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Research Paper

Novel technique for assessing the burnout potential of pulverized coals/coal blends for blast furnace injection

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ABSTRACT

It is imperative to achieve high coke replacement rates in blast furnaces which in turn are strongly influenced by the effects of combustibility of pulverized coal/coal blend due to extremely short residence time in the raceway. To overcome this issue, authors have developed a new methodology based on intrinsic properties of coal/coal blend to assess the suitability of pulverized coal injection grade coal for blast furnace application, named as Composite Burnout Potential (CBP). The CBP values evaluate the combustibility of a coal/coal blend in a vertical drop tube furnace at three different oxygen concentrations viz., 21%, 25%, and 31%. The results confirm that CBP and burnout of coal /coal blend are in close proximity. Drop tube furnace data was used for development and validation of the CBP model. The technique was successfully used for predicting the combustibility of coal/coal blend for better application in the blast furnace.

1. Introduction

The worldwide effort has been focused on efficiently counter the problems related to all coke operations and to reduce the energy cost; coal injection founds a potential avenue. Coal injection has become an integral part of blast furnace (BF) operation for replacing a part of metallurgical coke by injecting pulverized coal injection (PCI) grade coals in the blast furnace. It provides the possibility of substituting the more considerable amount of coke as compared to other fuels because of the less endothermic reactions occurring at the raceway. Under Indian conditions, PCI will significantly help in conserving the fast depleting scarce coking coal reserves and intensifying the blast furnace operation. The productivity of Indian blast furnaces is low as compared to the global average and operates at lower PCI rate. Hence, it is possible to increase PCI rate with increase in hot blast temperature and oxygen enrichment level to improve the blast furnace productivity.

Several studies had been conducted to investigate the role of coal properties during combustion in a blast furnace and related environmental issues [1–7]. The combustion efficiency can be controlled by modifying the location and the mode of injection lances [1,5] using oxygen-rich and hot blast gases [4]. High PCI operations often lead to lower combustion efficiency due to insufficient stoichiometric conditions [6] and short residence time (20 ms) in the raceway [1]. However, some operational difficulties might prevent the increase of PCI rate [8–10]. One of the critical operational issues to be addressed is the unburned char inside the stack of the blast furnace, which can cause several problems, such as reduced permeability, undesirable gas/temperature distribution and cohesive zone shape, excessive coke erosion and significant coal carryover [11–13].

The majority of blast furnaces inject coal blends in pulverized condition, rather than single coal, for optimizing the combustion level and also overall cost of fuels [14]. The burnout of coal influenced by several factors like particle size, fuel ratio, ash content and several other properties including volatile matter, carbon structure, rank and maceral composition of individual coals and it cannot be estimated by using the single parameter [15,16]. Unexpectedly, on some occasions, low-volatile coals displayed a better combustion performance [17,18]. Several studies reported that overall burnout of the blend is slightly higher than that of three component coals. It is because of the so-called synergistic combustion which was observed for binary coal blends experimentally [19,20] and explained numerically [21]. The relatively high volatile coals devolatilize earlier and generate a high-temperature field, which

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Table 1
Important properties of individual coals.

Sample ID	Coal A	Coal B	Coal C	Coal D	Coal E	Coal F	Coal H	Coal I	Coal J	Coal K	Coal L	Coal M	Coal N
Inherent Moisture, %	1.6	2.1	1.7	3.1	1.4	3.1	2.2	1.7	1.3	1.5	1.7	2.29	2.16
Ash, %	11.1	10.4	7.1	10.3	10.0	8.7	10.4	9.5	9.3	14.9	8.7	14.77	15.42
Volatile Matter, %	19.7	17.8	35.4	29.8	13.7	19.5	15.2	9.0	16.1	27.4	18.7	10.8	5.1
Fixed Carbon, %	67.6	69.7	55.8	56.8	74.9	68.7	72.2	79.8	73.3	56.20	70.9	72.14	77.32
Carbon, %	77.2	78.6	76.5	71.1	79.5	78.8	78.92	80.49	80.02	72.20	79.7	76.82	77.26
Hydrogen, %	4.0	3.9	5.2	4.5	3.8	3.7	3.82	3.35	3.71	4.68	4.03	3.35	2.10
Sulphur, %	0.69	0.49	0.82	0.36	0.34	0.17	0.62	0.61	0.5	0.84	0.52	0.46	0.18
Nitrogen, %	1.3	1.3	1.1	1.8	1.7	2.2	1.66	1.78	1.75	1.82	1.74	2.08	1.40
Oxygen, %	4.2	3.2	7.6	8.8	3.2	2.5	1.34	2.57	2.49	2.60	2.70	2.64	2.64
HGI	89	90	49	62	77	78	104	85	90	96	84	57	48
GCV, kcal/kg	7390	7420	7620	6910	7540	7340	7350	7480	7650	6970	7630	6750	6350
CSN	3.5	3.5	4.5	0	1	2.5	2	0	3	4.5	1.5	1	0

enhances the coal combustion of relatively low volatile coal and then the blend [22].

Many researchers have tried to develop the relationship between petrographic composition and burnout efficiency of coal [23–30]. Vitrinite maceral has been reported to burn readily [31], inertinite macerals have often been associated with burnout problems [32], although the rate of burnout will usually decrease as is reflectance increases [33]. Nevertheless, this is not always the case, and although it is useful to obtain the maceral composition of coal, other aspects also affect the reactivity of maceral groups such as its origin and rank. As a result, maceral content of coal may not singularly predict its combustion behavior. However, it is well known that the significantly higher proportions of inertinite present in Australian coals are highly reactive [34].

Several preliminary tests were performed for considering the fuel aspects such as ignition behavior [35–37], thermal reactivity, reaction rates, burnouts and ash fusion characteristics to be familiar with the combustion behavior in the raceway of the actual blast furnace. Researchers also tried to simulate the flow and combustion of binary coal blends under the conditions of this test rig through CFD model [21,38]. Nevertheless, this model was not able to simulate the combustion of coal blend for a broader range of coals due to model's limited applicability. In the past, the effect of some operational parameters, such as hot blast temperature, oxygen-enrichment in the hot blast and coal blending on coal combustion was studied [38,39]. The study provided a cost-effective way for the exploration of pulverized coal injection in the blast furnace.

The combustion behavior of pulverized coal blend in blast furnace has also been investigated using computational fluid dynamics (CFD), and the developed model has been validated by experimental data in a real blast furnace [40]. It was also reported that the combustion behavior of coal/biomass was simulated based on numerical modeling [41–48]. It was also reported that drop tube furnace (DTF) had been widely used for assessing their suitability for PCI grade coal/blend [14,40,49–62]. Few study emphasized on the effect of oxygen enrichment on combustibility of coal/blend. It has been reported that burnout efficiency of the coal blends did not change linearly with the volatile matter of blends. This unexpected combustion behavior cannot be understood entirely regarding the current understanding of coal properties, including their organic and inorganic compositions. Therefore, the burnout efficiency of a coal blend is more complicated than a single coal. Each of the coal components devolatilizes and combusts at different temperatures a, and hence their burnout could vary considerably.

The present study aimed to assess the combustion behavior of the coals/blends at different oxygen concentrations in a vertical DTF to simulate the PCI coals, as all blast furnaces don't operate at constant oxygen enrichment. Also, another objective of this study was to develop a methodology for assessing the burnout potential of coals/blends for efficient utilization in the blast furnace.

2. Experimental

2.1. Sample preparation

Thirteen coals (named as A, B, C, D, E, F, H, I, J, K, L, M, and N) of −20 mm and about 200 kg each were used in this study. The coals were crushed in a Jaw crusher and subsequently in double roll crusher to get a product of −3 mm size. Product coals were then pulverized to −16 mesh and −72 mesh samples for characterization study. These samples were ground in a ball mill to produce a product of 80% passing through 200 mesh for drop tube furnace test. Binary blends are prepared by mixing of coals in different proportions followed by grinding.

2.2. Characterization of samples

Selected coal samples were characterized by physical, chemical, ultimate analysis, free swelling index (FSI), hard grove grindability index (HGI) and gross calorific value (Table 1). For each sample, the petrographic analysis viz. mean Ro percentage; macerals and v-step distribution was also carried out by standard methods (Tables 2 and 3).

2.3. Grinding study

A batch ball mill was used for grinding study of coal/coal blend. The raw coal (−6 mm) fed into the ball mill and time is optimized to get the desired particle size distribution (about 80% passing through 200 mesh). Depending on different HGI value, grinding time was optimized. The second set of study, blend of varying coal in various proportions are fed into the ball mill for optimizing the particle size and grinding time.

2.4. Combustion studies in thermogravimetric analysis

A thermal analyzer (model: STA 449F3 Jupiter, NETZSCH, Germany) was used for assessing the combustion behavior of coal/coal blend. The required quantity of samples was heated up to 800 °C at a constant heating rate (10 °C/min) under a constant air/enriched oxygen (31% O_2) at a flow rate of 50 cm^3/min through the sample chamber. The thermograms were analyzed to determine various thermal parameters such as initial temperature (Ti), DSC peak temperature, DTG peak temperature and burnout temperature (BOT). The maximum rate of weight loss has been expressed as the reactivity parameter; Rmax indicates the maximum rate of burning at