Executive summary (not exceeding 500 words)

India has substantial resources of off grade ore (hematite <60% Fe) and magnetite. Magnetite is less reducible and therefore can not be considered as direct shipping ore. Therefore, it requires mandatory beneficiation and pelletization and partial reoxidation to hematite before it can be used for iron making in a shaft furnace. Additionally, carefully controlled operating conditions are required to prevent the pellets from swelling and disturbing the operations of the shaft furnace.

There is a possibility to explore partially beneficiated ore in a Rotary hearth furnace (RHF) which can be used as a chemical beneficiator cum reduction unit. In such a unit, the ore-coal composite pellets can be directly converted to iron and slag for subsequent separation by smelting. The possibility of swelling is likely to be less since the naturally indurated raw pellets entering the reduction zone are not strongly bonded and can perhaps accommodate volume changes. Also, because of intimate contact with the solid reducing agent, the energy efficiency can be higher than gas based reduction processes. Other favorable point for RHF is that unlike blast furnace (BF) and gas based shaft furnace sponge iron unit, material is stationary over hearth and thus does not undergo any degradation. Therefore, RHF may relax as far as the strength requirement of the burden material is concerned. Also design and operating parameters of the RHF may widely vary for treating off iron ore and coal fines of Indian origin for efficient running of the RHF.

The limitation of the RHF as used in commercialized process like fastmet is that it operates with one/two layers of pellets over hearth in a top heated fuel fired furnace. Making it a multilayer towards a more productive furnace is a challenge because heat and mass transfer resistance through the multi-layer bed may severely limit the degree of metallization in such reactor. Enhancement of thermal conductance of the multilayer bed will be attempted by tailoring the size, shape distribution of the pellets, suitable additives, and optimizing the operating parameters of the furnace. Finally, the up-scaling of the process will be done based on laboratory scale data and modelling exercise. A demonstration plant (5 tons/day) will be made and installed at the industrial site (ASP, Durgapur) for final tuning and modification to the need of the industry.

Background and motivation (not exceeding 500 words)

Treatment of off grade iron ores have not been reported in the literature using RHF. Also investigations have not been reported where magnetite is taken as the starting raw material for producing iron. Some authors (Standish et al. [1], Kotaro Ishizaki et al. [2]) studied the reduction of magnetite in presence of carbon in microwave furnace and indicated the superiority of charcoal over coke, and microwave heating as an effective alternative to solve slow heating problem of conventional reduction process. Nagata et al. [3] showed that the aspects of producing pig iron at very low temperature are optimum coal content in the pellet and ash content in the coal and also higher carbon content of reduced iron particles in a pellet carburized by CO gas during reduction stage. T. Coetsee et al. [4] made a clear point that the reductant must be selected carefully with an optimum composition and reactivity as carbon gasification has significant control over the process. Carlos et al. [5] observed a catastrophic swelling of CaO fluxed pellets in the temperature range between 900 and 1000 degree Centigrade due to formation of fibrous whisker iron, which was attributed to insolubility of CaO in wustite that causes preferential growth of iron on certain sites of the lattice. Tang et al.[6] reported MgO additives are beneficial for restricting swelling. Similar results was also reported by Srinivas etal.[7].

Usage of off grade ore including magnetite is not seen much today due to high cost associated with essential beneficiation and energy intensive induration process for pelletization. Furthermore, swelling is another serious problem accompanied with pellet reduction in shaft furnace. Rotary Hearth Furnace with wide range of operating parameters and fixed bed has already been proved to reduce iron ore coal composite pellets to sponge iron. Therefore, there is a possibility to explore the partially beneficiated off grade ore in a Rotary hearth furnace (RHF) which can be used as a chemical beneficiator cum reduction unit eliminating the need for separate pelletization unit. The present author have some expertise with reduction of composite pellets in laboratory scale RHF at IIT Kharagpur [8-16]. Authors have demonstrated the effect of shape of pellets on the reduction efficacy at RHF. They have also developed mathematical model for calculating rate parameters, evolution of phases, thermal efficiency . Upscaling of operating parameters, setting up demonstration plant at the industrial site and converting the low grade ore into useful iron in a more productive way at RHF are the major aim of this project.

Project outcomes (please list specific objectives): *The project should address a specific need of the industry/industries and there should be clear expected outcomes from the project. It is expected that joint patents will result from this project.*

1. Identify optimum design and operating parameters (size shape distribution of pellets, additives,
   time and temperature of the reduction zone) for multi-layer Rotary Hearth furnace for productive output based on laboratory scale experiments

2. Scale up study using process model

3. Development of large scale RHF based on laboratory experiments and model prediction

4. Setting up large scale setup at industrial site for fine tuning

5. Demonstration plant is supposed to supply sponge iron (metallics) to the plant at the rate of 5 tons/day
6. Possible patent on sponge iron production on multi-layer bed RHF

Scope (not exceeding 1500 words): *The scope should clearly lay out the contributions of the academic partner and the industry partner.*

In the present scenario of India's iron and steel market, utilization of off grade ore including magnetite is a major concern. Since the reserves of high grade hematite ore are fast exhausting, it will be inevitable for the steel makers in India to use off grade ore including magnetite as their starting raw materials. Conventionally, off grade ore requires costly beneficiation, pelletization. Swelling is another serious problem accompanied with the off grade ore pellets.

There is a possibility to explore partially beneficiated ore in a Rotary hearth furnace (RHF) which can be used as a chemical beneficiator cum reduction unit. In such a unit, the cold bonded ore-coal composite pellets can be directly converted to iron and slag for subsequent separation by smelting and thus it avoids costly induration process during pelletization. The possibility of swelling is likely to be less since the naturally indurated raw pellets entering the reduction zone are not strongly bonded and can perhaps accommodate volume changes. Besides, swelling may also be controlled by testing the operating parameters widely, which is possible at RHF. Besides, due to intimate contact of carbon with the solid reducing agent, the energy efficiency of RHF technology is supposed to be higher than gas based reduction processes. Other favourable point for RHF is that material is stationary over hearth and strength requirement of the burden material is not of concern.
RHF as used in commercialized process like fastmet operates with one/two layers of pellets over hearth in a top heated fuel fired furnace. Making it a multilayer bed reactor towards a more productive furnace is a challenge because heat and mass transfer resistance through multilayer bed limits its metallization.

Therefore, the aim of the project is to develop of more productive multi-layer bed RHF based technology towards sponge iron production using off grade ore. A demonstration plant should be designed and erected at the industrial site based on optimum parameters established through laboratory scale experiments and modeling exercise.
Since metallics demands by alloy steel plant in increasing due to shortage of scrap, development of such indigenous multi-layer more productive RHF technology treating off grade ore and supplying the sponge iron (metallics) would be boon for ASP, Durgapur.
Based on the scope described, the contribution from academic and industrial partner are envisaged as follows:

Contribution from academic partner

1. Laboratory scale experiments by varying design and operating parameters for RHF ore reduction towards achieving maximum metallization, and controlling swelling.
2. Characterization of reduced pellets by XRD, optical & electron microscopy
3. Mathematical model for estimating rate parameters, calculation of evolution of phases and thermal efficiency.
4. Atomistic simulation of additives in Pellets
5. Scaleup study using laboratory scale data and model prediction
6. Selecting optimum parameters for demonstration plant (5 tons/day)
7. Erecting the demonstration plant with the help of identified manufacturer
8. Working with ASP for testing and fine tuning of the Demonstration plant

Contribution from industrial partner:

1. All kinds of assistance including space, layout should be provided to the manufacturer for the establishment of the demonstration RHF (5 tons/day) at industrial site, ASP, Durgapur
2. All cost towards running the demonstration plant and ancillary units, including manpower, and consumables should be provided by the ASP.