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Review Article

A Review of Biomass Utilization as a Reducing Agent in Iron Ore Reduction

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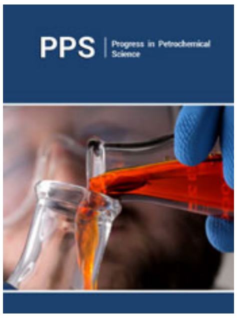

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Abstract

In recent years, it has been noted that more than 80% of India's total production of DRI comes from processes based on coal, which presents a significant difficulty in observing environmental regulations. Due to the direct usage of non-coking coal, DRI industries have a very high potential for pollution. In addition to being the world's largest producer of DRI, India's production of DRI requires particular consideration because it is predominantly coal-based, as opposed to the natural gas used by more than 90% of DRI plants throughout the world. India is an agricultural country and produces agricultural waste abundantly. Therefore, this agricultural waste can be utilized as a reducing agent in iron ore reduction.

Keywords: Minerals; Natural gas; Agricultural; Raw material; Iron

Abbreviations: DRI: Direct Reduced Iron; BF: Blast Furnace; MMDR: Mines & Minerals Development & Regulation; HBI: Hot Briquetted Iron; HYBRIT: Hydrogen Breakthrough Iron making Technology

Introduction

Iron ore, the primary raw material for the iron and steel industries, is abundantly available in India [1]. India is the world's fourth-largest iron ore producer and ranks sixth in the iron ore resource base [2]. India is rich in plentiful and high-quality iron ore reserves compared to other countries. The Union Budget's withdrawal of export taxes on low-grade ores will help India's iron ore output increase, as well as the nation's Mines & Minerals Development & Regulation (MMDR) Act, which will simplify licenses and revive closed mines. Although the MMDR Act will encourage an increase in mineral output, the sector's potential for total expansion will be constrained by the Act's royalties. Export taxes for lumps and fines of iron ore with a Fe content below 58% were eliminated as part of India's 2016 Union Budget, down from 30% and 10%, respectively [3]. The overall iron ore resources in India are estimated to be 28.52 billion tonnes, with hematite and magnetite distributions expected to be 17.96 billion tonnes and 10.55 billion tonnes, respectively [1]. A literature review was conducted to determine the prior research initiative and productive management in the DRI industry of India. The goal was to pinpoint research gaps and emphasize using biomass as a reductant in D.R.I. production due to environmental concerns.

Traditional Routes of Making Iron and Steel

A Blast Furnace (BF) has been the traditional route of making Iron and steel for many decades [4]. The BF can be considered a chemical reactor and a counter-current heat exchanger. It is a vertical shaft furnace in which pig iron is collected from the bottom of the furnace by reducing gas and coke with a mixture of iron ore, coke, and fluxed feed fed into the furnace from the top [5]. The hot blast of air enters the furnace through the tuyers and immediately burns the coke to CO_2, which enhances the tuyer's gas temperature up to 1800-2000 °C [6]. Above 1000 °C, this CO_2 combines with carbon and generates CO; further, this CO rises and reduces the iron ore.

Need for Developing Technologies for Ironmaking

Any nation's development is largely dependent on its iron and steel sector [7]. Coal is utilized in this sector as a source of energy and a reductant, which contributes to environmental pollution by releasing greenhouse gases into the environment [8]. India has large amounts of iron ore, but there is a scarcity of coking coal that can be utilized to prepare coke and its utilization in blast furnaces. Nowadays, solid waste disposal and minimum fossil fuel consumption and significantly their impact on the environment are worldwide concerns. In the past forty years, the Direct Reduction Process, a novel method of producing Iron, has grown fast [9]. In addition to the traditional way of producing Iron in a blast furnace, Direct Reduced Iron (DRI), also known as sponge iron, can be made from iron ore directly using a reducing agent based on coal or maybe a gaseous reducing agent below its melting point. DRI, which can be created as a lump or a pellet, is a solid-state product of direct reduction processes. Chemically consistent scraps can be effectively replaced when manufacturing steel with DRI [10]. Because it lowers the cost of coke, the DRI process is more cost-effective [11]. In its infancy in the second part of the 20th century, the DRI industry grew in India [12]. Until then, petroleum products were the second-largest component of our imports after steel scrap. Following the imposition of restriction measures, the Indian government started looking for alternatives. Several reductants, including lower-quality coals, natural gas, charcoal, etc., can be utilized in a direct reduction process. The rapid depletion of high-grade coking coal [13,14] supplies constrain the traditional blast furnace-oxygen steel-producing route.

Direct Reduction (DR) Process

Direct Reduced Iron (DRI) is successfully produced using coal or gas-based technologies in many locations worldwide; iron ore is reduced at 800-1050 °C using coal or reducing gas (H_2+CO). Compared to integrated steel plants, the particular investment and operational expenses of D.R. plants are lower, making them more suited for many developing countries [9]. Among the many direct reduction processes that turn iron ores into sponge iron, the SL/RN process is the most widely used coal-based technology. Gas-based reduction is commonly carried out using the Midrex and HYL processes. Gas-based processes, which accounted for nearly 92 percent of DRI production in 1999, predominate. The percentage of DRI production using coal-based is about 7.6%. Out of 84% of DRI production in the world, only 16 percent was Hot Briquetted Iron (HBI) [12,15].

Introduction of the HYBRIT Process

Hydrogen Breakthrough Iron making Technology (HYBRIT) is a new technology using only hydrogen as a reducing agent for iron ore reduction. The main aim of HYBRIT is to minimize CO_2 emissions by replacing coal with hydrogen in the steel-making process. This process is very similar to the existing DR process except for the emission of CO_2. When iron oxide reacts with hydrogen, it forms water instead of CO_2. Therefore, it is a kind of green technology to produce Iron. This technology is a joint venture between Swedish companies, LKAB (The largest producer of iron ore in Europe), SSAB (global leader in high-strength steel), and Vattenfall (one of the largest electricity producers in Europe). A comparison between HYBRIT and the conventional BF process is shown in Figure 1, [16].

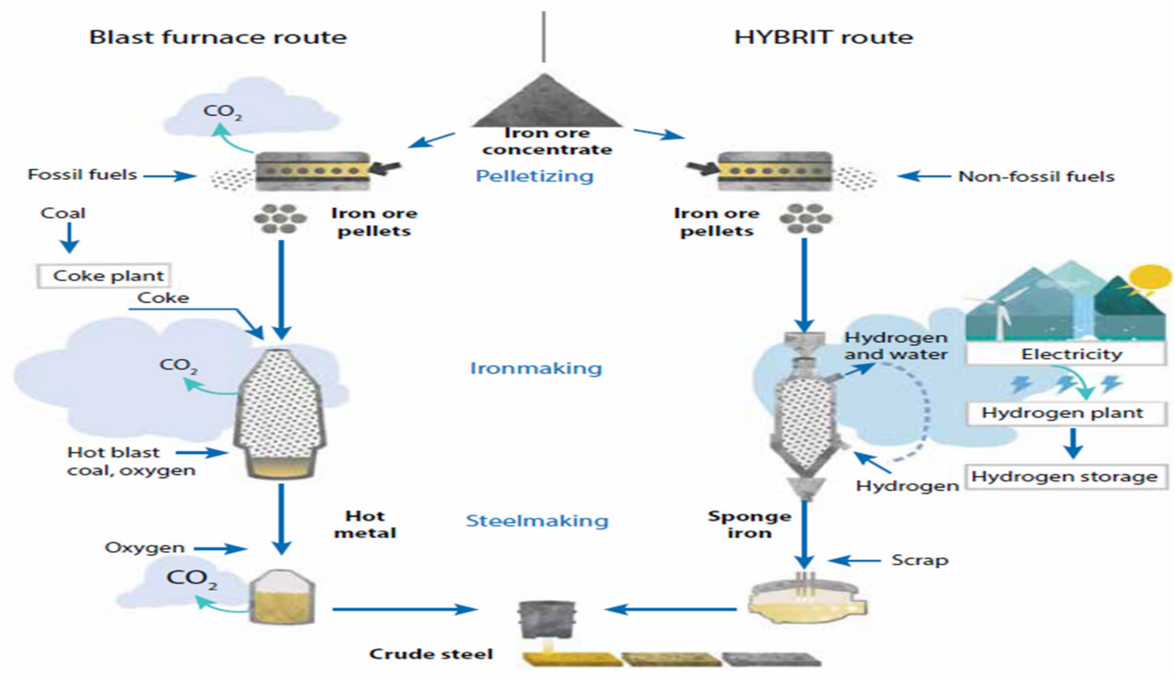

Figure 1: Schematic diagram comparing BF & HYBRIT process [16].

Biomass Scenario in India

Biomass is a fuel that can be produced from organic waste or by-products of living things and is a renewable energy source. The term "biomass" in biology refers to the organic plant material that is turned into fuel and used as an energy source. The country's main energy source has been biomass for a very long period. It is abundant, renewable, carbon-neutral, and can provide many jobs in rural areas. Figure 2 Shows the four common types of biomasses, i.e., agricultural waste, algae, forest residue, and Municipal Solid Waste (MSW). Biomass is also useful as a source of sustainable energy [17,18]. Biomass still supplies roughly 32% of the country's primary energy demands and more than 70% of its population's energy requirements. As a result of realizing the potential and significance of biomass energy in the Indian context, the Ministry of New and Renewable Energy has launched many programs to encourage the use of effective technologies in a variety of economic sectors, ensuring that the greatest possible benefits are obtained [19]. India, one of the world's major consumers of fossil fuels and emitters of greenhouse gases, has implemented several incentive programs around the country to reduce its reliance on fossil fuels by creating bioenergy from untapped non-fossil natural resources [20]. Biomass accounts for 32% of the country's overall energy consumption [21]. According to Antar M et al. [22], every year, roughly 189Mt of surplus biomass from agriculture and forest leftovers is available for energy generation. Biomass is a well-known alternative renewable energy source that can meet future energy needs [23]. Approximately 38% of all primary energy consumption in rural areas and 90% of all energy supply in developing countries are accounted for by biomass, which makes up 11-12% of the primary energy used globally [24]. To avert global warming, energy industries are expected to lower CO_2 emissions [25]. Biomass can be considered ideal renewable energy because it has fewer harmful elements (P, S, and others) and low carbon emission, which proves it to be a suitable energy and reductant source for reducing iron ore [26]. Biomass is carbon neutral since it emits the same amount of CO_2 it absorbs throughout its growth [27]. Therefore, CO_2 emitted by the iron and steel industry can be minimized using biomass and its volatile as a reducing agent [8]. Biomass can be an alternate solution to be used as an energy source and reducing agent for green steel production [28]. It should be emphasized that India, as an agricultural country, produces a lot of agricultural waste [29]. Over 750 million tonnes of renewable bio-feed stock are produced annually [30].

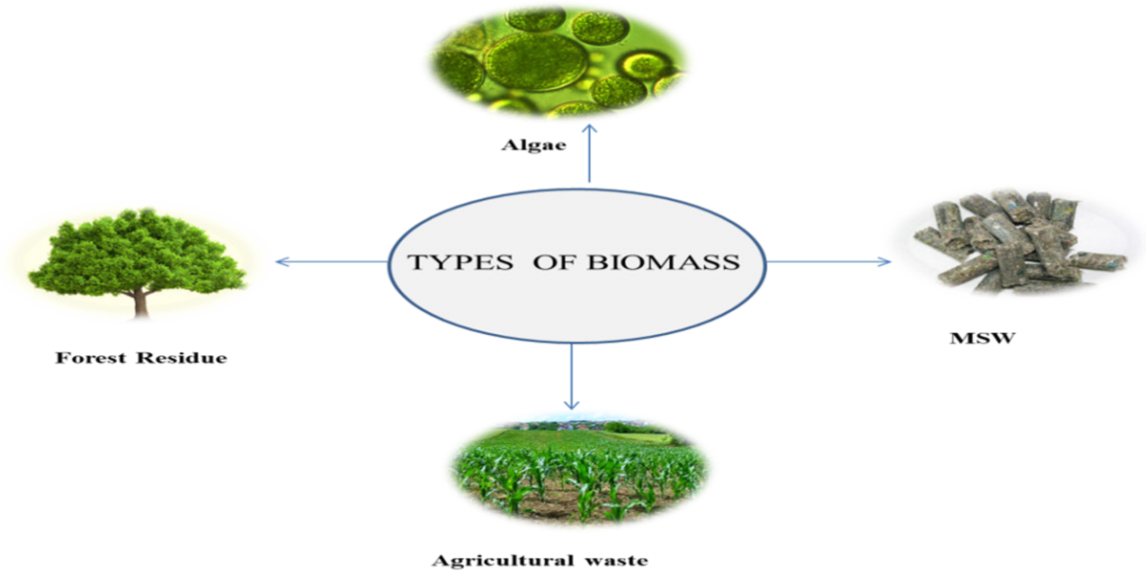

Figure 2: Different types of biomasses.

Biomass Potential to Utilize as a Reducing Agent in Iron Ore Reduction

Low-grade, non-magnetite iron ores can be converted to magnetite using biomass as a reducing agent, and then the iron ores can be enhanced via magnetic separation. The organic volatile produced by biomass pyrolysis was assumed to be the major reducing agent in the biomass reduction process [31]. Biomass can be used as a composite pellet and reach maximum reduction percentage in a shorter time w.r.t the iron ore pellets made without biomass. Hence, biomass addition can reduce energy consumption in a shorter time [15]. Syngas generated from biomass during the gasification and pyrolysis process was used as a reducing agent to reduce iron ore pellets. Like natural gas, biomass-derived syngas effectively reduced iron ore pellets [32]. Swagat et al. [33] were the first to use cow dung in the reduction roasting as a reductant of an Indian iron ore slime with a Fe content of 56.2 percent. After being treated with low-intensity magnetic separation, the resultant decreased mass generated a concentrate of 64 percent Fe with a weight recovery of 66 percent [33]. They also investigate the use of biomass briquette, made from unused vegetal remains, as an alternative reductant for the reduction roasting-magnetic separation of a 56.2 percent Fe iron ore slime sample. Rath et al. [33] demonstrate that the procedure, the first of it using biomass briquettes as a reductant, uses less water, requires less fine grinding, and provides 64-65 percent Fe at 63-64 percent yield. The continuously changing biomass market makes it difficult to choose suitable biomass fuels to consider for iron ore sintering. However, one form of biomass material that might be used well in sinter manufacturing is food processing wastes, shells, husks, and pits.

In the pyrolysis/gasification of biomass, it was discovered that the iron ore might be reduced first by lignin-derived hydrogen, then by CO and carbon [34]. Biomass can be used as composite pellets and reach maximum reduction percentage in a shorter time for the iron ore pellets made without biomass. As a result, the addition of biomass reduced energy consumption faster [15]. Mousa's study shows that using biomass in blast furnaces as briquettes i.e., torrefied pelletized sawdust, steel mill residues, and cement provides sufficient mechanical strength and lowers CO_2 emissions by about 33-40kg/tHM [35]. According to Yoichi Kaya [36], hydrogen can directly reduce iron ore to lower CO_2 emissions. And this hydrogen can be produced by the gasification of biomass. Using bioenergy with carbon capture and storage (bio-CCS) could lower CO_2 emissions significantly. According to the Kyoto protocol, biomass may significantly promote the commitment to solve the problem of greenhouse gas emissions [37]. The study demonstrates that the sole use of biomass can achieve CO_2 emission reduction goals of up to 20% [38]. Torrefied biomass with a Lower Heating Value (LHV) of less than 25MJ/kg is required for the production of steel; alternatively, torrefied biomass can be co-fired with coal to boost calorific value [39].

Conclusion

Agricultural wastes are the major resources of biomass available in India. The stored energy of biomass can be achieved by biochemical and thermochemical conversion methods. Pyrolysis, combustion, and gasification are the main thermochemical processes. The gases produced from the gasification and pyrolysis of biomass can be used as a reducing agent for iron ore reduction. Biomass can be used in composite pellets for iron ore reduction and reach maximum reduction percentage in a shorter time. The gaseous yield in biomass pyrolysis can be increased by increasing the pyrolysis temperature. The direct reduction process is less energy-consuming in which DRI is produced below the melting point of Iron. The HYBRIT process is a new technology using hydrogen as a reducing agent for iron ore reduction to make metallic Iron and water as a by-product.

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