Abstract

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Activity of young researches and engineers of microwave processing in foreign countries

Session organizer: N. Yoshikawa [Tohoku Univ.]

10:25-10:30
Opening Address: N. Yoshikawa [Tohoku Univ.]

Chair: N. Yoshikawa [Tohoku Univ.]

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Mechanical Challenges in Microwave Assisted Ironmaking Prototype Plant

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1. Purpose

The project was initiated with an objective to develop a novel, eco-friendly and economic process for production of pig iron, using powdery iron ore (low/high grade), which abundantly available around Indian ore mines and not readily used by industry. Another objective was replacing coke with powered coal to make the process cheaper & simpler. The main advantage of this process is the rapid heat generated by volumetric interaction of iron ore and coal with microwaves, enabling a fast rise in temperature that enhances reaction kinetics. This process is expected to eliminate coke and use coal and only sufficient for the reduction of iron oxides and not for supplying thermal energy for the reduction. This will reduce green-house gas emission almost by 50% and make the process environment friendly. This paper discusses the mechanical design challenges faced in the novel prototype plant designed by Chubu University, Japan and how they were overcome jointly for achieving the desired process conditions and controls.

2. Experimental procedure

After completion of laboratory scale research in India, a prototype plant was established with the co-operation of Chubu university of Japan. This plant was designed by Chubu University. It was reassembled and commissioned at IMRC, India.

After commissioning, first integrated run was conducted jointly during which few main problems were observed and it was realized that only after overcoming these problems, the production target could be achieved. These were

a) Rapid increase in the temperature of exhaust gases (beyond the safe limit of 250^{0}C)

b) Oxidizing atmosphere present in the reduction furnace (14-18%)

c) Insufficient microwave energy reaching (only 10-20%) to reduction zone causing inadequate intensity of microwaves in the crucible.

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The corrective action taken against each problem and its effect is summarized below:

a) Rapid increase in the temperature of exhaust gases: This problem was overcome by altering the position of the exhaust fan and increasing the cross-sectional area of the exhaust duct for rapid discharge of gases. A bypass provision was added for adding cold air in the exhaust gases before releasing in air, thereby controlling exhaust fan temperature within its safety limits.

b) Oxidizing atmosphere: The main process limitation was due to presence of oxidizing atmosphere in the system which was hampering reduction process. For avoiding this several attempts were made like controlling air/gas ratio thereby minimizing excess oxygen supply to burners, entry of burner exhaust gases in the reduction crucible was eliminated. Apart from this, the burner exhaust gases and reaction gases were separated from each other. The reaction gases which are rich in CO were passed through pellets to pre-heat them.

c) Insufficient microwave energy: Reaching only 10-20% microwave energy to reduction zone causing inadequate intensity of microwaves in the crucible. Details about overcoming this problem will be presented by my colleague in his paper entitled "Microwave Transmission Challenges in Prototype Pig Iron Production Facility".

3. Results

The combination of the above modifications has led to smooth running of the process and our first desired result of molten iron production could be achieved successfully. The following are the main results:

1. Exhaust fan temperature could be maintained below 150^0C.
2. % Oxygen in the reaction exhaust gases was measured to be as low as 0.1%
3. Molten iron and slag could be produced with >95% recovery.

4. Conclusions

After undertaking these mechanical modifications, we could achieve our first target to get liquid iron with slag. However, further optimization of process parameters such as feeding of material and discharging of the product in a continuous process is to be done.

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Microwave Transmission Challenges in Prototype Pig Iron Production Facility

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1. Purpose

A novel microwave assisted green process is being developed by Industrial Microwave Research Centre (IMRC), Navi-Mumbai, India in association with Chubu University of Japan for producing pig iron from Indian powdery iron ore and coal. For this joint developmental project, Chubu University supplied the basic design and equipment. The challenge in this process was to maximize transfer of microwave energy generated by magnetrons to the reduction zone to achieve desired reactions and achieve maximum energy efficiency. Towards this, Chubu University provided an engineering drawing of antenna to IMRC who fabricated the same. This paper presents the results of this research and reveals how the different changes made in the design of antenna resulted into increase in the microwave efficiency. Apart from this, the paper also discusses the attempts made for minimizing the electrical harmonics to achieve smooth operation of the high power microwave generating devices.

2. Experimental Procedure

Based on laboratory results and previous experience of high power microwave system designing, Chubu University of Japan designed a microwave assisted prototype plant for converting Indian powdery iron ore and coal mixture to pig iron. The system was designed with provision of 3 microwave source inputs (6 kW magnetrons) with their antennas for transmitting microwave energy to the reduction zone. These microwave antennas were fabricated locally in India using SS 304 as per design provided by Chubu University. Microwave antennas were tested for their microwave transmission efficiency using a standard procedure consisting of standard dead load and measuring the temperature changes. Apart from this, the efficiency of antennas was confirmed using simulation facility available at Society for Applied Microwave Electronics Engineering & Research (SAMEER), Mumbai, India. The best design where minimum energy loss was observed was selected and installed for conducting further actual production trials. Apart from antenna designs, it was noticed that for smooth operation of the high power microwave generators, it was essential to have harmonics free power supply. Few power surges were noticed in the industrial power supply available at IMRC. Hence,

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attempts were made to overcome this difficulty through appropriate design of filter circuits.

3. Results

The results indicated that microwave energy from magnetrons does not reduce significantly during their travel through metallic antennas. However, drastic decrease in the microwave energy was observed after they exit from the antennas and this energy decreases exponentially with the increase of distance between the antenna and sample. This may be due to their interference with each other. This resulted in loss of microwave power reaching the reduction zone. It was also found that the exit of the microwaves from antennas needs to be close to the reduction zone to avoid the above phenomenon. However, due to process limitations, i.e. the high temperature in the reduction zone (about 1450^{0}C), the openings of antenna could not be positioned in this area. Accordingly, an optimum distance was maintained between the antenna opening and the reduction zone. Based on this, a long antenna with a horn was designed and tested. This showed good improvement in the microwave field reaching in the reduction zone. To get targeted output from the prototype plant, it was essential to increase microwave input power by installing multiple magnetrons which is underway.

Based on the electrical surges monitored in the input power supply, calculations have been made to design different filter circuits. These were tested on magnetrons and klystrons and an optimum design was selected.

The above modifications have contributed significantly in our efforts to produce liquid pig iron on a small scale in this prototype plant.

4. Conclusion

Microwave generated from a single magnetron and fed through a single horn-antenna, with its opening close to requisite location, resulted into improved microwave efficiency. Keeping in consideration the space available in the prototype plant design, Chubu University is designing a multiple antenna for better transmission of microwaves. It is hoped that the above findings will play a very important role in the further development of this process.

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Metallurgical Challenges in Microwave Assisted Ironmaking Prototype Plant.

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1. Purpose

This paper presents challenges overcome during scaling up Microwave assisted ironmaking process from laboratory to pilot level. This was done by optimizing proportions of iron ore, coal, fluxes and binders and adjusting the viscosity and basicity of slag to get effective slag metal separation. Another important aspect was selection of sample holder in which reduction will take place under microwave field. The essential property of sample holder is that it should have better thermal spalling resistance with high temperature stability and minimum or no microwave interactions. Apart from the sample holder material, one more challenge was selection of its inner lining which must have stability at high temperatures (~1500^{0}C) and should do not have reactivity and wettability with molten iron & slag. The process being developed uses microwaves as heating source where it is expected that only the sample will be at higher temperatures compared to surroundings. This makes it essential to insulate the sample holder properly with a suitable insulation material which is to be transparent to microwaves for better energy efficiency. After overcoming the above challenges, all process parameters such as heating cycle, gas flow control, etc. were optimized. The overall challenge to this novel process is to attain high reduction efficiency with optimum energy consumption and production of pig iron and slag in liquid state while minimizing the green-house gas emissions.

2. Experimental procedure:

Since no previous experience and references were available on this scale (1T/PD), the initial experiments were carried out carefully selecting one parameter at a time. Combinations of 2-3 parameters were tried only in the later stages.

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The effect of following parameters was investigated:

i) Proportion of ore and coal were calculated based on stoichiometry of reduction reaction, and proportions of fluxes were determined based on the viscosity and basicity ratio calculations. All these materials were ground (-150 microns) and mixed thoroughly using a roller mixer and then pelletized using a disc pelletizer. The composite pellet size was in the range 6-10 mm.

ii) The first few trials were carried out using hybrid heating process where the initial heating of the sample was done by using Natural Gas and air. These trials showed that reduction was not taking place at all, and only fusion of material was taking place due to high temperature.

iii) The system of 1 ton/ day plant was modified to eliminate any contact between the combustion products and the pellets. This only gave a reduction degree of 30-40%. During this experiment, the visible light spectrometer observed luminescence of the raw material in the reaction vessel during microwave irradiation. In the wavelength range of 300 to 850 nm, continuous emission of carbon molecules and isolated line emissions of Fe I overlapped with blackbody radiation. Line emissions (Fe II) at 300~400nm have hardly been observed. They could appear associating to the ionization from Fe to Fe^+ and their recombination process. At longer than 600 nm, luminescence associated with carbon molecules is observed.

iv) Next step was to improve the percentage of microwave energy reaching the reduction zone, which was earlier only 10-15%. To overcome this deficiency the antenna design was investigated and modified. This gave an improvement in microwave delivery efficiency to a level of around 25%. With this, the reduction efficiency improved to around 50-60%. In this experiment, the continuous spectrum corresponded to carbon molecules increased at 600 nm and longer. Ionization line of Fe^+ did not observed. It means that the microwave excited the irons atoms but was not high enough to make ionization that might distinguish the microwave to ordinary thermal process.

v) At this stage it was felt that for improving the reduction efficiency and temperature, the heat losses must be minimized. Measurements showed that the crucible material was absorbing a lot of energy. Also, the radiation losses of heat were found to be quite high. To overcome it, the crucible material was changed from Morex to Mullite, and the crucible was thermally isolated using high alumina insulations. With these measures we could obtain liquid metal and slag with clear separation of both.

3. Results:

Yield of metal-slag in these experiments has been around 95%, rest 5% is lost in refractory lining. A typical composition of metal and slag in these experiments is given below:

Chemistry of Metal			Chemistry of Slag	
Constituents	%		Constituents	%
C	1.29		SiO_2	34.30
Si	2.07		Al_2O_3	13.78
Mn	0.12		CaO	34.45
P	0.095		MgO	6.19
S	0.055		Fe_2O_3	11.31

4. Conclusion:

The experiments conducted so far provided good learning and fair success. Further modifications are underway to develop an energy efficient and continuous mode of this process in near future.