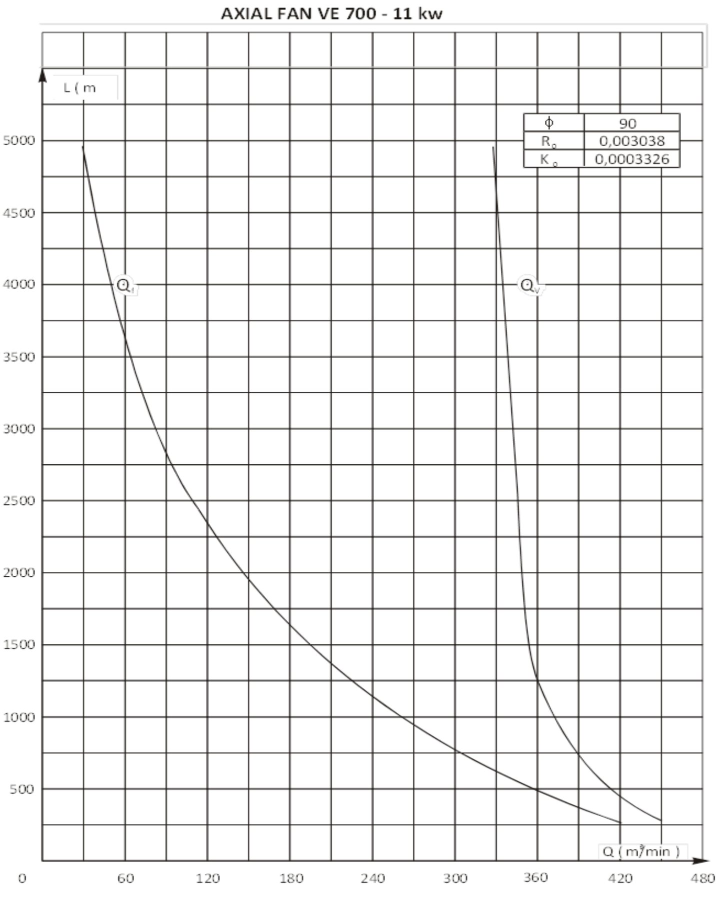

Fig 9. Nomogram for axial fan type VE 700-11 Kw

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Figure 10 (a – e) shows an example of the placement of VE 800-30 kW fans on the ventilation column with a diameter of 900 mm for a planned air flow at the working front of 236 m^3/min.

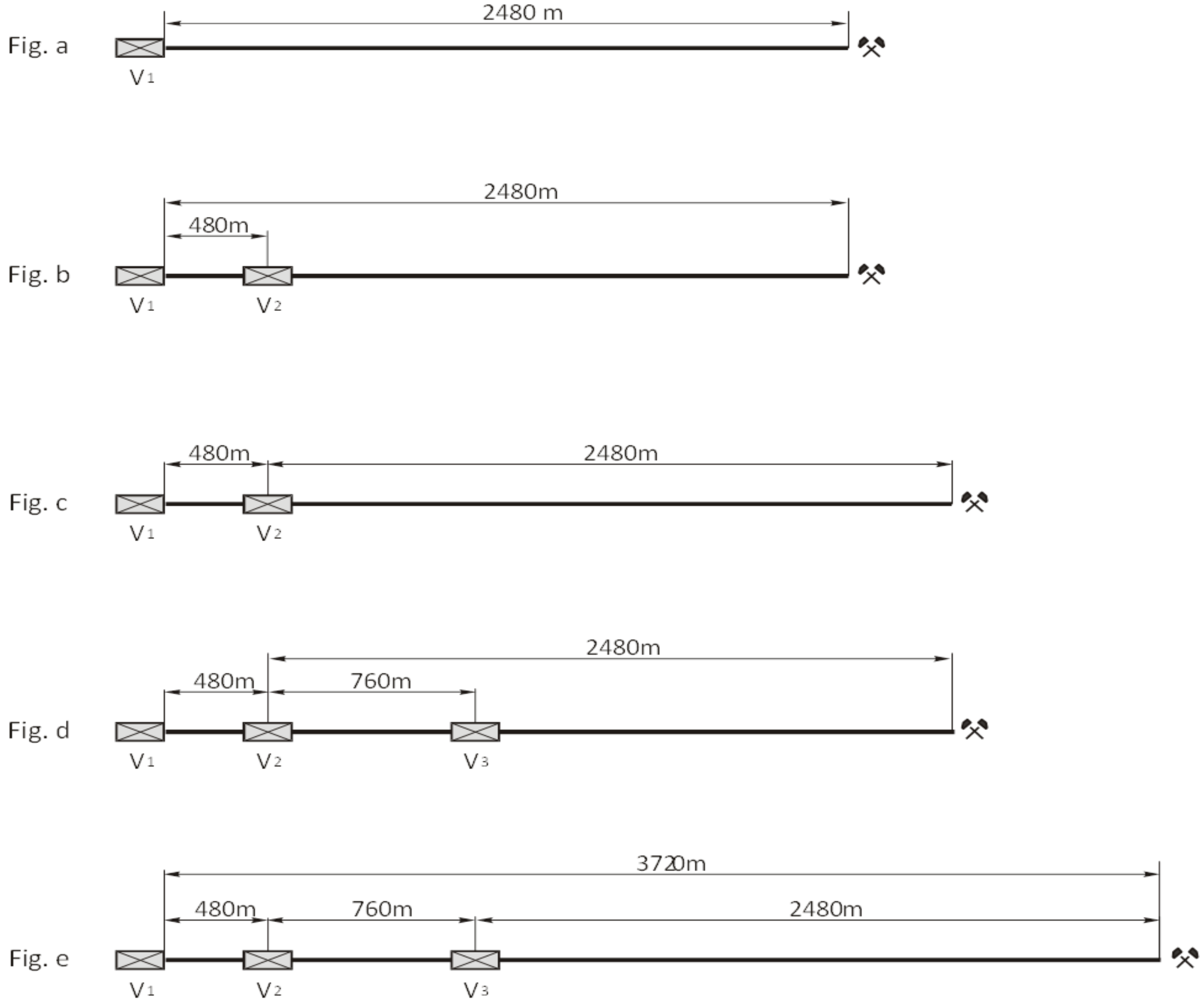

Fig. 10. Example of placement of VE 800-30 kW fans on the ventilation column

The arrangement of the fans on the ventilation column shown in figure 10 was made with the help of the nomogram shown in figure 8. According to this nomogram, the flow rate of 236 m^3/min can be circulated up to a maximum length of 3720 m, during the excavation of the mine working.

With one fan, the flow rate of 236 m^3/min is circulated over a length of the ventilation column of 2480 m, with 2 fans on 2960 m, with 3 fans on 3720 m. During the excavation of the mine working, the fans are located as follows (figure 10):

- fan no. 1 is located at the end of the ventilation column, ensuring the planned flow rate up to a column length of 2480 m (figure 10. a);
- fan no. 2 is located 480 m away from fan no. 1 (figure 10 b). Fan no. 2 will circulate the air over a length of 2480 m (figure 10. b). When the mine working has been excavated to a length of 2960 m, fan no. 3 will be mounted (figure 10. c);
- fan no. 3 is located 760 m away from fan no. 2 (figure 14. d), circulating the air over a length of 2480 m (figure 10. e).

Finally, fan no. 3 will circulate the air along a column length of 2480 m, fan no. 2 on a length of 760 m, fan no. 1 on a length of 480 m (figure 10. e). Table 6 shows the column lengths for each fan up to which the required air flow can be circulated at the working front (236 m3/min) as well as the maximum length over which this flow is circulated based on the drawn up nomograms.

Table 6. Column lengths related to each fan for a front air flow of 236 m³/min

No.	**Fan type**	**Duct diameter ϕ [mm]**	**Ro [kμ/m]**	**Ko [m³/s/m at 1 mm H_2O]**	**Flow rate required in front Q_{fp} [m³/min]**	**The related column length for each fan**			**Maximum length to circulate the air flow L_{max} [m]**
						L_1	**L_2**	**L_3**	
1.	V 496/5	900	$3.038x10^{-4}$	$3.326x10^{-4}$	236	2480	-	-	2480
2.	VE ϕ 700 – 11 kW	900	3.038x10	$3.326x10^{-4}$	236	275	475	1175	1925
3.	VE ϕ 800 – 30 kW	900	3.038x10	$3.326x10^{-4}$	236	1825	-	-	1825
4.	V 496/5	900	3.038x10	$1.8x10^{-4}$	236	3160	-	-	3160
5.	VE ϕ 800 – 30 kW	900	3.038x10	1.8x10	236	480	760	2480	3720
6.	dESN 9-300-30 Kw	900	3.038x10	1.8x10	236	600	920	2680	4200
7.	dESN 9-370-37 Kw	900	3.038x10	1.8x10	236	960	2790	-	3750

Analysing the data presented in table 6, it can be seen that the required air flow at the working front (236 m³/min) depends both on the unit air loss coefficient through the leaks in the column K_0 and on the aerodynamic resistance R_0 of the ducting column. The higher the aerodynamic resistance R_0, the shorter the maximum length of the air flow to the working front. As an example, in the case of using an auxiliary ventilation installation having $R_0 = 0{,}003038$ kμ/m and $K_0 = 3{,}326 \times 10^{-4}$ m³/s/m at 1 mm H_2O, to ensure the air flow at the working front of 236 m³/min with 3 VE 700-11 kW fans, this flow can be circulated up to a column length of 1925 m. With an individual fan type VE 800 30 Kw respectively a fan type V 496/5 flow rate of 236 m³/min, can be achieved on a column length of 1825 m or 2480 m. It is not recommended to use fans of different construction types or different parameters in cascade.

The use of a single fan for ventilating the main adduction gallery Front Castel amonte

The first option in the design of auxiliary (partial) ventilation installations for the purpose of aeration of mining works is the choice of the variant with a single fan on the ventilation column. It is known that with the increase in the length of the ventilation columns, the flow required by the fan increases due to the increase in air losses through the leaks in the ducting column. For these reasons, the circulation of large air flows in the working fronts of mining works with long lengths, raises problems that are difficult to solve [40], [41].

Considering that the final length of the ducting column will be 3500 m, the required parameters of the fan will have maximum values. Under these conditions, it is necessary for the ventilation to be carried out in several phases, using several ventilators corresponding to the respective phases of tunnel excavation. In this sense, the parameters required for the fan (Q_V and h_V) were calculated for the final length of 3500 m of the duct column. The required air flow at the working front (Q_{fp}) was considered to be 236 m³/min (for the dilution of exhaust gases from 45 HP locomotives).

The values of the R_0 and K_0 parameters currently realized and determined based on measurements were also taken into account. The necessary parameters for the fan (Q_V and h_V) were determined with the relations:

$$Q_V = Q_f + \frac{d \cdot k \cdot H^{0,6}{}_o}{1+0,6} \cdot L \ \ (m^3/s)$$

$$h_V = H_0 (1 + 0,77 \frac{Q_V - Q_f}{Q_f}) \ \ (mm\ H_2O)$$

where:

d – ventilation duct’s diameter, (m);
L – duct column length, (m);
H_0 – depression of the ventilation column without air losses, (mm H_2O)

$H_0 = R_0 \cdot L \cdot Q_f^2$ (mm H_2O);
R_0 – the unit resistance of the ventilation column (kμ/m);
K – air losses coefficient.

The calculation of the necessary parameters for the fan was carried out by giving "k" 2 values:

- k = 0.0003326 (average value resulting from measurements);
- k = 0.00018 (very good degree of sealing);

After performing the calculations, the following values of the air flow and the depression required to be achieved by a fan resulted:

- for k = 0,0003326 m^3/s/m at 1 mm H_2O and R_0 = 0,003038 kμ/m (average value resulting from measurements), at a work length of 3500 m, a fan would be required to achieve a flow rate of 17,905 m^3/s (1074 m^3/min) and a depression of 614 mm H_2O. Practically, these parameters required for the fan, using the coefficient K_0 determined by measurements, are possible to achieve with the use of a single fan.
- for k = 0.00018 m^3/s/m at 1 mm H_2O and R_0 = 0,003038 kμ/m (average value resulting from measurements), at a work length of 3500 m, a fan would be required to achieve a flow rate of 11,493 m^3/s (690 m^3/min) and a depression of 408 mm H_2O. These parameters required for the fan, using this sealing coefficient can be achieved with the use of a single fan.

4. Conclusions

The first option in the design of auxiliary (partial) ventilation installations is the choice of the variant with a single fan on the aeration column. As emphasized in article's content, with the increase in the length of the ventilation columns, the flow required by the fan increases due to the increase in air losses through the leaks in the ducting column. For these reasons, the circulation of large air flows in the working fronts of mine workings with long lengths raises problems that are difficult to solve.

In conclusion, the special importance of the degree of sealing of the ventilation columns for long mining works results. Practically, for the ventilation of the main adduction gallery Front Castel amonte, it is necessary to improve their degree of sealing in order to obtain a "K_0" coefficient of up to $1.8 \cdot 10^{-4}$ m^3/s/m at 1 mm H2O.

It follows that, for the ventilation of the main adduction gallery Front Castel amonte, it can be used:

- a high-pressure centrifugal fan type MZRU 1000 or MZRU 1120 at the current degree of sealing of the metal column, or type MZRM 900, 1000, 1120 for a very good degree of sealing of the column made of metal tubes.
- axial fans VE ϕ 800 - 30 kW, respectively Korfmann axial fans type dESN 9-300-30 Kw and dESN 9-370-37 Kw with their placement in cascade, under the conditions of ensuring a very good degree of sealing.

As a result, it was recommended to use domestic fans type VE 800 30 Kw with their placement in cascade, under the conditions of ensuring a very good degree of sealing. In order to avoid the accumulation of gases, at the ceiling of the mining work, it was proposed to use devices to disperse them.

References

[1] **Romanian Parliament**, 2006
Law no. 319 Regarding Occupational Safety and Health (in Romanian), Official Journal of Romania, Part I, No. 646/26.07.2006, Bucharest, Romania.

[2] **Drăgoescu R., Cămărășescu A.,** 2024
Optimization of Systems of Industrial Ventilation – Case Study. MATEC Web of Conferences, 389. 10.1051/matecconf/202438900006.

[3] **Moraru R.I., Băbuţ C.M., Băbuţ G.B.,** 2011
Aeraj, sănătate şi securitate în muncă, Focus, Petroşani, ISBN 978-973- 677-253-5, 348 p.

[4] **Romanian Government,** 2006
Government Decision no. 1425 for Approval of Methodological Norms for Applying Occupational Safety and Health Law no. 319/2006 (in Romanian), Official Journal of Romania, Part I, No. 882/30.10.2006, Bucharest, Romania.

[5] **Romanian Government,** 2010
Government Decision No. 955/2010 for the Modification and Completion of the Methodological Norms for the Application of the Provisions of the Law on Safety and Health at Work 319/2006, approved by Government Decision No. 1425/2006 (in Romanian), Official Journal of Romania, Part I, No. 661/27.09.2010.

[6] **Romanian Government,** 2011
Government Decision No. 1242/2011 for Changing the Methodology for the Application of the Law of Safety and Health at Work 319/2006, approved by Government Decision No. 1.425/2006 (in Romanian), Official Journal of Romania, Part I, No. 925/27.12.2011.

[7] **Chitoroagă O.,** 2015
Noxe profesionale, Colegiul Politehnic din Chișinău.

[8] **Pineau J.P.,** 2014
Analyse des risques d'installations industrielles, HAL Id:INERIS -00971953, INERIS, Paris.

[9] **Biegert B., Railio J.,** 2001
Industrial Air Technology – Description, Industrial Ventilation Design Guidebook, Academic Press, San Diego, California, USA.

[10] **Echeverri D.R., Cano S.H.R., Builes J.A.J.,** 2012
Detección y control de atmósferas explosivas en minas subterráneas de carbón usando programación estructurada, Revista Educacion en Ingenieria, No. 14, Vol. 7, ISSN 1900 – 8260.

[11] **Li Y., Nielsen P.V.,** 2011
Commemorating 20 Years of Indoor Air CFD and Ventilation Research. Indoor Air, 21: 442–453.

[12] **de Sousa E.,** 2002
Mine Ventilation, A.A. Balkema Publishers, Lisse, Netherlands.

[13] **Moraru R.I., Băbuţ G.B., Cioca L.I., Ragazzi M.,** 2017
Spontaneous Combustion Risk Analysis in Subsurface Environments: Carbon Monoxide Data Processing Tool, Environmental Engineering and Management Journal, Volume 16, Issue 6, pp. 1317-1322.

[14] **Cristea A.,** 1971
Ventilația și condiționarea aerului, Editura Tehnică, București.

[15] **Hayati A., Mattsson M., Sandberg M.,** 2019
A Wind Tunnel Study of Wind-Driven Airing Through Open Doors, International Journal of Ventilation, 18:2, 113-135, DOI: 10.1080/14733315.2018.1435027.

[16] **ACGIH,** 1995
Industrial Ventilation - A Manual of Recommended Practice. 22nd edition, ACGIH.

[17] **Litomisky A.,** 2006
New Saving Opportunity: On-demand Industrial Ventilation, Energy Engineering, 103:3, 25-40, DOI: 10.1080/01998590609509465.

[18] **Băltăreţu R., Teodorescu C.,** 1971
Aeraj şi protecţia muncii în mină, Editura Didactică şi Pedagogică, Bucureşti .

[19] **Cristea A.,** 1968
Ventilația și condiționarea aerului – Vol. I, Editura Tehnică, București.

[20] **Băltărețu F., Matei I.,** 1987
Ghid practic pentru proiectarea și verificarea instalațiilor de aeraj parțial, Ministerul Minelor, Petrolului și Geologiei.

[21] **Cioclea D., Lupu C., Gherghe I.,** 2013
Ghid pentru dimensionarea instalațiilor de ventilație industrială, Editura INSEMEX.

[22] **Dentinger L., Freysz O., Genet C.,** 2005
Ventilation Générale des Locaux de Travail, Master Prévention des Risques et Nuisances Technologiques, Projet UE, 05 - Facteurs d'Ambiance, Marseille, le 14/06/2005.

[23] **Maître M.,** 2015
Principes generaux de ventilation – Guide practique de ventilation, ED 695, INRS.

[24] **McPherson M.J.,** 1993
Subsurface Ventilation and Environmental Engineering, Chapman & Hall, London.

[25] **Drăgoescu R., Cioclea D., Chiuzan E., Matei A., Morar M.S.,** 2019
Development of New Concepts, Methods, Processes and Technologies Concerning the Security of Industrial Ventilation Systems, International Multidisciplinary Scientific GeoConference: SGEM; Sofia, Vol. 19, Iss.1.3, DOI:10.5593/sgem2019/1.3/S03.031.

[26] **Moraru R.I., Băbuţ G.B., Cioca L.I.,** 2013
Study of Methane Flow in Caved Goafs Adjacent to Longwall Faces in Valea Jiului Coal Basin, Proceedings of the 13th International Multidisciplinary Scientific Geoconference - SGEM 2013, Volume I, pp. 731-738, Albena, Bulgaria, 16-22.06.

 vol. 31, issue 1 / 2025
pp. 30-49

[27] **Şuvar M., Cioclea D., Gherghe I., Păsculescu V.,** 2012
Advanced Software for Mine Ventilation Networks Solving, Environmental Engineering and Management Journal July, vol. 11, No.7, 1229-1234.

[28] **Zhang X., Taipale A., Li X., Cao G., Gao J., Ye W.,** 2017
Celebrating 30 Years of Conference Series on Industrial Ventilation-Health, Comfort and Efficiency, International Journal of Ventilation, 16:3, 161-162, DOI: 10.1080/14733315.2017.1299512.

[29] **Teodorescu C., Gontean Z. Neag I.,** 1980
Aeraj Minier, Editura Tehnică, București.

[30] **Larsson U., Moshfegh B.,** 2017
Comparison of Ventilation Performance of Three Different Air Supply Devices: A Measurement Study, International Journal of Ventilation, 16:3, 244-254, DOI: 10.1080/14733315.2017.1299519.

[31] **Goodfellod H., Tahti E.,** 2001
Industrial Ventilation, Desing Guidebook, Academic Press.

[32] **Zhao B., Li X., Li D., Yang J.,** 2003
Revised Air-Exchange Efficiency Considering Occupant Distribution in Ventilated Room. Journal of the Air & Waste Management Association, 53: 759–763.

[33] **Sotnikov A.G., Borovitskiy A.A.,** 2012
Theoretical and Experimental Validation of the Air Changes in Industrial Ventilation Optimization Method. Magazine of Civil Engineering, 28(2), pp. 32-38. (Russian). DOI: 10.5862/MCE.28.5.

[34] **Steven E.G., Derrick W.B.,** 2001
An Evaluation of Industrial Ventilation Troubleshooting Methods in Experimental Systems, AIHAJ - American Industrial Hygiene Association, 62:6, 669-679, DOI: 10.1080/15298660108984673.

[35] **Gherghe I., Lupu C., Cioclea D., Boantă C., Morar M., Chiuzan E.,** 2010
Verificarea in situ a parametrilor R_0 şi K_0 care caracterizează instalaţia de aeraj parţial din cadrul aducţiunii secundare BISTRA – POIANA MĂRULUI, Revista Minelor, nr. 11/2010, ISSN 1220 – 2053.

[36] **Gherghe I., Lupu C., Cioclea D., Boantă C., Morar M., Rădoi F.,** 2013
In Situ Inspection of the Aerodynamic Parameters Related to the Ventilation Facility Used on the Main Front Castle Upstream Adduction Gallery from within A.H.E. Siriu-Surduc, Annals of the University of Petrosani. Mining Engineering, nr. 13, ISSN 1454-9174.

[37] **Moraru R.I., Băbuț G.B.,** 2014
Research on Methane Emission Mechanism and Pattern in a Longwall Coal Face at Livezeni Colliery, Proceedings of the 14th International Multidisciplinary Scientific Geoconference - SGEM 2014, Volume III, pp. 497-504, Albena, Bulgaria, 17-26.06.

[38] **Șuvar M., Arad V., Lupu C., Cioclea D., Ghicioi E., Vlasin N.,** 2013
Prospective Virtual Simulation of Ventilation Networks, International Multidisciplinary Scientific Geo- Conference SGEM, Bulgaria, Albena, 16th-22nd June.

[39] **Ojima J.,** 2002
Worker Exposure Due to Reverse Flow in Push–Pull Ventilation and Development of a Reverse Flow Preventing System. Journal of Occupant Health, 44: 391–397.

[40] **Wang Y., Cao Y., Liu B.,** 2016
An Evaluation Index for the Control Effect of the Local Ventilation Systems on Indoor Air Quality in Industrial Buildings. Build. Simul. 9, 669–676.

[41] Xing H., Hatton A., Awbi H.B., 2001
A Study of the Air Quality in the Breathing Zone in a Room with Displacement Ventilation. Building and Environment, 36: 809–820.