Operando Characterization of Iron Ore Reduction by MW Ar-H_2 Plasmas

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Abstract: We report on the reduction of iron ore in the afterglow of a MW-driven atmospheric pressure plasma operating in an argon-hydrogen mixture. The reduction of iron ore is determined using the *operando* measurement of water vapor by a Raman laser gas analyser (RLGA). This facilitates the study of a broad operational parameter range that not only facilitates reactor optimization but also yields insights on the rate limiting processes.

1. Introduction

The iron and steel making industry accounts for 7-9 % of global anthropogenic CO_2 emissions [1]. A significant amount of these emissions is due to incumbent iron ore reduction processes making the study of carbon free reduction processes of iron ore paramount. One such promising process is H_2 plasma enabled reduction. Plasma-produced radicals, ions and excited hydrogen species in non-thermal microwave (MW) plasmas have the potential to enhance the thermal reduction of iron ore and recombine with the oxygen to form water. The non-thermal MW plasma has previously been shown to enable fast reduction of iron oxide particles in the afterglow [2]. Studies suggest parameters such as gas temperature and gas composition influence the rate limiting steps [3].

Here, we study the impact of operational parameters on iron ore reduction. This study provides information which helps optimize the reduction process using MW plasma while providing insights on the rate limiting processes.

2. Methods

A MW-driven atmospheric pressure plasma was used to heat and activate an Ar + 10% H_2 gas mixture in a flow-through quartz tube reactor with a diameter of 1 inch. The hot gas containing excited and reactive species is transported down-stream of the plasma to a 300μ-size mesh on which 500 mg of Fe_3O_4 ore particles were placed. The MW plasma operated at an absorbed power between 0.6-3 kW. RLGA measurements of water vapor, the reaction product of the iron oxide reduction, was sampled at the exhaust of the reactor to determine the amount of reduction as a function of treatment time. The treatment time was varied from 3 to 45 minutes. *Ex situ* characterization of treated ore particles was performed by X-ray diffraction (XRD) as validation. Particle temperatures during the reduction are determined from their black body radiation.

3. Results and Discussion

Figure 1 compares the reduction measurement of Fe_3O_4 in the afterglow of the MW plasma reactor by RLGA and *ex situ* XRD as a function of treatment time. The two techniques show good agreement with a variation of about 16% which validates the RLGA approach for *operando* reduction measurements. Iron ore reduction in excess of 80% requires 30 minutes with a particle temperature of 1550 $\pm$ 40 K. The operando RLGA approach allows us to perform detailed parametric studies and assess the impact of power, gas flow rate, distance of particles from the plasma, etc. Results to date show a significant threshold effect in particle reduction as a function of downstream particle position in the afterglow while the temperature remains in good approximation constant. This observation points to short-lived plasma-produced species that enhance the reduction process. The observed impact of the gas flow rate on the iron ore reduction could also be explained by the importance of short-lived species. We ascribe this effect to H radicals and will discuss this in detail.

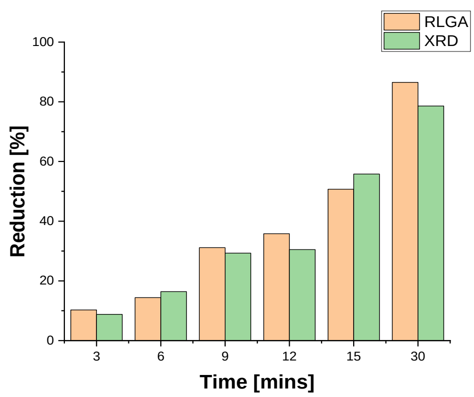

Fig. 1. Comparison between RLGA and XRD measurement in the afterglow (7 inches downstream from the core plasma). The particle temperature was 1550 $\pm$ 40 K.

4. Conclusion

Investigation of parameters impacting reduction using the MW plasma driven in Ar + H_2 gas mixture helps to identify parameters controlling rate limiting processes for reduction. The real-time reduction rate monitoring enabled by the RLGA's measurement of water vapor in the effluent provides us with a parametric data set that will be instrumental to determine optimal reactor conditions (and configurations) for MW plasma-enabled iron oxide reduction.

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References

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