Correlation between Ash Content of Size & Density Fractionated Coal Samples and their Corresponding Calorific Values

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Abstract. In this study, coal samples were collected from 2 coal seams of Üzülmez coal mine of Turkish Coal Enterprise operating in Zonguldak coal basin. Firstly collected coal samples were sieved into 5 size groups (“-100+50”, “-50+18”, “-18+10”, “-10+6”, “-6+0.5” mm). Secondly, float and sink analysis was carried out on each size group coal samples. Zinc chloride solutions with the densities of 1.30, 1.40, 1.50, 1.60, 1.70, 1.80 and 1.90 g/cm³ were used in the order of float and sink analysis. Float and sink analysis on each size group resulted as a total number of 70 coal samples. Thirdly ash content and calorific values of each of this 70 samples were determined. Finally a prediction method of calorific value in terms of ash content of coal sample for Zonguldak coal is proposed. According to the proposed prediction method, calorific value is strongly related to ash content of each coal sample. In other words, one can easily estimate the calorific value of a coal with defined ash content. Correlation between measured and predicted calorific values is statistically significant (R²=0.99). This prediction method of calorific value is going to be very user friendly and confident tool for field engineers, coal consumers and operators of coal cleaning plants. Initial quick estimates of calorific value employing just the ash content within 99% accuracy for a specified coal seam would be a possible. Future scope of this study is to establish an index of ash content and calorific value relevance for each coal seam in Zonguldak Coal Basin.

1. Introduction
Coal is an organic material that has different properties regarding the production site. Coal seams have different proximate analysis data i.e. moisture content, ash, volatile matter and fixed carbon. Proximate analysis of coal is the initial step to determine the coal characteristics and this analysis is carried out for almost all coal seams. Coal seams however may not show the same proximate analysis everywhere since formation of coal is complicated. In order to characterize the coal of a specific coal seam, mean values of coal seam proximate analysis data can be used. Regarding the combustion of coal, calorific value (CV) is the first criteria to be evaluated in order to decide the coal to be combusted.

Coal fired thermal power plants are operating with the specified coals and their boilers are designed to utilize qualified coals. In order to determine the coal quality, plant operators often need the determinations of calorific value, proximate analysis and ultimate analysis. Calorific value is defined as the amount of heat evolved when a unit weight of the coal is burnt completely and the combustion
products cooled to a standard temperature of 298 K [1]. It is usually expressed as higher heating value (HHV) (also termed gross calorific value, GCV. The experimental determination of CV of coal is a cost intensive process and it requires special instrumentation and highly time consuming. In addition it needs practical analyst to operate this special instrumentation and sometimes repetition of the experiment should be realized because of the malfunctioning of the instrument. However proximate analysis data can be obtained rather quickly and easily using an ordinary muffle furnace. In order to avoid these disadvantages of the CV experiments many correlations were developed for determining it from proximate analysis data of coal [2].

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Coal calorific value is important for power plants, for heating purposes of coal i.e. energetic usages of coal. It could be helpful to coal consumers to have a method to predict CV with the raw data of proximate analysis. Number of previous studies was addressed to prediction of CV in terms of proximate ultimate and petrographic analysis of coal. Costa et al. [3] carried out a research to understand the coal characteristics by using using thermal behavior and petrographic composition. Chen and Ma [4] investigated the petrographic characteristics of Chinese coals and the effect of petroglyphic composition on coal utilization processes. Mesroghi et al. [5] studied on the CV prediction using ultimate analysis of coal. Majumder et al. [2] studied 50 coal samples and proposed a method employing proximate analysis data of coal in order to estimate CV. Feng et al. [6] gives a summary of prediction methods of CV in terms of proximate analysis of coals from different countries including Turkey.

In this study an empirical relationship between ash content and calorific values of Zonguldak coals is proposed. This method would help better to identify Zonguldak coals calorific value rather than existing models for other type coals.

2. Experimental Method
Firstly collected coal samples were sieved into 5 size groups (“-100+50”, “-50+18”, “-18+10”, “-10+6”, “-6+0.5” mm). Secondly, float and sink analysis was carried out on each size group coal samples. Zinc chloride solutions with the densities of 1.30, 1.40, 1.50, 1.60, 1.70, 1.80 and 1.90 g/cm³ were used in the order of float and sink analysis. However at some densities no sample was floated. That is why, float and sink analysis on each size group resulted as a total number of 70 coal samples, 35 coal samples from each seam. All of these 70 samples were analysed in terms of ash content and calorific values. Ash content is determined in the order of ASTM D 3174. Each coal sample was ground under 200 mesh in the first step. And 0.5 g was taken from each pulverized coal sample and placed in crucibles and put down in oven for 500 °C for one hour and 850 °C for 2 hours. Ratio between the unburned residue in the crucible and the initial weight of the sample result in ash content percentage. Calorific value determinations on the other hand are more of a tougher to carry out. CV of these samples were determined by Bomb calorimeter (Model Adiabat-350) following the ASTM procedure (ASTM D5865).
3. Results and discussions

Coal samples from 2 different coal seams in Zonguldak were analysed in terms of ash content and calorific values. The results of these analyses are given in Table 1 and Table 2.

Table 1. Results of the ash content and calorific value determinations for Coal Seam A (partly adopted from the study of Sarihan [7]).

| SIZE   | Density | Coal Seam A Ash Content (%) | Calorific Value | SIZE   | Density | Coal Seam A Ash Content (%) | Calorific Value |
|--------|---------|-----------------------------|-----------------|--------|---------|-----------------------------|-----------------|
| -6+0.5 | -1.30   | 5.10                        | 8162.00         | -1.30  | -       | -                           | -               |
|        | -1.40   | 6.40                        | 7805.00         | -1.40  | 13.87   | 7782.00                    |                 |
|        | -1.50   | 16.18                       | 7117.00         | -1.50  | 11.10   | 7452.00                    |                 |
|        | -1.60   | 26.00                       | 6103.00         | -1.60  | 19.90   | 6038.00                    |                 |
|        | -1.70   | 34.70                       | 5327.00         | -1.70  | 36.55   | 5041.00                    |                 |
|        | -1.80   | 42.33                       | 4690.00         | -1.80  | 46.71   | 4497.00                    |                 |
|        | -1.90   | 49.96                       | 3858.00         | -1.90  | 48.19   | 3872.00                    |                 |
|        | +1.90   | 78.98                       | 938.00          | +1.90  | 84.72   | 693.00                     |                 |
| -10+6  | -1.30   | 3.80                        | 8248.00         | -1.30  | -       | -                           | -               |
|        | -1.40   | 8.31                        | 7735.00         | -1.40  | 12.86   | 7743.00                    |                 |
|        | -1.50   | 19.16                       | 6843.00         | -1.50  | 18.59   | 6760.00                    |                 |
|        | -1.60   | 26.42                       | 5977.00         | -1.60  | 30.28   | 6013.00                    |                 |
|        | -1.70   | 37.19                       | 5094.00         | -1.70  | -       | -                           | -               |
|        | -1.80   | 45.91                       | 4388.00         | -1.80  | -       | -                           | -               |
|        | -1.90   | 49.33                       | 3806.00         | -1.90  | -       | -                           | -               |
|        | +1.90   | 80.61                       | 831.00          | +1.90  | 87.62   | 713.00                     |                 |
| -18+10 | -1.30   | 3.79                        | 8221.00         | -1.30  | -       | -                           | -               |
|        | -1.40   | 8.76                        | 7796.00         | -1.40  | -       | -                           | -               |
|        | -1.50   | 17.50                       | 6858.00         | -1.50  | -       | -                           | -               |
|        | -1.60   | 28.33                       | 6057.00         | -1.60  | -       | -                           | -               |
|        | -1.70   | 35.27                       | 5205.00         | -1.70  | -       | -                           | -               |
|        | -1.80   | 40.11                       | 4532.00         | -1.80  | -       | -                           | -               |
|        | -1.90   | 52.69                       | 3793.00         | -1.90  | -       | -                           | -               |
|        | +1.90   | 85.18                       | 679.00          | +1.90  | -       | -                           | -               |
Table 2. Results of the ash content and calorific value determinations for Coal Seam B (partly adopted from the study of Sarihan [7]).

| SIZE     | Density | Coal Seam B | Coal Seam B |
|----------|---------|-------------|-------------|
|          | Ash Content (%) | Calorific Value | Ash Content (%) | Calorific Value |
|          |          |             |              |               |
| -6+0.5   | -1.30    | 3.46        | 8352.00      | -1.30         | 4.33          | 8217.00      |
|          | -1.40    | 6.70        | 7905.00      | -1.40         | 8.74          | 7818.00      |
|          | -1.50    | 16.66       | 7251.00      | -1.50         | 16.79         | 7116.00      |
|          | -1.60    | 38.14       | 4826.00      | -1.60         | 18.30         | 5907.00      |
|          | -1.70    | 34.23       | 5403.00      | -1.70         | 43.17         | 5374.00      |
|          | -1.80    | 29.34       | 5788.00      | -1.80         | 48.06         | 4038.00      |
|          | -1.90    | 50.32       | 3880.00      | -1.90         | -            | -            |
|          | +1.90    | 79.05       | 1079.00      | +1.90         | 85.72         | 449.00       |
| -10+6    | -1.30    | 3.76        | 8327.00      | -1.30         | 4.63          | 8195.00      |
|          | -1.40    | 8.51        | 7840.00      | -1.40         | 6.58          | 7798.00      |
|          | -1.50    | 18.22       | 7174.00      | -1.50         | 14.69         | 7242.00      |
|          | -1.60    | 28.48       | 5949.00      | -1.60         | -            | -            |
|          | -1.70    | 35.43       | 5431.00      | -1.70         | -            | -            |
|          | -1.80    | 39.51       | 4236.00      | -1.80         | -            | -            |
|          | -1.90    | 52.20       | 3817.00      | -1.90         | -            | -            |
|          | +1.90    | 81.98       | 859.00       | +1.90         | 89.34         | 428.00       |
| -18+10   | -1.30    | 4.57        | 8288.00      |               |               |              |
|          | -1.40    | 9.48        | 7851.00      |               |               |              |
|          | -1.50    | 17.47       | 7057.00      |               |               |              |
|          | -1.60    | 30.08       | 6005.00      |               |               |              |
|          | -1.70    | 35.57       | 5398.00      |               |               |              |
|          | -1.80    | 42.71       | 4317.00      |               |               |              |
|          | -1.90    | 51.47       | 3734.00      |               |               |              |
|          | +1.90    | 82.08       | 732.00       |               |               |              |

Second step after obtaining ash contents and corresponding calorific values of each sample is to obtain the relationship between them. Figure 1 and Figure 2 are the representations of the relationship between ash content and calorific value for each coal seam.
Figure 1. Graphical representation of the relationship between ash content and calorific value for each coal sample from Coal Seam A.

Figure 2. Graphical representation of the relationship between ash content and calorific value for each coal sample from Coal Seam B.

Referring to the Figure 1 and Figure 2, as ash content gets higher, lower the calorific value is. Correlation between ash content and calorific value is statistically significant, refer to the R² in each graphs; 0.99 for each coal seams. As for the formulation developed between ash content and calorific value, Equation 1 is proposed for both of the coal seams.

\[
\text{Calorific Value} = (-94)*AC + 8598
\]  \hspace{1cm} (1)

(AC stands for ash content)
Developing Eqn.1 would help to predict easily the same seam coals in Zonguldak as knowing the ash content. Regarding achievement of the Eqn.1 is validated with the comparison between measured calorific values and predicted ones. This comparison is provided graphically in Figure 3.

Majumder et al. (2008) studied for the development of a new proximate analysis based correlation in order to predict calorific value of Indian coals. So, basically this study is the corresponding research of these authors for Zonguldak coals. Although they evaluated some of the other proximate analysis elements, ash content was already enough to make a correlation with calorific value for Zonguldak coals. Calorific value always can be denoted as a function of ash content, because all type of coals have the relation “lower the ash content higher the calorific value”. And this is also supported with the developed equation (See Eqn.1), which is already has minus for ash content. Majumder et al. (2008) study found out a relation of calorific value which has the form of proximate analysis element (ash, moisture, volatile matter, fixed carbon) and ash content is negatively affecting the calorific value.

4. Conclusions
In this study in order to get to know better about Zonguldak coals, and to simplify the prediction of calorific value for specific coal seams, a relation between ash content and calorific value was demonstrated in an equation. This was a reliable and a statistically significant relation. Employing this relationship is user friendly and only the ash content data is needed. Determination of calorific value is already taking so much time and needs labouring. Utilization of coal always performed with market research of good quality coals. Qualification of coals mostly depend on the high calorific value and low ash content. Determination of ash content would be enough with the findings of this study and one can easily come to a conclusion about the calorific value referring to the method developed. Future studies might focus on one specific formulation of all type of coals and combine all other formulations into one.

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