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Evaluation of Coal Mine Wastes in Terms of Spontaneous Combustion Liability and Sulfur Content

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Abstract

In this study, a waste disposal location for coal mine was investigated in terms of waste possible potential of harmful effect for the environment. Coal mines either as regards to production or beneficiation can be questioned in terms of any problem to environment. Zonguldak, which is the hearth for the coal mine production in Turkey, has many companies for coal production along with TTK, i.e. Turkish Hardcoal Association. Governmental coal production is conducted by TTK and it has the major production. In this study, coal mine waste and the coal preparation plants waste from TTK were under interest and questioned in terms of the sulfur content and spontaneous combustion liability. This study was actually carried out to understand whether the location of waste dump is suitable or not. In the order of this purpose, waste should be characterized. A total of 26 coal samples were taken either from coal mine waste (production 13 samples) or from the coal preparation plant waste (13 samples). Latter their corresponding analysis was carried out and results show that negligible amount of sulfur included in each samples and no spontaneous combustion liability was observed. It can be further claimed the fact that coal mine wastes and coal preparation plant waste from Zonguldak TTK is not harmful to the environment at all.

Keywords: Coal, Mine Waste, spontaneous combustion, sulfur

1. INTRODUCTION

Coal mine wastes either from the production or from the coal preparation plants are significant in terms of their spontaneous combustion liability and sulfur contents. Sulfur is regarded as the main reason for the acid mine drainage problem. Acid mine drainage problem caused by the oxidation of pyrites and other sulfur bearings in the body of mine waste (Dutta et al. 2020). Coal mining according to Dutta et al. (2020) is one of the major sources of environmental degradation specifically for opencast mining facilities (Chandra et al. 2015). As many material wastes can cause environmental problem likewise coal and the associated trace elements can contaminate the soil (Dutta et al. 2017, Pandey et al. 2004). In addition referring back and forth to the study of Dutta et al. (2020), the authors simply claimed the fact that the deposition of coal and overburden dumps change the natural landscape and affects the natural drainage systems, and also retards the normal plant growth (Bradshaw and Chadwick 1980, Wali 1987, De and Mitra 2002). Acid mine drainage

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problem is widely encountered in coal mining areas and still mining and processing of coal, i.e. the preparation and cleaning, can have an accelerating role on exposing the pyrite to water and atmosphere (Johnson and Hallberg 2005, Akcil and Koldas 2006). According to Banerjee (2014), coal mining processes increase the rate of formation of acid because of the exposure of iron-sulfide minerals to the atmosphere. Not only coal mining areas are affected in terms acid mine drainage problems but also the concentration of heavy metals may lead to bioaccumulation which leads to an increase in the rate of mortality (Canli et al. 1998).

Although when the environmental effects of coal mining is under interest, most of the time, the open pit mining is being considered. Acharya and Kharel (2020) referred open pit mining as "surface mining" and they explained it as "it underpins the shallow mining method to extract coal embedded in earth by removing overburden covering a coal seam". The same authors abovementioned have explained the fact that surface coal mining accounts for nearly 63% of the 679 total mines in US (National Mining Association 2019, Acharya and Kharel 2020) which dominates the mining method and the coal mine productivity. Acharya and Kharel (2020) have tabulated the corresponding yearly productions underground and surface coal mining activities of US.

Surface mining is one of the worse in terms of environment as regards to coal mining. Reasons behind this fact abovementioned is the condenser economic, ecologic, hydrologic and geomorphic ramifications (Acharya and Kharel 2020). Although surface coal mining has much potential in terms of environmental pollution and acid mine drainage, the underground coal mining has also no negligible potential, respectively. Underground production is not always the production as it is desired and some waste is already being produced along with the coal. To be more clear, each production chamber has waste, and not always the aim is realized in terms of low percentage of waste and high percentage of valuable mine. Underground mining activities eventually result with a dumping location planning which should be environmentally stable. Here the problem is not the choice of the location of waste dump but the waste characterization and the potential to be harmful to environment. This is already reasonable as no one desires the coal mine waste dumping area to be polluted in a period of time.

Researchers more or less investigated the effects of surface coal mining facilities as regards to environmental perspective but no many researcher have already focused underground coal mining potential in this regard. This study aims to investigate this abovementioned by realizing the correct addressing the potential of the problem. Underground coal mining wastes can have high sulfur percentages and they might also be liable for spontaneous combustion. That is why in this study, underground coal mining facility of TTK was taken into consideration and their waste samples were collected. A total of 26, 13 by each (from production and process) sample was collected and analyzed in terms of their tendency to spontaneous combustion and their sulfur content.

2. MATERIAL AND METHOD

This study was conducted with two group of waste samples. First group of waste samples was originally the coal mine production waste, while second group of waste was coal processing waste. The representative samples of each was collected from the each abovementioned sampling locations. A total of 26 sample (13 sample from each) was collected with the help of TTK staff. Samples were rock samples and they were questioned in terms of their potential either for the spontaneous combustion liability or the sulfur content (acid mine drainage). Right after the collection of the samples, each sample was bagged with the corresponding tags. In the order of no possible contamination inclusion, they were tightened up and prepared for transportation.

Characterization of the samples were performed in two stages as well. First stage of the analysis is the sulfur content determination and in the order of this purpose, representative samples were taken from each sample. This stage covers the preparation of the samples for the sulfur standard analysis for coal, i.e. ASTM D-3177-75. Initially samples were crushed and coning and quartering was employed for the sampling. Later samples were ground to 200 mesh and placed on sample pots to determine their sulfur contents. Sulfur content analysis was carried out on LECO SC-132 equipment which is designed for this purpose. After the calibration of the equipment, each sample was tested in terms of sulfur content.

As for the second experimental characterization stage, spontaneous combustion liability of each sample was investigated. In order to do so, a spontaneous combustion oven and a sample reactor was employed. This oven is a special oven which composes of air inlet and out to the sample, and it tries to represent the coal sample atmosphere. As it is known, coals have a tendency to be burn under some specific condition and resulting in a fire. This is mostly faced on stock areas of coals and some accidents were recorded associated with coal mines already. Spontaneous combustion liability characterization is always the primary question for coals produced and it should also be questioned for the coal mine waste samples as well. Method of this determination for the spontaneous combustion liability basically covers "crossing point" temperature and there are some index values to be compared at the end. Samples have different ignition points and different initial temperature to be burned after by their selves. Spontaneous combustion liability tests were conducted as the method suggested by Feng et al. (1973). The method at the end results with index values with which the potential of this liability can be classified. Index values abovementioned are "FCC" index values indeed and they later be categorized as "low", "medium", and "high" risk of the spontaneous combustion. Coal spontaneous combustion liability tests were carried out with the experimental set up as shown in Figure 1.

Figure 1. The experimental set up for spontaneous combustion liability determination.

With the experimental set up shown in Figure 1, corresponding temperature profile of the sample was determined. After the evaluation of crossing point and the average temperature increase between 110 °C and 220°C, FCC can be calculated (See Equation 1). Further details of this experimental set up is already discussed by Bilen et al. 2019.

FCC Index = (average teperature increase between 110-220 °C)/(crossing point temperature °C) (1)

As regards to FCC index values, note that the temperature rise between 110 °C and 220 °C was chosen. Risk classification as regards to FCC values are provided in Table 1.

Table 1. Risk classification in terms of FCC index.

FCC Index	Risk Classification
0 - 5	Low
5 -10	Middle
> 10	High

Experiments carried out have the corresponding conditions as summarized in the following:

Amount of sample : 35 ± 0.1 g

Air Quantity : 100 ± 0.5 ml/min

Oven temperature rise : 0.5 °C/min

3. RESULTS AND DISCUSSION

After samples analysis either in terms of sulfur and spontaneous combustion liabilities, results were tabulated. In terms of sulfur analysis, samples have negligible amounts (See Table 2). The lowest sulfur content was observed on the production samples. Processing samples which were collected from coal preparation plant have higher percentages of sulfur as expected.

Table 2. Sulfur analysis results for the coal mine production and process samples.

Coal Mine Production Samples		**Coal Mine Process Samples**	
Sample ID	**Sulfur (S) (%)**	**Sample ID**	**Sulfur (S) (%)**
Prod1	0.024	Proc1	0.090
Prod2	0.021	Proc2	0.094
Prod3	0.019	Proc3	0.054
Prod4	0.031	Proc4	0.042
Prod5	0.028	Proc5	0.038
Prod6	0.041	Proc6	0.081
Prod7	0.017	Proc7	0.074
Prod8	0.021	Proc8	0.072
Prod9	0.024	Proc9	0.069
Prod10	0.023	Proc10	0.070
Prod11	0.040	Proc11	0.075
Prod12	0.023	Proc12	0.078
Prod13	0.022	Proc13	0.077

Referring to Table 2, sulfur contents can be considered low for both production and processing samples. In terms of environmental risk classification, it can be claimed that samples analyzed have no risk for the environment. Zonguldak coals are respectively have lower sulfur content and they are classified as hardcoals. It can be claimed that lower the amount of sulfur in the body of a coal, much lower is the risk in terms of environmental pollution associated with it. Lignites have higher percentages of sulfur comparing to hardcoals however. In order to better understand, Zonguldak coals have at most 1% sulfur while Turkish lignites in general have at least 3-4 % respectively. That is why, although this study considered hardcoal samples, more interested ones should be the lignite samples. Nowadays in Turkey, either in terms of obligations by the government or the regulations itself, coal companies are forced to characterize their waste samples before dump.

Many research in this regard have evaluated the potential of acid mine drainage. Referring to Zonguldak coal basin which has a history of coal mining for more than a century, no problem has been faced in this respect. However this does not really mean it would not accumulate in years. It can be better emphasized here that the accumulation rate would be low for Zonguldak coals, but respectively higher for lignite or low grade coals.

The study of Toroglu et al. (2019) has investigated the coal cleaning wastes from Malkara/Tekirdağ. Corresponding samples are the process samples collected from the coal preparation plant. The abovementioned study includes a lignite sample process wastes and their corresponding characterization. Toroglu et al. (2019) have concluded that the investigated lignite samples have little and ignorable impact for the environment in short term. Abovementioned researchers have implemented monolithic and dynamic leach tests to address the environmental risk potential of the samples. In order to better evaluate the environmental risk associated with coal mine waste, environmental regulations should be taken into consideration and the potential should be characterized with the leaching tests indeed. Still, compare to the results of Toroglu et al. (2019), the samples investigated in this study can be considered to have less impact to environment in short term. However in both cases, no interpretation can be established in long term, the characterization of the samples should have been carried out as regards to the regulations implemented by the Ministry of Environment and Urbanization of Turkey.

In addition to sulfur content determination for the coal wastes samples (production and process), a total of 4 spontaneous combustion liability tests were performed. This analysis is rather time consuming analysis and the representative samples were selected, i.e. 2 from each sample group. Corresponding samples are not the coal samples, instead coal mine waste samples and they can be regarded as shales which can be depicted as no combustible behavior. Still, in order to carry out the observation, samples were prepared as the details were mentioned previously in Material & Method section. Each samples tested (a total of 4 test, 2 for each sample group) has found out to have no FCC index at the end, since the crossing point temperature were not obtained during analysis. Results of the spontaneous combustion liability test were tabulated in Table 3 and graphical representations were provided in Figure 2, 3, 4 and 5.

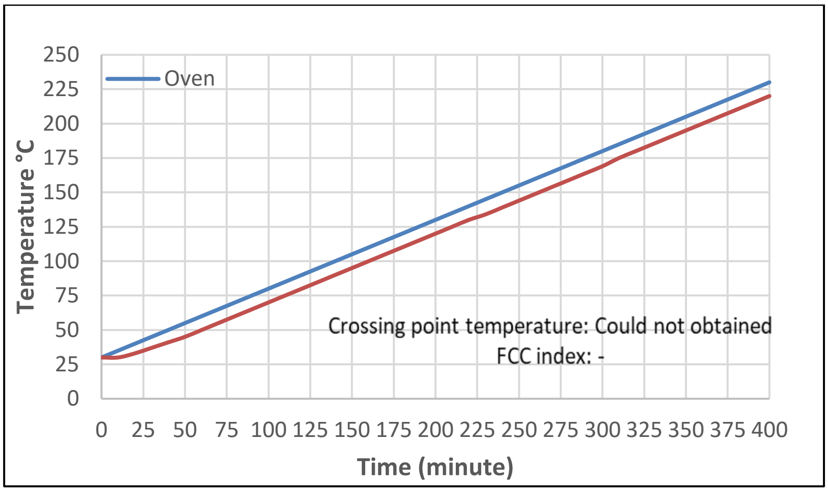

Figure 2. Spontaneous combustion liability test result for Prod1 sample.

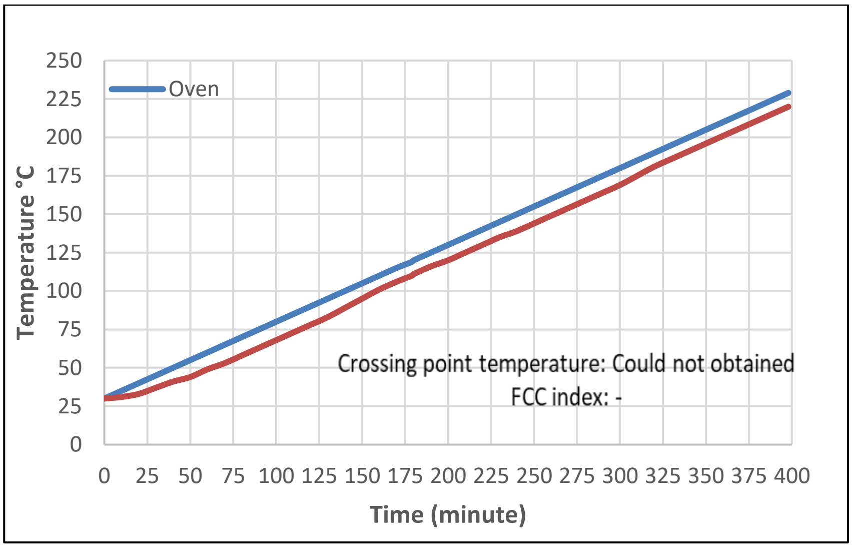

Figure 3. Spontaneous combustion liability test result for Prod2 sample.

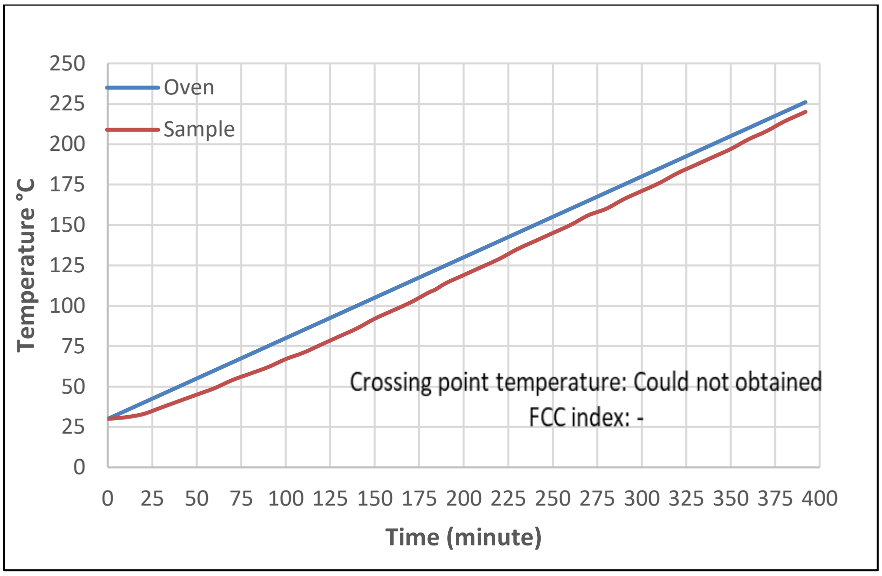

Figure 4. Spontaneous combustion liability test result for Proc1 sample.

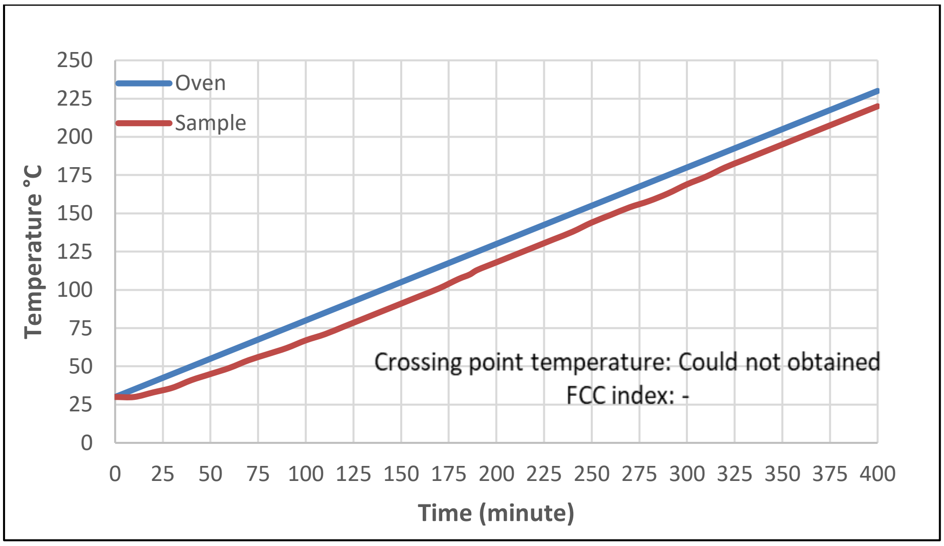

Figure 5. Spontaneous combustion liability test result for Proc2 sample.

Table 3. Spontaneous combustion liability test results.

Determined or Calculated Property	**SAMPLE**			
	Prod 1	**Prod 7**	**Proc 1**	**Proc 7**
Crossing Point Temperature (°C)	-	-	-	-
Average Temperature Rise for sample(°C/min)	0.50	0.50	0.51	0.52
FCC index (min^{-1})	-	-	-	-

As regards to the results tabulated in Table 3, samples have no spontaneous combustion liability at all. Analysis was carried out on 4 samples in total, and a general idea for all samples was stated out. The statement is as following: "The samples collected have no tendency for spontaneous combustion" .The assumption behind this statement is the form of the samples either from production or process. The samples collected can be regarded as in the form of shale which has limited amount of combustible material. Samples from coal mine waste should not be considered to have a tendency in terms of spontaneous combustion like in the case for coal itself. Although shale samples have no tendency as can be inferred from the results, this might not be valid for all waste samples of coal mine. In order to better understand the spontaneous combustion liability of a mine waste sample, correct characterization should be carried out in the beginning. The reason behind not employing the spontaneous combustion liability test for all samples is the time consuming nature of this test.

Although spontaneous combustion tests carried out for the studied samples resulted in such a way that no potential risk of any fire, correct characterization of mine wastes should include this test. Although regulations being implemented by the government in terms of mine waste characterization do not include this tests, fires spontaneously occurring in mine waste dumping sites can be linked to this potential already. Referring back to Toroglu et al. (2019) study, the mine waste samples studied were considered to have no impact to environment in short term. Although, analysis (monolithic, dynamic leach test) carried out by the abovementioned researchers (Toroglu et al. 2019) has wide considerations, it suffers from the lack of corresponding potential for the spontaneous combustion liability of this waste samples. Samples studied by Toroglu et al. (2019) are the lignite coal mining wastes and lignite coals are known to be liable in terms of spontaneous combustion. So as regards to this liability for lignite coals, the waste of lignite coal mine should be characterized in terms of this tendency, i.e. spontaneous combustion.

4. CONCLUSION

In this study, collected coal mine waste samples were analyzed in terms of their sulfur content and spontaneous combustion propensity. Mine wastes should be characterized in terms of environmental pollution potential and regulations as regards to this characterization are being implemented by the Ministry of Environment and Urbanization of Turkey. Coal mine wastes depending on the process or production or the origin of coal itself might have some potential risks for the environment as well as other mine wastes. Coal mine wastes should also be characterized in terms of spontaneous combustion liability, since any spontaneous occurrence of fire in a coal mine waste dumping site and the reason behind is nothing else but this tendency. Although regulations as regards to mine waste characterization do not include questioning of this potential (spontaneous combustion liability), risks associated with it keeps its significance. In this study both sulfur contents in terms of acid mine drainage and spontaneous combustion liabilities were considered for Zonguldak coal mine waste samples. Literature has a bunch of studies in terms of mine waste characterizations, and leach (monolithic, dynamic) tests are being employed mostly to meet the criteria of regulations. However correct addressing of the potential should be addressed not only with characterization in terms of leach tests but also spontaneous combustion liability tests. And that is why regulations as regards to this should include these tests to avoid any possible self oxidation of mine waste. This study was carried out with coal mine waste samples provided from TTK, which is the governmental association in Zonguldak Hardcoal Basin. Coal mine waste samples are found to have low sulfur content and no spontaneous combustion tendency. Depending on the process or production, or the origin itself coal mine waste samples might have higher sulfur content or they might have respectively higher tendency to spontaneous combustion. The spontaneous combustion liability tests were performed mostly for coal samples and it is known that lignite samples have higher tendency in this regard as compared to hardcoals. So, specifically for lignite coal mine waste samples should be characterized in terms of spontaneous combustion liability. Coal mine waste either from a hardcoal basin (this study) or from lignite basin (literature study referred) should not only be questioned in terms of leach tests (monolithic-dynamic leach tests regulated by the Ministry) but also they should be questioned accordingly in terms of spontaneous combustion tendency. This study would imply the fact that coal mine waste might have different characteristics and in order to avoid possible fire risk in coal mine waste dumping site characterization should be enriched with the tests conducted in this study, i.e. sulfur content analysis, spontaneous combustion liability analysis. This study would not only be a tool for the coal mine waste characterization studies but also it would decrease the risk of spontaneous fires within coal mine waste dumping sites. Not only correct addressing of the environmental risks associated with coal mine wastes would be better clear but also regulations would be revised accordingly.

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