# Ironmaking through the Rotary Heath Furnace

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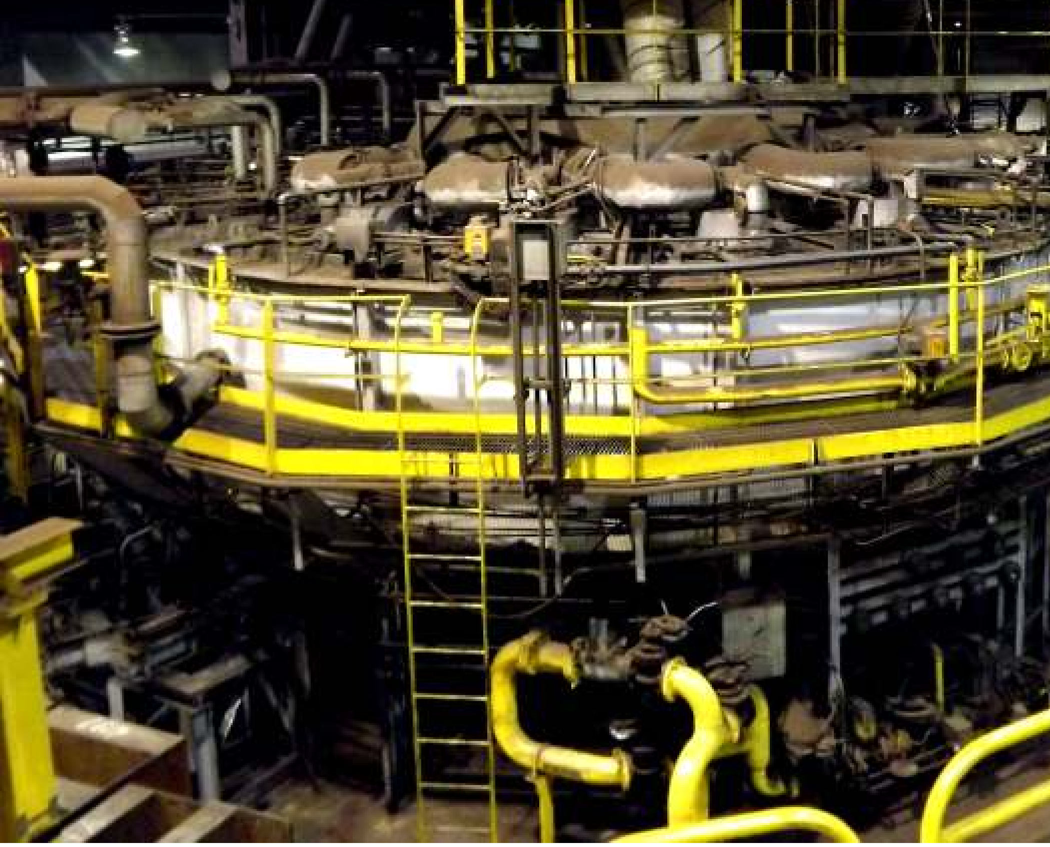


Global steel production steadily increased over the years and reached around 1583Mt in the year 20131. Out of this, around 70% of the steel was produced through the main primary production route, Blast Furnace (BF) – Basic Oxygen Furnace (BOF), while Electric Arc Furnace (EAF) steel production accounted for 30% of the total amount. Increase in green house gas emission due to growth and expansion of steel production worsened the global worming situation day by day. Along with the environmental concern, the steel industries face new challenges including the availability of good quality raw materials. Beneficiation of iron ores and agglomeration process has become more important for iron making industry. Especially, pelletizing technique attracts many investigators as it utilizes fine iron ores from mining sites as well as secondary materials generated from steel works such as mill scale and flue dust.

With the advancement of existing technology, there is dramatic improvement in the energy efficiency of BF process. An efficient blast furnace is already working close to its theoretical limits of carbon utilization. Therefore, there is only marginal scope for improvement in terms of lowering the energy consumption and CO2 emissions. It is hence necessary to identify and introduce viable breakthrough technologies for longer term. In China and India, where electricity and good quality scrap have not been as generally available, are mostly dependants on the BF/BOF route. Due to the lack of good coking coal within India, and dwindling supplies worldwide, new iron making processes are being developed to use cheaper coal supplies.

## Alternative Ironmaking Process Route

There exist two major alternative ironmaking technologies; one is direct reduction process and other one is smelting reduction process. Direct reduction iron-making was first industrialized in the 1960s, and various plants started to be built on the commercial and semi-commercial scales. Direct reduction iron-making processes roughly fall into two classes, natural gas based and coal based, depending on the reductant used. World DRI production touched 74 Mt in the year 2012; out of which around 77% was produced through gas based DRI process and rest was produced through coal based DRI. India has significantly increased its production volume in recent years. India's DRI production increased from 5.44Mt in the year 2000 to 20.05 Mt in the year 20122. It produces reduced iron mainly by the SL/RN process using coal as a reductant. On the other hand, in the Middle East, North Africa and Latin America, regions rich in natural gas, produced reduced iron using their natural gas as the reductant.

## Utilization of Composite Agglomerates

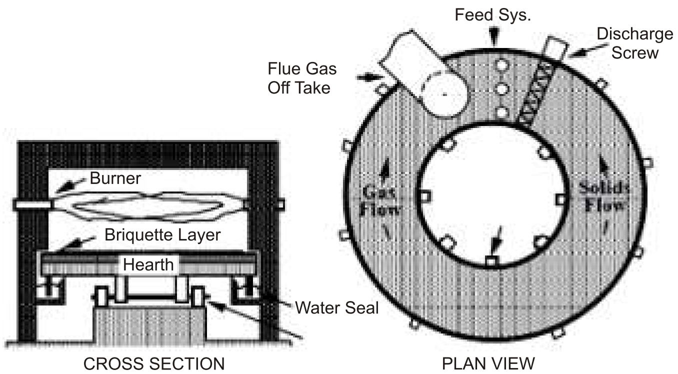
The interest in iron ore-carbon agglomerates is due to their advantage of having intimate contact between iron oxides and carbonaceous reductant. This close contact between the reactants generally has the effect of increasing the reduction rate. Apart from that, a wide variety of both iron sources and carbonaceous materials can be used. Composite agglomerates can be prepared by mixing iron ore fines and carbonaceous materials along with some binder to have some handling strength. During reduction at high temperature, the binder does not survive. Also, the carbonaceous material disappears during the progress of reduction leading to weakening of agglomerates due to increase in porosity. In the large part of the blast furnace, the counter current gas-solid reactions take place. Therefore, generation of fines from the collapse of the composite agglomerates is obvious and thereby adversely affecting the blast furnace productivity. For the same reason, it is fair to rule out the use of composite agglomerate in the shaft furnace. For this physical weakness, probability of using them in larger rotary kilns may also be ruled out. Thus, the rotary hearth furnace (RHF) has been the obvious choice for utilizing composite agglomerates prepared from a variety of fines and wastes of iron ore and carbonaceous materials.

## Rotary Hearth Furnace

The RHF is a donut shaped refractory lined chamber. Composite agglomerates consisting of iron ore fines and reductant are charged into the hearth of the RHF through a vibrating conveyor charging system. There are a series of burners placed at the sidewall of the RHF for burning the fuel to generate the required temperature around 1200-1400oC.

Natural gas, coke-oven gas, Liquefied Petroleum Gas etc may be used as fuel. The burning of released volatile matter of coal also contributes to the heat generation. The Agglomerates are rapidly heated up to the reaction temperature by the radiation heat. The movement of the furnace bed is in the direction opposite to the flow of the process gas allowing maximizing the surface area for reduction as well as heat transfer. To minimize the re-oxidation of the reduced iron a low oxygen potential is maintained near the bed. Figure 1 shows the plan and cross sectional views of a typical RHF.

**FIG. 1 : SIMPLIFIED CROSS SECTION AND PLAN VIEW OF THE ROTARY HEARTH FURNACE**

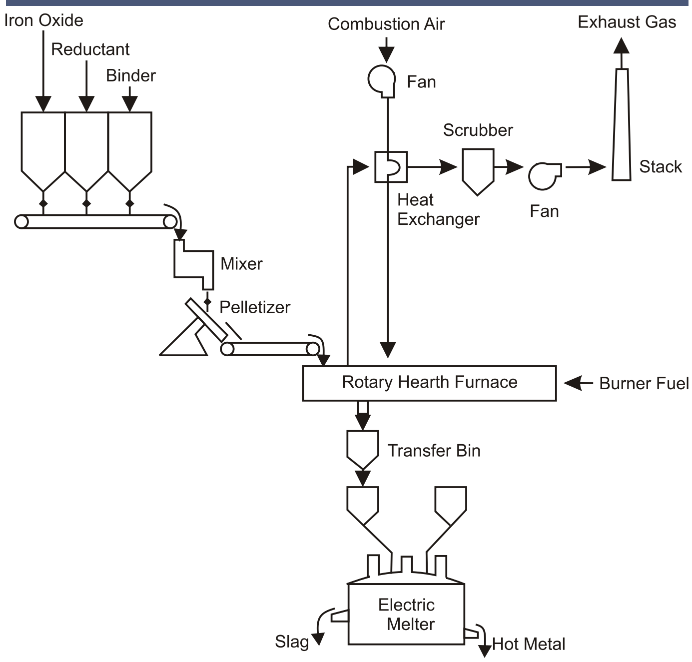



## Various Rotary Hearth Furnace based Ironmaking Processes

### The INMETCO Process

In INMETCO process4-6 pellets of stainless steel wastes are reduced at around 1260oC and subsequently it is melted in submerged arc furnace (SAF) and gangue removal accomplished. The process flow diagram is presented in Figure 2.

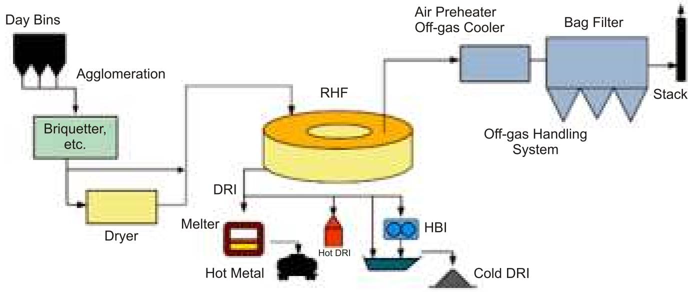
**FIG. 2 : SCHEMATIC FLOW DIAGRAM OF INMETCO PROCESS**




### The FASTMET/FASTMELT Process

In FASTMET process (3, 7-11), jointly developed by Kobe Steel, Japan and Midrex Direct Reduction Corporation, composite pellets consisting of hematite concentrate and medium volatile coals are continuously fed into the RHF and a mixture of coke-oven gas and Liquefied Petroleum Gas (LPG) was fired to generate heat. The pre-reduced pellets are subsequently melted in an AC submerged arc furnace. The remaining FeO in the DRI is reduced by the residual carbon in the DRI and no secondary carbon addition is needed. Lime is added for gangue and sulfur removal. The schematic of the process is presented in Figure 3.

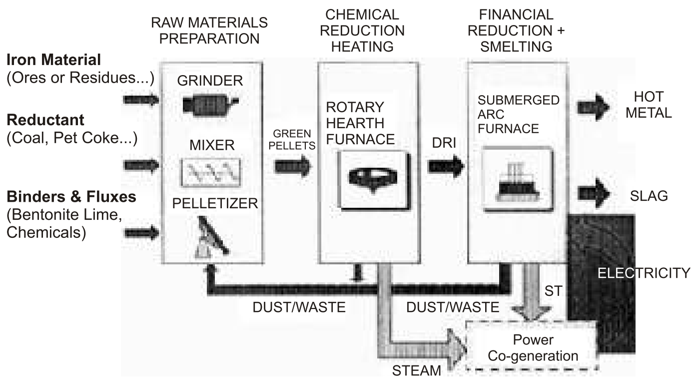
**FIG. 3 : SCHEMATIC OF THE FASTMET IRONMAKING PROCESS**




### The RedSmelt Process

In RedSmelt process12, similar to the INMETCO process, waste iron oxide composite pellets are reduced in RHF to achieve around 92% metallization. Subsequently, the DRI is smelted in a SAF to obtain hot metal. Gangue and sulfur removal take place by the addition of a suitable flux. The schematic of the process is shown in Figure 4.

**FIG. 4 : SCHEMATIC OF THE REDSMELT IRONMAKING PROCESS**



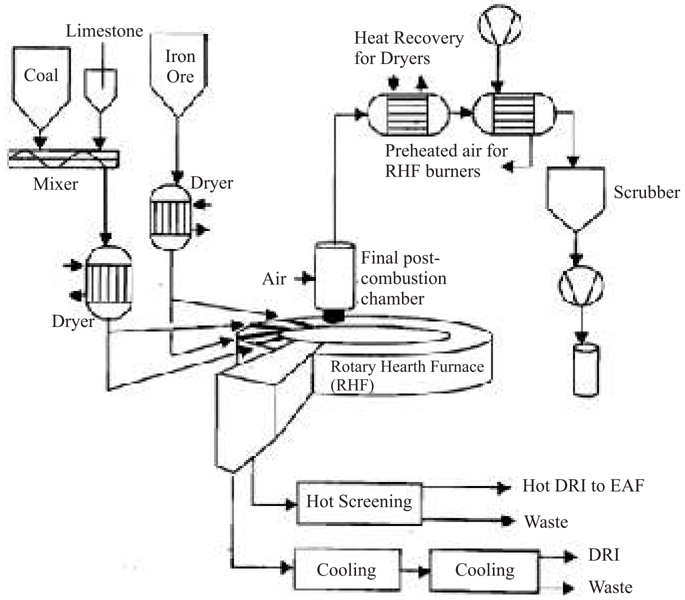

### The COMET Process

In COMET13 process, the iron-ore and coal fines are not mixed and pelletized unlike the other processes mentioned before. Instead, they are charged in the form of alternate layers on the hearth. Limestone is usually added in order to control the sulfur in the coal. The temperature in the reduction zone is around 1300oC. Natural gas, coke oven gas, pulverized coal etc are fired to generate the heat. Post-combustion of the volatiles and CO released during the reaction also provide some amount heat. The DRI layers undergo sintering due to the high temperature. However, the excess char remains powdery and can therefore, be easily separated using a screen. The off-gas undergoes further post-combustion outside the furnace and the heat is utilized to heat up the process air and the charge materials. Because of the higher load on the hearth in this process, the processing time in this process is usually much larger than its counterparts which use composite pellets. Figure 5 shows the process flow sheet of this route.

### The SIDCOMET Process

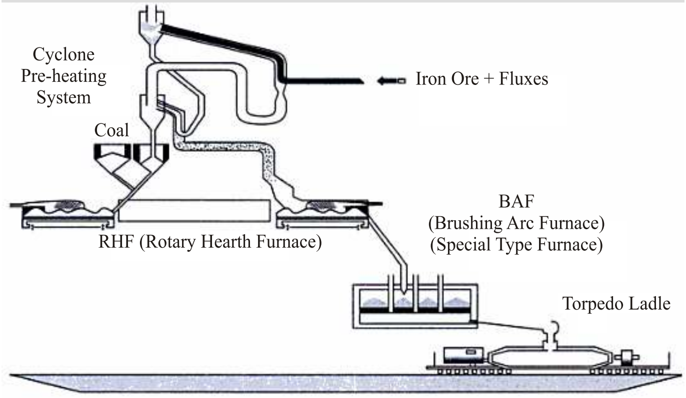
The SIDCOMET14 Process is similar to the COMET process described earlier. The only difference is that the iron-ore and coal fines

FIG. 5 : SCHEMATIC OF THE COMET IRON-MAKING PROCESS




are fed as a mixture in this case. The residence time is similar to the COMET process. Due to the higher residence time, the productivity of this process usually remains lower than the pellet based processes. The DRI is then melted in a separate electric arc furnace like in the other processes. Figure 6 shows the process flow diagram of this process.

FIG. 6 : SCHEMATIC OF THE SIDCOMET IRONMAKING PROCESS



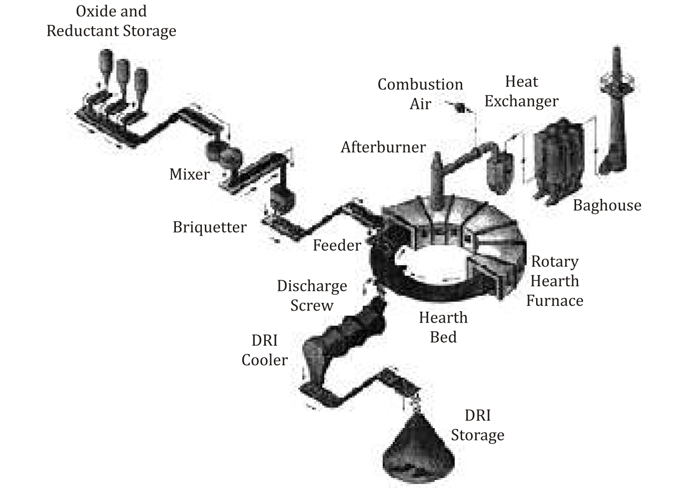

## The DRyIron Process

In DRyIron15,16 Process, dry briquettes made out of EAF dust, mill scale and coal are charged into the RHF in the form of a single layer. The oxides of highly hazardous metals like zinc and cadmium which exist in EAF dust are vaporized during DRI making and collected in the bag-house. The layout of this technology is given in Figure 7.

## The ITmk3 Process

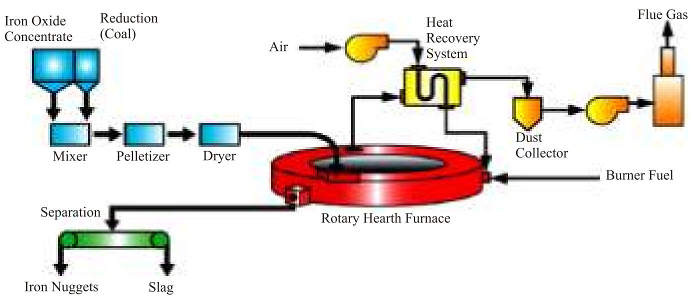
The ITmk317-21 process aims at production of iron nuggets directly from composite pellets consisting of iron-oxide and medium volatile coal fines in RHF. A unique feature of this process is the reduction and smelting of the DRI within the RHF itself. The green pellets are dried and subsequently fed into the RHF where they undergo preheating and reduction in two different zones. The volatiles are burnt in the preheating zone and the CO released during reduction is combusted in the reduction zone. This is followed by a third zone which is maintained at a higher temperature of around 1350oC. It is here where the pellets melt and the

FIG. 7 : SCHEMATIC OF THE DRYIRON IRON-MAKING PROCESS




slag separates from the metal. The metal nuggets and the slag granules can be easily separated post cooling using a screen or a magnetic separator. The iron nugget usually contains about 3.5% dissolved carbon. The nuggets can be directly fed into a BOF or an EAF. The schematic of the process is given in Figure 8.

FIG. 8 : SCHEMATIC OF THE ITMK3 IRONMAKING PROCESS




## The Hi-QIP Process

The Hi-QIP22 Process is quite similar to itmk3 process. However, there are some subtle differences between them. In Hi-QIP Process, mixture of iron ore and coal fines are fed, instead of composite pellet in itmk3, on a layer of carbonaceous material on the hearth. The carbonaceous layer not only prevents the refractory damage due to slag erosion and hearth sticking problems but also aids in the separation of slag and metal in the reduced product.

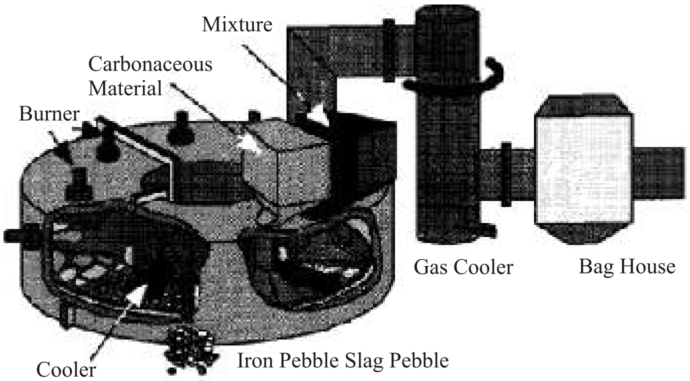
Hollows are formed on the carbonaceous layer at different locations. As the hearth rotates, the mixture is heated, reduced and melted in the furnace. Finally, metal pebbles free from slag are produced in the hollows on the carbonaceous material layer. Steel wastes can also be used instead of the mixture. The process schematic is shown in the Figure 9.

It should be noted that all of these processes discussed above have been completely successful commercially due to the some limitations associated with the RHF leading to poor productivity.

## Salient Features of RHF

- There are three to four major zones inside the RHF namely (a) Preheating zone (b) Main reduction zone (c) Final reduction zone and (d) Cooling zone. By properly regulating the fuel and oxygen ratio, the furnace atmosphere is controlled to meet the thermal and metallurgical requirements of the process. Higher oxygen potential is required in the

FIG. 9 : SCHEMATIC OF THE HI-QIP IRON-MAKING PROCESS




preheating zone in order to extract the maximum chemical energy stored in the burner fuel. Elimination of entrapped moisture and the volatile matters take place in this zone.

following two reduction zones have a much lower oxygen potential to prevent the re-oxidation of reduced pellets. In reduction zones, the iron-oxide and some other impurity metal oxides are reduced to their metallic forms. In the cooling zone the DRI is cooled below 300oC before discharging.

● Apart from the burning fuel, there are other sources of heat inside the RHF. The post combustion of CO gas generated during reduction helps to reduce the energy requirement of the process. Sometimes, secondary air is also injected to facilitate the post combustion purpose. Combustion of volatile matters also releases some heat. Some minor amount of heat is also generated during combustion of carbon present in the pellet.

● Low–grade carbonaceous materials including waste plastic can be used in the RHF as reductant. The utilization of these low–grade carbonaceous reductants would enable the RHF process to produce metallic iron only from secondary source materials and enhance the sustainability of steel and chemical industries.

However, percentage of volatile matters content in the low–grade carbonaceous reductants is very critical in selecting them for the use in RHF. The rapid evolution of gas increases the internal pressure that may lead to break down of pellet, which should be avoided to keep high lump ratio of the product DRI.

● The speed of hearth rotation can be externally controlled and it depends on the reactivity of the raw materials. The usual practice is to ensure a residence time long enough for the pellets to attain an average metallization degree between 80%-92%.

● The RHF is usually operated at a negative pressure in order to avoid the leakage of furnace gas to the external environment and is sealed using water seal troughs.

● The off gas from the RHF further undergoes complete post combustion by utilizing additional air. The energy obtained from this can either be used to preheat combustion air, dry the feed materials or generate steam in waste heat recovery boilers.

● The recovery of dust from bag-house is an extremely valuable resource for reclamation of volatile metals like zinc and cadmium which are otherwise considered to be toxic, if released into the external environment.

● It is usually advantageous to utilize the sensible heat of hot DRI by hot-charging into a smelter. In the event of delayed smelting, the usual practice is to convert the DRI into Hot Briquetted Iron (HBI) to minimize the degree of re-oxidation by reducing the available surface area.

● DRI produced from RHF containing high percentage of gangue can creates problem during subsequent steel making in an electric arc furnace because of higher lime additions for slag formation and electrode consumption.

● Heat transfer to the lower layers is one of the serious drawbacks of the RHF; particularly, when multilayer pellet bed is used instead of single layer to improve the productivity. The shrinkage of composite pellets is expected to facilitate the transfer of heat from top layer to the bottom. Shrinkage of the pellets occurs because of combined effect of chemical reactions and sintering of the iron oxides.

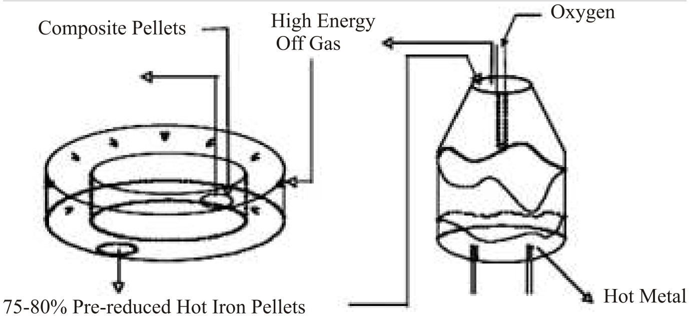
This enhances the reaction kinetics of the lower layers. It depends upon both the temperature and time. Some studies on shrinkage phenomena of an Indian iron ore by the present author, reveals that wood charcoal composite pellets have best shrinkage behavior than that of the bituminous coal char and graphite composite pellets.

## Future Trend

The limitation of RHF can be overcome by a proposed new alternative ironmaking process23-28 consisting of RHF and a smelter instead of RHF-EAF combination. The idea is to pre-reduce the iron-oxide in the RHF to about 75-80% degree of metallization to improve the productivity. Subsequent smelting step will complete the remaining reduction. The RHF would act as a pre-reducer. Use of pre-reduced ore is expected to decrease the energy consumption in the smelter.

Thus, combining the RHF with a smelter, the limitations of the individual reactors can be overcome. It is expected that the new process would have lower operating costs and be more environment-friendly because of the elimination of the environmentally challenging processing steps like coke-making and sintering, as in the blast furnace route. A schematic representation of ironmaking process consisting of RHF and a smelter is presented in Figure 10.

FIG. 10 : SCHEMATIC DIAGRAM OF IRONMAKING USING ROTARY HEARTH FURNACE AND SMELTER




## Conclusion

The steel industry is currently faced with a new set of major challenges requiring innovative technologies to lower the emission of green house gases, to reduce the energy consumption and also to recover the valuable materials from the waste. The major driving forces for development of competitive processes are to avoid the cokemaking and sintering steps preceding the blast furnace. The blast furnace process will continue to be the dominant process for iron making. But with changing world scenario, we have to be prepared for the future to meet the challenges.

The rotary hearth furnace based ironmaking processes have the potential to make iron from fines, low grade ore as well as from secondary resources.