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Direct reduction of pellets through hydrogen: Experimental and model behaviour

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ABSTRACT

This paper presents the hydrogen reduction behaviour of industrial pellets designed for the efficient hydrogen based direct reduction. The pellets were provided with very low non ferrous oxides percentage (0.52 of basicity index) and with the absence on TiO_2 oxides. The pellets measured diameters in the range 1.14–1.72 cm and were characterized in terms of porosity, pores size, tortuosity and compression strength. The pellets were reduced in hydrogen atmosphere in a laboratory shaft furnace in the temperature ranges of 600–1200 °C at the pressures of 1 and 5 bar. The pellets' reduction behaviour was analysed in terms of time to reduction, rate of reduction and kinetics constant. All the obtained results were analysed through the employment of a commercial multi-objective optimization tool (modeFrontier) in order to precisely define the effect of each single parameter on the pellets' reduction. It was also defined the effect of the ongoing reduction rate of the final metallization of the starting iron oxides.

1. Introduction

Many evolutions are going to be faced by the ironmaking and steelmaking industries at the present times and other important revolutions are expected to be faced in the very next future. These changes are due to the fundamental aspect that the traditional integrated route has always been accompanied with high levels of green house gases emissions. In 2021, the global steel production accounts for 1951 million tons (Mt) where the traditional blast furnace-basic oxygen furnace covers the 70 % of the overall crude steel [1].

Per each ton of crude steel, 1.8 ton of carbon dioxide is produced with the traditional integrated route. Now, given the continuous growing of the global steel production, the greenhouse gases emissions are destined to grow if only the integrated route is retained as production technologies. Given all this, the only way to reduce dangerous emissions is the deep application of the so-called best available techniques (BAT) [2].

Among BAT, direct reduction (DR) is considered the most advanced technology to reduce the emissions during the primary ironmaking production. Green hydrogen technology has the potential to reduce the carbon dioxide emissions from iron and steelmaking to nearly zero and mitigate climate change from the industrial sector [3]. Globally, the most employed technologies are based on shaft furnaces of the type Midrex and HYL [4,5].

Here, the processes were designed to employ syngas as the main reducing agent but remarkable differences in the plants configurations can be underlined [6]. This is driven by the aspect that many inconveniences must be managed for the optimal reduction kinetics of iron oxides in the $CO–H_2–CO_2–H_2O$ atmosphere generated in the shaft furnace [7,8]. This is because potential kinetics decelerations could lead to very high gas consumptions with consequent high energy needing for the overall oxides reduction [9,10]. The precise understanding of the pellets reduction behaviour as a function of the gas composition and processing parameters is fundamental to increase the overall process efficiency accompanied with high quality of the produced material [11]. Depending on the reducing atmosphere and temperature, the performance of the technology, such as the reduction rate, metallization degree, and behaviour of the iron ore, can be significantly modified [12].

All these variables conduce to important complications in the development of affordable models capable of providing robust

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