Plasma ladle furnace – alternative or additional refining for high specification grades

The Plasma Ladle Furnace primarily differs from a conventional ladle furnace by its watercooled torches which are used instead of conventional graphite electrodes. It is said to offer many advantages in metallurgical refining processes where cleanness, quality assurance and flexibility are important. Because an absolutely clean argon atmosphere can be maintained, steel grades with a carbon or nitrogen content in the ppm range can be treated, and desulphurisation of those ultra-clean grades is no problem.

BY HANS BEBBER

Secondary metallurgy in the ladle furnace (LF) forms the connecting link between melting and casting. On one hand it allows the UHP furnace to concentrate on short tap-to-tap times; on the other hand it assures a just-in-time melt service for casting. But the ladle furnace is not only used for adjusting casting temperature and for bridging waiting times. It also serves for alloying and quality assurance by providing refining process possibilities like vacuum treatment, inclusion removal, desulphurisation or homogenisation.

Therefore it is no surprise that many different furnace types and refining processes have been developed and are currently in use. Prominent examples for graphite electrode systems are the VOD/VAD ladle stands, or the ASEA-SKF units with induction stirring. For conventional furnaces arc stability could be improved by use of hollow electrodes (Ref 1) and a next development step might be the application of DC technology in parallel to the wide acceptance of DC arc furnaces for melting (Ref 2).

SYSTEM LIMITS

But all these systems reach their application limit when it comes to ultra-clean ultra-low carbon grades. Here a typical problem is the final desulphurisation which normally requires hot top slag treatment. It is impossible to heat the slag in this case by graphite, because unavoidable carbon pick-up would occur, and experience also shows that vacuum induction furnaces (VIF) cannot be used for top slag refining.

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The plasma ladle furnace (PLF) offers far better conditions because water-cooled metallic plasma torches are used for heating. Historically, the first installations were DC systems, requiring an electrical contact at every ladle to be heated (Ref 3). The first three phase AC unit was the 30t PLF at Krupp Stahl AG in Germany (Ref 4). For several years, Kobe Steel, Japan, has been operating two 80t AC plasma tundish heaters at its Kakogawa works (Ref 5), and at the end of 1995 Hitachi Metals started operation of the world's first plasma refining furnace at its Yasugi works in Japan.

PLASMA LADLE FURNACE

Fig 1 shows a schematic layout of a PLF equipped with two torches for heating. As the torches are relatively thin, stiff and flexible, they can be easily inclined and positioned according to process requirements. Mechanically, the torches are arranged on supporting arms allowing for vertical and lateral movements. The ladle itself is generally arranged in a ladle chamber to assure clean and controlled atmosphere during operation.

The plasma arcs are generated from torch to torch without electrical bottom contact. For high efficiency operation so-called transferred arcs are generated (TR-operation mode). This is very similar to the normal graphite-based ladle furnace operation. But for special purposes like the addition of electrically non-conductive synthetic slag, non-transferred operation is also available (NTR-mode). The torches are equipped with quick-coupling units at their upper ends, which attach them to fittings which form a part of the torch supporting unit. Thus, there are no hoses or cables near the torch on the furnace cover. Besides a compact design, this offers safe conditions for operation in hot surroundings, and easy handling if torch exchange is necessary.

Fig 2 shows a sectional view of a plasma torch for the generation of transferred arcs as they are used in a PLF. As can be seen from the figure, the torch comprises a central electrode unit and a surrounding nozzle unit. The active part of the electrode is made of tungsten and is designed for long life.

The equipment is completed by a gas station for feeding the stabilising plasma argon gas between electrode and torch nozzle, a cooling water station and an electrical power supply. Operation of all components is automatically managed by a process control unit.

Heating rating	0.5 - 8MW
Heating-up rate (max)	4K/min
Torch current	12kA max
Number of torches	1, 2 or 3
Ladle size	5 - 60t

Table 1: Typical values of technical performance data for a plasma ladle furnace.

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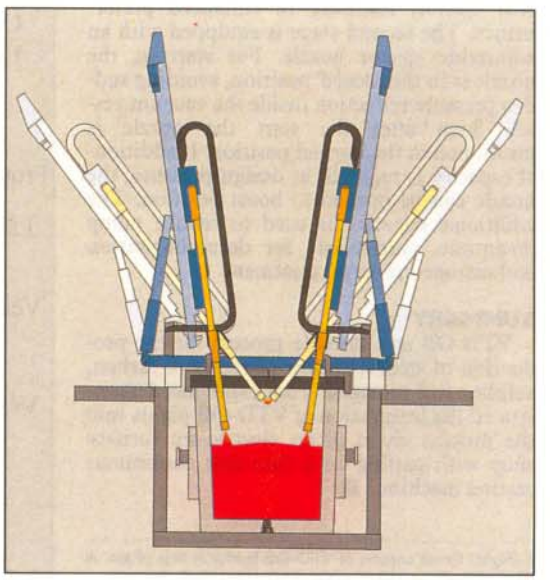
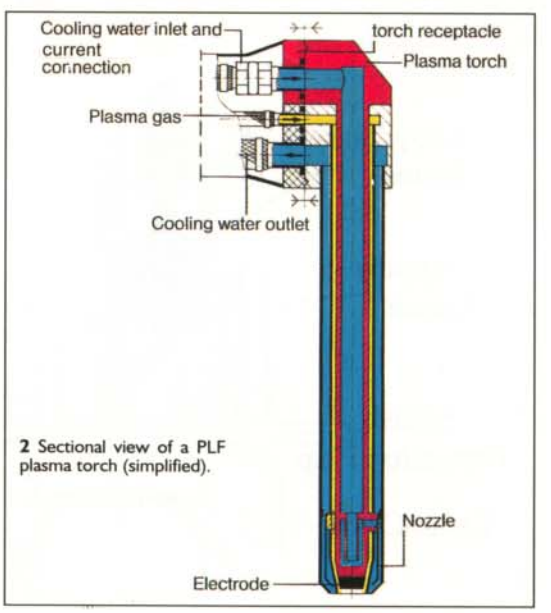
As the torches are operated with permanent tungsten electrodes using argon as plasma gas, the atmosphere in such a PLF will be very clean. This is the most prominent feature of a PLF compared to a conventional graphite-operated LF. It therefore has particular advantages for ULC grades or other sensitive qualities, eg Ti-stabilised steels.

Besides simple heating of sensitive qualities the PLF may also pave the way to new and more effective production opportunities. For example, Ti, W or Mo are being added as

1 Typical layout of a PLF





2 Sectional view of a PLF plasma torch (simplified).

alloying elements at a very late stage in the production process to avoid burn-off. With a PLF, these elements can be added at an earlier process stage resulting in much higher analysis precision and safety. This example shows that one should not simply add a PLF to an existing plant but optimise a production line by integration of a PLF.

PLF POWER SUPPLY

Basically, there is no difference from an electrical point of view between a PLF and a graphite electrode based conventional LF. Both furnaces generate electrical arcs between the electrode and the melt, the voltage being in the range of 100 - 250V. But in detail, two differences are worth mentioning:

First, the torches cannot be started by short-circuiting as with graphite electrodes. With plasma torches an HF spark together with DC pilot arcs are used for non-contact starting.

Second, the torch electrodes are relatively sensitive to overcurrents. Therefore, the current has to be limited by some means. As a consequence, most plasma power supplies are thyristor-controlled (Ref 6). But other systems have also been applied based on a so-called saturable reactor principle (**Fig 3**). Here additional components like balancer and compensation distribute the electrical energy to three phases and optimise the power factor.

The control philosophy of all systems is the same. Based on a preset heating power, current is controlled because voltage depends on non-electrical external conditions, ie voltage can freely develop according to arc parameters like length, atmosphere or temperature.

Required power input for a PLF depends on the operating conditions (Ref 7). If only the steel temperature has to be raised, a power demand in the range of 0.5MWh/tK is required. For synthetic slag refining additional power is necessary to melt and superheat the flux.

DESULPHURISATION

Conventionally, desulphurisation is done by adding a reducing basic synthetic slag with an optimised CaO concentration, and by CaSi wire injection together with intensive Ar stirring (Refs 8, 9). Although this process is well established in the steel industry, it suffers a lot from temperature losses which are in the range of 100°C (Ref 10).

Ultra-clean grades with carbon, phosphorus and nitrogen in the ppm range can only normally be produced by severe primary superheating causing refractory and process safety problems. Here the PLF offers a valuable alternative. As it heats from the top, the slag can easily be superheated increasing the reactivity and shifting the equilibrium to lower sulphur contents. **Fig 4** shows results from a 30t PLF. Sulphur content of both steel and slag decreased significantly (Ref 4). Hitachi Metals is the first company in the world to integrate this technology into the production of special steels (**Fig 5**).

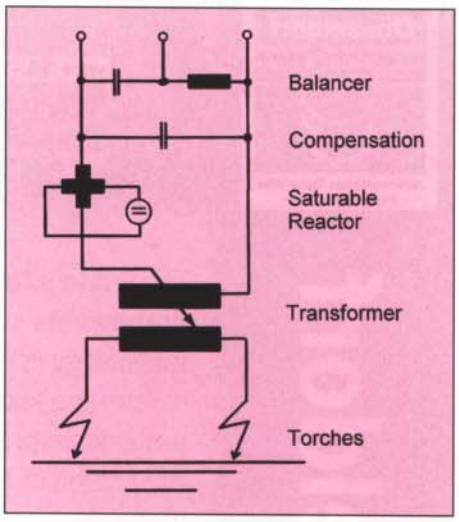
COMPARISON WITH COMPETITIVE SYSTEMS

In short, the PLF is not competitive to the LF but supplements and extends its application range in regards to quality. Having water-cooled torches and typically longer arcs its thermal efficiency is somewhat lower than that of an LF, and the maximum power is still limited to about 8MW. But in steel refining, where process requirements play the most important role, these disadvantages are more than outweighed.

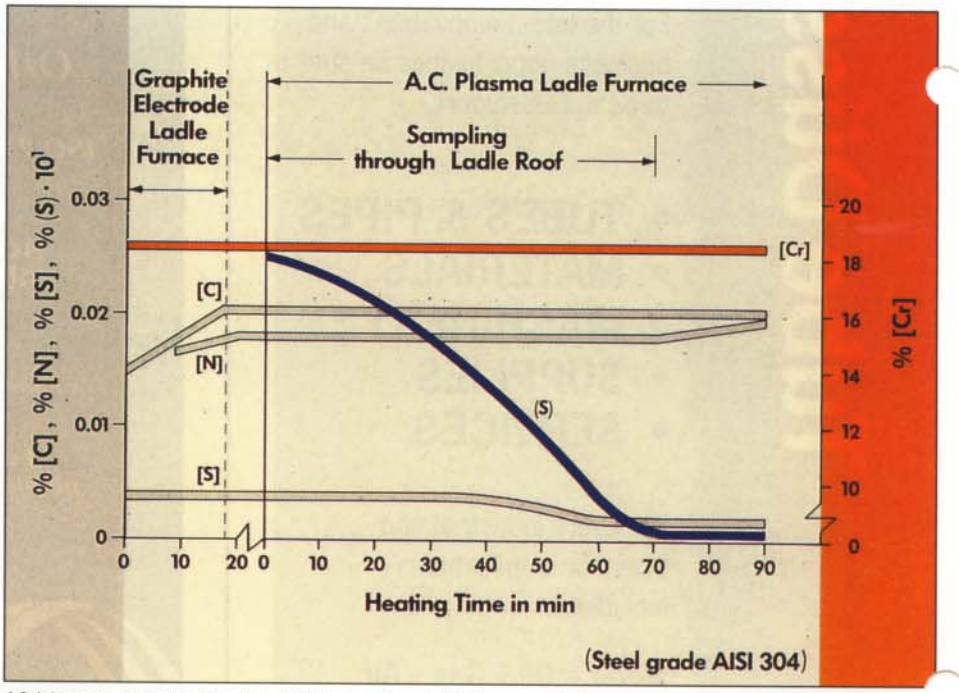
Compared to top blowing methods in a vacuum induction furnace (VIF) (Ref 11), the PLF claims advantages of higher efficiency, flexibility and controllability. Flux superheating is impossible in the VIF due to the lack of inductive coupling.

SUMMARY

This paper briefly outlines the present situation and the most important features of the plasma ladle furnace (PLF). Due to its inert atmosphere the PLF has advantages for clean steel production extending the application range of normal ladle furnaces to higher quality grades. Moreover, integration of a PLF into an existing steelworks provides the possibility of optimising the whole production line. ■



3 Power supply for a single-phase PLF.



4 Sulphur content in slag (S) and steel [S] during plasma ladle furnace operation.

References

1. Oliver J F, Stefanic S M, Kemeny F L, *I&SM*, July 1989, 17.
2. Kats Y L, Ryabov V V, Savov P, *Steel Technology International* (1995), 156.
3. Camacho S L, *I&SM*, July 1986.
4. Neuschütz D, Schubert K H, Bebber H J, *Steel Research 62* (1991), 390.
5. Iritani H, Saito T, Fujimoto H, Nakamura Y, Shimizu M, Kiyokawa N, Tokunaga H, Bebber H J, Steelmaking Conf (1991), Washington.
6. Birkenbusch D, Bebber H J, Espendiller B, *Elektrowärme International* 50 (1992) B212.
7. Bebber H J, Espendiller B, *Steel Times*, 1991, 665.
8. Fruehan R J, *Journal of Metals*, March 1985, 50.
9. Bannenberg N, Prothmann B, Scherrmann T, *Stahl und Eisen* 115 (1995) 89.
10. Smailer R M, Ikegami Y, *Iron and Steel Engineer*, Nov 1985, 29.
11. Shinme K, Matsuo T, Yamaguchi H, Morishige M, Kamegawa K, *Steel Technology International* 1993, 123.

5 The 3MW PLF at Hitachi Metals, Yasugi Works, Japan.