`INDUREF' - INDUCTION LADLE REFINING FURNACE FOR SECONDARY METALLURGICAL APPLICATIONS

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ABSTRACT

The bulk of plain carbon steel is produced through conventional Basic Oxygen or Electric Arc Furnace routes where the development of the AC Ladle Furnace has made it possible to also produce alloy steels. Smaller Ladle Furnaces have limitations such as lower efficiency; high electrode consumption and diminutive yields rendering them uneconomical to operate and making the processing of low carbon steel grades difficult due to carbon pick up.

The demand for special steels and alloys with strict specifications is increasing while commodity prices remain competitive. The production of special steels and alloys have specific process control requirements and the development of the induction melting furnace (IMF) has made it possible to produce smaller batches economically. Refining and alloying of the melt in the IMF further enhance the efficiency.

The INDUREF furnace offers increased productivity and flexibility through increased thermal efficiency and can be utilised for holding molten metal for further processing such as granulating, atomising, nitriding, alloy additions and desulphurisation of Ferro-alloys and steels. The system utilises a specially engineered ladle which is placed in an induction-heating assembly comprised of a stationary water-cooled copper coil and lamination packs. The addition of equipment for vacuum degassing and decarburisation of steels and alloys is also feasible.

Benefits are:
- *No electrode consumption or carbon pick-up*
- *Lower installation, operation and maintenance cost.*
- *No line-flicker facilitates operation on a weak power grid.*
- *Good power factor and balanced load*
- *No skull formation and reduced refractory consumption*
- *Higher yield of Fe-alloys*
- *Automatic controlled stirring*

1. INTRODUCTION

The bulk of plain carbon steel is produced either in integrated or in mini steel plants through conventional basic oxygen furnace (BOF) or electric-arc furnace (EAF) routes. Production of alloy steels was made possible in these steel plants after development of the AC-arc ladle refining furnaces (AC-arc LRF). However AC-arc LRFs of less than 25 t capacity have several limitations such as lower efficiency and high electrode consumption which render it uneconomic to operate.

The development of the induction melting furnace (IMF) made it possible to melt from 5 kg up to 20 t of alloys steel. Production of special steel or alloys has specific process control requirements as well as stringent quality specifications.

Productivity is adversely affected when refining and alloying is carried out in induction melting furnace to produce quality steel. As customers demand higher quality material without paying any premium, a furnace was required which could refine a medium size heat prepared in the IMF economically.

The Induref was developed to meet these specific operational requirements economically with increased productivity and flexibility. Electrotherm has successfully commissioned its first 15 t, 1500 kW Induref at R. L. Steels Ltd, Aurangabad, India in September 2002. The Induref can treat heats from 1-25 t and higher effectively.

2. PRESENT PRACTICE OF STEELMELTING WITH MEDIUM FREQUENCY INDUCTION FURNACE

The development of the medium frequency induction furnace (MF induction furnace) has been a boon to the small iron and steel producers and these furnaces are available from 5 kg to 20 t capacity. They are easy to install, operate and maintain. Scrap, DRI and ferroalloys are melted in MF Induction Furnace. Steel is tapped at required temperature and used in the foundries for billet or ingot casting or for further processing. Tapping of steel at high temperatures increases refractory erosion and power consumption.

Melting of selected raw materials is required for the production of specific quality steel when induction furnaces are used.

The need for secondary metallurgical operations to produce special quality steels and alloys led to the development of the AC-arc LRF. The AC-arc LRF however proved to be uneconomic to operate for smaller heat sizes due to high costs of installation, operation and maintenance. The high installation cost can be ascribed mainly to the requirement of high installed power due to poor efficiency. The high power and electrode consumption as well as refractory erosion results in increased operational cost.

Operation and maintenance of the AC-arc LRF is difficult due to the number of moving parts and the complex control system. Furthermore, use of electrodes for processing of low carbon steel grades causes carbon pick up resulting in production of off grade steel or high cost.

3. DEVELOPMENT OF LADLE REFINING FURNACE AT ELECTROTHERM

Electrotherm, a leading manufacturer of MF induction furnaces, committed themselves to develop a small capacity ladle refining furnace.

For small heats, three-electrode AC-arc LRFs are not successful because of high refractory erosion in the area adjacent to electrodes. Three arcs are deflected away from the electrodes and overheats sidewalls resulting in refractory erosion. Heat transfer efficiency is also poor. The single electrode DC-arc LRF was developed to overcome the problem of high refractory erosion of the sidewalls of the ladle (as shown in Fig.1). In this configuration, one graphite electrode (cathode) is inserted from the top through a water-cooled composite roof which can be lowered or lifted by an electromechanical device. One electrode (anode) is provided in the bottom refractory of the ladle. The bottom electrode needs to be connected to a DC power source after ladle placement at the treatment station. An 8 t, 1450 kW single electrode DC-arc LRF was commissioned in 1992 (Fig.2). but was not popular due to inconvenience experienced by operations personnel to connect the bottom electrode to the power supply. Heat transfer efficiency was also poor (about 10 %).

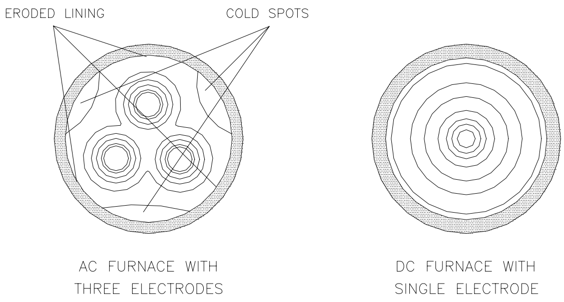

Figure 1. Temperature distribution in an AC LRF and Single Electrode DC LR.F.

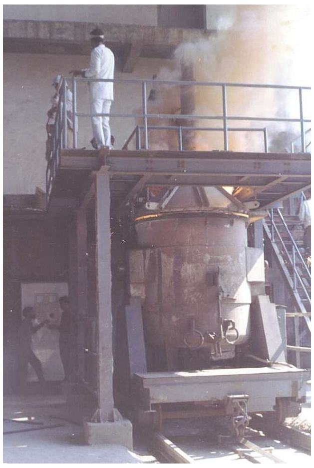

Figure 2. View of a Single Electrode DC Ladle Refining Furnace.

The double electrode DC-arc LRF was developed to overcome the problem of connecting the bottom electrode of the ladle to the DC power source. A 20 t, 2500 kW double-electrode DC-arc LRF is operating successfully in India since 1997 (Fig.3). In this LRF both the graphite electrodes (anode and cathode) are inserted from the top through the water-cooled composite roof. Both the electrodes are mounted on the electrode mast and are simultaneously lowered or lifted by an electromechanical device.

In the DC-arc LRF, the typical phenomenon of unequal electrode wear as observed where the anode is consumed faster than the cathode. To compensate for this, the polarity of electrodes is interchanged after some heats to achieve equal electrode consumption. In this type of LRF, refractory erosion is higher as arcs are deflected towards sidewalls of the ladle. Thermal efficiency is similar to the AC-arc LRF.

The Induref has been developed to overcome some of the shortcomings of an arc LRF. The first trial of a 1,5 t Induref was undertaken at 150 kW. Its performance was satisfactory but the expected temperature increase could not be attained. A second trial was undertaken at 250 kW and the desired temperature increase was attained (Fig.4). Electrical efficiency was 60%.

Figure 3. View of Double Electrode DC Ladle Refining Furnace.

Figure 4. View of 1.5t Induction Ladle Refining Furnace used for trials.

R.L. Steels were operating a 15 t AC-arc LRF but as their power, electrode and refractory consumptions were high they were in the market for a more efficient system. The Induref concept was introduced to them and after due consideration of all the parameters, the unit was ordered and installed.

Commissioning of this first Induref from Electrotherm in September 2002 at R. L. Steels was thus the result of the joint efforts of R.L. Steels and Electrotherm. It is obvious from the history of the development of the LRF by Electrotherm, that the Induref concept resulted in lower installed power capacity requirement as well as yielding better performance due to higher overall efficiency. Reduced power consumption and the elimination of the use of electrodes are significant contributors to the cost saving.

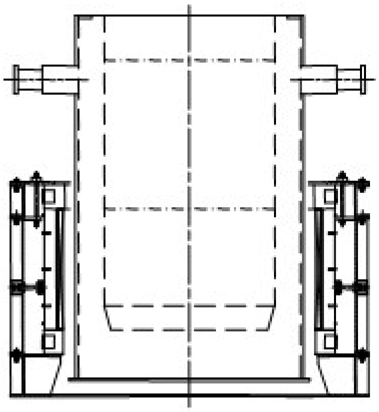

Figure 5. Schematic Arrangement of Induref.

Figure 6. 15 t Capacity Induction Ladle placed in an Induction Coil Assembly.

3.1 Equipment Details of Induref

The Induref comprises of an induction-heating coil, a solid-state generator and a specially engineered induction ladle. A schematic arrangement of the Induref is shown in Fig.5. The induction-heating coil comprises a stationary water-cooled copper coil and lamination packs (Fig.6). The induction coil is connected to a solid-state generator, which converts three-phase power of 50 Hz to single phase power of 60-80 Hz. The components of the solid-state generator are cooled by demineralised water. Power connected to the Induref is determined based on capacity of the induction ladle, refining process and its duration. A single line diagram of the Induref is given in Fig.7.

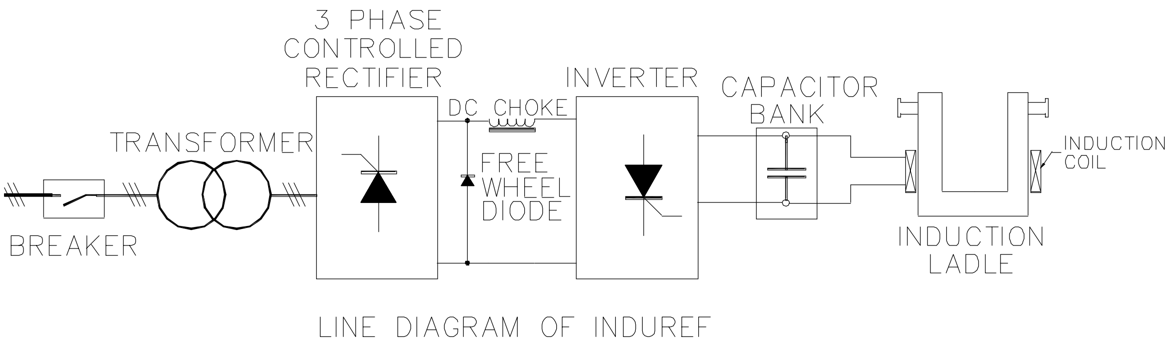

Figure 7. Single Line diagram of Induref.

4. OPERATION WITH INDUREF FOR STEEL REFINING

Molten steel is tapped at less than 1600^{0}C from the melting furnace into the induction ladle that is then placed in the induction-heating coil assembly. Power is switched on to start the process. Addition of fluxes and ferroalloys is done in the induction ladle (Fig.8).

Major advantages of the Induref is that tapping temperature of molten steel is reduced. This increases refractory life of the melting furnace and reduces power consumption, which results in increased productivity.

Figure 8. View of 15 t, 1500kW Induref operating
at R.L. Steels Ltd. Aurangabad, India.

5. ADVANTAGES OF `INDUREF' OVER ARC LRF

In an Arc LRF, the arc is struck between electrodes and the molten bath surface. Heating of the molten metal takes place by radiation from the arc to the molten metal. Argon purging is required throughout the refining process for thermal homogenisation by conduction and convection. The low thermal conductivity of the slag layer is the rate-controlling factor. High radiation losses due to the high temperature (about 6000^0C) of arc require a water-cooled roof. High slag temperature increases refractory erosion.

With the Induref, the metal is heated and stirred by the eddy-currents generated within the molten metal. The induction coil is located in the lower portion of the induction ladle, hence the metal in the lower portion is heated first. The downward movement of the cold metal from the top and the upward movement of the hot metal from the bottom to the top create a natural convection current. The synergistic effect of natural convection and induction stirring homogenise the bath and reduces the requirement of argon gas purging which is an essential requirement for successful completion of refining in an Arc LRF. Provision of argon gas purging is required only during post LRF treatment or for desulphurisation with injection refining. Radiation losses are comparatively less than that of an Arc LRF due to lower slag temperature. Lower slag temperature assists in achieving longer refractory lining life.

Poor power factor, high radiation losses and heat loss due to argon gas purging render Arc LRF less efficient than that of the same capacity Induref. Slag of high temperature absorbs gases and reduces yield of ferroalloys.

Benefits of the Induref over Arc LRF are as follows:

- Lower installation, operation and maintenance cost.
- Easy to operate and maintain.
- Reduced refractory consumption.
- Higher thermal and electrical efficiency.
- No line-flicker facilitates operation on a weak power grid.
- It has a good power factor and is a balanced load.
- No skull formation in the bottom of the ladle.
- No carbon pick-up.
- Higher yield of Ferro-alloys.
- Can be operated on diesel generator sets.

6. APPLICATIONS OF INDUREF

The Induref can be used as a Ladle Refining Furnace or for holding molten metal for further alloy processing such as atomisation of ferroalloys and metals, nitriding of ferroalloys and steel, alloy addition and desulphurisation of steel.

Most of the EAF's operating in the world are of 40-50 t capacity producing 16-20 heats per day with a combination of three to four strand bloom casters. With the Induref, longer casting times can be achieved where the induction coil is mounted on the continuous casting machine (CCM) stand. Therefor, fewer casting strands are required resulting in capital and maintenance savings.

Development of mini blast furnaces attracted many entrepreneurs to produce foundry grade pig iron. The economic survival of these pig iron plants was threatened, hence smaller capacity BOFs' were developed. The economy of these small iron and steel producers can be improved by utilising the Induref in conjunction with small capacity BFs and BOFs.

The Induref concept can also be used for vacuum degassing and decarburisation of steel and alloys by providing additional facilities.

A cost comparison between the Induref and the AC-arc LRF of 15 t capacity is given in Table 1.

Table 1. Cost Comparison of Induref with AC-arc Ladle Refining Furnace stated in South African Rand (R).

S.N.	**Description**	**Unit Rate**	**INDUREF (15 ton)**		**Conventional A.C. Arc LR F (15 ton)**	
			Norms	**Cost/ton**	**Norms**	**Cost/ton**
1	Capacity of Power Source	--	1.75 MVA		3 MVA	
2	Overall Heat Transfer Efficiency	--	40 %		20%	
3	Temperature Rise	--	2.8^{0}C		2^{0}C	
4	Power Consumption for 100^{0}C temperature rise	0.15 R/kWh	65 kWh/T	R 9.75	140.0 kWh/T	R 21.00
5	Electrode Consumption	20 R/kg	--	--	0.75 kg/T	R 15.00
6	Ladle Refractory Consumption	--	--	R 24.00	--	R 42.00
7	Total Operating Cost			**R 33.75 / ton**		**R 78.00 / ton**
8	Contribution of Induction Ladle Furnace in saving per t of liquid steel					**R 44.25 / ton**

7. CONCLUSION

The Induref is a new tool for metallurgical engineers to carry out different processes economically. It could be applied in many other applications as the need arises. It offers many advantages over the Arc LRF. Lower power and refractory consumption and elimination of electrodes make it a more attractive package for metal industry.

The Induref can be supplied from 1 ton to 50 t capacity as per the customer's requirement.