THE INFLUENCE OF PHYSICO-CHEMICAL AND ENVIRONMENTAL FACTORS ON THE EXPLOSIBILITY OF COAL DUST AND PREVENTION MEASURES

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Abstract

The explosiveness of coal dust is a complex process determined by the action of physicochemical and environmental factors. Among the most important physical factors are the particle size distribution and dust concentration in the air, where finer particles and an optimal concentration significantly increase the risk of explosion. The chemical composition, especially the content of volatile matter, directly affects flammability and combustion intensity, while the presence of inert substances reduces explosiveness by absorbing heat.

Environmental factors, such as the presence of methane, oxygen content, temperature, pressure, and ventilation, play a key role in the initiation and propagation of an explosion. Methane is particularly dangerous because it can act as an initial trigger of an explosion. Moisture in dust generally reduces explosiveness, but under certain conditions it may contribute to its intensity.

Preventive measures include controlling the concentration of dust and gases, effective ventilation, the use of inert dust, maintaining optimal humidity, and eliminating ignition sources. Through systematic implementation of these measures, it is possible to significantly reduce the risk and consequences of explosions in mines.

1. INTRODUCTION

A coal dust explosion means the rapid burning of a cloud of coal dust in the air in a confined or partially confined space. A coal dust explosion is accompanied by the release of a large amount of heat, a sudden increase in the volume of gases and the development of high pressures.

The coal dust ignition explosion process can be divided into three parts:

ignition of coal dust,

coal dust explosion process, i.e. its development and

phenomena accompanying the explosion of coal dust.

2. COAL DUST EXPLOSION AND INFLUENTIAL FACTORS

2.1. Coal dust ignition

For the ignition of coal dust, the main role is played by the separation and ignition of volatile constituents. Volatile substances are released from the coal particles under the thermal effect of the coal dust cloud explosion.

The mixture of volatile substances with air is explosive and easily flammable. By burning volatile substances, the flame is transferred to smaller and then to larger particles of coal dust [4].

The amount of volatile substances released from coal dust, as well as the burning time, depends on the degree of pulverization of the coal dust. It has been scientifically proven that dust, with a grain size of up to 0.5 mm, participates in the explosion.

Depending on the type of coal dust and the conditions of the explosion, the quantities of gas products of the explosion are different.

Analysis of a large number of gas composition samples after a coal dust explosion determined the following situation:

maximum carbon monoxide content of up to 10,8 %;

carbon dioxide content up to a maximum of 15,0 %;

maximum hydrogen content up to 3,7 %;

minimum oxygen content 0,1 % [5].

2.2. Coal dust explosion transmission

In the explosion zone, the air density is higher than in the air that is not included in the explosion. During a coal dust explosion, static pressures occur. Pressure in a coal dust explosion plays one of the main roles both at the beginning of the explosion and during its course. In a coal dust explosion, the pressure increase is related to the speed of the shock wave. Shock wave velocity, pressure rise and temperature, are directly proportional values.

By moving through the pit room, the shock wave raises (swirls) the deposited coal dust, partially moves it in the direction of the explosion flow and thus causes more dust in the explosion zone.

The pressure developed by the cause (initial) of the explosion must be at least 1 kN/m² (0,01 bar) in order for the deposited coal dust in the vicinity of the initial explosion to swirl and create a cloud of sufficient concentration for the explosion. Such a low pressure can only swirl fine and dry dust with convenient distribution in the mining room.

An increase in pressure in an environment increases the temperature. In the case of a coal dust explosion, the increase in pressure is related to the speed of the shock wave.

Under conditions of normal atmospheric pressure, coal dust is not capable of explosion.

2.3. Phenomena accompanying the explosion of coal dust

During the explosion, the flame front, which moves through the mining room, is preceded by a shock wave that causes an increase in the heat of the gas environment. The total heat of the explosion depends on the speed of the shock wave, and the speed of the shock wave depends on the speed of the flame. The total heat of the coal dust explosion represents the sum of the heat of combustion from separated volatiles (about 22

% of the total volatiles burn), the heat of combustion of coal dust (about 20% of the total dust present burns) and the heat generated due to the increase in the density of the environment [1].

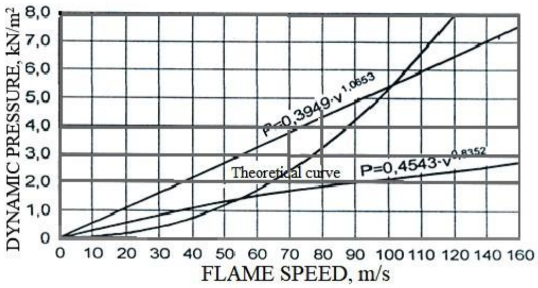

Figure 1. Dependence of dynamic pressure on flame speed of very weak coal dust explosions - Source 1

A coal dust explosion can be divided into three characteristic phases:

The first phase of the explosion is characterized by the fact that the explosion is initiated in one place. A coal dust explosion is most often initiated by ignition or explosion of methane or by unprofessional use of explosives [5].

In the second phase of the coal dust explosion, the flame covers the entire profile of the mining room.

The third phase of a coal dust explosion is the phase in which the explosion is the strongest and when the explosion can turn into detonation. In this phase, the speed of the flame and the shock wave are the same and can reach 2000 m/s.

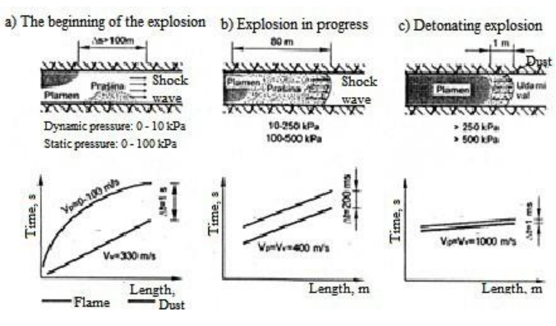

Figure 2. Elements of coal dust explosion flow

2.4. Conditions for explosion of coal dust

In order for a coal dust explosion to occur, the following conditions must be met:

there must be a sufficient amount of explosive coal dust,

coal dust must be dispersed in the air, must be stirred up,

air mixed with dust must have sufficient oxygen content and

there must be a strong enough initial to initiate the coal dust explosion process.

All four mentioned conditions must occur at the same time, which at first glance may lead to the conclusion that coal dust explosion is unlikely to occur.

However, practice has shown that coal dust explosions can easily occur. If there is a concentration of explosive coal dust in the mining room above the lower explosive limit, it is enough to cause a local explosion of methane or blasting with open stick mines, which could result in an explosion of coal dust [1].

The methane explosion will swirl up the deposited coal dust and its heat energy transfer to the surface and thus start the explosion of coal dust. This assumption does not mention the condition of sufficient oxygen content. It is only a theoretical and formal assumption because it is known that in all active mining premises there must be good quality pit air.

2.5. The influence of the chemical composition of coal dust

An explosion of coal dust can occur if its concentration is between the lower and upper explosive limits.

The strength of the explosion, among other things, also depends on the amount of coal dust in the explosive mixture with air. The strongest explosion occurs at a concentration of 111,4 g/m³ of dust, provided that all the dust is burned. Since only up to 20 % of dust participates in the explosion, the stoichiometric concentration of dust increases several times and ranges around 500 g/m³.

It has been proven that volatiles, with their presence, play the biggest, perhaps even decisive, role in the creation of an explosion.

In the coal dust explosion process, the volatiles, which are separated from the coal dust under the influence of high temperature, are the first to take over the burning.

After the volatiles, chemical substances (resins) are burned, which are separated from the dust through the pyrolysis process. After the volatiles and resin, first the finer and then the larger fractions of dust are burned.

The participation of individual gas components in the volatiles is different, and to the greatest extent depends on the type of coal dust, physical and chemical properties and conditions that cause the release of volatiles.

Based on the aforementioned facts, regulations were adopted according to which coal dust containing less than 14 % of volatiles is considered explosively harmless [5].

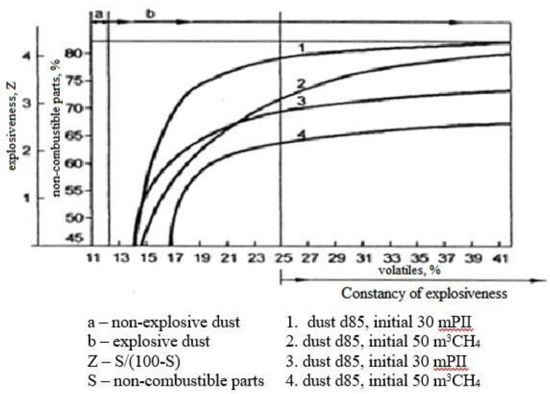

Figure 3. Dependence of coal dust explosion (z) on volatile content (V)

If coal dust contains more than 14% volatile dust, it is considered explosively dangerous, so according to the Regulations, further tests of other explosive characteristics must be carried out.

The percentage content of volatiles in coal dust depends on the age of the coal, that is, on the degree of carbonization. In younger coals with a lower degree of carbonation and lower caloric values, the content of volatiles is higher and vice versa. From these facts it follows that the coal dust of younger coals of Pliocene and Oligomiocene age is more explosive from the point of view of the influence of volatiles.

2.6. Effect of moisture in coal dust

The presence of moisture in coal dust reduces its explosiveness. The moisture content affects the reduction of the heat balance of the system, in addition, it supports the coagulation of small particles. As a result, the particles stick together, that is, the formation of larger dust [1].

If the air contains a large amount of moisture, the accumulated dust absorbs it. Moist coal dust is more difficult to swirl, which makes it difficult to create dust clouds.

In addition, it is more difficult to ignite, since it needs to dry first, and for that a certain amount of heat and time is needed. According to the orientation data, the average values of the moisture content in the dust of our coals of different ages are as follows:

coal dust contains 1 to 3 % moisture, brown

coal dust contains 4 to 5 % moisture,

lignite coal dust contains 10 to 25 % moisture [1].

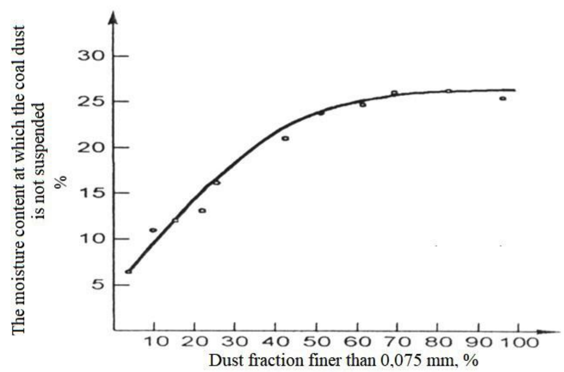

Figure 4. Coal dust buoyancy indicator depending on the content of the granulometric composition of the dust

It has been proven that dust with a higher moisture content can participate in an explosion and that such explosions are more powerful than an explosion with dry coal dust.

This phenomenon is explained by the fact that moisture in coal dust under the influence of high temperature creates highly explosive H2 and CO gases that accelerate the explosion.

2.7. The influence of the content of solid non-combustible particles in coal dust

The presence of solid non-combustible particles in coal dust reduces its explosiveness. The action of solid particles in preventing an explosion is based on the removal of heat, and their presence in the explosive environment shields the particles of coal dust from the heat of the radiation of the initials of the explosion [7].

For this reason, rock dust has found wide application as a means of preventing coal dust explosions. Stone dust was widely used in the construction of dams to prevent the transfer of coal dust explosions. Dust is considered non-explosive if its composition contains 70% of solid non-combustible particles in non-methane pits, or 80 % in methane pits [7].

2.8. The influence of the granulometric composition of dust

The fineness of coal dust is indicated by the specific surface area (cm^2/g). In order to determine as accurately as possible the amount of fine - very fine coal dust, which has a great impact in the explosion process, an international unit was adopted that indicates the percentage of the dust fraction with a grain diameter smaller than 0,075 mm.

This value is denoted, for example, by d30, which means that in the coal dust sample there is 30% fraction smaller than 0,075 mm. Coal dust with a higher percentage of finer dust is more explosive than larger dust.

This is explained by the fact that finer dust has a larger specific surface area, and as such it separates volatiles to a greater extent in the phase of thermal action on the surface. For the same reasons, there is also the fact that the ignition of finer coal dust requires a weaker initial explosion.

Another disadvantage of finer dust is that it is more difficult to bond with moisture, i.e. more difficult to coagulate.

2.9. Effect of methane content

Methane, as the most common explosive gas in coal deposits, was created with the carbonization process of the deposit. With the increase in carbonization of coal, the content of volatiles decreases, and the content of methane increases. The presence of explosive gases in the explosive mixture of coal dust and air increases the explosiveness. In the largest cases of coal dust explosions, inflammation or methane explosion.

When the methane content in the pit air is less than the lower explosive limit (<4,5 % CH4) of methane, its presence helps in the transmission of coal dust explosion.

If the methane content in pit air is below the stoichiometric mixture (<9,5 % CH4), then methane increases the explosiveness of coal dust. With the increase in methane content above 9,5 % and up to the upper explosive limit of 14 %, the presence of methane continues to increase the explosiveness of coal dust, but with a decreasing effect.

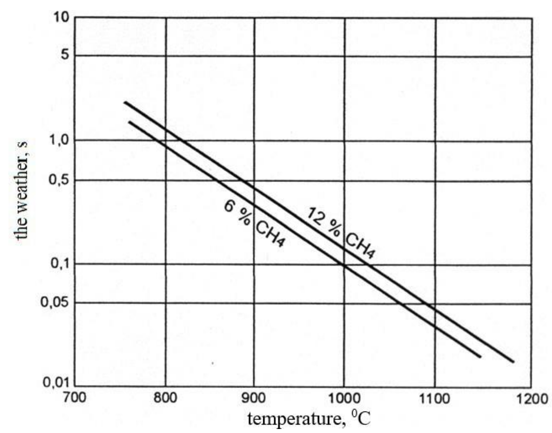

Figure 5. Dependence of methane ignition delay on initial temperature

2.10. The effect of coal dust ignition initials

The most common coal dust explosion initials are:

improper use of explosives,

methane explosion,

short circuit electric arc i

open flame.

The ignition temperature of deposited coal dust is always lower than the explosion temperature of coal dust. This is explained by the fact that the particles of deposited dust are very close to each other, so the transfer of heat from particle to particle is lossless. The burning rate of settled coal dust has less contact with air compared to suspended coal dust.

With the increase in the strength of the initial explosion, the lower limit of the explosiveness of coal dust decreases, the buoyancy of dust increases, the pressure in the explosion zone increases and thus the temperature of the environment, which also increases the explosiveness of coal dust. When the dust cloud comes into contact with the ignition source, which has a temperature of 300 to 400 °C, individual finer dust particles are ignited. When the initial temperature increases to 500 to 700 °C, the dust ignites with the appearance of a flame that quickly goes out, and when the temperature increases to 700 to 800 °C, the flame spreads throughout the cloud and an explosion occurs.

From the above, in some literature you can find different data for sparking, ignition and explosion temperatures of coal dust. These sizes are not constant and depend on the type of dust, degree of dispersion and other characteristics.

3. WORKING ENVIRONMENT OF EXAMINATION OF INFLUENTIAL FACTORS

The research on the explosiveness of dust as a function of the content of inert matter and particle size was carried out on coals of Miocene age from the central Bosnian coal basin.

The main coal seam was selected for research. The selection of the main coal layer for research was made due to the intensity of mining operations in this layer, continuous development and economic interest (the most interesting for exploitation).

4. PREVENTIVE MEASURES FOR COAL DUST EXPLOSION PREVENTION

Mine safety represents one of the most critical aspects of mining production. Given the high hazard of coal dust explosions, numerous preventive measures have been developed to reduce risk and protect both workers and equipment [8].

One of the fundamental measures is the regular removal and control of dust deposits. Dust must be removed from surfaces or neutralized (bound) to prevent it from becoming airborne and forming an explosive mixture.

Dust wetting (spraying) is also a highly effective method. Adding water reduces the dispersibility of particles and their flammability. This method is frequently used in combination with ventilation [3].

Ventilation systems play a key role in maintaining safety. Proper ventilation reduces the concentration of dust and methane in mine workings, thereby directly decreasing the possibility of an explosion.

The application of inert (stone) dust is one of the most important protective measures. This dust is spread throughout the mine galleries to reduce the concentration of combustible coal dust and prevent the propagation of flames.

The control of ignition sources also plays a vital role. This includes:

Proper use of explosives

Use of intrinsically safe electrical equipment

Prohibition of open flames

Regular maintenance of installations

In addition, continuous monitoring of methane and dust concentrations using modern measuring devices is essential. In the event of elevated values, work must be suspended immediately.

Worker education and the implementation of safety procedures are also of crucial importance. Trained workers can recognize hazards in a timely manner and prevent the occurrence of an accident.

CONCLUSION

Evo prevoda vašeg teksta na engleski jezik, uz primjenu standardne naučne terminologije koja se koristi u rudarstvu i istraživanju eksplozivnosti:

Translation

Results of multi-year research on the explosive characteristics of coal samples and deposited brown coal dust from the main seam of the Central Bosnian Basin (Kakanj, Breza, Zenica), conducted under laboratory conditions, were used to determine the correlation between explosiveness, inert matter content, and particle size.

According to the explosiveness assessment parameter - the maximum rate of pressure rise - the dust from this coal seam falls into the category of highly explosive dust [2].

The study examined the influence of moisture, ash, volatile matter, and particle size distribution (median size and the content of particles smaller than 75 µm) on dust explosiveness.

The investigation into the effect of moisture on coal dust explosiveness was performed on dust prepared from the coal seam with a precisely defined particle size distribution and constant ash and volatile matter values. It was established that dust with lower moisture content is more explosive than dust with higher moisture content. The presence of moisture in coal dust reduces explosiveness; specifically, as moisture content increases, explosiveness decreases, and vice versa. Consequently, the risk of a coal dust explosion is greater during prolonged production halts, as the deposited dust dries out.

The investigation into the effect of ash on coal dust explosiveness was conducted on dust prepared from the coal seam with a precisely defined particle size distribution and constant moisture and volatile matter values. It was determined that dust with lower ash content is more explosive than dust with higher ash content, indicating that the presence of ash has a positive effect on reducing coal dust explosiveness. This fact necessitates the application of inert dust as a measure for preventing and localizing coal dust explosions in mines. The study of the dependence of explosive characteristics on the percentage of volatile matter showed a low regression coefficient, meaning their influence can be considered constant.

Dust explosiveness in relation to particle size distribution was tested on dust prepared from the coal seam, while moisture, ash, and volatile matter were kept constant. It was found that dust with a smaller median (finer particles) is more explosive than dust with a larger median, and that explosiveness increases with the rise in the proportion of particles smaller than 75 µm.

From the perspective of occupational health and safety, the research results highlight the need for the consistent application of preventive measures to reduce the risk of coal dust explosions in mining areas. Particular importance is placed on the control of moisture, particle size distribution, the use of inert materials, as well as the regular maintenance and cleaning of working areas.

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