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Editorial

Advances in Primary Ironmaking and Steelmaking Processes

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1. Introduction

In the recent past, ironmaking and steelmaking saw the incorporation of various new processes and technologies that can be operated and organized in different combinations depending on the properties of raw materials and the required quality of the final products. Different raw materials, energy requirements, and investments can vary as a function of different plant configurations and the advanced technologies employed for to reduce emissions. Due to the low level of restrictions and international protocols active during the last 15–20 years, innovation has been growing so fast that knowledge of the best available technologies is fundamental for scientists and industrial operators.

Indications from the steel industry and local and global government institutions are that the breakthrough technologies for decarbonization will be based on hydrogen reduction. The employment of hydrogen in the ironmaking and steelmaking industries will push forward the global transformation of hard-to-abate industries. Given that the two main routes for primary steel production decarbonization will almost certainly be CCS (carbon capture and storage) and hydrogen-based reduction, public and private R&D spending, as well as investment in pilot plants, should focus on driving down their cost and increasing the efficiency of equipment and piloting and driving down the cost of hydrogen-based reduction.

For CO_2-lean process routes, three major solutions have been identified: decarbonizing, whereby coal would be replaced by hydrogen or electricity in the hydrogen reduction or electrolysis of iron ore processes; the introduction of CCS technology; and the use of sustainable biomass.

Through a hydrogen-based steelmaking route, CO_2 emissions would be reduced by more than 80%. Hydrogen steelmaking will depend profoundly on the availability of green hydrogen, which can be generated from natural gas by steam reforming, or from water by electrolysis. Today, hydrogen-based steelmaking is a potential low-carbon and economically attractive route, especially in countries where natural gas is cheap. In considering systems for increasing energy efficiency and reducing the environmental impact of steel production, CO_2 emissions may be greatly reduced by hydrogen-based steel production if the hydrogen is generated by means of carbon-free and renewable sources. Currently, the development of the hydrogen economy has received a great deal of attention in that H_2 is considered a promising alternative to replace fossil fuels. If H_2 is utilized as an alternative fuel, not only can the problem of the progressively exhausted fossil fuel reserves be solved, but the atmospheric greenhouse effect can also be mitigated. Based on hydrogen, the "hydrogen economy" is a promising clean energy carrier for decarbonized energy systems if the hydrogen used is produced from renewable energy sources or coupled with carbon capture and storage (CCS) or nuclear energy.

2. Contributions

Chen et al. [1] deeply analysed the basic thermodynamic conditions for the reduction of molten wüstite by hydrogen, with great significance for optimizing the ironmaking process, energy saving and reducing emissions. The results of this study provided fundamental data to support new hydrogen metallurgy technologies in the future. In Hauser et al. [2], a

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first experimental demonstration is presented of an approach to the utilization of process off-gases generated in a steelworks that produced methane and methanol in hydrogen-intensified syntheses. Specifically, the integration of two methane synthesis reactors and one methanol synthesis reactor into a steel plant is experimentally simulated. The online tests carried out show that the calculation, optimization, and control architecture can lead to promising and satisfying results. In Cavaliere et al. [3], an innovative steel processing route developed by employing direct hydrogen reduced pellets and an open slag bath furnace is illustrated. The paper illustrates the direct reduction reactor employing hydrogen as a reductant on an industrial scale. The solution allows for the production of steel from blast furnace pellets transformed in the direct reduction reactor. The reduced pellets are then melted in open slag bath furnaces, allowing for carburization for further refining. The proposed solution is clean, contributing to the decarbonization of the steel industry. In Liu et al. [4], the effects of the width of the mould on the surface velocity, flow field pattern, turbulent kinetic energy distribution, and surface-level fluctuation in the mould were studied using the rod deflection method to measure the flow velocity near the surface of the mould at a high temperature, as well as numerical calculation. In actual production, the argon gas flow rate and the immersion depth of the submerged entry nozzle should be adjusted reasonably to optimize the flow field in the mould with different widths under the same fixed steel throughput. In El-Tawil et al. [5], coking coal blends with 5% and 10% additions of bio-coals (pre-treated biomass) of different origins and degrees of pre-treatment were carbonized at laboratory scale and at a technical scale using a 5% bio-coal addition, aiming to understand the impact on the bio-coal's properties (ash amount and composition, volatile matter content) and the addition of bio-coke reactivity. Types of bio-coke produced at the technical scale showed low reactivity in the thermogravimetric analysis but also showed a higher quality in standard tests for reactivity, strength after reaction, and mechanical strength. This indicates that the coking coal blend with a 5% high-temperature torrefied bio-coal could be suitable for industrial use. Steer et al. [6] conducted research comparing the laboratory-measured properties of injection coals that were used over a two-month production period compared to the process variables and measurements of the blast furnace during that study period. In Sun et al. [7], the effect of dephosphorization endpoint temperature on the dephosphorization of hot metal was studied for the double slag converter steelmaking process under the conditions of low temperature and low basicity using industrial experiments. Considering the experimental results and thermodynamic calculation results of the industrial experiments of the double slag dephosphorization process, the optimal temperature range for intermediate deslagging is about 1400–1420 °C. In Diniz et al. [8], a new algorithm is proposed to predict the silicon content time series up to 8 h ahead, immediately after the molten iron chemical analysis is delivered by the laboratory. The proposed model proved to be a promising tool for the prediction of pig iron silicon content, and it can be extended to other blast furnaces, with appropriate changes. In Hu et al. [9], the numerical simulation software ANSYS Fluent 18.2 was used to simulate the velocity field of molten steel under the condition of bottom-blowing stirring in different stages in the EAF steelmaking process. The properties of bottom-blowing and the kinetic conditions of the steel–slag interface were investigated. The physical model's verification confirmed the results; that is, the viscosity of molten steel decreased as the smelting progressed, and as the flow velocity of the molten steel caused by the agitation of bottom-blowing decreased, the effect of bottom-blowing also decreased. Based on these results, a theoretical basis was provided for the development of the bottom-blowing process. Finally, in the review from Cavaliere et al. [10], the main available technologies for water electrolysis for hydrogen production were described. The fundamentals of water electrolysis and the problems related to purification and/or desalinization of water before electrolysis were discussed. As a matter of fact, the authors underlined the energy efficiency issues, with particular attention given to the potential application of water electrolysis in the steel industry. The fundamental aspects related to the choice of high-temperature or low-temperature technologies are reviewed.

3. Conclusions and Outlook

This Special Issue aimed to focus on those traditional or innovative routes capable of reducing energy consumption and harmful greenhouse emissions. Obviously, discussions of energy took into account the direct and indirect energy consumption for each analysed technology. The methods to improve energy efficiency are energy consumption optimization, online monitoring, and energy audits.

This Special Issue describes some of the main approaches to produce and synthesize iron and steel through hydrogen-based technologies. For this Special Issue, we accepted contributions from both universities and the industry that evaluated the industrial feasibility of each selected technology. The main goal was to describe the most efficient solutions being applied by ironmaking and steelmaking factories all around the world.

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