Abstract

Depletion of coking coal reserves, generation of fines, strict environment norms have motivated the researchers to look beyond the blast furnace. One such alternative strategy is to use iron ore and coal fines in the form of cold bonded composite pellets and reduce those in a Rotary Hearth Furnace (RHF). The intimacy between the iron oxide and carbon particles improves the mass transfer efficiency, carbon utilisation that lowers CO_2 emission. However, the RHF suffers from low productivity due to heat transfer limitations that restricts the number of layers on the hearth. In the present research, a comprehensive study has been carried out on the reduction behaviour and kinetics in multi-layer bed RHF. Efforts have been made to increase the heat and mass conductance in multi-layer bed by tailoring the size, shape of the pellet, varying the internal carbon content, employing suitable additives, and different bed packing materials. Iron ore-coal composite pellets have been reduced in a laboratory scale three-layer bed RHF at 1250°C for 20 minutes. Pellets were packed in three layers in a SiC-graphite crucible and placed on the rotating hearth. The reduced pellets have been characterised through weight loss measurement, estimation of porosity and shrinkage, qualitative and quantitative phase analysis by XRD, morphology study by SEM, and measurement of compressive strength. The reduction results of the RHF has been analysed using an existing mathematical model (developed in our laboratory) to estimate the rate parameters and phase evolution with time. The model has also been used to calculate the thermal efficiency of the system.

The variation in size and shape of the pellets in RHF produced a significant variation in the extent of reduction between the layers in three-layer bed RHF. The top layer showed higher degree of reduction (DOR) in the case of smaller and tablet shaped pellets, whereas, the bottom layer showed higher DOR with bigger and spherical pellets. The middle layer did not show much variation and registered the minimum value among the three layers. The results have been explained in terms of volatile usage, bed packing, specific surface area, and heat diffusion distance of the pellets.

The amount of coal in the pellet, represented in terms of C_{Fix}/Fe_2O_3 molar ratio, showed a significant influence on the reduction efficiency in multi-layer bed RHF. It has been observed that there is an optimum level of carbon (C_{Fix}/Fe_2O_3 ratio

of 1.66), which is well below the upper stoichiometric level for direct reduction of hematite (C/Fe_2O_3 ratio of 3), caused maximum reduction, better carbon utilisation, and productivity in multi-layer bed RHF. It has been inferred that low carbon containing pellets promotes indirect reduction that leads to better utilisation of carbon and higher extent of reduction. Top layer showed higher extent of reduction when the carbon content in the pellet was low (C/Fe_2O_3 ratio < 2.33), whereas, the bottom layer showed higher DOR in high carbon containing pellets (C/Fe_2O_3 ratio > 2.33), which has been attributed to better volatile usage at bottom layer under lower heating rate.

Some experiments were carried out with pellet bed packed with graphite, sand, and coal to examine the effect of such packing materials on the efficiency of heat transfer to the pellets. The bed without any packing material or packed with coal demonstrated better reduction results compared to the bed packed with graphite and sand. Against the general conviction, the worst result produced by the high conducting graphite as the bed packing material has been attributed to unfavourable heat partitioning between graphite and pellet.

The effect of CaO has been studied at two carbon levels in the pellet. The addition of CaO to the pellet has been found to be beneficial only at high carbon level (C/Fe_2O_3 ratio of 3) at an optimum level of 4% CaO. Both thermodynamic calculation and experimental results (SEM/EDS) indicated that the presence of CaO restricts the formation of liquid fayalite and promotes crystalline phases that favour reduction through better gas movement. However, presence of CaO showed no beneficial effect in low carbon containing pellets (C/Fe_2O_3 ratio of 1.66). Thermodynamic study indicated at low carbon level fayalite is more likely to form.

The coal with higher fixed carbon, lower volatile and ash content produced better reduction results in three-layer bed RHF.

The reduction data of the RHF has been analysed using an existing mathematical model for different carbon containing pellets. The beauty of the model is that it uses two input data at the input and output of RHF and predicts continuous evolution of solid phases with time. The model estimated apparent activation energy for wustite conversion is found to be lowest indicating a mixed controlled kinetics. The apparent activation energy value has also been found to be lowest for three layer bed. Thermal efficiency calculated based on model data, is found not to vary significantly with increase in the number of layers at least up to three layers. However, thermal efficiency is found to decrease with the increase in carbon content in the pellet, which has been attributed to higher carbon consumption through endothermic carbon gasification reaction.

In order to generate temperature and time dependent data which was not easily possible in RHF, some single pellet experiments were done in a tube furnace. The reduction results of single pellet experiments indicated that the reduction in low carbon containing composite pellet was more temperature sensitive compared to that in the high carbon containing pellets, which are more likely to be controlled by heat and mass transfer.

Key words: Iron Ore-Coal Composite Pellet, Rotary Hearth Furnace, Reduction Efficiency, Carbon Efficiency, Productivity, Rate Parameters, Thermal Efficiency.