

Mixing Energy And Mass Transfer During Mixed Blowing

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Abstract

Simulation experiments have been performed to understand the effect of bottom-air blowing rate on mass transfer during top surface injection process i.e. mixed blowing. Earlier investigators on this subject have commonly reported their findings relating mixing time with mixing energy. But, it is noticed that under a given set of experimental conditions mixing time does not remain same but varies with location of tracer added. So, in the present investigation, a more generalized factor such as volumetric mass transfer coefficient has been successfully correlated with mixing energy. The results show that bottom blowing is very effective in increasing the mixing energy and thereby volumetric mass transfer coefficient.

Introduction :

Injection metallurgy process has made a great impact in secondary refining of steel [1]. Mass transfer between liquid melt and injected power is of great importance to understand the process efficiency. The rate of mass transfer controlled chemical reaction can be accelerated by stirring [2], which favours mixing by transporting the liquid and breaking it in to eddies promotion eddy diffusion [3]. The minimum size of eddies ensures complete mixing at macroscopic scale. The transport of liquid and breakdown of eddies depend on amount of mixing energy [3].

It is reported [4] that in top surface injection, almost entire kinetic energy of gas and 87% of kinetic energy of particles are consumed to form crater. The mixing energy may effectively be enhanced through injection of gas from the bottom of vessel, which increases stirring of the bath. This gas stream also increases the retention time of particles in the melt. The literature reported [5-7] correlations between various forms of energies contributing to mixing and experimental parameters are:

1. Energy due to thermal expansion of gas [6], ϵ_T

$$\epsilon_T = 371.V_g.T_B / W. (1 - T_0/T_B)..... (1)$$

Where, V_g is volumetric flow rate of gas; T_0 & T_B are bath and gas temperatures respectively; W is mass of the bath liquid.

2. Energy due to buoyancy of gas [6], ϵ_B

$$\epsilon_B = 371.V_g.T_B / W. \ln (P_0/P_1)..... (2)$$

Where, P_0 & P_1 are pressure of gas - at nozzle at temperature T_0 and in bath due to expansion at temperature T_B respectively.

3. Kinetic energy of gas [7],

$$\epsilon_{Kg} = Vg^3. \rho_g / 2.W. A_0^2.....(3)$$

Where, ρ_g is density of gas and A_0 is cross sectional area of nozzle.

4. Kinetic energy of solid particle [7],

$$\epsilon_{Kp} = m_p. u_p^2 / 2.W.(4)$$

Where, mP is feed rate of particle and uP is velocity of particle.

Number of investigators [3,5] has related mixing time with mixing energy, ϵ as :

$$t_{mix} = A. \epsilon^{-B}(5)$$

Where, t_{mix} is mixing time and A, B are constant.

Due to uncertainty in mixing time w.r.t. mixing energy, it was thought to correlate mixing energy with a more generalized and representative factor such as volumetric mass transfer coefficient. This factor is represented by a product of mass transfer coefficient, K and initial surface area of particle, A and is related to bath concentration as [8]:

$$\ln \{C_s - C_0 / C_s - C_t\} = K.A.t/V (6)$$

Where, C_0, C_s & C_t are initial bath concentration, saturation concentration and bath concentration at time, t , respectively; V is volume of bath. $\ln \{C_s - C_0 / C_s - C_t\}$ is term as dimensionless bath concentration.

In the present study, a simulation model has been used to understand the effect of bottom-gas flow rate and solid feed rates on the mass transfer.

Experimental Set-up And Procedure:

The experimental set-up used is schematically shown in Figure 1. It consists of a specially designed powder feeding system providing independent control of gas and powder feed rate. 51.0 liters of water representing liquid is filled in a cylindrical Perspex vessel of 50 cms diameter and 60 cms height. Both the nozzles (top & bottom) are placed centrally with the top nozzle adjusted at a fixed height. The combination electrode is positioned in water bath in such a way that its tip is at half of bath depth and axially at one half of the radius of the vessel. Surface injection of potash alum powder carried by air from top and bottom blowing of air are made into the bath for a predetermined time and simultaneously the X-Y recorder is started. After termination of injection, a period of 10 seconds is allowed for the suspended particles to settle. Once, the suspended

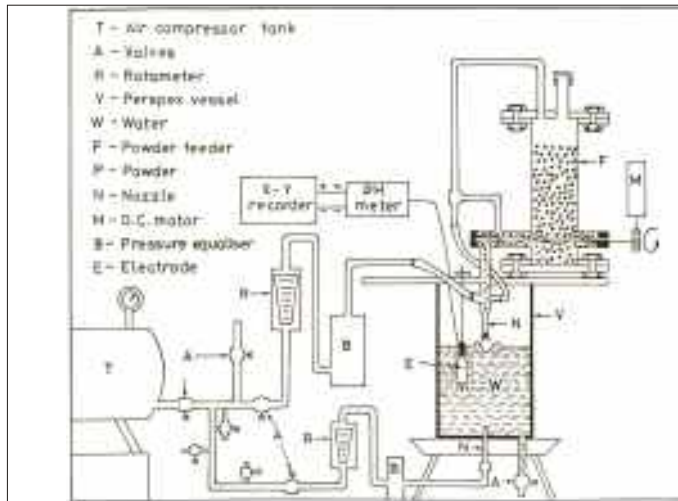


Fig. 1 Schematic Diagram of Experimental Set-up for mass Transfer Investigation

particles are settled, an extra airflow from bottom at 25 $\text{cm}^3 \cdot \text{sec}^{-1}$ rate is maintained to homogenize the bath. The

Table 1: Experimental conditions for mass transfer studies during mixed blowing.

Average particle size= 0.0776 cms, Nozzle height= 3.0 cms, Top air flow rate= 667.0 $\text{cm}^3 \cdot \text{sec}^{-1}$, Volume of water= 51.0 liters

| Sl.no. | Powder feed rate, gm.sec-1 | Bottom-air flow rate, $\text{cm}^3 \cdot \text{sec}^{-1}$ |
|--------|----------------------------|---|
| 1. | 0.500 | 0, 25.0, 55.0, 85.0, 123.0 |
| 2. | 0.967 | 0, 25.0, 55.0, 70.0, 85.0, 105.0, 123.0, |
| 3. | 1.333 | 0, 25.0, 55.0, 85.0, 105.0, 123.0 |

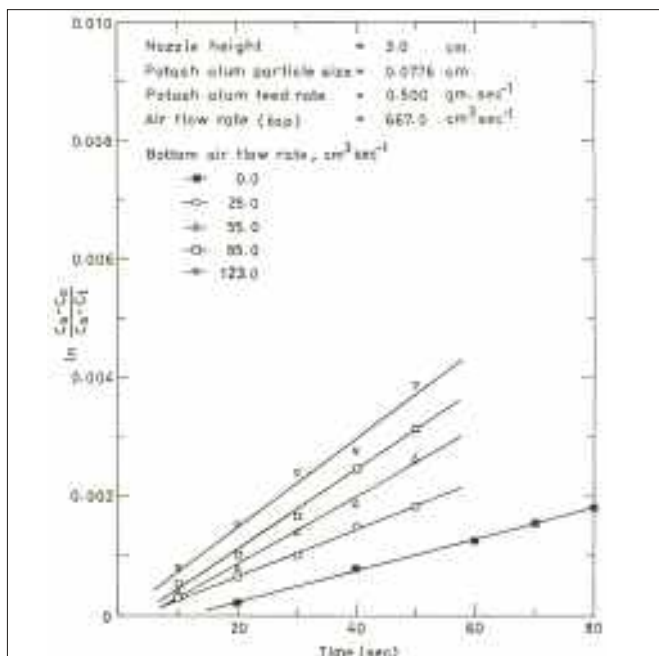


Fig. 2 Plot of Dimensionless Concentration of Potash Alum Vs. Time for Various Bottom Air Flow Rates with Fixed 0.5 $\text{gm} \cdot \text{sec}^{-1}$ Solid feed rate.

various experimental conditions and parameters used in the present study are shown in Table 1. The bath temperature is maintained at room temperature, which varied from 28°C-31°C.

Results:

The values of change in bath concentration C_t with injection time is obtained from the plot of X-Y recorder. The value of initial bath concentration C_0 is zero, whereas saturation concentration of potash alum in water bath C_s at corresponding bath temperature is obtained from literature [9]. From the values of C_t , C_0 and C_s so obtained during change in various experimental parameters, dimensionless bath concentration is calculated and its values are plotted against time. One such plot is shown in Figure-2.

These figures clearly indicate that dimensionless bath concentration increases with increase in injection time as well as bottom-air flow rate for all three solid feed rates.

Discussion :

From the plot between dimensionless bath concentration and injection time, KA is calculated using Equation 6. The mixing energy for mixed blowing (top + bottom blowing) is calculated with the help of Equations 2 to 4. For this purpose, only 13% of the kinetic energy of solid particles is considered for top blowing, whereas, buoyancy energy and kinetic energy due to air are considered for bottom blowing. As the experiments have been performed at room temperature so there is no thermal expansion of gas and therefore energy contribution due to this is zero. The

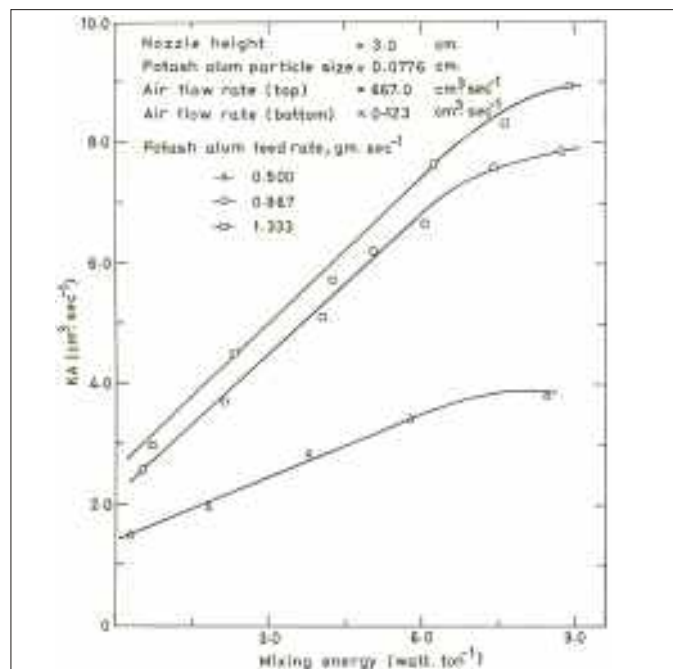


Fig. 3 Effect of Mixing Energy on Volumetric Mass Transfer Coefficient (KA) for mixed Blowing.

Table 2: Effect of mixing energy on volumetric mass transfer coefficient.

Nozzle height= 3.0 cms, Particle size=0.0776 cms, Air flow rate (top)= 667.0 cm³.sec⁻¹

| Sl.no. | Bottom air flow rate Cm ³ .sec ⁻¹ | Kinetic energy (K.E.) due to bottom air Watt.ton ⁻¹ | Energy due to buoyancy of gas Watt.ton ⁻¹ | Feed rate of potash alum, gm.sec ⁻¹ | | | | | | | | |
|--------|--|---|---|--|---|--|--|---|--|--|---|--|
| | | | | 0.500 | | | 0.967 | | | 1.333 | | |
| | | | | 13% K.E. of particle Watt.ton ⁻¹ | Total mixing energy Watt.ton ⁻¹ | KA cm ³ .sec ⁻¹ | 13% K.E. of particle Watt.ton ⁻¹ | Total mixing energy Watt.ton ⁻¹ | KA cm ³ .sec ⁻¹ | 13% K.E. of particle Watt.ton ⁻¹ | Total mixing energy Watt.ton ⁻¹ | KA cm ³ .sec ⁻¹ |
| 1 | 0.0 | 0.0 | 0.0 | 0.273 | 0.273 | 1.48 | 0.529 | 0.529 | 2.58 | 0.729 | 0.729 | 2.94 |
| 2 | 25.0 | 0.0036 | 1.58 | 0.273 | 1.857 | 1.98 | 0.529 | 2.110 | 3.71 | 0.729 | 2.313 | 4.51 |
| 3 | 55.0 | 0.0376 | 3.47 | 0.273 | 3.781 | 2.86 | 0.529 | 4.040 | 5.12 | 0.729 | 4.237 | 5.73 |
| 4 | 70.0 | 0.0780 | 4.42 | - | - | - | 0.529 | 5.030 | 6.21 | - | - | - |
| 5 | 85.0 | 0.1397 | 5.37 | 0.273 | 5.783 | 3.39 | 0.529 | 6.040 | 6.67 | 0.729 | 6.239 | 7.66 |
| 6 | 105.0 | 0.2633 | 6.63 | - | - | - | 0.529 | 7.420 | 7.58 | 0.729 | 7.623 | 8.31 |
| 7 | 123.0 | 0.4230 | 7.76 | 0.273 | 8.456 | 3.82 | 0.529 | 8.710 | 7.86 | 0.729 | 8.912 | 8.93 |

mixing energy of mix blowing is calculated by adding the energy contributions of top and bottom-blowing condition as is presented in Table 2. Effect of mixing energy on KA for the three different solid feed rates is shown in Figure 3. The points on extreme left of each curve are for 100% top blowing. It is observed from the figures that for all three feed rates, KA increases rapidly with increase in mixing energy up to 7.0 watt. ton⁻¹, but beyond this value, the effect of mixing energy progressively decreases. The reason for increase in KA with increase in mixing energy is due to enhanced stirring action of bath provided by kinetic and buoyancy energy of air blown from the bottom. This increase in stirring action, allows more and more liquid to come in contact with solid particles at a faster rate resulting in high dissolution rate and thereby higher volumetric mass transfer coefficient. As bottom-blowing of air also allows more resident time for particles to remain suspended in liquid bath, a higher recovery of additives may be achieved. At fixed mixing energy, the value of KA is observed to increase with increase in feed rate. This is mainly due to increase in the amount and thereby the total surface area of solids exposed to the bath.

Conclusions:

On the basis of the study and analysis of data, following major conclusions may be drawn:

1. Mixing energy can definitely be correlated to a more generalized factor as volumetric mass transfer coefficient.

2. The volumetric mass transfer coefficient increases rapidly with increase in mixing energy.
3. Bottom-air blowing may appreciably enhance mixing energy.

References:

1. D. Apelian, R.O'Malley and C. Dremann: Scaninject II, Proc. Int. Conf. Of Injection Metallurgy, Lulea, Sweden, 1980, 7.1.
2. K. Nakanishi and K. Komodo: Steel Times International, December, 1980, 24.
3. A. Ghosh: National Seminar on Secondary Steel Making, organized by IIM, Kolkata and Tata Steel, Jamshedpur, India, 1989.
4. E. Kimura: Transaction ISIJ, 23, 1983, 522.
5. U.P.Sinha and M.J.McNallan: Metallurgical Trans B, 16B, 1985, 850.
6. Y. Sundberg: Sacn. J. Met., 7, 1978, 81.
7. N.J.Themelis and P.Goyal: Can.Met. Quart., 22, 1983, 313.
8. L.R.Farias and G.A. Irons: Metallurgical Trans B, 16B, 1985, 211.
9. Hand Book of Chemistry and Physics: Ed. C.D. Hodgman, 40th edition, Chemical Rubber Publishing Co., Cleaveland, USA, 1959, 1699.