Control of Spontaneous Combustion of Sub-Bituminous Coal by Means of Heat Exchanger Submersion inside the Piles

Hanifa Khansa Zhafira¹, Anindia Setyo Widiani¹ and Yulianto Sulistyono Nugroho¹
¹Department of Mechanical Engineering, Universitas Indonesia, Indonesia

eyulianto.nugroho@ui.ac.id

ABSTRACT

The low-rank coal, such as sub-bituminous and lignite has become a widely used alternative fuel for power generation. During the transportation process from mining location to power plant, coal on the barge might be stored for a long period of time. A control mechanism of spontaneous combustion of coal in barge was simulated in laboratory scale by means of submerging heat exchanger inside the coal bed. The low-rank coal is more prone to self-ignition (spontaneous combustion) which is quite difficult to detect, due to the complex event of spontaneous combustion involving many factors from both intrinsic and extrinsic factors, such as particle size, moisture content, ambient temperature, barometric pressure, etc. A laboratory scale experiment was set up to study the smouldering combustion phenomenon of coal samples and means of control by using heat exchanger submersion in a coal bed. The coal sample was placed inside a wire mesh cube with a coiled copper tube installed in the middle of the coal bed. Fresh water was flowed through the coiled copper tube with controlled intake temperature about 28 °C. Approximately 65 grams of coal is heated in the oven at 210 °C until the temperature in the middle of the pile reaches up to 320 °C, then water is discharged through a copper tube to the middle of the pile and cooling it down. It is found that the temperature of coal sample can be brought down to 200 °C depending on the water flow. Thermocouples are used to measure the coal’s temperature in the middle of the pile. This method shows that the heat generated can be reduced to below the critical temperature for spontaneous combustion. The water flow rate has significant impact on temperature reduction of the coal inside the bed. This method has a potential benefit for controlling spontaneous combustion problem during barge transportation of coal.

KEYWORDS:
Coal; stockpiles; combustion; heat transfer; self-ignition; smouldering.
INTRODUCTION

Coal is one of the natural products that plays an important role in human life. Coal became one of the most widely used energy source in many countries. It is a natural resource that can be used in various fields, from fuel, gas producer, power source, even in industrial sector such as in making a component of-material and also support the state economy. Coal shipment often stored coal in barge for a long period of time, this event tends to lead to self heating of the coal and progress to combustion [1]. Several cases were reported regarding burning coal barges due to spontaneous combustion.

Shippers are required to provide a cargo declaration, especially if the cargo has a history of selfheating. One of the problems faced by coal producers is self-heating and spontaneous combustion [2,3]. Flaming is a chemical reaction that occurs between a fuel and an oxidizing agent, which results in the chemical energy stored in the outlet fuel being released as heat. Flaming is also called oxidation reaction because it involves Oxygen (O₂). During the transportation process from mining location to power plant, coal on the barge might be stored for a long period. The self-heating of stored coal can lead to spontaneous combustion that will reduce the coal quality, i.e. decreasing caloric content, volatile matter, and swelling capacities. Exothermic reactions that generate heat can reach the initiation temperature which ultimately forms hotspots in the hot spot of the coal if not lose [4].

The heat release occurs on the solid surface of the fuel and oxidation reaction and in the latter, these occur in the gas phase surrounding the fuel is the fundamental difference between smouldering and flaming combustion [5]. One of the most persistent types of combustion phenomena that leads to the largest fires on earth is a smouldering combustion. The slow, flameless, low-temperature burning of porous fuel [4]. Heterogeneous chemical reactions and the transport of heat, mass, and momentum in the gas and solid phases is fundamental combustion problem in smouldering [6].

The cooling unit affects the temperature gradient on the self-sustained smouldering combustion [7]. The energy transfer that occurs due to the different temperature between objects and material. A fluid passes over a solid surface of heat then energy is transferred to the fluid from the wall by heat conduction. These energies will be transported or conjugated, downstream by fluid, and diffused by fluid by conduction in the fluid them. This type of energy transfer process is called displacement heat convective [8]. The fluid motion raise heat transfer, then the higher velocity the higher heat transfer rate. This paper studies the application of heat exchanger submersion in the coal piles to control the spontaneous combustion occurrence at laboratory scale tests.

EXPERIMENTAL

This experiment uses sub-bituminous coal from Kalimantan, Indonesia. This type of coal is classified as medium calorie coal. The sub-bituminous coal contains more volatile matter and moisture than other bituminous coal types but has lower sulphur contents. The main properties of the coal are given in Table 1.

| Particle size : ≤ 2000 mm | Proximate Analysis | Ultimate Analysis |
|--------------------------|--------------------|------------------|
| % Moisture               | As Received        | Dry              |
| % VOLATILE matter        | 23.18              | 4.64             |
| % Fixed Carbon           | 36.04              | 47.910           |
| % Ash                    | 3.98               | 5.15             |
| % C                      | 52.58              | 68.45            |
| % H                      | 4.93               | 6.41             |
| % N                      | 0.85               | 1.11             |
| % S                      | 0.20               | 0.26             |
| % O                      | 14.29              | 18.60            |
| Calorific Value (Cal/ gram) | 5115              | 6658             |
The samples were sieved using wire mesh 10 to obtain a sample with a particle size of ≤ 2000 mm. Figure 1 shows the coal sample used in this experiment. The apparatus consists of a temperature-controlled oven and wire mesh cube with an open top and 50 mm sides made from stainless steel 201 to hold the samples during experiment. The wire mesh cube was suspended in the re-circulating air oven. Two K-type thermocouples were used in this experiment. One thermocouple was placed in the middle of the wire mesh cube to measure the temperature of coal and one thermocouple was used to measure the temperature of the oven. The thermocouple was connected to a data acquisition device so that it can be read on a standard personal computer.

The coal sample was placed into the wire mesh cube that was then suspended in the oven. The oven was set to the temperature of 210 °C. The coiled copper tube with the diameter of 0.8 mm was installed inside the wire mesh cube. This tube was connected to a water supply from the disposable infusion set with bag. The configuration of a coiled copper tube and wire mesh cube is shown in Figure 2.

The experiment work was parted into two different procedures. The first procedure was developed in three stages. First, the coal inside wire mesh cube with installed coiled copper tube was suspended in the oven until the coal reach temperature of $320 \pm 2 ^\circ C$, then the water was distributed through the tube to the temperature differential of maximum 90 °C. When the coal’s temperature was starting to increase, the water flow was stopped. Second, coal was suspended in the oven until temperature of $340 \pm 2 ^\circ C$. Later, water was distributed again like the first stage. The third stage was where the temperature of coal reach $360 \pm 2 ^\circ C$ and water were distributed for ± 30 minutes until the coal’s temperature was no longer reduced and has surpassed 360 °C. This procedure was repeated with a different flow rate. The variety of water flow rate that was used in this experiment are 40 mm/s; 55 mm/s; and 70 mm/s.

The second procedure was the coal inside wire mesh cube with installed coiled copper tube was suspended in the oven until coal reach temperature of $250 \pm 2 ^\circ C$, then the water was distributed through the tube continuously until the coal reach its lowest temperature.

For the third experiment the samples were sieved using wire mesh 10 to obtain a sample with a particle size of ≤ 2000 mm and wire mesh cube with an open top and 70 mm sides made from stainless steel 201 to hold the samples. Four K-type thermocouples were used in this experiment. One thermocouple was placed in the middle, one in the edge and one in the corner of the wire mesh cube to measure the coal’s temperature and one thermocouple was used to measure the temperature of the oven. First, the coal inside wire mesh cube with installed coiled copper tube was suspended in the oven until the coal which in the middle of the wire mesh reach temperature of $250 \pm 2 ^\circ C$, then the water was distributed through the tube. In this experiment, the water flow which being used is 70 mm/s only.
RESULTS

The heating process that was applied to the coal cause self-sustained combustion on coal which makes its temperature took off to 320 °C. By distributed water in the tube, the heat inside coal was transferred to the water by conduction and convection. Figure 3 shows the decreasing of coal temperature when the water was distributed and when the water flow was stopped, the temperature was starting to rise rapidly.

For the water flow rate of 40 mm/s and the capacity of 0.5 mL/s, the temperature of coal decreased by 92 °C from 319 °C to 227 °C as the first stage. At the second stage, where the water started to distribute at coal temperature of 339 °C, the temperature difference of coal degraded to 86 °C. The temperature difference of the third stage is dropped for about 68 °C, from 359 °C to 291 °C and started to increase again, although the water was still distributed.

The same phenomenon was found in the experiment with water flow rate of 55 mm/s and the capacity of 0.7 mL/s. The temperature difference of the first stage, second stage, and third stage were 18 °C from 322 °C to 304 °C; 9 °C from 342 °C to 333°C; and 7 °C from 362 °C to 355 °C.

For the water flow rate of 70 mm/s and the capacity of 0.9 mL/s, the temperature of coal decreased only by 6 °C at the first stage from 322 °C to 316 °C, and at the second stage was 4 °C from 342 °C to 338 °C. The interesting phenomenon happened at the third stage where the water started to distribute at coal temperature of 362 °C, the temperature of coal did not decrease. It can be seen as the heat absorbed by distributed water is lower than heat released by the coal. So whenever the water stops, the temperature will rise and it will not be lower than before.

Fig. 3. The temperature of oven and coal during heating and water distributed stopped and go

The result of the second procedure experiment can be seen in Figure 4. For the water flow rate of 40 mm/s and the capacity of 0.5 mL/s experiment (Fig. 4A), the peak point is where the coal’s temperature reached 318 °C, it is the coal’s take-off temperature. Then the water was started to distribute through the copper tube. The water flows for about 6 hours continuously. By the end of the experiment, for the water flow rate of 40 mm/s and the capacity of 0.5 mL/s, the temperature difference of water is 16°C as well as the temperature difference of coal is 113 °C. For the water flow rate of 55 mm/s and the capacity of 0.7 mL/s (Fig. 4B), the temperature difference of the coal is 116 °C and the temperature difference of the water is 12°C. And for the water flow rate of 70 mm/s and the capacity of 0.9 mL/s, (Fig. 4C) the temperature difference of the coal is significantly high at 226 °C from 320 °C to 94 °C and the temperature difference of the water is 34°C. Whenever the higher flow rate of water flows continuously, the more heat is absorbed by the water, the heat absorbed by distributed water is higher than the heat released by coal.
Fig. 4. The temperature of oven and coal during heating and continuous water distributed process; (A) water flow rate of 40 mm/s and the capacity of 0.5 mL/s; (B) water flow rate of 55 mm/s and the capacity of 0.7 mL/s; (C) water flow rate of 70 mm/s and the capacity of 0.9 mL/s

Fig. 5. The temperature of oven, coal temperature in the middle, edge and corner during heating and continuous water distributed process
The result of the third procedure can be seen in Figure 5. For the water flow rate of 70 mm/s and the capacity of 0.9 mL/s (Fig.5), the peak point is where the coal’s temperature reached 240 °C. It is the coal’s take-off temperature. The water was started to distribute through the copper tube. The water flows for about 6 hours continuously. By the end of the experiment, for the water flow rate of 70 mm/s and the capacity of 0.9 mL/s, the temperature difference of water is 57°C.

CONCLUSION

The result of the experiment shows that as water flowed through a pipe inside the coal bed temperature decreased significantly. When the water in the tube was stopped and released in sequence, a trend of temperature rise was observed. Flow rate of the cooling water inside the heat exchanger played a great role in controlling the development of the hotspots within the coal wire mesh basket. The effectiveness of cooling mechanism depended upon the flow rate and the initial temperature of the coal when water flow was started. By using a larger wire mesh basket with a dimension of 7 cm sides, it was observed that the critical temperature for spontaneous combustion of coal decreased from 240 °C (5cm sides basket) to 159 °C. Application of the heat exchanger for larger basket shows that temperature at the corner of the wire mesh that did not pass by the pipe can decrease significantly. As the effect of self-heating phenomenon that leads to spontaneous combustion in the coal pile is affected by the heat balance and the availability of oxygen from the surrounding atmosphere, it is critical to define the best position of the heat exchanger submersion inside the coal bed for real application of this approach in real stockpile or coal barge design.

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