Zero-Carbon Emission Iron Production Using Non-Thermal Rotating Gliding Arc Hydrogen Plasma

Alkaka, Hatem (School: Dhahran Ahliyya Schools)

With steel demand set to increase ~15% by 2050, current iron reduction methods still emit 2–3 tons of CO_2 per ton of steel, making the shift to hydrogen-based technologies essential to mitigate emissions. Hydrogen plasma smelting reduction (HPSR) offers a zero-carbon alternative with enhanced reactivity, but its scalability requires a deeper understanding of particle-plasma interactions during the reduction process. This study investigates the effect of the hydrogen-to-argon ratio in non-equilibrium rotating gliding arc plasma on the in-flight reduction of hematite (Fe_2O_3) at atmospheric pressure. Four parameters of the reduction process were analyzed: the degree of metallization and the iron particle, gas, and electron temperatures. The degree of metallization is quantified using X-ray diffraction and Rietveld Refinement. Optical Emission Spectroscopy (OES) is employed with a Boltzmann plot to calculate the rotational and electron temperatures. OES is also used to process black-body radiation to determine iron particle temperatures. Partial reduction (50%) was achieved with 82% hydrogen at a residence time of 20–30ms without electrode degradation. Results indicate that argon dilution negatively affects the degree of metallization. They also confirm the non-equilibrium nature of the plasma-particle system, characterized by a non-thermal plasma (~900K) alongside localized heating of the hematite particles (~2400K). This novel approach to iron reduction highlights HPSR's potential in decarbonizing the iron and steel industry as a fast and efficient zero-carbon alternative, paving the way for larger-scale industrial applications.

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