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Fluid Dynamics in a Copper Converter: an Investigation on Mixing Phenomena in an Experimental Model

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ABSTRACT

In this study, the mixing phenomena in a physical model and fluid dynamics in a copper converter were experimentally investigated using a physical model. The physical model is a 1:5 horizontal tank made of Plexiglas. The mixing phenomena were characterized by experimentally measuring the mixing time using a tracer dispersion technique. Moreover, the effects of the air flow rate and lance submergence on the slopping in the model were studied. The experiments were carried out for the air flow rates of 10, 15, 17 and 20 l/min with the lance submergences of 8.5, 9.5, 10.5 and 11.5 cm. The results showed that the mixing time decreased with increasing both air flow rate and lance submergence. In addition, the slopping reduced as the lance submergence increased while the air flow rate decreased. Based on the results of the mixing time and the slopping, an optimum condition for air injection was obtained which not only ensured the sufficient mixing, but also resulted in less slopping in the model. Furthermore, the mixing times were evaluated in terms of the specific mixing power. A correlation was established for estimating the mixing time in the model with respect to the specific mixing power.

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1. INTRODUCTION

Among the metal manufacturing processes, copper converting is very important, because, after iron, copper is the second practical metal [1]. In one of the intermediate stages of copper converting, the injection of gas into the copper matte is used. Matte is molten supplied of the heavy metals, and the copper matte, basically consisting of FeS and Cu_2S, is an intermediate product in the extraction of copper from the supplied ores. In order to remove the impurities of the matte copper, i.e. Fe and S, air is injected into the matte copper, and methane gas is then injected into the molten copper containing dissolved oxygen [2]. The higher the mixing of the injected gas and the matte, the higher the quality of the final product. After gas injection, the impurities are removed from the copper converter as slag. These processes are carried out in a copper converter. There are various copper converters in industry which Peirce-Smith and Teniente converters are the most widely used.

Despite the vital role of gas injection in the copper converting process, it causes several problems. Problems leading to dissipation of energy are slopping and splashing. Part of the injected gas energy results in splashing. Owing to the high kinetic energy, the injected gas carries out the liquid particles to the top of the molten matte surface. This, not only causes the dissipation of energy, but also wears the inner wall of the copper converter. Another undesirable phenomenon occurring during the gas injection is the slopping of the free surface of the molten matte. In general, when the gas is injected into the molten matte, some surface waves are formed within the copper converter. This is originated from the high kinetic energy of the injected air. The splashing also causes both the dissipation of energy and erosion of the inner wall of the copper

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converter, especially at the region in contact with the slag. The slag has an acidic property, so it causes the erosion of its area in contact with the copper converter refractory. Therefore, as the slopping increases, the erosion of the area increases. The refractory used in the copper converter is made of specific materials, hence they are very expensive. Generally, a great deal of energy of the injected gas which must be expended for the refining purposes not only is dissipated, but it also increases the maintenance costs of the copper converter.

Many researchers have studied the copper converters in order to overcome the mentioned problems and improve the copper converting process. Vaarno et al. [3] simulated the fluid dynamics of the Peirce-Smith converter. They modeled the fluid dynamics and evaluated the controlling forces of a submerged gas injection. They also verified their model with a 1:4 scaled water model, and carried out a parametric study with the mathematical model of the submerged gas injection for Peirce-Smith and the ladle injection processes. They indicated that the best condition in order to oxidize the reaction is near the tuyere, where the lately discharged gas meets the circulatory flow of matte. They concluded that a large part of the oxidation reactions happens during the bubble formation. Rosales et al. [4] conducted a numerical study to investigate the fluid dynamics of flow characteristic in a Teniente converter. They considered two different cases: slicing in the smelting zone and a three-dimensional simulation including walls reactor. Their results presented velocities field, splashing, gravity waves amplitude, shear stress distribution and phase distribution. Valencia et al. [5] numerically investigated the fluid dynamics effect on water within a slice model of the Teniente copper converter with one tuyere. They studied the effect of Froude number on bath dynamics, especially jet stability and splashing, and concluded that with increasing the Froude number from 10.8 to 13.1, the unfavorable fluid splashing could be diminished, while with Froude number of 15.7 and 18.4 the fluid splashing again becomes significant. In another work, Valencia et al. [6] conducted numerical simulations and experimental visualization to investigate the fluid dynamics in a Teniente copper converter. Performing the experimental observation in a 1:5 scaled water container in which the air was injected through 50 submerged tuyeres, they measured mean amplitude and frequency of water bath oscillation. Their numerical simulation was also able to predict the axial displacement of slag layer, the jet formation and the oscillation of the water bath.

An alternative technique to improve the mixing efficiency, while avoiding excessive reactor splashing is the bottom injection method [7]. A Peirce-Smith converter with bottom air injection was explored by Real et al. [7]. They numerically simulated a multiphase three-dimensional system with different air velocities. Among the different criteria used to evaluate the liquid mixing efficiency, they used the turbulent kinetic energy in order to quantify the copper matte mixing. They observed an almost linear relationship between the inlet velocity of air and the kinetic energy of the copper matte. However, they reported that with a medium inlet velocity of air, the lowest mixing efficiency could be obtained. As another bottom blowing study, it can be pointed to the investigation of Gonzalez et al. [8]. They conducted a numerical study of the effect of the bottom injection of air at low inlet velocity on the fluid dynamics behavior in a Peirce-Smith converter. Paying special attention to the bubbles formation of air and its effect on the bath mixing of copper, they reported that there is a nonlinear relationship between the inlet air velocity and bath mixing. This means that very high velocities of air are not necessary in order to obtain sufficient mixing conditions of the copper matte.

Investigation of the factors affecting the splashing in a Peirce-Smith copper converter was performed by Hasanzadeh et al. [9]. They studied the effects of blowing angle, air volumetric flow rate and the distance of the blowers from water surface. They found that the splashing may be reduced if the air speed in the tuyeres and the nozzle distance from the melt free surface are in certain ranges. In a distinct work, Rosales et al. [10] experimentally and theoretically studied the formation of slopping in a copper converter and presented a methodology for controlling the slopping by employing combined lateral and bottom gas injection.

The influence of the simulated slag layer on the mixing characteristics and flow pattern in an industrial Peirce-Smith converter was studied by Chibwe et al. [11]. They carried out two and three dimensional simulations of a three phase system. In order to perform the physical simulations, they designed a 1:5 scaled water model using the similarity principles. Examining the effect of varying injection conditions and simulated slag quantities on the mixing, they evaluated the mixing time in terms of the total specific mixing power, and presented two mixing time correlations in order to estimate the mixing times in the model of Peirce-Smith converter for both low and high slag volumes. Their results revealed that the mixing efficiency of the converter can be affected by the presence of the overlaying slag layer and the air volumetric flow rate.

Using the combined lateral and bottom gas injection, Valencia et al. [12] conducted a numerical study to investigate the fluid dynamics in a model of Teniente converter. They carried out the three-dimensional simulation of the two-phase system in a 1:5 scaled water slice model for three different gas injection Froude numbers based on the bottom tuyere. They found that due to the simultaneous operation of the lateral and bottom tuyeres, an increase in the fluid mixing can be achieved without increasing the surface kinetic energy. Koohi et al. [13] also investigated the splashing in the

Peirce-Smith copper converter numerically and experimentally. Considering the air flow rate and the distance of air blowers from the surface as two key factors on splashing, they concluded that the splashing may be significantly reduced by controlling the air flow rate into the convertor.

Almaraz et al. [14] conducted a numerical and experimental analysis of biphasic flow and the onset of turbulence in Peirce-Smith copper converter. They observed different regimes of bobbling and jetting for various conditions of the gas injection. More recently, Almaraz et al. [15] simulated the fluid flow in a Peirce–Smith converter with one and three tuyeres. They concluded that the flow pattern within the converter can considerably change by increasing the number of injection points.

As reviewed, Peirce-Smith and Teniente converters have been extensively investigated. However, the new copper converters have been designed and developed in recent years. The fundamental distinction between these new copper converters and the old ones is originated from the gas injection conditions. In new converters, the injection is carried out using the lance submerged in the molten bath, while in the old ones the gas is injected through the tuyere. The lance is a pipe made of a material with high strength and is laterally inserted into the molten matte. To the best of the author’s knowledge, no attention has yet been paid to the copper converter with gas injection using lances. This study aims to experimentally investigate the mixing phenomena and fluid dynamics in this new copper converter in which the gas is injected through the lance. The experiments are performed in a 1:5 scaled water model of the copper converter used in Kashan Copper World Company. To characterize the mixing phenomenon, it is quantitatively evaluated by the mixing time using a tracer dispersion technique. In addition, the effects of the air flow rate and lance submergence on the slopping in the model are studied.

2. COPPER CONVERTING PROCESS

As mentioned earlier, the action of gas injection into the copper matte is carried out within the copper converter. There are different kinds of copper converter in industry of which the Peirce-Smith and Teniente converters are the most extensively used ones. Figure 1 shows a schematic representation of a copper converter. As shown in this figure, the air is blown through several horizontal tuyeres into the molten matte.

The copper converting is an exothermic process with the bath temperature in the range of 1100-1300˚C. This process, in which the iron and sulphur are oxidized, takes place in two stages; the slag forming stage and blister copper forming stage.

2. 1. Slag Forming Stage

This stage involves the oxidation of iron sulfide to ferrous oxide, magnetite and sulfur dioxide according to the following reactions [2]:

$$FeS+\tfrac{3}{2}O_2\rightarrow FeO+SO_2 \tag{1}$$

$$3FeS+5O_2\rightarrow Fe_3O_4+3SO_2 \tag{2}$$

To form the slag, the oxides of iron then are combined with the silica flux. As the slag builds up, it is skimmed from the free surface of the matte and silica is added. This cycle of operation continues until the charge consists of only a white metal, namely Cu_2S.

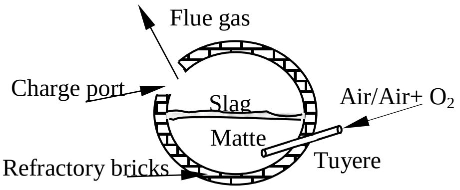

Figure 1. Cross section schematic representation of a copper converter

2. 2. Blister Copper Forming Stage

During this stage, the white metal is oxidized to blister copper according to the reaction [2]:

$$Cu_2S+O_2\rightarrow 2Cu+SO_2 \tag{3}$$

To remove the dissolved oxygen, the product which is approximately 99% copper, is treated in an anodic furnace according to the following reaction [2]:

$$3[O]_{Cu}+CH_4\rightarrow CO+2H_2O \tag{4}$$

After this stage, the copper is electrolytically refined. A three-dimensional simulation model using computational fluid dynamics (CFD) method is created to research the in-cylinder charge motion under variable valve actuation strategy. Figure 4 shows the dynamic grid for the CFD model.

3. MIXING PHENOMENA AND SPECIFIC MIXING POWER

Mixing phenomena intricately affect the inherent efficiencies of many chemical processing operations carried out in present copper converters. Mixing can cause the chemical reactions to be enhanced by bringing reactants together and removing products from reaction sites [14]. Hence, ascertaining the extent of mixing is desirable in order to evaluate the copper converters performance.

The investigation of mixing phenomena has attracted much attention for many years, and some methods have been proposed by investigators in order to quantitatively evaluate the mixing. Very often, the concept of the mixing time, T_{mix}, has been used to characterize the mixing phenomena and represent the agitation state in the reactor vessels. So, the mixing time has been considered as an index of the process efficiency. According to studies carried out by Chibwe et al. [11], Sinha and Mcnallan [16], Krishna et al. [17] and Turkoglu and Farouk [18], T_{mix} is defined as the total time required for the concentration of the tracer at one location to reach 95% of the steady state concentration after the introduction of a tracer at another location.

As reported in the literature, the mixing time can be related to the intensity of the stirring in a stirred vessel. Furthermore, the results of several studies relevant to metallurgical processing have been successfully correlated by the following equations [16]:

$$T_{mix} = A\varepsilon^{B} \tag{5}$$

In the above equation, T_{mix} is the mixing time, ε the specific mixing power, and A and B are constants which should be determined experimentally. These empirical constants depend on the nature of the mixing process, the dimensions of the vessel, and the procedure by which the mixing time is measured [16].

The mixing energy supplied to a bath comes from two sources. Most often, the largest source of mixing energy is that due to the rise of gas bubbles through the melt driven by buoyancy. The second source is the kinetic energy transferred to the bath by gas jet [16]. Therefore, the specific mixing power, ε, of the system can be calculated as an algebraic summation of the buoyancy specific power, ε_b, and the kinetic specific power, ε_k as fallows:

$$\varepsilon = \varepsilon_b + \varepsilon_k \tag{6}$$

The buoyancy specific power is given by the following equation [11]:

$$\varepsilon_b = \frac{2QP_a}{W} ln\left(1 + \frac{\rho_l gh}{P_a}\right) \tag{7}$$

Also, the specific power due to gas kinetic energy is given by the following equation [11]:

$$\varepsilon_k = \frac{\rho_g Q^3}{2WA^2} \tag{8}$$

In the above equations, W (kg) is the effective bath weight, Q (Nm^3s^{-1}) the total gas flow rate, P_a (kPa) the atmospheric pressure, A (m^2) the total tuyere cross sectional area, h (m) the tuyere submergence which is defined as the distance of the tuyere from the water free surface, and ρ the density [11].

There are many investigations reported in the literature on the effects of pertinent parameters such as gas flow rate and bath height on the mixing time in the water and molten metal baths [11, 16-18]. A summary of experimental configurations and mixing time correlations reported by various investigators has been presented by Mazumdar and Guthri [19]. Many investigations have been reported in the literature on the effects of pertinent parameters on the mixing phenomena in water and molten metal baths. However, the vessel designed and employed for this study is a unique apparatus and has not been yet employed in any investigation. In this study the effects of the air flow rate and the lance submergence, which is defined as the distance between the tip of lance and matte free surface on the mixing phenomena and the fluid flow in a water model at room temperature are experimentally investigated.

4. EXPERIMENTAL TECHNIQUE

4. 1. Physical Simulation In order to experimentally simulate the fluid dynamics in the copper converters, physical model, having less dimensions than the prototype, have been employed. Some conditions must be met to ensure the similarity of the physical model and the prototype flows. These requierments are geometric, kinematic and dynamic similarities. Using a scale factor, λ, on all physical dimensions, geometric similarity is observed as follows.

$$\lambda = \frac{I_{model}}{I_{prototype}} \tag{10}$$

where, I_{model} and $I_{prototype}$ are dimensions of the physical model and the copper converters, respectively [11].

The kinematic and dynamic similarities can be achieved through consideration of dimensionless numbers of Morton, Mo, and Modified Froude, $Fr_{Modified}$, respectively. Morton number and Modified Froude number are given below [11]:

$$Mo = \frac{g\mu^4}{\rho_l \sigma^3} \tag{11}$$

$$Fr_{modified} = \frac{\rho_g V^2}{g\left(\rho_l - \rho_g\right)d_0} \tag{12}$$

In the above equations, μ is the dynamic viscosity of the liquid (Pas); σ the surface tension of the liquid (N/m), V the air velocity (m/s); ρ_g the air density (kg/m^3), ρ_l the density of the simulated matte (kg/m^3), g the acceleration due to gravity (m/s^2) and d_0 the lance diameter (m) [11].

Physical properties of the fluids as well as the blowing conditions and dimensions of the industrial copper converter and the model are summarized in Table 1.

4. 2. Experimental Set-Up The experimental set-up consists of a Plexiglas vessel containing water, a rotameter for controlling the air flow rate, and a pH meter in order to evaluate the mixing phenomenon in the model. The vessel used consists of a horizontally placed tank with a square cross-section of 0.4m×0.4m and 1 m length. The dimensions ratio between the vessel and the industrial copper converter is 1:5.

Morover, the tank is filled with water 14 cm in height in order to simulate the actual condition of the copper converter operation. In order to simulate the gas injection, the air is injected through three straight pipes having a 4.4 mm diameter. The rotameter used to measure the air flow rate, ranging between 10 to 100 l/min, is of AZM-LZB-15MT type.

4. 3. Mixing Time Measuring Technique In order to measure the mixing time, T_{mix}, in the model, a tracer dispersion technique using a kind of acid and pH meter was employed. For this purpose, in each experiment, 6ml of 98% sulfuric acid (H_2SO_4) as the tracer was injected in the midpoint of the model at 100 mm below the water free surface. A pH meter was placed in the opposite direction of the tracer injection point at the lateral wall of the model. The mixing time was defined as the time required for pH changes to reach a constant value at a specific point.

Among the effective parameters on the mixing phenomena and fluid dynamics within the copper converter, such as lance submergence, depth of matte and air flow rate, only the lance submergence and air flow rate are considered as variable parameters. Furthermore, from geometric and dynamic similarities, it is possible to determine the ranges of the lance submergence and the air flow rate in the model, respectively. Therefore, the experiments were carried out for the air flow rates of 10, 15, 17 and 20 l/min with the lance submergences of 8.5, 9.5, 10.5 and 11.5 cm.

4. 4. Slopping Quantification To evaluate the slopping in the model, the distance between the lower and the higher levels of free surface of water, δ, is measured when the air injection is carried out. Based on observations, it was found that the maximum value of δ in the experiments would be approximately 9 cm. For investigating the effects of the air flow rate and the lance submergence on the slopping, percentage of the slopping is defined by following expression:

$$\%\ slopping = \frac{\delta_{avg}}{\delta_{max}} \times 100 \tag{13}$$

TABLE 1. Physical Properties of the Fluids and Blowing Conditions of Prototype and the Model

System	Prototype	Model
Converter length, m	5.25	1.05
Cross-section, m×m	2×2	0.4×0.4
Number of lance	3	3
Air flow rate, m^3/hr	110	0.918
Tuyere gas velocity, m/s	80.38	16.75
Modified Froude number	36.04	36.04
Dynamic viscosity, Pas	0.01	9×10^{-4}
Kinematic viscosity, m^2/s	2×10^{-6}	1×10^{-6}
Liquid density, kg/m^3	4600	998
Surface tension, N/m	0.93	0.0728
Morton number	2.65×10^{-11}	2.65×10^{-11}

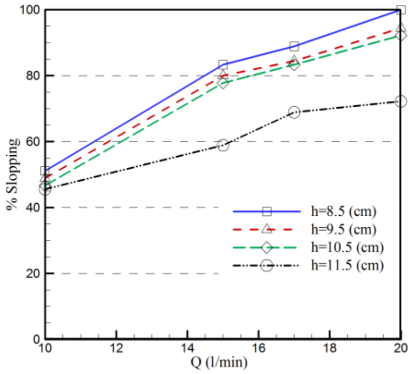

Figure 2. Effect of the air flow rate on the slopping percentage for different lance submergences

5. RESULTS AND DISCUSSION

Figure 2 shows the effect of the air flow rate on the slopping in the model for different lance submergences.

As observed from Figure 2, at constant lance submergences, increasing the air flow rate would increase the slopping in the model. In addition, at a given flow rate, the slopping decreases as the lance submergence increases. This can be due to the damping effect of hydrostatic force on the injected air. Therefore, it may be concluded that by decreasing the air flow rate in the converter, the slopping may be reduced. However, it must be mentioned that the low flow rate itself can causes some problems. If the air flow rate is low when the lances are submerged, there will be the blockage possibility of the lances. Moreover, the low air flow rates may not ensure sufficient mixing in order to progress the required reactions. The lower the air flow rate, the lower the kinetic energy of the air jet. Generally, when the air jet has low kinetic energy, it may not completely penetrate through the molten matte in the copper converter. Also, it may not stir the molten matte in the copper converter very well. Accordingly, not only the desired mixing will not be obtained, but also the mixing time will increase in the model. Because of the high production costs, increasing the mixing time is not favorable. Hence, it is important to determine an optimum condition for blowing in the converter.

Regarding the above considerations, the mixing time in the model for different air flow rates and lance submergences was also determined using an especial method mentioned in Sec. 4.3. Variation of the mixing time with the air flow rate for different values of lance submergence is presented in Figure 3.

As shown in this figure , the mixing time decreases as the air flow rate and lance submergence increase. This observation is in agreement with that reported by Krishnamurthy et al. [17]. As observed from this figure, the shortest mixing time occurs at the air flow rate of 20 l/min and lance submergence of 11.5 cm. So, it may be concluded that the best condition for the injection is the air flow rate of 20 l/min and lance submergence of 11.5 cm. However, it must be noted that at lance submergence of 11.5 cm, the tip of lance is very close to the bottom wall of model. Therefore, the injected air jet impinges on the bottom surface of the model. Because of the high kinetic energy of the injected air, this causes the erosion of the bottom surface which is not favorable. This interpretation can be generalized to the industrial copper converter. Due to the high temperature of the matte in the copper converters, their inner walls are covered with refractory materials. There are two very sensitive regions for refractory materials in the copper converter; the first region is in contact with slag on the surface of the matte, and the second one is the bottom surface of the copper converter. As pointed out earlier, the area in contact with the slag on the surface of the matte is seriously subjected to the wear due to the acidic nature of the slag. Therefore, this area is covered with the refractory materials having high quality; hence, they are very expensive. Duo to the energy transfer from the injected air to the molten matte, slopping will necessarily occur in the copper converter. This leads to the increase of the area in contact with the slag. Hence, as far as possible, the slopping must be avoided in the copper converter.

The splashing also increases in the model as the air flow rate increases. It is physically obvious that the air injection with high flow rates results in more stirring in the model. Hence, the splashing proportionally intensifies. Figure 4 illustrates the air injection into the model at the lance submergence of 10.5 cm for different air flow rates. As shown in Figure 4, with increasing the air flow rate, both splashing and slopping increase in the model. Based on this figure and Figures 2 and 3, it seems that at the air flow rate and lance submergence of 17 l/min and 10.5 cm, respectively, an optimum condition for gas injection is established. Under this optimum condition, not only the energy dissipation is reduced, but also the erosion of the inner walls is decreased. These two achievements are very important in the performance of the copper converters and in the energy saving.

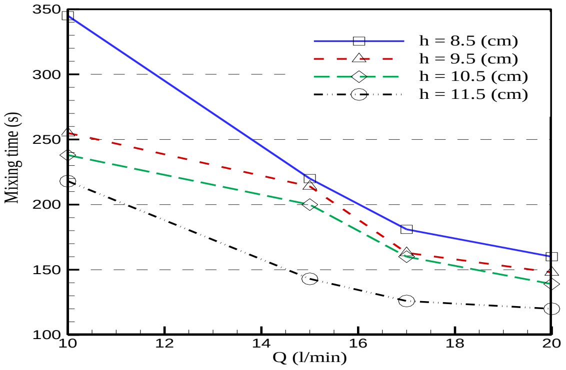

Figure 3. Variation of the mixing time with the air flow rate for different lance submergences

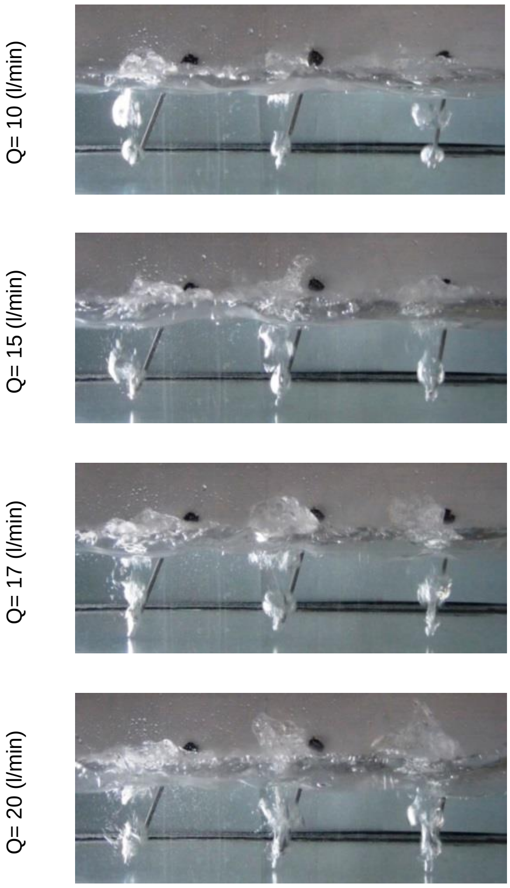

Figure 4. Air injection phenomena in the model for different air flow rates at h=10.5 (cm)

As mentioned earlier, the mixing power supplied to the water bath comes from two sources: the buoyancy specific power, ε_b, and the kinetic specific power, ε_k. To examine the significance of each one of these two powers, the ratio of the kinetic specific power to the total specific power is presented in Figure 5. As Figure 5 indicates, with increasing the air flow rate, the kinetic specific power becomes more effective as compared to the buoyancy specific power. In addition, at a given air flow rate, the effect of kinetic specific power becomes less significant as the lance submergence increases. However, the buoyancy specific power plays a more important role in the mixing. This is, as mentioned by Sinha et al. [16], due to the rise of the air bubbles through the water driven by buoyancy which causes the buoyancy specific power to become larger than the kinetic specific power.

Although the value of the kinetic specific power is less than the buoyancy specific power, the contribution of the kinetic specific power to the total specific power should not be neglected. This is taken into account when relating the mixing time to the total specific power. It is also assumed that all of the kinetic and buoyancy specific powers contribute towards the model agitation. This assumption has been considered in other relevant studies reported in the literature [11, 16-18]

According to the studies carried out by Chibwe et al. [11], Sinha and Mcnallan [16], Krishnamurthy et al. [17] and Turkoglu and Farouk [18], a correlation for mixing time is fitted on the experimental data, as shown in Figure 6. Figure 6 depicts the measured mixing time with respect to the specific mixing power at different lance submergences. As illustrated in Figure 6, with increasing the specific mixing power, the mixing time in the model decreases. This observation is in agreement with that of Chibwe et al. [11]. They observed that the mixing time decreases with increasing the specific mixing power for the cases in which the slag thickness is either zero or thin.

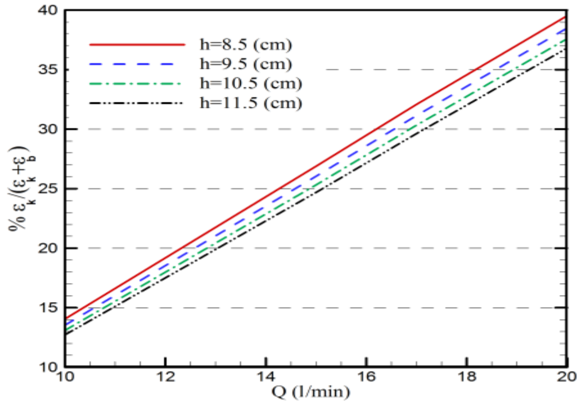

Figure 5. The ratio of the kinetic specific power to the total specific power

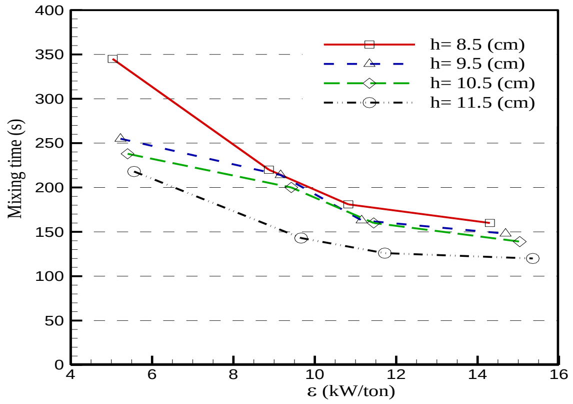

Figure 6. Effect of air flow rate on mixing time at different lance submergence

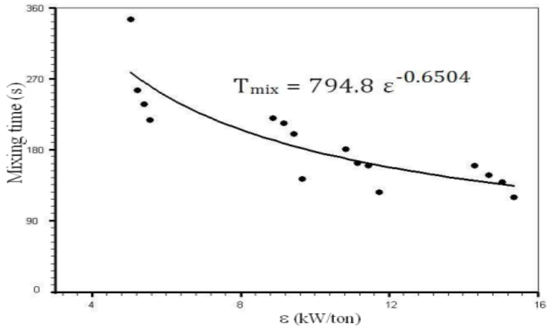

Figure 7. Fitting a correlation on the data

Figure 6 also indicates that the data for each lance submergence can be fitted to a line so that they can be represented by a relation in the form of $T_{mix}=A\varepsilon^B$. Representing the data by an equation of the form $T_{mix}=A\varepsilon^B$ has been also employed in other relevant studies reported in the literature [11, 16-18]. A least squares fit of the data with a correlation coefficient of 0.875 is presented in Figure 7. The obtained correlation is as follows:

$$T_{mix} = 794.8\varepsilon^{-0.6504} \tag{14}$$

The exponent in Equation (14) may be higher than those reported in the literature [11, 16-18]; however, it is now generally accepted that the geometry of vessel and mode of energy input influence the mixing phenomena considerably [19].

Equation (14) shows that increase in the specific mixing power results in decrease in the mixing time. This is due to the increased stirring in the model caused by the increased energy input.

6. CONCLUSIONS

In this study, the mixing phenomena and fluid dynamics in a 1:5 scaled water model of an especial copper converter were experimentally investigated. With considering the air flow rate and lance submergence as the key parameters and employing a tracer method, the mixing phenomena in the model was quantitatively evaluated. Moreover, the effects of the air flow rate and lance submergence on the slopping in the model were studied. Based on the experimental data, the mixing time was correlated with the specific mixing power. The results showed that the mixing time decreases with the increase of both air flow rate and lance submergence. Furthermore, the slopping reduces as the lance submergence increases while the air flow rate decreases. However, an optimum condition for air injection was found to be at the air flow rate and lance submergence of 17 l/min and 10.5 cm, respectively. Under this optimum condition, not only the energy dissipation is reduced, but also the erosion of the inner walls is decreased.

7. ACKNOWLEDGMENT

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Fluid Dynamics in a Copper Converter: an Investigation on Mixing Phenomena in an Experimental Model

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چکیده

در این تحقیق، پدیده‌های اختلاطی درون یک مدل فیزیکی و دینامیک سیال درون یک کنورتور ذوب مس، با استفاده از یک مدل فیزیکی، به صورت تجربی مطالعه شده است. مدل فیزیکی استفاده شده یک مخزن افقی در مقیاس ۱:۵ از جنس پلکسی گلاس می‌باشد. با اندازه‌گیری تجربی زمان اختلاط توسط یک روش دنبال کننده پخشی، پدیده‌های اختلاطی توصیف شده‌اند. علاوه براین، اثرات دبی هوا و عمق غوطه‌وری لنس بر پدیده موج‌دار شدن سیال درون مدل بررسی شده‌اند. آزمایش‌ها در شرایط دبی هوای ۱۰، ۱۵، ۱۷ و ۲۰ لیتر بر دقیقه و عمق غوطه‌وری لنس ۸/۵، ۹/۵، ۱۰/۵ و ۱۱/۵ سانتی‌متر انجام شده است. نتایج نشان می‌دهد که با افزایش دبی هوا و همچنین عمق غوطه‌وری لنس، زمان اختلاط کاهش می‌یابد. همچنین، با افزایش عمق غوطه‌وری لنس و کاهش دبی هوا، پدیده موج‌دار شدن سیال تقلیل پیدا می‌کند. با توجه به نتایج زمان اختلاط و موج‌دار شدن سیال، یک حالت بهینه برای تزریق هوا پیشنهاد شد که نه تنها اختلاط کافی را تضمین می‌کند، بلکه موج‌دار شدن کمتر سیال درون مدل را ناشی می‌شود. علاوه براین، نتایج مربوط به زمان اختلاط بر حسب توان مخصوص اختلاط ارزیابی شدند. یک رابطه برای تخمین زمان اختلاط درون مدل بر حسب توان مخصوص اختلاط ارائه شد.

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