Domestic Utilization of Coal in Zonguldak-Turkey and Unburned Carbon in Ash

Mehmet Bilen, Serdar Yilmaz
1 Department of Mining Engineering, Zonguldak Bülent Ecevit University, 67100, Zonguldak, Turkey

mehmetubilen@yandex.com

Abstract. In this study, Zonguldak, a Turkish city popular with coal mining, was taken into consideration. Coal was the main source of energy for domestic heating in Zonguldak and tonnes of ash were dumped to environment. The ash samples were containing carbon and this carbon was aimed to recycle from these waste. In the order of this recycling, firstly classification of collected ash samples in terms of size groups was carried out. For each size groups sink and float analysis was carried out. Sink and float analysis was carried out with densities (1.30, 1.45, 1.60, 1.90 g/cm³) for a total of 5 size groups of ash (+18.00mm, -18.00+10.00mm, -10.00+6.00mm, -6.00+2.36mm, -2.36+0.50mm) and each floated product was analysed in terms of final ash percentage. Size group -18+10 mm was floated at 1.30 g/cm³ and it was observed that this group of coal ash has the highest percentage (%58.84) carbon.

1. Introduction
Ash with carbon is not a waste rather it is an economical loss and environmental pollution. Growing population and industrialization means more energy need now and future. Nowadays most of the energy need is met by coal. Coal is not only used in thermal power plants for energy conversions but also it has more of an importance in domestic heating. Household stoves burning solid fuels in China have been subject of interest recently because they are important emission sources of various pollutants including toxic organic compounds such as polycyclic aromatic hydrocarbons [1]. Zonguldak which is in the north west of Turkey is popular with coal mining, and either because of that or not, coal was widely utilized in terms of domestic heating purposes in this city. That is why tones of ash is released into environment as waste. In the study of Hossain et al [2], researchers well established the environmental impacts of coal mine and coal-based thermal power plant to the surrounding environment of Barapukuria, Dinajpur. The ash of domestic utilized coal was presented in Figure 1.

As it is seen in Figure 1, populated areas are more subject to this coal ash environmental pollution. This coal ash spill would not be easy to clean up in Zonguldak likewise in the case of Danvile park from which 2500 tons of ash removed [3]. According to the study of Lemly [4], selenium which is in coal waste is dissolved and carried into nearby lakes, rivers and wetlands; which causes severe reproductive impacts on fish. Many researchers [5], [6], [7] claim that the fact that ash deposits will persevere and contaminants will move up the benthic food chain into fish and wildlife. Coal ash is hardly integrated into the nature and higher the silica and alumina content of coal ash is higher the resistivity of ash [8]. In the study of Gottlieb et al. [9] how toxic coal ash leachate is summarized and they refer to EPA’s report emphasizing the fact that “the levels of toxic constituents leaching out of coal ash can be hundreds
to thousands of times greater than federal drinking water standards”. Coal ash is not only released by the domestic utilization of coal in terms of heating purposes, instead most of coal ash is released by thermal power plants. According to Ali et al [10] study, more than 88.5 % As (arsenic) in coal can be released to the atmosphere during combustion of coal for power generation. In Figure 2, bottom ash particles from a power plant including some carbon particles is presented.

![Figure 1. Representation of domestic utilized coal ash in Zonguldak wasteyard.](image1)

![Figure 2. Bottom ash particles from Çan Thermal power plant. (Carbon particles are shown as black)](image2)

Referring to the Figure 2, bottom ash or fly ash, in general coal ash, is released to environment at a bigger proportions and still it has some coal (carbon) particles in its form. Either from the study of Bilen et al. [11] or from the study of Bilen and Kizgut [12], unburned carbon in fly ash or bottom ash presence is more or less related to coal particles size distribution. In their study of Bilen et al. [11], they claimed the fact that “unburned carbon resulted from the existence of coarse coal particles though they have small mass fraction”. Gao et al. [13] have expressed the fact that particles larger than 140 µm have contribution of 70 % on total amount of unburned carbon while the fraction of this abovementioned particles is only about 20 % [11]. This is basically for power plants operating with modern technology.
boilers which is still unburned carbon presence is up to 10% [14], higher rates of unburned amounts can
be observed coal utilization for domestic heating purposes.

Rasskazova et al. [15] referred floatation as the most efficient method of extraction unburned coal
particles, i.e. unburned carbon. In the same study of Rasskazova et al. [15], it was emphasized the fact
that the high amount of unburned carbon disabling the usage of ash and limiting its recycling into
construction materials. Although, the ash produced by domestic heating, in other words coal ash
produced by stoves or combined heating system with coal combustion have less amount in total with
respect to power plants utilization, still the amount of unburned carbon could be comparable as regards
to all around the world. In addition Altun et al. [16] have tried to separate unburned carbon from fly ash
using a concurrent floatation column and they have cleaned ash product with less than 1% unburned
carbon at the end. Sahbaz et al. [17] have observed the recovery level of combustible matter between
45.7 % and 84.0 % within the context of the study of floatation method employed for the unburned
carbon recovery from bottom ash.

In this study, collected ash samples from domestic utilized coal were analyzed in terms of sieve
analysis and sink and float analysis. Possibility of the recycling of carbon from domestic coal wastes
was researched with the experimental findings.

2. Experimental Method

Collected coal ash samples (approximately 500 kg) were crushed with jaw crusher. Among this crushed
ccoal ash sample, sieve analysis was carried out. Sieves used for sieve analysis were 18, 10, 6, 2.36, 0.5
mm. Schematic representation of crushing and sieve analysis is provided in Figure 3.

![Figure 3. Schematic representation of crushing and sieve analysis of coal ash sample.](image)

In order to remove the impurities and dust, coal ash samples were all washed with water initially and
they were dried at open air. Mediums with densities (1.40, 1.45, 1.60, 1.90 g/cm³) were prepared with
ZnCl2. Dried coal ash samples were sunked and floated as following the representation given in Figure
4.
3. Results and discussions

Coal ash samples were analyzed in each size group and their carbon percentages were observed. In Table 1, unburned carbon percentages of size fractionated coal ash samples are given.

Table 1. Unburned Carbon percentages of size fractionated coal ash samples.

| Size Groups (mm) | Amount (%) | Amount Σ (%) | Amount Σ (%) | Carbon (%) |
|------------------|------------|--------------|--------------|------------|
| +18.00           | 12.86      | 12.86        | 100.00       | 27.88      |
| -18.00+10.00     | 38.50      | 51.36        | 87.14        | 27.52      |
| -10.00+6.00      | 7.13       | 58.49        | 48.64        | 25.91      |
| -6.00+2.36       | 17.51      | 76.00        | 41.51        | 20.11      |
| -2.36+0.50       | 15.00      | 91.00        | 24.00        | 18.29      |
| -0.50            | 9.00       | 100.00       | 9.00         | 19.63      |
| Total            | 100.00     | -            | -            | 23.06      |

Regarding to Table 1, more than 50% of coal ash sample was over 10 mm and average carbon content for all sample is 23.06 %. The lowest Carbon content is in the +18 mm size group of material and the highest is in the -2.36+0.5 mm size group.

Coal ash samples was fractionated in each size group and sink and float analysis was carried out in each size group. In Table 2, results of sink and float analysis for each size group was presented.

Referring to the Table 2, coal ash samples can be beneficiated with dense mediums in terms of carbon content between 9 and 59 %. Carbon recover proportions have no relation between density of mediums neither with size groups. The best carbon recover is realized for the -18+10 mm size group of coal ash at the density of 1.30g/cm$^3$. For each size group, washing the coal ash with 1.30 g/cm$^3$ seems to be an efficient method in order to recover important amount of carbon from domestic coal ash ps.

Float amount of coarse size fraction of ash (+18mm) is high because of slag formation. Due to porous structure of slag, it is favored to float in coarse fractions. That is why, lower the size of ash is lower the fraction of float in 1 g/cm$^3$, i.e. water. The highest recycle of unburned carbon is realized in the finest size fraction (-2.36+0.5mm). For the studied collected ash samples, after floating the +18mm size fraction in water (1 g/cm$^3$), the sink part can be mixed with other fractions. This mixture can be floated and unburned carbon recycle can be realized with 52% with a product amount of 30 %.

If the dense medium separation was realized in 1.60 g/cm$^3$, product amount would be up to 50 %, however unburned carbon recycle would decrease to 40 %. The fraction floated in 1.30 g/cm$^3$ does not only have a potential usage in cement industry but also it has potential usage as a fuel in power plants,
etc. It can be further claimed that the float fraction of 1.60 g/cm$^3$ has also the potential usage in cement industry.

| Size Group (mm) | Medium Density (g/cm$^3$) | Amount (%) | Amount Σ (%) | Carbon (%) |
|----------------|--------------------------|------------|--------------|------------|
| +18.00         | -1.00                    | 31.69      | 31.69        | 8.43       |
|                | -1.30+1.00               | 15.10      | 46.79        | 35.57      |
|                | -1.45+1.30               | 7.34       | 54.13        | 28.20      |
|                | -1.60+1.45               | 12.44      | 66.57        | 28.80      |
|                | -1.90+1.60               | 19.67      | 86.24        | 25.10      |
|                | +1.90                    | 13.76      | 100.00       | 5.57       |
|                | Total                    | 100.00     | 100.00       | 19.40      |
| -18.00+10.00   | -1.00                    | 11.43      | 11.43        | 39.18      |
|                | -1.30+1.00               | 36.29      | 47.72        | 58.84      |
|                | -1.45+1.30               | 17.08      | 64.80        | 24.81      |
|                | -1.60+1.45               | 11.41      | 76.21        | 23.41      |
|                | -1.90+1.60               | 15.35      | 91.56        | 10.51      |
|                | +1.90                    | 8.44       | 100.00       | 3.37       |
|                | Total                    | 100.00     | 100.00       | 34.64      |
| -10.00+6.00    | -1.00                    | 7.40       | 7.40         | 26.86      |
|                | -1.30+1.00               | 35.46      | 42.86        | 50.51      |
|                | -1.45+1.30               | 13.70      | 56.56        | 27.84      |
|                | -1.60+1.45               | 7.30       | 63.86        | 17.05      |
|                | -1.90+1.60               | 18.09      | 81.95        | 12.54      |
|                | +1.90                    | 18.05      | 100.00       | 3.85       |
|                | Total                    | 100.00     | 100.00       | 27.92      |
| -6.00+2.36     | -1.00                    | 3.83       | 3.83         | 25.22      |
|                | -1.30+1.00               | 26.19      | 30.02        | 47.25      |
|                | -1.45+1.30               | 17.30      | 47.32        | 27.86      |
|                | -1.60+1.45               | 9.87       | 57.19        | 21.46      |
|                | -1.90+1.60               | 24.85      | 82.04        | 14.13      |
|                | +1.90                    | 17.96      | 100.00       | 2.73       |
|                | Total                    | 100.00     | 100.00       | 27.23      |
| -2.36+0.50     | -1.00                    | 2.93       | 2.93         | 44.15      |
|                | -1.30+1.00               | 8.51       | 11.44        | 22.26      |
|                | -1.45+1.30               | 6.46       | 19.91        | 41.83      |
|                | -1.60+1.45               | 5.60       | 23.50        | 35.36      |
|                | -1.90+1.60               | 37.23      | 60.72        | 20.12      |
|                | +1.90                    | 39.27      | 100.00       | 4.34       |
|                | Total                    | 100.00     | 100.00       | 19.62      |

Referring to above-cited literature studies about unburned carbon, there have not been a research like this concept, however most of the studies includes bottom ash or fly ash from power plants in terms of unburned carbon. Coal ashes resulting from the domestic heating sources can be mixed with other fuels and it can be raw fuel source for energy production. Decreasing the level of unburned carbon in coal ashes is actually harder than it is considered since modern technology installed boilers also have some amount of unburned carbon at the end of the process. Referring to the both studies by Acma et al. [18] and Acma and Yaman [19], they tried to decrease the level of unburned carbon amounts with a tube furnace in oxygen enriched conditions. However this would not be applicable for domestic heating.
systems, and it can be finally claimed that decreasing the amount of unburned carbon is impossible for these abovementioned purposes of house heating boilers or stoves.

4. Conclusions
The city in the northwest of Turkey, Zonguldak, can be named as the capital in terms of coal mining. Not only thermal power plants located in the city are causing environmental pollution but also the combustion residues of coal utilized in terms of domestic heating purposes are the reason for Zonguldak polluted environment. The cumulative amount of domestic waste of coal ash not only from Zonguldak but also from other cities cannot be underestimated in terms of total recover of unburned carbon. In this study, coal ash samples were collected in the wasteyard and they were analysed in terms of carbon recover. Beneficiation of carbon content of these coal ash samples can be realized with dense medium, i.e. 1.30 g/cm$^3$. Carbon content recovered with sink and float is up to almost 59%. Coal ash should not be dumped into environment due to its harmful content such as selenium and arsenic. This harmful content of coal ash can easily be leaked to the surface or underground water. Carbon recovery should rather be taken into consideration instead of dumping this waste directly to environment. Another contribution of this study is that, dense medium separation can be a pre-enrichment design before sorting, i.e. optical sorting. With further studies, pros and cons of this problem and convenient disposal of coal combustion residues in general, should be discussed in detail.

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