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Influence of the sparger in a down flow jet loop reactor on the neutralization of alkaline solution by carbon dioxide absorption

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The gas absorption efficiency in an absorption tower is largely affected by the gas residence time and the absorption rate. Because of some major setbacks of packed columns, spray towers, bubble columns and agitated vessels such as high power consumption in an agitated vessel, huge pressure drop in a packed column and poor absorption rate in a bubble column, an alternative in the form of jet loop reactor has been developed by the researchers. In the jet loop reactor, the liquid jet performs the functions of distributing and dispersing the gas as fine bubbles in the liquid and also in circulating the gas liquid mixture by momentum transfer. To investigate the performance of a jet loop sparged reactor with a straight-throat ejector, CO_2 absorption experiments in alkaline solution were performed. In our study, we analyzed the performance of a jet loop sparged reactor based on alkaline solution neutralization time and CO_2 absorption by changing influent flow rates of the alkaline solution. We observed that due to the presence of sparger down the straight-throat ejector, the neutralization time of the alkaline solution by CO_2 in the reactor was reduced up to 50% when compared with that in a reactor with a conventional straight-throat ejector. Also, the absorption of CO_2 and production of Na_2CO_3 in the reactor with sparger was higher by about 10-15% than those in a reactor with conventional straight-throat ejector.

Keywords: Jet loop reactor, Jet loop sparged reactor, Straight-throat ejector, CO_2 absorption, Neutralization time.

INTRODUCTION

The gas absorption efficiency in an absorption tower is largely affected by the gas residence time and the absorption rate [1]. In order to achieve maximum absorption efficiency developments were made on many types of absorption equipment such as packed column, spray tower, bubble column and agitated vessel which are used in various applications. Because of some major setbacks of the above said systems such as high power consumption in an agitated vessel, huge pressure drop in a packed column and poor absorption rate in a bubble column an alternative in the form of a jet loop reactor has been developed by the researchers.

Bohner [2] developed a jet loop reactor that can form very small bubbles to achieve a higher absorption rate and to improve the turbulence intensity of the gas-liquid absorption system. The liquid jet performs the functions of distributing and dispersing the gas as fine bubbles in the liquid and also in circulating the gas-liquid mixture by momentum transfer. The majority of investigations reported on jet loop reactors considered a central draft tube and two fluid nozzles installed at the bottom of the reactor [3, 4]. This type of construction was characterized by a jet or an annular nozzle in which the liquid jet enters the reactor space through a nozzle which is in the centre of a gas jet. The operational difficulties such as blockage of nozzle and lower residence time of the gaseous phase led to the development of a new jet propelled loop reactor where gas was introduced from the top of the reactor [5].

Raghavan [6] reported that using the Venturi ejector in a reactor for air-water system, internal circulation and turbulence in the main holding tank, as well as external circulation of the dispersion were found to be low when compared with the straight-throat ejector. Secondary dispersion in the main tank was less uniform. In addition, the opposing buoyancy force of the gas bubbles resulted in relatively low internal and external circulation of the dispersion. When Venturi ejectors are used in the reactor to handle an electrolytic aqueous solution, the bubble sizes are much smaller because of shrinkage and breakage of primary bubbles at the exit of the throat.

Various authors have investigated the absorption of CO_2 in an alkaline solution by a down flow jet loop reactor with two fluid nozzles and also two fluid swirl nozzles [7-11]. However, no systematic investigation of the CO_2 absorption characteristics of a jet loop sparged reactor with a down flow straight-throat ejector nozzle has been reported in the literature.

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The present work was undertaken to study the performance of a jet loop sparged reactor based on alkaline solution neutralization time and CO_2 absorption by changing influent flow rates of the alkaline solution.

EXPERIMENTAL

The schematic diagram of the experimental setup used for the absorption of CO_2 in alkaline solution is shown in Fig. 1. The apparatus is made of an acrylic column of 14.2 cm i.d. and 60 cm height. The jet loop reactor consists of two sections, top gas induction tube of straight-throat ejector type and middle cylindrical tube. The gas induction tube is a Gi pipe of 3 cm diameter with CO_2 entry on top whereas the alkaline solution enters tangentially. The dimensions of the straight-throat ejector used in this work fell within the dimensional range of ejectors studied by Ogawa [12]. A sparger of 4 mm diameter as shown in Fig. 1 is attached at the bottom of the induction tube. According to Henry's law, the water pressure is greater at higher flow rate, which indicates that the increased pressure from the sparger allows greater dissolution of gases into the water [16]. The sparger used definitely determines the bubble sizes observed in the column. Perforated plates with small orifice, as shown in Fig. 1, enable the formation of smaller sized bubbles and greater gas hold up [17-19]. The solution is continuously withdrawn from the reactor and circulated back to the reactor through the gas induction tube by means of a liquid circulation pump *via* a calibrated flow meter. The high-velocity liquid flow through the nozzle sets up the suction of the gas into the reactor, which is the principle of the ejector mode operation.

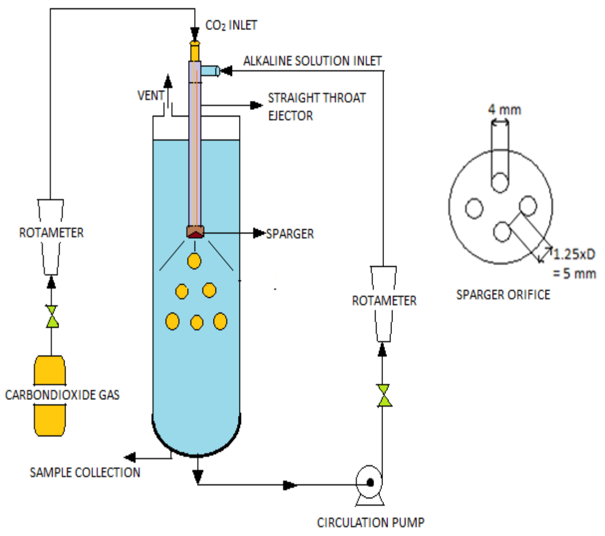

Fig. 1. Schematic diagram of the jet loop reactor

To operate the reactor, the jet loop sparged reactor was filled manually with 9 L of alkaline solution having a pH value of 11. The alkaline solution flowed into the liquid induction tube with the straight-throat ejector using the circulation pump. Simultaneously, the gas containing CO_2 was supplied through the gas induction tube. With the commencement of recirculation flow, the high velocity of the jet created a low pressure in the suction chamber which, when connected to the gas space, entrained the gas across the diffuser. It was subsequently dispersed in the circulating liquid both in the diffuser region and in the main holding vessel, depending on the operating variables such as gas and liquid flow rates and the pressure difference between the exit from the diffuser throat and the gas inlet. A good amount of the dispersed gas was also recirculated through the external pipeline as a gas-liquid mixture. The gas was separated and discharged through the gas discharge valve in the upper part of the reactor [13] and the liquid was recirculated through the circulation pump to outside the reactor and discharged again through the straight-throat ejector.

To compare the performance of the reactor containing a straight-throat ejector with and without sparger in the semi-batch mode, the straight-throat ejector with and without sparger was placed separately in the reactor initially filled with 9 L of the alkaline solution. The circulation flow rates (Q_R) of the alkaline solution were changed from 4 to 8 LPM, and the pH variations of the alkaline solution were measured at a constant gas flow rate (Q_G= 2 LPM). The time taken for the pH of the alkaline solution to be neutralized from 11.0 to 7.0 was defined as the neutralization time. In addition, the CO_2 absorption in moles per litre was continuously measured at constant time intervals by a standard titration method. About 10 ml of sample was collected at regular time intervals and titrated with 0.1 N HCl. Two indicators (phenolphthalein and methyl orange) were added to estimate the amount of CO_2 absorbed in the sample of alkaline solution.

RESULTS AND DISCUSSION

Neutralization time dependence on changes in the liquid circulation flow rate

To compare the performance of the straight-throat ejector with sparger and without sparger in the semi-batch mode, the pH variation characteristics affected by the changes in the liquid circulation flow rates (Q_R=4-8 LPM) were measured. This took place while the gas was continuously being injected into the jet loop reactors without sparger and with sparger separately at a constant gas flow rate (Q_G= 2 LPM). Figs. 2 and 3 show the tendency of the alkaline solution to be neutralized and of the pH to decrease during the continuous injection of the gas with an inlet CO_2 flow rate of 2 LPM. This was attributed to the absorption of the CO_2 in the gas into the alkaline solution, its reaction with OH-, and the neutralization of the solution. Based on such results, the time required for the pH of the initial alkaline solution to change from 11 to 7.0 due to the changes in the liquid circulation flow rate (Q_R) in the cases with and without sparger in a straight-throat ejector, that is, the neutralization time, was measured. The results are shown in Fig. 4.

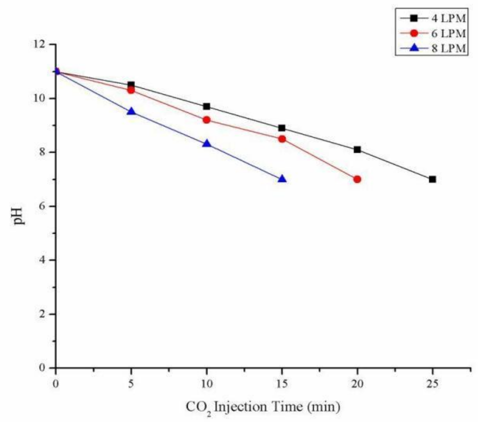

Fig. 2. pH changes with respect to the liquid circulation flow rates in the reactor without sparger at Q_G= 2 LPM.

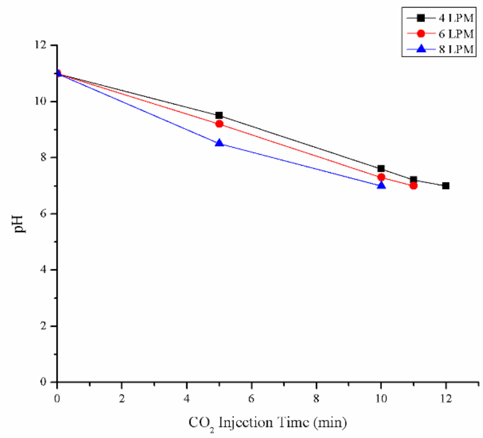

Fig. 3. pH changes with respect to the liquid circulation flow rates in the reactor with sparger at Q_G= 2 LPM.

The straight-throat ejectors without and with sparger presented above show different neutralization times (Fig. 4). The neutralization time decreased with the increase in the liquid circulation flow rate (Q_R), reaching its lowest value at 8 LPM. Because of the increase in the turbulence intensity as the liquid circulation flow rate increased and due to the increase in the mass transfer rate in the gas-liquid system, the neutralization time decreased. In all cases, the neutralization time was shorter for the reactor with sparger than without sparger at the same liquid circulation flow rate (Fig. 4).

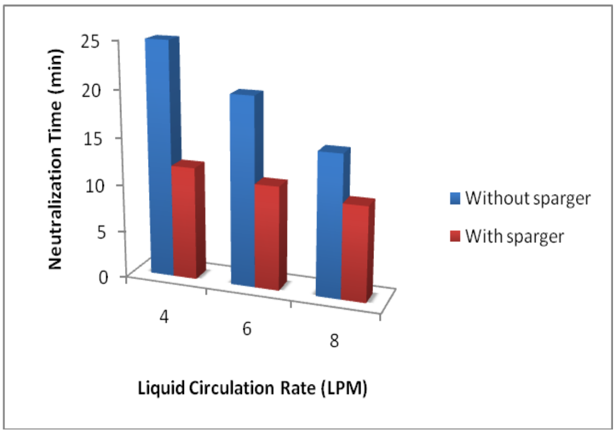

Fig. 4. Effect of the liquid circulation flow rate on the neutralization time at Q_G= 2 LPM.

This result was attributed to the turbulent flow formed at the sparger tip of the straight throat ejector. By design, the sparged reactor forms a turbulent flow and enhances the turbulence intensity in the gas and liquid films, thus resulting in an improved mass transfer rate between the gas and the liquid.

Carbon dioxide absorption

Absorption of CO_2 in the alkaline solution was estimated by a standard titration method. Sodium carbonate and water will be formed when CO_2 reacts with sodium hydroxide according to the following reaction (1):

$$2\ NaOH + CO_2\ (g) \Rightarrow Na_2CO_3 + H_2O \qquad (1)$$

When a known volume of the sample is titrated with 0.1 N HCl in presence of phenolphthalein, the acid reacts with all of the sodium hydroxide and only half of the carbonate. Similarly, when the sample is titrated with HCl in presence of methyl orange, the acid reacts with all of the hydroxide and all of the carbonate. Thus, we may be able to estimate the amount of CO_2 absorbed in the alkaline solution sample at regular time intervals once we calculate the amount of sodium carbonate produced. From Figs. 5 and 6 it is clear that CO_2 absorption shows an increasing trend with respect to flow rate and gas injection time. The one with sparger shows better absorption of CO_2 (about 0.653 moles / litre, see Fig. 6) for the same flow rate of 8 LPM and injection time of 20 min.

Sodium carbonate produced

Sodium carbonate (Na_2CO_3) produced as a result of CO_2 injection in alkaline solution was measured in order to predict the behaviour of the reactor without sparger and that with sparger as discussed in previous cases.

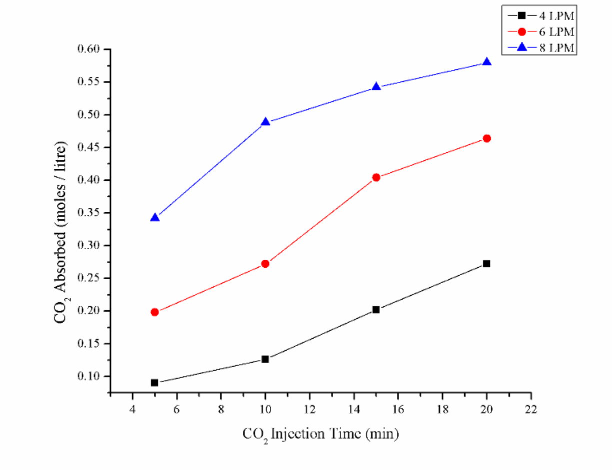

Fig. 5. Effect of CO_2 injection time on CO_2 absorption in alkaline solution with respect to the liquid circulation flow rates in the reactor without sparger at Q_G= 2 LPM.

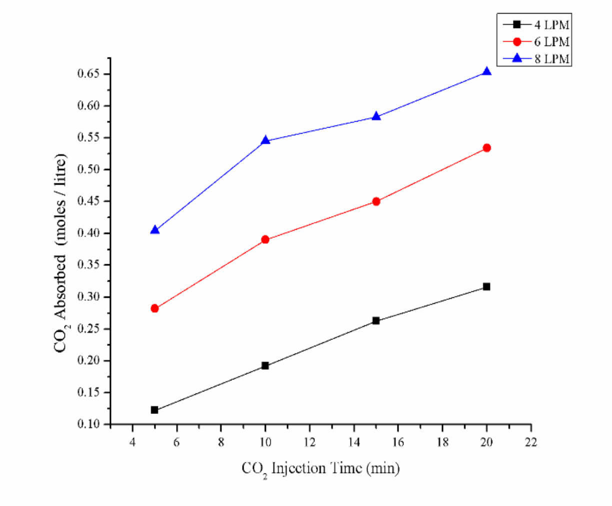

Fig. 6. Effect of CO_2 injection time on CO_2 absorption in alkaline solution with respect to the liquid circulation flow rates in the reactor with sparger at Q_G= 2 LPM.

The results presented in Figs. 7 and 8 show that the influence of the sparger in a straight-throat ejector for liquid flow rates (Q_R=4-8 LPM) towards the production of Na_2CO_3 is higher by about 10-15% for the reactor with a sparger compared to that without sparger.

Carbon dioxide mole fraction in the outlet gas stream

The mole fraction of CO_2 in the outlet gas stream increased as the solution pH decreased by th3 following reactions during the absorption of CO_2 in the alkaline solution [14, 15]:

$$CO_2\ (g) + H_2O \Leftrightarrow CO_2\ (aq) \quad (2)$$

$$CO_2\ (aq) + OH^- \Leftrightarrow HCO_3^- \quad (3)$$

$$HCO_3^- + OH^- \Leftrightarrow CO_2^{2-} + H_2O \quad (4)$$

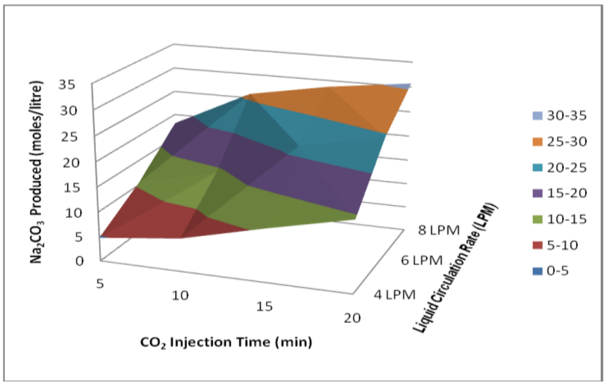

Fig. 7. Effect of CO_2 injection time and liquid circulation flow rates on Na_2CO_3 produced in the alkaline solution for the reactor without sparger at Q_G= 2 LPM.

In the alkaline solution with higher pH, the aqueous CO_2 absorbed in the solution by reaction (2) was rapidly consumed by reactions (3) and (4) because of the high OH^- concentration. However, reaction (3) was limited by the lower OH^- concentration in the solution with lower pH, as shown in Fig. 9. Therefore, the mole fraction of CO_2 in the outlet gas increased with the lower pH of the alkaline solution.

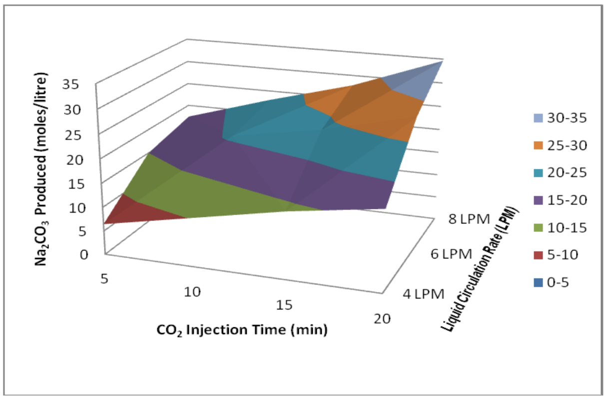

Fig. 8. Effect of CO_2 injection time and liquid circulation flow rates on Na_2CO_3 produced in the alkaline solution for the reactor with sparger at Q_G= 2 LPM.

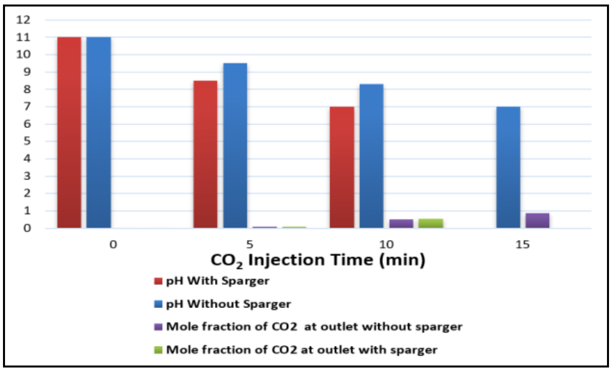

Fig. 9. Comparision of pH value and mole fraction of CO_2 in the outlet gas stream at Q_R= 8 LPM and Q_G= 2 LPM.

CONCLUSIONS

To investigate the performance of a jet loop reactor with a sparged straight throat ejector, CO_2 absorption experiments in the reactor were performed in an alkaline solution. The results obtained were compared with an equally sized jet loop reactor with a conventional straight-throat ejector. The following conclusions were made, summarized in Table 1.

1. At a constant gas flow rate (Q_G=2 LPM), the neutralization time in the jet loop reactor without and with sparger decreased with the liquid circulation flow rate (Q_R), reaching the minimum value at Q_R=8 LPM. Furthermore, the neutralization time decreased in the case of the straight-throat ejector with sparger compared to that without sparger at the same Q_R.

2. When CO_2 gas was continuously injected into the jet loop reactor without and with sparger, at an arbitrary time t, the CO_2 absorption was higher by about 10-15% when the straight-throat ejector with sparger was used compared to the one without sparger.

3. At a constant gas flow rate (Q_G=2 LPM) into the jet loop reactor without and with sparger, at an arbitrary time t, the Na_2CO_3 produced was found to be higher by about 10-15% when the straight-throat ejector with sparger was used compared to the one without sparger.

Table 1. Comparison of straight-throat ejector with and without sparger in a down flow jet loop reactor

S.No	Straight-Throat Ejector				
	Name of the investigation	Process variables	Without sparger (@ 8 LPM & 20 min)	With sparger (@ 8 LPM & 20 min)	Inference
1	Neutralization time (min)	Liquid flow rate (4,6,8 LPM)	15	10	50% decrease
2	CO_2 absorption (moles / litre)	CO_2 Injection time (5,10,15,20 min)	0.58	0.653	11% increase
3	Na_2CO_3 produced (moles / litre)		30.74	34.65	11% increase

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