RH metallurgy

Since its introduction more than 40 years ago vacuum degassing has developed from being used primarily for hydrogen removal to an essential part of secondary steelmaking, with an ability to refine, alloy, heat and deoxidise steel. Metallurgical reactions are influenced by thermo-chemistry and vessel design as well as vacuum level.

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During the past 30 years there has been a tremendous improvement in the secondary processing of steel. In the first stage of this development simple ladle metallurgical processes were developed to:

- Improve deoxidation control
- Remove inclusions by gentle bath stirring
- Desulphurise steel by synthetic slags and injection metallurgy
- Modify inclusions primarily by calcium

In the next stage of development, ladle furnaces were implemented in order to improve productivity and the quality of steel. These have been used to:

- Reheat steel and control temperature
- Buffer heats for sequence casting
- Add large quantities of alloys
- Homogenise composition and temperature
- Produce ultra clean steels with an extended gentle gas stirring
- Desulphurise and, in some cases, dephosphorise steel with synthetic slags

Since its introduction more than 40 years ago, vacuum degassing had been used primarily for hydrogen removal. Today, however, vacuum degassing processes are also used for secondary refining and have become increasingly important in the modern steelmaking industry, mainly because of the rising demand for cold-rolled sheet with improved mechanical properties. Pressure dependent reactions are the reason for the treatment of liquid steel under vacuum (see Table 1).

The dominating vacuum degassing system is the RH type degasser (see Figure 1). This process was named after the companies Ruhrstahl and Heraeus where the process was developed. The amount of steel requiring vacuum treatment will continue to grow and every international competitive integrated plant and many electric furnace plants will require vacuum degassing if they are to remain competitive.

RH/RH TOP PROCESS

The mechanism of the vacuum treatment of liquid steel is shown in Figure 1. The unit consists mainly of a refractory lined reaction vessel and two steel pipes attached to the bottom of this vessel. These are the inlet and outlet snorkels. Both of them are completely refractory lined on the inside but only the lower part is refractory coated on the outside. The inlet snorkel is equipped with a number of gas injection pipes arranged in the lower section in one or two levels and equally distributed around the circumference.

The degassing process is started after both snorkels are sufficiently immersed into the melt. Before snorkel immersion the injection of inert gas, usually argon, is started in the gas pipes of the inlet snorkel. Having achieved the required immersion depth, the reaction vessel is evacuated by means of a vacuum pump system which is connected to the reaction vessel via an off-take duct. The density of liquid steel is assumed as 6.94t/m^3 at 1,600°C. The atmospheric pressure exerted on the ladle surface causes the steel in the snorkels to rise to a barometric height of approximately 1.45m under deep vacuum conditions.

Due to the economic benefits achieved by using secondary metallurgical equipment the processes of steel treatment
RH KINETICS

RH vacuum processes, in general, do not reach equilibrium and the amount of hydrogen, carbon and nitrogen removed are governed by kinetic considerations.

Decarburisation

The decarburisation mechanism is fairly complex as the reaction kinetics depend both on the circulation rate and rate of decarburisation. The effect of bath mixing on decarburisation is well known and many studies have been performed to enhance this reaction. Based on a simple simulation, molten steel in vacuum refining equipment can be divided into two vessels (see Figure 3): a reaction vessel, where the decarburisation occurs, and a mixing vessel.

Between the two vessels, the molten steel circulates at constant speed. The mass balance of carbon in the mixing vessel is represented by the following equations [3]:

\[ \text{Mass of Carbon in Mixing Vessel} = \text{Mass of Carbon in Reaction Vessel} \]

\[ \text{Mass of Carbon in Mixing Vessel} = \text{Initial Mass of Carbon} - \text{Decarburised Carbon} \]

\[ \text{Decarburised Carbon} = \text{Rate of Decarburisation} \times \text{Time} \]

\[ \text{Rate of Decarburisation} = k \times \text{C} \]

where \( k \) is the rate constant and \( C \) is the concentration of carbon.

### Table 1: Comparison of various degassing systems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RH technology</th>
<th>Tank &amp; ladle technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon content – final product, ppm</td>
<td>RH-OB, RH-TOP</td>
<td>30-40</td>
</tr>
<tr>
<td>Decarburisation rate</td>
<td>Very high</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Decarburisation time, min</td>
<td>&lt; 13</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Hydrogen removal</td>
<td>All systems have sufficient performance</td>
<td></td>
</tr>
<tr>
<td>Steel cleanliness</td>
<td>All systems improve steel cleanliness / VD-OB, VOD, tank and ladle need soft stirring period</td>
<td></td>
</tr>
<tr>
<td>Desulphurisation</td>
<td>Powder injection by lance – seldom</td>
<td>Very efficient</td>
</tr>
<tr>
<td>Relative capital costs</td>
<td>1</td>
<td>0.8-0.9</td>
</tr>
<tr>
<td>Operating costs</td>
<td>Decreasing</td>
<td></td>
</tr>
</tbody>
</table>

The development of vessel geometry (size and shape), cross-section of snorkels and production capacities of RH units is demonstrated in Figure 2 [2]. It shows the vessel design of RH units in Thyssen’s steelmaking shops since the beginning of RH technology.

**RH PROCESS CHARACTERISTICS**

When the RH process was introduced, the primary target was the reduction of hydrogen in liquid steel. The first results were not as successful as expected due to an insufficient vacuum in the vessel, however, the application of steam ejector vacuum pumps in the early 1960s enabled sufficiently low pressure to be reached, leading to hydrogen contents of less than 1 ppm.

The application of the RH process for decarburisation was introduced at the end of the 1970s. Today, extremely low final carbon contents of less than 20 ppm can be obtained, as required for the production of automotive sheets. The addition of alloying elements during degassing has the advantage of achieving high yields for alloys and high accuracy of chemical analysis of steel due to the absence of air and the avoidance of metal-slag reactions.

Further developments were the use of gaseous oxygen during RH treatment in RHO, RH-OB, RH-KTB, RH-MESID and MFB processes. The targets for these processes were to accelerate the decarburisation reaction, to reheat liquid steel by alumino-thermic reaction, to remelt skulls, to keep vessel at high temperature by converting generated CO gas into CO₂ during the decarburisation period, and to heat the refractory lined vessels between treatments. Recently, some RH TOP lances have also been used for blowing powder onto the liquid steel for reducing sulphur or carbon contents to the lowest contents. Today, all these processes, except RH-OB, are called RH TOP.
If equations 1 and 2 are solved, assuming that:

\[ C_1 = C_2 = C_{0} \text{ at } t = 0 \]  

and \( v \) is considerably smaller than \( V \), the following equations are obtained as approximate solutions:

\[ (C_1 - C_e) = (C_1^0 - C_e) \exp(-k \cdot t) \]  

\[ k = \frac{Q'}{V_M} \cdot \frac{ak}{Q' + ak} = \beta \cdot \rho_M \cdot \frac{A}{W_M} \]

where:
- \( \beta \) is mass transfer coefficient for carbon in liquid steel
- \( k \) is apparent rate constant
- \( V_M \) is \( v + V \)
- \( A \) is surface area of metal exposed to the vacuum

The effects of the circulation rate \( Q' \) and the volumetric coefficient of decarburisation on the apparent rate constant are calculated and shown in Figure 4. The figure shows the presence of three regions:

1. **Reaction control** region where \( k \) increases slightly by increasing the circulation rate
2. **Recirculation control** region where \( k \) increases slightly by increasing the volumetric coefficient \( ak \)
3. **Mixed control** region where \( k \) is affected equally by the circulation speed \( Q' \) and the volumetric coefficient \( ak \)

The improvement of the operational conditions to increase \( k \) (shortening the decarburisation time), can be investigated using Figure 4. If the recirculation rate is small, the apparent rate constant, \( k \), is controlled by the circulation and can be improved by increasing the recirculation rate. This can be accomplished by increasing the snorkel diameter or, in some cases, by increasing the flow rate of the lift gas. In this case, the volumetric coefficient of decarburisation is sufficiently high. In other words, bath mixing has a strong influence in the early and middle periods of the decarburisation process, when decarburisation proceeds rapidly with decreasing vacuum pressure.

Equations (1), (2) and (3) in this diagram represent three phases of an investigation to increase the decarburisation rate at a 270t RH plant. In the beginning of the investigation the conditions were in phase (1). As the size of the snorkel was increased to increase the recirculation rate, the conditions were improved to phase (2). Finally, as \( ak \) was augmented by agitating molten steel in the vessel more vigorously and increasing the interfacial reaction between gas and molten steel, the conditions were improved to phase (3).
DEGASSING
Hydrogen and nitrogen removal in RH TOP plants follow similar equations. In general, the rate constant for hydrogen is greater than for carbon because the mass transfer coefficient for hydrogen is a factor of three times higher than carbon. However, at low hydrogen levels $H_2$ may become important and must be taken into account.

Nitrogen removal is controlled by liquid phase mass transfer and chemical kinetics. The chemical aspects depend on the oxygen and sulphur content. This is because oxygen and sulphur segregate to the surface of the lift gas bubble and impede the formation of $N_2$. In general, the nitrogen removal rate increases as the oxygen and sulphur contents decrease. The rate is slow compared to hydrogen removal. If oxygen and sulphur are low, the rate is controlled by liquid phase mass transfer, which is also slow. The rate constant is about one third of that of hydrogen.

LIFT GAS, SNORKEL GEOMETRY AND STEEL RECIRCULATION
As the RH process is based on the exchange of molten steel between the ladle and the RH vessel, the rate of steel recirculation determines the velocity of the metallurgical reactions and the duration of the process assuming a defined metallurgical target. Melt circulation depends on the geometry of the equipment such as snorkel diameter, the radius of the equipment, and the position and number of lift gas tuyeres.
The parameter H has been evaluated several times by users of the Ono formula and is defined as the length of the inlet snorkel used by the lift gas. With increased H-value the velocity of the up-stream in the inlet snorkel will also be increased. Equation (6) allocates the strongest influence to the snorkel inner diameter.

These theoretical investigations were considered for the engineering and design of SMS MEVAC’s new RH units, with the recommendation for an optimised relation between the ladle capacity and process related lift gas rates shown in Figures 6 and 7.

CONCLUSIONS

The RH process, now in industrial use for nearly 50 years, has been continuously developed to satisfy ever more stringent demands of the steel producer. Further developments are ongoing to provide an economic tool for decarburisation and hydrogen removal to even lower levels within a shorter treatment time and thus make the RH ‘fit for the future’. With achievable high levels of cleanliness and accurate composition and temperature control, the RH process is a key facility in modern steelmaking.

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REFERENCES


