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Effect of Oxygen Blowing Parameters on the Performance of Ruhrstahl-Heraeus Refining Process

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#8 Ruhrstahl-Heraeus is the first refining facility possessing the function of pressure control at China Steel (CSC), which can be used to evaluate the optimal vessel vacuity during the period of oxygen blowing. In this study the experiments were conducted at different pressures during oxygen blowing for decarburization and temperature raising processes. It was observed that increasing vessel pressure during oxygen blowing had an adverse effect on decarburization but a high vacuum period still dominated the result of the whole reaction. After adequate treatment each RA[C] could reach a level of less than 15 ppm for a vessel pressure of 90 to 195 mbar. The pressure tests were also conducted for the operation of temperature elevation and the results showed that they all achieved the expected level. The influences of the height of the top lance were also evaluated in this study. It was found that each RA[C] could reach a level of less than 15 ppm and the performance of the temperature elevation also met the requirement for regular operation for a height of 550 to 650 cm. Accordingly, it is feasible to reduce splashing by adjusting vessel pressure and the height of the top lance depending on the situation so as to mitigate the damage to the RH facility.

Keywords: Ruhrstahl-Heraeus (RH), Vacuity, Oxygen blowing

1. INTRODUCTION

Due to the increasing demand for ultra low-carbon steel the Ruhrstahl-Heraeus (RH) process plays a very important role in the refining process to reduce the carbon content in liquid steel. Studies of the decarburization mechanism and how to improve the decarburization rate in an RH degasser have received considerable attention over the years(1-5). However attention should be, paid to the corresponding effects on the whole process while decarburization proceeds. Decarburization and temperature raising processes accompanying oxygen blowing, tend to cause vigorous reaction, often leading to excessive splashing. The droplets of splashed steel may accumulate around the hot-off take and alloy gate of the RH facility so as to affect vessel vacuity and alloy addition adversely. Furthermore, the accumulated metal on the inner wall of the vessel, is a source of contamination, which may fall into the molten steel of the following heats. Both RH performance and steel quality may deteriorate due to this heavy splashing accumulation.

The objectives of this study are to evaluate the effects of vessel pressure during the period of oxygen blowing on decarburization and temperature elevation by utilizing #8 RH, which possesses a pressure control function, so as to find the optimal vacuity to reduce splashing. Besides, the splashed steel droplets also tend to accumulate on the top lance, whose life is often reduced by adhesion of metal, so the influences of the height of the top lance are also discussed here.

2. EXPERIMENTAL METHOD

All the experiments were conducted in #8 RH, which were mainly focused on evaluating the effects of oxygen blowing parameters on decarburization and temperature raising processes. Oxygen blowing parameters discussed here were vessel pressure, namely, vacuity and the height of the top lance. For the evaluation of vessel pressure during oxygen blowing the height of the top lance was kept at 550 cm and the tests of decarburization and temperature elevation proceeded at 90, 110, 150 and 195 mbar, respectively. For the discussion of the height of the top lance the vessel pressure was kept at 90 mbar and the tests were performed at 550, 600 and 650 cm, respectively.

3. RESULTS AND DISCUSSION

3.1 Mechanism of splashing

Figure 1 is the schematic representation of how the RH process works with oxygen blowing. As the treatment starts, Ar gas is blown into the molten steel in the form of bubbles through an up leg to promote the circulation of molten steel. The CO bubbles, which form from the decarburization reaction, and Ar bubbles will inflate and float up in the molten steel. When these bubbles float to the steel surface, they will give rise to splashing, which is inevitable. However, in the early stage of decarburization, reaction of carbon and oxygen proceeds vigorously due to high carbon content and rapid pressure drop, which will aggravate splashing. If forced decarburization is conducted with oxygen blowing in the early stage, the reaction of carbon and oxygen will be further enhanced due to high oxygen content and the formation of a hot spot(6). Besides, metal elements in molten steel react with massive amounts of oxygen, which causes local over-oxidation, resulting in a lot of heat forming into a hot spot. Iron and other alloys tend to gasify at a hot spot with high temperature under high vacuity. As a result, blowing oxygen onto the molten steel under high vacuity certainly gives rise to heavy splashing due to the vigorous reaction of carbon and oxygen and gasification of the steel. Similarly, the temperature raising process, which needs to blow oxygen, also encounters this problem due to gasification of the steel. Splashing often leads to the formation of tiny steel droplets, which will accumulate around the hot off take and alloy gate of the RH facility, they even accumulate on the top lance during the process of rapid suction of the vacuum system, thus affecting the vacuity and regular production. Moreover, if the accumulated metal grows to a certain extent, it may drop off into the following heats, thus influencing the composition and quality of the steel, especially for ultra-low carbon/nitrogen steels. Accordingly, excessive splashing often happens in the early stage of decarburization, particularly for the cases with oxygen blowing.

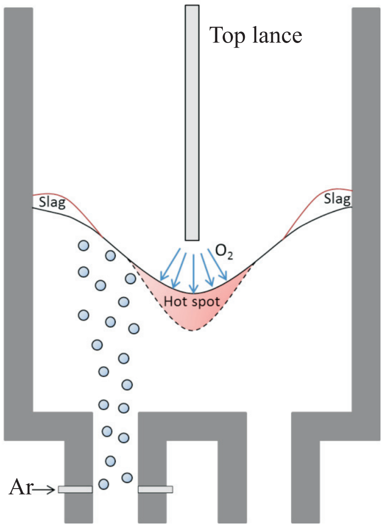


Fig.1. Schematic representation of how RH process works with oxygen blowing.

The formation of tiny steel droplets is kinetically beneficial for decarburization due to the increased surface area, but the main reaction proceeds in the molten steel in the early stage of decarburization higher concentrations of carbon and oxygen are present. Decarburization reaction on the surface of molten steel and bubbles is not dominant until the carbon content is lower than 40 ppm(7-9), that is, the effect of tiny steel droplets is less significant in the early stage of decarburization than the later one kinetically. Therefore, if the pressure can be raised appropriately during the period of oxygen blowing for forced decarburization, splashing will be alleviated due to the mitigation of a vigorous reaction and gasification at the hot spot, which should not affect decarburization obviously in terms of kinetics. Although higher pressure is also not thermodynamically beneficial for decarburization, its effect can be reduced under suitable pressure, especially in the early stage with higher carbon and oxygen content. Besides, increasing the operational pressure can decrease the pressure difference between inside and outside of the vessel, leading to a decrease in the height of the molten steel surface in the vessel, which can reduce the probability of splashing steel droplets onto the hot-off take, alloy gate and top lance.

On the other hand, it was reported that a higher ratio of the Kawasaki Top Blowing (KTB) operation, namely, temperature raising process would aggravate the adhesion of steel on the hot off take(10), meaning that oxygen blowing tended to cause vigorous splashing. Because the temperature raising process often proceeds after decarburization, the splashing mainly results from the gasification of steel at the hot spot under high vacuity instead of the reaction of carbon and oxygen.

Consequently, the oxygen blowing operations for decarburization and temperature raising processes are the main reason for heavy splashing. It is expected that splashing can be reduced by increasing vessel pressure during oxygen blowing. The work in this study is to clarify how the performances of decarburization and temperature raising processes are affected by vessel pressure during oxygen blowing, thus helping the operators to choose suitable pressure for production.

3.2 Effects of vessel pressure during oxygen blowing on decarburization and temperature raising processes

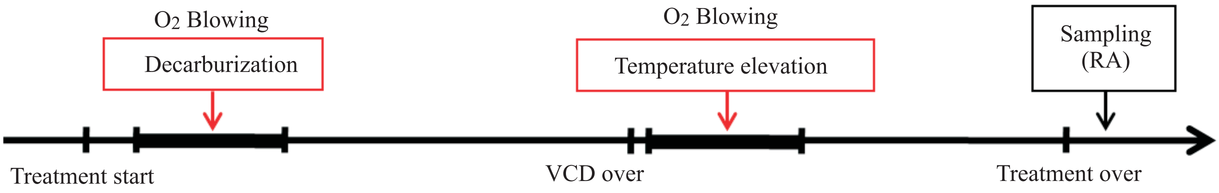


Fig.2. Procedure of RH treatment.

In order to understand the effects of vessel pressure during oxygen blowing on decarburization, the tests were conducted at 90, 110, 150 and 195 mbar during this period, respectively. The samples were taken at 1 and 12 minutes after oxygen blowing finished, respectively, which were used to calculate the rate constants of decarburization reaction K (min^{-1}) through the following equation$^{(11)}$:

$$K = \frac{1}{t} \ln \left(\frac{[C]_S}{[C]_E}\right) \quad \text{(1)}$$

where t is the total time from the beginning of oxygen blowing to the sampling time (min), $[C]_S$ is the carbon content before decarburization (ppm), and $[C]_E$ is the carbon content at sampling time (ppm). The procedure of RH treatment is as shown in Fig.2, and the variances of vessel pressure and oxygen flow rate are illustrated in Fig.3. The pressure during oxygen blowing used for past regular production was 90 mbar. The corresponding height of the molten steel surface, that is, the height difference of the molten steel surface between the inside and outside of the vessel, at each pressure is calculated and shown in Table 1. When the pressure increases from 90 to 195 mbar, the height of the molten steel surface decreases by 16 cm, which can slightly reduce the extent of steel splashing onto the hot off take and alloy gate.

The relationship between K1 and pressure during oxygen blowing is as shown in Fig.4. K1 is the K value calculated from the beginning of oxygen blowing to the time 1 minute after oxygen blowing finished, which can describe the decarburization rate during the period of oxygen blowing. It was observed that K1 decreased with the increase of pressure during oxygen blowing, revealing that increasing pressure was not beneficial for decarburization for this period. The relationship between K12 and pressure during oxygen blowing is as shown in Fig.5. K12 is the K value calculated from the beginning of oxygen blowing to the time 12 minute after oxygen blowing finished, which can describe the decarburization rate during the whole decarburization process. It was observed that K12 only slightly decreased with the increase of pressure during oxygen blowing, revealing that increasing pressure affected the whole decarburization insignificantly. Compared to K1, although increasing pressure during oxygen blowing was not beneficial for decarburization, the treatment during

Table 1 Corresponding heights of the molten steel surface to pressures

Vessel pressure (mbar)	90	110	150	195
Height of the molten steel surface (cm)	135	132	126	119

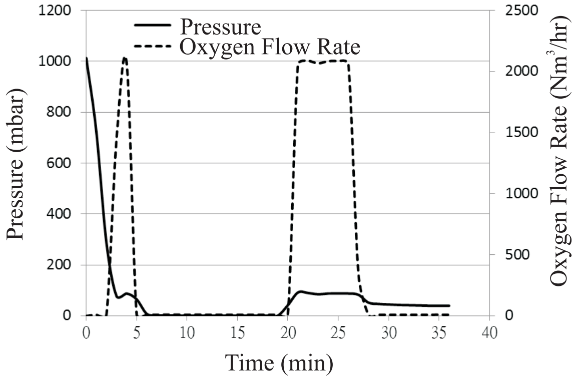


Fig.3. Variances of vessel pressure and oxygen flow rate.

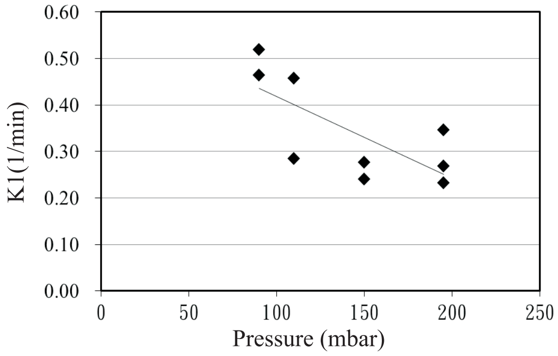


Fig.4. Relationship between K1 and pressure during oxygen blowing.

the period of high vacuity (lower than 1 mbar) after oxygen blowing was more important than that duration, namely, the latter period dominated the result of the whole decarburization process.

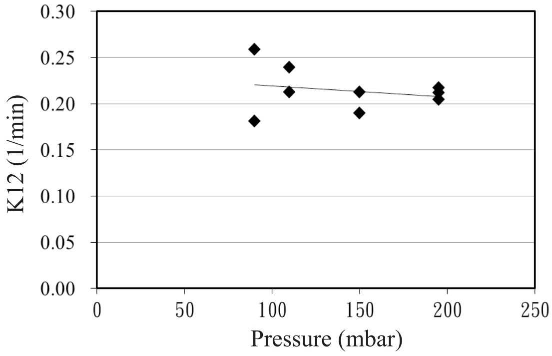


Fig.5. Relationship between K12 and pressure during oxygen blowing.

The relationship between RA[C] and pressure during oxygen blowing is as shown in Fig.6. RA[C] denotes the carbon content obtained at the end of RH treatment. It was found that RA[C] varied insignificantly with the increase of pressure during oxygen blowing, and each case showed very low carbon content. The period of high vacuity would last about 14 minutes after oxygen blowing for ultra-low carbon steel, which ensured that the carbon content could achieve a very low level and meet the requirement, revealing that a similar performance of decarburization was obtained within this pressure range. The relationships between RA[C] and as volume of blowing oxygen under 195 and 90 mbar are as shown in Fig.7, respectively. In normal cases, blowing a larger volume of oxygen needed a longer amount of time to maintain a high pressure, which was not beneficial for decarburization, but it was found in Fig.7(a) that RA[C] almost achieved a level of lower than 20 ppm for different volumes of blowing oxygen under 195 mbar. Low RA[C] would be obtained with the appropriate treatment during the period of high vacuity. Compared to 90 mbar in Fig.7(b), both of them possessed similar performance of decarburization.

The relationships between TD[N] and volume of blowing oxygen under 195 and 90 mbar are shown in Fig.8, respectively. TD[N] denotes the nitrogen content measured in the tundish, and the heats discussed here are low nitrogen steels with nitrogen content of lower than 50 ppm. It could be observed that the distributions of TD[N] were almost lower than 30 ppm for both cases, revealing that blowing oxygen at 195 mbar showed good levels of removing nitrogen similar to that at 90 mbar.

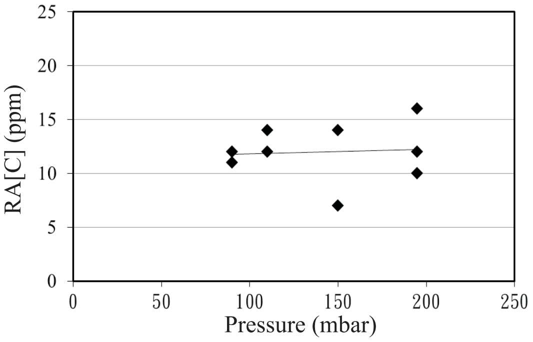
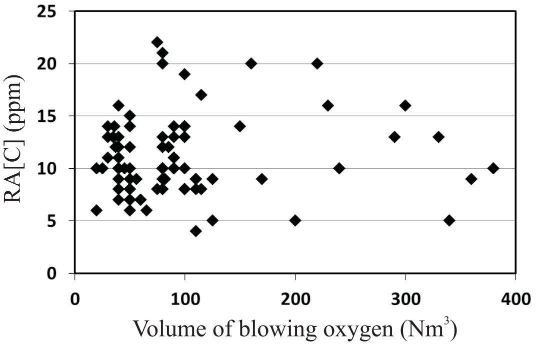
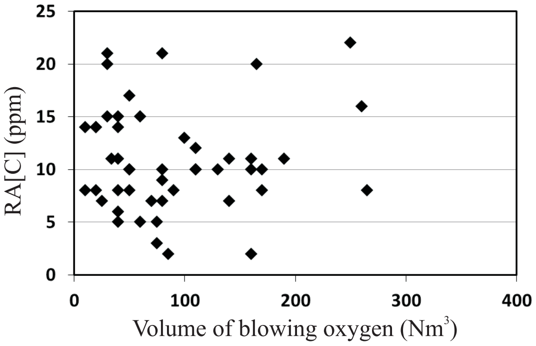


Fig.6. Relationship between RA[C] and pressure during oxygen blowing.



(a)



(b)

Fig.7. Relationships between RA[C] and volume of blowing oxygen under (a) 195 and (b) 90 mbar.

The tests for temperature raising were also conducted at 90, 150 and 195 mbar, respectively. The performance of temperature raising was judged by the difference between actual and predicted temperature. The actual temperature was measured at the time 3 minute after oxygen blowing had finished, and the predicted one was calculated by the empirical formula for the case of 90 mbar. The positive and negative values of the difference mean the performances are better and worse than expected, respectively. The relationship

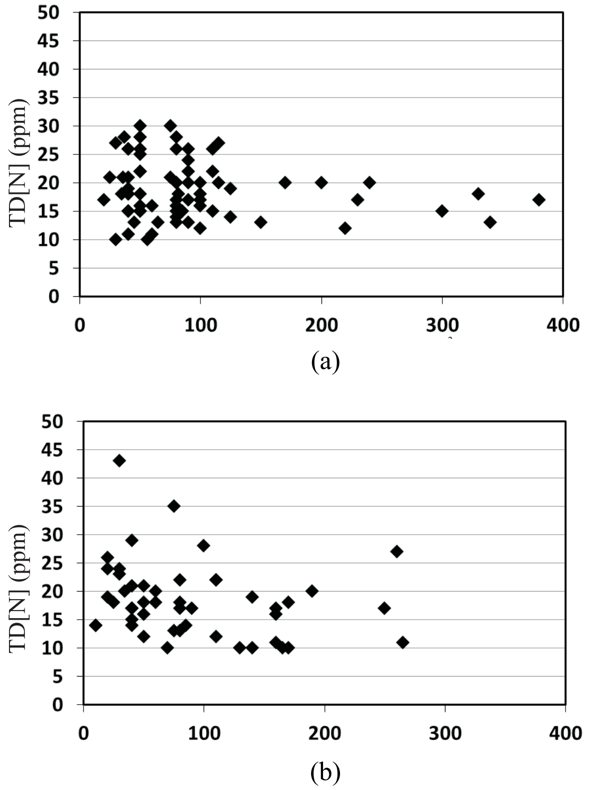


Fig.8. Relationships between TD[N] and volume of blowing oxygen (Nm^3) under (a) 195 and (b) 90 mbar.

between temperature difference and pressure during oxygen blowing is shown in Fig.9. It was observed that most heats showed differences of within ±3℃ except for three with differences of 9, 11 and 11℃, respectively. The reason why their differences were much higher than the others was the amount of raised temperature for these three heats were so large (over 50℃) that the results were beyond the prediction of empirical formula. A reasonable explanation for this is that one part of the heat offered by means of adding aluminum alloy and blowing oxygen on to the molten steel is usually offset by the ladle and vessel with a lower temperature. Once the offered heat is so much that a large part of that heat is used to raise the temperature of the molten steel, the temperature will increase more than what is expected. Accordingly, the effect of pressure during oxygen blowing on temperature elevation is not significant, meaning that similar performance of temperature raising can be achieved in the range of between 90 and 195 mbar. The relationships between temperature difference and volume of blowing oxygen under 195 and 90 mbar are as shown in Fig.10, respectively. It was found that most heats showed differences within ±10℃ except for a few ones that were beyond -10℃ for both cases at 195 and 90 mbar, revealing that they possessed similar performance. The differences within ±10℃ were reasonable due to the condition variance of ladle and vessel. For the cases with differences beyond -10℃, they usually happened due to facilities being left unused for a long period of time, which was production related.

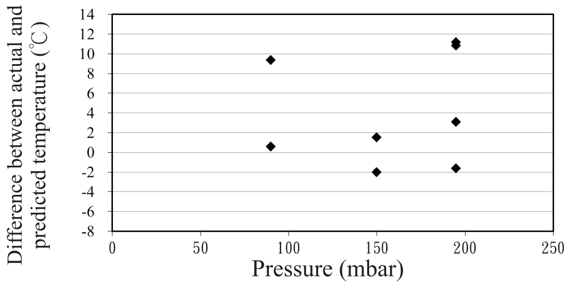


Fig.9. Relationship between temperature difference and pressure during oxygen blowing.

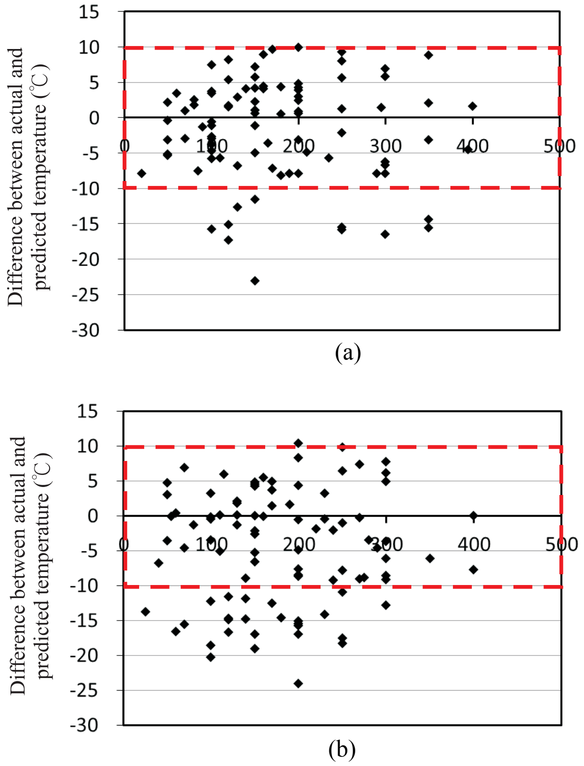


Fig.10. Relationships between temperature difference and volume of blowing oxygen (Nm^3) under (a) 195 and (b) 90 mbar.

Through the performance evaluation of decarburization and temperature raising processes at different pressures, it is feasible to reduce splashing by increasing vessel pressure so as to mitigate the damage to the RH facility.

3.3 Effects of height of top lance on decarburization and temperature raising processes

In order to understand if the damage of splashing to the top lance could be reduced by increasing the height of the top lance, the experiments were conducted to evaluate the performance of decarburization and temperature raising for different heights of the top lance. The arrangement for the tests of decarburization were similar to that of the former part, but the evaluation of the vessel pressure was changed to that of height of the top lance, namely, the experiments would be conducted with the heights of the top lance at 550, 600 and 650 cm, respectively. The samples were also taken at 1 and 12 minutes after oxygen blowing finished, which were used to calculate K1 and K12, respectively.

K1 and K12 values at different heights of the top lance are as shown in Fig.11 and 12, respectively. It was observed that both K1 and K12 slightly increased when the height increased from 550 to 600 cm. However, they decreased when the height increased from 600 to 650 cm. The results showed that the best performance of decarburization occurred at the height of 600 cm, but the difference is not very big.

The relationship between RA[C] and the height of the top lance is as shown in Fig.13. It was also found that the lowest RA[C] was obtained at the height of 600 cm, but all of them were lower than 15 ppm, which could meet the requirement of ultra-low carbon steels.

The arrangement for the tests of temperature raising was also similar to that of the former part, whereas the experiments would be conducted with the heights of the top lance at 550, 600 and 650 cm, respectively. The performance of temperature raising was also judged by the difference between actual and predicted temperature. The relationship between temperature difference and height of the top lance is as shown in Fig.14. The performances of temperature raising for these heights were similar, and the differences higher than 9℃ were the cases with the amounts of raising temperature over 50℃.

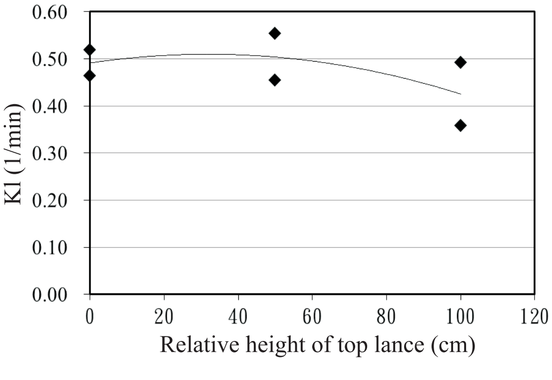


Fig.11. K1 values at different heights of the top lance. (0 represents 550 cm)

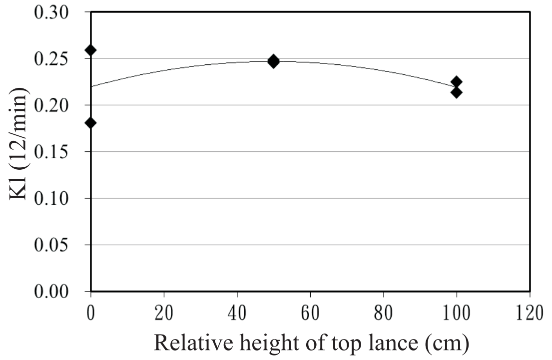


Fig.12. K12 values at different heights of the top lance. (0 represents 550 cm)

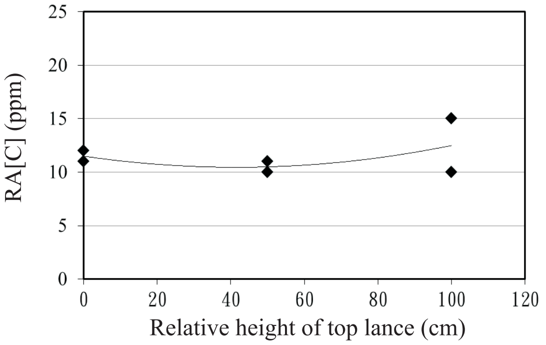


Fig.13. Relationship between RA[C] and height of the top lance. (0 represents 550 cm)

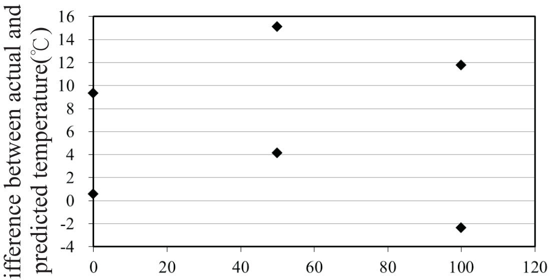


Fig.14. Relationship between temperature difference and height of the top lance. (0 represents 550 cm)

Through the performance evaluation of decarburization and temperature raising processes at different heights of the top lance, it is feasible to reduce the damage of splashing to the top lance by increasing operational height.

4. CONCLUSIONS

(1) Increasing vessel pressure had an adverse effect on decarburization during the period of oxygen blowing but a high vacuum period still dominated the

result of the whole reaction. After adequate treatment each RA[C] could reach a level of less than 15 ppm for a vessel pressure from 90 to 195 mbar. The pressure tests were also conducted for the operation of temperature elevation and the results showed that they all achieved the expected level.

(2) The influences of the height of the top lance were also evaluated. It was found that each RA[C] could reach a level of less than 15 ppm and the performance of temperature raising also met the requirement of regular operation for the height from 550 to 650 cm.

(3) It is feasible to reduce splashing by adjusting vessel pressure and the height of the top lance depending on the situation so as to mitigate damage to the RH facility.

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