ARTICLE IN PRESS

Biomass and Bioenergy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Biomass and Bioenergy

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

Research paper

Biomass briquette as an alternative reductant for low grade iron ore resources

Swagat S. Rath*, Danda Srinivas Rao, Alok Tripathy, Surendra K. Biswal

CSIR-Institute of Minerals and Materials Technology, Bhubaneswar 751013, India

ARTICLE INFO

Keywords:
Biomass briquettes
Reduction roasting
Iron ore slime
Taguchi

ABSTRACT

The present study explores the application of biomass briquette, produced from the unutilized vegetative remnants, as an alternative reductant for the reduction roasting-magnetic separation of an iron ore slime sample assaying 56.2% Fe. The X-Ray Diffraction (XRD) studies indicated tridymite and quartz to be the only crystalline mineral phases present in the biomass briquettes while the Fourier Transform Infra Red (FTIR) spectra identified several organic functional groups representing the biomass. Iron ore concentrates with ∼65% Fe and ∼64% weight recovery were obtained with reduction conditions such as temperature: 650–750 °C, reductant to feed ratio: 0.15, reduction time: 30–45 min and reductant size: −3 + 1 mm. The analysis of the statistically designed experiments suggested that temperature is the most crucial factor followed by time, reductant to feed ratio and reductant size. Magnetite and hematite were found to be the only major phases present in the magnetic fractions produced from roasting at the optimum conditions. Many feebly magnetic phases like wustite, fayalite and clinoferrosilite appeared at higher temperature and reductant to feed ratios, which was confirmed by XRD, reflected light microscopy and quantitative mineralogical analysis.

1. Introduction

The gradual exhaustion of high-grade iron ores is a major concern for the iron and steel industries. As a result, selective mining and beneficiation have become inevitable during which a good amount of the mined ore is left unutilised. Slimes, which are the rejects from the washing plant, constitute the majority of the rejected iron ore resources. These slimes being extremely fine in size and poor in iron content, cannot be directly used in iron making and hence, discarded into tailing ponds. The generation of such slimes is likely to go up in future owing to the increase in the production of iron ore. The handling of the enormous quantities of slimes, which also pose environmental threats, is going to be a herculean task in future.

There have been several attempts to develop cost effective beneficiation technologies in order to recover additional iron values from these dumped slimes so that the beneficiated slimes can be a raw material to produce pellets and be utilized in blast furnaces. The most recent reports of iron ore slime beneficiation include hydrocycloning followed by magnetic separation [1,2] and selective flocculation [3,4]. Most of the slimes, when subjected to physical separation methods do not give rise to good iron recovery because of their complex mineralogy and poor liberation characteristics. Now-a-days, reduction roasting followed by magnetic separation is emerging as an alternative technology to beneficiate the low grade iron ore resources. The process involves reduction of the hematite and goethite phases present in the ore to magnetite followed by low intensity magnetic separation, wherein the iron values in magnetite form can be suitably recovered [5,6]. Usually, coal and coke are used as the reducing agent in this process. With the shortage of high grade coking coal and strict environmental regulations, it is worthwhile to develop alternative reductants.

Biomass is being considered as a renewable source and hence, the energy derived from it falls into the category of renewable energy [7]. The huge quantities of agro-residues such as rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks generated in many of the developing countries are used as fuel. As such, biomass is considered to be an option to lessen the green house gas emissions [8,9]. Additionally, it has many other environmental benefits such as reduced SO_X and NOx formation [10]. However, the direct burning of such biomass not only results in a poor thermal efficiency but also creates several other potential pollutants such as CO and particulate matters because of the incomplete combustion [11–13]. Briquetting of the biomass has an answer to these problems. The plant residues when given a regular shape by the process of densification are called biomass briquettes. The studies on biomass briquettes comprising of 80% low grade coal and 20% biomass revealed that they generate

* Corresponding author.
E-mail address: ssrath@immt.res.in (S.S. Rath).

http://dx.doi.org/10.1016/j.biombioe.2017.10.045
Received 16 February 2017; Received in revised form 26 October 2017; Accepted 30 October 2017

Please cite this article as: Rath, S.S., Biomass and Bioenergy (2017), http://dx.doi.org/10.1016/j.biombioe.2017.10.045

little smoke and particulate matters during the combustion process, and have better combustion controllability and efficiency compared to the coal briquettes or lumpy coal [14,15]. Moreover, the difficulties in the transportation, storage, and handling of the biomass arising due to some of its properties such as low bulk density, irregular shape and sizes, and high moisture content are not encountered while using the same in the form of briquettes [16,17]. That is why biomass briquettes are now being used as an alternative to many conventional fuels like coal, firewood, diesel, kerosene, and furnace oil. They are widely used in boilers, furnaces, foundries; for heating houses, in drying processes and in gasification plants [18,19]. It may be noted that India being an agriculture based country produces massive agricultural residues. As per a survey, over 500 million tonnes of renewable bio-feed stock is generated every year [20]. Moreover, the use of biomass briquettes is being encouraged by linking it to carbon credits. For example, in India, charcoal is being replaced by biomass briquettes as a boiler fuel. The Indian government is promoting the production of biomass briquettes by offering financial benefits and as a result, many small scale biomass briquetting industries are operational these days [21]. Therefore, it is assumed that the biomass briquette industry is on the rise and sufficient briquettes for different applications will be available in future.

Biomass has the ability to act as a reductant in iron making. However, the use of fresh biomass results in a poor yield because of very fast reaction kinetics [22–25]. Fick et al. [26] investigated many biomass sources such as charcoal, bio-oil, syngas, torrefied biomass and biogas, and ended up with the conclusion that charcoal or carbonized biomass can be the best reductant for iron making. Recently, Agirre et al. [27] have reported the production of charcoal from agricultural residues using a semi-continuous semi-pilot scale pyrolysis screw reactor. However, no attempts to apply biomass briquettes as reductant have been reported yet to the best of the authors' knowledge.

Taking into account the above-mentioned facts, the present study aims to explore the possibility of the application of biomass briquettes in the reduction roasting of an Indian iron ore slime sample. The motive behind this approach is to recover iron values from the slimes while establishing a new bio-reductant that would be an alternative to coal in future. The experiments have been carried out using the Taguchi based statistical design of experiments while different characterization studies have been undertaken to understand the process and the phase conversion as a function of the roasting parameters.

2. Materials and methods

2.1. Sample

The biomass briquette samples were collected from Shanmugha Bio Fuels, Erode, Tamilnadu, India. They were found to be very hard and cylindrical in shape (Fig. 1). The manufacturers indicated that the briquettes were prepared using a combination of different biomass residues comprising of saw dust, ground nut shell and juliflora crusher residue each to the tune of 30%, and a mixture of coffee husk, tamarind residue, coconut shell and dried coconut leaves accounting for the rest 10%. The briquettes are generally produced using a hydraulic press for applying load on a die containing the biomass. The die section has an outer heating element, which is thermostatically controlled and a temperature of 70–90 °C is maintained while briquetting [28]. For the present work, the biomass briquettes were crushed to below 10 mm and the different size fractions such as $-10+6$ mm, $-6+3$ mm, $-3+1$ mm, and -1 mm were subjected to characterization and reduction roasting studies.

A dried iron ore slime sample with a Fe mass fraction of 56.2% was obtained from the slime pond of the Barsua mines, Western Odisha, India. The sample comprised of around 25% by weight of coarse particles of $+500$ µm while 46% of the samples reported below 45 µm. The detailed mineralogical report of this sample can be found elsewhere [2].

2.2. Characterization techniques

Different integrated instrumental characterization studies were carried out for the reductant (biomass briquettes), some of the roasted and LIMS products. The lumpy pieces of the biomass briquettes cakes were characterized by stereomicroscopic studies using a Leitz instrument. The microscopic studies of the polished roasted products were conducted using the reflected light microscope supplied by Leitz, Germany. The proximate analysis and gross calorific value (GCV) were determined in a Leco make thermo gravitometric analyzer and a bomb calorimeter respectively. A Philips X-ray diffractometer (XRD) with Cu-Kα radiation (PANalytical, X'pert equipped) operated at 40 kV and 30 mA was used to record the diffractogram. The FTIR spectra of the sample were recorded on a Shimadzu instrument in the range of 400–4000 cm^{-1} over KBr discs pellets. The Thermogravimetric and Differential Scanning Calorimetric (TG-DSC) studies were carried out using the Netzsch Sta 449 C equipment up to a temperature of 1000 °C at a heating rate of 283 K min^{-1}.

2.3. Reduction roasting and magnetic separation

All the reduction roasting experiments were conducted in a muffle furnace. The iron ore slime sample of 100 g along with the desired amount of biomass briquettes was thoroughly mixed and kept in a refractory crucible. Four such crucibles accounting for 400 g of the iron ore slime and the relevant amount of biomass briquettes were placed inside the furnace set at the desired temperature. The samples after being roasted for the required time were taken out and immediately water-quenched. The roasted mass was ground to -150 µm size and subjected to magnetic separation using Low Intensity Magnetic

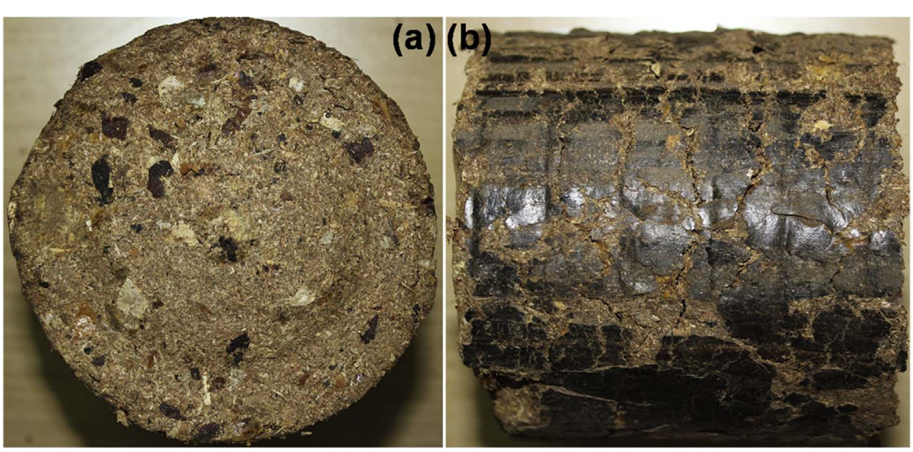

Fig. 1. (a) Top and (b) side view of as received biomass briquettes.