NEW CONCEPT FOR HIGH-PRODUCTIVITY RH PLANTS[1]

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Abstract
Since its development in Germany in the 1950s, RH plants - or vacuum circulation plants - have been applied in the steel industry to improve the quality of steel and to increase the range of the steel products. The RH process has undergone continuous development over the years, including the application of a top lance to promote forced decarburization, chemical heating, refractory heating and skull removal. Also, to increase the productivity of RH plants and to reduce the total treatment time, the diameter of the RH vessel and snorkel have been enlarged, the argon flow rate increased and the evacuation time of the vacuum system reduced. In this paper a number of developments in vacuum-degassing technology is presented. In particular, the design of RH plants as twin-station treatment facilities—allowing even more than 40 heats to be processed per day—and the use of quick-exchange vessels to support high productivity rates are discussed.
Key words: High productivity; Twin station; Quick exchange vessel.

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INTRODUCTION

The demand for clean and high-quality steels is increasing year by year, particularly for the automotive industry (e.g., IF/interstitial-free steels), oil and gas transportation (pipelines), construction (HSLA/high-strength low-alloyed steel), heavy plates (ship building), tire cord, cans and wires, etc. To fulfill these requirements and at the same time to enhance the capability of a steel plant to increase its product mix, the installation of degassing units within the steel shop has become a standard feature of a modern steel mill.

From the construction point of view, there are commonly two degassing unit types available for the steel industry today; Vacuum Degassing (VD) tanks and RH degassers (Vacuum Circulation Process). For the production of ultra-low carbon (ULC) steel within a short time, the RH degasser is superior to the VD process. However the VD process is more suitable for slag metallurgical tasks such as desulphurization.

In this paper various design, process and logistical improvements are presented for the production of high-quality steel at high outputs using the RH degasser unit. Two aspects are considered. The first concerns improvements to shorten the time required for its metallurgical tasks such as decarburization, dehydrogenation and denitrogenation. The role of the RH degasser for producing clean steel is discussed. The second aspect focuses on steps towards reducing production-time losses in connection with the transportation of the ladle to and from the RH station, the exchange of the RH vessel for snorkel maintenance, the replacement of refractories as well as an improved utilization of the vacuum pump unit. As a decisive contribution to an improved output of RH plants, SIEMENS VAI Metals Technologies has introduced twin-station RH plants with fast vessel exchange.

Currently, four twin-station RH plants with quick exchange vessels are to be started up in China for the production of several steel grades, including ultra-low carbon steel, electric steel, enamel steel, structural steel, steel for vessel and boiler, pipe steel, steel for oil tank, ship steel, high strength low alloy steel, weather-proof steel and automotive steel. These twin-station RH plants have the following heat sizes; 150 tons at Nanjing Iron and Steel United Co., 150 tons at Jinan Iron and Steel Co., 180 tons at Taiyuan Iron and Steel Co., and 300 tons at Maanshan Iron and Steel Co.

RH DEGASSER AS A METALLURGICAL FACILITY

At the time of its original development in 1957 by the steelmaking company **R**uhrstahl AG and the vacuum pump manufacturer **H**eraeus, the RH process was mainly used for steel degassing, especially in the early 1960s. The quality of steel had to be enhanced by reducing its gas content. With the increased demand for low-carbon steel since the 1980s, the RH plant has also served as a decarburization unit. A reduction of the treatment time in the RH vessel was important for increasing the productivity and capability of a steel plant. As a metallurgical unit, the steel melt is refined in a RH vessel by reducing the carbon, hydrogen, nitrogen and oxygen contents under reduced pressure. The system thermodynamics and reaction kinetics have a major affect on the time required for metallurgical reactions.

Decarburization

The decarburization process in an RH vessel takes place according to the following reaction:

$$(C)_{Fe} + (O)_{Fe} = \{CO\}_g$$

The thermodynamic equilibrium constant is given by the equation below:

$$\log K_{CO} = \log \frac{a_C \cdot a_O}{P_{CO}} = -\frac{1168}{T} - 2.076$$

At a temperature of 1,600 °C and with a lower content of alloying elements, the above equilibrium equation can be stated in a simple form:

$$(\%C) \cdot (\%O) = 0.002 \cdot p_{CO} \ (\text{atm})$$

A plot of the decarburization equilibrium equation is depicted in Figure 1.

Natural decarburization can be successfully performed by the RH process at a low initial carbon content (200–300 ppm) of the steel. At high initial carbon contents, the available oxygen is not sufficient to oxidize the carbon naturally and an external oxygen supply is necessary for conducting forced decarburization. This became possible thanks to the introduction of the RH–O process (developed by Thyssen Krupp Stahl in 1969,1 the KTB lance in 1991[2] and the multifunctional T-COB (Technometal Combined Oxygen Blowing) lance in 1998.[34] Even with high-carbon and low-oxygen contents of the steel at the beginning of treatment, a carbon content of less than 20 ppm can be attained thanks to these technical solutions. Additional advantages, such as the possibility to tap high-carbon steel from the LD (BOF) converter (thus enabling a shorter blowing and tap-to-tap time), lower iron oxide content in the slag at the end of the blow phase (higher iron yield) as well as converter tapping at lower temperatures are also possible when an RH-TCOB plant is installed downstream of the converter.

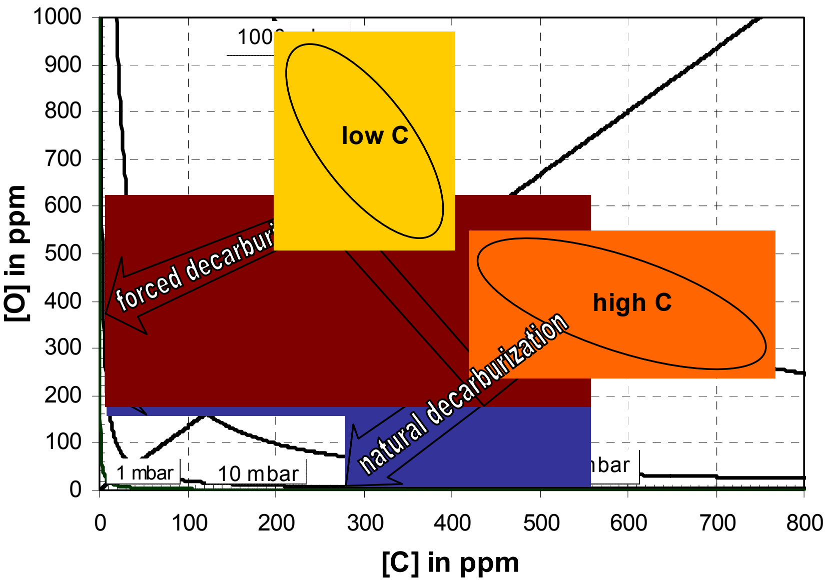


Figure 1: Decarburization in an RH Vessel

The decarburization reaction occurring during treatment in an RH vessel is given by the following first order reaction rate:

$$\frac{dC}{dt} = -k_c \cdot (C - C_{eq})$$

The kinetic constant rate (k_c) can be predicted using following equation:[5]

$$k_c = \frac{Q}{V} \cdot \frac{ak}{Q + ak}$$

The circulation rate of molten steel is estimated by:[6]

$$Q = 1.63\, G^{1/3}\, D^{4/3} \left(\ln\left(\frac{P_{at}}{P_{vac}} \right) \right)^{1/3}$$

Whereas
k_c = Decarburization rate constant (1/min)
C_{eq} = Carbon content (%) in the molten steel at equilibrium
V = Total volume of molten steel (m^3)
Q = Circulation rate of molten steel (m^3/min)
G = Lift gas flow rate (Nl/min)
D = Snorkel diameter (m)
p_{at} = Atmospheric pressure (mbar)
p_{vac} = Vacuum pressure (mbar)
ak = Volumetric coefficient for decarburization reaction (m^3/min), proportional to cross sectional area of vacuum vessel.

According to the above equations, the decarburization rate can be enhanced by increasing the vessel and snorkel diameters of an RH plant as well as by increasing the flow rate of the lift gas (e.g., argon) to ensure a high circulation rate of the molten steel. The contribution of SIEMENS VAI Metals Technologies towards significantly reducing the treatment time of the RH process by increasing the vessel and snorkel diameter of an RH plant by a factor of 1.4 to 1.6 can be seen in Figure 2.

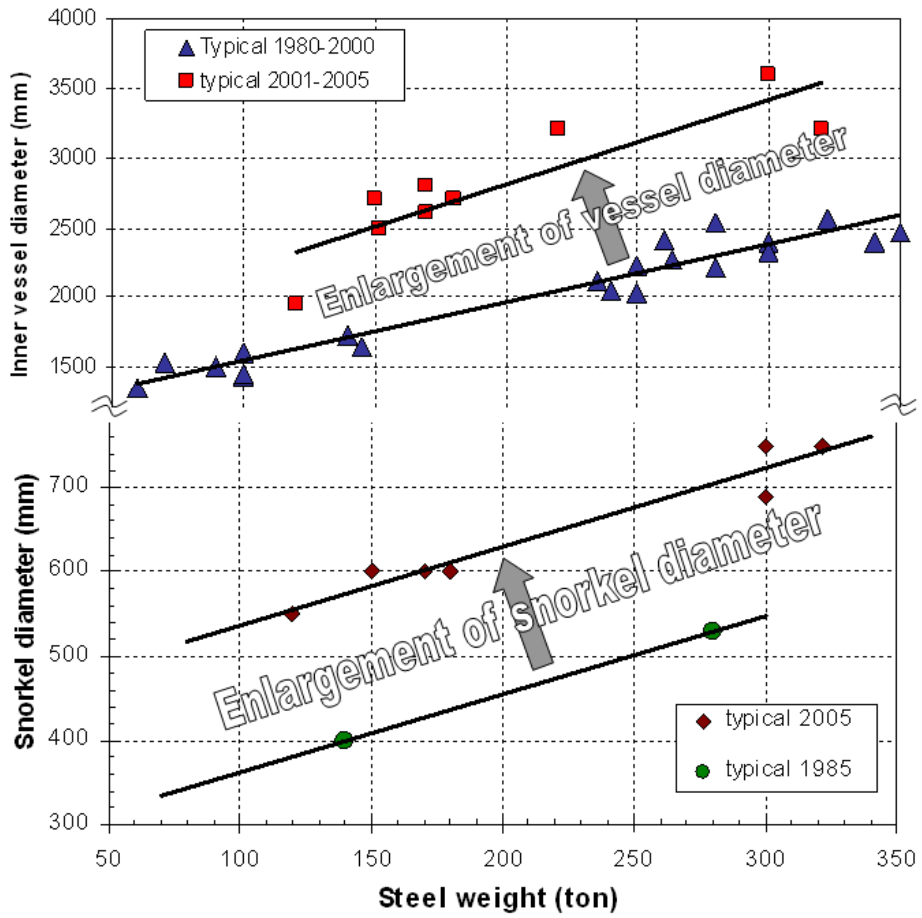


Figure 2: Increased Capacity of RH Plants through the Enlargement of the Vessel and Snorkel Diameters

Through the continuous improvements in the design of RH vessels and vacuum pumps, a faster decarburization rate and a lower carbon content at the end of RH treatment has been achieved. A comparison of decarburization rate curves for the new and old designs is seen in Figure 3. Consequently, a carbon content of 15 ppm is possible in 15 minutes with the new design, compared to 30 ppm in 20 minutes with the old design. However, the future target will be 10 ppm carbon content after decarburization.

Denitrogenation and Dehydrogenation

The nitrogen and hydrogen contents at equilibrium in steel melt can be estimated using the following equation:[7]

- Denitrogenation:

  $(N) = \frac{1}{2}\{N_2\}$

  $(\%N) = 0.045\ p_{N_2}^{0.5}$ (at T = 1600°C)

- Dehydrogenation

  $(H) = \frac{1}{2}\{H_2\}$

  $(\%H) = 0.0025\ p_{H_2}^{0.5}$ (at T = 1600°C)

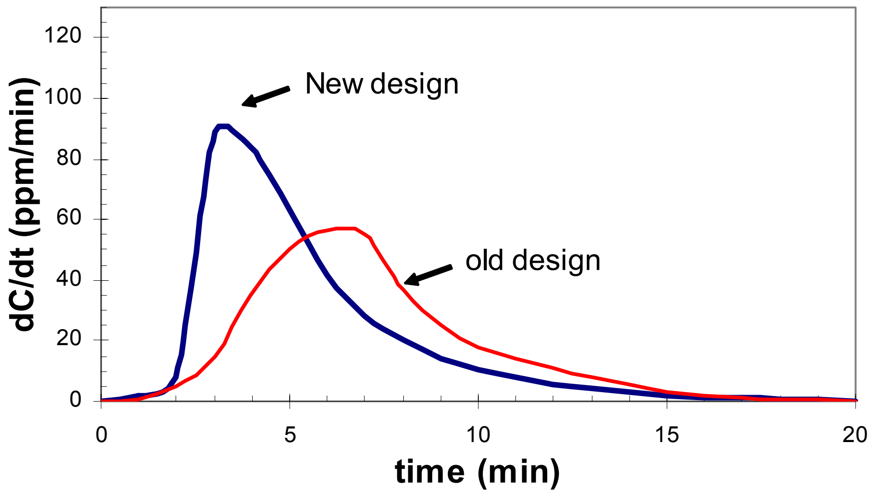


Figure 3: Decarburization Rate of New and Old RH Plant Designs

Both of the above equilibrium equations are plotted in Figure 4 whereas the hydrogen can be reduced more easily than nitrogen. The partial pressure of hydrogen and nitrogen is reduced due to the blowing of argon through the melt or due to the development of CO gas as a result of decarburization. In practice, the equilibrium contents of nitrogen and hydrogen will not be reached due to reaction kinetics.

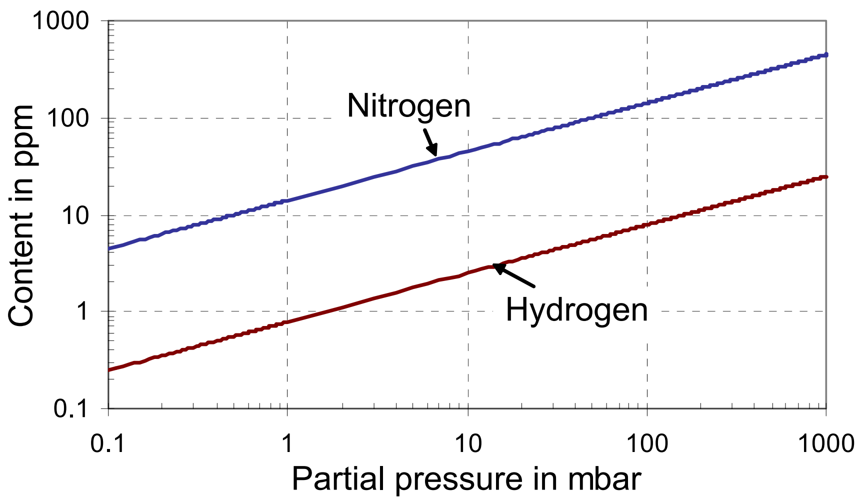


Figure 4: Hydrogen and Nitrogen Contents Under Equilibrium Conditions

Typical trends of nitrogen and hydrogen contents during RH treatment are shown in Figure 5 and Figure 6 respectively.8 At the end of the converter process, the nitrogen content is relatively low (20–30 ppm) due to development of CO gas, which purges out the nitrogen from the liquid steel. A high carbon content is desired for denitrogenation because of the increasing nitrogen activity in the melt.

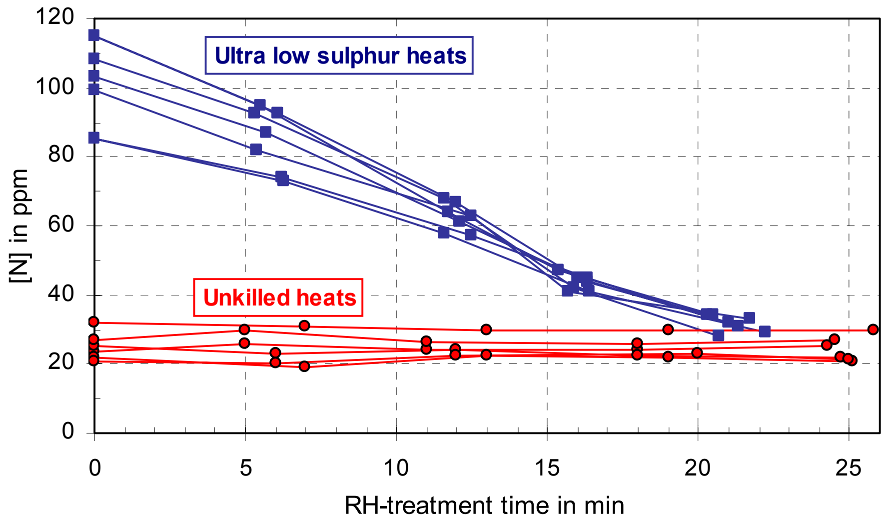


Figure 5: Trend of the Nitrogen Content in the Steel Melt During RH Treatment[8]

For ultra-low sulfur heats, some alloying agents are added which cause nitrogen pick-up in the steel melt. However, at the end of RH treatment, a nitrogen content of less than 40 ppm can be achieved due to the lower oxygen and sulfur contents in the steel (Figure 5). Sulfur and dissolved oxygen are surface-active elements which prevent absorption and desorption of nitrogen.

As explained above, the final hydrogen content in the steel at the end of RH treatment depends on the pressure within the vacuum vessel, the steel-circulation rate, driven by the lift gas, and the CO gas development. At higher initial hydrogen contents, the drop in the hydrogen content is greater (Figure 6). This phenomenon is due to the fact that for high hydrogen contents there is a high difference between the hydrogen partial pressure in the steel bath and the vacuum atmosphere of the RH vessel. If this difference is high, a faster reaction towards the equilibrium will result, which enhances hydrogen removal.

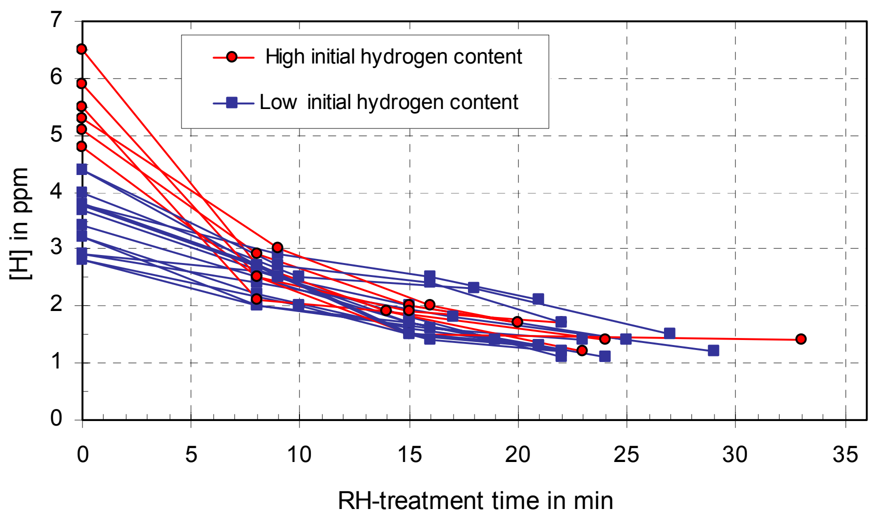


Figure 6: Trend of the Hydrogen Content in the Steel Melt During RH Treatment8

Total oxygen

As the demand for high-quality steel increases, liquid steel cleanliness is becoming increasingly important as well. The total oxygen content, which can form oxide inclusions, is usually used as an indicator whether the steel is clean or not. A low total oxygen content in the liquid steel is desired because the size of the inclusions becomes smaller. The application of RH plants can improve steel cleanliness because it promotes inclusion growth and removal.[8] Moreover, the RH degasser can decrease the required consumption of aluminum for deoxidation so that the formation of aluminum oxide inclusions can be minimized. At the same time the consumption of aluminum for steel alloying can also be reduced.

TWIN-STATION RH PLANT DESIGN

The reduction of the required treatment time in an RH vessel and several steps to improve the productivity of this unit were reviewed up until now from the metallurgical point of view. In this section the reduction of the production time of RH plants through construction-design improvements is discussed. The introduction of twin-station RH plants in combination with a quick-exchange vessel design offers new perspectives for increasing the output of treated steel at minimized costs. The waiting time for vacuum pump operation can be eliminated with the installation of a second RH treatment station.

Plant description

To ensure an optimum coordination of vessel exchange, vessel preheating and relining work in a twin-station RH plant, at least five to six quick-exchange vessels are normally supplied. Two of the vessels are installed at the two treatment stations to perform the metallurgical work, two of the vessels are placed in the stand-by position as quick-exchange units where they undergo preheating with a burner so that they can immediately replace an operating vessel in case of failure, and one to two vessel is either being relined or undergoing preheating in preparation for the process.

A twin-station RH plant consists of two treatment stations connected to one vacuum pump and one common alloying system (Figure 7). Each treatment station is equipped with one hydraulic ladle-car-lifting stand. In order to observe the ladle car lifting and lowering procedure, one operator station for each lifting stand is built close to the control room with a view of the snorkel-immersion area.

One multifunctional T-COB lances is installed at each treatment station. This fulfills the tasks of oxygen blowing for forced decarburization and chemical heating, oxygen and gas injection for vessel-refractory heating, and the removal of skull following RH treatment. The lance head and its position for decarburization, heating and deskulling is depicted in Figure 8. The lance can be outfitted with a camera to observe the steel circulation, alloying additions during treatment, the flame development during burner function for safety reasons, as well as for refractory inspection. Moreover, a pyrometer can be installed inside the vessel for temperature measurements to avoid damage to the refractories and for the continuous measurement of the steel temperature.

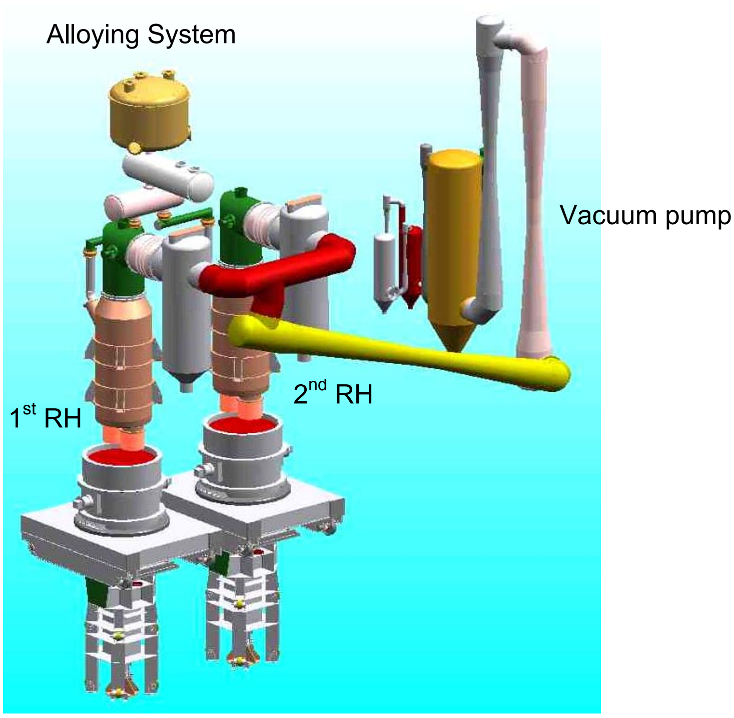
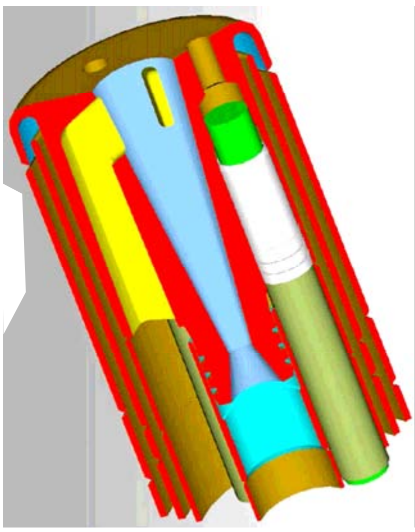
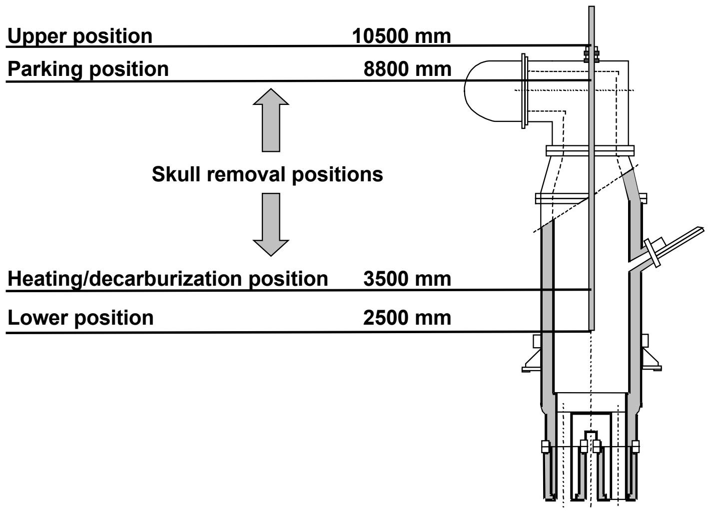


Figure 7: Schematic Layout of a Twin-Station RH Plant

In order to effectively and quickly carry out snorkel maintenance the plant has a separate service car equipped with an integrated gunning machine. The service car can be positioned directly below the RH vessel at the treatment station. Snorkel deskulling is generally executed every five to eight heats.



a. T-COB lance



b. Lance positions of T-COB lance

Figure 8: Design of the T-COB Lance

Vessel exchange

Quick-exchange vessels are a standard feature in the new twin-station RH plant design. To facilitate the vessel exchange using the shop crane, each RH vessel is mounted in a vessel-transfer car. During vessel exchange the vessel transfer car moves to the vessel-exchange position after lifting the top of the vacuum vessel. The shop crane places the vessel into a maintenance stand at the relining area and takes the new preheated vessel directly back to the vessel-transfer car. After placing the vessel onto the vessel-transfer car, the utility connections (argon, bottom cooling air, thermocouple, etc.) to the vessel are carried out by means of quick couplings. The vessel-transfer car then moves the vessel into the treatment position and the T-COB lance heats the refractories to the necessary temperature for degassing operations. A vessel change is completed within one hour in comparison with about 12 hours required for a conventional replacement system. A typical vessel exchange sequence is shown in Table 1. This short time supports a high availability of the RH vessel to ensure a continuous steel production.

Table 1: Vessel Exchange Sequence

Activities	**Time in Minutes**
Vessel car moves to stand-by position	
Disconnection of utilities	
Lifting and transfer of existing vessel	
Transport of new preheated vessel	
Reconnection of utilities	
Vessel car moves to transfer position	
Total Time	**44**

Figure 9 shows an example of the treatment time in a twin-station RH plant. The treatment time in the first RH vessel starts with the transfer of a ladle to the RH treatment station. After a sample is taken, the snorkel is immersed into the steel bath. During these steps, the vacuum pump is still in operation at the second vessel to complete its metallurgical tasks there. After the completion of vacuum treatment at the second vessel, the vacuum pump is immediately switched to the first vessel for evacuation and to conduct decarburization and degassing of the first vessel. In the second vessel, the ladle is lowered and transferred to the lift position. This is followed by maintenance of the snorkel in the second vessel until the next ladle comes for treatment. Otherwise, this phase could be used to remove skull in the vessel or to hold the temperature until the next heat. After the completion of the vacuum decarburization and degassing processes in the first vessel, the vacuum pump is again switched to the second vessel. The treatment station of the first vessel is now ready for the next heat.
With the implementation of a twin-station RH plant, the number of heats treated per day can be significantly increased. Figure 10 shows a comparison of the daily number of heats that can be treated in single- and twin-station RH plants, which is clearly greater in the latter. Roughly 40 heats and more per day are possible. This means that with the use of a single vacuum pump, the capacity of an RH plant can be increased by a factor of 1.2 to 1.4, depending on the steel grade. To optimize the

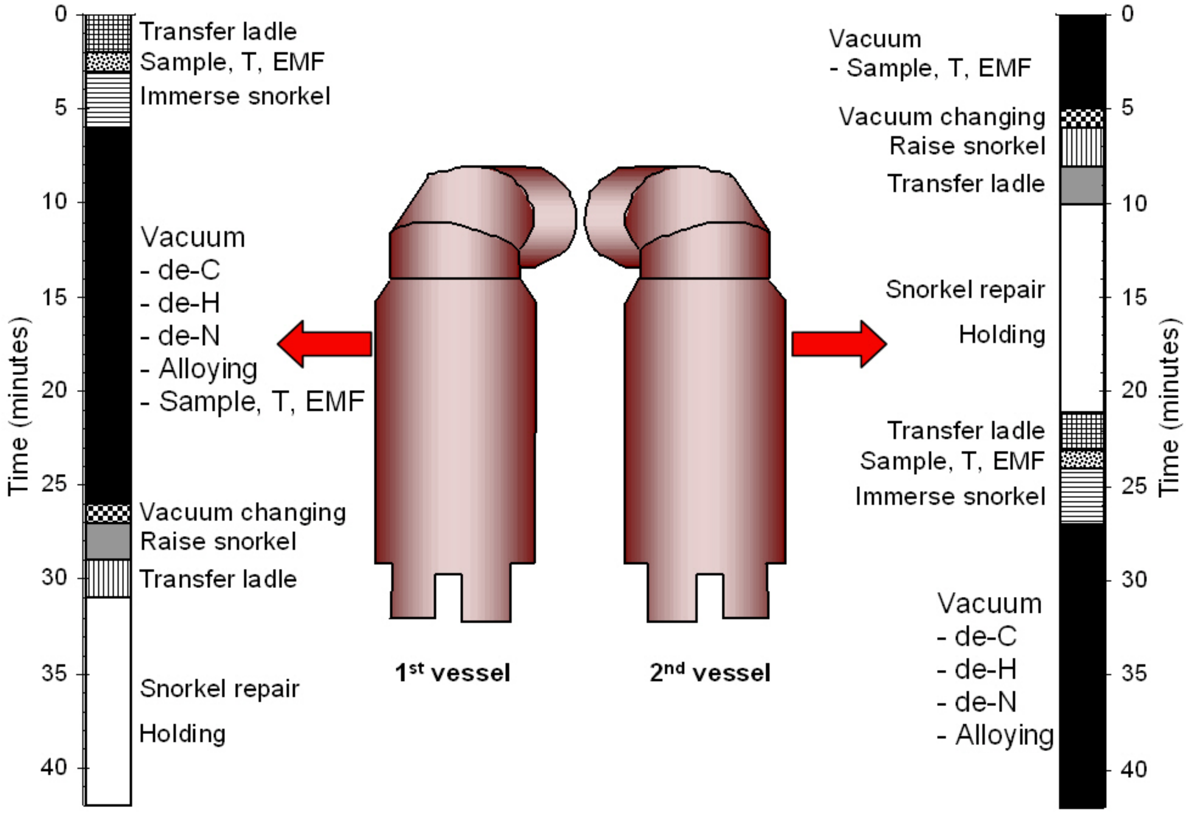


Figure 9: Typical Cycle of a Twin-Station RH Plant

operation of a twin-station RH plant, it is again the task of the metallurgist to shorten the decarburization and degassing times.

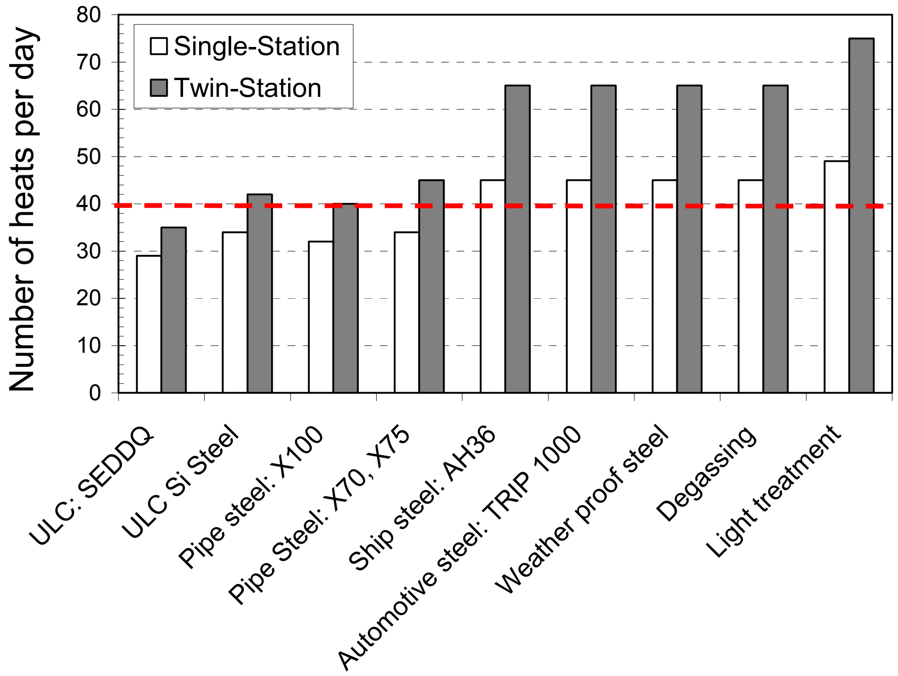


Figure 10: Comparison of the Daily Number of Treatable Heats in Single- and Twin-Station RH Plants

SUMMARY

The quality and quantity of steel treated in an RH vessel can be enhanced through the optimization of the metallurgical reactions occurring during vacuum treatment and with an improvement in the equipment design and plant layout to reduce production-time losses. The enlargement of the diameter of the snorkel and vessel contribute to an accelerated reaction rate inside the vessel and to an increase in the overall productivity of an RH plant. With the introduction of twin-station RH plants in connection with a quick vessel-exchange design, the loss of production time due to ladle transfer, vessel exchange and snorkel maintenance can be significantly reduced. As outlined in this paper, the production rate of a plant of this type can be increased by a factor of 1.2 to 1.4, depending on the steel grades to be treated. More than 40 heats per day are possible with the application of a twin-station RH plant.

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