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Numerical Investigations on the Effect of Gas Flow Rate in the Gas Stirred Ladle with Dual Plugs

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Abstract. Ladle or secondary steelmaking is an essential metallurgy process in which the steel is adjusted to the chemical compositions required in the final product. The objective of this study was to predict 95% mixing time curve using CFD simulation in order to investigate the possibility to optimize the gas flow rate in gas stirred ladle systems. The commercial software, Flow-3D, was used in this study. This study was divided into three parts. The first two parts of the study was the investigation of the effects of bubble sizes and diffusion coefficient on the mixing time by setting constant-volume gas flow rate. The last part was the study of the effect of gas flow rate on the mixing time. The ladle geometry and operation condition from the example steel plant, Millcon Steel PLC were used in this study. The simulation results indicated that different sizes of bubble have minor effects on the mixing time. The investigation of the effect on the mixing time with and without diffusion coefficient showed that the diffusion coefficient has no significant influence on the mixing time but has significant effects on the characteristics of the plume regions and the velocity flow field. Finally, it was found that gas flow rate has significant effects on turbulent kinetic energy, the mixing time and the steel cleanliness. The results can support the example steel plant to optimize the mixing process concerning productivity and cleanliness quality of the liquid steel.

1. Introduction

The stirring with an inert gas is widely used in the ladle refining process [1]. In the refining process, the gas (mostly argon) is injected into the liquid steel through porous plugs [2]. The gas bubbles from porous plugs generate the recirculation flow pattern in the ladle, which enhances mixing efficiency to homogenize the chemical composition and temperature [1]. The desired degree of mixing used is normally fixed at 95%, which means that the mixing time is the time when compositions reaches or remains constant within 5% range of the final concentration [3]. The mixing time is an important factor that determines the operation time and the mixing efficiency in the ladle furnace. Steelmaking plants often reduce the operation time by using high gas flow rate to increase level of productivity. However, excessive gas flow rates or long stirring times may cause the slag entrainment and re-oxidation [4,5]. Thus, it is necessary to optimize the gas flow rate that maintains the mixing efficiency in the ladle furnace in order to reduce the inclusion in the liquid steel.

Over the past decades, there has been a number of research studies into the flow and mixing phenomena in gas stirred ladle systems. D. Mazumdar et. al. [6] studied the physical modeling and mathematical modeling of gas stirred ladle systems. In their study, a number of literature reviews on various phenomena of gas stirred ladle systems such as turbulent fluid flow, mixing, gas-liquid interactions, etc. has been investigated. The results provided the understanding of the extensive mathematical modeling which lead to the process simulations. Numerous previous studies [7-8] presented the use of Froude scaling criterion. It was shown that the appropriate range of gas flow rates in the two systems between the model and the full-scaled ladle are related according to $Q_{mod} = \lambda^{2.5}Q_{f.s}$. The research works [1,2,9] described the bubble size prediction model which is related to the stirring flow rate.

The purpose of this study is to investigate the effects of the bubble sizes, the diffusion coefficient and the gas flow rate on the mixing time in a gas stirred ladle with dual plugs configurations by using numerical simulation, the Flow-3D software. The ladle geometry and operation condition from the example steel plant, Millcon Steel PLC are used in this numerical study. A 1:5 scaled water model is also numerically simulated in order to compare with the experimental results of water model in the next study. The results from this study can support the example steel plant to optimize the gas flow rate concerning operation time and cleanliness quality of the liquid steel.

2. Geometry of ladle model and simulation conditions

A 1:5 scaled water model of the example steel plant was used in the simulation. Figure 1 shows the ladle furnace of the example steel plant, Millcon Steel PLC (a), the arrangement of porous plugs and the tracer inlet (b) and meshing model of the ladle (c). The simulation was carried out via the discrete phase model (DPM), which was used to track motions of individual bubble, volume of fluid model (VOF) and RNG k-ε turbulence model. The total number of the cells used for solving flow equation is 734,456 cells. The dimensions of the 1:5 scaled water model and the full-scaled system are shown in Table 1.

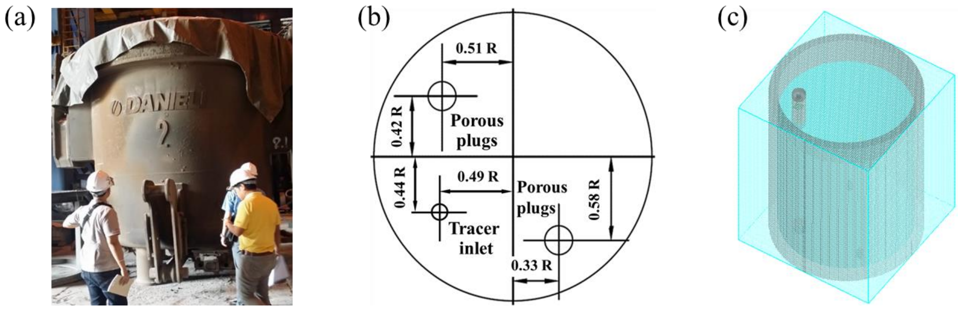

Figure 1. Geometric model of the ladle: (a) The full-scaled ladle furnace, (b) Arrangement of porous plugs and the tracer inlet and (c) Meshing model

Table 1. The simulation conditions and ladle dimensions

Model	Liquid density (kg/m^3)	Liquid viscosity (Pa.s)	Gas Density (kg/m^3)	Liquid temperature (K)	Ladle diameter (mm)	Porous plugs diameter (mm)	Ladle height (mm)	Liquid height (mm)	Tracer cylinder height (mm)	Tracer cylinder diameter (mm)
Water model scale 1:5 (Water-Air)	1000	0.001	1.225	298	467	20.4	600	500	120	17
Full-scale (Steel-Argon)	7020	0.0055	1.6228	1873	2335	102	3000	2500	600	85

The scope of this study was divided into three parts. The first two parts were carried out using a 1:5 scaled model. The constant-volume gas flow rate for both cases is 5.4 L/min. The first part was studied by adjusting different sizes of the bubble between 2 mm and 5 mm with a constant diffusion coefficient. The second part was investigated by setting the simulations with and without diffusion coefficient with bubble sizes of 2 mm and 5 mm. For the last part, the simulation of both water model and the full-scaled (steel-argon) ladle furnace were carried out using the geometrically and dynamically similar systems. The gas flow rates in full-scaled system were reduced from 300 L/min,

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200 L/min and 100 L/min to 5.4 L/min, 3.6 L/min and 1.8 L/min, respectively. Additional simulation conditions are shown in Table 1.

For the boundary conditions, no-slip boundary condition was used at the bottom and side wall. The gas bubbles were assumed to escape at the surface of liquid. Tracer was injected for two seconds at tracer inlet with fixed mass fraction and flow rates. At the porous plug, the gas flow rate and the bubble diameter were specified.

3. Simulation results

3.1 The effects of bubble sizes and diffusion coefficient on the mixing time

The examples of 95% mixing time curve of the 2 mm and 5 mm bubbles are shown in Figure 2(c). The results from the simulation indicated that the mixing time of the 5 mm bubble is around 220 seconds which is 15 seconds faster than that of the 2 mm bubble. It can be seen that the different sizes of bubbles have minor effects on the mixing time. The results of diffusion coefficient on the mixing time indicated that the mixing time with diffusion coefficient is 10 seconds faster than the mixing time without diffusion coefficient. Cone-shaped plumes occur in the simulation with diffusion coefficient as shown in Figure 2(a, b), while in case without diffusion coefficient, the plume regions appear in columnar shapes. The diffusion coefficient has no significant effect on the mixing time but has significant influence on the characteristics of the plume regions and the velocity flow field as shown in Figure 2(a, b).

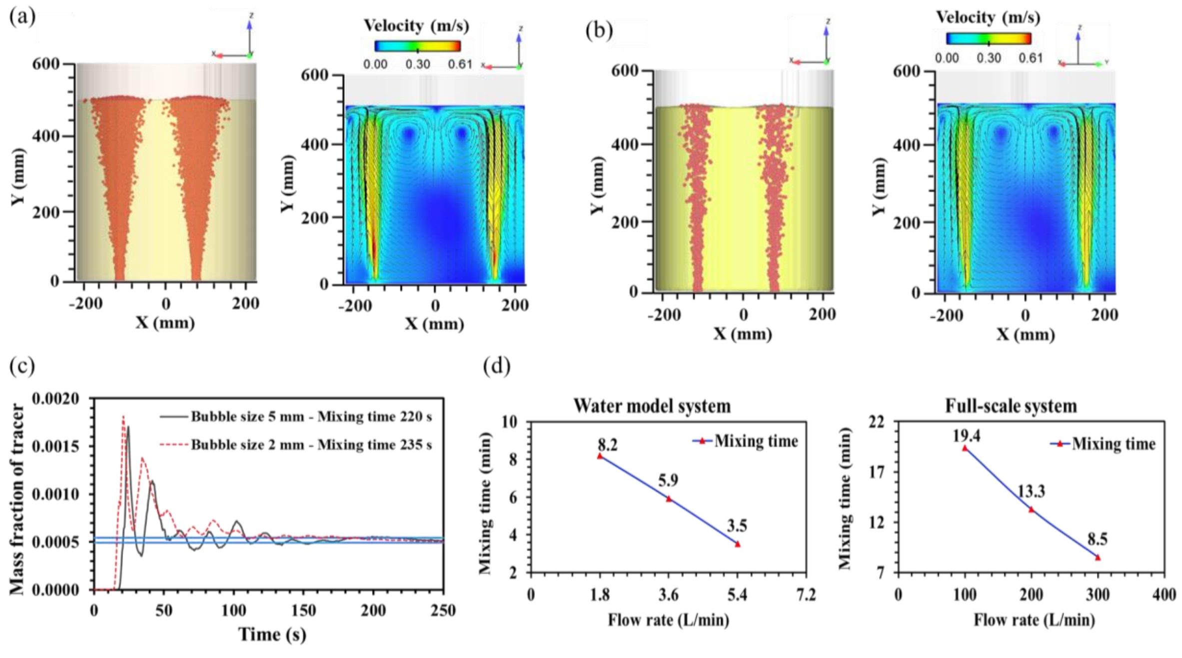

Figure 2. The results from the simulation; Plume regions and the velocity flow field of the bubbles with diffusion coefficient (a) 2 mm, (b) 5 mm, (c) 95% mixing time curve comparing between 2 mm and 5 mm bubble, (d) The mixing time from water model and full-scaled (steel-argon) systems

3.2 The effect of gas flow rate on the mixing time and the turbulent kinetic energy

The simulation results showed that high gas flow rate decreases the mixing time in the 1:5 scaled water model and full-scaled systems as shown in Figure 2(d). In addition, high gas flow rate significantly increases the turbulent kinetic energy as shown in Figure 3. Typically, high turbulent kinetic energy increases slag open-eye size which results in re-oxidation and slag entrainment on the liquid surface. Therefore, the gas flow rate should be optimized in order to improve the cleanliness quality of the liquid steel by decreasing the turbulent kinetic energy.

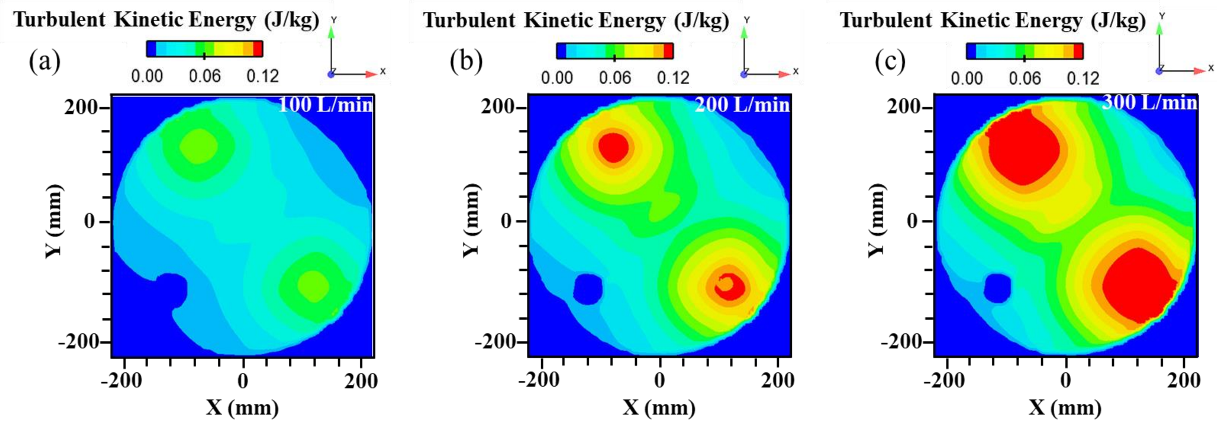

Figure 3. The turbulent kinetic energy with different flow rates from a full-scaled (steel-argon) system

4. Conclusion

In this study, the different sizes of bubble, the diffusion coefficient and the gas flow rate were numerically investigated by the CFD simulation. Different sizes of bubbles have minor effects on the mixing time. The diffusion coefficient has no significant effect on the mixing time but has significant influence on the characteristics of the plume regions and the velocity flow field. This study showed the importance of gas flow rate in the gas stirred ladle with dual plugs. It was found that gas flow rate has significant effects on turbulent kinetic energy, the mixing time and the steel cleanliness. Therefore, it is important for the steel plant to optimize the gas flow rate in order to achieve both productivity and quality of the liquid steel product.

5. References

[1] H. Liu, Z. Qi and M. Xu 2011 Numerical Simulation of Fluid Flow and Interfacial Behavior in Three-phase Argon-Stirred Ladles with One Plug and Dual Plugs, *steel research int.* **82** No. 4 pp. 440-458

[2] D. Mazumdar and J. W. Evans 2009 *Modeling of Steelmaking Processes*, Taylor & Francis Group, 451 p.

[3] H. M. Issa 2016 Power Consumption, Mixing Time, and Oxygen Mass Transfer in a Gas-Liquid Contactor Stirred with a Dual Impeller for Different Spacing, *Hindawi Publishing Corporation Journal of Engineering* **2016** pp.1-7

[4] Yan. Liu, Zhu He, and Li. Pan 2014 Numerical Investigations on the Slag Eye in Steel Ladles, *Hindawi Publishing Corporation Advances in Mechanical Engineering* **2014** pp.1-6

[5] D. Mazumdar and J. W. Evans 2004 Macroscopic Models for Gas Stirred Ladles, *ISIJ International* **44** No. 3 pp. 447-461

[6] D. Mazumdar and R. l. L. Guthrie 1995 The Physical and Mathematical Modelling of Gas Stirred Ladle Systems, *ISIJ International* **35** No. 1 pp. 1-20

[7] D. Mazumdar, H.B. Kim & R.I.L. Guthrie 2000 Modelling criteria for flow simulation in gas stirred ladles: experimental study, *Ironmaking & Steelmaking* **27** Issue 4 pp. 302-309

[8] D. Mazumdar, P. Dhandapani and R. Sarvanakumar 2017 Modeling and Optimisation of Gas Stirred Ladle Systems, *ISIJ International* **57** No. 2 pp. 286-295

[9] M. Madan, D. Satish and D. Mazumdar 2005 Modeling of Mixing in Ladles Fitted with Dual Plugs, *ISIJ International* **45** No. 5 pp. 677-685

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