CONSTRUCTION OF A RH DEVICE'S PHYSICAL MODEL ITLE OF PAPER

Jacek PIEPRZYCA, Tomasz MERDER, Karel MICHALEK

Silesian University of Technology, ul. Krsinskiiego 8, Katowice, 40-019, Poland,
jacek.pieprzyca@polsl.pl
VŠB-Technická univerzita Ostrava, 17.listopadu 15, Ostrava-Poruba, Czeska republika,
karel.michalek@vsb.cz

Abstract

One of the main goal, that steel makers have to deal with is continuously increasing metallurgical's quality and purity. It triggered a rapid progress of the secondary metallurgy. Treatment of secondary metallurgy steel is an important step in getting the technology required to ensure quality outcomes. Continuous development of the civilization causes demand on new construction materials. This also applies to steel metallurgy. Therefore the aim is to produce new, not yet melted steel grades. This has a need to conduct multiple researches of a scientific nature, that provide the necessary information to innovate in the technology of steel production. In the cathedral of Metallurgy of the Silesian University, researches conducted for many years on the modeling of metallurgical processes. The scope of these tests is very wide, because of the extensive laboratory equipment in metallurgical aggregates models. It includes the processes of raw material (blast furnace) and steelmaking (oxygen converter and COS). Currently the laboratory is enriched by the devices to test the phenomenon occurring during secondary metallurgy of steel. Specifically, it concerns the station to study the processes taking place during the purge of liquid steel in the ladle with inert gases in steelmaking and position to research the phenomenon occurring during vacuum degassing of steel in RH circulating device. The article presents the physical model construction of a device for vacuum degassing of RH steel. The model is made of transparent materials and equipped with extensive control-measuring apparatus. It enables research of analysis on the flow of liquid steel by RH device and optimize the process.

Keywords:
steel, secondary metallurgy, physical modeling.

1. INTRODUCTION

Vacuum steel processing is a method of obtaining the required results in the production of steel of high and very high metallurgical purity. This applies in particular to the content of harmful gases (hydrogen, nitrogen). Nowadays, operations of removing gases from the volume of liquid steel are carried out in the treatment ladle, and the most common methods of conducting that process are [1]:

- degassing of the steel in the ladle in a vacuum tank with argon blowing through it, with no heat provided (VD),
- degassing of the steel in the ladle, with possibility to heat the liquid steel with electric arc and mixing (ASEA-SKF i VAD),
- steel treatment with lower pressure and blowing through oxygen gas at the same time (VOD),
- portioned and circulated degassing of steel in a vacuum chamber (DH i RH).

From the foregoing methods of steel vacuum treatment - especially in the mass production - method of RH is one of the most efficient.
It is characterized by high efficiency of degassing and ability to refine molten steel from non-metallic inclusions. This method belongs to a group of progressive methods that are constantly evolving and improving [2]. Example of such solutions is a process called RH-KTB in which an oxygen lance is used to allow injection of oxygen directly above the metal bath. This solution is mainly aimed to save energy. Blew oxygen is used to burn the CO, and the heat generated heats the treated steel. This allows to begin the process of degassing of molten steel at a temperature 20 K lower than the classical process of RH. Additional savings would result from the fact that steel melted in an oxygen converter is directed to vacuum treatment with a higher carbon content. Another variation of the RH process is RH-OB process in which a mixture of O$_2$ + Ar gases is introduced directly into the steel bath through the lance located in the side wall of the vacuum chamber. An even more advanced version of this process is the process of RH-POSB that has modified design of the side lance to allowing the introduction of alloy to the steel bath in the form of powders. Another variation of RH process is the process of RH-PB, or otherwise known as the RH-IT. Here, the changes apply to the construction of the steelmaking ladle to which the lance is installed in such a way that it's outlet was under the nozzle manifold. This allows the introduction of gas-powder mixture to the bath. As the refinee materials powders can be blown, this method achieved good efficacy of steel dephosphorisation and desulphurisation.

2. THERMODYNAMIC CONDITION AND KINETICS OF DEGASSING OF LIQUID STEEL IN RH DEVICE

In the process of circulated degassing of the liquid steel comes to intense evolution of gas bubbles, because the inert gas (argon) contributes to the nucleation of bubbles of other gases H$_2$, N$_2$, CO, and also to absorption of them. Rapid nucleation of bubbles leads to extension of the area reaction of the molten steel - gas phase. This results in faster diffusion of harmful gases. At the same time it comes to rapid exchange of the interface liquid steel - vacuum. This in turn allows the intense desolation of the gases from the surrounding liquid steel. Thermodynamic condition for removal of gases from the metal bath at constant temperature and reduced pressure above the metal bath determines the inequality [1]:

\[ P < p_i \quad \text{therefore} \quad p_i - P > 0 \quad (1) \]

where:
- \( P \) - general pressure above the bath, Pa,
- \( p_i \) - equilibrium pressure of dissolved gas above the bath, Pa,

The solubility of diatomic gases in the liquid metal is determined by the Sievert's law:

\[ [\% i] = \frac{K}{f_i} \cdot \sqrt{p_i} = k_s \cdot \sqrt{p_i} \quad (2) \]

where:
- \([\% i]\) - content of the dissolved gas in the steel, %,
- \( K \) - equilibrium constant of reaction,
- \( f_i \) - Henry's activity coefficient of the gas in steel,
- \( k_s \) - Sievert's constant.

According to this law, molar fraction of gas atoms with diatomic corpuscles in the liquid metal, undergoing at the time of dissolution in the metal dissociation is proportional to the square root of the pressure of the diatomic gas component adhesives over liquid metal [3].

The fulfillment of the thermodynamic condition of the gas removal from the steel under reduced pressure is not sufficient to assess the effectiveness of the methods used.
Industrial practice shows that the factors determining this process are the kinetic factors. Equation (3) describes the change in concentration of the removed gas (N₂, H₂, CO) as a function of time of steel being vacuum treated [1]:

$$- \frac{dc}{dt} = \beta_i \cdot \frac{A}{V_m} \cdot (i - i_{eq})$$  \hspace{1cm} (3)

where: $\frac{A}{V_m}$ - effective area of the steel bath,
$\beta_i$ - mass transfer coefficient,
$i$ - gas concentration in the steel,
$i_{eq}$ - gas concentration in equilibrium determined by the equilibrium constant of reaction $K$.

Decisive influence on the kinetics of vacuum steel degassing has the size of the effective surface of the steel bath and the mass transfer coefficient.

These parameters depend on the design of the degassing unit (size of the vacuum chamber) and the intensity of liquid steel mixing. The intensity of the mixing in RH device is mainly related to it's flow rate. This intensity can be represented by the following empirical formula [1]:

$$Q = 7.43 \cdot 10^{-1} \cdot (G)^{\frac{1}{3}} \cdot (D)^{\frac{3}{2}} \cdot \left(\ln \frac{P_1}{P_2}\right)^{\frac{1}{2}}$$  \hspace{1cm} (4)

where: $Q$ - intensity of the steel flow, kg · min⁻¹,
$G$ - intensity of the lifting gas flow, m³ · min⁻¹,
$D$ - diameter of the nozzle, cm,
$P_1$ - atmospheric pressure, Pa,
$P_2$ - pressure in the vacuum chamber, Pa.

Less important is equilibrium concentration of the gas due to the continuous removal of gas from the device's vacuum chamber using the vacuum pumps.

3. INFLUENCE OF LOW PRESSURE (VACUUM) ON THE BEHAVIOR OF NONMETALLIC INCLUSIONS IN MOLten STEEL

Vacuum conditions create additional thermodynamic and kinetic capacities of purification of the liquid steel – refining of nonmetallic inclusions. This include [4, 5]:

- thermal decomposition of nonmetallic inclusions (oxides, sulfides and nitrides),
- reduction of nonmetallic oxide inclusions with carbon contained in liquid steel,
- flotation of inclusions using the gas bubbles, especially CO bubbles.

Detailed analysis of the effectiveness of secondary metallurgy of liquid steel vacuum treatment indicates that steel purification from nonmetallic inclusions occurs mainly through their transfer to assimilating phase (slag) by gas bubbles flow (CO), and moving steel convection streams. Depending on the chemical composition of steel, the degree of oxygenation, temperature, and used vacuum's "depth" 25 to 40% non-metallic inclusions are removed. In the conditions of very deep vacuum (10⁻³ – 10⁻⁴ mmHg) the degree of non-metallic inclusions removal increases to 60%. Capabilities to remove the nonmetallic oxide inclusions (including oxygen) from the liquid steel as a result of thermal dissociation of oxides are limited. As a result of thermal dissociation of a simple oxide (oxide inclusions) of type:
\[ M_x O_y = x[M] + y[O] \]  
(4)

Emerging oxygen \([O]\) diffuses to the surface – the border division of molten steel - gas phase and desorbs into the gas phase in the form of \(O_2\). Thus the total process of thermal dissociation can be determined with reaction:

\[ M_x O_y = \frac{y}{2} \{O_2\} \]  
(5)

However, this process can take place only in case when dissociation's pressure (resilience) \(P_{O_2}\) of the oxide \(M_x O_y\) is greater than the partial pressure of oxygen in the vacuum chamber. According to [4], dissociation pressure (resilience) of the oxides (e.g. \(CaO, MgO, Al_2O_3, FeO\)) are very small (<10\(^{-8}\) atm) in comparison to the pressure prevailing in most metallurgical vacuum devices (10\(^{-5}\) to 10\(^{-4}\) mmHg). Therefore, the reverse reaction should rather be expected, i.e., the transition of oxygen from the gas phase to the liquid steel. The presence of carbon in liquid steel significantly changes the destruction process of the oxide inclusions, which in these conditions, can be described with the reaction of reduction:

\[ M_x O_y + y[C] = x[M] + y[CO] \]  
(6)

Under conditions of low pressure, carbon deoxidation “ability” is growing strongly and reduction reaction becomes a reaction that precedes the process of thermal dissociation. CO embryos formed on the surface of reduced oxide grow to the form of bubbles, and after reaching the critical dimensions it flows to the division of phases border: liquid steel - gas phase. With the drawn gas bubbles (CO) also flow out of nonmetallic inclusions processes may develop on the basis of the phenomenon of flotation and / or elevation of the inclusions from the volume of liquid steel with convection currents. The effectiveness of these phenomena in the purification of liquid steel from nonmetallic inclusions depends on the method of vacuum treatment of steel and its chemical composition. It is believed that the circulation method (RH) is one of the most effective among modern methods of refining steel from nonmetallic inclusions, and the amount of nonmetallic inclusions removed by coal reduction stands at 20%.

**4. PHYSICAL MODEL OF RH DEVICE PROJECT**

Physical model of vacuum degassing of steel device built was design to study hydrodynamic phenomena occurring during that process. The main goal of this research is to understand the mechanisms of liquid steel flow in the device and optimize its operating parameters. The device model is RH installation working in one of the Polish steel mills. The basic geometric and technological parameters of the real RH device shows table 1.

<table>
<thead>
<tr>
<th>Table 1 The basic geometrical and technological parameters of the actual RH device.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The nominal capacity of steelmaking ladles</td>
</tr>
<tr>
<td>The nominal diameter of the vacuum chamber</td>
</tr>
<tr>
<td>Nominal diameter of suction spout</td>
</tr>
<tr>
<td>Nominal diameter of return spout</td>
</tr>
<tr>
<td>Spouts height</td>
</tr>
<tr>
<td>Number of nozzles in the suction spout</td>
</tr>
<tr>
<td>Diameter of rising gas supply pipes (Ar)</td>
</tr>
<tr>
<td>The level of liquid steel in a vacuum chamber</td>
</tr>
<tr>
<td>Process duration</td>
</tr>
<tr>
<td>Circulation of liquid steel duration</td>
</tr>
<tr>
<td>Rising gas flow rate (Ar)</td>
</tr>
</tbody>
</table>

The physical model of described device is made of transparent material (Plexiglas) to enable results acquisition in form of a process visualization. Factor in liquid steel
modeling is water. It is a classic example of a segment water model. The adopted linear model scale is \( S_L = 1:8 \). As previously designed and built at the Department of Metallurgy, Silesian University of Technology physical models of metallurgical reactors, it satisfies the requirements in this type of structures arising from the theory of similarity [6, 7, 8]. The dynamic similarity of the model to the real device is performed basing on a set of the criterial numbers determined by dimensional analysis method in accordance with equation:

\[
\phi(\text{Fr}, \text{Re}, \text{Eu}, S_L) = 0
\]  

(7)

While kinetic similarity is determined by scales method based on the Froude criterion.

Diagram and the basic dimensions of built vacuum chamber physical model of the device for circulated degassing of RH steel shows fig. 1.

For building the test system a specialized control-measuring apparatus were used. To generate the vacuum in the vacuum chamber model a rotary vacuum pump with a nominal capacity of 8 m\(^3\)/h and final pressure of 2 mbar was used. As the source of lifting gas double piston compressor with a capacity of 225-320 l/min and maximum pressure of 8 bar in 100 l gas tank was applied. In order to provide appropriate pressure measure parameters of the experiment the mass gas flow meter with a measuring range from 0 to 10 l/min and accuracy <1% was applied. The meter works with the gas mass flow controller, which have similar accuracy and repeatability <0.25%. This allows for very precise control of conducted experiments. This control is realized through microprocessor regulator for gas flow control equipped with LED display for measuring values and references. For visualization studies a marker of an aqueous solution of KMnO\(_4\) is used. The study of mixing kinetics (efficiency of ongoing process) based on measuring the change in conductivity of the liquid model was implemented. KOH was used as a marker.

To measure the conductivity changes of the liquid conductivity meter with a measuring range 0 - 20 mS/cm with immersion sensors was used. All measuring signals are directed to a multi-channel electronic recorder. The recorder is equipped with 16 universal inputs (RTD, TC, mA, V), 4 two-stage inputs, 16 mathematical functions, 8 alarm outputs, and a color LCD display. The internal memory of recorder is 2 GB. Recorded data are transferred to a computer where, thanks to dedicated software that is installed MPICRAPORT are processed and visualized in real time. Diagram for the entire test stand for testing of hydrodynamic phenomena occurring during the process of circulated degassing of steel by RH is shown in figure 2. The diagram also includes the measurement and control equipment installed on the steelmaking ladles model. It may be a separate test stand to conduct experiments on refining liquid steel by inert gases.
5. CONCLUSION

The main priority of modern metallurgy is the production of steel with the highest quality properties at the lowest possible cost. This demand is realized, among others, by implementation of innovative solutions in steel-making technology. These innovations are based on the experience acquired in industrial conditions and also in researches conducted in the laboratory. The built test stand of hydrodynamic processes that occur during the process of circulated degassing of steel with use of RH method is reaction to the present needs of the steel industry. Significantly enhances the research capabilities of the Department of Metallurgy, Silesian University of Technology. It should be emphasized that the critical importance in the construction of a physical RH device model, has working with the Department of Metallurgy and Foundry employees of VSB-TU in Ostrava.

ACKNOWLEDGEMENTS

to the State Committee for Scientific Research (MNiSW) for financial support (project N N508 589839).

LITERATURE