Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 35 (2019) 242–245

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Materials Processing and Manufacturing

(SMPM 2019)

A review of ironmaking by direct reduction processes: Quality requirements and sustainability

Comfort Ramakgala*, Gwiranai Danha

Department of Chemical, Materials and Metallurgical Engineering, College of Engineering and Technology, Botswana International University of Science and Technology, Plot 10071 Boseja Ward, Private Bag 16 Palapye, Botswana.

Abstract

Currently the majority of the world's steel is produced through either one of the two main routes; the integrated Blast Furnace – Basic Oxygen Furnace (BF – BOF) route or the Direct Reduced Iron - Electric Arc Furnace (DRI - EAF) route. In the former, the blast furnace uses iron ore, scrap metal, coke and pulverized coal as raw materials to produce hot metal for conversion in the BOF. Although it is still the prevalent process, blast furnace hot metal production has declined over the years due to diminishing quality of metallurgical coke, low supply of scrap metal and environmental problems associated with the process. These factors have contributed to the development of alternative technologies of ironmaking, of which Direct Reduction (DR) processes are expected to emerge as preferred alternatives in the future. This study reviews the different DR processes used to produce Direct Reduced Iron, providing an analysis on the quality requirements of iron-bearing ores for use in these processes. The study also discusses the environmental sustainability of such processes. DR processes reduce iron ore in its solid state by the use of either natural gas or coal as reducing agents, and they have a comparative advantage of low capital costs, low emissions and production flexibility over the BF process.

Peer-review under responsibility of the organizing committee of SMPM 2019.

Keywords: Direct Reduced Iron; sustainability; Ironmaking; Direct reduction processes

* Corresponding author. Tel.: +267 71856825; fax: +267 4900102.
E-mail address: comfort.ramakgala@studentmail.biust.ac.bw

2351-9789
Peer-review under responsibility of the organizing committee of SMPM 2019.
10.1016/j.promfg.2019.05.034

1. Introduction

Ironmaking represents the first step in steelmaking. The iron and steel industry is the most energy-intensive and capital-intensive manufacturing sector in the world (Strezov, 2006). Steelmaking processes depend on different forms of iron as primary feed material. Traditionally, the main sources of iron for making steel were blast furnace hot metal and recycled steel in the form of scrap. Blast furnace ironmaking requires separate coke making and sintering plants and often has reduced operating flexibility (Lu, Pan and Zhu, 2015). Coking coal is regarded as premium quality coal that attracts relatively higher cost and there are concerns over the limited reserves (Chukwuleke, Iiu-ju and Chukwujekwu, 2009). The use of coal in reduction of iron ore is associated with pollution and greenhouse gas emissions, particularly CO_2 (Yilmaz and Turek, 2017). The supply of scrap steel is also diminishing due to its ever increasing use in both BF – BOF and DRI – EAF steel making routes (Kirschen, Badr and Pfeifer, 2011). The iron and steel industry is under increased pressure to transform both existing and new iron recovery processes to become more environmentally sustainable operations to abate the growing pollution and climate change problems. To this effect, recent developments have been focused on the utilization of renewable energy sources to replace fossil fuels and employment of alternative direct iron ore reduction technologies (Xu, 2010). DRI (also known as sponge iron) is an important advancement in the ironmaking industry due to its high productivity and strong adaptability to raw materials (Guo *et al.*, 2017).

2. Overview of DR processes

Direct reduction processes reduce iron ore (in the form of lumps, pellets or fines) to the solid state using a reducing gas to produce Direct Reduced Iron (also known as sponge iron). DRI is often compacted to reduce its porosity and to convert it to Hot Briquetted Iron (HBI) for sale or storage (Indian Bureau of Mines, 2011). Depending on the source of reducing gas, DR processes can be described either as gas-based or coal-based (Lu, Pan and Zhu, 2015). In the gas-based process, the reducing agent is a chemically reformed mixture of natural gas and off-gas from the reducing reactor in the presence of a nickel based catalyst to produce a gas that is rich in hydrogen and carbon monoxide (Lu, Pan and Zhu, 2015). The reactors typically used are shaft furnaces, fluidized beds or retorts as shown in Table 1. However, for coal-based DR the reductant is generated from non-coking coal and rotary kilns, rotary hearth furnaces and multi-hearth furnaces are used (Ghosh and Chatterjee, 2017). It has been estimated that approximately 65-75% of sponge iron production cost is attributed to the cost of raw materials (Indian Bureau of Mines, 2011). As a measure to improve process flexibility and reduce operational costs, DR processes resort to the use of fine ore instead of lumps, as well as cheap waste gases (Friedl *et al.*, 2018).

Table 1. Alternative ironmaking processes

DR process	Type of reactors	Commercial processes
Coal-based	Rotary Kiln	ACCAR, DRC, Krupp Rein
	Rotary Hearth	Fastmet
Natural gas-based	Shaft furnaces	MIDREX
	Fluidized beds or retorts	HYL - III

3. World production of DRI

Table 2 summarizes the world production of DRI from the year 2010 to 2017 as recorded by World Steel Association. Production of DRI has increased from 72 Mt in 2010 to 86.3 Mt in 2017, accounting for 7% of the total iron ore production in 2017 (World Steel Association, 2018). India is the largest producer of DRI accounting for 30% of world production in 2017, followed by Iran which produced 23% in the same period. India has vast coal resources, consequently DRI production in India is primarily coal based (Indian Bureau of Mines, 2011). Today, gas-based DR processes account for over 90% DRI production capacity in the world, with the MIDREX process being the most widely used (Kirschen, Badr and Pfeifer, 2011).

Table 2: World production of DRI (2010 to 2017)

Year	DRI Production (million tons)
2010	72.0
2011	76.7
2012	76.9
2013	79.6
2014	81.3
2015	76.0
2016	78.3
2017	86.3

4. Quality requirements for raw materials

DR processes are designed to accommodate a combination of lump ore, fine ore and/or pellets in different proportions as feed materials. DR-grade ore is required to contain a high grade of Fe (>65%) and low amounts of gangue minerals (Lu, Pan and Zhu, 2015). This is because unlike blast furnace ironmaking, DR processes do not incorporate mechanisms of separating the gangue minerals from reduced iron. Sulphur and phosphorus are deleterious elements in steelmaking, therefore they need to be reduced to very low concentrations in DR-grade iron ore (Ghosh and Chatterjee, 2017). Moreover, when Sulphur forms H_2S, it is known to deactivate the nickel based reforming catalyst by chemisorption on the metal surface, reducing the process efficiency. The nominal size for DR-grade pellets is -16+6 mm at 95% passing while for lumps its -35+10mm at 85% passing. In all DR processes the metallization required is a minimum of 93%, therefore pellets and lumps must have high reducibility (Ghosh and Chatterjee, 2017). To overcome the problem of ore clustering during reduction at high temperatures, DR-grade iron ores are coated with a thin layer of limestone, cement or bauxite (Lu, Pan and Zhu, 2015). This increases production by up to 20%.

5. Environmental sustainability

On a comparative basis, DR processes emit only one-third of the CO2 per ton of steel of a BF – BOF route. In the HYL III process for example carbon dioxide emissions range from 0.77 – 0.92 ton CO2 per ton of DRI produced (Lu, Pan and Zhu, 2015). Environmental protection legislations throughout the world have driven the advancement of research into the use of clean energy sources and environmentally friendly mining technologies to abate climate change. Biomass is one of the most promising renewable energy sources. To this effect, Yuan et al. investigated the possibility of using biomass reductants instead of fossil fuels to produce DRI in rotary hearth furnace. The results indicated straw fiber as an optimal reductant in DRI formation as compared to fossil fuels (Yuan *et al.*, 2017). Guo et al. used biomass derived syngas as a reducing agent for the direct reduction of oxidized iron ore pellets (Guo *et al.*, 2016). The authors found out that the reducibility of iron increased to 99.95% at a reduction temperature of 1323K. The results also showed that the biomass derived syngas had an iron pellet reduction efficiency similar to that of natural gas, but presenting a possibility of an ironmaking process with no net CO2 emissions. Strezov mixed iron ore with biomass wood waste in different ratios and found that, the iron ore was successfully reduced to metallic iron phase when up to 30% by weight of biomass was introduced (Strezov, 2006). Technical innovations towards the production of clean DRI and reduction of CO2 emissions present opportunities of sustainable practices in processing of iron ores.

References

[1] Chukwuleke, O. P., Iiu-ju, C. and Chukwujekwu, S. (2009) 'Shift From Coke to Coal Using Direct Reduction Method and Challenges', 16(2), pp. 1–5. doi: 10.1016/S1006-706X(09)60018-2.

[2] Friedl, A. *et al.* (2018) *Direct Reduction of Iron-Ore in Fluidized Beds*, *28th European Symposium on Computer Aided Process Engineering*. Elsevier Masson SAS. doi: 10.1016/B978-0-444-64235-6.50039-5.

[3] Ghosh, A. and Chatterjee, A. (2017) *Ironmaking and Steelmaking: Theory and practice*. Dehli: PHI Learning Private Limited.

[4] Guo, D. *et al.* (2016) 'Direct reduction of oxidized iron ore pellets using biomass syngas as the reducer', *Fuel Processing Technology*. Elsevier B.V., 148, pp. 276–281. doi: 10.1016/j.fuproc.2016.03.009.

[5] Guo, D. *et al.* (2017) 'Direct reduction of iron ore / biomass composite pellets using simulated biomass-derived syngas : Experimental analysis and kinetic modelling', *Chemical Engineering Journal*. Elsevier B.V., 327, pp. 822–830. doi: 10.1016/j.cej.2017.06.118.

[6] Indian Bureau of Mines (2011) 'Iron and Steel: Vision - 2020'. Nagpur, pp. 112–146.

[7] Kirschen, M., Badr, K. and Pfeifer, H. (2011) 'In fl uence of direct reduced iron on the energy balance of the electric arc furnace in steel industry', *Energy*. Elsevier Ltd, 36(10), pp. 6146–6155. doi: 10.1016/j.energy.2011.07.050.

[8] Lu, L., Pan, J. and Zhu, D. (2015) 'Quality requirements of iron ore for iron production', in *Iron Ore: Mineralogy, Processing and Environmental Sustainability*, pp. 476–504. doi: 10.1016/B978-1-78242-156-6.00016-2.

[9] Strezov, V. (2006) 'Iron ore reduction using sawdust : Experimental analysis and kinetic modelling', *Renewable Energy*, 31, pp. 1892–1905. doi: 10.1016/j.renene.2005.08.032.

[10] World Steel Association (2018) *World Steel in Figures 2018*. Available at: https://www.worldsteel.org/en/dam/jcr:f9359dff-9546-4d6b-bed0-996201185b12/World+Steel+in+Figures+2018.pdf.

[11] Xu, C. C. (2010) 'A Brief Overview of Low CO 2 Emission Technologies for Iron and Steel Making', *Journal of Iron and Steel Research International*. Central Iron and Steel Research Institute, 17(3), pp. 1–7. doi: 10.1016/S1006-706X(10)60064-7.

[12] Yilmaz, C. and Turek, T. (2017) 'Modeling and simulation of the use of direct reduced iron in a blast furnace to reduce carbon dioxide emissions', *Journal of Cleaner Production*. Elsevier Ltd, 164, pp. 1519–1530. doi: 10.1016/j.jclepro.2017.07.043.

[13] Yuan, P. *et al.* (2017) 'Study on the formation of direct reduced iron by using biomass as reductants of carbon containing pellets in RHF process', *Energy*. Elsevier Ltd, 141, pp. 472–482. doi: 10.1016/j.energy.2017.09.058.