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ASIA-PACIFIC
SOLAR RESEARCH CONFERENCE

Solar Agglomeration of Iron Ores

Purohit S.[1, 2], Brooks G. [1], Rhamdhani M. A. [1] and Pownceby M. I. [2]

[1]Department of Mechanical and Product Design Engineering, Swinburne University of Technology, John Street, Hawthorn, Melbourne, Victoria 3122 Australia
[2]CSIRO Mineral Resources, Private Bag 10, Clayton South, Victoria 3169 Australia

Keywords: Solar Flux, Solar Simulator, Magnetite Ore, Agglomeration, XRD, SEM

Introduction

In the last decade, several concentrated solar power (CSP) plants have been installed worldwide with over 300 MW capacity. New developments in the solar receiver systems and heat engines are constantly being carried out for CSP technologies. Recent work by Pye et al. suggests that an average thermal efficiency of over 97 % is possible to achieve using a tubular cavity receiver [1]. As well, molten salts such as Na-K and eutectic Pb-Bi (LBE) molten metal mixtures are being investigated for high temperature storage [2]. Given the high success rate of CSP, the commercialization of concentrated solar thermal (CST) is highly feasible, particularly in areas with strong solar fluxes like Australia, though the capital cost is sensitive to the cost of heliostat systems. Studies conducted by CSIRO (Commonwealth Scientific and Industrial Research Organisation of Australia) suggested the potential of using solar energy for high temperature processing of bauxite, iron ores and copper under Australian conditions [3]. In this paper, an overview of the existing solar thermal research on iron ore processing is provided. The paper also includes laboratory investigation on solar agglomeration of magnetite ores to understand the practicality of its commercialisation.

Solar thermal processing of iron ores

The process of steel making from iron ores involves three main pyrometallurgical stages: (1) agglomeration processes of iron ore fines such as pelletisation and sintering, (2) reduction of iron ores to produce solid or liquid iron and (3) purification of iron and alloy addition to produce steel. The majority of the CO_2 emissions from steelmaking come from the 2nd stage i.e. the reduction of iron ore. In this stage, carbonaceous fuels are used to supply heat as well as reducing gases to produce iron. There are few reported literature studies on the solar reduction of iron ores that examine the feasibility of iron ore reduction using concentrated solar flux [4-6]. Different types of reducing agents such as coke breeze, methane and graphite were used to reduce the iron ores under solar flux and various degree of metallisation (maximum of 78 % Fe) were obtained [4-6].

Prior to the reduction stage, iron ores are agglomerated to produce sinters or pellets of desirable strength and reducibility. The existing pelletisation and sintering processes utilise carbonaceous fuel sources as a heat source to obtain temperatures of over 1200 °C. Fernández-González et al. studied the iron ore sintering process inside a 1.5-kW vertical-axis solar furnace at Odeillo [7]. Sintering was carried out at 1200 to 1400 °C for 12 and 20 min in air. The experimental results suggested non-uniform reaction across the sinter bed and therefore, the authors suggested solar heating would have limited applicability in iron ore sintering. In our previous papers, we proposed a solar smelting process for iron ores that works with iron ore fines thereby eliminating the need for an agglomeration stage. The process utilises a hybrid rotary hearth reactor with provision for natural gas heating and a heliostat field source to direct the sunlight towards a reflecting shine-down mirror which redirects the concentrated light to a receiver cavity [8]. The concept was tested in a solar simulator and hybrid reactor set up to reduce composite pellets of magnetite concentrate (89 wt. % Fe_3O_4) and pulverised lignite coal. The degree of reduction in the solar reactor was found to be similar to that in electrically heated pellets with a metallisation of 55 % at 1130 °C reaction temperature after 1.5 hr of reaction. The emission analysis of the solar smelting process suggested about a 20 % reduction in CO_2 emissions compared to the conventional composite pellet process. The preliminary techno-economics evaluation of the solar-smelt process suggested a payback period of about 2.5 to 3 years for a 200,000-tonne capacity plant under Australian conditions.

In this paper, the potential of using CST for an alternative agglomeration route is investigated. The alternative route involves the formation of $CaFe_3O_5$ (CWF) phase in lime magnetite pellets (LMPs) at temperatures of 950 to 1050 °C and has the potential to reduce the CO_2 emission from existing agglomeration processes - details can be found in our previous papers [16-19]. The LMPs are found to have comparable strength and reducibility to industrial sinters and is therefore a possible feed for ironmaking plants. In this paper, the feasibility of CWF formation under solar flux has been investigated using laboratory solar experiments.

Experimental Procedure

The LMPs of stoichiometric (1 mole Fe_3O_4 and 1 mole $CaCO_3$) and half-stoichiometric (1 mole Fe_3O_4 and ½ mole $CaCO_3$) compositions were prepared using laboratory grade chemicals following the procedure outlined by Purohit et al. [9]. The dried pellets of both compositions were reacted in a solar simulator and hybrid reactor setup using two 6-kW rated metal halide lamps, with a peak flux ranging from of 117 kW/m^2 to 148 kW/m^2 for each lamp. Experiments were carried out inside a fused-quartz sample holder and the temperature inside the reactor (just above the sample position) was measured at a 10 second interval using N-type thermocouples. The hybrid furnace was preheated using electricity for both solar and electric experiments prior to loading the samples and afterwards the experiments were conducted under solar and electric heating. The reaction temperature of the electric heated LMPs was mostly between 940 to 950 °C, while the solar heated ones were between 980 to 930 °C over the 1 hr reaction. The reactions were carried out under mildly reducing condition (CO/CO_2 of 1:4) and after the completion of the reaction, LMPs were cooled inside the reactor under Argon atmosphere. The reacted LMPs were characterized for microstructure and phase analysis using X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM).

Results

A comparison of XRD results of the stoichiometric and half-stoichiometric LMPs are shown in Figure 1. Similar XRD patterns fromsolar and electric heating of the LMPs were obtained for both compositions. The CWF phase was found in both LMP types however the Fe_3O_4 peak was more obvious for half-stoichiometric LMPs. Both LMPs showed the presence of C_2F ($Ca_2Fe_2O_5$), which is consistent with previously reported studies under similar experimental conditions [9]. The SEM micrographs of the stoichiometric LMPs heated under electric and solar heating are shown in Figures 2a and b, respectively. The micrographs suggest that the matrix of the LMPs to be mainly CWF phase with a random distribution of minor Fe_3O_4 and C_2F phase throughout the microstructure. The micrographs look identical to each other and to the previously reported results, suggesting no change in the reaction mechanism of LMPs under solar irradiation.

Summary and Future Work

The solar agglomeration of magnetite ores was investigated using a solar simulator-hybrid reactor set up. Results indicated a similar microstructure and chemistry for LMPs produced under both solar and electric heated conditions, suggesting no change in the reaction mechanism under solar irradiation. Future studies on solar agglomeration of a bulk sample is needed to understand the optimum size of pellet bed. Given the experimental results and the medium operating temperature of 950 to 1050 °C, the solar agglomeration of LMP is a strong candidate for commercialisation.

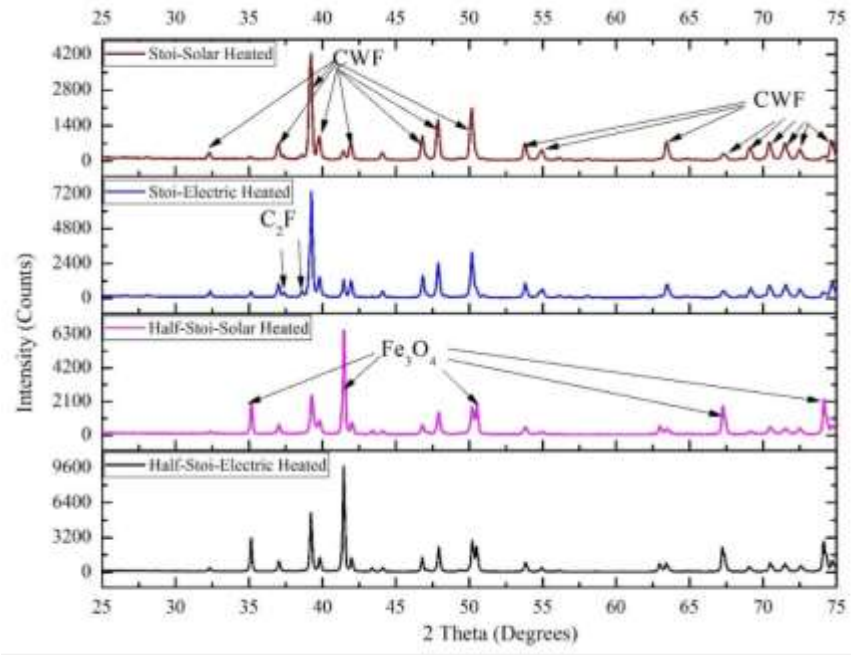

Figure 1. XRD patterns for stoichiometric and half-stoichiometric LMPs reacted under electric and solar heating conditions.

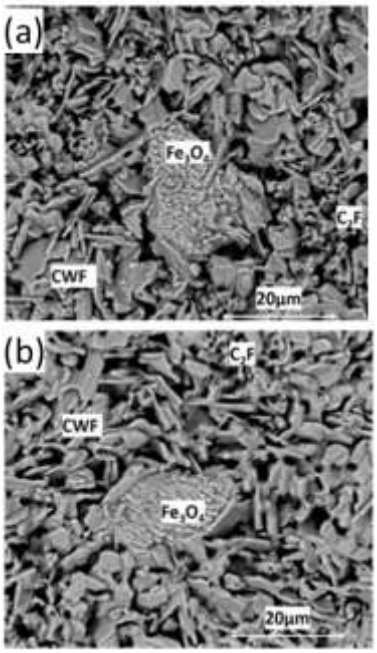

Figure 2. Seconary electron micrographs of stoichiometric LMPs reacted under (a) electric and (b) solar heating.

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