Sponge Iron Based Steelmaking

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Sponge Iron or Direct Reduced Iron generally having iron content in the range of 80-90%, is obtained from direct reduction of iron oxide. Oxygen in the iron oxide is removed leaving void space and it acquires a spongy internal structure. Hence, Direct Reduced Iron (DRI) is also called sponge iron. It is an important raw material for steel making through the electric arc furnace (EAF) or electric induction furnace (EIF) route of steel production. Sponge iron is an ideal substitute with its higher metallization, balanced carbon content and low residuals but has the limitation of higher power consumption compared to scrap based process and longer processing time in EAF/EIF due to its gangue content. Scrap recovery in India varies widely which is low considering the volume of steel production. The low dependence on scrap as a source of metallics leads to rise in use of DRI and alternative iron inputs for production of steel in EAF/EIF.

Background - Sponge iron as a raw material for Steelmaking

Sponge iron is used as an important raw material for steelmaking through electric furnace route, partially substituting and supplementing scrap. Although scrap is a relatively better alternative in electric steelmaking, availability of required quality of scrap in the international market is not certain and is gradually declining. With the technological developments, the in-plant scrap generation has been reduced due to higher yields both during steel production and subsequent processing. The generated scrap is consumed within the plant. The purchased scrap quality is often unpredictable. The scrap recovery system in India also needs improvement. As a result, the scrap prices have increased its availability in market has been reduced and its price has become volatile. This led the steelmakers of electric steelmaking route to look out for alternative metallics. Sponge iron was the obvious choice in-terms of chemical composition, lower tramp elements and assured supply. Also, India has a ready domestic availability of significant reserves of high quality iron ore for producing sponge iron. As direct reduction is the process for reducing in the solid state, it requires much less investment than blast furnace process and requires no coke and thus gained importance. DRI is suitable from operational point of view also, owing to continuous charging process, high carbon efficiency and improved residual properties in electric furnaces. The present trend is to charge hot metal in EAF along with DRI and scrap which leads to higher productivity and lower power consumption amongst other benefits. A combination of corex process for producing hot metal and DR plant for producing hot and cold DRI with EAF is another alternative of producing high quality steel with high productivity. Reference of such plant combinations can be found in India also. Utilization of syn gas through coal gasification to produce DRI is in the initial stages of operation in one of the steel plants in India.

Sponge Iron Industry in India

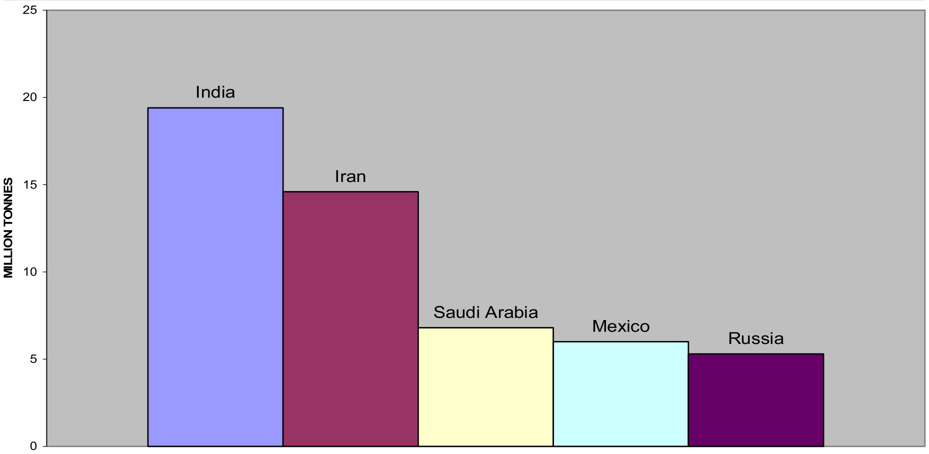
India is the world's largest producer of sponge iron. The development of the coal based DR processes has relaxed the restrictions on the DR plant locations, which in the past had been primarily in natural gas producing regions. Therefore DRI is now combined with scrap adding versatility in the production of high-grade steel by the electric steelmaking routes. The world's direct reduced iron production in the year 2014(1) is given in the Fig. 1.

The domestic sponge iron production is dominated by the coal based route having a share of more than 80% in the market. During the last ten years there has been a exponential 14% growth in the coal based DRI production route which lead to the growth of the sponge iron industry at a CAGR of 8%. The overall growth of the coal based DRI had been guided to some extent by the limited availability of natural gas for the production of direct reduced iron and the market fluctuations on the steel industry. The details of a survey on the Indian sponge iron Industry(2) is given in the Table-1.

TABLE-1: A SURVEY ON INDIAN SPONGE IRON INDUSTRY

Parameter	Survey Finding : Ref Year : 2012-13
No. of Units Surveyed	372
No. of Units in Coal Based Route	369
No. of Units in Gas Based Route	3
No. of Units Expanding	38
No. of Units in the SSI Segment	79
No. of Units in the Non-ssi Segment	293

Fig. 1 : World's Top Five DRI Producing Countries in 2014



DRI Characteristics for Steelmaking

In the process of direct reduction, with the removal of oxygen from iron ore, the concentration of the other constituents in the feed material increases. The properties and end composition of DRI are influenced by the input levels of the oxides, to a large extent on the total iron content, the direct reduction process employed and the operating parameters. The main characteristic features of DRI for use in EAF is its degree of metallization, gangue content and carbon content. DRI process roughly fall into two classes depending on the reductant use, namely natural gas based processes and coal based processes. DRI is mainly produced from shaft furnaces and fluidised bed processes for gas based production and from rotary hearth and kiln for coal based production. The typical DRI compositions produced by the different process are given in the Table-2 below.

TABLE - 2 : TYPICAL DRI COMPOSITIONS PRODUCED BY THE DIFFERENT PROCESS

	Gas Based				Carbon Based	
	Shaft Furnaces			Fluidised Bed	Rotary Hearth	Kiln
	Plant 1	Plant 2	Plant 3			
Total Iron (%Fetotal)	94.30	92.70	91.80	93.00	90.00	90.50
Metallic Iron (%Femet)	88.30	85.70	85.40	85.00	81.90	83.00
Metallization (%Met)	93.60	92.40	93.00	91.40	91.00	91.70
Iron Oxide (FeO)	7.70	9.00	8.20	0.30	10.40	9.60
Carbon (C)	1.00	0.40	1.50	1.00	2.00	0.20
Gangue	2.74	3.68	4.81	2.80	4.96	6.97

EAF operate with a V ratio of 2 to 3 which is the ratio of the basic oxide (CaO +MgO) to the acidic oxide (SiO2 + Al203). The V ratio in the product DRI is much lower than that required in EAF. The required V ratio is obtained by adding adequate quantity of lime which in turn increases the energy required for melting. Lime additions also affect the slag fluidity, viscosity and the extent of desulphurization. Therefore this feature of DRI should be suitably considered while selecting the percentage of DRI in the total charge-mix.

The percentage of carbon in DRI is also an important factor. As carbon percentage increases, the iron content decreases correspondingly. Decrease in %Fe in turn lowers the percentage metallization. Decrease in metallization increases the energy consumption and decreases the liquid steel yield. It has been found that a drop of metallization from 94.5% to 92%, the electrical energy consumption increases by 20 kWh/ton and the relative steel yield decreases from 1.03 to 1.0. It has also been observed that 0.215% of theoretical carbon is required to neutralize 1% of FeO contained in DRI. The carbon which is in excess to that required for neutralizing the FeO, can be combusted with oxygen in EAF, reducing the total energy requirement. Presently as metallic yield of the DRI plants are increasing and also producing higher carbon levels, the EAF yield and productivity shall also increase, allowing EAF shops to reap substantial financial and technical benefits.

Use of DRI in EAF

Production of steel with lower operating cost and increased productivity is the driving force today for the steelmakers. Improved operating practice, together with the need for cost effective production, has lead to high carbon DRI and hot DRI (HDRI) use. DRI usage in EAF has various advantages and disadvantages as given in the Table-3.

TABLE-3 : ADVANTAGES AND DISADVANTAGES OF DRI IN EAF

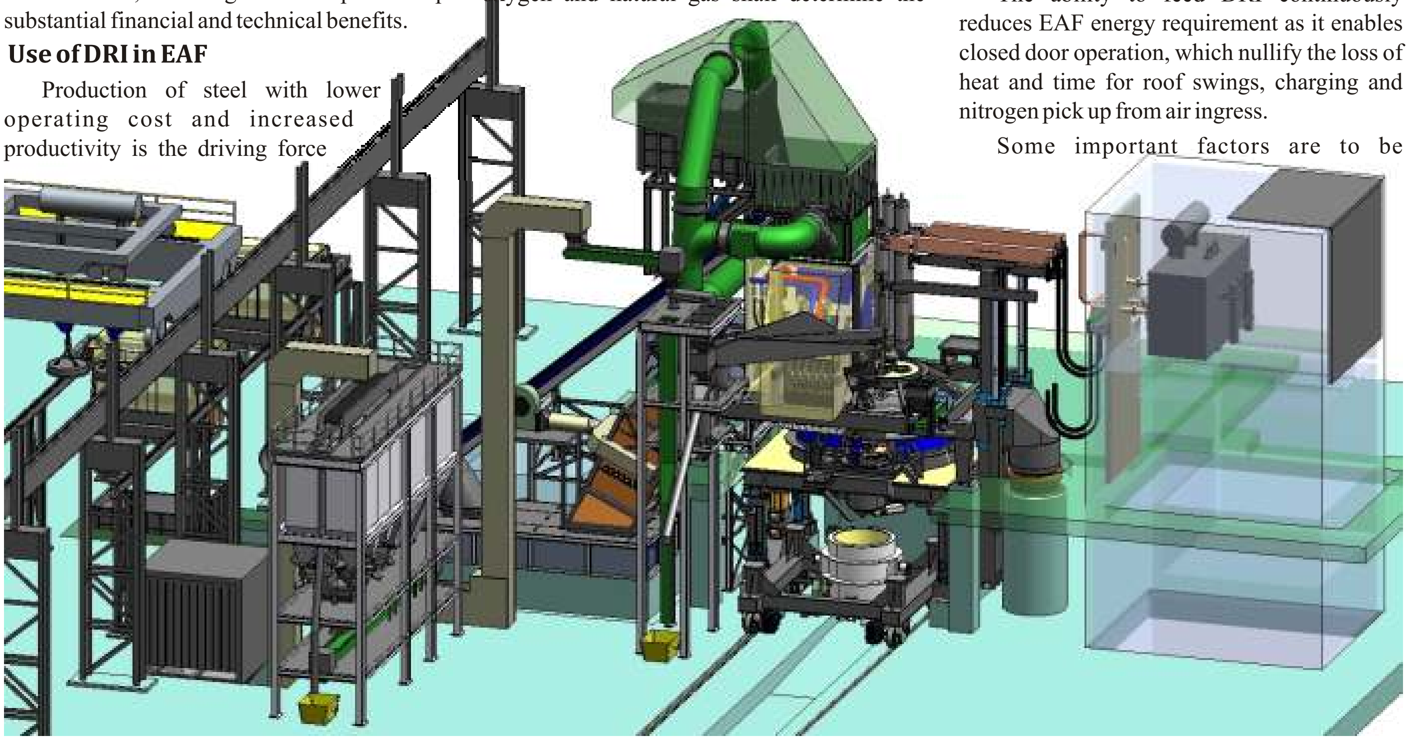
Advantages	Disadvantages
Lower cost compared to scrap especially in regions where natural gas is available.	EAF wall and roof exposed to the arc No scrap during initial power on. High quantity of hot heel required.
Continuous feeding. Less heat loss & oxidation from open roof charging.	High specific electrical energy consumption. High electrode consumption.
Known, chemical composition which leads to improved EAF efficiency.	Lower yield.
Low residuals beneficial for high quality steel. Stable bath, no scrap cave-ins. Fewer electrode breakages.	Uncontrolled residual elements cause inconsistency in the processing lines during hot and cold rolling and annealing.
High density for a fixed volume.	Increased lime usage.

As carbon is combined with DRI, it has an combustion efficiency which is greater than 90% as compared to the 25-75% efficiency of the injected carbon as this injected carbon may not cut through the slag layer, may be burned or can be sucked by the off gas system of the furnace. However, the site specific cost of oxygen and natural gas shall determine the economic feasibility of increasing the carbon percentage in DRI and melting it in EAF. The carbon also assists the foamy slag practice.

HDRI is charged in EAF to reduce electrical energy consumption, increase productivity and reduce electrode consumption. This becomes even more attractive as carbon-dioxide emissions are lowered. The way of transportation of HDRI need to be sealed and inertised and largely varies with the DR plant supplier from conveying by bucket conveyor, transport in closed containers or pneumatic feeding.

The ability to feed DRI continuously reduces EAF energy requirement as it enables closed door operation, which nullify the loss of heat and time for roof swings, charging and nitrogen pick up from air ingress.

Some important factors are to be



considered for the charging of DRI into EAF are as follows:

- Considerable quantity of hot heel is to be maintained for immediate start of furnace and for the melting reaction to start at a high temperature.

- Continuous charging of DRI is to be maintained with available power input (available from ultra high power transformer) for feeding to be completed within the required power on time. The feed rate of DRI is defined in mass per time (kg/(min) per electrical power input (MW). The complete feeding system from the discharge of DR plant upto the feeding point in the EAF roof has to be designed for these high feed rates. All operating profiles such as electric power input, oxygen and carbon injection rates shall be suitably attuned to the DRI ratio and the DRI quality.

The usage of high proportions of hot metal and coal based DRI in EAF is mainly confined to the Indian steel industry and pose many challenges. The FeO in DRI reacts violently with carbon in hot metal causing eruptions which has to be suitably controlled.

The feed rate of DRI and power input must also be controlled to avoid iceberg formation. As the energy content of hot metal comprises of both sensible and chemical energies, its use together with coal based DRI makes the process economically advantageous.

The main impact of DRI on the downstream of EAF results from the lower residual content. Uncontrolled residual elements cause inconsistency in the processing lines during hot and cold rolling and annealing. Optimization of continuous caster and rolling mills produces lower incidence of process problems.

EAF using DRI produce greater quantities of slag as compared to scrap. Crushing, screening and metal recovery are commonly used method for slag processing. The transportation cost to a potential industrial consumer is often large, which limits the sale of these low value materials for commercial consumption. However, EAF slag finds application mainly in land filling, road Construction, asphalt pavement and aggregate for concrete.

DRI is chemically reactive and this makes it dangerous to be stored or shipped in bulk quantities. Therefore, DRI should be kept dry all the time and inertised. Safe and hazard free transportation of DRI requires special precautions and prescribed guidelines and recommendations to be maintained.

Conclusion

A rapid growth in electric steelmaking has revolutionalized the iron and steel industry during the past years. As the amount of steel produced in electric arc furnace (EAF) is increasing, a significant evolution has emerged in the raw materials for EAF and the way steel is produced through it.

With the rising trends of usage of different combination of raw materials, the impact of producing steel through EAF should be observed through a larger spectrum of sustainability. It has now been proved that effective use of DRI shall lead to significant savings and attain optimum performance. Thus in this spectrum of sustainability, sponge iron has stood out to be one of the major raw materials for steelmaking.

References

1. World Steel in Figures 2015 – World Steel Association

2. The Indian Sponge Iron Industry – A Report by JPC