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Effect of elevated temperature and pressure on the leaching characteristics of Indian coals

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HIGHLIGHTS

- It was possible to reduce the ash content up to 70% by this method.
- Silica and alumina content reduces by nearly 51.3% and 58.8% respectively.
- The product coal was not contaminated by alkali content.
- Significant reduction in phosphorus content observed after the acid treatment.
- The crucible swelling number of the feed coal does not get significantly affected after the alkali and acid treatments.

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ABSTRACT

The Indian coal washing circuits are cursed with the availability of high ash coals having poor liberation characteristics as feed material. This result in unacceptably very low product yield (i.e. 10–15%) when aspiring for low ash clean coal (around 8–10%) for efficiently utilising it in iron making process in the form of coke. In this context, a chemical beneficiation route has been explored for demineralising high ash Indian coals. In this work, the effect of aqueous alkali leaching followed by acid washing on the removal of mineral matter from two different captive coals of Tata Steel at elevated temperature and pressure have been explored. The research study revealed that it is possible to reduce the ash content up to 70% by this method. The effect of process conditions such as alkali concentration, temperature and pressure upon the demineralisation kinetics have been investigated. The alkali content of the product coal does not increase whereas the silica and alumina content reduces by nearly 51.3% and 58.8% respectively. Significant reduction in the phosphorus content is observed after the acid treatment. The process does not significantly affect the crucible swelling number index for coking property of coal.

1. Introduction

The Indian steel industry is growing at a rapid pace and is expected to be the second largest steel producer in the world after China. To cope up with this growth and also, to sustain it, the industry needs to focus on sustainable development, i.e., to meet the present need without compromising on the ability of the future generations to meet their own needs. Raw materials, particularly coal, play a vital role towards overall economics of an integrated iron and steel making plant in India. About 35–40% of the cost of crude steel is on account of coal. Major problem with Indian coals is with its high ash content. High ash in coal is not desirable. It leads to drop in blast furnace productivity and increase in energy consumption. It also leads to more CO_2 emission and generation of more of solid wastes causing hazards to society and environment. In addition, over time the calorific value and the ash content of thermal coals in India have also deteriorated as the better quality coal reserves are getting depleted as surface mining and mechanisation expand. This poses significant challenges. Physical coal beneficiation or washing is the process of removal of undesirable material from the Run-of-Mine (ROM) coal by employing the separation processes which are able to differentiate on the basis of the physical and the surface properties of coal and impurities. Through coal preparation, a uniform product is achieved. Washing of such coals is invariably practiced to bring down the ash content to a desirable value. Although an ash content of about 10–12% in the

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clean coal is most desirable from iron and steel making point of view, the same could not be practiced mainly due to very high drop in yield of clean coal during the washing as the inorganic or ash constituents of Indian coals are finely disseminated through the organic or carbonaceous constituents [1,2]. This makes the process uneconomical and environmentally unfriendly. As a result, most of the Indian steel companies are depending on import of metallurgical coal from Australia, New Zealand, etc. However, due to high price of imported coals, the companies are losing in their cost competitiveness in the global market. Coal security is also a major threat for these companies in coming years. In light of the many benefits associated with the beneficiation of coal, considerable interest has been given in recent years to the development of processes that are capable of improving the quality of coals produced and used in India. As a result, enormous efforts are being extended to make coal a better source of energy by removing the mineral matter. Accordingly, improvements in the physical beneficiation processes have been attempted as well as chemical coal beneficiation processes have been explored. Physical beneficiation techniques such as dense media cyclone (DMC) and froth flotation highly depend on the liberation characteristics as well as the surface properties. Further, they are operated on the basis of trade off between ash content and yield. Hence, the production of low ash coal is not practically achievable in the process like DMC and froth flotation.

The typical physical beneficiation circuit of an Indian coal washery is depicted in Fig. 1. At present, Tata Steel's washeries, using physical beneficiation techniques produce coal with ash level of 14–15% at 35–40% yield. Producing low ash coal below 8% ash level, using the current washing techniques, implemented at Tata Steel, is not a practically viable option as it brings down the yield to a very low value, only 10%. Chemical leaching process on the other hand involves addition of chemicals which react with the mineral matter and allows it to be easily removed.

Various processing methods using acid and alkali leaching under elevated pressure and temperatures as well as leaching by molten caustic baths etc. have been studied at laboratory scale for chemical cleaning of coals from different origins [3,4]. The removal of sulphur and ash from coal treated with aqueous hydrogen peroxide/sulphuric acid solutions has been studied at ambient temperature, under a variety of experimental conditions [3,4].

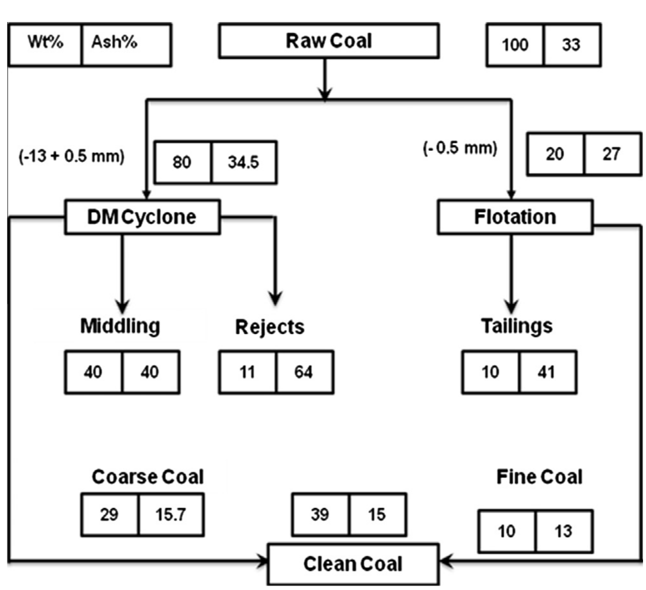

Fig. 1. Typical physical beneficiation circuit of an Indian coal washery.

Demineralisation and desulphurisation of coal by aqueous or fused sodium hydroxide alone or followed by treatment with mineral acids have been reported by many investigators [1,2,5–10]. Sharma and Gihar [2] applied the method of chemical cleaning of low-grade coals through alkali-acid leaching employing mild conditions under ambient pressure resulting in nearly 75% demineralisation. Nearly 90% reduction of the mineral matter content of coal from Australia through caustic wash has been reported by Waugh and Bowling [5]. Wang et al. [6] applied caustic wash to two different coals, one with high ash content (15.5%) and the other with low ash content (7%). They reported that the parameters affecting the process were temperature, concentration of the caustic solution, contact time and particle size. The effects of leaching sub-bituminous coal samples from Boragolai and Ledo collieries of Makum coal field, Assam, India, with aqueous sodium hydroxide solution on removal of ash and sulphur, were investigated by Mukherjee and Borthakur [9,10]. They reported that alkali treatment leads to over 70% removal of the inorganic sulphur in the coal sample and desulphurisation increases with increase in alkali concentration and treatment time.

Researchers and scientists around the world have tried out many such processes [11]. Araya et al. [12] observed increase in desulphurisation and demineralisation of a sub-bituminous coal with reaction time, temperature and concentration of sodium hydroxide solution. Many inorganic acids have also been used in the process of chemical leaching to produce ultra clean coal as reported by Steel and Patrick [13,14]. Besides, the amount and rate of removal of mineral matter from coal during chemical leaching process depend on various parameters such as type of mineral matter, percentage of mineral matter, porosity of coal, rank of coal, size of coal, reagents used for dissolution, time of dissolution, temperature, and pressure. Dash et al. [1,15,16] reported that alkali leaching of Indian coals at 80–85 °C under ambient pressure followed by acid treatment resulted in a reduction of the ash content by up to 60% with more than 70% yield. It was also mentioned that with increase in temperature, a clear improvement in the degree of demineralisation was observed. It is important to note that the chemical leaching process can never be a substitute for physical beneficiation as the latter one has the huge cost competitive edge. However, it can be added to the existing washing circuit as a complementary method to increase the overall yield and thereby conservation of mine life.

In the context of growing demand for clean coal and coal derivatives in the steel industry and power sector, and with the implementation of stringent environmental regulations, clean coal technology development programs have gained significant importance worldwide. While the foregoing treatments undoubtedly represent progress in the art towards lowering the content of impurities in coal to acceptable levels for different applications, there still remains a need for a process to produce low ash clean coal from high ash containing and poorly liberated coals of Indian origin. No significant effort has been made in this regard for Indian coals which are of drift origin and having high ash content with finely distributed mineral matter. Besides, all the studies have been carried out at diversified operating conditions and an elaborate research report is non-existent. Most of the research works have been carried out for thermal coals and hence the effect of this chemical treatment method on coking properties has not been investigated thoroughly. Apart from this, the impact of this upgradation method on mineralogical composition and morphology of coals has also not been critically looked into. In that sense, identification of optimal process parameters to produce low ash coal through chemical leaching for Indian coal is very much different from the other studies existing in the literature. The present work addresses the above issues particularly for coals of Indian origin.