In-flight iron ore reduction in atmospheric microwave hydrogen plasma

M.Kazemi, S.Kumar, J.Held, U.Kortshagen
Department of Mechanical Engineering, University of Minnesota, Twin Cities, USA

Abstract: This study investigates the in-flight reduction of iron oxide fines in an atmospheric pressure argon-hydrogen microwave plasma. Under some conditions, some fraction of the particles are pushed to the wall by the swirl flow. The reduction of these particles deposited on the wall was enhanced almost by a factor of 2 by using thermal insulation due to the resulting higher temperatures at the wall.

1. Introduction

Carbon dioxide emissions from the steel industry contribute 7-9% of global emissions, mainly due to traditional iron production using coke-based reduction in blast furnaces [1]. Hydrogen plasmas offer a promising alternative, replacing CO_2 emissions with water by using green hydrogen and providing a higher reducing potential through energetic species like hydrogen atoms. While hydrogen plasma reduction of iron oxide has been explored, in-flight reduction remains little studied [2]. This study investigates in-flight iron ore reduction using microwave-driven argon-hydrogen plasma, focusing on a particular population of iron oxide particles that are deposited on the reactor walls through gas dynamic effects.

2. Methods

A microwave reactor, operating at an input power and frequency of 1.6 kW and 2.45 GHz, respectively, generates an argon-hydrogen plasma. Argon-hydrogen gas mixture (90% and 10% by volume, respectively) is injected tangentially into the reactor at a flow rate of 30 slm, while pure argon (5 slm) is used as a carrier gas to transport iron ore particles from a feeder into the hot plasma region. The particle feed rate used in this study is around 0.28 g/min, with particle sizes between 25-44 µm. X-ray diffraction (XRD) analysis of particles enables the determination of the reduction percentages of iron oxide particles after exposure to the plasma.

3. Results and Discussion

Particles injected into the plasma experience varying temperature regions, resulting in different heating rates where some particles begin to melt and evaporate at 1900 K, as demonstrated in a previous studies [3]. After passing through the plasma, some particles are directed toward the reactor wall due to the centrifugal force caused by the swirl flow necessary to maintain plasma stability. These particle trajectories are investigated by particle trajectory modeling. Under unfavorable conditions, a large fraction of the particles adhere to the quartz wall, from the center of the plasma to the bottom of the quartz tube (225 mm total length), with poor reduction of only 30% despite being exposed to the afterglow plasma for 30 minutes. To remediate this potential problem and improve the reduction efficiency, an increase of the wall temperature can lead to better solid-state diffusion of oxygen and gas diffusion, resulting in better reduction [4]. When the quartz tube was insulated with a ceramic wool capable of withstanding temperatures up to 1500 K, the reduction of deposited particles increased to 55%. Figure 1 shows the XRD patterns of untreated, treated particles without insulation, and treated particles with insulation.

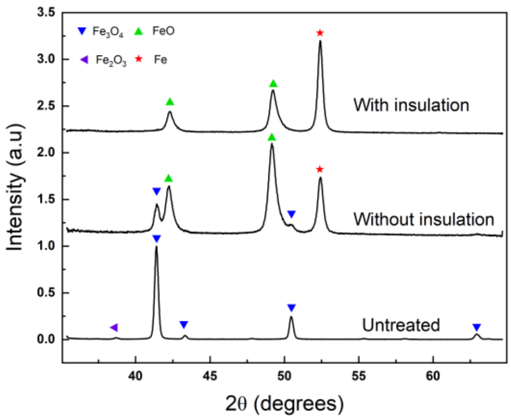

Fig. 1 XRD spectra (Co Kα source) of the untreated particles, and treated particles with and without insulation, collected from the quartz tube.

4. Conclusion

The study of in-flight iron ore reduction with hydrogen plasma shows that the centrifugal force caused by a swirl flow can drive some particles toward the wall, leading to their sticking. The reduction of this population of particles is enhanced by a factor of 2 by increasing the wall temperature by using a thermal insulation.

Acknowledgment

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