

Mass Transfer between Gas and Liquid in Bottom Blown Process*

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Synopsis

Desorption of carbon dioxide from water during bottom blowing of nitrogen was studied. Volumetric mass-transfer coefficient of carbon dioxide was evaluated by following the change of carbon dioxide concentration in the bath. The volumetric mass-transfer coefficient was found to increase with the increase in the flow rate of nitrogen gas.

A model for the estimation of volumetric mass-transfer coefficient was developed. The model uses Higbie equation for the estimation of mass-transfer coefficient. The prediction of the model is in reasonable agreement with the experimental observations.

Key words: mass transfer; bottom blown process; kinetics; gas-liquid system.

I. Introduction

In the bottom blown processes, the gas jet coming out of the nozzles or porous plug forms large bubbles at their tip. These bubbles while ascending through the turbulent recirculating liquid disintegrate due to fluid-dynamic instability and form bubble swarm. These lead to rapid exchange of mass between the gas and liquid bath.

Mass transfer from a single bubble in static liquid bath has been widely investigated. Higbie equation provides a fair estimate of mass-transfer coefficient in the liquid phase for this case.¹⁾ In gas stirred system, measurement of mass-transfer coefficient is difficult. So mostly volumetric mass-transfer coefficient, *i.e.*, the product of mass-transfer coefficient and the area of bubble-liquid interface per unit volume of bath, is measured. Bhavaraju²⁾ showed volumetric mass-transfer coefficient can be reasonably estimated using Higbie equation provided appropriate choice of various parameters are made. Recent results of Bessho³⁾ on the carbon dioxide absorption into water also support this view.

Recently Kawakami⁴⁾ measured rate of nitrogen transfer during submerged gas injection. Kawakami studied the radial distribution of nitrogen bubble frequency at different height in liquid pig iron bath and the rate of nitrogen absorption at 1250°C. From their results they could obtain the value of mass-transfer coefficient of nitrogen both in liquid and gas phase. Their results indicate that the mass-transfer coefficient in liquid phase for bubble stirred system is 5 to 9 times smaller than that in levitation or induction stirred melts.

In the present work, rate of carbon dioxide removal from the water bath during bottom blowing of

nitrogen has been studied.

II. Experimental

The experimental setup was made up of a perspex cylindrical reaction vessel of height 0.45 m and diameter 0.3 m. The gas was injected through a nozzle of 2 mm ID fitted at the centre of the base plate of reaction vessel. Most of the experiments were carried out with water bath height of 0.3 m and gas flow rates in the range of $3.33 \times 10^{-5} \sim 4.5 \times 10^{-4}$ Nm³/s.

Initially carbon dioxide was dissolved in the bath to near saturation level. Then nitrogen gas was passed through the nozzle at constant flow rate. Bath samples were collected at regular intervals to analyse the carbon dioxide content of the bath. Simultaneously two samples were collected from two different locations of the bath and the average carbon dioxide content of these two samples were taken as that of the bath.

III. Results

Mixing time studies for the system showed that the mixing time is in the range of 15~30 s. The lower value corresponds to gas flow rate of 4.5×10^{-4} m/s. This suggests that at any instant the bath is not expected to be completely homogenous. However, assuming mixing time to be zero, the change in the carbon dioxide content of bath during nitrogen flushing is given by

where, c : the carbon dioxide concentration in the bath at any instant

K: the mass-transfer coefficient of carbon dioxide

a: the bubble-liquid interface area per unit volume of the bath

c_e : the concentration of carbon dioxide in water which is in equilibrium with carbon dioxide in the nitrogen bubble.

Obviously, in the present case $c_e \approx 0$ hence Eq. (1) becomes

$$-\frac{dc}{dt} = Kac \quad \dots \dots \dots \quad (2)$$

Integrating Eq. (2)

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For the present experimental condition where the liquid flow in the plume zone was highly turbulent, (Reynolds number of the liquid in the plume zone was about 24 000 for the lowest gas flow rate), bubble diameter is given by²⁾

$$d = 0.7 \frac{\sigma^{0.6}}{\rho^{0.4} \rho^{0.2}} \left(\frac{\mu}{\mu_q} \right)^{0.1} \dots \dots \dots \quad (11)$$

where, μ_g , μ : the viscosity of the gas and liquid, respectively.

When d calculated by Eq. (11) is less than 0.0045 m, diameter of the bubble is taken as²⁾

The estimation of volumetric mass-transfer coefficient, Ka , by Eqs. (6)~(13), requires the knowledge of plume diameter. Assuming that the plume diameter, d_p , is same as the gas jet diameter on the top surface of the bath and bath depth is much greater than the nozzle diameter;

$$d_p = 2H \tan \frac{\theta_c}{2} \quad \dots \dots \dots \quad (14)$$

where, θ_c : the jet cone angle.

Themelis⁷⁾ found that θ_c for air–water system is about 20° hence Eq. (14) becomes

In the present case, plume diameter was estimated by visual observation as 0.08 m for 0.3 m bath height. This figure compares favourably with the estimate obtained from Eq. (15).

Figure 2 shows the calculated values of Ka for bath height of 0.3 m along with the experimental results. Diffusivity of carbon dioxide in water was taken⁸⁾ as $D = 1.8 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$. It is apparent from the figure that calculated values give a rough estimation of volumetric mass-transfer coefficient. At low flow rates, orifice Reynolds number less than 5 000, calculated values are less than the experimental ones but at higher flow rates the calculated values are greater than the experimental ones and the difference between the two seems to decrease with the increase in flow rates. Equations (6)~(13) indicate that Ka is roughly proportional to $d^{-1.5}$ and independent of bath height. Thereby the estimation of Ka by the above mentioned equations is very sensitive to the estimation of the diameter of the bubbles.

Kawakami⁴⁾ reported $K = 1.05 \times 10^{-5} \text{ m/s}$ and $Ka = 3.9 \times 10^{-4} \text{ s}^{-1}$ for transfer of nitrogen in liquid pig

iron at 1250°C when nitrogen was injected at a flow rate of $0.33 \times 10^{-3} \text{ Nm}^3/\text{s}$. Diffusivity of nitrogen in liquid pig iron is not known. Extrapolation of high temperature data⁹⁾ of diffusivity of nitrogen in pure iron show that at 1250°C diffusivity is equal to $3.12 \times 10^{-9} \text{ m}^2/\text{s}$. Sano and Mori¹⁰⁾ showed that the bubble diameter in liquid metal may be estimated by

$$d = 6.83 \left(\frac{\sigma}{\rho} \right)^{0.5} V_s^{0.44} \quad \dots \dots \dots \quad (16)$$

where, V_s : the superficial velocity of the injected gas in the bath.

Calculation shows that for the experimental condition of Kawakami, $K = 2.2 \times 10^{-4}$ m/s and $Ka = 7.5 \times 10^{-4}$ s⁻¹. It may be noted that although the calculated value of mass-transfer coefficient is about 20 times larger than the experimental ones, the agreement for Ka is reasonable. This observation and present experimental results suggest that although Higbie model, Eq. (7), may not be valid for the submerged gas injection system, an estimate of volumetric mass-transfer coefficient can be obtained using the same.

V. Conclusion

- (i) Volumetric mass-transfer coefficient of carbon dioxide in water increases with the increase in the flow rate of injected nitrogen.
 - (ii) A reasonable estimate of the volumetric mass-transfer coefficient can be obtained using Higbie equation for mass-transfer coefficient.
 - (iii) Estimation of mass-transfer coefficient by Higbie equation may be wrong by order of magnitude.

REFERENCES

- 1) R. Clift, J. R. Grace and M. E. Weber: Bubbles, Drops and Particles, Academic Press, New York, (1978), 169.
 - 2) S. M. Bhavaraju, T.W.F. Russel and H. W. Blanch: *AIChE J.*, **24** (1978), 454.
 - 3) N. Bessho, S. Taniguchi and A. Kikuchi: *Tetsu-to-Hagané*, **71** (1985), 1623.
 - 4) M. Kawakami, Y. Kitazawa, T. Nakamura, T. Miyake and K. Ito, *Trans. Iron Steel Inst. Jpn.*, **25** (1985), 394.
 - 5) Y. Sahai and R.I.L. Guthrie: *Metall. Trans. B*, **13B** (1982), 193.
 - 6) M. Sano and K. Mori: *Trans. Iron Steel Inst. Jpn.*, **23** (1983), 169.
 - 7) N. J. Themelis, P. Tarasoff and J. Szekely: *Trans. Metall. Soc. AIME*, **245** (1969), 2425.
 - 8) D. M. Himmelblau: *Chem. Rev.*, **64** (1964), 527.
 - 9) M. Inouye, Y. Kojima, T. Choh, S. Uekawa and Y. Yamada: *Trans. Iron Steel Inst. Jpn.*, **13** (1973), 29.
 - 10) M. Sano and K. Mori: *Trans. Iron Steel Inst. Jpn.*, **20** (1980), 675.