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Advancing Hydrogen Plasma Smelting Reduction: Process Simulation and technical and environmental assessment

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The steel industry is responsible for 7% of global CO_2 emissions, with the blast furnace–basic oxygen furnace (BF-BOF) process accounting for approximately 70% of the total emissions from steel production. Given the significant environmental impact, the European Union has set a target to achieve net-zero CO_2 emissions by 2050. Reducing carbon carriers, mainly in the form of coke consumption is essential to reaching this goal. As an initial step, natural gas has been introduced in the direct reduction routes (DR) as a substitute, significantly lowering carbon emissions. However, this approach alone remains insufficient, as the reduction process still relies on carbon, resulting in CO_2 and CO as byproducts. A promising alternative is the use of ionized hydrogen as a reducing agent in the Hydrogen Plasma Smelting Reduction (HPSR) method where the primary byproduct of the reduction process is water vapor (H_2O). In this process, a mixture of hydrogen and argon is introduced into the DC electric smelter through a hollow electrode. HPSR utilizes fine iron ore as input, eliminating the need for conventional BF-BOF agglomeration processes. The pilot plant can process up to 200 kg of iron ore per hour and currently operates in batch mode, with efforts underway to develop a continuous process. In this work, a flowchart-based HSC simulation of the HPSR pilot plant is developed, aligning with experimental data from the current setup. To enhance efficiency, the system is further optimized by incorporating a preheating cyclone that recirculates HPSR off-gas and reduces electricity consumption. A technical and environmental analysis is conducted to compare the HPSR process with conventional steelmaking processes, such as the BF-BOF route and direct reduction with an accompanying electric arc furnace smelting step. The analysis evaluates differences in CO_2 emissions and electricity consumption, with the total power demand remaining comparable to the conventional routes.

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