Effect of chemical properties of coal on its combustion behavior

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Abstract

The purpose of this study is to investigate the effect of coal properties on heat release rate and combustion characteristics of coal. Coal sample of the same source was separated based on its size and was subjected to proximate analysis, gross calorific value determination and thermogravimetric analysis to study its combustion behavior. Experimental results show that each size fraction of coal, as typically fired in a power station, has substantially different proximate analysis result and burning profile. Ash content of coal varied from 30.3%-37.2% when the coal size varied from +50 mm to -2.54 mm. Combustion studies show that maximum coal burning rate (DTG max) also varied significantly, from 6.28% to 7.19%, size by size. Maximum burning rate data indicates that an increase in ash content from 30% to 37%, leads to burning time increase from 13.91 to 15.96 minute per kg of coal.

Keywords: Proximate analysis, TGA-DTG, combustion characteristics, burning profile.

1.Introduction

The most signification role of coal power has been in the generation of electricity. Approximately 56% of annual energy generation is from coal, making it the nation's most significant source of electricity. Combustion pattern of any fuel is an important parameter used in the design of burners for any application. Apart from common utilities, oxygen/air flow rates, fuel feed rates and fuel properties are commonly used in the design of industrial furnaces. For coal fired power plants, furnace design is done essentially based on amount of energy required for steam production and amount of heat available from coal per unit mass. Coal combustion process primarily consists of two stages. One is the pyrolysis or devolatilization of the coal due to an applied thermal stress. The second one is the heterogeneous combustion of the remaining char according to carbon oxygen reaction. Thermal analytical techniques such as thermo gravimetric Analysis (TGA) have been used extensively in characterizing the thermal behavior of coals. It is essential in making valid predictions of the thermal properties of coal. The important parameters which are calculated with the help of TGA are the volatile release profiles and burning profile of a coal in combustion chamber. The burning profile provides information about the combustion rate including intensity of reaction, heat release rate and residence time requirement for a coal. It also gives idea about peak temperature, burnout temperature and activation energy of coal and combustible material. Objective of the present study was to characterize and identify the burning and combustion profile of coal from a specific source, with emphasis on the effect of two major proximate analysis parameters of coal such as ash and volatile matter content on its combustion behavior and heat release rate during combustion.

2. Experimental

120 kg ROM coal sample was collected from Nirsa area of Dhanbad. It was crushed to +50 mm using jaw crushers. The crushed coal was mixed manually by using scoop for homogenization purpose. Then the coal sample was divided in two by coning and quartering method. One part was used for size separation and size by size combustion analysis. Another part is being used for density separation by sink–float method followed by density by density combustion analysis. Screens of various apertures sizes were used to generate different size fractions (Table 1) for size by size combustion analysis. Further each size fraction was crushed and ground to -72# (212 micron) and sampled by a sequence of coning and quartering method to prepare representative sample of approximately 60gm. The entire coal sample was subjected to proximate analysis, ultimate analysis, GCV determination and Thermo gravimetric Analysis (TGA). The proximate analysis was done by standard Method (ASTM D3173, ASTM D3174, ASTM D3175). Ultimate analysis was carried out by CHNSO analyzer (Vario EL III Elemental Germany). GCV was determined by using automatic bomb calorimeter (AC 350 Leco USA). The combustion behavior was studied using TGA by heating the coal in presence of oxygen (rate 60 ml/min) at heating rate (10^0C/min).

Derivative Thermo Gravimetric (DTG) analysis at different temperatures can measure the combustibility of coal. A burning profile is a plot of the rate at which a solid fuel sample changes weight as a function of temperature, when heated at a constant temperature, at a constant heating rate. The major characteristic temperatures to interpret a burning profile are as follows. Initiation

Temperature of combustion, at which the rate of weight loss accelerates due to the onset of combustion of char (IT), Peak temperature (PT) where the rate of weight loss is maximum, the burn out temperature (BT), where the weight of residue becomes constant at the completion of combustion. The initial temperature of combustion (ICT) is defined as the temperature at which the rate of weight loss exceeds 1.0 %/min after the initial moisture loss peak. The peak temperature (PT) is defined as the temperature at which the rate of loss is, maximum. Burnout temperature (BT) is the temperature at which the rate of weight loss decreased to 1.0 %/min. Lower these temperatures, it is easy to ignite the coal and better is its combustibility. By knowing the maximum weight loss percentage, it is possible to measure how easily coal reacts with oxygen during combustion. This is called reactivity of coal and it depends on the chemical composition and petrographic properties of coal. The reaction rate can be expressed in a general form, in the case of solid-fluid systems as

$$r_A = \frac{1}{W_0}\frac{dw}{dt}$$

Where, r_A is the maximum reactivity, W_0 is the initial weight ash free basis and (dw/dt) is the maximum rate of fixed carbon loss. Higher is the reactivity, better is the combustibility of coal.

3.0 Result and Discussion

3.1 Characterization of coal

Table 1 shows the variations of ash, volatile matter, fixed carbon and gross calorific value of the coal varying with different sizes of the crushed coal. With decrease in size of coal from +50 mm to 2.54 mm, volatile matter increased from 21 % to 22.8%. Fixed carbon initially increased from 40.9% to 46.4% and then decreased to some extent to the level of 44.4%. Similarly, for ash content it can be noted that, it initially decreases from 37.2% to 30.3% with the decrease in size from -50 mm to -12.5 mm and then increases to some extent 32.1% in case of -2.54 mm coal, possibly because of the larger presence of clay. The variation of fixed carbon, ash and volatile matter with different sizes is due to the uneven distribution of mineral matter and combustibles in coal matrix at larger sizes. During crushing the coal gets crushed differently due to different mechanical strength of mineral matter rich portion and combustible portion (fixed carbon and volatile matter).

Table 1: Size by size characterization of coal

Size ranges in mm	Wt. %	Proximate analysis %				GCV in kcal/kg	Ultimate analysis %				
		Ash	Moist	VM	FC		C	H	N	S	O
+50	1.03	37.19	0.88	20.99	40.92	4869	52.8	3.37	1.26	0.54	3.96
-50+38.1	21.77	33.65	1.10	22.13	43.10	4957	55.64	3.50	1.37	0.51	4.23
-38.1+25.4	27.8	32.00	1.16	22.63	44.20	5247	56.35	3.56	1.41	0.56	4.96
-25.4+19.05	10.16	31.91	1.23	22.48	44.35	5581	57.32	3.6	1.43	0.6	3.91
-19.05+12.7	14.16	30.30	1.24	22.07	46.37	5434	58.06	3.66	1.48	0.6	4.66
-12.7+6	10.51	31.37	1.13	22.59	44.90	5377	58.12	3.52	1.62	0.65	3.59
-6+2.54	5.19	30.76	1.24	22.77	45.21	5038	58.08	3.61	1.46	0.58	4.27
-2.54	9.38	32.09	1.23	22.84	44.05	4341	55.29	3.99	1.93	1.12	4.35
Overall calculated	100	32.04	1.17	22.43	44.36	5158	56.68	3.60	1.49	0.62	4.40

Table 1 also shows the variation of GCV with different sizes. GCV initially increases from 4869kcal/kg (1.0 wt. % coal) to 5581 kcal/kg (10.2 wt.% coal) from +50 mm to -25+19 mm with fluctuation and then continuously decreases to 4341kcal/kg for -2.54 mm (9.4 wt.% coal). Variation of GCV for different size ranges of coal samples is due to the presence of different types of combustibles in coal across the different sizes as represented by volatile matter and fixed carbon. Further Table 1 also summarizes the variation of elemental compositions of elements C, H, N, S, O present in the coal. It is observed that carbon percentage initially increases from 52% to 58% with decreases in size of coal from -50 mm to -25+19 mm and remains practically same for the lower size fractions and finally decreases to 52% for -2.54 mm. This observation is broadly in line with the variation of GCV reported earlier in this section. As carbon molecules are the major source of energy, with increase in carbon percentage in coal, GCV increases and later decreases.

3.2 TGA and DTG analysis

Fig 2 shows the TGA plots of all the size fractions of the coal used. Insignificant weight loss is observed up to 150^0C which is known as moisture peak. As the name suggests which is due to removal of moisture in coal samples, the content being very low (<1.24%) as reported in Table-1. Up to 350^0C temperature around 1-5% weight gain is observed for all samples. This is known as chemical adsorption of O_2 gases in the porous structure of coal. This adsorption helps in combustion by increasing the contact surface area between O_2 and combustibles present in coal. After 350^0C rate of weight loss increases due to release of volatile matter from coal samples, decomposition and devolatilization of less complex organic structure. After moisture peak coal samples irrespective of initial size show maximum weight loss rate (DTG_{max}=6.93%/min) in the temperature range 470-477^0C. After approximately 520^0C weight loss appears to be insignificant as combustible materials completely burn and coal reaches its final ash content. It can be noticed that all the values of IT, PT of coal samples irrespective of size are almost same. Rate of weight loss obtained calculated from DTG analysis shown in Fig 3. Various parameters IT, PT, BT as elaborated in the previous section, were estimated from Fig 3 and summarized in Table 2. It is observed that IT of the coal varies between 359-369^0C with variation in size. Over all variations is about 10^0C. Similarly, PT varies between 471-477^0C and BT varies between 547-550^0C. Over all it can be observed that variation between the sizes is within 3-10^{0}C. The findings signify that combustion behaviors of coal across the various sizes are almost similar.

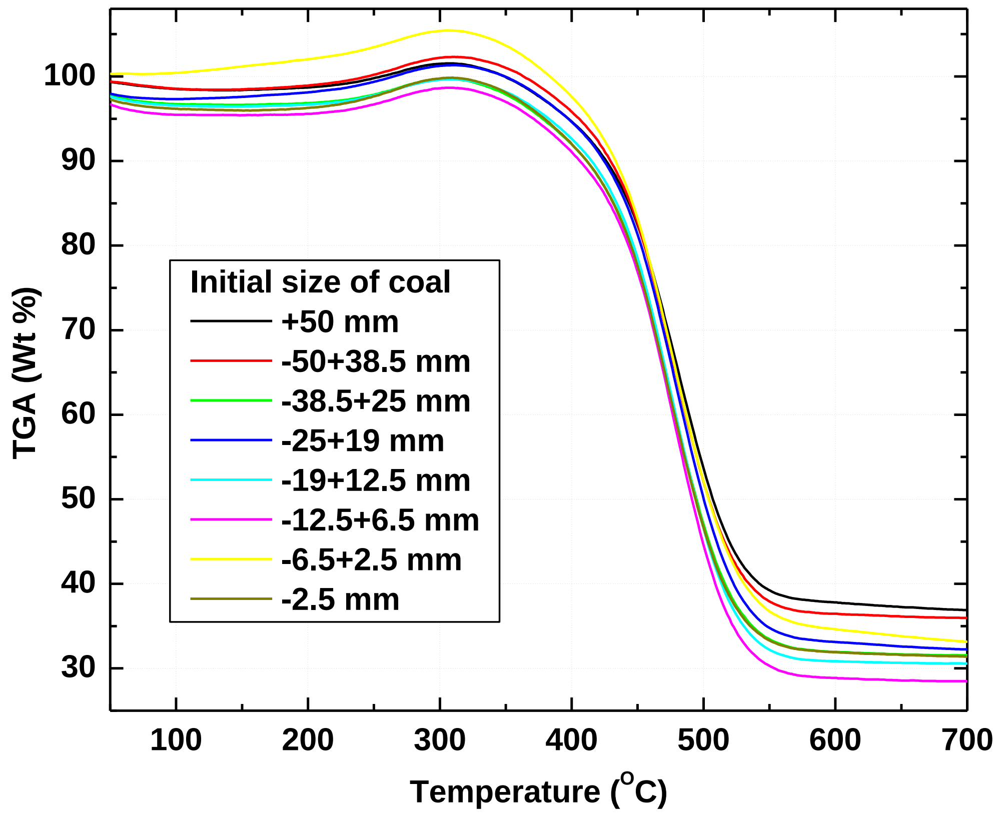

Figure 2: TGA curves of all eight size fractions

Table 2: Size by size values for IT, PT, BT

Size ranges in mm	IT^{0}C	PT^{0}C	BT^{0}C	DTG $_{max}$%/min
+50	366	477	547	6.26233
-50+38.1	369	472	548	6.66847
-38.1+25.4	362	473	547	6.67518
-25.4+19.05	367	477	549	6.85637
-19.05+12.7	367	473	548	6.93592
-12.7+6	360	476	547	7.18985
-6+2.54	361	474	550	6.71524
-2.54	359	471	547	6.71609

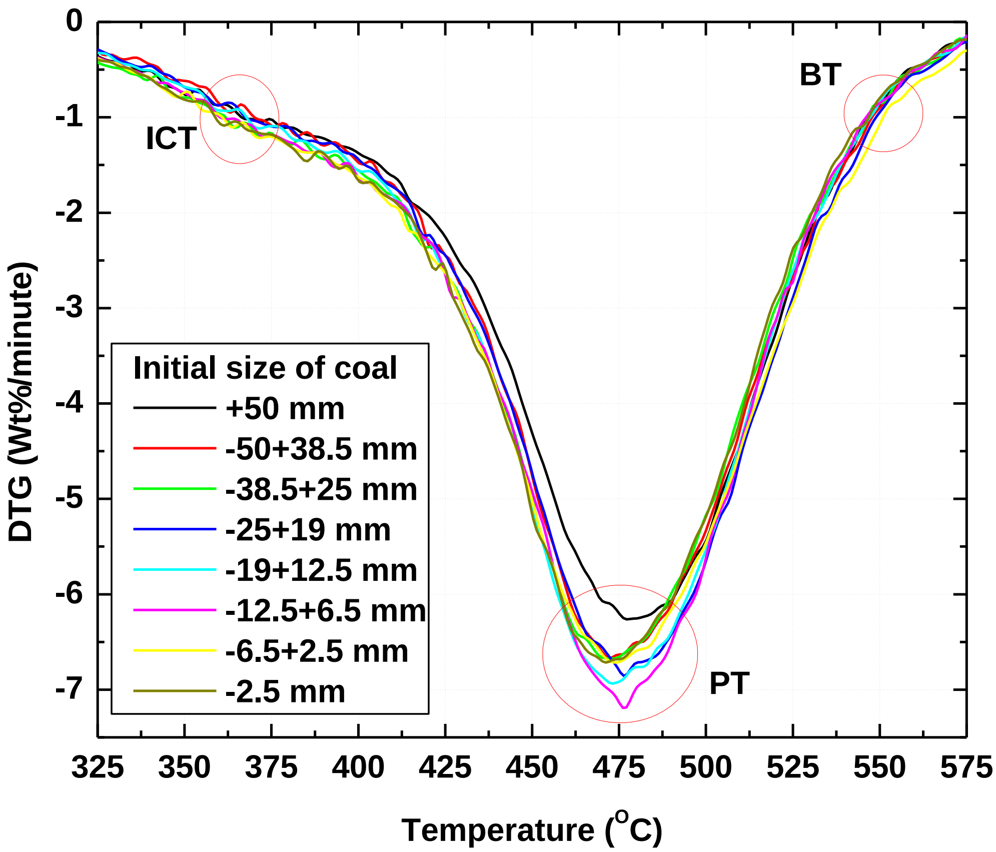

Figure 3: DTG graphs of all 8 samples

3.3Burning time heat release

Fig.4 shows that burning time and approximate heat releasing (in kcal/min) characteristics of coal samples vary with ash content. Increase in ash content requires gradually increasing burning time. Similarly with increase in ash content heat release profile becomes somewhat monotonous, higher ash indicating less heat releasing capacity. Increase in ash content by 10% leads to increase in burning time by about 2 minutes. Correspondingly heat release decreases by 100-120kcal/min. Therefore ash content appears to have a significant effect on burning time and heat release. More is ash more is burning time requirement and less heat release.

4. Conclusion

Based on the experimental results, it can be concluded that, properties of coal contributing to

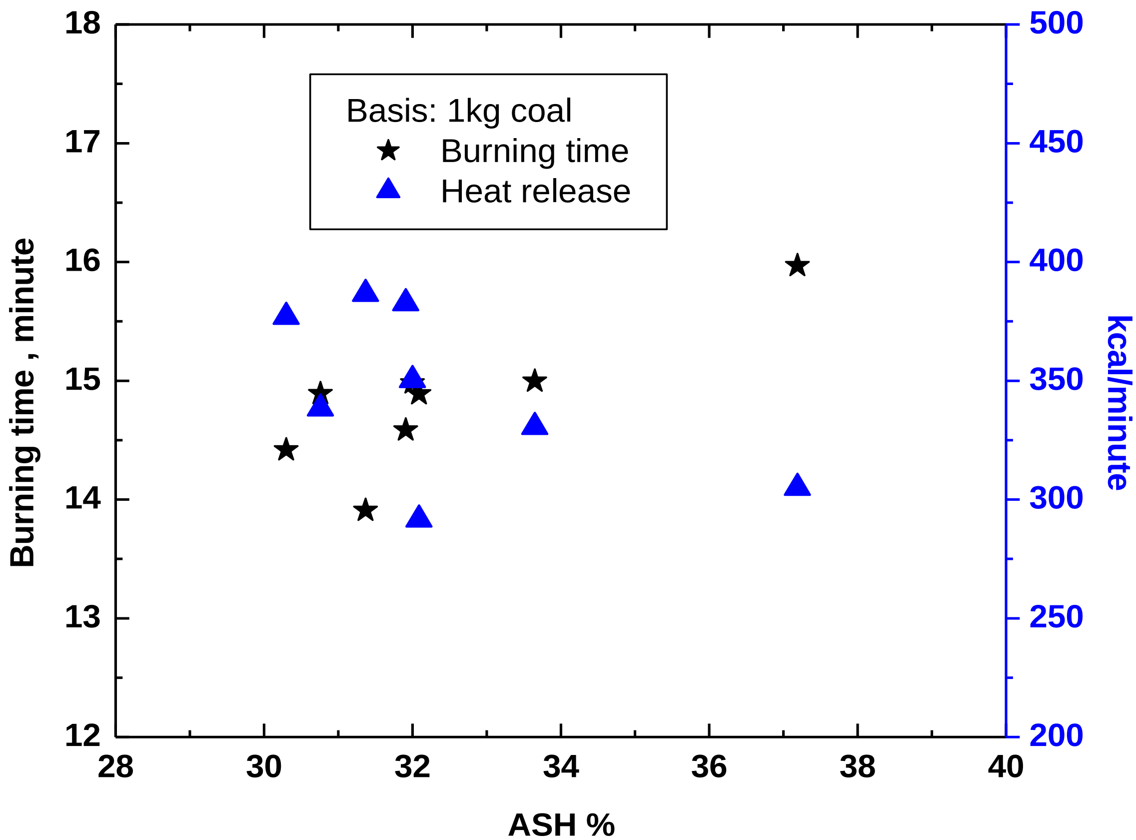

Fig 4: Effect of burning time with respect to Ash%

Combustion varied significantly across the sizes. This is particularly true for ash and fixed carbon in proximate analysis and carbon content in ultimate analysis. Each size fraction of coal shows different burning characteristics irrespective of nearly same volatile matter content. Experimental data support the observation that less variation in volatile matter signifies less variation in ignition temperature. Otherwise combustion behaviors of coal across the various sizes are almost similar. Increase in ash content by 10% leads to increase in burning time by about 2 minutes. Correspondingly heat release decreases by 100-120kcal/min. Therefore ash content and possibly ash composition appears to have a significant effect on burning time and heat release.

5. Acknowledgement

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