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Safety improvement achieved by prevention actions related to aerological hazards – sample cost analysis

The article features the characteristics of expenditure incurred by mining companies on occupational health and safety operations. It was indicated that proper measures and methods have to be selected to improve the safety of mining operations. This can be done by proper prevention actions, particularly in the realm of aerological hazards. A typical longwall in a Polish mine was characterized, along with the related prevention actions undertaken to mitigate aerological hazards with a view to achieve safe exploitation of the longwall. Based on the data collected in production preparation and controlling departments, the costs of materials and workdays within the applied prevention actions were estimated. The obtained figures were used to calculate the following: total costs of prevention, percentage indicators of prevention actions costs in the generated income, costs of prevention actions per 1 Mg of extracted coal, and total costs of prevention actions for the analyzed longwall. It was pointed out that work safety should be improved by proper selection of prevention measures.

Keywords*: work safety, aerological hazards, prevention, costs of prevention actions.*

1. INTRODUCTION

Mining works that are conducted in hard coal mines today are exposed to considerable danger related to increasing natural hazards, particularly aerological hazards. The danger is caused mainly by exploitation going down to deeper and deeper beds and by sublevel exploitation which is often conducted in mines where it is impossible to develop new, lower exploitation levels.

Mining has been carried out in more and more difficult conditions recently. Therefore the mines allocate more and more funds on safe mining exploitation. Table 1 features the costs incurred by mining companies on occupational health and safety per one Mg of extracted coal [7]. It is possible to observe that these costs increase every year, practically in every mining company. There was some decrease in this expenditure in 2014 due to generally bad performance of hard coal mining. The expenditure, though indispensable, increases the cost of one tonne of extracted coal.

As it was mentioned earlier, the expenditure on occupational health and safety is indispensable as it includes the costs of all prevention actions applied to achieve safe exploitation. The undertaken prevention actions must have proper procedures which determine the use of suitable measures and methods in hazardous situations. The measures and methods should be selected in such a way as to reduce or even eliminate the occurring hazardous state [4]. The selection of hazard-fighting methods is based on the recognition of circumstances in excavations, goafs and rock mass [10].

Work safety is increased by proper selection of safety measures within the applied prevention actions.

It is not possible to overestimate the significance of prevention actions, particularly with respect to aerological hazards, as these actions maintain a proper level of safety in the longwall areas [2, 6].

Table 1

Expenditure on occupational health and safety in the period 2010-2014 per 1 Mg of extracted coal [7]

Mining company	Expenditure on occupational health and safety in the period 2010-2014 per 1 Mg of extracted coal [PLN/1 Mg]				
	2010	2011	2012	2013	2014
KW S.A.	20.33	21.54	23.79	25.35	24.74
KHW S.A.	27.60	27.34	29.00	28.80	33.10
JSW S.A.	38.64	44.92	46.26	44.90	52.15
TAURON Wydobycie S.A	18.22	19.46	16.30	17.13	14.86
LW "Bogdanka" S.A.	11.67	13.37	12.81	12.10	12.03

Aerological hazards which occur in the longwall areas have to be kept on a safe level. In order to fight against them it is necessary to adopt a continuous prevention policy which will reduce the range of hazards and their impact in the longwall area and in the neighbouring excavations which outline the mine section.

The necessity of continuous prevention in exploitation areas [9, 11] is particularly important in the case of methane-, fire-, climatic-, and dust-explosion hazards and has influence on the cost of exploitation in the longwall area.

The article contains the analysis of costs incurred by a mine in order to maintain work safety during mining works. The volume of these costs was estimated on the basis of unit costs of aerological-hazard prevention actions for a sample longwall in a hard coal mine.

The described longwall is a typical longwall exploited in a Polish hard coal mine.

2. CHARACTERISTICS OF A LONGWALL AND ITS HAZARDS

2.1. Longwall parameters and hazard levels

The A-1 longwall [8] was developed in the 401 bed with the thickness of 1.5÷2.5 m, in the central part of the mine, between the levels 900 m and 1,050 m. The longwall was cut between the A-1 haulage incline and the A-2 transport incline. The total longwall life was 578 m. The thickness of the exploited 401 bed was about 1.5÷2.5 m and was increasing eastwards.

The nether roof of the bed contained mudstone with traces of coal, carbonaceous shale with the thickness of about 1.2÷2.7 m, and shale with coal. The floor contained mainly mudstone and sandy shale.

The longwall was ventilated with the use of the reversed Y method with reblowing from the A-1 haulage incline and air disposal along the goafs towards the A-2 transport incline. The air draft was provided to the longwall along the A-1 haulage incline and was about 2,700 m^3/min. The air of about 800 m^3/min was transported directly to the longwall along the N-1 road.

In order to reblow the final section of the longwall, the air draft of about 800 m^3/min was provided along the N-2 road. Table 2 presents the characteristics of the longwall, while Fig. 2 features the diagram of the A-1 longwall area.

2.2. The scope of prevention actions in the longwall area

The 401 bed was classified as a IVth category one in terms of methane hazard, with absolute methane-bearing capacity of about 25 m^3/min. Therefore the methane drainage process was conducted [3]. Series of methane drainage boreholes were made immediately along the advancing longwall from the N-2a road. The drainage boreholes were directed towards the caving, along the advancing longwall and were liquidated as the N-2a road was liquidated between the parallel roads connecting N-2 and N-2a. As the longwall was advancing, the N-1 road was liquidated by initiating falls. In the lack of falls, the road was completely filled with light foam.

In order to reduce air migration through the goafs, there was a ventilation-canvas lagging installed from the side of the N-1 road. The lagging covered the goafs of N-1 and extended as far as the last but one section of the powered support. There was a constant airflow provided every 30 m to the lower route of the conveyor. In the case of increased values of methane concentration in the working space of the longwall final section, auxiliary ventilation equipment was used to thin down the methane and air mixture until it reached admissible concentration values. The drainage boreholes took away about 7÷8 m^3CH_4/min during the whole exploitation of the A-1 longwall, which resulted in 30% efficiency of the methane drainage process.

Table 2

Characteristics of A-1 longwall in 401 bed [8]

Longwall length	up to 235 m
Longwall exploitation height	1.5÷2.5m
Longwall longitudinal inclination	1°÷ 5°
Longwall transverse inclination	-5°÷ +5°
Longwall life	578 m
Average output	4,500 Mg/day
Exploitation system	along the strike with roof caving
Methane hazard	IVth category methane hazard
Fire hazard	Ist group of spontaneous combustion – very low coal vulnerability to spontaneous combustion
Fire incubation period	84 days
Coal-dust explosion hazard	Class B of coal-dust explosion hazard
Climatic hazard	Critical level III (high)
Rock-burst hazard	Ist degree of rock-burst hazard
Water hazard	Ist and IInd degree of water hazard

In order to protect the longwall area against uncontrolled increase in methane concentration, the A-1 longwall area was equipped with an automatic methane measurement system. Figure 1 presents the distribution of automatic methane measurement sensors.

During the tests of coal samples, aimed at checking their vulnerability to spontaneous combustion, the following were determined: the values of spontaneous combustion indicators $Sz^a(237)$ = 36ºC/min, $Sz^{a'}(190)$ = 7ºC/min, the value of activation energy of coal oxidation A = 69 kJ/mol, and fire incubation time – 84 days. Thus the coal from the 401 bed was classified to the 1st group of spontaneous combustion due to its spontaneous-combustion vulnerability. Nonetheless, different prevention actions were undertaken [3] mainly due to the adopted reverse-Y ventilation system with reblowing. For example, pure extraction was used with special attention paid to the roof layer. In addition, as the longwall was advancing and successive sections of the N-2a road were liquidated between the parallel roads connecting N-2 and N-2a, the liquidated sections were filled with fine-grained slurries.

The longwall area was covered by a system for early detection of spontaneous fires in order to determine current values of fire coefficients in the streamlined air current and goafs. The content of carbon oxide in the air was monitored by CO measuring equipment (Fig. 1). If there was local increase of fire hazard in the goafs of the longwall, antipyrogenic agents were forced behind the power support sections, together with light urea foams. The goafs were continuously insulated by fine grained slurries. Additionally, nitrogen was provided to the goafs with a view to reduce the concentration of oxygen. In order to maintain the size of the N-2 road, a support and insulation belt was being constructed. The N-1 road was being liquidated by withdrawing the support and filling empty areas with light urea foam.

The longwall area was equipped with standard fire protection equipment and a fire protection line. In addition, it was protected by district and in the district dams (Fig. 1).

The climatic hazard which occurred in the longwall area resulted from very high primary temperature (about 42ºC) of the rock mass. This situation had impact on considerable emission of heat, accumulated in the rock mass, to the air which flows along the excavations outlining the A-1 longwall.

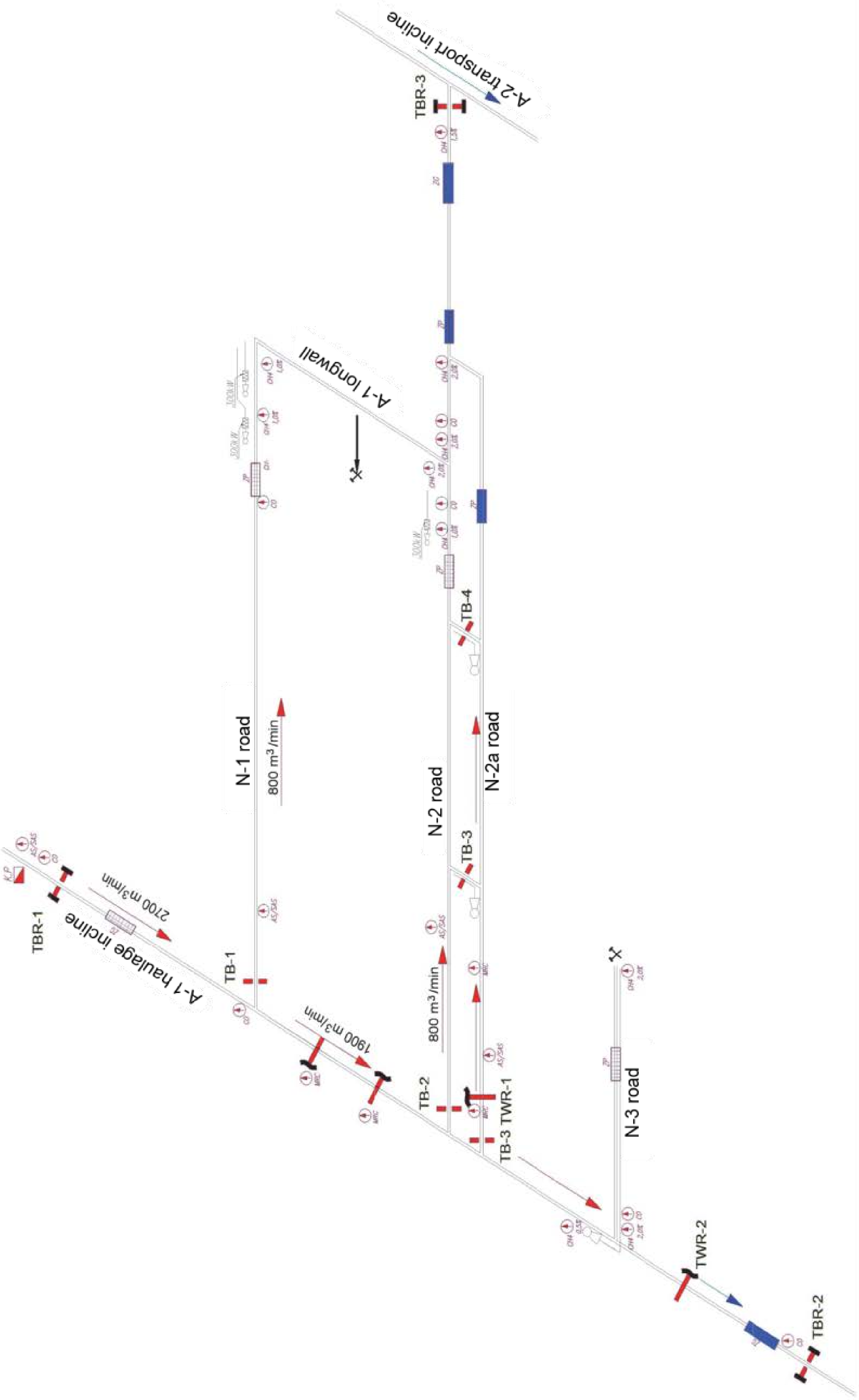

Fig. 1. Diagram of A-1 longwall area [8]

The climatic hazard prevention [3] was based, first of all, on air cooling. For this reason, three air conditioning devices were located directly in front of the parallel road: two devices in the N-1 road, at the face end (Fig. 1), and one device in the N-2 road, where the reblowing air stream flows to the crossing with the parallel road. What is more, the ventilation intensity was increased periodically. Thus the cooling intensity of excavations increased too due to a more voluminous air stream flowing through the longwall excavations. Additionally, in the case of unfavourable climatic conditions, shorter work shifts for the personnel were applied and the ventilation of the longwall path was intensified.

Due to the class-B coal dust explosion hazard in the longwall area, protection zones were marked out. In the places where hazardous coal dust settled, the excavations were sprayed with rock dust. In the places where mined rock transfer points were located, water spraying was used in order to reduce the volatility of coal dust. In addition, the longwall area was protected with explosion barriers [3]. The main barriers were located in the haulage incline, north of the N-1 road, south of the N-3 road, and at the end of the N-2 road towards the A-2 transport incline. District dams were located in the N-1 and N-2 roads, in front of the longwall, according to mining regulations, as well as in the drilled N-3 road and the last existing section of N-2a between parallel roads to N-2. An extra district dam was located in the return air stream in the N-2 road, behind the last parallel road which connects N-2 and N-2a. Due to high absolute humidity of the air flowing from the longwall area, the main outlet dams and district outlet dams were built as water dams.

3. ANALYZING THE COSTS OF AEROLOGICAL HAZARDS PREVENTION IN A-1 LONGWALL

3.1. Costs characteristics

The cost analysis of aerological prevention actions for the A-1 longwall was based on costs by type [1] which included the costs of durable materials and wages incurred on prevention [5].

Other costs, such as depreciation costs, wear and tear of materials and energy consumption, were not taken into account as, in many cases, it was impossible to estimate them. These costs were insignificantly small and had no decisive impact on the total costs of undertaken prevention actions. The method to fight a given hazard by adopting a proper prevention action was employed mainly to improve work safety in the longwall area.

Tables 3-6 feature the range of the most important prevention actions and the costs incurred to adopt them.

Table 3

Costs of methane hazard prevention [5]

No	Cost	Amount/number	Unit cost [PLN]	Total cost [PLN]
1.	Making drainage boreholes. Boring the holes: use of exploitation materials (grill bits, lining pipes, insulation materials)	–	–	1,394,000
2.	Ventilation-canvas lagging; insulation of the N-2 road caving with light foam, injectors	–	–	86,000
3.	Work days spent on fighting methane hazard	670	188	125,960
4.	Total cost of prevention			1,605,960

Table 4

Costs of fire hazard prevention [5]

No	Cost	Amount/number	Unit cost [PLN]	Total cost [PLN]
1.	Roadside packs	–	–	394,500
2.	Chemical materials: - foamed inhibitor - phenol foam - insulation foam	 9,340 dm^3 37,250 dm^3 39,230 dm^3	 3.5 PLN/dm^3 5.5 PLN/dm^3 1.9 PLN/dm^3	 32,690 204,875 74,537
3.	Mineral materials: - mineral-cement binder - Portland cement - washed sand	 155 Mg 8.5 Mg 20 Mg	 774.2 PLN/Mg 256 PLN/Mg 16 PLN/Mg	 120,001 2,176 320
4.	Precast concrete cuboid blocks	4,200 pcs	3.5 PLN/pcs	14,700
5.	Inertization with nitrogen	112,250 m^3	3.37 PLN/m^3	378,283
6.	Work days spent on fighting fire hazard	3,407	191 PLN	650,737
7.	Total cost of prevention			1,872,819

Table 5

Costs of climatic hazard prevention [5]

No	Cost	Amount/number	Unit cost [PLN]	Total cost [PLN]
1.	MK-300c cooler	2 pcs	375,000	750,000
2.	MK-300 cooler	1 pcs	220,000	220,000
3.	Auxiliary fans	3 pcs	85,000	255,000
4.	Ventube fans, including ventubes	2 pcs	78,000	156,000
5.	Auxiliary materials	–	–	123,000
6.	Work days spent on fighting climatic hazard	690	188	129,720
7.	Total cost of prevention			1,633,720

Table 6

Costs of coal dust explosion hazard prevention [5]

No	Cost	Amount/number	Unit cost [PLN]	Total cost [PLN]
1.	Ordinary rock dust	185 Mg	218.94	40,504
2.	Containers for water barriers (40 dm^3)	1,340 pcs	49.00	65,660
3.	Wooden and steel structures for explosion barriers	–	–	34,500
4.	Work days spent on fighting coal dust explosion hazard	550	188	103,400
5.	Total cost of prevention			244,064

The analysis of prevention actions costs demonstrates that the expenditure on labour and on materials vary from each other. This can be seen in Fig. 2.

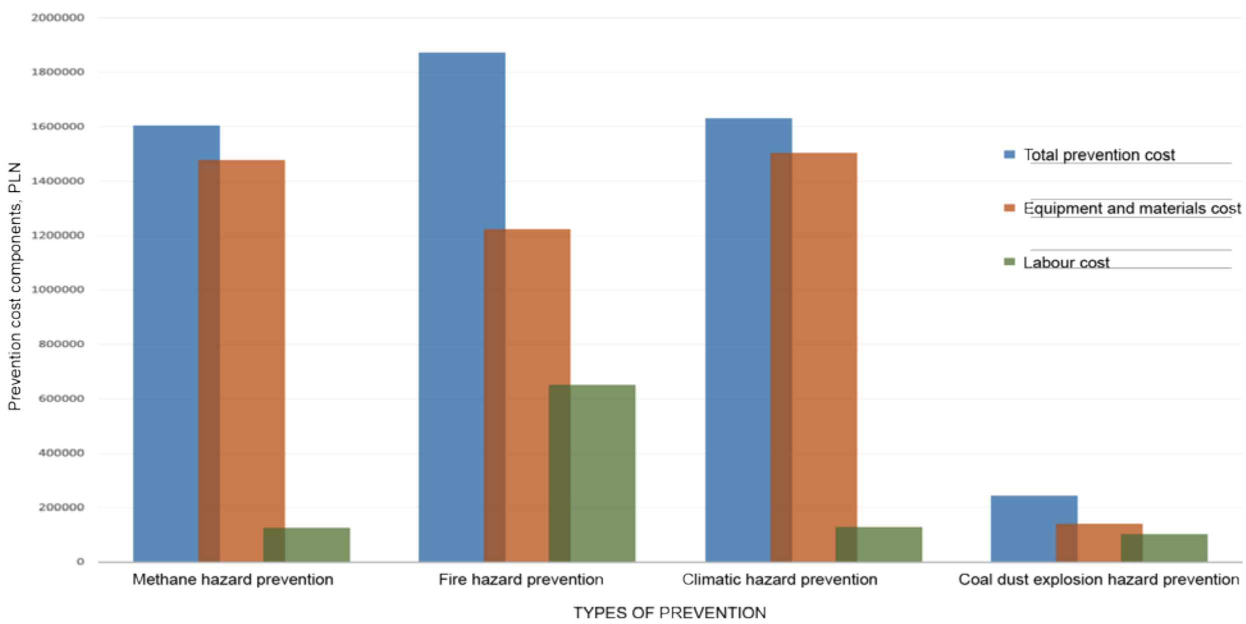

Fig. 2. Comparison of materials costs and labour costs in the prevention of aerological hazards

3.2. Cost indicators of aerological prevention

During the exploitation of the 401 bed by means of the A-1 longwall, the total expenditure incurred by the coal mine for the improvement of safety amounted to 5,310,199 PLN. The money was spent on prevention actions undertaken to reduce aerological hazards in this area. The A-1 longwall was exploited for 115 days. The average daily output during this exploitation period was 4,500 Mg. Thus the total output was:

$$W_C = W_d \cdot d_r = 4500 \cdot 115 = 517\ 500,\ \text{Mg} \quad (1)$$

where:
W_C – total output, Mg,
W_d – daily output, Mg/day,
d_r – number of exploitation days.

During the exploitation by means of the A-1 longwall the unit price of one tonne of coal was 510 PLN. Thus the achieved total income for the assumed unit price of one tonne of coal amounted to 263,925,000 PLN.

The percentage of prevention actions costs in the achieved income can be calculated from the following formula:

$$U_P = \frac{K_P}{P_C} \cdot 100\% \quad (2)$$

where:
U_P – percentage of the applied prevention actions, %,
K_P – total costs of the applied prevention actions, PLN,
P_c – total income, PLN.

Based on formula 2, the percentage of particular prevention actions costs in the total income was the following:
- methane hazard prevention U_{PM} = 0.61%,
- fire hazard prevention U_{PP} = 0.71%,
- climatic hazard prevention U_{PK} = 0,62%,
- coal dust explosion hazard prevention U_{PWP} = 0.092%,

which is demonstrated in Fig. 3.

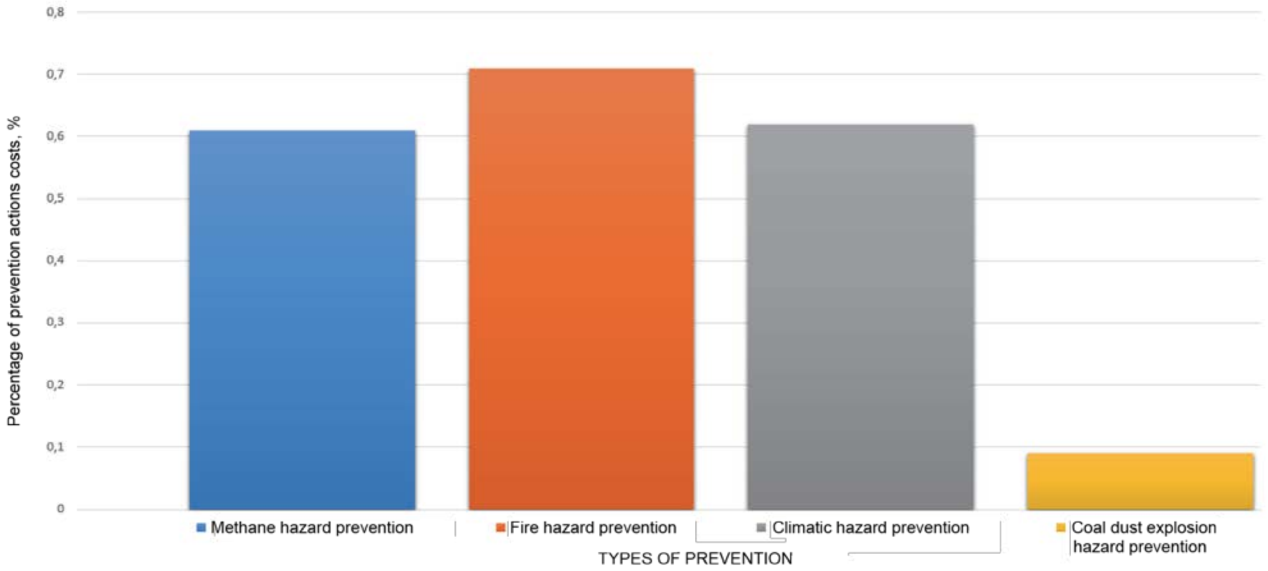

Fig. 3 Percentage of aerological hazards prevention actions costs in total income

Thus the total percentage of aerological hazards prevention costs in the total income was the following:

$$U_C = U_{PM} + U_{PP} + U_{PK} + U_{PWP},\ \% \quad (3)$$

so,

$$U_C = 0,61 + 0,71 + 0,62 + 0,075 = 2,032\%$$

The costs of prevention per 1 Mg of extracted coal can be calculated from the following formula:

$$K_{PMg} = \frac{K_P}{W_C},\ \text{zł} \quad (4)$$

So the costs of prevention actions are the following:
- methane prevention costs K_{PMgM} = 3.10 PLN,
- fire prevention costs K_{PMgP} = 3.62 PLN,
- climatic hazard prevention costs K_{PMgK} = 3.15 PLN,
- coal dust explosion hazard prevention costs K_{PMgM} = 0.38 PLN,

which was shown in Fig. 4.

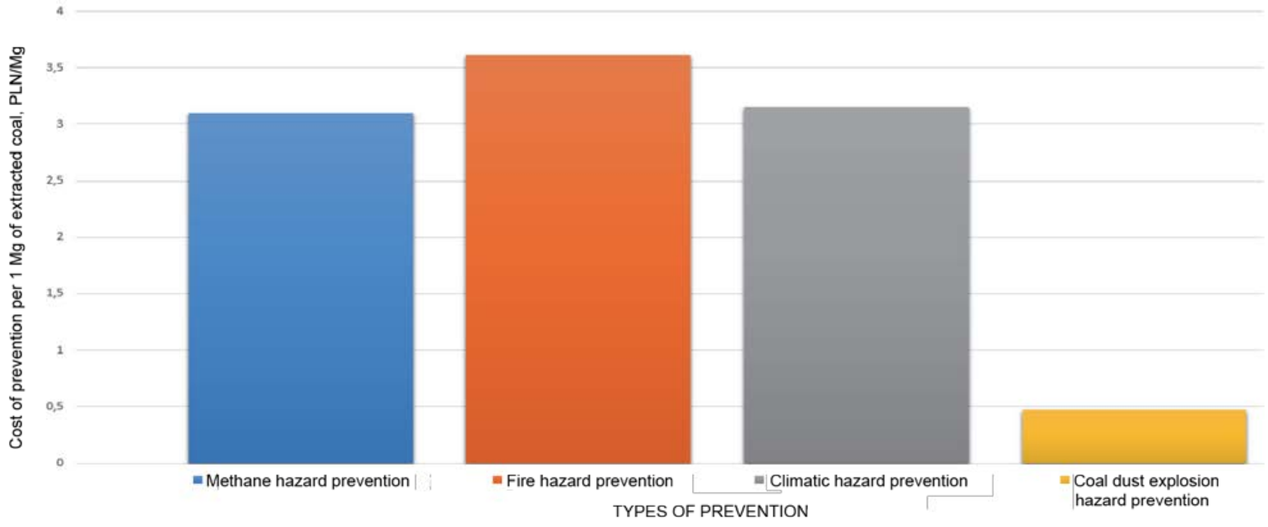

Fig. 4. Costs of aerological hazards prevention per 1 Mg of extracted coal

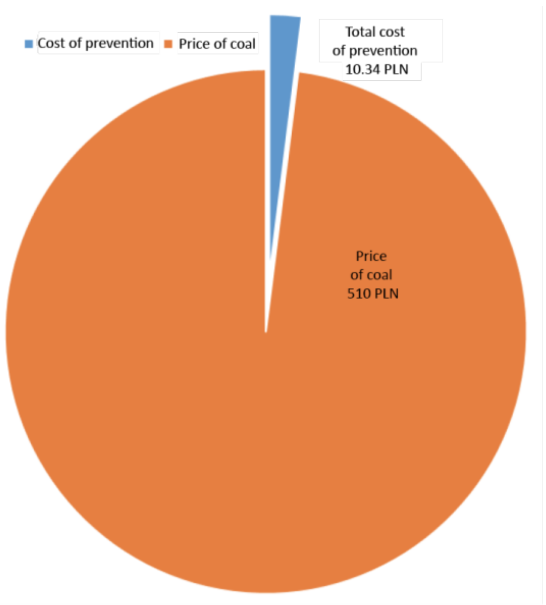

Fig. 5. Cost of aerological hazards prevention actions per 1 Mg of coal

The total cost of aerological hazards prevention actions per one tonne of coal amounted to 10.34 PLN, which, at the coal price of 510 PLN, amounts to about 2.02% – Fig. 5.

4. CONCLUSIONS

Maintaining work safety in the mining area is an indispensable condition to carry out mining works. Ventilation hazards are the most frequent ones in the exploitation area. It is necessary to reduce their impact on the longwall exploitation process in order to have proper and safe bed mining in the longwall area. Prevention actions applied against ventilation hazards reduce the risk of the hazard occurrence and enable more efficient and safer exploitation. The necessity to carry out prevention actions reduces the risk of the hazard occurrence to acceptable values on one hand, but on the other hand it generates extra costs which have to be included in the coal unit price, making the selling price higher. The chief element that impacts the percentage of the applied prevention actions cost is, apart from the number of prevention actions indispensable to apply in the longwall area, the total output from the working excavation. This is the latter factor that impacts the total cost of undertaken prevention actions per one tonne of coal extracted from the longwall area.

In the analyzed example, the total cost of applied prevention actions amounted to about 2% of the price of one tonne of coal. Now, due to significant reduction of coal prices on the market, this cost would be as much as 5-10% of the price of one tonne of coal. It is important to note that the necessity to apply prevention actions is an essential element that impacts the increase of the output efficiency. However, first of all, it impacts the maintenance of a proper level of functional safety in the longwall area which is the most vulnerable production element in the mine.

Maintaining a proper safety level in the working place and striving for its constant improvement should be the primary element of mining exploitation. If the cost to maintain the proper safety level is too high, it is necessary to analyze whether it is profitable to run mining works in the area.

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