Iron Segregation Roasting as a Potential Decarbonization Pathway for Ironmaking

P. Kerr[1] (✉), Q. Liu[2], and T. H. Etsell[2]

[1] MINEPROMET, Quebec City, QC, Canada
pkerr@ualberta.ca
[2] University of Alberta, Chemical and Materials Engineering, Edmonton, AB, Canada

Abstract. Ironmaking accounts for 80% of steelmaking greenhouse gas (GHG) emissions, while steelmaking accounts for 8% of global GHG emissions. These significant contributions to GHG emissions illustrate the value of decarbonizing ironmaking through the implementation of iron segregation roasting where applicable.

Keywords: Iron segregation · Ironmaking · Direct reduced iron (DRI)
Decarbonization · Segregation roasting

1 Introduction

Ironmaking accounts for 80% of steelmaking greenhouse gas (GHG) emissions, while steelmaking accounts for 8% of global GHG emissions. These significant contributions to GHG emissions illustrate the value of decarbonizing ironmaking through the implementation of iron segregation roasting where applicable.

Iron segregation is ideally used with difficult-to-beneficiate iron ores where the ore is roasted at an elevated temperature with a carbonaceous reductant and a chloride additive in a closed reactor to allow for reducing conditions and contain the volatile chlorides. Although iron segregation roasting need not be limited to complex iron ores, oxide minerals of aluminum, titanium, and chromium are complex in nature and are frequently associated with ferrous/ferric oxides, vanadium, niobium and tantalum oxides, and rare-earth-bearing oxides [1]. Iron segregation roasting provides a potential upgrading solution for these complex ores as it allows for the ferrous and ferric oxides to be separated and upgraded to metallic iron thereby simplifying subsequent processing of the desired elements while producing a widely used value-added product. Powder metallurgy samples generated in this manner have high purity, ideal physical properties for powder metallurgical processing due to their cubic structure while they are resistant to oxidation at atmospheric conditions and are, in turn, not pyrophoric [2]. The iron product that does not meet the requirements for powder metallurgy can be subsequently briquetted and transported to an electric arc steelmaking facility or fed into an iron blast furnace as a scrap iron substitute.

Proceedings of the 61st Conference of Metallurgists, COM 2022,
https://doi.org/10.1007/978-3-031-17425-4_30

The chemistry of segregation is essentially the same for iron as for copper and nickel where a halide salt is hydrolyzed by steam in the presence of gangue (usually a silicate) producing substantial HCl exothermically at an elevated temperature, but significantly below the melting point of the metal (~950 °C for iron):

$$SiO_2(s) + CaCl_2(s) + H_2O(v) = CaSiO_3(s) + 2HCl(g) \tag{1}$$

The HCl then reacts endothermically and relatively slowly with the metal oxide in turn mobilizing iron for transport:

$$FeO(s) + 2HCl(g) = FeCl_2(g) + H_2O(g) \tag{2}$$

Hydrogen is formed endothermically by the carbonaceous reductant:

$$C(s) + H_2O(v) = CO(g) + H_2(g) \tag{3}$$

The metal chloride is then reduced by hydrogen on or near the carbonaceous reductant. In turn, segregating it from the metal oxide's original position and liberating HCl to react with additional metal oxide completes the cycle and resulting in a catalytic behavior as a less than stoichiometric amount of chloride:

$$FeCl_2(g) + H_2(g) = Fe(s) + 2HCl(g) \tag{4}$$

The process is followed by some form of physical separation to liberate the metallic iron from the gangue.

Iron segregation roasting lends itself well to decarbonization as the reactor type is ideally an indirect fired kiln or screw conveyor furnace, in order to contain the volatile chlorides, which act as a transport catalyst within the reactor [3–11]. Efforts to develop a direct-fired process have been studied and they have been met with limited success [12]. In turn, an electrically heated reactor can take advantage of a renewable electrical energy source.

An additional benefit that comes from the transport catalyst phenomena is that comminution energy requirements can be significantly reduced by avoiding the necessity of fine grinding as the iron is transported away from the gangue material. In turn, capital expenditures can also be reduced in this case, as less grinding equipment is needed.

Unlike coke required to maintain bed stability and a reducing atmosphere in traditional blast-furnace ironmaking, iron segregation roasting can use different types of renewable biochar, as the bed is not fluidized.

At the same time, hydrogen injection at the end of the process can also be used to increase metallization and further reduce the amount of carbon reductant necessary for ironmaking. Although the exact ratios possible have not been optimized, the concept has been proven [4].

While iron segregation roasting has only been tested in the laboratory and up to the small-pilot scale, it holds great potential for difficult to beneficiate ores, especially in the context of decarbonization in ironmaking.

Acknowledgments We thank Dr. Edward Bertram for providing literature and guidance regarding grain enlargement. This work was supported by grants from the Natural Sciences and Engineering Research Council of Canada (NSERC).

References

1. Sanchez-Segado S, Makanyire T, Escudero-Castejon L, Hara Y, Jha A. Reclamation of reactive metal oxides from complex minerals using alkali roasting and leaching – an improved approach to process engineering. Green Chem. 2014;17:2059–80.
2. Williams CE, Henderson AS. Method of producing crystalline iron by the hydrogen reduction of ferrous chloride. U.S. Patent No. 2,418,148A. Washington, DC: U.S. Patent and Trademark Office; 1947.
3. Stewart DF, Pollard LJ. Process of beneficiating titaniferous ores in the presence of hydrogen chloride. U.S. Patent No. 3,854,929. Washington, DC: U.S. Patent and Trademark Office; 1974.
4. Bertram E, Harris P, Myroniuk DW. Beneficiation process for oxidized iron ore. U.S. Patent No. 4,246,025. Washington, DC: U.S. Patent and Trademark Office; 1981.
5. Fensom DJ. Processes of iron segregation. U.S. Patent No. 4,295,878. Washington, DC: U.S. Patent and Trademark Office; 1981.
6. Reeves JW, Zander BH, Ericson AS. Method for beneficiating titanium-bearing material containing iron. U.S. Patent No. 5,660,805. Washington, DC: U.S. Patent and Trademark Office; 1997.
7. Al-Ajeel AA, Mahdy SN. Beneficiation of Al-Hussainyiat low grade iron ore by segregation roasting. Iraqi Bull Geol Min. 2006;2(2):103–13.
8. Kerr P, Liu Q, Etsell TH. A study of the reaction mechanisms of the iron segregation process, IMPC2016, Quebec City, QC. Paper No. 185.519-26; 2016.
9. Kerr P, Liu Q, Etsell TH. Beneficiation of the Clear Hills ironstone, COM2015, Toronto, ON. Paper No. 8936; 2015.
10. Kerr P, Liu Q, Etsell TH. Iron segregation roasting processes. In: Davis B, et al., editors. Extraction 2018. The minerals, metals & materials series. Cham: Springer; 2018. p. 1029–37.
11. Bhattacharya M. Reaction mechanism and thermodynamics of segregation roasting of iron oxide. Int J Miner Process Extr Metall. 2016;1(5):64–9.
12. Hernandez V, Peake K, Dalvi A, Brown R, Olurin J, O'Farrell T, et al. Process development of a new DRI technology for oolitic iron ores. In: The iron and steel technology conference and exposition (AISTech). Pittsburgh, PA; 2013. p. 519–26.