Phosphorous Control in Induction Furnace Steel Melting using LD Slag

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***Abstract* - Now a days in India induction furnace steel melting process contribute an important role in total steel production. Though previously only steel melting was done in induction furnace but now steel refining also can happen in it to some extent. The main problem of induction furnace is to control the phosphorous amount in final product. In this present work, a detail thermodynamic studies have been done. Here a 5 Kg laboratory based induction furnace with acidic lining is available and used. Generally phosphorous (P) removal is to be carried out in high basic environment. Since the available furnace lining is acidic a high basicity of 3.5 is maintained for effective P removal. However with basic lining, even with lower basicity the same result may be obtained. It is used to control the phosphorous amount of the final product. Steel scrap and direct reduced iron (DRI) are used as a raw material. They have been mixed in different amount at the time of charging. To control the phosphorous amount high basicity is needed. So by adding CaO in the form of limestone, a high basicity of 3.5 has been maintained. For phosphorous removal high oxidizing potential is also needed in the bath. This is achieved by using synthetic slag (LD slag) and DRI in the charge material. After every heat, the metal samples are collected and are chemically analysed by weight analysis after fusing method. Then the degree of dephosphorization are calculated. In this present work up to 54.44% degree of dephosphorization is achieved.**

Keywords - Induction furnace, DRI, Synthetic slag, Phosphorous, Thermodynamics, Basicity, Acidic lining, Degree of dephosphorization.

INTRODUCTION

World's economic growth is much dependent upon the growth of the Iron & Steel industry. Consumption of steel is taken to be an indicator of economic development..

Steel production in India has increased by a compounded annual growth rate (CAGR) of 8 percent. Though per capita consumption of steel in India is around 57.8 kg, which is far below the world average (182 kg) and that of the developed countries (400 kg). [1]After an increase in steel demand of 0.7% from 2014 to 2015, the steel industries faced a demand inclination of -1.7% in 2015. But World Steel Association forecasted that in 2016, the world steel demand will increase 0.7% and will reach 1,523 Mt. Steel demand in India, Mexico and other countries in ASEAN and MENA regions are expected to high due to their positive domestic demand. [2]

The domestic scenario of Indian steel industry is little bit better than other countries. Indian steel industry has entered into new era from 2007-08. Now India is the 3rd largest producer of crude steel and largest producer of direct reduced iron (DRI). Indian steel investment is monitored by Inter Ministerial Group (IMG) which is functioning in Ministry of Steel, under the Chairmanship of Secretary (Steel).[3] In coming years, there is a high scope of investment in integrated steel plant and mini steel plant in this country.As integrated steel plant needs a lot of investment, in India now a days the demand for mini steel plants are increasing. A mini steel plant can produce quality steel in low capital cost investment and low pollution rate. As the number of mini steel plants are increasing in India, the demand of electrically heated furnaces are also increasing.Mainly two types of electrically heated melting furnaces are used now a days. One is Electric Arc Furnace (EAF) and the other is Induction Furnace (IF).

Aninduction furnace is an electrical furnace in which the heat is applied by induction heating of metal. It is a clean, energy-efficient and well-controllable melting process compared to most other means of metal melting. Since there is no arc or combustion, the temperature of the material can be controlled easily. However, one major drawback of induction furnace usage in a foundry is the lack of refining capacity. Induction furnace is better than electric arc furnace due to lower cost of production. [4].

In India a subsequent amount of steels are produced in Induction Furnace nowadays. Though it is a very effective process, but it has certain limitations also. In Induction Furnace it is very difficult to control Phosphorous (P). Though initially P level comes down, but at high temperature P again rises in liquid steel. In induction furnace the phosphorous cannot be removed easily by lancing the oxygen in the bath. This furnace has small diameter to height ratio and at the time of operation they are almost full in volume. So if oxygen is lanced from outside, then there is a high chance of splashing of metal. It leads to decrease metallic yield. It is known that P has a detrimental effect in steel quality. Low content of phosphorus in steel is a critical requirement for thin sheets, deep drawn steel grades and all applications needing high uniform deformability. Phosphorus makes steel susceptible to embrittlement during heat treatment and leads to poor electrical properties [5,6].Dephosphorization is favoured by low temperature, high oxygen content in the metal bath and high slag fluidity [8].For this reason IF produced steel is again often taken to other secondary furnaces for purification. It increases the cost and decreases the productivity.

In the present work, it is being tried to develop a suitable technique for controlling the P level in steel in Induction Furnace. For this the thermodynamics of steel melting slag which is used as additives for dephosphorization have been studied in detail and necessary parameters will be tried to be identified for application during IF steel melting in laboratory scale with the aim of extending the knowledge to industrial scale.

In basic oxygen converter (LD converter) the slags which are produced are one of the waste materials of the steel plant. Generally they have limited use. They are deposited in storage yard. In case of environmental and economic consideration, they have detrimental effect. So reuse of LD slags are very important now a days. In this project, synthetic slag is replaced by LD slag. As LD slags have high FeO and CaO content, they are used to get high degree of dephosphorization.

Experimental Set Up

The experiments were carried out in a 5 kg/25 KW capacity corless induction furnace. This furnace was supplied by Megatherm. This furnace had acidic lining. Still the experiment has been carried out due to the availability & low cost. The ramming mass mainly contained silica. The charging materials were steel scrap and DRI with different proportion. Calculated amount of synthetic slag and lime were also added to maintain the required FeO amount and basicity. The temperature of the experiments were maintained in the range of 1575^0 to 1650^0 C. A basic calculation was done to know the amount of charging. Before every charging, the induction furnace was dried for some time. Then at first the scrap materials were putted inside. The power of the furnace was increased step by step. After some time when the scrap materials started to melt, then the DRI was charged into it. After the full melting of scrap and DRI werecompleted, then synthetic slag was added from outside.

After 5-10 minutes, the preheated limestone was added into the furnace to maintain proper basicity. Then the melting was done for a definite time. After completion of the whole melting process, the slag which float at the top of the metal was skimmed by the skimmer. Then by tilting the induction furnace, liquid metal was poured. The metal samples were collected and sent to the "Duttcon Industrial Research and Development Lab "to know the chemical composition. By the weight analysis after fusing chemical composition of the samples were known.The melting and tapping in the induction furnace is shown in the figure 1.

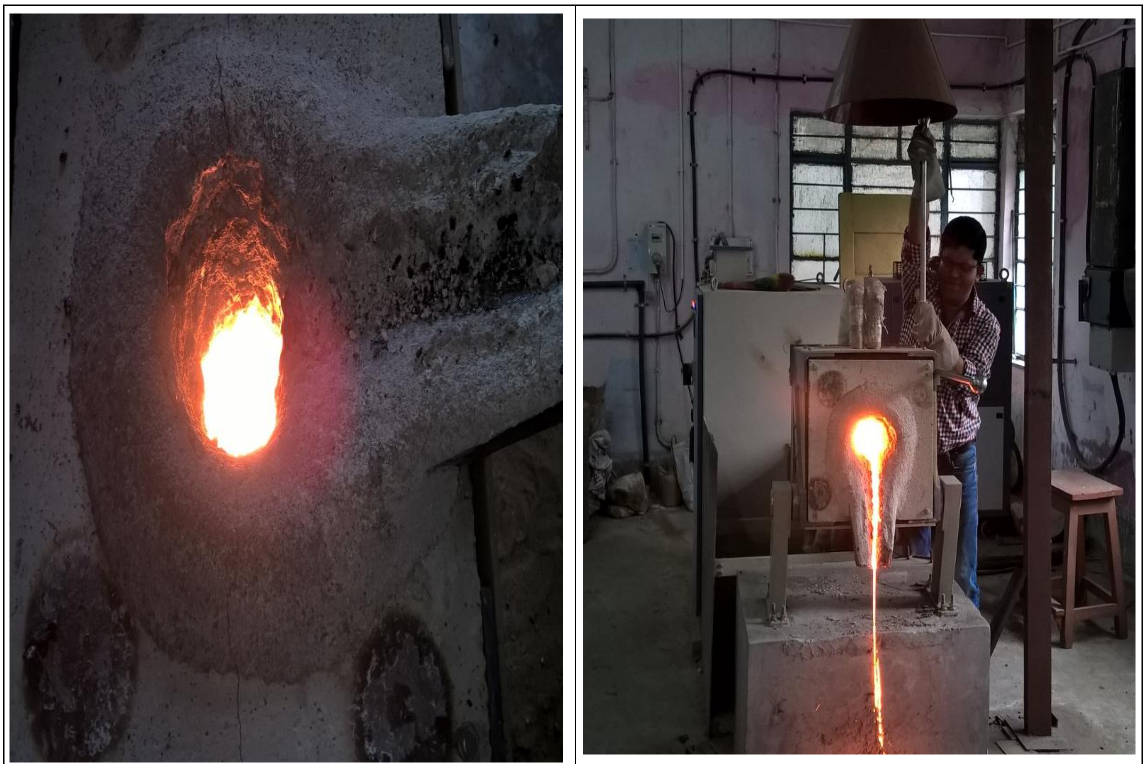

Figure 1 : During melting and tapping process of induction furnace

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In the present experiments total five heats were taken. In Heat No.1, 100% steel scrap was melted with basicity 3. Then in Heat No. 2, the same 100% steel scrap was melted with basicity 3.5. The degree of dephosphorization were compared between them. The best basicity was taken for further experiments. In Heat No. 3, mixture of 90% steel scrap and 10% DRI, was taken with appropriate basicity. In Heat No. 4, mixture of 80% steel scrap and 20% DRI and Heat No. 5, mixture of 70% steel scrap and 30% DRI were taken with proper basicity.]

RESULTS AND DISCUSSION

In induction furnace steelmaking without oxygen lancing, no direct oxygen is able to come in contact with the bath. So to purify the steel, iron oxide (FeO) plays an important role in the bath. FeO helps to oxidise the impurities. In this experiment, this FeO is supplied through the addition of synthetic slag and sponge iron.

Chemical Composition of Raw Materials

At first the chemical analysis of the steel scrap, DRI and synthetic slag were done. Their chemical analysis are shown in are shown in table 1.1.

Chemical Composition in wt. (%)	Carbon(C)	Phosphorus (P)	Sulphur (S)	Manganese (Mn)	Magnesium (Mg)	Silicon (Si)
Steel Scrap	0.335	0.09	0.047	0.590	0.0027	0.203
DRI	0.09	0.053	0.015	0.11	0.09	2.72

Table 1.1: Shows the chemical composition of Scrap and DRI

The chemical analysis of synthetic slag which was basically a LD slag taken from Vizag Steel, is shown in the table 1.2.

Slag	SiO_2	FeO	MnO	Al_2O_3	CaO	MgO	P_2O_5	Basicity
Wt%	18.21	18.61	1.14	1.28	47.2	1.14	1.25	2.79

Table 1.2: shows the chemical composition of the synthetic slag.

The chemical composition of the lime is shown in the table 1.3.

Lime	SiO_2	Al_2O_3	CaO	MgO
Wt%	2.5	0.50	83.00	2.00

Table 1.3: shows the chemical composition of the lime.

Heat No. 1

In Heat No.1, 100% steel scrap was taken. The basicity of the molten bath was maintained 3.

The result of the chemical analysis of the finished steel is given in the table 1.4.

Chemical Composition in wt. (%)	Carbon(C)	Phosphorus (P)	Sulphur (S)	Manganese (Mn)	Magnesium (Mg)	Silicon (Si)
Finished Steel for Heat No.1	0.18	0.068	0.028	0.03	Trace	0.02

Table 1.4: shows the chemical analysis of Heat No.1

The degree of dephosphorization:

$$= \frac{\text{(Initial phosphorus amount - Final phosphorus amount)}}{\text{(Initial phosphorus amount)}} *100$$

$$= \frac{0.09-.068}{0.09} *100$$

= 24.44%

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HEAT No. 2

In Heat No.2, 100% steel scrap was taken. The basicity of the molten bath was maintained 3.5.

The result of the chemical analysis of the finished steel is given in the table 1.5.

Chemical Composition in wt. (%)	Carbon(C)	Phosphorus (P)	Sulphur (S)	Manganese (Mn)	Magnesium (Mg)	Silicon (Si)
Finished Steel for Heat No.2	0.17	0.057	0.023	0.03	Trace	0.02

Table 1.5: Shows the chemical analysis of Heat No.2.

The degree of dephosphorization:

$$= \frac{\text{(Initial phosphorus amount - Final phosphorus amount)}}{\text{(Initial phosphorus amount)}} * 100$$

$$= \frac{0.09 - .057}{0.09} * 100$$

= 36.66%

Among the two, the better result was found in Heat No.2. As the degree of dephosphorization was more in second heat. So for the remaining experiment basicity 3.5 was selected. The Figure 1.2 shows the comparative study of the two heat.

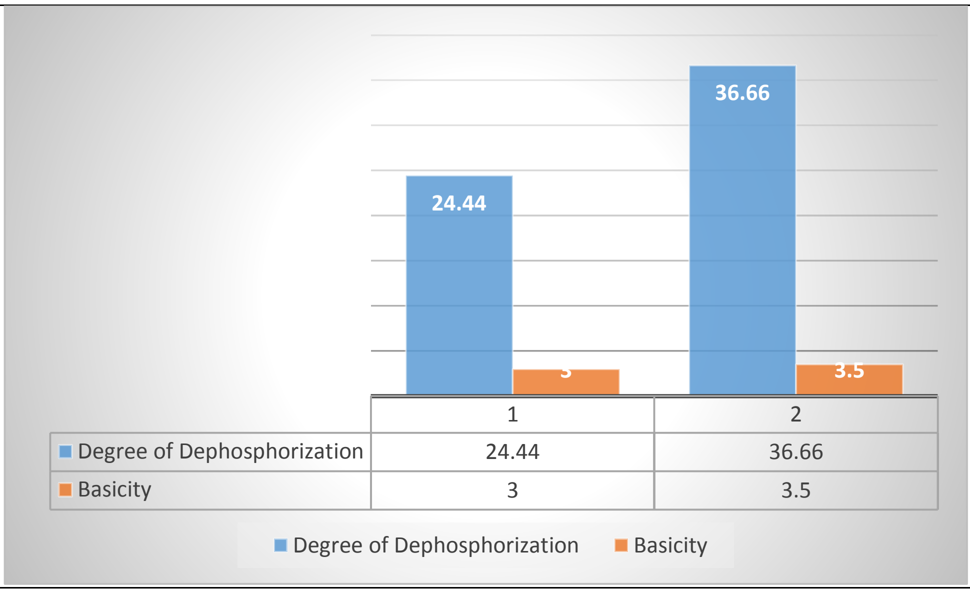

Figure 1.2: Shows the Degree of Dephosphorization vs. the Basicity

HEAT No. 3

Here 90% scrap and 10% DRI was melted with a basicity of 3.5. The result of the chemical analysis is given in table 1.6.

Chemical Composition in wt. (%)	Carbon(C)	Phosphorus (P)	Sulphur (S)	Manganese (Mn)	Magnesium (Mg)	Silicon (Si)
Finished Steel for Heat No.3	0.13	0.051	0.024	0.02	Trace	0.04

Table 1.6: Shows the chemical analysis of Heat No.3.

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The degree of dephosphorization:

$$= \frac{\text{(Initial phosphorus amount - Final phosphorus amount)}}{\text{(Initial phosphorus amount)}} *100$$

$$= \frac{0.09-.051}{0.09} *100$$

= 43.33%

HEAT No. 4

Here 80% scrap and 20% DRI was melted with a basicity of 3.5. The result of the chemical analysis is given in table 1.7.

Chemical Composition in wt. (%)	Carbon(C)	Phosphorus (P)	Sulphur (S)	Manganese (Mn)	Magnesium (Mg)	Silicon (Si)
Finished Steel for Heat No.4	0.10	0.046	0.018	0.02	0.01	0.04

Table 1.7: Shows the chemical analysis of Heat No.4

The degree of dephosphorization:

$$= \frac{\text{(Initial phosphorus amount - Final phosphorus amount)}}{\text{(Initial phosphorus amount)}} *100$$

$$= \frac{0.09-.046}{0.09} *100$$

= 48.88%

HEAT No. 5

Here 70% scrap and 30% DRI was melted with a basicity of 3.5. The result of the chemical analysis is given in table 1.8.

Chemical Composition in wt. (%)	Carbon(C)	Phosphorus (P)	Sulphur (S)	Manganese (Mn)	Magnesium (Mg)	Silicon (Si)
Finished Steel for Heat No.5	0.08	0.041	0..021	0.02	0.01	0.04

Table 1.8: Shows the chemical analysis of Heat No.5.

The degree of dephosphorization:

$$= \frac{\text{(Initial phosphorus amount - Final phosphorus amount)}}{\text{(Initial phosphorus amount)}} *100$$

$$= \frac{0.09-.041}{0.09} *100$$

= 54.44%

In the following Figure (1.3) the Degree of Dephosphorization of different Heat are shown.

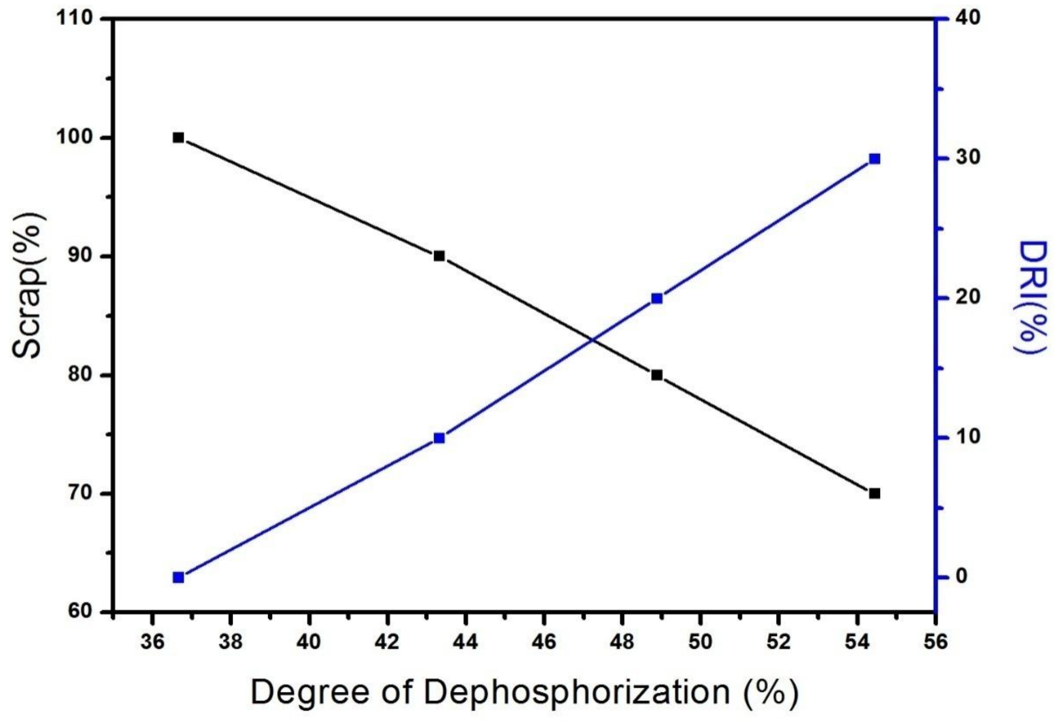

Figure 1.3: Shows the Degree of Dephosphorization of different Heat

On the above figure it is shown that from Heat No.2 to Heat No. 5 the degree of dephosphorization have increased steadily. As this particular DRI has less phosphorus amount than the scrap, so the amount of phosphorous becomes less when percentage of DRI has increased in the melting. If in this experiment, any scrap with less amount of phosphorous than DRI is used, then the reverse trend may be followed.

DISCUSSION

- Experimental result suggests effective dephosphorization can be possible in induction furnace.
- The extent of dephosphorization in the induction furnace with available DRI and steel scrap is in the range of 24.44% to 54.44% by using LD slag
- Experimental result it shows that the aluminium and silicon level in the final product have increased. The acidic lining of the induction furnace may be responsible for it. However it seems that in practise with basic lining, P removal to the same extent or higher will be achieved with lower basicity. Eventually Si and Al content could remain in the acceptable range.

CONCLUSION

Now a day's not only melting processes but also refining processes are going on in Induction Furnace. From the present work it can be concluded that:

- A mixture of scrap and DRI can be melted successfully in acidic lining. However though acidic lining is much cheaper still it would be eroded. Therefore basic lining will be preferred.
- Phosphorus can be removed by maintaining a proper basicity in the slag by addition of CaO.
- For a high degree of dephosphorization, FeO in the slag is to be increased and the same is achieved by addition of synthetic slag (LD slag).
- The temperature must be maintained in the range of 1575^0 to 1650^0 C. Otherwise at a temperature above 1650^0 C, phosphorus may revert back.
- In the present work maximum level of approx. 54.44% dephosphorization has been achieved.
- As the silicon and aluminium content in the final product have increased, it is better to use basic lining or neutral lining in induction furnace.
- The synthetic slag which is used here is LD slag from Vizag Steel. As usage of LD slag is very less and every iron and steel sectors faces problems for dumping LD slag. This may be a good utilization of plant waste like LD slag.

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