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Composition, mineral matter characteristics and ash fusion behavior of some Indian coals

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HIGHLIGHTS

- Evaluation of chemical and mineralogical compositions of coal samples of India.
- Correlation of chemical and mineral composition to ash fusion temperatures.
- Identification of mineral phases present in coal and ash samples.
- FactSage prediction of equilibrium phase transformations and ash fusion behavior.

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ABSTRACT

The present study aims to evaluate the chemical and mineralogical compositions of coal samples collected from three different seams of a particular borehole of Samaleswari Block, Ib river coalfield, Odisha, India. Different experimental and theoretical studies were conducted to predict and correlate the chemical and mineral composition of coal ash to ash fusion temperatures. The experimental techniques used include proximate analysis, ultimate analysis, gross calorific value determination and chemical analysis of coal ash for quantification of major oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, SO_3 and TiO_2. In addition, X-ray diffraction (XRD) and electron probe micro analysis (EPMA) techniques were used to identify the mineral phases present in coal and ash samples. Finally, FactSage Thermodynamics Model (FactSage 6.3) was used to understand the ash fusion behavior and to predict the phase transformations that occur during the process of coal combustion.

1. Introduction

Coal is the dominant energy source and one of the major natural resources available in India. Nearly 55% of country's primary commercial energy supply and about 70% of total electricity generation is from coal [1,2]. Therefore, detail information on elemental and mineralogical composition of Indian coal is essential to optimize coal utilization technologies such as combustion, gasification, liquefaction and coking as well as for environment considerations. The quality of Indian coal is generally poor having high ash content (ranging from 30% to 50%), high moisture content (4–20%), low sulfur content (0.2–0.7%), and low calorific values (between 10.5 and 20.9 MJ/kg) [1,2]. Indian coal seams are generally inter-banded with mineral sediments and amount of ash in coal increases as one move from the core of the coal seam to its floor, hence, the quality of coal gets worsen with increasing depth [1,2]. Although some preliminary studies have been carried out on petrographic characteristics and mineral matter content of Indian coals [3–6], little information has been published on the nature and relative proportions of the individual minerals, the modes of mineral occurrence, and the associations between the different groups of minerals present within the Indian coals.

During burning of coal, minerals undergo thermal decomposition, fusion, disintegration and agglomeration. This causes major industrial problems such as ash clinkering, slagging, fouling, agglomeration, and deposition on heat exchange surfaces. The nature and distribution of mineral matter in coal determines the degree to which these problems are likely to occur during coal combustion [7]. Ash fusion temperatures (AFTs) are the parameters commonly used to predict the behavior of coal ash (ash fusibility and melting behavior) during the processes of coal combustion, gasification, liquefaction and ash utilization. It is more or less established that AFTs depend strongly on the chemical composition of

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coal ash and a number of studies have found empirical and statistical correlations between coal ash compositions and AFTs [8–11]. Many experimental techniques like scanning electron microscope (SEM), energy dispersive X-ray spectroscopy analyzer (EDX), X-ray diffractometry, thermogravimetric analyzers [12–17] and some theoretical models like thermodynamic computer package FactSage, partial least-squares regression method, back propagation neural network model [18–20] have been used to either predict or calculate AFTs from chemical composition of coal ash. However, correlation between mineral matter composition and ash fusion temperatures has not been reported so far for Indian coals.

The present study aims to evaluate the chemical and mineralogical compositions of coal samples collected from three different seams of a particular borehole of Samaleswari Block, Ib river coalfield, Odisha, India. Subsequently, different experimental and theoretical studies were conducted to predict and correlate the chemical and mineral composition of coal ash to AFTs. The experimental techniques used include proximate analysis, ultimate analysis, gross calorific value determination and chemical analysis of coal ash for quantification of major oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, SO_3 and TiO_2. In addition, X-ray diffraction (XRD) and electron probe micro analysis (EPMA) techniques were used to identify the mineral phases present in coal and ash samples. Finally, FactSage Thermodynamics Model (FactSage 6.3) was used to understand the ash fusion behavior and to predict the phase transformations that occur during the process of combustion.

2. Geological setting

In the mineral map of India, the state of Odisha occupies an important position in terms of both deposit and production of coal. The coal samples used in the present investigation were collected from Samaleswari block of Ib valley coal field, Odisha, India. The coal field falls within latitude of 220 03′ 32″ & 220 04′ 11″ (N) and longitude of 830 42′ 18″ & 830 44′ 08″ (E). The coal bearing strata are made up of different coal seams as shown in Fig. 1. Coal samples were collected from three different seams, C1 (depth: 20–24 m), C15 (depth: 100–140 m) and C96 (depth: 217–260 m).

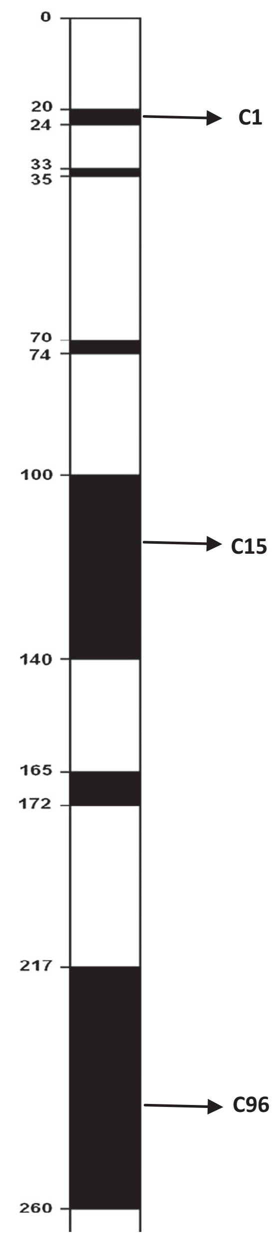

Fig. 1. Stratigraphy of the Samaleswari block of Ib valley coal field, Odisha, India and its coal seam nomenclature.

3. Materials and methods

3.1. Preparation of coal samples

Coal samples collected from three seams C1 (depth: 20–24 m), C15 (depth: 100–140 m) and C96 (depth: 217–260 m) were crushed, pulverized and passed through 72 mesh sieve using a sieve shaker. The method of sampling and sample preparation for the chemical analysis was according to Indian Standard (IS: 436, 1964). Coal samples were ashed by heating at 750 °C in air for 1 h in a muffle furnace as per ASTM D3174-11.

3.2. Chemical characterization

Proximate analysis on air dried basis was conducted using TGA-1000 automated proximate analyzer (Navas Instruments, USA). Ultimate analysis was conducted using Vario EL III CHNS analyzer (Elementar GmbH, Germany). The gross calorific value was determined using Parr 6200 bomb calorimeter (Parr, USA). Chemical analysis of major inorganic elements present in coal and its ash samples were carried out by using VARIAN Vista MPX Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) after microwave digestion as per ASTM D6349-09.

3.3. Mineral matter characterization

Mineral matter composition of the coal and its ash samples were determined using D8 Discover XRD instrument (Bruker, Germany). Ni-filtered Cu Kα was the radiation source and the scan was performed at 2θ range of 10–70° at a scan rate of 2°/min. High Score Plus software package was used to analyze the XRD curves. Localized determination of mineral grain size and mineral composition present in coal samples and its corresponding ash samples was carried out using electron probe micro analyzer (EPMA) model JXA 8230, JEOL, Japan.

3.4. Measurement of ash fusion temperatures

Ash fusion temperature determinator (AF 700, LECO, USA) was used to investigate AFTs of coal ashes under oxygen atmosphere. The procedure involves heating an ash cone at 15 °C min^{-1} up to