Indian Journal of Chemical Technology
Vol. 16, May 2009, pp. 278-282

Interfacial area measurement in a gas - liquid ejector for a sodium chloride - air system

P.T. Raghuram
Department of Chemical Engineering
Indian Institute of Science, Bangalore 560 012, India
Email: ptr@chemeng.iisc.ernet.in

Received 11 July 2008; revised 15 February 2009

Interfacial area measurement has been carried out experimentally by measuring the bubble size and holdup for air-sodium chloride solution system. The size of the bubble is predominantly established by the air hold up. High speed photography technique for bubble size measurement and gamma ray attenuation method for holdup measurements are followed. The measured values are compared with the theoretically predicted values. Interracial area as a function of the liquid flow rate and also its distance from the nozzle of the ejector has been reported in this paper. The results obtained for this non-reactive system are also compared with those of air-water system.

Keywords: Gas-liquid ejector, High speed photography method, Air-sodium chloride system

Ejector is one of the contactors which offers relatively high interfacial area, adjustable time of contact and is a co-current flow device. The liquid phase is introduced in the form of a jet through the main nozzle and the other phase, gas is either sucked or introduced under slight pressure. The latter method gives a higher degree of control over the gas liquid flow rate ratio. The interfacial area generated in the ejector directly depends on the bubble size. The bubbles generated due to intense mixing of the two phases, slowly grow in size and attain a steady size. Hence, the bubble size plays an important role in this and has to be measured for its further use in the calculation of interfacial area, mass transfer etc. However, the size of the bubble is predominantly established by the air holdup. Hence, it is equally important to measure the corresponding holdup. These two values are used to estimate the interfacial area. The present work is intended to test the performance of the ejector for air - sodium chloride solution system and obtain the information which will be helpful to develop a model for the performance of the ejector as a conventional reactor for chemical system.

Performance of water jet ejectors has been studied by Reddy and Kar[1] who optimized the design data, which has been used in present work. Gas liquid mass transfer characteristics and effective specific interfacial area has been studied by Ogawa *et al*.[2] whereas mass transfer characteristics and the physical interfacial area has been studied by Miyami and Tojo[3]. A transport equation for the interfacial area has been developed by Lehr and Mewes[4] using population balance of the bubble and basic approach has been used in modeling the interfacial area density, which is semi-empirical in nature. Bubble size distribution and gas liquid interfacial area in a modified down flow bubble column has been measured as a function of axial location, and nozzle diameter by Kundu *et al*.[5]. The literature survey has indicated a situation where the ejector can be utilized as a chemical reactor; this work being the extension of the earlier work. Here, a non-reactive chemical system is tried as first step to investigate the interfacial area enhancement.

Experimental procedure

Bubble size measurement

The method for bubble size measurement has been reported earlier[6] and the main features of the same are given for the quick reading to have first hand information of the work followed. The gas liquid ejector has been designed[1,7] and fabricated of borosil glass for the studies. The experimental set up (Fig. 1) includes a 200 liters HDPE tank with stainless steel baffles, containing the sodium chloride solution and this has been pumped through a stainless steel centrifugal pump (3 H.P-18 meters head) with proper control valves, rotameter, etc to the ejector, which is mounted above the tank by means of a platform (not shown in the figure).The details of the ejector are given in Table 1. A secondary line, through which air enters the ejector, is also monitored by means of manometer to ascertain the air flow rate. Air is taken from a compressor with suitable filters, by-pass line, etc. At the nozzle of the ejector, the pressure energy is converted into kinetic energy thereby reducing the pressure to the negative value. This enables air to enter in and gets dispersed into the liquid. As it moves down, the mixing intensity falls slowly and at the same time the bubble size increases due to

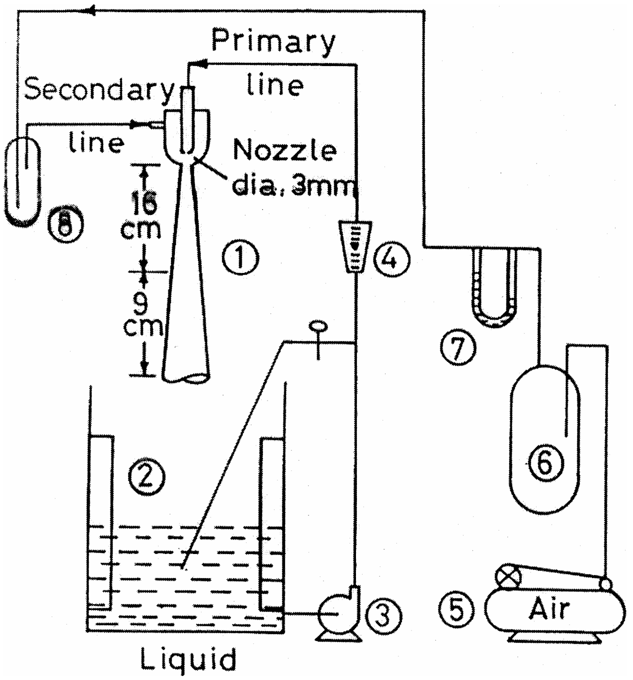

Fig. 1—Experimental set up for gas-liquid ejector. (1) Ejector; (2) Tank with baffles; (3) Centrifugal pump; (4) Rotameter; (5) Compressor; (6) Surge tank; (7) Flowmeter; (8) Mixing chamber

Table 1 — Details of the ejector

Driving nozzle diameter	3 mm
Main nozzle diameter	11 mm
Nozzle length	21 mm
Angle of diversion	9 degree
Throat diameter	3 mm
Throat length	21 mm
Suction tube diameter	44 mm
Material of construction	Glass

coalescence and attains a steady value by the time it reaches the end of the diverging section. In such situation the holdup also varies accordingly.

High speed photographic method

High speed photographic method is best suited for the bubble size measurement in this system. Only direct system of measurement is possible and high speed photography is adopted using a Fastax 8000 camera with 320 ASA 100 ft ORWO film at 700 frames per second speed and 5.6 to 8.0 diaphragm setting. Back lighting passing through a ground-glass sheet is kept behind the ejector to avoid curvature and bright spots effects. A reference marking (known length of wire) is also kept and picturised together to take care of the magnification factors. The details on this have been published elsewhere[6].

Sauter mean diameter

In each frame of the film, the ejector is divided into n segment of one cm height. For each segment, a number of frames about 30 at the same location are analysed and the individual bubble diameter (d_i) is measured. Then the Sauter Mean Diameter d_{32} is calculated using the formula:

$$d_{32} = \sum_{i=1}^{n}(N_i\, d_i^3) / \sum_{i=1}^{n}(N_i\, d_i^2) \qquad \ldots (1)$$

Similarly the Sauter Mean Diameter in all the segments are calculated. The maximum value of the bubble diameter, $d_{\max}$ has been theoretically estimated using the Sprow's correlation[10].

Holdup measurement

Gamma ray attenuation technique is used for holdup measurement in this gas liquid system. The main features of the reported work[9, 10] are highlighted here. The radiation attenuation method[11] for holdup measurement is based on the absorption of gamma rays from a radioactive source which can be measured and related to void volume fraction. The density of the substance is related to the attenuation of mono-energetic gamma ray by the equation

$$I = I_0 e^{(-\mu x)} \qquad \ldots (2)$$

The linear coefficient of absorption in turn, is related to the density of the absorber by the expression

$$\mu = (N/Z)\rho\sigma \qquad \ldots (3)$$

When the gamma ray is perpendicular to the layer of the two phase system, the equation for the holdup by Petrick and Swanson[11] is

$$\varepsilon = \ln(V/V_f)/\ln(V_e/V_f) \qquad \ldots (4)$$

Experimental set-up

The set up consisted of 60 mCi Thulium 170 radio active source (obtained from, Isotope Group, Bhaba Atomic Research Centre, Mumbai, India), a photo-multiplier tube with sodium iodide scintillation crystal, linear amplifier and counter (All these are supplied by Electronic Corporation India Ltd, Hyderabad). The gamma rays were directed through the test section of the ejector, where holdup is to be measured. The unabsorbed rays are received in the PM tube and signal produced. This signal is amplified and transmitted to the counter. The gamma assembly is mounted on a platform which encircles the ejector column. The platform can be moved up and down through a pulley arrangement and can be fixed at any location.

The experimental part is quite simple. The instrument is calibrated at the stipulated voltage (700 V). The source is loaded and the 'Counts' V_e are noted for the empty ejector (ε =1). Then the ejector is completely filled with the solution (ε =0) by temporarily fixing a rubber bung at the outlet and the 'Counts' V_f are noted. Then the actual air-liquid system is generated by the experimental conditions and 'Counts' V is noted. By substituting these in the above equation, the holdup value is found.

Theoretical holdup values are estimated using the feed data of air and the liquid flowrates, by using the following equation.

$$\text{Theoretical } \varepsilon = Q_{\text{air}} / (Q_{\text{air}}+Q_{\text{liquid}}) \quad \dots (5)$$

Interfacial area measurement

Four different liquid flowrates 75.8, 94.7, 113.6 and 132.6×10^{-6} m^3/s with corresponding air flow rate being 65.1, 68.4, 72.6 and 79.5×10^{-6} m^3/s have been tried for the bubble size and holdup measurement. These values are used to calculate the interfacial area using the equation.

$$a = 6 (\varepsilon) /\text{bubble diameter}$$

Experimental values of the interfacial area is calculated using d_{32} as bubble diameter and ε, holdup measured by radiation method, whereas theoretical interfacial area has been calculated using $d_{\max}$ as bubble diameter and ε, holdup based on flow rate of feeds. The results are shown in the figures, where the lines represent the theoretical values and the points give experimental values.

Results and Discussion

In the estimation of interfacial area for the gas liquid system in the ejector, measurements are made from a distance of 16 cm away from the nozzle and up to the end of the diverging section, since dispersion and bubble growth stabilize in this range. An explanation to this phenomenon has been given by Bhutada and Pangarkar[12]. Depending upon the pressure profile and mass ratio, various regimes of two - phase flow have been observed in the diverging section of the ejector. The flow regimes being coaxial and then homogeneous, bubbly flow are observed in this, which greatly influences the interfacial area generation. Hence up to a distance of 16 cm, coaxial flow occurs and there after, bubbly flow is observed in the ejector. Measurements are done within this range and are discussed here.

The relationship between interfacial area as a function of its distance from nozzle is shown in Figs. 2 to 5. It is seen for a given flow rate of air and liquid, the interfacial area decreases slowly as the dispersion is moving away from the nozzle. As the dispersion moves down in the ejector, the bubble size increases due to coalescence and this lead to the reduction in interfacial area. The value becomes steady when the dispersion reached the end of the divergent section of the ejector. This can be inferred from Fig. 6.

The flowrates for this system, sodium chloride – air are kept identical to that of earlier work on air-water system[8]. This gives greater advantage of comparing the ejector for its suitability to recommend it as a chemical contactor. Besides the effect of physical properties variation on holdup, bubble size and interfacial area can also be monitored. The concentration of sodium chloride is 2% (weight basis) and air is drawn through the compressor using proper filters.

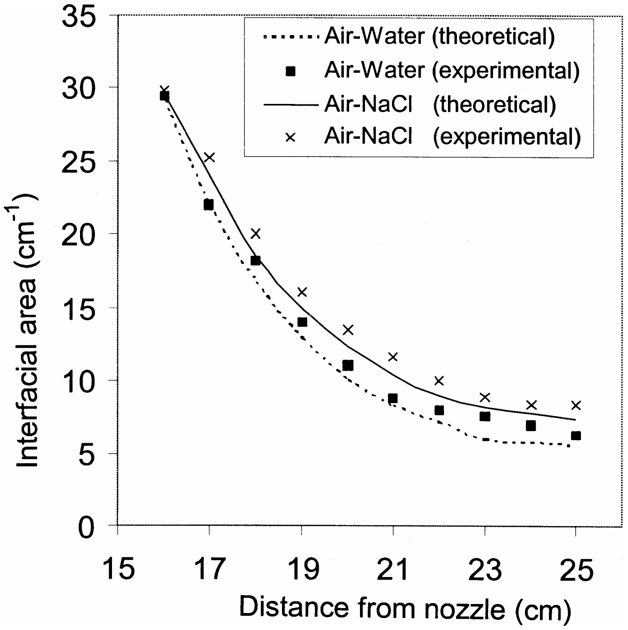

Fig. 2—Effect of interfaical area at different places from the nozzle for air flowrate of 65.1×10 $^{-6}$ m^3/s and liquid flowrate of 75.8×10^{-6}m^3/s

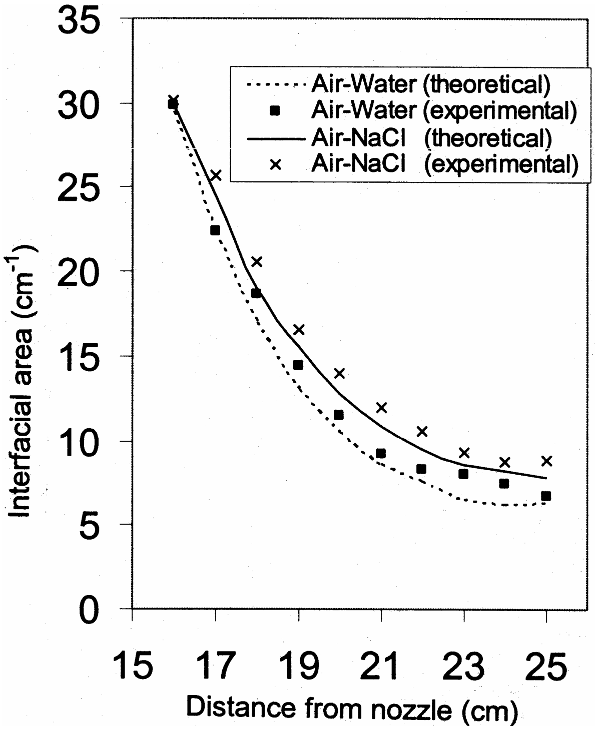

Fig. 3—Effect of interfacial area at different places from the nozzle for different systems with air flowrate of 68.4 × 10^{-6} m^3/s and liquid flowrate of 94.7 × 10^{-6} m^3/s

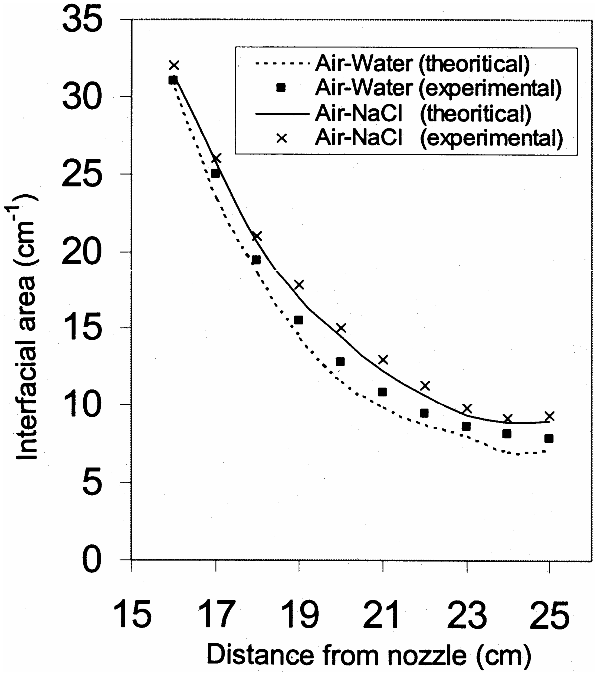

Fig. 5—Effect of interfacial area at different places from the nozzle for different systems with air flowrate of 79.5 × 10^{-6} m^3/s and liquid flowrate of 132.6 ×10^{-6} m^3/s

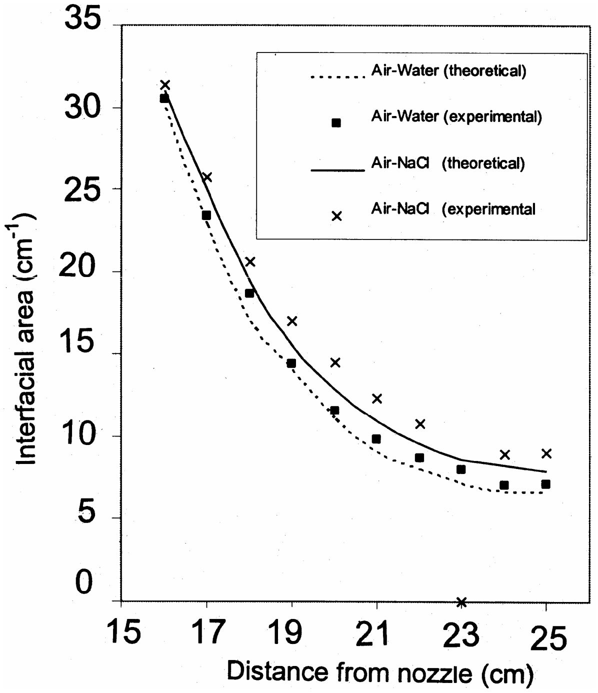

Fig. 4—Effect of interfacial area at different places from the nozzle for different systems with air flowrate of 72.6 × 10^{-6} m^3/s and liquid flowrate of 113.6 × 10^{-6} m^3/s

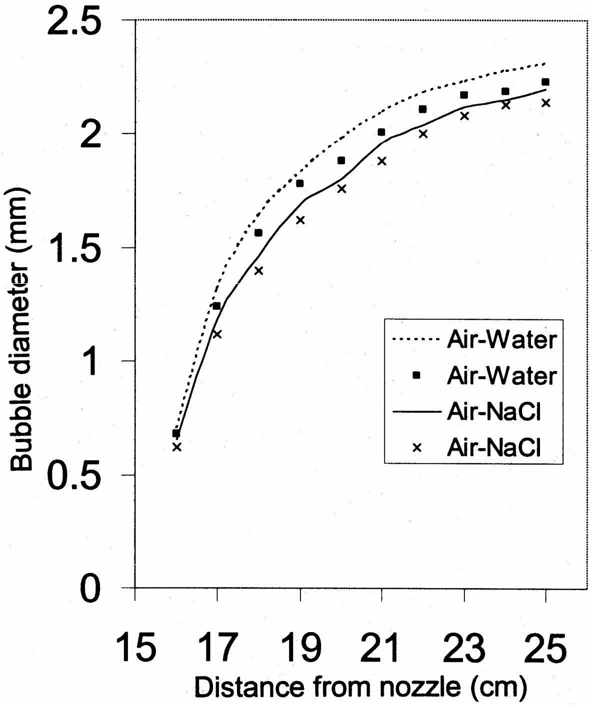

Fig. 6—Effect of bubble size at different places from the nozzle for different systems of air flowrate of 65.1 × 10^{-6} m^3/s and liquid flowrate of 75.8 × 10^{-6} m^3/s

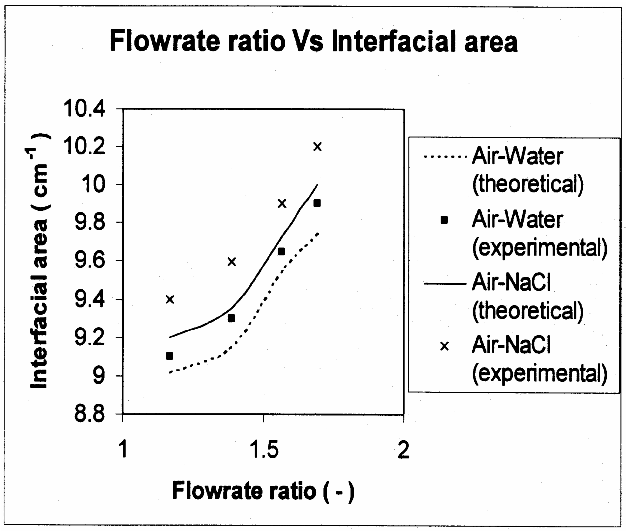

Fig. 7—Effect of interfacial area for different liquid to air flowrates for different systems.

The effect of liquid to air flow rate on the interfacial area generated in the system is shown in Fig. 7. As the liquid to air flow rate is increased, the velocity and thereby the kinetic energy of the liquid stream increases, but the bubble size decreases. This enhances the interfacial area, even though there is only a slight increment, which can be seen from the curve in the figure. Interfacial area is a linear function on both the diameter and the holdup. When both these two parameters decrease, the interfacial area should also decrease. However the decrease in bubble size is faster than the decrease in the holdup for air-chloride solution system and as a result the interfacial area increases, though it follows the above linear equation. This aspect is shown in the figure and this corresponds at the outlet of the ejector. The trend is same, similar curves for any segment in the ejector, between a distance of 16 cms from the nozzle upto the end of the diverging section of the ejector.

Conclusion

An experimental set up has been constructed to investigate the possible utilization of the gas liquid ejector as a chemical contactor. For this, the required data of bubble size and holdup are measured experimentally and the interfacial area calculated. In order to have these verified, theoretical considerations are made using Sprow's correlation for bubble size, holdup calculated and then theoretical interfacial area calculated. The results obtained are reasonably in good agreement and the interfacial area generated in the ejector (5-25 cm^2/cm^3) is relatively high when compared to the conventional contactors, like spray column (about 0.6 cm^2/cm^3), agitated vessels (about 2 cm^2/cm^3)[13] etc. This influences that the contactor can be recommended to be used as chemical reactor for systems like absorption, gas liquid reaction etc, with the advantage that there is no moving parts in the ejector.

Acknowledgment

The author is grateful to Prof R.Kumar for the immense help received in discussions and to Prof. T R Das for encouraging all throughout the work.

Nomenclature

a = interfacial area (m^{-1})
d_i = diameter of individual bubble (m)
d_{max} = maximum diameter of bubble (m)
d_{32} = Sauter mean diameter (m)
I = intensity of gamma ray at x (A/m^2)
I_o = intensity of gamma ray at source (A/m^2)
N = Avogadro number 6.028 x 10^{26} (nuclei/kg mole)
N_i = number of bubbles (-)
Q = flowrate (m^3/s)
V_e = counts, when the column is empty (-)
V_f = counts, when the column is full of liquid (-)
V = counts, for the actual two phase system (-)
x = thickness of the absorber (m)
Z = atomic weight (kg/kg mole)

Greek symbols

σ = microscopic absorption cross section (m^2/nuclei)
ρ = density of absorbing medium (kg/m^3)
ε = holdup (-)
ε = 1, when the column is devoid of liquid
ε = 0, when the column is full of liquid
μ = linear coefficient of absorption (m^{-1})

References

1 Reddy Y R & Kar S, *J Hydraulic Division, ASCE* 94, 5 (1968) 1261.
2 Ogawa S,Yamaguchi H,Tono S & OtakoT, *J Chem Eng Japan*, 16 (1983) 419.
3 Miyami K & Tojo K, *Chem Eng J,* 24 (1982) 89.
4 Lehr F & Mewes D, *Chem Eng Sci*, 56 (2001) 1159.
5 Majumdar S K, Kundu G & Mukherjee D, *Chem Eng J*, 122 (2206) 1.
6 Raghuram P T, Mukherjee A K & Das T R, *Indian Chem Eng,* XXXIII (1991) 75.
7 Raghuram P T, Mukherjee A K & Das T R, *Indian Chem Eng*, 34 (1992) 40.
8 Raghuram, P T & Das T R, *Indian J Chem Technol*, 13 (2006) 144.
9 Raghuram P T & Das T R, *Indian Chem Eng*, 38 (1996) 135.
10 Sprow F B, *Chem Eng Sci*, 22 (1987) 435.
11 Petrick M & Swanson B S, *The Review of Scientific Instruments*, 29 (1958) 1079.
12 Bhutada S R & Pangarkar V G, *Chem Eng Commun*, 61 (1987) 239.
13 Coulson J M & Richardson J F, *Chem Eng*, 3 (1971) 82.