Inductive melting in steelworks

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After the development of induction technology with inverter outputs of over 40 MW for crucible furnaces with capacities of more than 65 t, the induction furnace offers itself as an alternative to the electric arc furnace. Because of the high yield from the feed materials the induction furnace is particularly suitable for the production of stainless steels. Promising results have also been obtained in recent times for the inductive melting of carbon steels. In what follows, the characteristic properties of the induction furnace are first described before some example systems for steelmaking are discussed.

Apart from saving the costs of electrodes and the low requirements on the electricity grid, the main benefits offered by induction furnaces are the high yield from the feed materials and low pollution of the environment and workplaces. The low metal losses become an economic factor, particularly when stainless steels are produced.

CHARACTERISTIC FEATURES OF INDUCTION FURNACES

Fig. 1 contains a diagram of an induction melting system. Its main components are the power supply unit (with transformer, frequency converter and capacitor bank), the crucible furnace itself, the charging system, the cooling systems for the power supply and furnace coil, the fume extraction equipment and the process control system.

Power transmission without over temperature

The crucible furnace itself is a melting unit with a fairly simple construction. As shown in Fig. 1, this basically consists of the refractory crucible and the surrounding coil borne by magnetic yokes and a steel frame. Alternating current flows through the coil, creating an electromagnetic field. This field induces eddy currents in the metallic melting stock which, in accordance with Joule's law, cause the feed materials to heat up and finally to melt.

The heat is thus generated directly in the melting stock itself, without over temperature, so that the emissions generated by furnaces heated by fuel or electric arc during power transmission do not occur in the induction furnace.

Depending on the quality of the feed materials, the volume of dust produced is 0.5 to 1 kg/t of melt, the slag ratio is 10 to 15 kg/t. Further benefit is that the burnout of the feed materials and alloying agents is minimal.

Inductive bath agitation

The interplay between the eddy currents induced in the melt and the magnetic induction creates electromagnetic forces, which cause a bath flow in the form of two eddy toroids with opposite directions of turn. The inductive bath agitation firstly leads to an ideal homogenization of the melt with regard to the chemical composition and temperature. It is furthermore beneficial for stirring in specific light materials, such as chips, stamping remnants, shredded scrap and sponge iron.

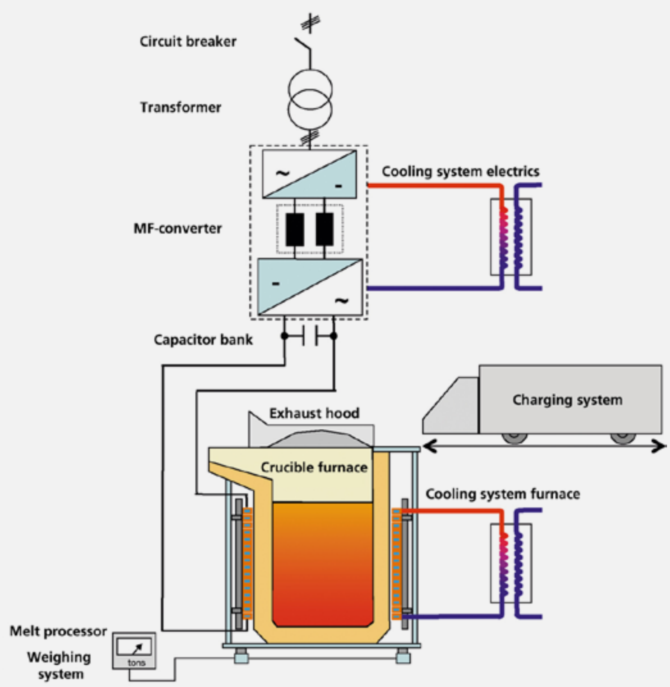

Fig. 1: Structure of an induction melting installation, ABP type [1]

Table 1: Characteristic features of electric arc and induction furnaces [2]

Feature	Electric arc furnace	Induction furnace
Operation costs:		
Electrical energy	500 kWh/t	540 kWh/t
Refractory	4 kg/t	3.5 kg/t
Electrodes	2.5 kg/t	none
Oxygen	15 Nm^3/t	none
Slag builder	25 kg/t	none
Melting:		
Melt losses	7 to 10 %	1 to 2 %
Alloying	Not exact	Simple and exact
Metallurgical work:		
Decarburizing	Possible by oxygen blowing and slag reaction	Restricted by refractory wear
Desulphurizing		
Dephosphorizing		
Environment conditions:		
Dust	5 to 10 kg/t	approx. 1 kg/t
Noise	90 to 120 dB(A)	83 to 85 dB(A)
Slag	60 to 70 kg/t	10 to 15 kg/t
Electrical supply net:	High load	Low load
	Flicker disturbances	No flicker disturbances

Inverter power supply

Power is supplied to the furnace coil via a transformer, a frequency converter and a capacitor bank to compensate for the furnace reactive power, as depicted in Fig. 1. At a cos Φ of some 0.95 in the range of 60 to 100 % of the nominal power, for the electrical supply grid the induction furnace thus represents a "pure" Ohm load. Moreover, this is constant in time, thus without short-term fluctuations. In addition, as the furnace is switched on via a time ramp, all types of flickers and grid loading through rush currents are prevented. That makes it possible to feed the induction furnace by power from relatively weak electrical grids or from diesel or gas driven generators.

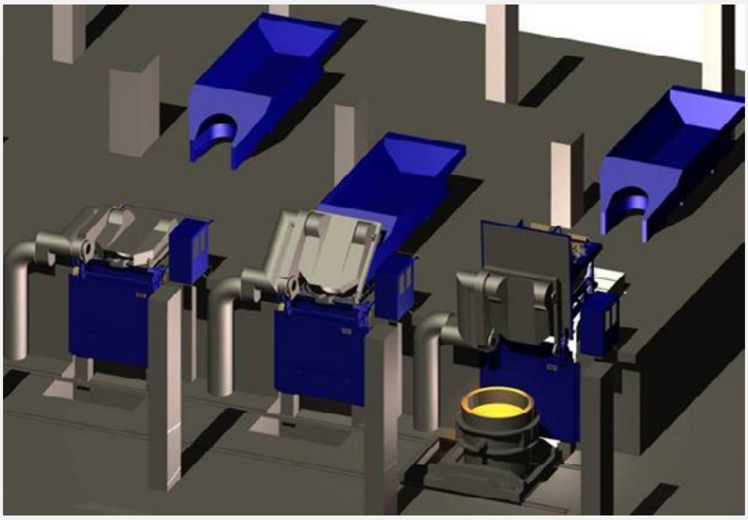

Fig. 2: Structure of the three-furnace installation at Viraj

Operating behavior and environmental compatibility

The principle of direct energy transmission, as described above, produces a high yield from the feed materials with lower levels of dust emission. Noise levels are kept within admissible limits below 85 dB(A). The low levels of heat released into the surroundings also make the induction furnace a melting unit which is friendly to the workplace.

Refractory lining

As a rule, crucible furnaces are lined with powdery dry masses. These are sintered in the furnace into a monolithic, although elastic crucible. The induction process thereby places particular requirements on the refractory lining, which are fulfilled by spinel forming dry masses on MgO and Al_2O_3 basis.

The induction furnace compared to the electric arc furnace

Table 1 compares the main features of electric arc and induction furnaces for melting steel in mini-mills. According to this, an induction furnace has the following economic/technical benefits:

- Low requirements on the electricity grid; also suitable for power supplied by generators driven by diesel or gas,
- Little expenditure for environmental compatibility and clean workplaces,
- High yield from the metallic feed materials, above all the alloying agents,
- No electrode costs,
- Relatively low investment costs and small space requirement,
- Largely automatic operation in a simple manner.

Drawbacks are the sensitivity of the refractory lining and the request on higher scrap quality.

PRODUCTION OF STAINLESS STEEL AT VIRAJ PROFILE

The particular benefits of melting stainless steel by induction have been reaped by the Indian steelmaker Viraj Profile in Tarapur, Maharashtra, near Mumbai. This stainless steel mill started in 1991 with a 7 t/2,500 kW induction melting furnace and one 10 t AOD-converter. Via some investment steps Viraj increased the capacity to 14,500 t per month using several induction furnaces and one 55 t AOD-converter so that Viraj became to one of the largest Indian producers of flat stainless steel products [3].

Based on the positive experience made, a modern ABP induction melting system is now installed, which is consisting on three 25 t crucible furnaces each with a connected load of 18 MW (**Fig. 2**). Two of the 25 t furnaces run in melting mode and deliver a 50 t melt charge in hourly cycles. These melts are finished in the AOD converter ready for subsequent continuous casting. The third furnace waits for the periodic installation of new refractory and sintering. Each one of the three furnace systems has to be seen as a complete and independent system. To have more flexibility each control system is able to generate all necessary data about each other system and each power unit can be supplied to each crucible at any time. The key data of the melting unit are shown in **Table 2**.

Following the Fig. 2, each of the three furnaces is charged with a movable charging car, which is filled by buckets on crane (**Fig. 3**a) and which feeds the charge material into the crucible more or less continuously via a vibration channel. The charging car is docked on to open exhaust hood in such a way that an enclosed system is formed for the furnace to be charged consisting of the hood and the front part of the charging car. This offers reliable protection against splashes and enables all the fumes and flames released during melting to be extracted (Fig. 3b).

Table 2: Key data of the ABP-25 t/18 MW induction melting system at Viraj [3]

Key data	
Tap-to-tap time	< 60 minutes at 18 MW
Scrap	heavy and shredded scrap, bundles
Melting time	54 to 57 minutes
Energy consumption	520 to 540 kWh/t
Tapping temperature	1,640 °C
Lining life (Alumina)	120 heats, using patching
Residual dust in clean gas	Max 10 mg/Nm³ dry, according to VDI 2066

COMBINATION OF ELECTRIC ARC FURNACE AND INDUCTION FURNACE

Nasco is operating an induction system in its electric steel works in Dammam, Saudi Arabia since the end of 2008 as an additional melting unit to the electric arc furnace to produce over 900 kt/a of construction steel [4]. Liquid charges of 100 t are produced in 55 min cycles. The electric arc furnace melts an 80t charge which is supplemented with 20 t of melt from the induction furnace. The 100 t charge put together in this way is treated in the ladle furnace and subsequently transported to the four-line continuous casting facility.

The induction system consists of two 23 t crucible furnaces with a 16 MW/250 Hz-Twin-Power® energy supply fed from a diesel generator system. One furnace runs in melting mode whilst the other is kept on stand-by waiting for new refrac-

a) 

b) 

Fig. 3: a) Loading of the charging car, b) Approaching of the charging car to the opened ABP-Ecotop exhaust hood at Viraj [3]

Fig. 4: 2 x 23 t-melting system at Nasco: a) Shredded scrap, b) Charging car, c) Scrap container, d) Filling of steel melt for sintering [4]

Table 3: Consumption statistics for induction and electric-arc furnaces in US$/t at Nasco [4]

	Induction furnace	Electric arc furnace
Shredded scrap	313	310
Electrical energy (IO: 520 kWh/t)	18.7	16.1
Refractory (IO: 100 charges/lining)	6	1.6
Electrodes	0	9.7
Fluxing agent	0	4.7
Oxygen	0	2.3
Alloy materials	5.5	13.4
	343.2	**357.8**

tory to be installed. Shredded scrap in differing quality is used as melting stock (**Fig. 4**a). For loading the charging car (Fig. 4b) is driven underneath one of the two supply containers (Fig. 4c). The induction furnace is running in batch mode for the production of 16 to 23 t charges per hour (depending on the specifications of the electric arc furnace) at full power, around the clock, seven days per week. The service life of the refractory lining made from spinel forming Al_2O_3 dry mass meanwhile averages 100 charges, which is a consumption of 3.5 kg mass per ton of melt. The evenly worn crucible is pressed out completely with the hydraulic press-out equipment after around four days in operation. Whilst the second furnace takes over melting operations for the next four days, there is then enough time to install new refractory, which can be accomplished in 1½ days in an emergency. The option of liquid sintering is particularly beneficial here, in that the sinter melt is poured from one furnace to the other from a stopper ladle (Fig. 4d).

After reaching the tapping temperature of 1,650 °C, the melt is usually poured without skimming into the 100 t ladle and, after filling the 80 t EAF charge, transferred to the ladle furnace.

After five years of trouble-free operation, Nasco's induction system has now proved its high availability and economic efficiency. This is shown in **Table 3** by the operating figures for the induction furnace in comparison to the electric arc furnace, which demonstrate a cost benefit of 15 US$/t of melt [4].

THE MOST POWERFUL INDUCTION FURNACE IN THE WORLD

The Chinese steelmaker Tisco (Taiyuan Iron Steel Co. Ltd.) operates a steel works in Taiyuan with an output of 10 Mt/a, of which 3 Mt/a are stainless steels. The company devotes a great deal of research in the stainless steel manufacturing process. By this way it was decided to produce the raw steel and the alloy melts separately. For that, the ferroalloys are

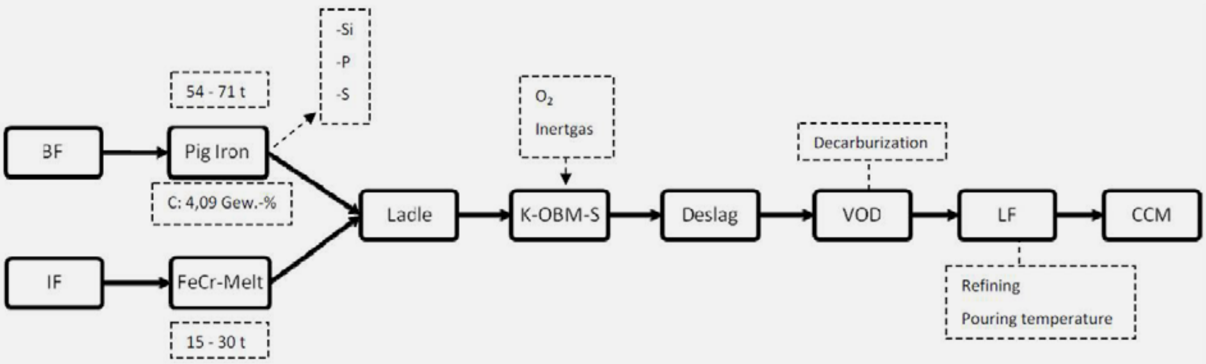

Fig. 5: Process route at Tisco-South

Fig. 6: Tisco-South: 2 x 30 t-/24.4 MW induction furnaces for melting ferroalloys [5]

melted in induction furnaces and added to the steel melt in liquid form as shown in **Fig. 5** as example of the installation in Tisco-South. The choice of the inductive instead of the arc furnace is based on the high smelting yield from the precious metals by avoiding the oxidation and burning-out losses. The practical experience demonstrates that the yield of Cr in the inductive FeCr melting will increase from 93 to 98 % which means a saving of around 1 billion RMB per year for Tisco.

The project has been realized in two steps. Since 2013 the system delivered for the south bay of Tisco is successfully operating; it is consisting of two 30 t crucibles with a common power supply of 24.4 MW (**Fig. 6**). The process looks for, that only one furnace is operating while the other crucible is on stand-by for the relining work. To realize the electric sintering by the standby crucible, an additional sintering converter in special IGBT design is provided. The project for the North bay of Tisco is commissioned in the second half of 2014 and the production output is mainly stabilized. This system is consisting on six 65 t crucibles; three are in operation while the other three crucibles are in stand-by for relining works. Each operating crucible is connected to power supply of 42 MW. In the total the ABP melting power installed for the North bay project is 126 MW. Similar as for the South bay project, three additional sintering converters in IGBT design are provided to realize the electrical sintering of the stand-by crucibles. **Fig. 7** gives a first impression of this induction furnace systems which represent the highest powered induction furnaces manufactured with medium frequency converter in the world, breaking new ground for the induction furnace technology.

Fig. 7: Tisco-Noth: 6 x 65 t / 3 x 42 MW induction furnaces for melting ferroalloys [5]

CONCLUSION

The experiences made in several steel mills demonstrate that the induction furnace is on the way to be established as an alternative electrical melting unit for the steel production. This belongs particularly to the application for the production of stainless and high alloyed steels where the high yield from the precious alloys constitutes an important economical factor. There, the induction furnace is able to produce the alloyed steel melt or to melt the Ferroalloys separately. In mini-mills the application of the induction furnace could be profitable as unique melting tool or as complement for the arc furnace. Positive results are existing too for the inductive melting of sponge iron, on which will be reported in future. Apart from that, the application of inductive melting is always reasonable in case of the electrical energy supply by weak electricity grids or generators.

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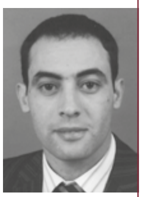

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