Inert Compositions For Underground Fire Fighting in Mines

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Abstract: The properties of the inert compositions obtained by liquid nitrogen and water co-spraying are shown. The high performance of inert compositions made of gas-borne ice particles to extinguish underground in worked-out mine area is demonstrated. A reduction in coal reactivity after treatment with inert compositions is established.

Keywords: mine; worked-out mine area; spontaneous combustion; underground fire; nitrogen; inert composition.

1.Introduction

Underground fires cause enormous economic damage to mines, threaten the health and life of miners due to the release of toxic gases, combustible gas explosion hazards and coal dust. At Kuzbass coal mines the endogenous fires ignited by spontaneous combustion of coal clusters are the most common accident. The coal cluster formed in the worked-out areas of left pillars and in the places of geological faults in coal beds ignite spontaneously most often. Extinguishing fires occurring in the worked-out mine areas usually lasts a long time because of the fire seat inaccessibility the lack of accurate data on the location of the fire seat. At the time of the fire extinguishing the fire area is isolated from existing mine workings, which may lead to the loss of the whole coal and mining machinery. The rapid suppression of the fire seat allows improving significantly the mine safety and reducing the economic losses resulted from the endogenous fires. The conducted analysis showed that in Kuzbass in the case of immediate extinguishing of the place of spontaneous combustion at the early stage of its development, the average economic damage is reduced by 6.3 times.

The process of underground fire extinguishing differs significantly from fire fighting on the ground. On the surface, the refrigerant supplied to the fire seat usually evaporates into the atmosphere with the combustion products. Therefore, due to the large heat removal from the fire seat the supplied refrigerants (usually water or water solutions) rapidly cool burning substance. Phase transitions of the refrigerant used such as water evaporation take away heat particularly efficiently. The resulting vapor is then condensed in the upper atmosphere, warming the surrounding air.

In underground conditions in the refrigerant heated in the fire seat is distributed in the cluster of coal and rock, transferring its heat to them. The vapor formed from water also condenses in the worked-our space heating it. The result of such suppression is the redistribution of heat produced during the coal combustion and concentrated in a small size fire seat, throughout much more spacious worked-out area in which the refrigerant movement occurred. In such circumstances, the cooling efficiency is determined mainly by the initial temperature of the supplied refrigerant and its specific heat capacity.

For rapid elimination of underground fire seat, the refrigerants allowing absorbing the maximum amount of heat from the heated cluster should be used. For this

purpose it is necessary to apply the substances, in which the phase transitions with the heat absorption occur at relatively low temperatures. Taking into consideration that that endogenous fire is considered to be extinguished when the coal temperature drops to 25 ° C, the phase transitions of the supplied refrigerant must occur at lower temperatures. Such refrigerants include liquefied gases such as nitrogen. However, the application of liquid nitrogen in the fire seat may cause an explosion due to its rapid evaporation.

One of the best refrigerants is water, which has the maximum value of the specific heat capacity and greater density. However, when applied in the worked-out area, water flows down the soil of the bed, without impacting on the fire. The compositions which allow treating the rubblized coal clusters are the most efficient for fire extinguishing in the worked-out spaces. Such refrigerants include inert gases, foam [1,2]. However, the inert gas has a slight density and specific heat capacity, that's why it requires a larger amount of gas and a longer time of its supplying to cool the heated coal. The disadvantage of foam is the small radius of its distribution in the worked-out area due to its rapid decay [3,4].

2.Characteristic of the work

The use of ice particles supplied into the stream of inert gas will enable to improve significantly the efficiency of extinguishing the burning coal clusters. This composition produces the spacious treatment of the worked-out area and the created inert atmosphere prevents coal oxidation and heat liberation. The range of transportation of the supplied ice particles in the gas stream will increase significantly compared with drops of liquid, and the cooling process will be improved through the additional removal of heat for heating the ice particles and their transition to the liquid state.

The amount of heat absorbed by the inert composition, consisting of gas and the particles of ice, moving through the heated coal, can be determined from the expression

$$Q = G_G c_G (t_1 - t_0) + G_W c_L (t_T - t_0) + G_W c_W (t_1 - t_T) + G_W r, \qquad (1)$$

where G_G - the consumption of the refrigerant passing through the coal cluster, kg/s; c_G - inert gas specific heat, Joules / (kg K); G_W - the water consumption to form ice particles, kg/s; c_L , c_W - the specific heat of ice particles and water respectively, J / (kg K); t_1 - the temperature of composition passed through the coal cluster, K; t_0 - the temperature of composition supplied to the coal cluster, K; t_T - temperature of transition of ice to the liquid state, K; r - specific heat of phase transition of the liquid to the solid state, Joules/kg.

Analysis of equation (1) shows that the efficiency of the refrigerant used for fire extinguishing, increases with its initial temperature decrease, and also with its density, specific heat and transition phase heat increase. To decrease the initial temperature of the inert composition, the co-spraying of nitrogen and liquid water is done, which leads to the heat exchange between the components and transfer of cryogenic liquid to the gas state, and the water particles to the solid state.

The studies conducted have shown that the properties of the inert composition, consisting of nitrogen and ice particles can be controlled within wide limits by changing the proportion of the initial components and their initial temperature. The ratio of the consumption of co-

sprayed liquid nitrogen and water to the parameters of the generated inert composition and source components can be described by the equation

$$\frac{G_A}{G_W} = \frac{c_W(t_W - t_T) + r + c_L(t_T - t_C)}{r_G + c_G(t_C - t_G)}, \qquad (2)$$

where G_A – is the consumption of liquid nitrogen for the inert composition, kg/s; t_W – the temperature of the water used for the inert composition K; t_C - the temperature of the resulting inert composition, K; t_G – the evaporation temperature of liquid nitrogen, K; r_G – latent heat of liquid nitrogen vaporization, J/kg.

Calculated from the formula (2) the parameters of the inert composition of -195° C temperature, obtained by mixing of water with different initial temperatures and liquid nitrogen are shown in Table 1.

Table 1: Parameters of the inert composition of -195° C temperature, obtained by mixing of water and liquid nitrogen

The initial water temperture, °C	The ratio of nitrogen consumption to water (G_G/G_W)	The mass of the water supplied for 1 kg of nitrogen, kg/kg	The mass ratio of ice particles in the composition, %	Heat capacity of the composition, kJ/(kg·K)
0	3,72	0,269	21,2	1,23
20	4,15	0,24	19,4	1,21
40	4,57	0,22	18,0	1,20
60	5,00	0,20	16,6	1,18
80	5,42	0,18	15,6	1,17
100	5,85	0,171	14,6	1,16

In the case of the inert composition temperature increase the consumption of water required for the gasification of liquid nitrogen increases. Parameters of inert composition having a temperature - 100 °C are shown in Table. 2.

Table 2: Parameters of the inert composition of -100° C temperature, obtained by mixing of water and liquid nitrogen

The initial water temperture, °C	The ratio of nitrogen consumption to water (G_G/G_W)	The mass of the water supplied for 1 kg of nitrogen, kg/kg	The mass ratio of ice particles in the composition, %	Heat capacity of the composition, kJ/(kg·K)
0	1,820	0,549	35,5	1,39
20	2,105	0,475	32,2	1,35
40	2,398	0,418	29,5	1.32
60	2,680	0,373	27,2	1.30
80	2,960	0,337	25,2	1.28
100	3,250	0,307	23,5	1,26

The data show that the temperature of the refrigerant being increased, the mass ratio of ice particles in the composition and its specific heat capacity also increases. When the temperature of the used water is increasing, the mass ratio of ice par ticles in the composition and their heat capacity decrease. The calculations showed that the inert composition comprising gas-borne ice particles cools the heated coal efficiently compared with the inert gas (nitrogen) or even the foam.

Thus, for 1 kg of coal cooling from 200 °C to 25 °C more than 15 m^3 of inert gas with the initial temperature of 15° C is required. The same effect can be achieved using 0.83 m^3 of foam with expansion rate of 200 or 0,32 m^3 of the inert composition consisting of nitrogen and ice particles with the initial temperature of -50° C. Fire extinguishing in underground mines with the inert composition is advisable after the gas survey carried out on the surface [5], to determine the location of the fire seat.

The modification of chemical reactivity of coal after its exposure to the refrigerant influences significantly impact on the efficiency of fighting the endogenous fires in the worked-out spaces. Increasing or maintaining the initial reactivity of the treated cluster promotes the intensive coal oxidation by atmospheric oxygen and the development of spontaneous combustion. Therefore, to avoid recurrence of endogenous fires, it is necessary to evaluate the effect of each refrigerant on the chemical activity of the treated coal.

One of the most important factors affecting the development of spontaneous coal combustion process is the temperature of the cluster[6]. Given that the used inert compositions may significantly reduce the temperature of the treated coal cluster, the study of coal reactivity at different temperatures was conducted. The results of the experiments are shown in Table 3.

Table 3:Modifications of coal reactivity under refrigeration

Coal temperature, ^{0}C	Specific sorption rate, cm^3/(g·h)			
	Time from the beginning of sorption, h			
	24	65	148	252
20	0,0625	0,0416	0,0216	0,0109
7	0,0268	0,0173	0,0112	0,0069
3	0,0127	0,0074	0,0043	0,0037
0	0,0079	0,0039	0,0021	0,0017
-5	0,0058	0,0026	0,0015	0,0011
-10	0,0044	0,0021	0,0009	0,0007

Analyzing these data, we can conclude that the cooling effect of inert compounds can significantly reduce the reactivity of coal, which will prevent the recurrence of spontaneous combustion process.

The studies in of the influence of gaseous nitrogen and liquid phase of inert compounds formed after the ice melting and settling of ice particles on the surface of the coal were conducted at the next stage of experiments. The samples of the crushed coal prior to placing it in the sorption vessel were purged with pure nitrogen and nitrogen with the atomized water particles. Simultaneously the untreated coal was studied. The results are shown in Table. 4.

Table 4: Modifications of coal reactivity after treatment

Mode of coal treatment	Specific sorption rate, cm^3/(g·h)			
	Time from the beginning of sorption, h			
	24	65	148	252
Untreated	0,0563	0,0324	0,0175	0,0092
Treated with nitrogen with water particles	0,0356	0,0263	0,0131	0,0063
Treated with gaseous nitrogen	0,0598	0,0352	0,0183	0,0105

The studies conducted have shown that the water particles deposited on the surface of coal after the inert composition supplying produce antipyrogenous effect on the coal. Thus, the reactivity of not oxidized coal was decreased by 1.58 times. The coal being oxidized, the antipyrogenous effect of its treatment with water decreases. The treatment only with the gaseous nitrogen resulted in a slight increase in chemical reactivity of the coal. This effect can be explained by removal of oxygen physically adsorbed onto the coal surface by the nitrogen flow. Therefore, after the restoration of air flow the coal begins to absorb the oxygen more intensely.

3.Conclusion

Thus, studies have shown that the combined liquid nitrogen and water or water steam spraying allows obtaining the inert composition, comparable in its cooling effect to the medium expansion foam. The use of the compositions consisting of inert gas-borne ice particles can significantly reduce the time of extinguishing of spontaneous combustion occurring in the worked-out areas of mines. The inert compositions may also be used as antipyrogens to prevent spontaneous combustion of coal, and recurrence of fires after their extinguishing.

4.References

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