MACHINERY FOR OPENING AND CLOSING OF STEELMAKING FURNANCES TAP HOLES

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Abstract

The problem of the furnace slag penetration into the ladle is inseparably connected with the process of steel furnaces tap holes closing and opening. We are talking about the so-called slag free tapping. Different closure designs are used just in connection with the so-called slag free tapping. All these devices practically try to minimize the penetration of furnace slag into the ladle during tapping. In practice, however, it is never a complete avoidance of the furnace slag penetration into the ladle. The design and layout of the tap holes vary according to the furnace type. For this reason, the conditions for opening and closing the tap holes (openings) are also changed, consequently the design of the device for the tap holes closing and opening differs. Various ways for closing and opening of metallurgical aggregates tapping holes are used in practice. There may be also some complications during the opening process. There are complications especially with the tap holes, into which a mixture of liquid slag and metal penetrates during the tapping and subsequently, this mixture solidifies. The paper presents selected designs of devices for closing and opening tap holes and examples of their use in practice.

Keywords: Steelmaking, tap hole, slag free tapping, tapping process, slag detection

1. INTRODUCTION

The slag in steelmaking furnaces contains various chemical elements and also oxides which are chemically unstable. If they are in contact with the deoxidized steel they may penetrate back into the steel. This fact may be a problem in the production of certain steel grades. For example, such chemically unstable oxides contained in the furnace slag may in the end prevents or degrades performance of other refining processes and thus make steel production more expensive because we have to use more deoxidation and alloying additives. Variety of devices and procedures are used to prevent furnace slag penetration into the ladle. The aim of this article is to introduce selected types of stoppers and to show their advantages or disadvantages.

2. STOPPERS DIVISION

In principle, two procedures are used to reduce the presence of furnace slag in the ladle:

1) Limiting the outlet of the furnace slag to the ladle during tapping from the primary furnace, then we are talking about so-called "slag-free tapping"
2) Removal of furnace slag directly from the ladle, we are talking about so-called "slag removal" that may happen: a) by means of slag skimming either manually or with help of skimming machine,
   b) by means of vacuum removal equipment,
   c) in this context, we can also mention reladling technology, which is casting from one ladle (contains furnace slag) to the second empty one.

In general, stoppers of the metallurgical aggregates can be divided as follows:

1) internal stoppers - of the so-called plug type, ball-shaped (free, suspended), cone-shaped (dart-shaped)
2) external stoppers - bott-type stopper (classic, gas), slide gate, siphon shape stopper, flap stopper.

3. INTERNAL STOPPERS

Plug-type of internal stoppers are mainly used in oxygen converters (Basic Oxygen Furnaces). This type of stopper is transported by special mechanical device to the space above the tap hole when the end of tapping period is approaching.

3.1. Ball-shaped stopper

The most common type of inner stopper is a ball-shaped stopper or we can say also spherical stopper. The specific weight of the material from which the sphere is made is such that the sphere penetrates the slag layer and floats on the liquid metal surface (**Figure 1**). The average specific weight of the sphere is about 3.8 to 6.5 g.cm^{-3}. The sphere core may be made of ceramic or metallic material. In the case of a ceramic core, the cover is the metal envelope (cast iron - after conveying the sphere into the liquid bath it is wrapped in a furnace slag and therefore does not melt during tapping). In the case of a metal core, the cover is ceramic. Free sphere is centered by a vortex that forms above the tap hole. The vortex acts on the sphere until the tapping hole is closed - to the end of tapping period [1].

The disadvantage of the free spherical stopper is the fact that some of the furnace slag is entrained by the swirl above the tap hole and thus penetrates to the ladle. This unpleasant feature of the free spherical stopper may be restrict by the so-called hinged ball stopper that is hinged on the arm of the mechanical device throughout the tapping period (**Figure 1**).

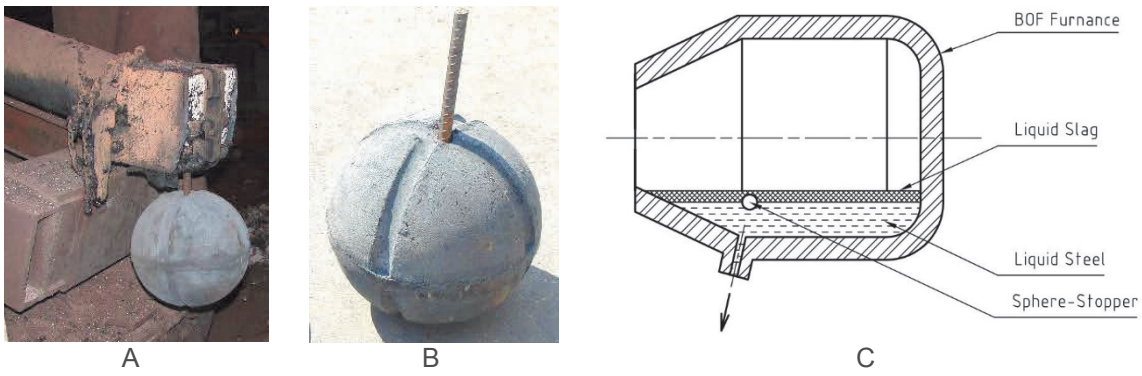

Figure 1 Detail of the hinged spherical stopper (A, B) [2] ; Free spherical stopper in oxygen converter (C)

3.2. Cone-shaped stopper

Another type of internal stopper is cone-shaped or dart stopper (**Figure 2**) which has the advantage over the spherical stopper that it prevents, to a greater extent, the formation of swirls in the area above the tap hole and thus also to entrain a part of the furnace slag into the ladle. In this view, it appears to be more advantageous than the sphere stopper.

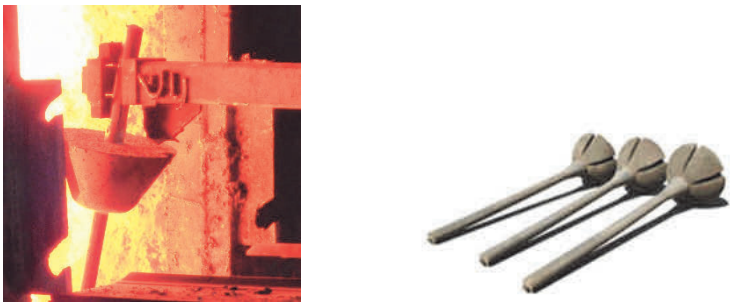

Figure 2 Detail of the dart stopper of the oxygen converter tap hole [3]

4. EXTERNAL STOPPERS

4.1. Bott-type stopper

Outer bott-type stoppers are used primarily for oxygen converters and electric furnaces. It is essentially a lever mechanism at one end of which is a stopper that closes the tap hole and at the other end is a stopper actuator actuating the movement of the plug itself. The plug itself, like the closure element, can be made in a conventional manner or as a plug with a gas inlet. This slag stopper system can be operated either in manual or automatic mode and will be able to reduce the slag content in the liquid steel to levels lower than 4 $kg.t^{-1}$, which will result in reduced rephosphorization and resulfurization of the steel [4]. We could compare the classic design to a "plug" that is inserted into the tap hole from the outside. The force controlling the lever lock mechanism can be derived from the weight of the counterweight or the pneumatic cylinder (**Figure 3**).

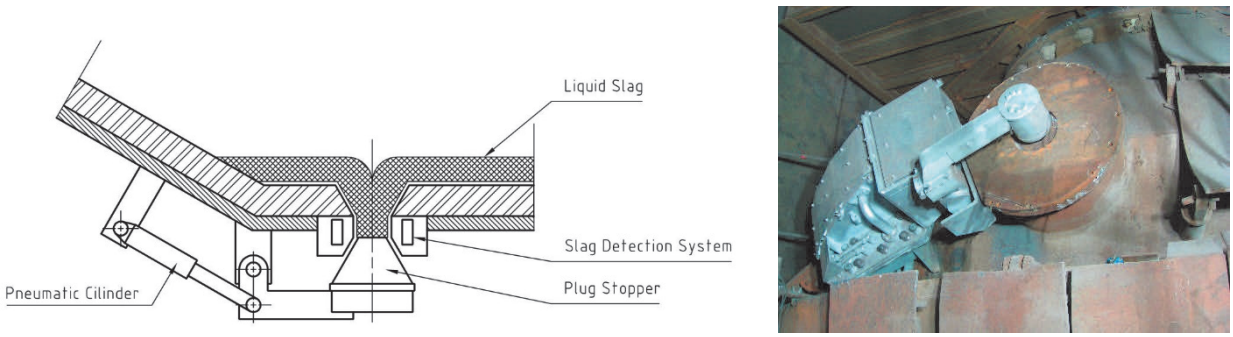

Figure 3 Scheme of the plug-type stopper principle and its detail on the oxygen converter tap hole [4]

4.2. Slide gate stopper

This type of closure can be used for oxygen converters (**Figure 4**), electric furnaces and open-hearth furnaces. This is a similar design as for sliding gates which are used in ladles. The drive is provided by a hydraulic cylinder connected to the hydraulic station. The slide gate is replaced as a whole (the whole cassette - **Figure 4**). Mounting on the base plate, which is a part of the furnace tap hole design can be solved for example by means of wedges. The slide gate exchange takes less than 15 Minutes [5]. Slide gate stopper can be closed at any time within a few tenths of a second without the need of tilting furnace back. Slide gate stopper lifetime is tens of melts (30 to 50 melts).

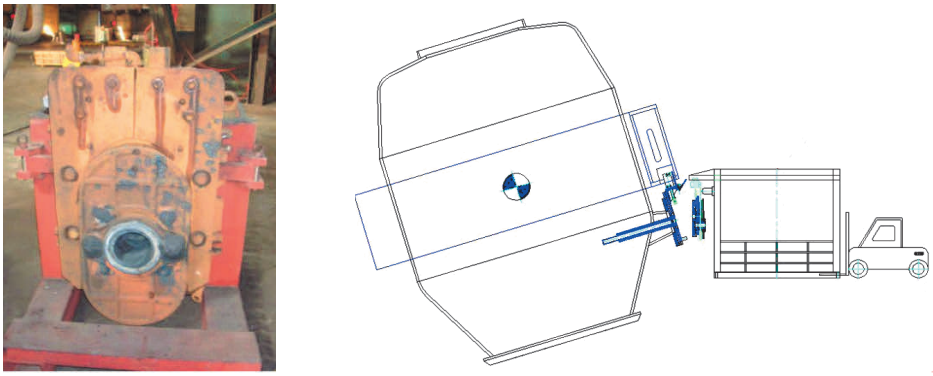

Figure 4 View of the slide gate stopper prepared for instalation and scheme of its mounting on the oxygen converter tap hole [6]

When the 100 t electric arc furnace is tapped and the 1.5 t of steel is left in the furnace, less than 200 kg of slag passes into the ladle. With the residue of 2 to 3 tons, practically no furnace slag will penetrate into the ladle. The main advantages of the slide gate stopper can be characterized as follows:

- removing of the open tapping channel and the resulting reduction in operating costs associated with the maintenance of channel,
- due to the possibility of quick tap hole closing, the amount of solidified residue on the ladle collar is greatly reduced, this facilitates the perfect operation of further equipment for steel processing,
- compact pouring stream to prevent thermal losses of liquid steel and penetration of gases from the environment, improving steel cleanness.

4.3. Siphon-type stopper

This is practically a kind of tapping hole extender (adapter) which was developed by Kawasaki steel. This extender is designed on the principle of a siphon closure (stopper). It is an investment-less facility functional principle of which ensures a relatively reliable separation of slag from metal. This type of stopper is very demanding for operational maintenance, this fact makes its operation expensive in comparison with other types of stoppers.

4.4. Flap stopper

Modern electric arc furnaces are designed with so-called eccentric bottom tapping. In this case, the furnace is equipped for example with a hydraulic cylinder for tilting the furnace, which allows the furnace to be tilted to the initial horizontal position in moment when furnace slag appears in tapping stream for the first time, thereby interrupting the tapping. Using an eccentric bottom tapping, the classic open tapping spout is replaced by a shorter tap hole made at the bottom of the furnace's hearth. The tap hole design is similar like in case of oxygen converters. To close this vertical tap hole, an external flap stoppers may be used. The use of this system has certain advantages:

- increasing of area for placing water-cooled panels on the furnace shell (more than 90% of the side walls may be covered by these panels),
- compact casting stream and thus less oxygen, hydrogen and nitrogen absorption in the ambient atmosphere of flowing steel and lower heat losses at tapping (saving up to 20kWh of heat per tonne of cast steel),
- shorter tap time (up to 50%),
- improved steel cleanness.

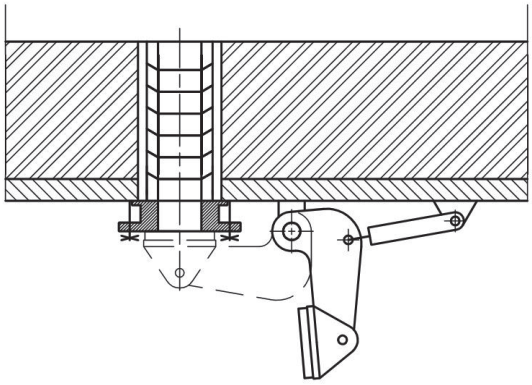

Figure 5 Tap hole equipped by flap stopper

5. SYSTEMS FOR EARLY FURNACE SLAG DETECTION

As regards the penetration of furnace slag to the ladle, the different types of stoppers solve only the question of how to close the tap hole. It does not solve the question of when to close the tap hole. In order to be able to

answer the question "when" with maximum accuracy, it is necessary to equip the tap holes of metallurgical furnaces with equipment for the early indication of the furnace slag appearance. Such device may operate on the basis of an electromagnetic field induced by the transmitting coil and received by the receiving coil (**Figure 6**). This device is known under the abbreviation EMLI and it can operate in temperatures above 600°C without cooling [7].

A transmitter sensor is supplied with a current of a selected frequency which creates an electromagnetic field that in turn induces a corresponding voltage of the same frequency in the receiver sensor. When a 100% steel flow exists between the transmitter and receiver there is an induced voltage (a) at the receiver. As soon as the flow becomes a steel/slag mix, the induced voltage immediately increases (b) - see in (**Figure 6**) [8]. This device eliminates a subjective human factor, and in combination with a suitable tapping stopper the results are better in comparison with those of the conventional tappings. This device allows to considerably reduce the furnace slag carry-over, for example, from the converter to the ladle, it means under three kilogram per one tonne of steel.

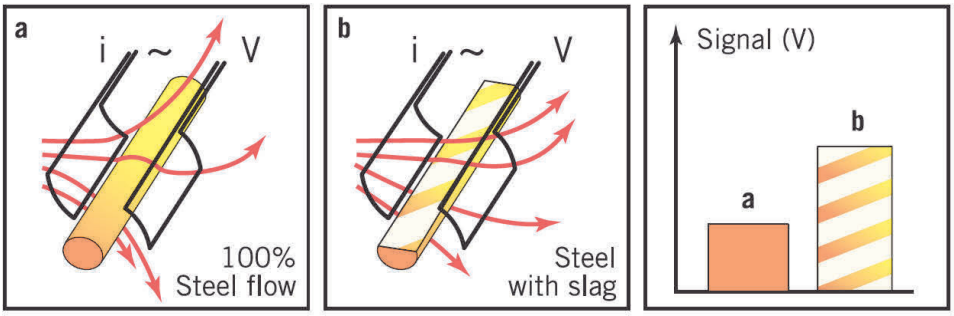

Figure 6 The principle of EMLI system [8]

Infrared detection system is another system for slag detection in the tapping stream that is used in practice. The system utilizing the infrared camera measures the intensity of this radiation coming from the hot surface of the casting stream of the liquid metal. The surface of liquid steel and liquid slag at the same temperature emit radiation of varying intensity, that is, these phases have different emissivity (radiance) that makes it possible to distinguish between the two phases (**Figure 7 A**). It has been shown that infrared wavelengths in the wavelength range of 8-12 μm are the most favorable range with respect to the optimal contrast between slag and steel and, moreover, this range of wavelengths is poorly absorbed by the surrounding (**Figure 7 B**).

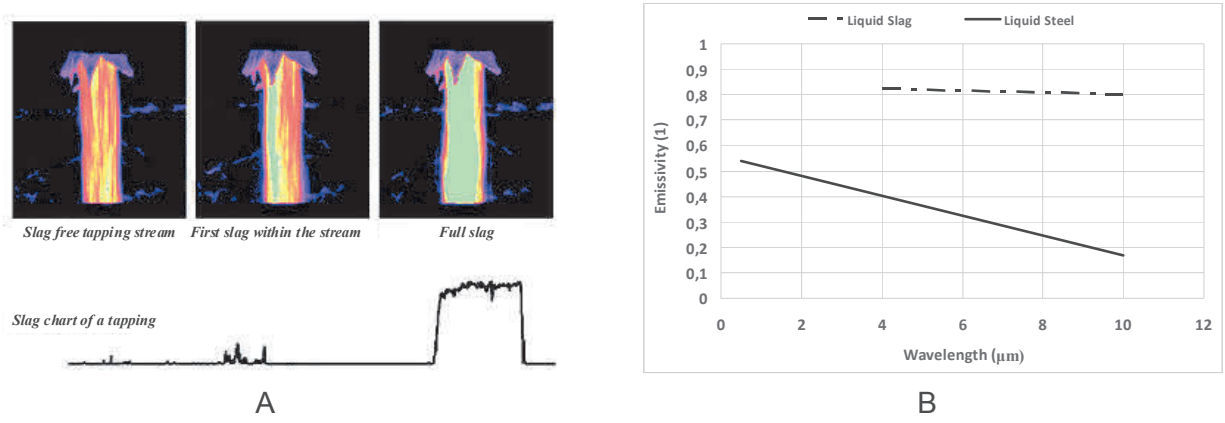

Figure 7 A - The principle of EMLI system [9], B - Liquid slag and steel emissivity

The advantage of a system using the infrared radiation camera compared to the EMLI system is that it is installed outside the furnace and therefore there is no need to interfere with furnace design. The infrared

camera is located at a distance of about 15 to 30 meters from the flow of liquid steel from the furnace. Both investment and operating costs for this system are lower than the EMLI. The reason is an easier installation.

Based on the above features of the infrared camera and EMLI system, the infrared camera is preferred for converters with larger capacity which work in longer campaigns (lining change is in longer intervals), while the EMLI system is recommended for electric arc furnaces and in cases where is a risk of swirling, for example, in furnaces equipped with EBT (Eccentric Bottom Tapping).

6. CONCLUSION

The article presents several technologies for limiting of furnace slag carryover to ladle. These technologies are different in principle. In practice, only those technologies that are suitable for operational and economic use are used. These technologies are implemented by the respective machinery, which is designed for given purpose and for given type of steelmaking furnace. The most widely used internal stoppers are ball-shaped stopper and dart stopper. Plug, flap and slide gate type of external stoppers are the most widely used. If we want to achieve the so-called "slag-free" tapping, then it is necessary to operate a appropriate type of stopper together with the suitable early slag detection system of furnace slag in molten steel tapping stream during tapping period. It can be said that by combining a suitable stopper and furnace slag detection system, the best results can be achieved, which correspond to the current steel quality requirements.

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