Applied Thermal Engineering 60 (2013) 145–151

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

# Evaluation of combustion characteristics in thermogravimetric analyzer and drop tube furnace for Indian coal blends

P. Sarkar*, A. Mukherjee, S.G. Sahu, A. Choudhury, A.K. Adak, M. Kumar, N. Choudhury, S. Biswas

*CSIR-Central Institute of Mining and Fuel Research, Digwadih Campus, Dhanbad 828108, Jharkhand, India*

## HIGHLIGHTS

- Combustion behaviour of Indian coal blends is uncertain and mostly non-additive.
- Choice of blend combination and blend composition is very much crucial.
- TGA gives significant inputs for pre-assessment of combustion behaviour of blends.
- Estimation of low rank inertinite may lead to prediction of burning behaviour.
- Total reactive content holds good correlation with burning characteristics.

## ARTICLE INFO

*Article history:*
Received 13 February 2013
Accepted 26 June 2013
Available online 6 July 2013

*Keywords:*
Coal blends
Carbon burn out
TGA
DTF
Macerals
Total reactive

## ABSTRACT

Availability of low ash coals is diminishing in India very fast. As such, trend of utilization of high-ash coals by blending with low ash coals is rapidly growing in Indian power plants with the growing demand of coal and with emerging environmental strictures to reduce green house gas emission and to restrict the ash limit to a targeted value. Quick decision on acceptance of certain blends in power stations very often leads to various operational problems/uncertainties. To address such uncertainties in coal combustion, three blend combinations of high-ash–low-ash coals have been examined in this study through lab- and bench-scale combustion experiments. Combustion parameters are found to be mostly non-additive. Both synergistic and anti-synergistic combustion characteristics were noticed at different combustion-stages. This study reveals necessity of pre-assessment of certain blends through lab/bench scale studies before those are adopted in power plant. This work also attempts estimation of low rank intertinite (i.e., reactive component of inertinite having Rr $\leq$ 1.30) followed by 'total reactive content' for prediction of burn out characteristics in TGA/DTF. Here, total reactive content is the sum of low rank inertinite and other traditional reactive macerals viz., vitrinite, semi-vitrinite and liptinite. Interestingly, satisfactory correlations between 'combustion parameters' and the 'total reactive maceral content' were found.


## 1. Introduction

Blending in Indian power scenario is becoming more and more important with advancement of time frame. Presently, the ash content of Indian coals used in power stations varies in the range of 30–55%. Average ash content of Indian thermal coals is increasing day by day and to deal with such continuous deterioration of coal quality, ash-based blending strategy is one of the most popular options for Indian power plants. Keeping in view the future power production target and the new technologies to come in power sector, import of thermal coal to India is expected to increase significantly. This will make formulation of blending strategy more crucial. In fact blending of coals for power generation has been adopted as a routine practice in the pulverized coal power stations as it provides the flexibility of accommodating different coal types either for improvement of combustion behaviour or to comply with the environmental stipulations. Practice of blending also attempts to reduce cost, control ash deposition, enhance fuel flexibility and extend the range of acceptable coals. Experience has shown that behaviour of blends very often does not comply with the expected weighted average value of parameters from the pure coals comprising the blend. As a result, desired burn out performance may not sometimes be obtained with the use of blends. Thus, interaction among the coals of the blend has to be accounted for

* Corresponding author. Tel.: +91 326 2388286 (O); fax: +91 326 2381113.
*E-mail address:* pscfri@rediffmail.com (P. Sarkar).

1359-4311/$ – see front matter 
http://dx.doi.org/10.1016/j.applthermaleng.2013.06.054

observed deviations from such averaged behaviour [1–3]. The non-additive behaviour of blends towards combustion is more pronounced in case of blends of widely varying rank and petrographic mix [4]. To understand the nature and variation of interactive effects during combustion of coal blends require the study of some characteristic combustion parameters those affect the combustion efficiency. For a long term strategy for power generation using blends, laboratory and pilot scale experimentations are often recommended to identify the acceptable type of coals and the appropriate blend compositions. Such assessment is very much required to avoid problems in the utility operations.

The indigenous coals that are being used in the Indian power stations are high-ash coals and those are generally inertinite rich [5]. To meet the environmental restrictions on long distance supply of high-ash coals above 34% ash, one of the options is to achieve the target through blending. Setting the ash target only (as blending strategy) calls for judicious approaches and detailed investigations for accommodating highly heterogeneous Indian coals of different types as blend components. As the coal blend often deviates from the expected averaged performance of the constituent coals, use of blends in the utility sector leads to economic losses, limits the utilization potential of fly ash (by-product) and sometimes poses unexpected slagging/fouling problems. It has also been observed that criteria/parameters which have earned a several degree of success in predicting combustion behaviour of single coal, e.g., fuel ratio [1,6], particle size, rank, reactive macerals [7–17], petrofactor [5], etc. usually fail to assess the blend performance as was reflected in earlier studies [1,18]. Thus it would be a right step at the moment, particularly under Indian scenario, to pursue combustion studies with some typical blends for predicting possible deviations from the expected combustion behaviour for a blend combination or for a particular blend proportion. Such investigations with blends of high- and low-rank coals as well as of low- and high-ash coals are essential as the boiler design may or may not permit certain coal blends.

In Indian context, practice of utilization of coal blends are increasing very fast and it is very much needed to address the uncertainties associated with use of different kinds of blend formulations. The effects may be additive or synergistic or anti-synergistic depending upon the nature of the blend-constituents and their proportion. As pre-assessment of combustion behaviour of blends are very much necessary to take judicious decision on utilization of certain blends, an attempt has been made in this paper to evaluate combustion characteristics of coals and their blends by lab-scale TGA (Thermo Gravimetric Analysis) and bench-scale DTF (drop tube furnace) studies.

Moreover it is very difficult to correlate combustion behaviour of blends with constitutional parameters. Although the conventional reactive macerals (viz., vitrinite and liptinite) are known to play a significant role [12,13] towards combustion reactivity, it has also been established that some of the inertinite macerals can show very good reactivity towards combustion, even higher than vitrinite [19]. These inertinites, which are highly reactive towards combustion, have been identified as low reflecting inertinites with reflectance up to 1.30% (where1.30% is a chosen reactive–unreactive boundary) [5,15,20,21]. In this paper a separate attempt has been taken to measure reflectance of inertinite macerals – a technique which utilizes Qwin Image Analysis software. This sort of image analysis technique was earlier adopted by various researchers, e.g., Barranco et al. [17]. Finally, with the estimated amount of 'total reactive maceral content', i.e., total amount of vitrinite, semi-vitrinite, liptinite and reactive inertinite ($Rr < 1.30\%$), this work explores whether there exists any relationship between total reactive content and observed combustion parameters in TGA/DTF.

## 2. Experimental section

### 2.1. Sample preparation

Three Indian coals (A, B, C) of varying rank from high volatile bituminous coal to low volatile bituminous coals were selected for the preparation of binary blends with a high volatile low ash coal (D). The low ash coal D have been blended in the proportion 20:80, 30:70, 50:50,70:30 and 80:20 with each of the three high-ash coals. The binary blend samples have been identified as A/D, B/D, C/D respectively. The powdered samples (<75 μm) were used for both TGA and DTF study.

### 2.2. Proximate and ultimate analysis and petrographic studies

Proximate and ultimate analysis of coals were done using standard procedures i.e., IS: 1350-Part-I: 1984, Part III: 1969, Part IV/1:1974, Part IV/2: 1975. Polarized light microscope (Leica made and DMRXP system) had been used for petrographic measurements. The mean random reflectance (Rr%) was measured under oil immersion (IS: 9127-Part 5: 1986/ISO 7404-Part 5: 1994). And the macerals were measured (IS: 9127-Part 3: 2002/ISO 7404-Part 3: 1994) using both white light and fluorescent light irradiation in same system (IS – Indian Standard, ISO – International Standard Organization). The reflectance of inertinite was measured using grey value technique with two standards applying Qwin Image Analysis software [5]. After obtaining reflectance pattern of inertinites, reactive part of inertinites (i.e., the inertinites having reflectance value less than 1.30%) was estimated which may be termed as reactive inertinite content. Total reactive maceral content (or 'total reactive content') of the samples were estimated as the total amount of vitrinite, semi-vitrinite, liptinite and reactive inertinite ($Rr < 1.30\%$), each estimated on mineral matter free basis. The total reactive content of the blends have been calculated based on the total reactive contents of component coals and their proportional maceral contribution in blend samples. For this care has been taken to assure uniformity of blending. It has also been checked that calculation of total reactive content (volume %) of the blends using blend composition in weight ratio instead of using the blend composition in volume ratio does not introduce significant error in the assessment.

### 2.3. Thermal analysis, DSC/TGA/DTG

Combustion behaviour of four coals and the blends were studied with 50 ml/min air flow in a simultaneous thermal analyzer (model STA409C, NETZSCH, Germany). The TGA thermogram was analyzed to determine the relevant combustion parameters like $T_i$ (temperature in the initial phase where rate reaches at 1.0%/min) [1,17], burn out temperature ($T_b$, temperature at terminal phase where rate reduces to just 1.0%/min) [4,7,22] and $T_{50}$ (temperature at the level of 50% loss of combustibles) [23,24].

### 2.4. Drop tube furnace study

The burning behaviour of the coals and their blends were studied in a drop tube furnace (DTF). The details of the DTF have been described elsewhere [4,20]. The DTF used in this study consists of a ceramic tube of length 2500 mm and ID 100 mm having five zones. All the five zones are heated electrically by externally heated canthal wire and the temperature in all five zones could be raised up to 1100 °C. After each zone there was provision of sample (solid and gases) collection through water-cooled probe. The specially designed water-cooled probe having vacuum pump and cyclone was used for collection of solid samples.