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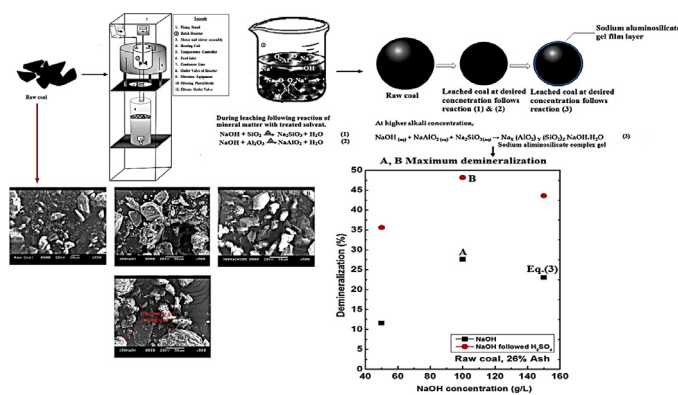
Chemical demineralization of high ash Indian coal by using alkali and acid solutions

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HIGHLIGHTS

- Adequate demineralization of high ash coal obtained by acid and alkali treatment.
- Degree of demineralization depends on coal particle size and process conditions.
- More than 50% minerals present in coal are leached out by acid/alkali treatment.
- The sodium complex formed restrict the demineralization at higher alkali solution.
- The calorific value increased with the degree of demineralization.

GRAPHICAL ABSTRACT



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ABSTRACT

In the present work an attempt have been made to upgrade the low grade Indian coal to high grade coal by using caustic (NaOH) leaching followed by acid (H₂SO₄) treatment. The experimental works aimed at a selective attack on in situ MCL (Mahanadi Coal Limited) coal, Odisha, India with some fluxing agents like NaOH and H₂SO₄. The leaching experiments were carried out in a stainless steel batch reactor of 2.5 L capacity with controlled heating facility. Initially, the coal sample with –16+100 mesh particle size was leached with 50–150 g/L of NaOH solution at 100 °C for one hour and then subjected to leach further with 20% sulfuric acid. The maximum demineralization from the level of 26% ash with NaOH (100 g/L) leaching 27.5% is achieved and with combined chemical treatment method (100 g/L NaOH followed by 20% H₂SO₄) was obtained 48% effectively. In addition, the results showed that the percent of demineralization improved adequately by decreasing the particle size also with rise of the leaching time and temperature. Coal characterization of raw and treated coal was done by Scanning Electron Microscopy (SEM)/ Energy Dispersive Spectroscopy (EDS) analysis and also showed that the calorific value of coal was increased with increase the percent of demineralization of coal.

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1. Introduction

The low cost and availability of low grade coal are best feed materials for fuel and energy production. The high ash coals are unsuitable for use in combustion, gasification, carbonization or liq-uefaction process. However these coals have several drawbacks

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like lower specific energy due to low carbon content, highly mineral and moisture contents and also low calorific value [1–6]. Coal contains variable amounts of largely incombustible mineral matter co-existing with the organic matrix called as impurity. Mineral matter is consist of all the inorganic minerals (discrete phases), as well as all elements (apart from C, H, O, N and S) that are in, or associated with, coal. The mineral matter in coal exists in different forms such as the coal discrete crystalline particles, amorphous mineral phases, inorganic elements chemically bound to the organic material and compounds dissolved in the pore or surface water of the coal [7]. Clay minerals are the most abundant mineral species and quartz is the second most abundant mineral phase in the coal [8,9]. Except this, other mineral matters are also found in the original coal that includes silicas or shales (kaolinite type), calcite, gypsum, siderite, carbonates, pyrites, disulfides, sulfides, sulfates, feldspars and trace elements [5,10].

The presence of mineral matter in the coal has adverse affects on coal utilization and processing. Mineral matter is the inert solid material in the coal which form ash during combustion [11]. The effects of treatments on different forms of the mineral matters may be different from coal to coal. It is difficult to reduce ash content to a minimum limit by physical method because the ash forming mineral are intermixed to the organic part of coal. In the physical method the coal is crushed into fine particles and the removal of mineral matter based on their physical properties like surface phenomena (wettability) and specific gravity [12–14]. It is only possible in the chemical method for removal of associated mineral and bound to coal matrix or structure. The mineral species is dissolute in water acid or alkali solution in the chemical method. The method used in the chemical cleaning of coal include acid leaching or alkali leaching and or followed both acid and alkali at varying physical parameters. It is more expensive than physical methods concerning of total cost (fixed and operating cost). Chemical cleaning of coal is using simple equipment and an aqueous solution of common industrial chemicals and operation is easier when it operate under mild condition but the cost of chemicals needed [15].

A review of the literature on the chemical leaching of coal reveals that the methods of acid and aqueous alkali or combined leaching under moderate temperature and pressure conditions to demineralize and desulfurize from various coals is suitable technique. Sharma et al. reported the method of chemical leaching of low grade coals through alkali-acid leaching under mild condition at atmospheric pressure resulting 75% demineralization [4]. Araya et al. observed demineralization of sub bituminous coal from the La Union are treated with aqueous alkali, and the elimination of ash increases with reaction time, temperature and concentration of solution [16]. Various organic acids and aqueous alkali used in the demineralization studies for production of ultra clean from different types of coal reported by (Steel and Patrick, steel et al., Nabeel et al.) and also the removal of mineral matter during chemical leaching depend on the coal characteristics, types and quantity of mineral matter, size of coal particle, and solvent concentration and contact time of leaching [17–20]. Culfaz et al., observed from investigation the effect of temperature, caustic concentration and time on the degree of demineralization of Turkish low and high grade lignite coal (Beyazari 35.6% ash, and Soma 7% ash) are treated with Caustic and after washed with HCl solution. In the effect of caustic treatment, most of silica (SiO_2) and calcium oxide (CaO) in the ash were removed. However, most of iron oxide (Fe_2O_3) and Sodium oxide (Na_2O) remained in the coal matrix. The degree of demineralization was obtained 90% for both coal seams [21]. Karaca et al. studied the leaching effect of hydrogen peroxide (H_2O_2) on Turkish two lignites (Beyazari and Tuncbilek

seam) and Investigated the effect of concentration, contact time and temperature on the removal of ash and sulfur. They reported maximum demineralization was achieved from 30 to 70% from lignite coal type [22]. Onal et al. studied six Turkish lignite coal were treated with HCl or $\text{CH}_3\text{CH}_2\text{ONa}$ solution at 150 °C. They concluded from the investigation, HCl treatment was effective demineralization but not $\text{CH}_3\text{CH}_2\text{ONa}$ while effective desulfurization by $\text{CH}_3\text{CH}_2\text{ONa}$ treatment but not HCl [7]. Adeleke et al. reported the effect of multistage caustic leaching of Nigerian Lafia-Obi coal. The average ash reduction was achieved 38.66% at low molar concentration 1:20 mass reagent ($\text{H}_2\text{O}-\text{Na}_2\text{CO}_3-\text{H}_2\text{O}$) to coal in the absence of stirring [23].

A literature review revealed that the demineralization of coal can be improved by chemical leaching process. Several authors' has been studied the demineralization with low ash coals to generate ultra clean coal while, in the present investigation we select high ash Indian coal. Since the Indian coals are high ash content and the nature of low ash coal is completely different from Indian coal. In the present communication, an effort has been made to investigate the effect of alkali concentration and followed by acid treated on the demineralization of high ash coal by varying leaching temperature and contact time and also particle size. The characterization of raw and leached coal was analyzed by SEM-EDS and XRF analysis.

2. Material and methods

2.1. Materials

In the present investigation, the coal sample were collected from Bhubaneswari OCP (Open Cast Project) of Mahanadi Coal Field (MCL), Orissa. The coals were crushed in a ball mill and sieved to $-16+100$ British standard sieves (BSS) mesh size particle, was used for conducting the experiments. Before the actual start of the experiment, the coal sample was characterized by using standard proximate (ASTM D3172 – 13) and ultimate (ASTM D3176 – 15) analysis method. The results are summarized in Table 1. The chemical reagent used in the present work is the commercially available sulfuric acid (98% concentration by wt.%) and sodium hydroxide pellets.

2.2. Experimental set up and procedure

The leaching experiments were conducted in a bench scale unit consist of a batch reactor of capacity 2.5 L with heating facilities, condenser provision for reflux and temperature measured by a thermometer. The batch reactor made up stainless steel reactor (SS-316) which consist of 0.11 m diameter and 0.22 m height with Teflon coating inside. The reactor is heated with four heating coils

Table 1
Chemical analysis of coal sample.

Bhubaneswari coal seams	
<i>Proximate analysis (wt%, dry basis)</i>	
Ash	26.3
Volatile matter	38.7
Fixed carbon	35.0
<i>Ultimate analysis (wt%, daf)</i>	
Carbon	52.9
Hydrogen	4.5
Nitrogen	1.5
Sulfur	1.3
Oxygen (by difference)	39.8
Calorific value (kcal/kg)	4632

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