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Capturing of Carbon Dioxide in Liquid Foam Bed Reactor

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Abstract—*A great threat is faced by environment and ecosystems due to a continuous increase in temperature on a global scale. Large emissions of carbon dioxide from various thermal power plants are the major concern, besides vehicular emissions. But, the compositions of flue gases from thermal-power plants consist of only 11-15 % v/v of carbon dioxide. At large scales of discharge, selective capture of carbon-dioxide gas at such low partial pressures is a great challenge. For this purpose, carbon-dioxide capturing plant requires either a large volume of solvent or a reactor having high gas-liquid interface areas and large contact times. A combination of liquid foam-bed reactor and a novel ionic liquid as absorbing medium offers maximal absorption of carbon-dioxide gas. Chemical absorption of carbon-dioxide gas in the aqueous triethylenetetrammonium lactate (TETAL) ionic-liquid solutions has been experimentally investigated in a semi-batch liquid foam-bed reactor.*

In this experimental investigation, efficient absorption of carbon dioxide is achieved through high gas-to-liquid ratios, long times of contact, and large gas-liquid interfacial areas in foam. The experiments are carried out using synthetic flue gas containing 15 % v /v of carbon-dioxide gas and 85 % v/v of pure N_2 gas. The parameters studied are foam-bed height, initial concentration of TETAL in aqueous solution, gas-flow rate, and the surfactant concentration in the aqueous solution of TETAL. The effects of height of foam bed and of gas-flow rate reveal the promise and potential of thefoam-bed reactor for the absorption of carbon dioxide.

Keywords: *TETAL, ionic liquid, absorption, carbon dioxide, foam-bed reactor.*

1. INTRODUCTION

In the earth atmosphere very minimal amount of carbon dioxide is present currently constituting 0.04%.But it has the capacity to retain heat which results in increase in the global temperature. In theKyoto protocol, 37 industrialized countries and the European Community committed to reduce Green House gas (GHG) emissions to an average of five percent against 1990 levels. During the second commitment period, Parties committed to reduce GHG emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020 on climate change shows concerned and started the required action on the reduction of carbon dioxide emission rate[1]. To reduce carbon dioxide gas emission, CO_2 separation and capture technologies are playing a significant role. Commercially used technologies for post combustion carbon capture system are absorption, adsorption, membrane separation and cryogenic distillation [2]. However the widely used technology for capturing low pressure CO_2 is the absorption process using a reactive solvents. The flue-gas stack of thermal power and petrochemical power plants consist of 14-15% carbon dioxide. Due to the low partial pressure of the CO_2, It is very difficult to capture it completely at large scale. For this purpose, carbon-dioxide capturing plant requires either a large volume of solvent or a reactor having high gas-liquid interface areas and large contact time. Liquid foam bed reactors were widely investigated by Kumar et al. as a gas-liquid contactors.The reactor can be operated in counter-current, co-current or static modes with respect to gas phase and liquid phase[3].

1.1 Description of foam bed reactor

Liquid foam bed reactor is a cylindrical column made of glass have two sections: storage section and foam section. The shallow pool of liquid composed of the storage section and the section contains the foam, is called as the foam section.The distributor plate made of metal was placed between the cylindrical column and the bottom conical section of the foam-bed reactor. The conical section is responsible for the uniform distribution of the stabilized flow of gaseous mixture through the distributor holes [4].Foam is generated by sparging the mixture of gases from the bottom of the distributor plate into the liquid. The Liquid hold-up and temperature in the foam can be measured with four tappings provided at various heights. Samples for analysis are taken from the storage section .The reactor can operate either in continuous mode or in semi-batch mode.In the semi-batch mode the gas is continuously passed through the batch of liquid and when both the gas and the liquid flow continuously along and across the reactor, the reactor is operating in the continuous mode.

1.2 Working and principal of foam bed reactor

On continuous gas supply in the storage section contains aqueous solution of surfactant and solvent, thegas bubbles come out from the liquid pool and form a bed of foams. Initially gas bubbles are spherical in shapewhich get distorted into polyhedrons[5]. The liquid in the foam section is present in the form of films and Plateau borders. In a foam bed, two adjacent bubbles are having a liquid film of pentagonal shape and at the junction of such three films a Plateau border is formed. The Plateau borders form an interconnected network.On continuous supply of gas mixture, the foam bubbles along with the associated films and Plateau borders move upward through the foam section. Due to the gravity there is a continuous thinning of the rising bubbles film and they are no longer stable. As a result, they break and released liquid returns to the storage section through the Plateau borders. The absorption of carbon dioxide took place at both sections partially in the liquid pool of storage section and completely in the foam section. Due to the continuous drainage of liquid from the foam section to the storage section the concentration of the storage section changes.The reaction is assumed to occur in the liquid films of foams surrounded by limited amounts of gaseous solute. The Plateau borders offers negligible contact area for reaction so no reaction assumed to be occur.

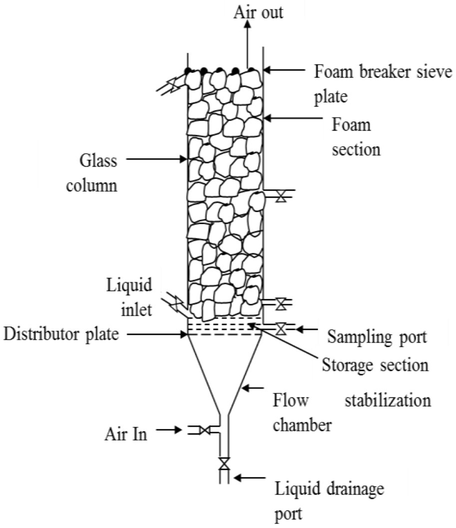


Fig. 1: Schematic diagram of the foam bed reactor

Description of Foam bed reactor:
Material of construction: Glass
Inner diameter of the reactor = 7.6×10^{-2} m
Outer diameter of the reactor: 9.6×10^{-2} m
Height of the foam-bed reactor = 0.7 m

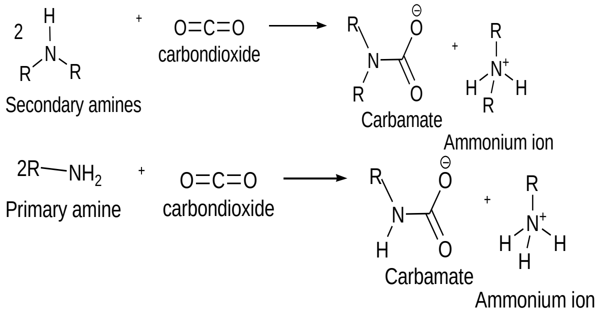
Description of distributor plate:
Material of construction: SS
Number of holes: 15
Diameter of 1 hole: 1×10^{-3} m

2. REACTION OF CARBON DIOXIDE IN FOAM BED REACTOR”

No reaction between sodium lauryl surfactant and carbon dioxide is assumed to occur due to the absence of basic sites.

3. REACTION MECHANISM

In an amine- based carbon dioxide capturing plant, the primary and secondary amines are converted into carbamate salt upon absorbing carbon dioxide [6].



De-protonation of ammonium ion took place in the presence of a base i.e. water, -OH, amine group species [7].

Due to the low stability of carbamate, it readily undergoes hydrolysis forming bicarbonates and releasing free amine molecules. The regenerated amine again reacts withmore carbon dioxide and thus the absorption capacity increases.

4. EXPERIMENTAL WORK

4.1 Chemicals

All chemicals used in the experiments were of analytical grade. Triethylene tetramine (TETA, CDH), Lactic acid (LOBA CHEMIE), Sodium lauryl sulphate (Sigma Aldrich), concentrated Hydrochloric acid (Sigma Aldrich), methyl orange indicator (Sigma Aldrich) were used without purification. Carbon dioxide (CO_2, 99.99%) and nitrogen (N_2, 99.99%) gases were purchased from Sigma Aldrich. Purity of gases was checked by ULTIMA-2100 series gas chromatograph of Nettle make. All solutions were prepared using de-ionised water in volumetric glassware.

5. EXPERIMENTAL SET-UP

The experimental set-up is shown in Fig. 2.

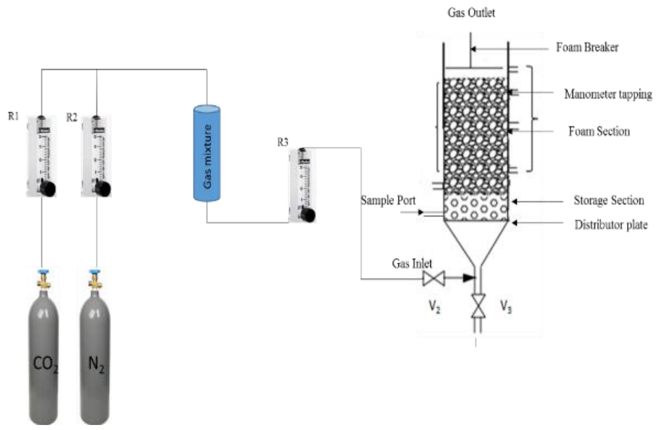


Fig. 2: Schematic diagram of Experimental setup

All the experiments were conducted at 298 K and 1 atm. For the experiment, the synthetic gas is prepared using 15 % CO_2 and 85% N_2 v / v. Calibrated rotameters are used for measuring the flow rate of each gases before and after entering the reactor.At the beginning of an experimental run, the glass column was thoroughly rinsed with distilled water. Initially the N_2 gas is passed through the reactor till a steady flow rate is attained .Then the reactor is charged with 100 ml of aqueous solution of ionic liquid and SLS surfactant with known concentration through the inlet port. The aqueous solution started foaming and the foam began rising through thecylindrical reactor column. With the help of sieve plate wetted with amyl alcohol suspended from the top break and maintain the foam at a required height.Once the foam height achieved, the CO_2 gas valve opened with a desired flowrate. As the reaction starts, samples of the reaction mixture were collectedfrom the storage section of the reactor through the sampling port using 1mm syringe at different time intervals till the reaction was complete. Thesesamples were analysedusing the chittik apparatus for the CO_2 absorbed bytitrating with 2M HCl solution. Eachexperiments wererepeated for getting the consistency in results.

6. RESULTS AND DISCUSSION

6.1 Effect of nature of surfactant

For the foam formation three different types of surfactants were tried out.

i. Non-ionic – Triton X-100 and Tween 80,
ii. Cationic – CTAB (cetyltrimethylammonium bromide), and
iii. Anionic – SLS(Sodium lauryl Sulphate)

The aqueous solutions of TETAL did not foamingwith the non-ionic surfactant even with less concentration. With CTAB, the foaming was well but large non-uniformity in the size of the bubbles and not stable.

The anionic surfactant foams well with aqueous solution of ionic liquid and have uniform sized bubbles shown in Fig. 3.

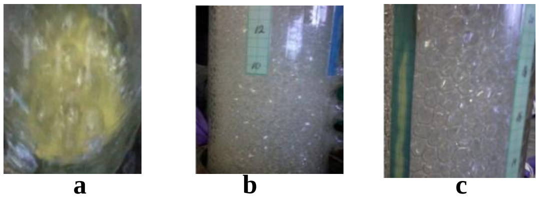

a b c

Fig. 3: Photographs of formation of foams with (a) Non-ionic (b)CTAB (c)SLS

Different researchers have analysed theeffect of different types of surfactants on gas-liquidinterfacial areas and observed a negligible effect on mass transfer coefficient[8].Surfactant molecules diffused through the liquid phase to thegas-liquid interface, and accumulated at the surface, thereby reducingthe interfacial area effective for mass transfer. In literature many researchers showed a continuous decrease in the valueof the mass-transfer coefficient with increasing surfactantconcentration in the liquid phase. In the present work, below the CMC concentration of SLS,there is a continuous decrease in the mass transfer coefficient and then at higher concentration there is a clear increase and thenremain constant as shown in Fig. 4. This reduction has been attributed to the increment in the transport resistance caused by thepresence of surfactant molecules on the gas liquid interface.

The concentration of surfactant used during the experiments were 8.18 $\times 10^{-4}$ M to 3.55 $\times 10^{-2}$ M.

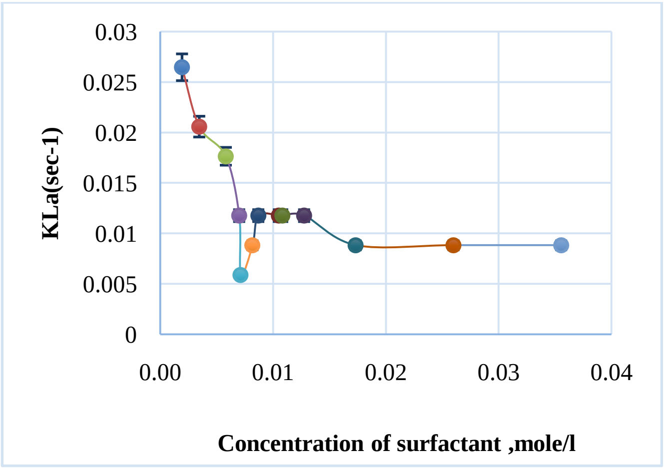


Fig. 4: Effect of concentration of surfactant on volumetric mass transfer coefficient

6.2 Effect of gas-flow rate

With the increase in gas-flow rate, the absorption of carbon dioxide increases due the increase in foam film thickness. As a result high concentration gradient of carbon dioxide is created which increases the masstransfer of the gas.The high gas flow rate also help in renewed the film surface and the space got free from the surfactant molecules[9].

During the experiment the gas-flow rate was increased from 9.58×10^{-5} m^3/s to 1.92×10^{-4} m^3/s, it was observed that the absorption of carbon dioxide increases till 1.73×10^{-4}. Further increase in flow rate did not show significant change as shown in Fig. 5.

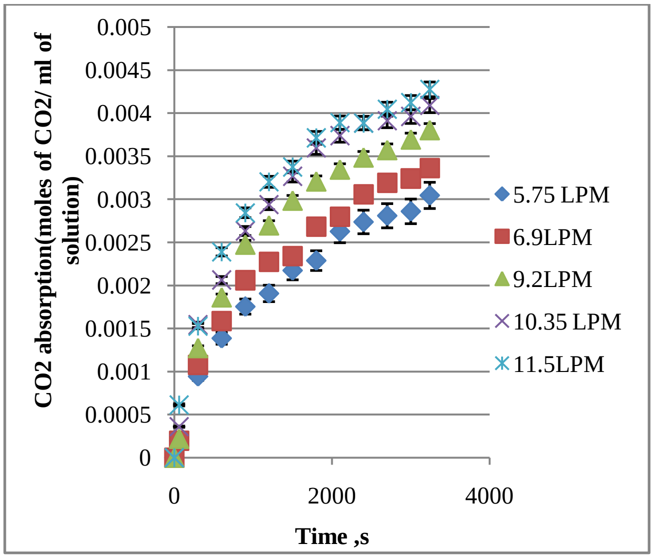


Fig. 5: Effect of gas flow rate on carbon dioxide absorption rate

6.3 Variation of Liquid hold up with height

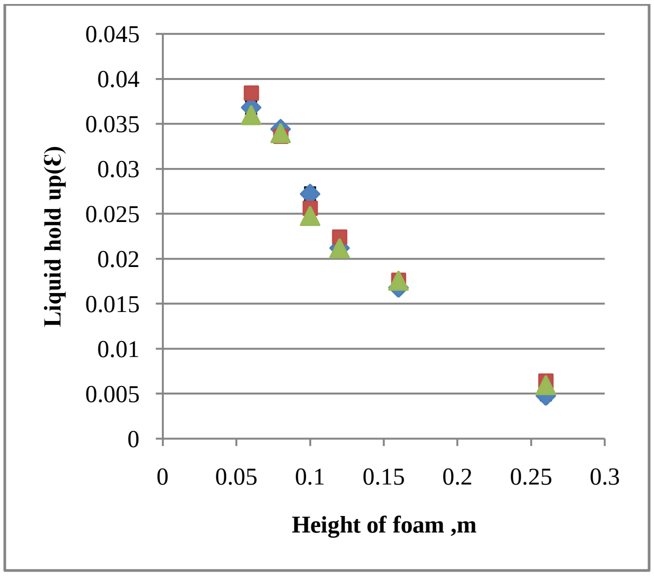


Fig. 6: Variation in liquid hold up with increasing height of the foam bed

The liquid holdup played a very important role in the absorption of carbon dioxide. As shown in Fig. 6, there is a gradual decrease in the liquid hold up with increased height of the column. This study reveals that the conversion of carbon dioxide into product decreases with height.

7. CONCLUSIONS

Liquid foam-bed reactor provides the higher gas to liquid ratio, high interface area and low pressure drop in comparison tothe other conventional reactors. Increased gas flow rate, low concentration of surfactant and high liquid hold up maximized the absorption of carbon dioxide in the given ionic liquid solution. There was an optimum surfactant concentration 1.73×10^{-2} M and optimum gas flow rate 1.92×10^{-4} m^3/s at which maximum conversion was achieved.

8. ACKNOWLEDGEMENTS

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REFERENCES”

[1] http://unfccc.int/kyoto_protocol/items/2830.php.

[2] Ramdin, M., de Loos, T.W., and Vlugt, T. J. H., “State-of-the-Art of CO_2 Capture with Ionic Liquids”,*Ind. Eng. Chem. Res.*, 51, 2012, pp. 8149−8177.

[3] Gaikwad, A. A., and Bhaskarwara, A. N.,” Absorption of pure carbon-dioxide gas in a foam-bed reactor”, *Proceedings of European Congress of Chemical Engineering (ECCE-6)Copenhagen*, 16-20 September 2007.

[4] Bhaskarwar, A.N., PhD Thesis, *Dept. of Chem. Eng*., 1986, IISc Bangalore.

[5] Biswas, J. and Kumar, R., *Chemical Engineering Science*, 36, 1981, pp. 1547-1556.

[6] Caplow, M.,“Kinetics of carbamate formation and breakdown”, *J. Am. Chem. Soc.*, 90, 1968, pp. 6795–6803.

[7] Crooks, J. E., and Donnellan, J. P., “Kinetics and mechanism of the reaction between carbon dioxide and amines in aqueous solution”,*J. Chem. Soc. Perkin Trans.*, 2, 1989, pp. 331–333.

[8] Sharma, R.K., Gaikwad, A. and Bhaskarwar A.N., *Chemical Engineering Communications*, 192, 2005, 597-619.

[9] Go´mez-Dı´az, D., Navaza, J.M., and Sanjurjo. B.,”Mass-Transfer Enhancement or Reduction by Surfactant Presence at aGas-Liquid Interface”,*Ind. Eng. Chem. Res.*, 48,2009, pp. 2671–2677.