AFFECTING THE ATMOSPHERE BY THE SPONTANEOUS COMBUSTION OF COAL IN STORAGE AREA

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Abstract: *Coal is one of the carbonaceous materials which, under certain conditions, can combust spontaneously as a result of its oxidation with atmospheric oxygen. Coal oxidation is an irreversible exothermic reaction and its rate increases with temperature. In mines or in storage, the deficiency of the heat dissipation capacity of the coal bulk with respect to its heat generation capacity can result in heat accumulation which subsequently leads to higher oxidation rates due to higher temperatures. This process, if not averted with appropriate action, results in the spontaneous combustion of the coal. The heat generation and dissipation capacities of a coal bulk depend on a number of factors. It is the outcome of the interactions between these factors that determines the occurence or nonoccurence of spontaneous combustion.*

INTRODUCTION

Spontaneous combustion of coal is a major problem in mining, transportation and coal related industries in general. Coals may combust spontaneously when the temperature in the coal mine or coal pile has reached such a level that the slow oxidation reaction between coal and oxygen turns into a combustion reaction.

The consequences of an outbreak of spontaneous combustion in mines or stockpiles cannot be understated. There are numerous reports, dating back to the 19th century, of extensive fires and lost lives resulting from spontaneous combustion of coals. Understanding, prevention and early detection of spontaneous combustion in coal mines and coal storage are of paramount importance in eliminating unintentional fires or, at least, minimizing the hazards to life and property in the case of an outbreak of fire.

1. Self-heating, autoignition and spontaneous combustion

Self-heating (spontaneous heating) and autoignition (selfignition or spontaneous ignition) are the precursors of spontaneous combustion. All coals self-heat to some extent, both in mines and storage; but only if the conditions are favourable they may autoignite. And, again under favourable conditions, they may combust in an uncontrolled manner. The results of the field study conducted by Bouwman and Freriks [2] on self-heating in a coal pile are shown in Figure 1.

Spontaneous combustion of coals is the result of the complex phenomena associated with the atmospheric oxidation of coals. This low temperature reaction may occur in mines, during mining or postmining stages whenever the coal is exposed to oxygen. It is an exothermic reaction and its rate increases with temperature [6]. If the heat generated by coal oxidation is not dissipated at the same rate, heat is accumulated in the mine/seam, or the pile, and the temperature increases. With higher temperatures the rate of the reaction and, therefore, the rate of heat generation increases. In such cases, when the ignition temperature of the coal is reached, the coal autoignites.

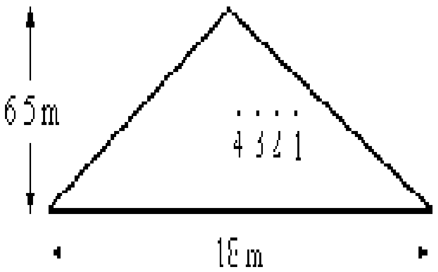

Figure 1. Self-heating in a coal pile. Temperature readings after 10 months of storage: point 1 (1 m) – 43 C; point 2 (2 m) – 67 C; point 3 (3 m) - 78 C; point4 (4m) - 79 C.

Since heat generation in coal mines or stockpiles is the thermal outcome of the oxidation process, the factors that affect the rate of heat generation are those that affect the rate of the oxidation process.

2. Low temperature coal oxidation

The reaction takes place between the oxygen-reactive sites in the coal material and molecular oxygen in the surrounding atmosphere under ambient conditions. The products are CO, CO_2 and H_2O and oxygen-containing functional groups in the coal material. The chemical mechanisms generally proposed for coal oxidation include the following sequence of free radical reactions [12]:

$$RH + O_2 \rightarrow R\cdot + HOO\cdot$$
$$R\cdot + O_2 \rightarrow ROO\cdot$$
$$ROO\cdot + RH \rightarrow ROOR + H\cdot$$
$$ROO\cdot + RH \rightarrow ROOH + R\cdot$$
$$ROOR \rightarrow 2RO\cdot$$
$$ROOH \rightarrow RO\cdot + \cdot OH$$
$$HOO\cdot + H\cdot \rightarrow HOOH$$
$$HOOH \rightarrow 2HO\cdot$$
$$RO\cdot \rightarrow products$$
$$HO\cdot \rightarrow products$$
$$coal + O_2 \rightarrow oxidant\ coal + CO + CO_2 + H_2O$$

Since coal consists of various types of organic structures with different reactivities towards oxygen, new types of reactions emerge as the temperature increases. Decarboxylation reactions gain significance around 80 C generating additional heat due to their exothermic nature.

Figure 2 illustrates the change in the self-heating rates of five Jiu Valley coal samples. Below 80 C, the rate of self-heating hardly changes, but at arround 80 C a rapid increase is observed.

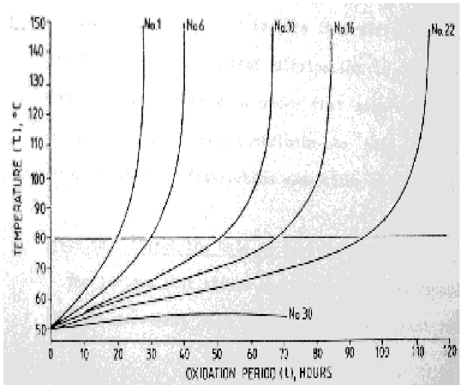

Fig.2. Typical self-heating curves of coal

3. Factors affecting the autoignition tendence of coals

The rate of coal oxidation is very low under ambient conditions. It is possible for the reaction to continue for a long time if no autoignition occurs, until it reaches its natural limits as determined by the reaction mechanism shown in the previous section.

Wether or not the ambient oxidation of a coal results in autoignition and spontaneous combustion, depends on the relative rates of heat generation and heat dissipation in the given location.

There are a number of factors that affect the rates of heat generation and heat dissipation in a coal-air system. Studies have also shown that sorption between coal and moisture can contribute to both the heat generation and heat dissipation capacities of the coal.

3.1. Factors that affect the rate of heat generation

The factors that affect the heat generation capacity of a coal are those that affect its oxygen reactivity:

Coal rank. Oxygen reactivity of coal degreases with rank. This emanates from fact that the amount of oxygen reactive sites in the coal material decreases as rank increases.

Temperature. Rate of coal oxydation increases with temperature. Also, additional exothermic reactions start taking place as temperature increases thus increasing tha rate of heat generation further.

Oxygen pressure. Observations on the relationship between oxidation rate and oxygen partial pressure reveal that oxidation rate increases with oxygen partial pressure.

Extent of previous oxidation. The relationship between the rate of oxidation and time varies with coal type, temperature and duration of observation. It is for this reason that a number of different models have been developed describe the coal oxidation process. However, observations generally show that oxidation rate decreases with extent of oxidation, especially in the initial stages.

Particle size. It is widely reported that the rate of coal oxidation increases with decreasing particle size. However, the effects of particle size may depend on the porosity of the coal, with highly porous coals, the size of the coal particles may not affect the rate of the process in the size range where less porous coals are affected.

Minerals. The effect of minerals on the oxygen reactivity of coals depends on the type and form of the minerals in the coal. The catalytic effect of cations as salts of coal acids is widely reported.

3.2. Factors that affect the rate of heat dissipation

Heat is dissipated from the hot parts of the coal either by conduction through the coal-air mass or by convection due to the circulation of air. The factors that affect the rate of heat dissipation are therefore the thermal conductivity of the seam, or the pile, and its receptiveness to air circulation.

Thermal conductivity. Heat is carried away from the hot parts of the seam/pile by conduction through the coal-air-water mass. The amount of heat that can be conducted depends on the overall conductivity of the seam/pile. The overall conductivity of the seam/pile is determined by the thermal conductivities of the individual constituents, i.e. coal, air and water, and their overall geometry.

Receptiveness of the seam/pile to air circulation. Convection is another way of heat dissipation from a hot spot. Depending on the amount of air circulating through the mine/seam/pile, the generated heat can be transferred out of the hot zone by convection.

It should be noted that the amount of air circulating within the zone, as determi-ned by the geometry of the zone, also determines the prevailing oxygen partial pressure. And, the partial pressure of oxygen has a direct effect on the heat generation rate.

3.3. Effects of coal moisture and atmospheric humidity

The sorption process between coal and water is a physycally reversible process with thermal effects. Adsorption of moisture by coal is exothermic whereas desorption is endothermic. Comprehensive investigations on the subject reveal the following:

The observed self-heating of a coal can be solely attributed to the oxidation of the coal only if an equilibrium exists between the humidity of the surrounding and moisture in the coal.

When there is an increase in the humidity of the air relative to the vapour pressure exerted by the coal moisture, the generation of heat during oxidation increases due to the simultaneous sorption of water by the coal.

When there is a decrease in the humidity of air relative to the vapour pressure exerted by the coal moisture, water desorbs from the coal utilizing the heat produced by the oxydation of the coal. The subsequent result is a coal temperature lower than it would have been if all the heat released by the coal oxidation were utilized for self-heating.

These findings reveal that the effects of coal moisture and atmospheric humidity cannot be divorced from one another. They interact and the thermal outcome of this interaction may promote or retard seld-heating of the coal.

4. Prevention and control of spontaneous combustion

The dominating view in the coal industry regarding the problem of spontaneous combustion is that “prevention is better than cure”. Prevention is closely related to the physical/chemical characteristics of the mine/stockpile, the mining technology employed and stockpile design. Monitoring of critical parameters like gas composition and temperature, in the mine or the pile, is another method of prevention.

4.1. Safe mining and storage

The principle that applies in all recommended methods of prevention is to control the heat generating and heat dissipating factors so as to reduce the rate of heat generation and to increase the rate of heat dissipation. Air flow into the mine should be controlled at a level and pattern that minimizes coal oxidation but allows heat transfer out of the mine.

Partial extraction which leaves part of the coal seam in the goaf should be avoided.

The design of the pillars should be such that they do not promote self-heating in the seams. The electric equipment used should be flame proof.

Air flow into the mined out areas should be prevented. Gateroad side fillings and foams should be used where necessary.

The safety recommendations made with regard to stockpile (stockyard/ transportation) design and management are:

Storage area should be level, firm, well drained and free of easily burning material.

The long axis of the stockpile should be oriented in the direction of the prevailing winds. Height of the pile should be kept to a minimum because:

- the effective resistance to heat flow is lower;
- size segregation is less;
- it is easier to remove hot spots when they occur.

Size segregation should be avoided since zones of coarse coal act as chimneys for conducting air into the pile. Stockpiles should therefore be well consolidated by compacting after each addition of about a meter thick layer of coal. The outer surface of the pile sould also be compacted.

Top of the pile should be levelled since size segregation is promoted in conical stockpiles. Preferably coal should not be piled in hot weather.

Coals from different sources should not be piled together. Wet coals should not be piled with dry coals.

In the case of very reactive coals, it may be necessary to use protective coatings or inhibitors.

The electric equipment used should definetely be flame proof.

4.2. Monitoring and early detection of spontaneous combustion

Despite all the care that might have been taken during mining and stockpiling, reactive seams and stockpiles need to be monitored continually in order to avert fire dangers promptly and effectively. The two widely used monitoring methods are gas analysis and temperature measurement.

Monitoring of gases. The gaseous products of oxidation, and therefore of self-heating, at the very early stages are CO, CO_2 and H_2O. Methane, hydrogen and other light hydrocarbons are released as the temperature rises and other heat generating reactions start off. It has been found that monitoring the levels of CO in the coal atmosphere is the most effective way of detecting signs of spontaneous combustion at an early stage. The ratio of carbon monoxide concentration to oxygen deficiency (CO/O_2 deficiency) in the mine atmosphere, Graham's Index, has become the most widely used indicator of the occurrence of spontaneous combustion.

Monitoring of temperature. Since rising temperature are signs of self-heating, temperature monitoring is widely used in the detection of hot zones at or below the surface in mines or stockpiles. Infra-red detectors are found to be most suitable in the measurement of surface temperatures. In the subsurface measurements, temperature probes are generally used. These probes are basically a thermocuple mounted in a sturdy external case with appropriate geometry to allow the intimate contact of the coal with the sensor.

CONCLUSIONS

Coal may combust spontaneously in mines or in storage when and if the rate of heat generation exceeds the rate of heat dissipation. In order to avoid spontaneous combustion of coals, the principle of minimizing the heat generationa and maximizing the heat dissipation capacities of the coal bulk should be applied in all stages of mining, handling, transporting and stockpiling of coals.

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