ADVANCED RH TECHNOLOGY[1]

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Abstract

Vacuum degassing gains growing importance in the modern steelmaking industry mainly because of the increasing demand for cold-rolled sheet with improved mechanical properties. The dominating vacuum degassing system is the RH (Ruhrstahl Heraeus) degasser. Vacuum degassing by means of the RH process is mainly used for the production of ultra-low carbon steels. In the past steel shops have installed new RH facilities or they revamped existing plants. Now, they are facing the task of increasing the productivity and the quality of the steel at the same time. There are three important approaches to achieve these targets. The first one is to analyse and to introduce new practices in order to simplify treatment patterns. The second approach is to develop various models to support the operators throughout the treatment. The third approach, which is subject of this paper, is to improve the hardware such as the vacuum system and/or the geometric parameters. Since 2000 SMS Mevac GmbH has received more than 30 contracts for erection of new RH units or revamping of existing ones.

Keywords: RH process; Vessel design; Decarburisation; Steel circulation; Splash control.

TECNOLOGIA RH AVANÇADA

Resumo

O Sistema de Desgaseificação a Vácuo ganha importância crescente na moderna indústria de fabricação do aço principalmente devido à crescente demanda por chapas laminadas a frio com propriedades mecânicas melhoradas. O Sistema de Desgaseificação a Vácuo dominante é o desgaseificador RH (Ruhrstahl Heraeus). A desgaseificação por meio do processo RH é utilizada principalmente para produção de aços com ultra-baixo teor de carbono. No passado as Aciarias instalaram plantas RH novas ou reformaram plantas existentes. Agora elas estão sob o desafio de aumento contínuo de produtividade e de qualidade do aço, simultaneamente. Existem três diferentes enfoques para atingir estes objetivos. O primeiro é analisar e introduzir novas práticas com a finalidade de simplificar os padrões de tratamento. O Segundo enfoque é desenvolver vários modelos para dar suporte aos operadores durante o tratamento. O terceiro enfoque, que é objetivo deste trabalho, é melhorar o equipamento em itens tais quais o sistema de vácuo e/ou os parâmetros geométricos. Desde 2000 a SMS Mevac GmbH foi contemplada com mais de 30 contratos para fornecimento de novas unidades RH ou reforma de unidades existentes.

Palavras-chave: Processo RH; Desenho do vaso; Descarburação; Desgaseificação a vácuo; Controle de projeção.

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1 INTRODUCTION

In secondary metallurgical refining operations the RH process is used to decarburise liquid steel in order to achieve ultra-low Carbon contents below 30 ppm in the final product. The mechanism of a vacuum treatment of liquid steel via the RH circulation process is shown in Figure 1. The unit mainly consists of a refractory lined reaction vessel and two steel pipes attached to the bottom of this vessel. These are called ''*inlet snorkel*'' and ''*outlet snorkel*''. Both of them are completely refractory lined from inside and in the lower part also from 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 specific weight of liquid steel is assumed as 6.94 t/m^3 at 1600°C. The atmospheric pressure exerted on the ladle surface, causes the steel in the snorkels to rise to a barometric height of approximately 1.43 m under deep vacuum conditions.
The demand for high-quality steels with excellent press formability, such as interstitial free steels has resulted in the stringent requirement that the amounts of carbon and nitrogen in steel are strictly limited. To produce such steels, advanced vacuum degassers are world-wide required. The main improvements include the use of large snorkels, the increase of the flow rate of circulating gas and the use of vacuum pump systems with high performance.
In recent years numerous steel plants have installed new RH facilities and/or revamped their existing installations.

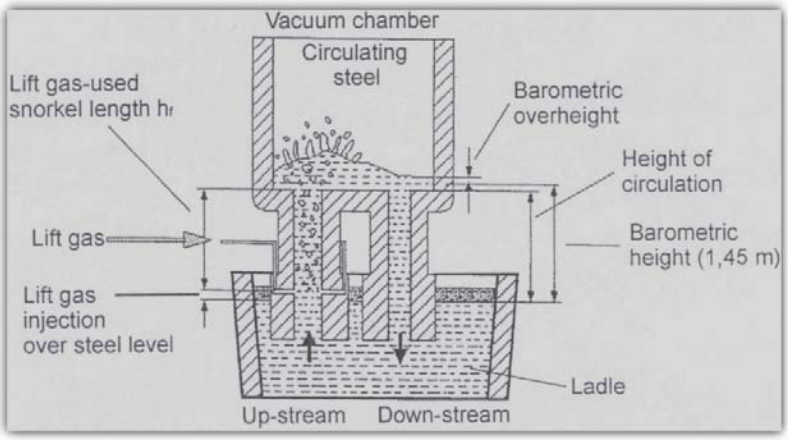

Figure 1: Schematic view of the reaction area of the RH process.[1]

2 LIFT GAS, SNORKEL GEOMETRY AND STEEL CIRCULATION

As the RH process is based on the exchange of molten steel between the ladle (atmospheric part of the reaction unit) and the RH vessel (the evacuated part of the unit), the rate of steel circulation determines the velocity of the metallurgical reactions and the duration of the process assuming a defined metallurgical target. It is generally accepted that the decarburisation rate increases as the circulation flow rate increases.[2] Melt circulation depends upon the shape of the equipment such as

snorkel diameter, the radius of the equipment, the position and number of nozzles. It also depends on the operating conditions such as the vacuum pressure.
In order to clarify the different process parameters of the RH process, a lot of different model tests had been executed in the past, mainly by means of water. Other tests were made with Wood's metal because of the low melting point at 70 °C and due to the fact that the specific weight is similar to that of liquid steel.
Figure 2 shows first results about the circulation speed as a function of the specific lift gas rate. The diagram indicates a parabolic relation between the circulation speed and the lift gas rate. Later some trials had been performed at full-scale RH units by means of radioactive tracers (dots in Figure 2), showing similar values. Also the results of further investigations illustrated in Figure 3 are corresponding with the data in Figure 2.
A significant influence on the circulation is given only in a range of a lower circulation gas flow. With increased gas flow rates the slope of the illustrated functional relation decreases. This is caused by an overlapping of each plume, which is formed by the gas blown at each nozzle.

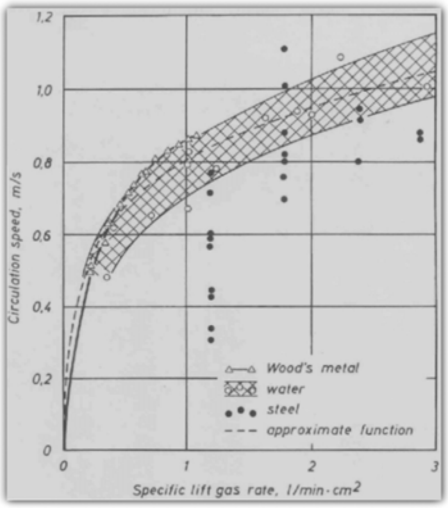

Figure 2: Circulation speed vs. lift gas rate.[1]

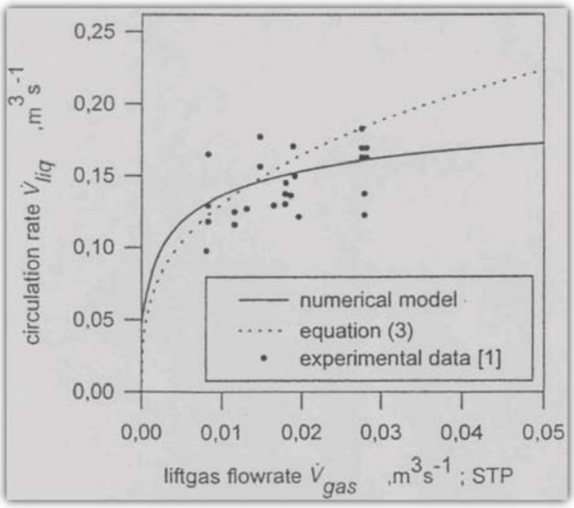

Figure 3: Circulation speed vs. lift gas rate.[3]

For RH plants applied to higher ladle capacities the size of the inner diameter on the circulation rate becomes more and more important. Figure 4 shows the influence of snorkel inner diameter on the steel circulation rate. The curves are based on the following process parameters:

- Circulation gas flow rate 1,000 … 4,000 Nl/min
- Level of lift gas injection below vessel bottom 1,200 mm
- Operation pressure in the RH vessel 0.67 mbar

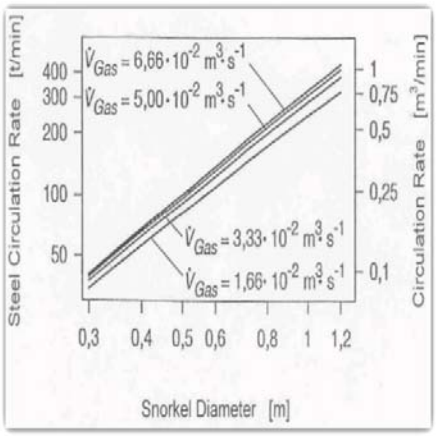

Figure 4: Influence of snorkel diameter on the steel circulation rate [4]

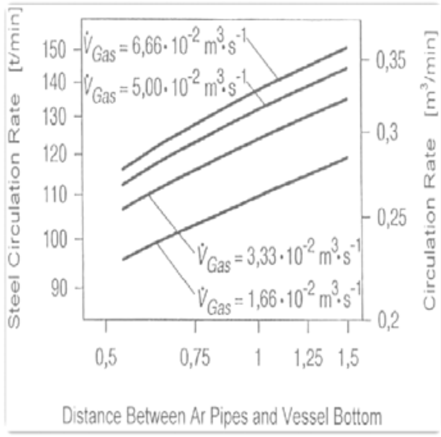

Figure 5:Influence of the position of Argon nozzles on the steel circulation rate [5]

The circulation rate increases significantly with increasing snorkel diameters. The influence of circulation gas flow values higher than 180 Nm³/h is comparatively low and can be neglected. Increased circulation gas flow rates on the same snorkel diameter show a parabolic influence on the steel circulation. In order to ensure high circulation rates of liquid steel, the lift gas amount must be increased with enlarged inner diameter of the inlet snorkel.
The location of circulation gas injection into the liquid steel is shown in Figure 5. The circulation rate increases with increasing distance between the injection level and the refractory lined bottom of the RH vessel. The results are based on the following process parameters:

- Circulation gas flow rate 1,000 … 4,000 Nl/min
- Inner snorkel diameter 600 mm
- Operation pressure in the vessel 0.67 mbar

3 CALCULATION OF STEEL CIRCULATION

First simple functional relations between steel circulation rate, snorkel inner diameter and argon flow rate were published from 1963 to 1965.
In 1971 Hupfer et al.[6] tried to describe the influence of geometrical factors of the snorkel design on the steel circulation rate. The calculation formulas developed by Kuwabara,[7] Lutz [8] or Kleimt [9] consider beside the above mentioned characteristics the effect of the operation pressure (vacuum) on the steel circulation. Table 2 contains some of these formulas.
The empirically derived formula (*Eq. 1*) for determination of steel circulation rate, defined by Ono et al.[10] considers the so-called "plume zone" (H), the distance between point of lift gas injection and refractory lined vessel bottom.

$$\mathrm{U} = 3.8 \cdot 10^{-3} \cdot D_u^{0.3} \cdot D_d^{1.1} \cdot G^{0.31} \cdot H^{0.5} \qquad \text{(Eq. 1)}$$

with:

- U Steel circulation rate t/min
- D_u Diameter of the up-snorkel cm
- D_d Diameter of the down-snorkel cm
- G The flow rate of lift gas Nl/min
- H The length of snorkel used by the lift gas (plume zone height) cm

The parameter H - the "plume zone height" – has been evaluated several times by users of the Ono formula. It is defined as the length of the inlet snorkel used by the lift gas (see also Figure 1). With increased “H”-value the velocity of the up-stream in the inlet snorkel will be increased too i. e. also the steel circulation rate is increased, as shown also in Figure 5.

Equation (1) allocates the strongest influence to the snorkel inner diameter. Up to a specific rate of lift gas flow of 0.5 Nl / (min·cm^2) the up-stream speed in the snorkel rises proportionally. Up to approx. 1.0 Nl / (min·cm^2) the increase is sub-proportional and above this value the speed-up rate develops asymptotic and approaches to a maximum.

The circulation rate within the RH vessel has been modelled extensively and it has been shown that another key factor affecting the circulation rate is the correct relationship between the number of Argon tuyeres in the up-leg, the inner diameter of the snorkels and the lift gas flow rate.

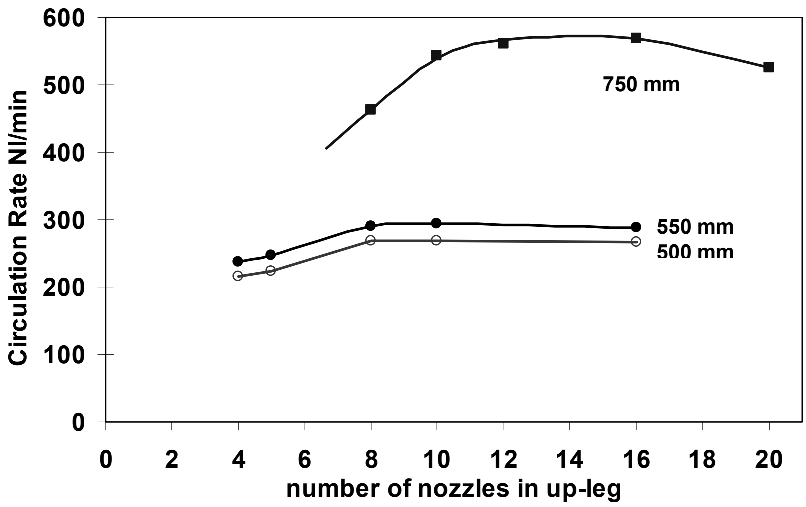

Figure 6: Number of nozzles vs. circulation rate

It has also been shown that too many tuyeres will result in a decrease of the steel circulation rate. Similarly, when the Argon flow rate in the tuyeres is increased, a peak flow was found, beyond which there is a sudden reduction in circulation rate, see Figure 6.[13]

4 RECOMMENDED PARAMETER RELATIONS FOR ADVANCED RH SNORKEL DESIGN

The above described theoretical investigations are of course considered for the engineering and design of SMS MEVAC’s new RH units. SMS MEVAC’s recommendation for an optimised relation between the ladle capacity and process related lift gas rates is shown in the Figures 7 to 8. These figures demonstrate layout data of existing RH units, respectively of those which are under construction. In general it must be considered, that sometimes an optimized design can not be realised because of some limitations by ladle dimensions or other technical or economic restrictions.

Figure 7 deals with the relation between the ladle capacity of a steel plant and the required inner diameter of the inlet and outlet snorkel of its RH unit. The typical ladle capacity for RH facilities is between 100 and 320 t. But there are also exceptions with smaller and bigger ladle contents. The respective snorkel diameters are usually in the range between 400 and 750 mm. Smaller snorkel diameters result from some of the a.m. limitations. Snorkel diameters above 750 mm are unusual because of economic reasons.

In Figure 8 the recommended lift gas flow rates are set in relation to the respective inlet snorkel diameter for different metallurgical process situations. The highest flow rates are usually applied for degassing treatments of fully killed heats but also for chemical and thermal homogenisation. The decarburisation process is separated in two stages: The main decarburisation step during the first half of the treatment and the final decarburisation. For both stages different lift gas flow rates are recommended.

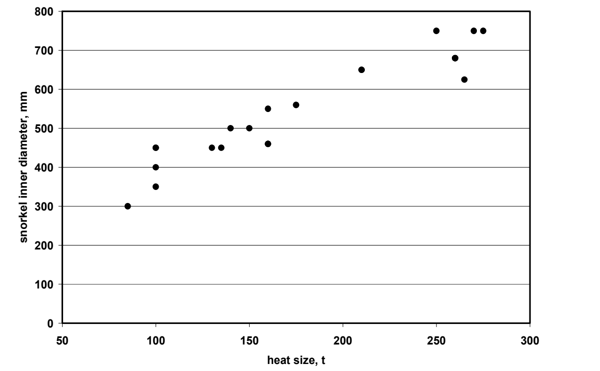

Figure 7: Snorkel inner diameter vs. heat size

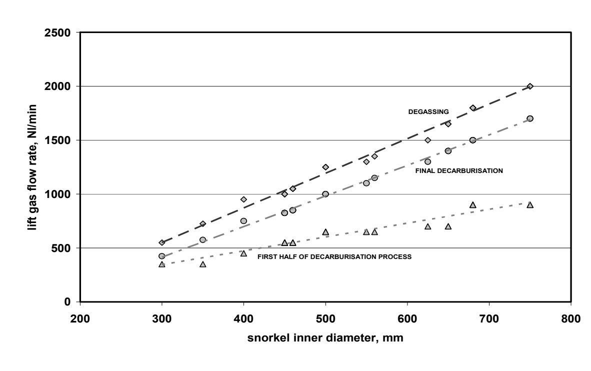

Figure 8: Lift gas flow vs. snorkel inner diameter

5 PROCESS OPTIMISED DESIGN OF VACUUM PUMP SYSTEMS

In order to attain shortest treatment times it is essential to design a vacuum pump with suction capacities which match the pump down requirements considering the generation of exhaust gas due to intensive CO gas reaction, especially when blowing oxygen by means of the top lance.

Most RH vacuum systems consist of an arrangement of steam ejectors mounted in series with steam condensers. In some plants, where steam availability is limited, the steam ejectors are supplemented by mechanical pumps – water-ring pumps.

The performance of the vacuum systems is designed based upon the capacity of the ladle and the chemistry of the steel to be degassed. Considering high initial Carbon contents of more than 0.04 %, for producing ULC grades the vacuum system is generally designed to have a large mass flow capacity at the middle vacuum range between approximately 60 and 200 mbar. Typical pumping performance curves for a 280 t RH TOP plant are given in Figure 9. The plant had been commissioned in 2005 by SMS Mevac.

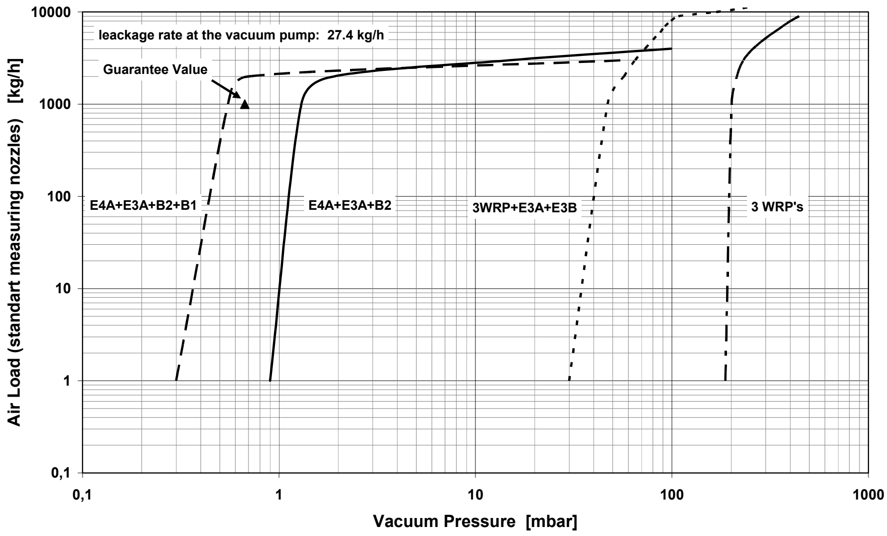

Figure 9: Typical pumping down performance curve – 280 t RH TOP

For the production of ULC steels, the decarburisation stage needs an essential part of the entire vacuum process and should be limited to 15 minutes. In order to reach Carbon contents of less than 15 ppm during this period the installed vacuum capacity should enable a pump down period of maximum 7 minutes to reach a vacuum pressure of less than 2 mbar. Typical pump down curves of the above mentioned RH TOP plant is shown Figure 10.

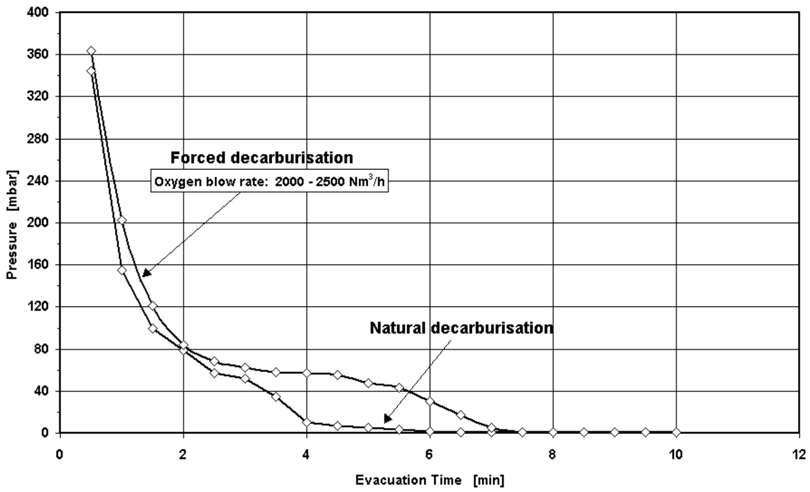

Figure 10: Pump down behaviour for decarburisation processes – pre-evacuated vacuum system

The latest vacuum pump systems now incorporate a number of ''Add-ons'' to improve performance, reliability and economy. These are variable steam nozzles to optimise steam usage and vacuum control to a specific set point. Current pump systems are able to rapidly reduce the pressure in the degasser already in an early stage of the treatment. In case of a decarburisation treatment such a rapid pump-down is not always desired because it leads to a very intensive formation of CO inside the vacuum vessel. The intensive reaction of the CO formation then initiates an uncontrolled splashing of melt inside the vessel. Assuming the worst case liquid steel can get as far as into the pump system and may lead to severe production losses.

It is surely possible to reduce the formation of skulls inside the vessel or to remove them by installing a TOP lance(14,15) and the application of such a lance is a must in a state-of-the-art RH facility. Splashing of liquid steel even into the pump system, however, can neither be avoided nor stopped by this lance.
The reason for splashing is a physical power resulting form an expansion of gas – Argon and Carbon-monoxide – developing at the interface liquid steel and gas atmosphere inside the vacuum chamber. For optimum utilisation of the suction capacity of the vacuum pump the pump-down procedure should be optimised in several steps. Strong splashing occurs when liquid steel enters the vacuum chamber and during the main decarburisation stage. Therefore, especially in a pressure range between 350 and 80 mbar the pump down procedure must be controlled. The RH vacuum units recently installed by SMS Mevac are already equipped with such a high-sophisticated pressure regulation system. Such units are called RH-SC - ***R***uhrstahl ***H***eraeus ***S***plash ***C***ontrol.

6 FUTURE DEVELOPMENTS FOR PROCESS OPTIMISATION

During the RH treatment of unkilled heats carbon monoxide is generated as a product of the decarburisation reaction. This reaction can be so intensive that portions of the melt are dashed several meters high into the upper part of the vacuum vessel. Skull formation in this area and even in the off-take duct could be the undesired result and may lead to logistic disturbances and also to a loss of quality.
The splashing of liquid steel during the vacuum process is in direct connection with the geometric design of the RH unit (vessel and snorkels), the process gases which are to be considered (carbon monoxide and argon), the change of pressure as well as the metallurgical process parameters (activity of carbon and oxygen). The understanding and consideration of these connections finally enables an optimized control of the vacuum pressure during pump-down, which on the one hand fulfils the requirements of the production process and on the other hand leads to a tailor-made design of the vacuum system.
The problem to develop an optimized pump-down control is the “in situ” measurement of the decarburisation speed. The measurement of the waste gas composition has always a certain time shift depending on the measuring device. Generally a decarburisation treatment runs acc. to a unique scheme. At the beginning of the treatment, in the main decarburisation stage, there is a very intensive reaction, resulting from a high decarburisation speed. After some minutes this speed slows down remarkably. During the second half of the treatment, the so called final decarburisation stage, the decarburisation speed is quite low and nearly no splashing occurs anymore.
SMS MEVAC is currently working on a measuring device which enables a quantitative measurement of the above only qualitatively described development of the decarburisation reaction. This could be realized by recording the quantity of splashing. The final target is to control the pressure reduction in a way that the splashing height does not exceed a certain maximum value but is fast enough to ensure an optimized decarburisation time. In future this can enable an adjustment of the process development to a given vessel design to ensure a save production and a sufficient availability of the RH unit.
To realize this several preconditions must be fulfilled:

- The splashing must be measured as a quantitative amount
- The measured result must be modified so to create a continuously available process parameter
- Based on this process parameter the several controlled variables can be adjusted to achieve an optimized process development.

Table 1: MEVAC's RH units worldwide since 2000

COUNTRY	CUSTOMER	CONTRACT	PRODUCTS	TYPE	HEAT SIZE
PRC	TANSHAN	2007	Flat	Duplex	125 T
RC	DRAGON STEEL	2006	Flat	Fast vessel exchange	210 T
PRC	ANSHAN (RH #4)	2006	Flat	Fast vessel exchange	260 T
FRA	SOLLAC ARCELOR	2006	Flat	Fast vessel exchange	270 T
PRC	QSQM	2006	Flat	Duplex	100 T
PRC	HANDAN	2006	Flat	Duplex - Fast vessel exchange	250 T
RUS	OEMK (RH #3)	2006	Long	Single vessel	160 T
PRC	BEI TAI	2006	Flat	Duplex	135 T
PRC	ANSHAN (RH #3)	2006	Flat	Fast vessel exchange	260 T
SPA	ACERALIA	2005	Flat	Fast vessel exchange	290 T
ROK	SEAH BESTEEL	2005	Long	Single vessel	85 T
RUS	NTMK	2005	Flat + Long	Duplex	160 T
PRC	SHOUGANG	2005	Flat + Long	Fast vessel exchange	210 T
PRC	JYXC	2005	Long	Fast vessel exchange	100 T
PRC	ANSHAN (RH #2)	2004	Flat	Fast vessel exchange	260 T
PRC	ANSHAN HSM	2004	Flat	Fast vessel exchange	100 T
PRC	ANGANG NEW STEEL	2004	Flat	Fast vessel exchange	100 T
USA	AK STEEL	2004	Flat	Single vessel	175 T
RUS	OEMK (RH #1)	2004	Long	Single vessel	160 T
RC	CHINA STEEL (RH #4)	2004	Flat	Single vessel	260 T
RC	CHINA STEEL (RH #2)	2004	Flat	Fast vessel exchange	260 T
ROK	POSCO (RH #5)	2004	Flat	Fast vessel exchange	275 T
PRC	BENXI	2004	Flat	Duplex - Fast vessel exchange	150 T
PRC	ANSHAN (RH #2)	2004	Flat	Fast vessel exchange	175 T
MEX	IMEXSA	2003	Flat	Single vessel	220 T
PRC	ANSHAN (RH #1)	2003	Flat	Fast vessel exchange	260 T
ITA	RIVA ILVA S.P.A	2003	Flat	Fast vessel exchange	350 T
IND	TISCO	2003	Flat	Single vessel	140 T
RUS	OEMK (RH #2)	2003	Long	Single vessel	160 T
RC	CHINA STEEL (RH #3)	2002	Flat + Long	Single vessel	160 T
PRC	PANZHIHUA	2001	Long	Fast vessel exchange	130 T
BEL	COCKERILL SAMBRE	2000	Flat	Single vessel	200 T
GER	TKS BEECKERW. (RH #2)	2000	Flat	Fast vessel exchange	265 T

Table 2: Selected calculation formulas for estimation of steel circulation rate

Author	Year	Calculation formula for circulation rate in t/min
H. Watanabe et al: *(11, 12)*	1968	**$U = 0.02 * Q_{Ar}^{0.33} * D_S^{1.5}$** (3-1)
		D_S = snorkel diameter (cm) Q_{Ar} = Argon flow rate (Nl/min)
P. Hupfer et al.: *(6)*	1971	**$U = 4.8 * 10^{-3} + \quad + f_1 + f_2 + f_3 + Q_t^{0.25} + A_S$** (3-2)
		A_S = snorkel cross section (cm²) Q_t = Q_{Ar} * (1+(T-293) / 273) (Nl/(min*cm^2)) Q_{Ar} = specific Ar flow rate (Nl/(min*cm^2)) = density of liquid steel (kg/cm³) f_1, f_2 = geometrical factors (approx. 1) f_3 = relation of cross section of inlet and outlet snorkel $q_d = q_u$: $f_3 = 1$; $f_3 = 1+1.06 * \lg(q_d/q_u)$
T. Kuwabara et al.: *(7)*	1987	**$U = 11.4 * Q_{Ar}^{1/3} * D_S^{4/3} * (\ln(p_0/p_1))^{1/3}$** (3-3)
		D_S = snorkel diameter (cm) Q_{Ar} = Argon flow rate (Nl/min) p_0 = ambient pressure (Torr) p_1 = operating pressure RH (Torr)
Lutz, W. *(8)*	1995	**$U = 1.63 * Q_{Ar}^{1/3} * \quad * D_S^{4/3} * (\ln(p_0/p_1))^{1/3}$** (3-4)
		D_S = snorkel diameter (cm) Q_{Ar} = Argon flow rate (Nl/min) p_0 = ambient pressure (mbar) p_1 = operating pressure RH (mbar) = density of liquid steel (t/m^3)
B. Kleimt et al.: *(9)*	1996	**$U = F_U * Q_{Ar}^{1/3} * D_S^{4/3} * (\ln(p_0/p_1))^{1/3}$** (3-5)
		D_S = snorkel diameter (m) Q_{Ar} = Argon flow rate (Nm^3/min) p_0 = ambient pressure (mbar) p_1 = operating pressure RH (mbar) F_U = circulation factor (123) (t/m^3)

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