A Theory on the Mechanism of an Outbreak of Spontaneous Combustion of Coal

Its application to precautions against and preventive measures of spontaneous combustion:

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Contents

I. Introduction

"A theory of an outbreak of spontaneous combustion"[1),2)] has already been published following a quantitative study of causal factors of spontaneous combustion. These studies are concerned with the rise in temperature accompanied by oxygen absorption from the air.

In this paper the results of new developements of the theory are reported. Here an application of the theory as a preventive measure of spontaneous combustion of coal was made.

Generally when the causes are unknown, preventive steps can not be taken. However, records of outbreaks of spontaneous combustion incidents provide clues to various causes based on which various countermeasures have been made. In other words, we have various countermeasures based on experience. However no scientific or systematic studies are available. Thus, an investigations was made with our theory and the causal factors were explained quantitatively. It was shown that the present theory was applicable to on the site cases.

II. Causes of Spontaneous Combustion

When coal is exposed to air, a gradual absorption of oxygen occurs and the

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temperature rises ; 1 cc of the absorbed oxygen generates 4.4 cal. in the case of Ôyûbari lower coal. Usually in such a case the heat is conducted to the adjacent layer of coal or rock, and it is dissipated and cooled by the air. However, if the coal is fresh and there is not an adequate current of air to cool the generated heat, the heat is accumulated and the temperature rises.

(1) **The relation between the rate of oxidation and time**

The relation among the rates of oxidation and the quantity of the absorbed oxygen and the resulting temperature rise, of Ôyûbari coal, are shown in Fig. 1. In the figure maximal accumulation of the generated heat and the maximal heat dissipation are seen.

When the oxidation at P produces no rise of heat, we have the straight line PR. When the heat is accumulated maximally, the temperature rises and the oxidation may be plotted as curve PQ. In other words, the reaction at an optional point P is the oxidation and the heat generation progressing rightward within QPR. But actually the first rise of the heat appears at lower temperatures than that of Fig. 1, which is explained in "a theory of an outbreak of spontaneous combustion."

According to Fig. 1 a step-wise rise of heat of 25°C corresponds to a two fold oxidation of coal. The rate of the oxidation decreases according to the lapse

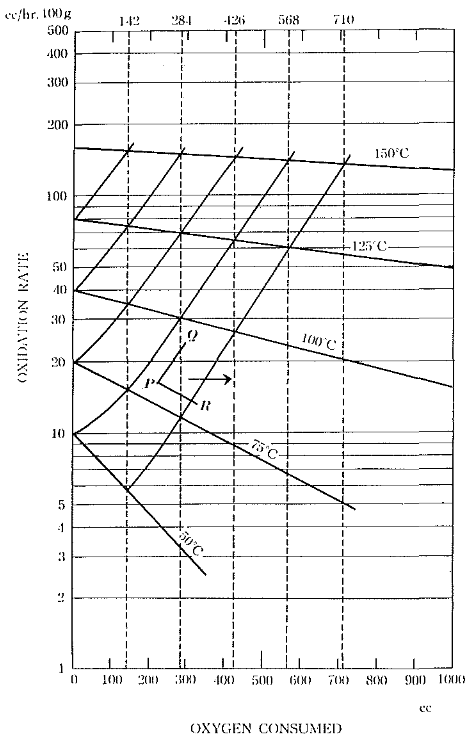

Fig. 1. The theory of an outbreak of spontaneous combustion of coal, size 20–28 mesh.

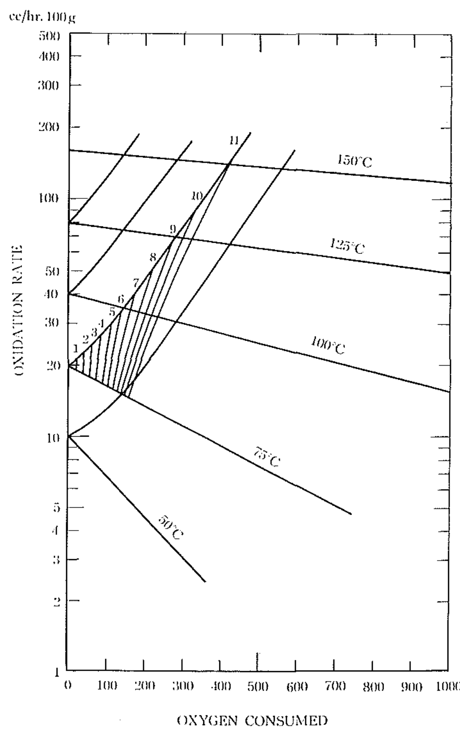

Fig. 2. Oxidation time from start vs. oxidation rate and oxygen consumed.

of the oxidation time when the calories generated by the oxidation of coal are dispersed completely and the oxidation occurs under the same temperature as shown in the curve of perfect dissipation of heat.

Fig. 1, in which the quantity of the oxygen absorption is shown on the abscissa, shows that the coal retains its freshness and the oxidation rate shows no changes with the lapse of time provided that no oxygen absorption occurs. The relation between the oxidation time and the oxidation rate during the absorption of oxygen in the air is shown in Fig. 2. It shows that the quantity of the absorption of oxygen varies according to the accumulation or dissipation of heat.

(2) The relation between the oxidation rate and the rate of the rise of temperature

Fig. 1 shows:

$$\text{Rate of temperature rise} = \frac{\text{rate of heat generation} - \text{rate of heat dissipation}}{\text{weight of materials} \times \text{specific heat}}$$

and in the case of the perfect accumulation of heat.

Rate of temperature rise

$$= \frac{\text{generated calories per unit of oxygen consumed} \times \text{rate of oxidation}}{\text{weight of materials} \times \text{specific heat}}$$

In other words the rate of temperature rise in one hour in the case of Ôyûbari coal is:

Rate of temperature rise

$$= \frac{4.4 \times \text{rate of oxidation}}{100 \times 0.25}$$

Fig. 3 shows the rate of temperature rise according to the corresponding temperature of coal when the generated heat by the oxidation of coal is not dissipated and is totally accumulated. The 20～28 mesh and the 65～100 mesh of the curves were obtained from the theory of the generation of spontaneous combustion, and the solid line shows the measured values.

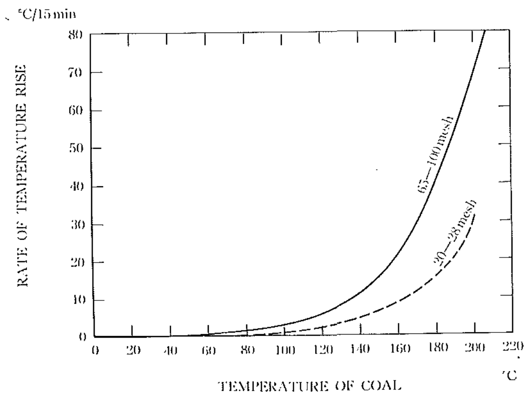

Fig. 3. Rate of temperature rise.

(3) The relation between the rate of oxidation and the rate of the size

According to our previous report the rate of oxidation of coal at the beginning is in proportion to the total surface area of the particles of coal, as shown in Fig. 4. It shows the relation between the rate of oxidation of coal grains with a diameter of 0.2 cm each, 20～28 mesh and 35～48 mesh, at 75°C and the absorbed quantity of oxygen. It also shows the grain size and the temperature, and that the coal with a diameter of 0.2 cm at 7.5°C has a lower rate of oxidation than that of 20～28 mesh at 50°C or 35～48 mesh at 25°C.

The cause of spontaneous combustion in a coal pit is more strongly related to the grain size than to the underground temperature. Normal measurements for a larger part of the pit show 25°C and sites which give measurements of 50°C are rare. When the temperature rises by 25°C or the diameter of a grain becomes half, the oxidation rate is doubled. Readily pulverized coal shows a higher rate of spontaneous combustion.

(4) The relation between the oxidation rate and the density of oxygen

The decrease of the oxidation rate of coal, as a result of the reduction of the density of oxygen, is numerically shown by multiplying the coefficient of the density of oxygen in the atmosphere. Fig. 5 shows the relation between the coefficient p and the density of exhausted oxygen.

The density of oxygen is related to the exposure time and the temperature of coal in the air. The exposure time has a definite relation to the speed of the air current, the air leakage, the length of contact passages and the quantity of remaining coal.

Since the density of oxygen is greatly affected by temperature, sometimes the area behind a high temperature generation point is heated and the temperature rises high without oxidation —here the coal seems to have a high potentiality of oxidation. In this case, however, the rising speed of the temperature does not go beyond the scope of the curves of total heat accumulation without a fresh supply of air as introduced by excavation or a change of air passages.

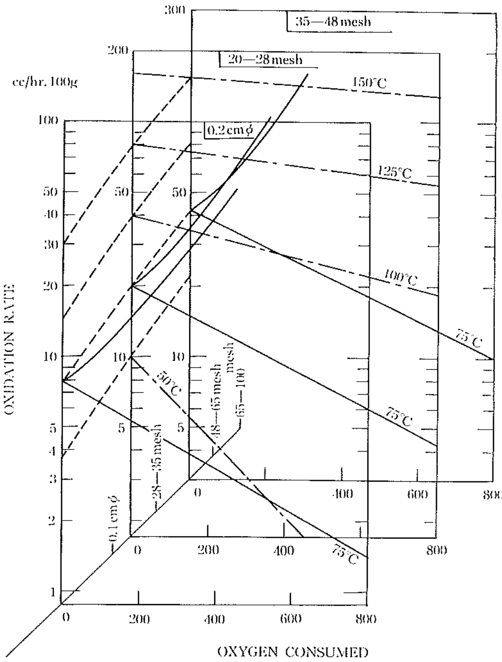

Fig. 4. Particle size of coal vs. oxidation rate and oxygen consumed.

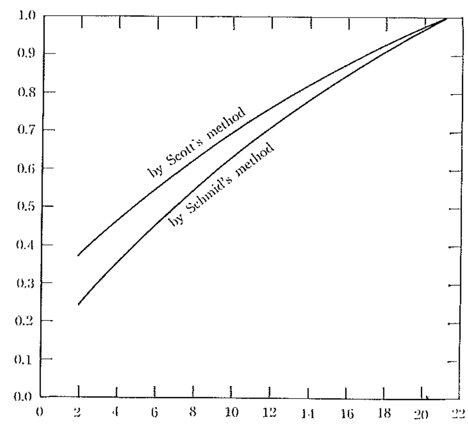

Fig. 5. Relation between effective oxygen concentration in contact with coal and oxygen concentration in effluent gases when entering gases contain 20.93 percent oxygen.

III. The Relation between the Causes of Spontaneous Combustion and Preventive Measures

It is generally accepted that causes of spontaneous combustion are numerous. For example, moistened coal is reported to have a tendency to lead to spontaneous combustion. However no direct evidence has been provided to indicate that moistened coal tends to generate heat by oxidation. It is known on the other hand that a considerable amount of water is released in the course of oxidation and generation of heat. This water flows to the exhaustive side of the air in the area of oxidation and generation of heat. Part of this water is cooled into ordinary visible water. In this case, moistened coal is not a cause but rather a result of generation of heat.

Props in the pit are said to be a cause of spontaneous combustion. The props support the roof locally, and the crushed coal at the base is severely compressed. Where there is a subsidence of the roof, the rate of the voids among the compressed coal grains is small, and where there is no subsidence, it is large. In other words, props provide pathways of air leakage. Consequently the coal near props is locally oxidized and generates heat, and at times props are scorched black, though at other places the temperature rises first. Thus it may not be said that the cause of combustion can be found by comparing the ignition temperatures of wood and coal.

In the present work the quality of coal was found to be one of the causes of spontaneous combustion, which is related to the liability of spontaneous combustion of coal. According to the results of the experiment, the oxidation rate of a different types of bituminous coal seldom shows values higher than twice as that of other types of coal. However, in the case of the same type of coal, fresh coal shows a far greater oxidation rate than that which has absorbed oxygen. Therefore a comparison of the oxidation rate between two different types of coal used in an experiment while presenting evidence as to their readiness or difficulty to lead to spontaneous combustion does not provide a basis for practical preventive methods.

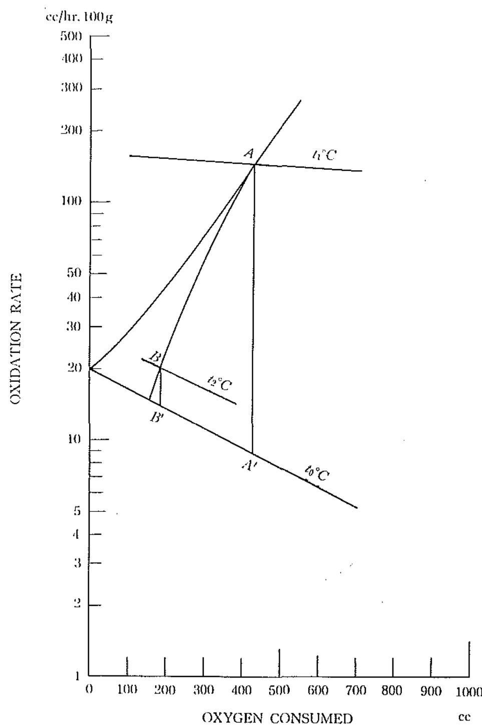

Fig. 6. Relation between high temperature, cooling and oxidation of coal.
(If high temperature coal will be cooled, it does not rapidly heating.)

Moreover, it was clearly shown that the oxidation rate of coal is definitely related to the rate of its freshness and the quantity of oxygen absorbed. Thus it may be said that coal which absorbs oxygen from the air under higher temperature absorbs more oxygen than that under lower temperature even though the exposure time to the air is the same. This explains why coal which readily leads to spontaneous combustion in the pit does not ignite spontaneously when stored outdoors.

Coal which shows a high temperature and absorbs much oxygen in a pit is cooled down to about the same temperature as other coals, when selected outside and exposed to cool air. Thus it is possible that the coal which is warmed in the pit shows a lower rate of oxidation than that which is not warmed. Consequently it is more difficult for the temperature of this coal to rise again. Fig. 6 shows the relationship: coal A whose temperature has risen up to t_1°C shows an oxidation rate at A′ when cooled down to t_0°C, while the coal B at t_2°C shows an oxidation rate at B′ when cooled down to t_0°C. The oxidation rate at B′ is higher than that at A′.

Coal from a layer which shows a ready tendency to spontaneous combustion underground loses this tendency when stocked on the surface. These are the Yûbari, Ôyûbari and Akabira coal in Hokkaido. Coals which show a low tendency to spontaneous combustion underground, at times are known to ignite spontaneously when stored on the surface. These are coals from hard layers such as the Taiheiyô and Horonai coal in Hokkaido. The reason has not been explained. Thus, an interpretation was presented here.

There are certain types of coal layers that lead to spontaneous combustion in or out of the pit such as Chikubetsu coal in Hokkaido. This may be attributed to the fact that the coal here is selected only by hand and is not sufficiently cooled and it has also been suggested that washing the coal in water may prevent spontaneous combustion of this coal.

As stated before, the temperature is strongly related to oxidation of coal. However, measurements hardly ever show 50°C, except for places undergoing combustion or sites under the influence of a hot spring, where the oxidation rate is double that of places of 25°C of the earth temperature that are found frequently. Therefore the temperature at the beginning cannot be said to have a serious relation to the rise of temperature. When spontaneous combustion occurs, an insufficient treatment worsens the statusquo and thus results in a tendency to enhance another one.

Next, if the other conditions are the same, the effects of the size of coal grains are related to the size of the total surface area of the coal particles. In other words, a coal layer which readily pulverizes in a pit or was previously crushed by earth pressure has a high potential to be oxidized and show a rise in temperature.

Thus, prevention by solidification or compaction to avoid crushing and by providing props with a sufficient strength is an indirect preventive method against spontaneous combustion. At the base of the props, making the supporting pillars strong not only prevents the coal from crushing but also reduces the pressure difference in ventilation. According to an English periodical[3] various cases in which adequate prevention against spontaneous combustion was attained by merely providing steel arch without any other preventive measures.

The quantity of remaining coal in the pit is related to the accumulation and generation of heat. Since an air supply is needed for the oxidation of coal which induces the rise of temperature, incoming air dissipates the heat and thus a complete accumulation of heat is impossible. However, the generated heat makes the coal warmer by contact. Thus in a long air passage there are sites which allow for a complete accumulation of heat. In other words a large quantity of remaining coal in the pit is a cause of spontaneous combustion: here the remaining does not mean the residual coal in the seam but the crushed coal or that which has a possibility of being crushed.

Leakage of air is an oxygen supply to coal and a necessary condition for generation of heat by oxidation. The quantity of the leaking air through the crushed coal is in proportion to the difference of the pressure. Consequently when the difference of air pressure between the air in the incoming and outgoing passages is large, the possibility of spontaneous combustion increases. Hence a reduction in pressure difference is a preventive means agaiust spontaneous combustion. This is especially effective in Yûbari and Ôyûbari where there are slightly inclined layers of coal.

The cause of an air leak is brought about chiefly by the difference of pressure, temperature, a mixture of methane or other chemical changes. The directions of the case of pressure difference and the others do not coincide. Fig. 7 shows the relation between the slant of coal layers and the power of the air leakage.

Thus in the case of a steep slant, particulary in coal layers which spout a considerable amount of methane, an attempt to decrease the parssure difference may not be very effective to prevent spontaneous combustion. Air leakoge increases gradually with the rise of temperature, particulary in coal layers with a steep slant, and it supplies enough air to accelerate the generation of heat. For

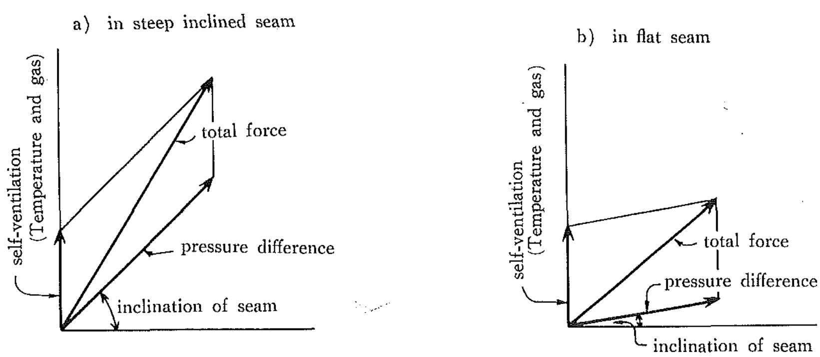

Fig. 7. Leakage force.

this reason Akabira coal mines, which has coal layers with an especially steep slant, has a potential of a high velocity of fire.

Summarizing the above, it may be said that for the prevention of generation of spontaneous combustion, it is necessary to elliminate remaining coal and to stop the air leakage and prevent pulverization of coal. A strict adherence to of one of these (three terms) will prevent spontaneous combustion, however this is impossible. Thus, an effort towards making the three terms complete as possible is the only way to prevent spontaneous combustion. We are of the opinion that these three terms should be taken into consideration from a standpoint of the coal mining, timbering and ventilation.

IV. Preventive Measures Used in Coal Mines in Japan

In this chapter we have dwelt on studies on preventive measures against spontaneous combustion in Japan. In Yûbari air leaks are stopped by tightly closing the goaves, and in Akabira, a refrigeration method which consists of admitting fresh and cool air into the goaves, are used. Decreasing air leaks and pumping in fresh and cool air seem to be in a contradiction. However our theory concerning the generation of spontaneous combustion shown in Fig. 1 explains that this is not a contradiction. The former is a method of preventing oxidation reaction from progressing rightwards, but the latter is done intentionally to assist the reaction rightward under a condition of a perfect dissipation.

Now, as for the application of the above mentioned methods, the direction of the oxidation reaction is not changed in the Yûbari method: in other words the coefficient p of the oxygen density is brought to zero with respect to the generation theory. In this method an equal number of calories corresponding to the air leak is generated and the heat is accumulated. As far as this method is concerned the quantity of coal left undug is not a crucial factor. The artificial prevention of air leakage generally slows down the speed of spontaneous combustion. Thus this method should be applied in a coal mine with a layer slant of less than 25° and with thick seams, such as seen in Yûbari, Ôyûbari, Chikubetsu and other collieries where a danger of spontaneous combustion exsists.

On the contrary the Akabira method positively makes the oxidation reaction progress rightward under a perfect dissipation of heat. In this case it is important to dig as much coal as possible. If much coal is left undug, an air leak results, and the heat which is generated in the coal enhances the rise in temperature of other coal and at the end of a passage of air leakage heat accumulates.

A small amount of coal left undug coupled with a short passage of air leakage shows a low oxidation rate and a gradual heat dissipation takes place, although there may be a tentative rise in temperature. Therefore, it is a crucial factor to leave the least amount of coal undug.

This method should be applied to a coal layer with a slant of more than 40° and which releases a large amount of gas. In a steep slant layer the directions of air leakage as induced by fans and that by a natural current of air by a temperature rise are the same. Thus the air leak increases with the velocity of the spouting of gas and the temperature rise: see Fig. 7. Consequently, in a goaf with a steep seam it is very difficult to stop an air leak by the Yûbari methods. Thus the Akabira method is highly effective in the presence of coal layers slanting steeply and spouting a large volume gas is present and the remaining coal can be cleared out thoroughly.

The Yûbari method prevents air leakage, and the coal is maintained in a fresh state. Since the coal is fresh, the generation of heat by oxidation of coal is as active as it was at the beginning of the excavation, which includes a possibility of spontaneous combustion, especially when an air leak occurs by other methods of mining or digging. Particulary the slicing method or close layers mining methods should be used with caution.

V. Conclusion

In this paper attempts have been made to clarify the phenomenon of spontaneous combustion in coal mines, which hitherto has not been explained, from a standpoint of a theory of generation of spontaneous combustion which was led forth by experiments with oxidation of coal in a previous paper.

It was shown that a possibility of preventing spontaneous combustion may be brought about by leaving no coal, by minimizing pulverization of coal or by stopping air leakage. This conclusion was led forth from our theory of generation of spontaneous combustion; however the methods are already in use. This paper, however, seems significant in showing the relationship among the factors in tables and charts and in giving a possible way of calibration, and in emphasizing the importance of using these three factors.

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