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Spontaneous Combustion in Coal Stockpiles with Different Particle Sizes

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Abstract: In this study, the spontaneous combustion behavior of stocks created with coals of 3 different particle sizes (0-18/18-28/25-100 mm) was examined for 2 months and the results were analyzed. For this purpose, daily temperature changes in the stockpiles were recorded by means of temperature measurement probes placed in the stocks designed in 2x3x10 m size. According to the results obtained; Coal stocks with grain sizes of 18-25 and 25-100 mm started to catch fire before the end of the first month of storage. While no open flame ignition was observed in the stock with the finest grain size (0-18 mm), at the end of the 2nd month, a temperature increase was observed only at a single point according to the wind direction.

Keywords: Coal, spontaneous combustion, stockpile, particle size.

Introduction

Due to the intensive use of coal-based energy technologies around the world and climate change, greenhouse gas emission, and the increasing awareness of occupational health and safety, coal has become increasingly popular. The issue of combustion still faces intense interest from researchers. Self ignition of coal causes environmental disasters such as greenhouse gas emissions and hazardous trace elements, especially in the coal field (Carras et al., 2009; Wang & Chen, 2015). This trouble can be encountered in electric producing stations using coal, including coal stocks, in open pit mines, in old underground production areas, in overburden yards, and even in long-distance transportation conditions such as ships or trains (Fierro et al., 1999; Arisoy et al. al., 2006; Pone et al., 2007).

Fires caused by self ignition of coal stand out as a major problem especially in coal producing countries (Muduli, 2018). Many fire cases caused by spontaneous combustion have been recorded in the world. In coal mines in China, a lot of gas emissions and underground mine fires occur as a result of self combustion (Xia et al., 2016). While it is stated that about half of coal mines in China are at risk of spontaneous combustion and million tons of coal are lost every year (Kong et al., 2017). Likewise, it has been stated that fires in coal fields in India, especially in Jharia and Raniganj regions, are based on self combustion (Mohalik et al., 2016; Nimaje & Tripathy, 2016). In Australia, 125 spontaneous ignition cases occurred between 1960-1991 years (Wang et al., 2015a). It has been expressed that one-third of the mine fires reported in South Africa between 1970-1990 were caused by spontaneous combustion (Liang et al., 2018). Many cases resulting from spontaneous combustion were also recorded in the Ostrava-Karvina coal mining area of the Czech Republic in between 1995 and 2002, and about half of incidents occured between 2004-2006 (Taraba & Michalec, 2011; Taraba et al., 2014). In America, a total of 71 fires occurred as a result of spontaneous combustion in different mining operations between 1990 and 1999. Major countries around the world that have encountered spontaneous ignition problems and their combustion regions are given in Figure 1.

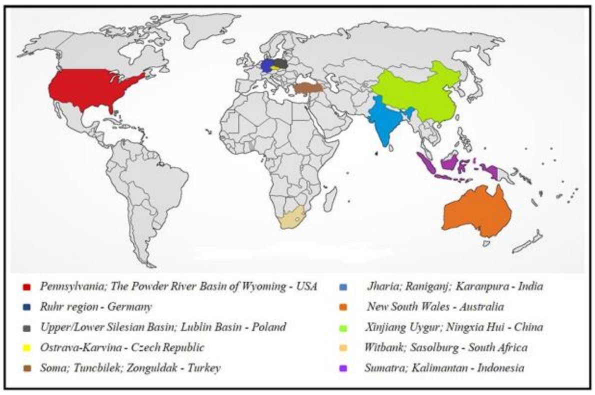

Fig. 1 Widespread spontaneous combustion fire sites around the world.

Spontaneous Combustion Mechanism in Coals

Detailed studies have been realized on the spontaneous combustion mechanisms of coal since the beginning of 17th century. Although many theories have been managed to explain this mechanism, the one currently accepted is the oxygen interaction theory (Qi et al., 2010). This theory occurs in two stages such as direct burnout and chemical adsorption. In the direct burnout phase that occurs below 50°C, CO, CO_2 and H_2O are released as a result of the reactions between coal and oxygen (Carras & Young, 1994; Wang et al., 2003). In the chemical adsorption stage, the temperature gradually rises and the hydrocarbons in the coal decompose. If the heat in the environment cannot be removed at later temperatures, combustion occurs when the coal reaches its ignition temperature (Gürdal et al., 2015). Although ignition temperatures may be different for each coal, 60-80°C is thought to be an important range for combustion (Wang et al., 2015b).

The fact that coal has a complex physico-chemical structure and that even coal samples from the same seam have different properties in time has revealed the necessity of considering the spontaneous combustion phenomenon from different perspectives. The parameters that are effective in the spontaneous combustion process, which is affected by multiple properties of coal in different ways, are mainly stated as intrinsic (endogenous) and extrinsic (exogenous) factors (Uludağ, 2001). The parameters that are ascented on spontaneous combustion are shown in detail in Table 1.

Table 1. Parameters affecting the self heating of coal.

Intrinsic (endogenous) factors	
Coal properties	**Geological features**
Carbonization degree, Petrographic structure	Coal stamp thickness, Faults
Moisture content, Grain size	Coal stamp slope, Collapsible feature
Mineral substance content, Pyrite content	Depth, Geothermal gradient
Extrinsic (exogenous) factors	
Atmospheric conditions	**Factors related to mining**
Heat	Production Method, Advance rate, Pillar conditions, Filling
Moisture	Air leakages, Coal losses, Worked out areas
Oxygen concentration	Ventilation pressure, Air humidity

Among these factors, the degree of carbonization, grain size and moisture load are the most effective in spontaneous combustion.

Carbonization Degree (rank)

Generally speaking, lower rank coals are more susceptible to self ignition than higher rank coals because they contain more reactive moisture, oxygen and volatile matter (Ramlu, 1991). As carbonization progresses, the increase in aromaticity and the decrease in effective groups in the coal configuration, takes place. In fact these few functional groups can only be oxidized at high energies and are shown as another factor (Önal et al., 2014). Studies show that the oxygen exploitation of coal decreases with extending carbonization degree (Winmill, 1915; Schmal, 1989: Wang et al., 2003; Coward, 1957). Apart from this, the increase in the pores in the coal structure in low-rank coals is also shown as a factor, and accordingly, oxygen molecules find more comfortable surfaces to bind (Chamberlain & Hall, 1973). In addition, with a method called R70, developed by Australian researchers and used to measure the tendency for spontaneous combustion in coals, it was determined that self-heating increases as the degree of carbonization decreases (Beamish et al., 2001).

Moisture Content

Coals may contain different amounts of moisture depending on their degree of carbonization. Peats can contain 80-90% moisture, lower rank coals such as lignite and brown coal have 30-70% moisture, and hard or bituminous coals have 10% or less (Allardice & Evans, 1978). Moisture in coal is divided into two: surface moisture and internal moisture. Surface moisture can be subdivided into adhesion moisture, intergranular moisture and adsorption moisture (Kemal & Arslan, 2010). Surface moisture refers to the moisture that does not occur naturally with coal, but has entered the coal through fractures and cracks in its configuration (Kural, 1998). Different opinions are put forward on the outcome of moisture content in coal on self heating. In general, it has been stated by researchers that there is a cirtical moisture range value for the maximum oxygen consumption of coal, and that oxygen consumption rates decrease for coals above or below this moisture range (Huggins & Huffman, 1989; Chen & Stott, 1993; Clemens & Matheson, 1996: from Wang et al., 2003). There are studies that oppose this theory and claim that the tests in question were carried out on altered coals (Bhat & Agarwal, 1996: Beamish & Hamilton, 2005). Yohe (1958) stated that the moisture content in coal does not have any effect on oxidation and that the degree of carbonization is essentially decisive on spontaneous combustion.

Particle Size

Coal oxidation and the resulting spontaneous combustion process are generally considered to be an event that takes place on the surface and pores of coal. In research conducted till date, it has been stated that the surface area of coal increases as a result of the reduction in coal grain size and that it plays a role in increasing spontaneous combustion due to the formation of additional surfaces that come into contact with oxygen (Akgün & Arisoy, 1994; Ren et al., 1999). Carpenter & Sergeant (1966) emphasized in their studies that the oxidation rate increases as the coal grain size decreases, and this rate remains constant after reaching a certain value. While this critical grain size was determined by researchers to be between 138-387 µm, However in many later studies, different critical grain sizes were determined in a range ranging from 501 µm to 5 mm (Özdeniz, 2003). Nugroho et al., (2000) examined the effect of grain size on the oxidation kinetics of Indonesian coals with different carbonization degrees and observed that the risk of self heating of coal increased with decreasing grain size.

Materials and Methods

The coals of the stock piles were supplied from the Çan district of Çanakkale province, located in the west of Turkey. Analysis values of coals are given in Table 2.

Table 2. Analysis values of coal specimens.

Moisture (%)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)	Sulphur content (%)	Calorific value (kcal/kg)
24,22	23,79	27,78	24,21	6,79	3574

Three separate stocks with different particle sizes were formed from these coals. These stocks, with particle sizes of 0-18, 18-25 and 25-100 mm, are designed to be 2 x 3 x10 m height-width-length (Fig. 2). Thermal measurement probes shown in Figure 3 were placed at seven different points of the designed stock piles and temperature changes in the stocks were monitored in every five minutes for two months.

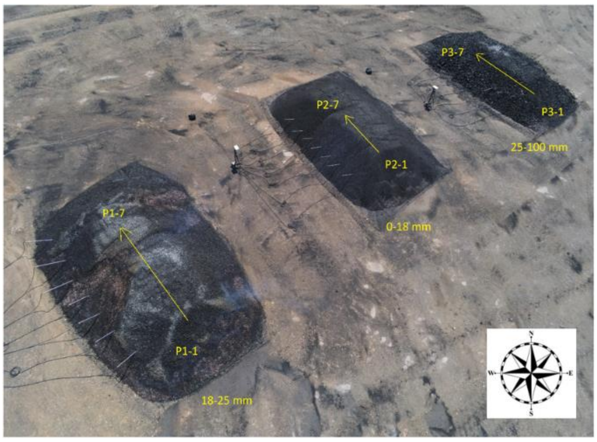

Fig. 2 Formed coal stockyards and measurement points

Fig. 3 Temperature measurement probes and data logger

Results and Discussion

Temperature data obtained from stocks are given in Table 3-5. While the data in question was recorded every 5 minutes during the day, in order to avoid data crowding, the daily averages of these data were taken and presented in the tables considering a certain date range. When the results obtained were examined, no signs of overheating were observed in the coal stock with the finest particle size (0-18 mm) during the 2-month measurement period, while a temperature increase was recorded only at the measurement points P2-6 and P2-7 compared to the other points. It is thought that this temperature difference is caused by the wind blowing mostly in the northwest-southeast direction during the measurement period. The heating in the stocks created with particle sizes of 18-25 and 25-100 mm occurred approximately in the 1st month of the measurement period. In both stocks, the heating that developed at measurement point 4 occurred earlier in the 18-25 mm stock compared to the 25-100 mm stock. It is noticeable that in the time periods after the combustion occurred, the temperature values increased at points 3 and 5, close to measurement point 4. Based on the results obtained it was concluded.

• When the temperature measurement results were compared, it was determined that the coal stock with the finest grain size was more advantageous than other stocks in terms of spontaneous combustion. The main reason for this is thought to be the limited air inflow into the stock created with fine particle size due to the compression factor of the grains.

• Stock with 18-25 mm particle size has been determined as the stock with the highest risk in terms of spontaneous combustion. The heat that occurred in a region close to the center point of the stock also affected other measurement points, causing the stabilization of the measurements to deteriorate.

• In the stock with 25-100 mm grain size, heating occurred in the central region of the stock, similar to that of 18-25 mm, but this heating occurred much later and without causing an open flame fire. The milder intensity of heating resulted in stable recording of temperature values at other measurement points. Especially with the increase in particle size, the decreasing surface area causes the probability of coal to overheat to decrease. In addition, irregular particle sizes facilitate the entry of air into the stock yards with high wind income, creating a suitable environment for spontaneous combustion and subsequent open flame fires. In this study, 18-25 mm grain size was determined to be the most risky storage size considering these reasons.

Table 3. Temperature data for stock with 0-18 mm grain size

Time Span	P2-1	P2-2	P2-3	P2-4	P2-5	P2-6	P2-7
23-27.06.23	27,81	29,22	26,88	26,77	27,70	29,55	26,47
28-02.07.23	36,20	41,26	34,07	33,95	34,79	42,93	33,89
03-07.07.23	42,44	48,07	39,59	39,42	39,02	49,66	39,34
08-12.07.23	47,67	52,03	44,25	43,90	41,58	52,60	43,81
13-18.07.23	51,11	55,58	47,46	47,02	44,26	55,13	46,80
19-25.07.23	56,15	60,90	52,33	51,85	48,78	60,06	51,26
26-31.07.23	58,40	63,06	54,81	54,20	50,43	61,36	53,70
1-11.08.23	62,58	67,21	58,59	58,01	55,58	74,13	67,91
12-18.08.23	69,71	73,97	65,31	65,02	64,52	83,32	82,58
19-28.08.23	72,21	74,92	67,62	67,61	68,56	93,12	91,10

Table 4. Temperature data for stock with 18-25 mm grain size.

Time Span	P1-1	P1-2	P1-3	P1-4	P1-5	P1-6	P1-7
23-27.06.23	41,60	39,82	23,45	33,61	38,24	37,15	33,27
28-02.07.23	68,56	66,30	41,48	35,84	51,44	48,75	44,17
03-07.07.23	81,70	73,57	53,70	54,78	71,52	70,47	60,31
08-12.07.23	58,32	53,24	21,08	Heating	79,42	69,12	56,60
13-18.07.23	29,01	50,18	37,29	Heating	36,40	42,45	31,64

Table 5. Temperature data for stock with 25-100 mm grain size

Time Span	P3-1	P3-2	P3-3	P3-4	P3-5	P3-6	P3-7
23-27.06.23	29,00	28,07	31,11	24,93	32,57	32,07	29,36
28-02.07.23	31,56	28,98	37,52	33,19	44,79	45,12	26,94
03-07.07.23	34,26	31,46	43,70	37,66	54,51	56,07	29,54
08-12.07.23	39,29	38,67	54,97	46,88	63,56	64,85	32,18
13-18.07.23	79,05	54,40	Heating	Heating	Heating	60,78	32,80

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