SPLASH GENERATION AND FORMATION OF SURFACE WAVES IN A BOTTOM BLOWN FERROALLOY REFINING VESSEL

G. Akdogan and R.H. Eric

University of the Witwatersrand, South Africa.
E-mail: gakdogan@prme.wits.ac.za E-mail: rhe@prme.wits.ac.za

ABSTRACT

Splashing and wave formation has been studied experimentally by using one-seventh water model of CLU (Creusot-Loire Uddeholm) reactor with two different tuyere configurations by using paraffin and water as simulated slag and simulated metal respectively. Experimental results have been discussed in terms of total splash volume, relative slag volume in splash (dispersed-slag phase holdup in splash), wave frequency and wave amplitude with respect to gas injection rate and tuyere configuration at bath heights between 0.25m and 0.38m. Gas flow rates ranged from $0.00599m^3/s$ *to* $0.01312\ m^3/s$*.*

The results of splash measurements showed that splash volume increased with increasing gas flow rate and decreasing bath heights for both tuyere arrangements. However, off-centre configuration resulted in relatively higher amounts of splash. The slag volume in splash (Dph in splash) was also found to increase with decreasing bath heights and increasing gas injection rates. The high speed photography revealed that the frequency and wave amplitude increased with gas injection rate. The experimental results also showed that the frequency and vertical displacement of the rotating wave increased when the tuyere orientation became off-centered. This might be used to explain why off-center configuration resulted in generating higher splash volumes than the center configuration.

1. INTRODUCTION

Splashing and slopping due to gas injection is a common phenomenon in almost all high-strength gas blown metallurgical vessels. Gas injection plays an important role in metallurgical operations such as ferroalloy refining, steelmaking and refining, non-ferrous extractions and refining. However, this intensive agitation of the metal bath by gas injection results in splashing and wave motion, which in turn cause metal losses and refractory erosion.

In the literature, there are very few studies done on the formation of surface waves in upright cylindrical reactors. Leroy and Cohen de Lara[1] reported that the absence or presence of a standing wave was dependent on the geometrical parameters and position and number of tuyeres. They also showed that the period of wave was a function of bath depth, gas flow rate and bath diameter for upright cylinder geometry. Etienne[2] and Leroy[3] reported that in bottom injected baths the amount of splashed increased with increasing gas flow rate and decreasing bath depths.

Dubke and Schwerdtfeger[4] looked at the development of surface waves in physical modeling of drainage of cylindrical metallurgical vessels. They also predicted the wave frequencies from wave theory. Schwarz[5] investigated the waves formed in gas agitated baths. He developed a mathematical model for the linear wave amplitude as a function of bath depth and gas flow rate. He reported that there was a critical gas flow rate below which no wave motion takes place.

Liow and Gray[6] investigated the effect of paraffin layer on water for an attempt to reduce the intensity of slopping and splashing. The results suggested that oil layer could reduce slopping in cylindrical vessels. Xie and Oeters[7] studied the bath oscillation in a bottom blown converter by using water/air system. They characterized the wave formation by the ratio of bath height to vessel diameter and gas flow rate.

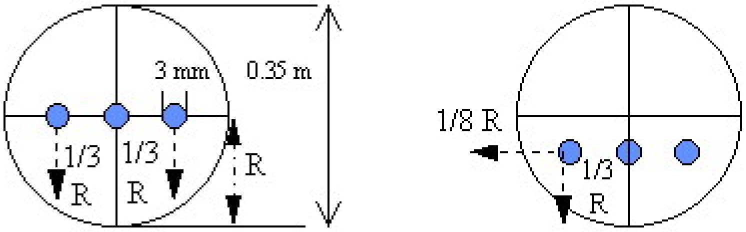
In a separate investigation, Liow and Gray[8] observed that the amplitude of the rotating wave increased monotonically with increasing gas flow rate to a maximum and then decreased to a fixed value in a water model of top submerged injection. They also reported the average splash height decreases with increasing bath depth and decreasing gas flow rates.

The correlation and understanding between splash generation and wave characteristics of different nozzle arrangements might be used to fully elucidate both wave formation and splashing phenomena as well as how they affect the behavior of one another in industrial operations.

The present study was carried out to understand the influence of gas injection rate and tuyere configuration on the splash generation and formation of surface waves in a water model of CLU vessel. Experimental results are given in terms of total splash volume, dispersed phase hold-up in splash, wave frequency, and wave amplitude with respect to gas injection rate and bath heights.

2. EXPERIMENTAL TECHNIQUE

The experimental set-up consisted of a cylindrical clear PVC tank, which is one-seventh model of a CLU converter tapered from 0.5m in diameter at the top to 0.35m in diameter at the bottom. Air was purged into the bath through three nozzles placed at the bottom of the tank. The modified Froude number similarity criterion was satisfied in the model study to correlate the gas flow rate between the scale model and full scale system. Air was purged into the bath through off-centered and centered nozzle arrangements that consisted of three 3mm inner diameter nozzles placed at the bottom of the tank as illustrated in Figure 1. During experiments the air flow rates varied between 0.00599m^3/sec and 0.01312m^3/sec.



Center Configuration *Off-Center Configuration*

Figure 1. Tuyere configurations used in the present study.

The bath height was ranged from 0.25m to 0.38m throughout the experiments. A high speed motion picture camera at a speed of 2000 frames per second was utilized to film the surface waves generated within the bath. The experimental set-up and has been described in detail elsewhere[9] and only the more important aspects will be given here.

For simulation purposes, water and kerosene were used as metal and slag phases respectively. Water and kerosene levels were adjusted to constitute a slag to metal height ratio of 0.086 which is encountered in ferroalloy refining operations. After filling water and kerosene into the tank to the desired heights, experiments were run by injecting air into the tank. About 15 minutes of air injection was sufficient for obtaining steady bath circulation.

The total volume of splash generated and the volume of dispersed-slag phase holdup (kerosene) in total splash volume were determined by collecting the splashed liquid in a PVC tray situated at heights from which defined locations in the model reactor of 12 to 18 cm from the liquid surface. The tray was inclined at an angle of about 10^o to allow drainage through outlets which were connected to measuring cylinders. After the phase separation, the volumes of water and kerosene were read, and the dispersed slag phase hold-up was determined by dividing the volume of kerosene by the volume of the splash emulsion.

Splashing tests were carried out for 20 minutes and repeated five times for one sampling location. Thereafter the mean splash volume and dispersed-slag phase were calculated. It was observed that the percent deviation from the mean value varied from 0.02 to 10.08 for the splash and the dispersed-slag phase volume readings.

3 RESULTS AND DISCUSSION

3.1 Splash volume

The variation of total splash volume versus bath height and gas injection rate is shown in Figure 2. It can be seen that the amount of splash increased with increasing gas flow rate. From this figure it can also be observed that the splash volume decreased with an increase in the bath height at a fixed gas injection rate. Figure 3 depicts the change in splash volume according to different tray heights (collection points above liquid surface) at a gas flow rate of $0.01081 m^3/s$. This illustration might be used to determine the height at which a fixed volume of splash was collected at different bath heights. For example 400 ml splash can be collected at tray heights of about 13, 16.5, 17.5 cm for 38, 29 and 25 cm bath heights respectively.

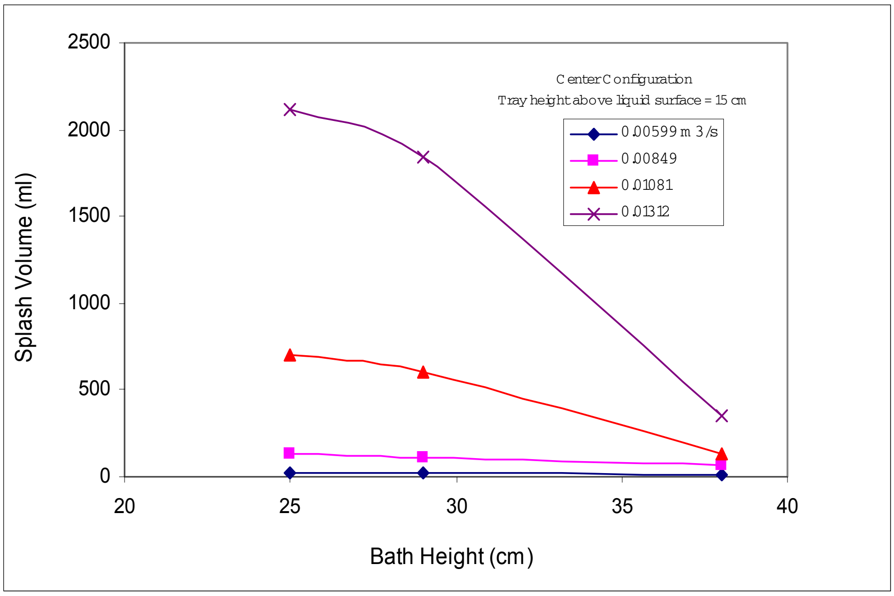


Figure 2. Variation of the splash volume according to bath height for Center Configuration at different gas injection rates.

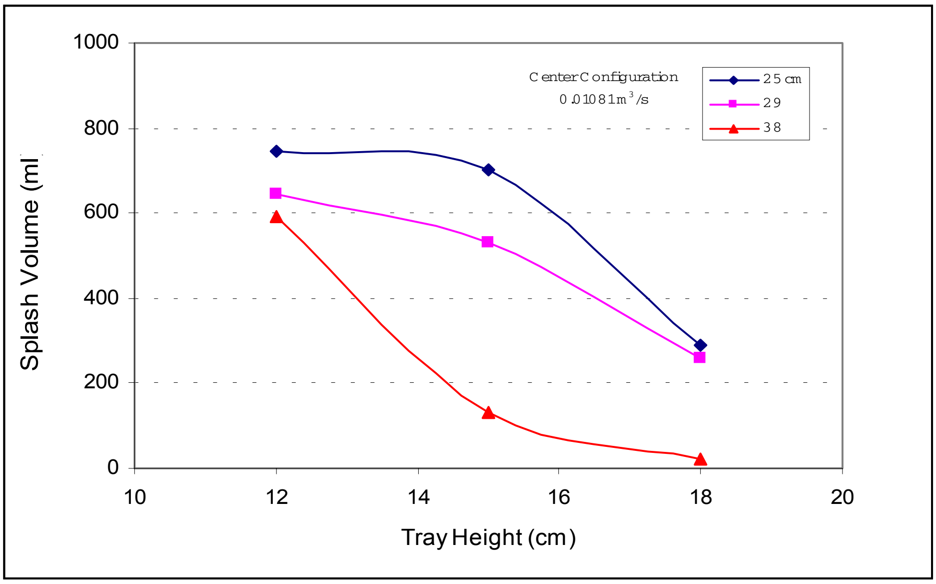


Figure 3. Variation of the splash volume at different tray positions (heights) and bath heights for Center configuration.

Figure 4 and 5 show the influence of the gas injection rate on the splash volume for Center and Off-center configurations at a constant bath height of 38 cm at different tray locations above the liquid surface. The above figures illustrate that the gas injection rate, at which a fixed volume of splash was collected, decreased with a decrease in tray position (height) in other words the splash volume increased with the gas injection rate at a fixed splash or tray location. However, at gas flow rate of 0.00599m^3/s the splash volume was very small as compared to higher gas flow rates.

These results are also in line with the findings of the previous workers[2,3]. These investigators reported that the amount of splash increased with increasing gas flow rate and decreasing bath heights in bottom injected baths. Liow et al.[8] studied splashing in a cylindrical bath with top-submerged injection and found that the amount of splashed liquid increased with increasing gas flow rate. They also stated that the amount splashed was sensitive to lance depth but not to bath height.

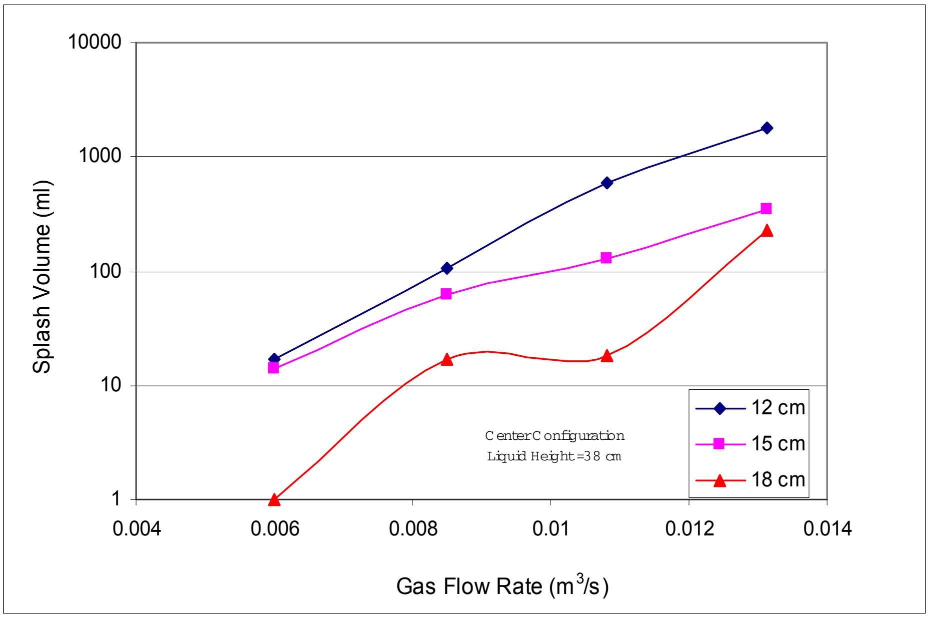


Figure 4. Splash volume at different gas injection rates and tray locations (heights) above Liquid surface for Center Configuration.

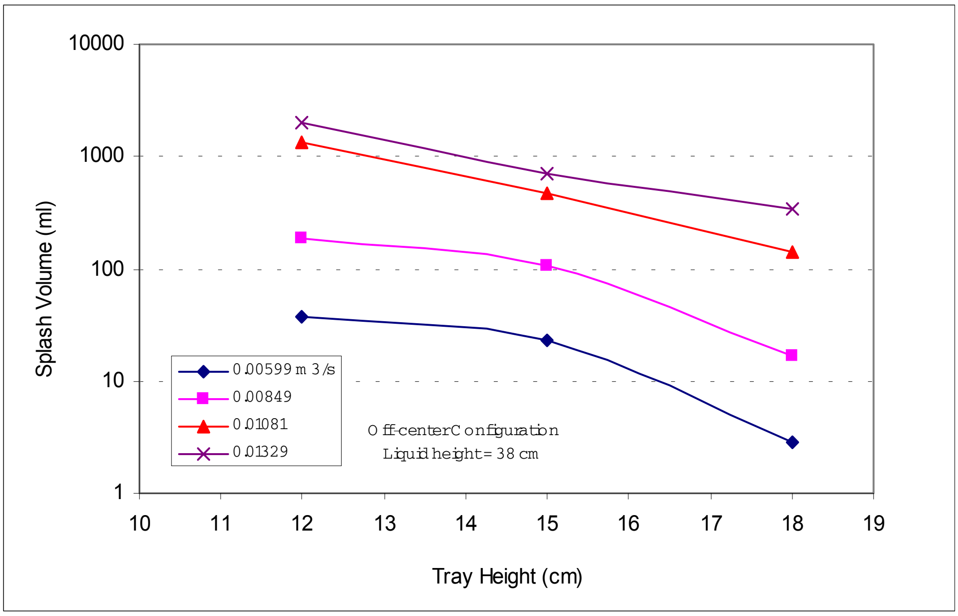


Figure 5. Change in the splash volume at different gas injection rates and tray locations (heights) for Off-center configuration.

The volume of splash generated was found to be influenced by tuyere arrangement and was relatively higher when the tuyere arrangement changed from Center to Off-center configuration (Figure 6).

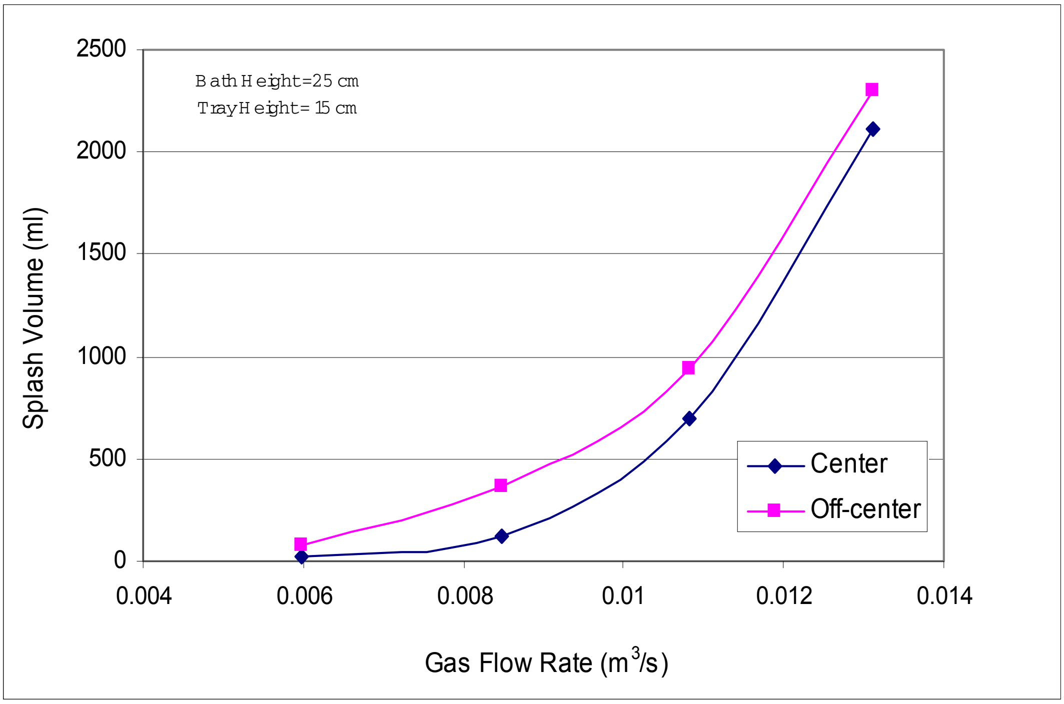


Figure 6. Comparison of the splash volume for Center and Off-center configuration at different gas injection rates and at a constant bath and tray location (height).

3.2 Dispersed-slag phase in splash

Figure 7 illustrates the effect of gas injection rate and bath height on dispersed-simulated slag phase holdup (ratio of volume of dispersed kerosene phase to total volume of emulsion, Dph) in total splash volume. As seen from Figure 7, at a fixed gas injection rate, the dispersed-slag phase holdup in splash increased with a decrease in the bath height. Dph in splash also increased with an increase in gas injection rate.

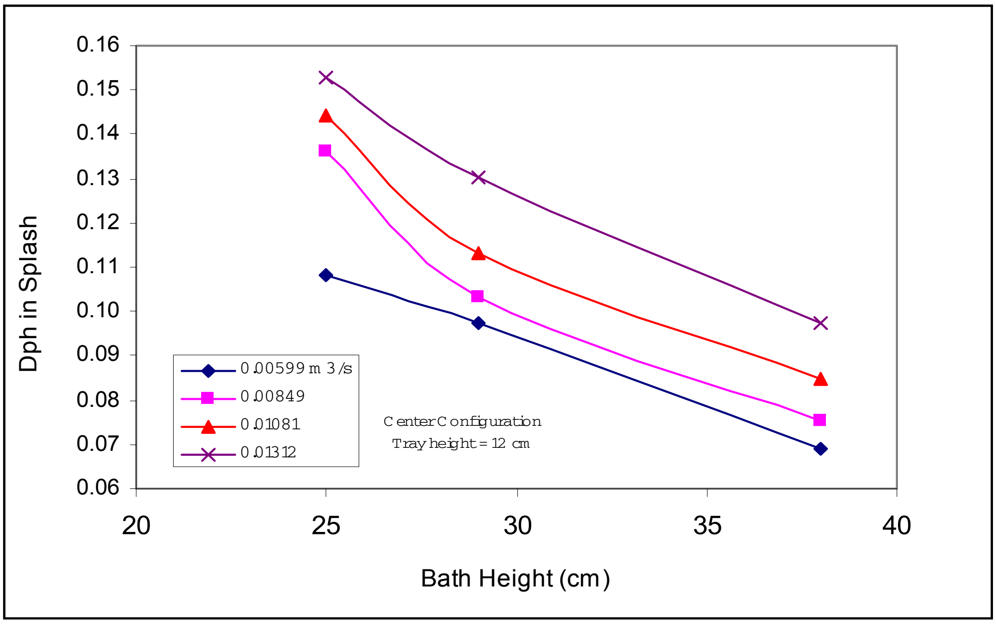


Figure 7. Dispersed-slag phase holdup at different gas injection rates and bath heights for Center configuration.

Dispersed-slag phase holdup in splash was found to increase when the tuyere arrangement changed from Center to Off-center orientation (Figure 8) at gas flow rates between 0.00599 and 0.01312m^3/s. In an earlier study of the dispersed phase holdup in a CLU process with particular reference to tuyere configuration and gas injection rate Akdogan and Eric[10] found that the dispersed phase holdup of the model bath increased with the gas injection rate. They also reported that the Off-center configuration displayed better dispersion results as compared to the Center configuration.

These results might be used to explain the higher values of dispersed-slag phase in splash when switched to Off-center configuration. During Off-center arrangement the slag entrainment in the metal phase takes place more intensely especially at bath levels close to the surface. These surface layers are more likely to be propelled into the space above the free surface by the rising liquid within gas-emulsion plume which might lead to increased slag amounts (Dph) in the splash.

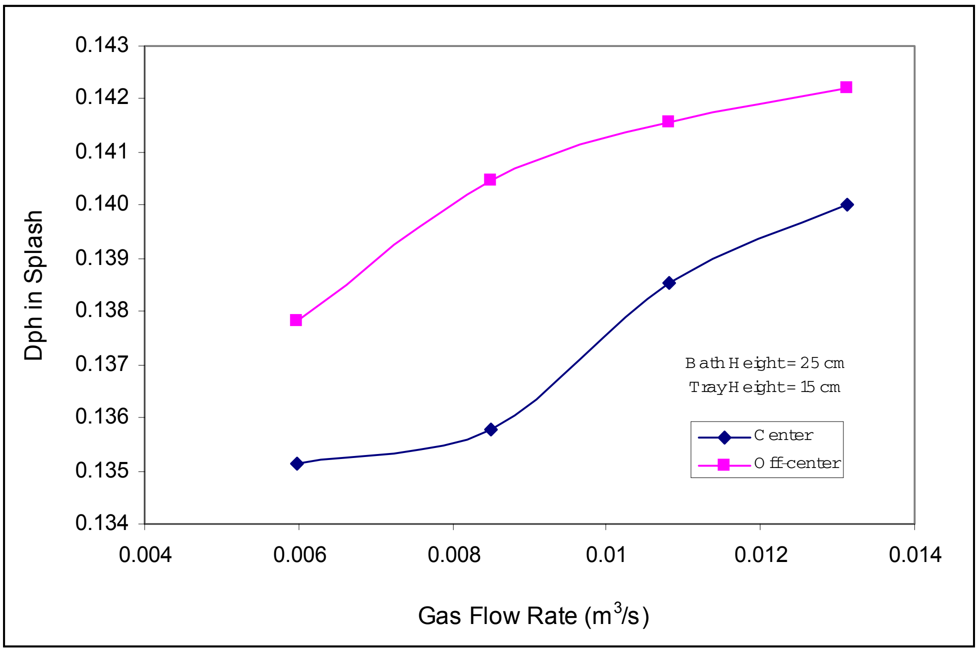


Figure 8. Comparison of the dispersed-slag phase holdup for Center and Off-center configuration at different gas injection rates and at a constant bath and a tray location (height).

3.3 Wave formation

High-speed photography technique revealed that the rotating waves formed on the bath surface and circulated around the tank in a clockwise direction. A previous investigation[11] reported that that the maximum vertical displacement or wave amplitude above the undisturbed surface increased with gas injection rate. Off-center tuyere configuration resulted in higher rotational speeds than those of Center configuration with or without simulated slag layer.

Figure 9 highlights that frequency of the wave increased with an increase in gas injection rate. It was also established that higher vertical displacements encountered when Off-center orientation was utilized. Figure 10 illustrates a comparative chart demonstrating the influence of tuyere pattern on rotating maximum vertical displacement. As seen from the figure that Off-center orientation gave rise to higher vertical displacements than that of Center configuration with or without slag layer. High speed visual observations indicated that at low gas flow rates, the amplitude was small and caused little or no splashing. At gas injection rates higher than 0.00849m^3/s, wave amplitude increased considerably to about 10.5cm. Although this was slightly reduced with simulated slag layer to about 9.5cm, it is still considerably high amplitude. This might be attributed to the higher splash volumes observed at high gas injection rates. This result also suggests that due to the rotating surface wave localized high dispersed-slag phase regions near the free surface might be easily reporting to the splash increasing the dispersed-slag phase volumes.

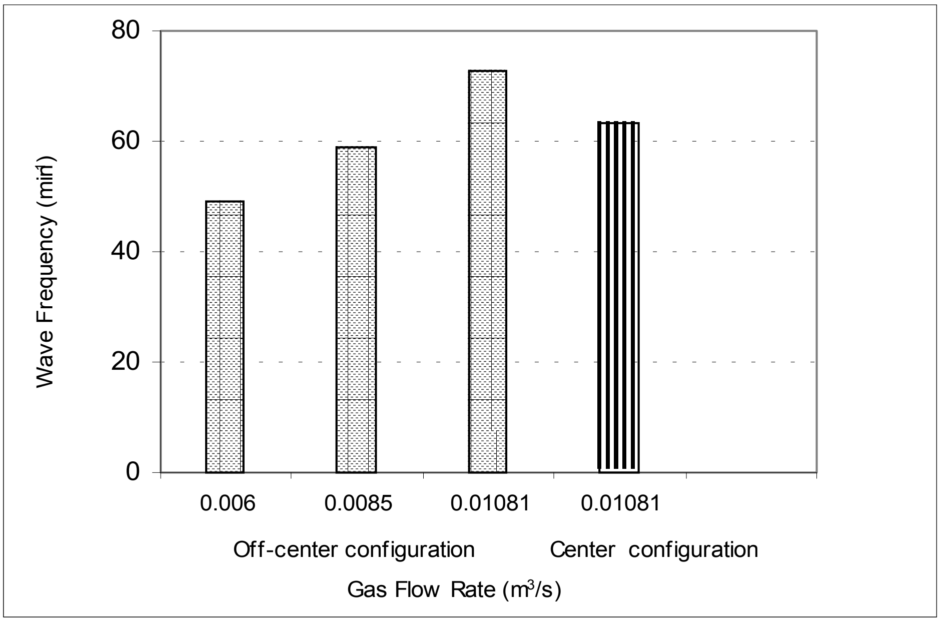


Figure 9. Variation of wave frequency for different gas injection rates and tuyere configuration.

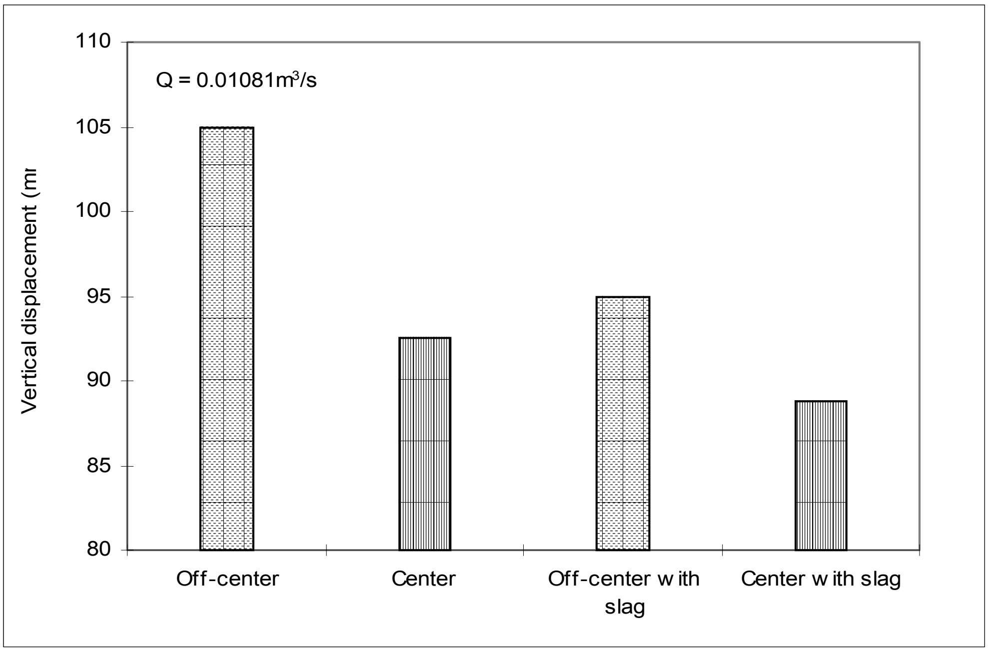


Figure 10. Comparison of wave amplitude for different tuyere orientation at a constant gas injection rate.

4. SUMMARY AND CONCLUSIONS

In the light of present findings, following conclusions can be deduced;

- The splash volume increased with increasing gas flow rate and decreasing bath heights.
- The volume of splash generated was found to be influenced by tuyere arrangement and was relatively higher when the tuyere arrangement changed from Center to Off-center configuration.
- Dispersed-slag phase in splash increased with increasing gas injection rate and decreasing bath height.
- Dispersed-slag phase holdup in splash was found to increase when the tuyere arrangement changed from Center to Off-center orientation.
- Rotating waves formed on the bath surface and circulated around the tank and wave amplitude above the undisturbed surface increased with gas injection rate.
- Off-center tuyere configuration resulted in higher rotational speeds and vertical displacements than those of Center configuration with or without simulated slag layer.

- At low gas flow rates, the amplitude was small and caused little or no splashing in contrast to higher injection rates which resulted in higher wave amplitudes and considerable increases in splash volumes and dispersed-slag phase holdup in splash.

These findings may have significant impact on the actual CLU operations in terms of the efforts to minimize the wave motion, splashing intensity and refractory wear. Further studies are required to reach to firm conclusions for the actual ferroalloy refining reactor in terms of designing tuyere locations for maximum possible efficiency in view of the observed facts that the Off-center tuyere configuration resulted in much higher splash and dispersed-slag phase holdup together with high recirculation and wave formation. This is in contrast to other observed advantages[12] of Off-center tuyere arrangement in terms of mixing time, mass transfer and in bath dispersion.

5. REFERENCES

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