



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 3, May 2015

# The Effect of Liquid Droplets and Fine Particulates on Mass Transfer with and without Chemical Reaction

D.E.Ibrahim<sup>1</sup>, H.M.Mustafa<sup>2</sup> and A.E.Elhassan<sup>3</sup>

<sup>(1)</sup> Karary University, Department of Chemical Engineering, Sudan.

<sup>(2-3)</sup> University of Science and Technology, Department of Chemical Engineering, Sudan.

**Abstract:** *The effect of fine inert particulates and immiscible liquid droplets on the mass transfer rate with and without chemical reaction has been studied; in a stirred vessel absorber, where carbon dioxide is absorbed in distilled water, aqueous sodium hydroxide solutions, a resin and a type of lubricating oil, respectively. It has been shown that the presence of the inert micro fine resin particulates decreases the mass transfer rate initially followed by an increase to a maximum and then a decline. The addition of oil decreases transfer rate for pure water drastically, as the oil droplets occupy part of the interfacial area. But -for the reacting system- an opposite effect occurred with an increase of the mass transfer rate up to a maximum and then a decline. It is noticed that the reacting system behaved in a different manner to that of the physical system, the alkaline solution reacted with the aqueous phase changing the physiochemical properties of the solution for example depressing effect of the interfacial tension.*

**Index term:** Absorption, CO<sub>2</sub>, resin particulates, oil droplets, enhancement factor.

## I. INTRODUCTION

Mass transfer with chemical reaction in multiphase systems has large practical relevance in the chemical industry, process metallurgy, biotechnology and environmental sciences [1, 2, 8].

The chemical reactions that are employed for separation purposes must be extraordinarily fast. At low reaction rate, chemical reactions change the bulk concentration of the transferring solute, thus increasing the driving force. While for reasonably fast reactions the concentration gradient near the interface is affected leading to an "enhancement" of the mass transfer rate [1].

Previous studies both experimental and theoretical on many types of micro phases were available in the literature dealing with gas absorption, liquid-liquid extraction and solid dissolution with and without accompanying chemical reactions [1, 2 and 10]. Many researchers consider the process as a process of micro phase catalysis [5].

The process of gas absorption and reaction in presence of such entities can be visualized as the transfer of gaseous solute across the gas liquid interface. At the same time while the diffusion process is proceeding the solute may also be taken by the fine particles or droplets and transferred to the bulk liquid-phase, i.e. providing another route to mass transport. This uptake of solute by the micro droplets or micro particles leads to a steeper concentration gradient in the vicinity of the interface resulting in an enhancement of the specific rate of mass transfer.

## II. MATERIALS AND METHOD

Materials used in this study are: Sodium hydroxide (NaOH) with concentration: 1N and 2N, carbon dioxide, distilled water, resin and oil. Resin specifications: The ion exchange resin produced by DOW Chemical Company, having a particle size of 500- 800 microns, particle diameter 0.15 mm, and Mesh size 100.

- Oil specifications: The oil was produced by "Tappco Lubricants" and having the designations of the table below.

A.C.E.A A3,B4,E2	API CH4 / SJ	MB 228.1,229.1	MAN 271
VDS.VW 505	ALLISON C4	MACKEO-LNMTU TYPE 1	

(A.C.E.A: European Automobile Manufacturer Association, API: American Petroleum Institute, MB: Mercedes Benz, VDS.Vw: Volkswagen)

**Equipment**

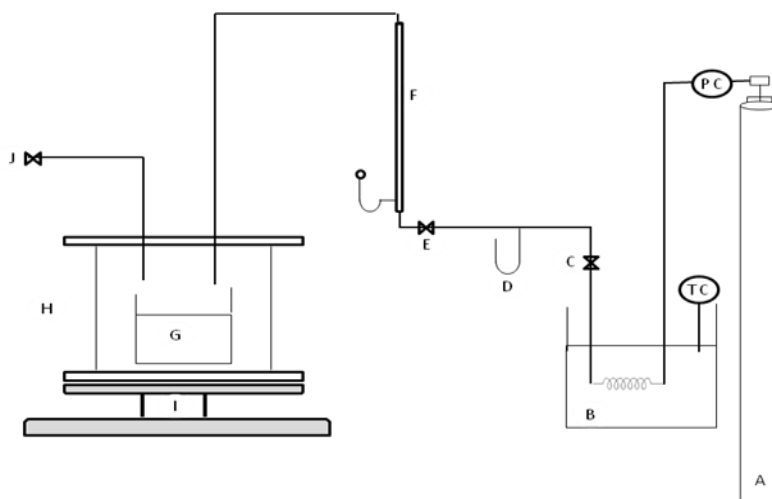
The apparatus used in this study was a magnetically stirred vessel. The stirred vessel absorber has been used by many authors [2] to get information on gas liquid reactions. The apparatus could be run batch wise –with respect to the liquid – or continuously if the change of the bulk composition is too rapid. Stirring could be providing by either a turbine, such as a mechanical agitator or by using a magnetic stirrer. A magnetic stirrer is used in this study. A schematic diagram of the unit is shown in Fig (2.1).

**Method**

Carbon dioxide,  $CO_2$ , was fed from a cylinder, A, via a pressure regulator, PC, to plastic coil in a constant temperature bath, B, thermostatically controlled to within  $\pm 0.1^\circ C$  then the gas flowed via stopcock valve E, into soap-bubble flow meters, F. From the soap-bubble meter the gas entered the absorption chamber H, the gas in the chamber reacted with the liquid reactant contained in the absorption vessel, G. the liquid in the absorption vessel was stirred continuously. The stirring action was produced by a magnet driven by the electric motor, I, with a magnetic follower dropped in the absorption vessel. The excess gas from the absorption chamber was vented to the atmosphere through tap, J.

Glass, Perspex and rubber were the materials used for construction of the apparatus and feed lines. The absorption chamber is essentially a glass section 15cm outside diameter 14.5 cm inside diameter 25cm long with four side arms for fittings connection. The vessel was provided with two cover plates (25×25) cm<sup>2</sup>, 6 ml thick. The top cover plate is fitted with a soft rubber ring having a 17cm outside diameter and groove of 0.5cm deep. The vessel and the cover plates were tightly assembled together with four tie rods having nuts and washers at each end.

The absorption vessel was a glass beaker 9.4cm outside diameter 0.2 cm thick and 11.5cm long. The vessel was placed concentrically inside the absorption chamber and provided with a magnetic follower dropped at the bottom of it. Stirring was produced by a magnetic stirrer, the electric motor and the stirrer magnet just beneath the bottom cover plate of the absorption chamber.



**Fig (2.1): Schematic Diagram of Absorption Apparatus**

- |   |                           |   |                   |
|---|---------------------------|---|-------------------|
| A | gas cylinder              | F | soap bubble meter |
| B | constant temperature bath | G | absorber vessel   |
| C | stopcock valve            | H | absorber chamber  |
| D | water manometer           | I | magnetic stirrer  |
| E | Valve                     | J | stopcock tap      |



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 3, May 2015

III. RESULTS AND DISCUSSION

A. Experiments were done in two parts:

Firstly: The Physical Absorption experiments were done as:

- Absorption of carbon dioxide in distilled water.
- Absorption of carbon dioxide in distilled water with resin.
- Absorption of carbon dioxide in distilled water with oil.

Secondly: the chemical absorption experiments were done as:

The system carbon dioxide / sodium hydroxide was chosen because it is well characterized in terms of the physicochemical properties and the reaction is known to be very fast with a high rate constant. The chemical absorption experiments were done as:

Absorption in 1N NaOH:

- Absorption of carbon dioxide in Sodium hydroxide 1N.
- Absorption of carbon dioxide in Sodium hydroxide 1N with resin.
- Absorption of carbon dioxide in Sodium hydroxide 1N with oil.

Absorption in 2N NaOH:

- Absorption of carbon dioxide in Sodium hydroxide 2N.
- Absorption of carbon dioxide in Sodium hydroxide 2N with resin.
- Absorption of carbon dioxide in Sodium hydroxide 2N with oil.

The data was collected as the absorption rate per unit area,  $\bar{N}_T$  at 26°C against time and for different particulate amounts. The results of experiments were tabulated in Table (3.1 and 3.2) and plotted enhancement  $\phi$  versus amount of particulates and droplets added in Fig (3.1 and 3.2).

Enhancement factor  $\phi$  can be defined the ratio of the average rates of mass transfer in presence of reaction to the average rate without reaction.

Effect of inert fine solid particulates:

The results so obtained are reported in table (3.1) and plotted Fig (3.1) for the effect of the resin:

Table (3.1) the effect of resin on absorption rate of carbon dioxide into Distilled water and 1N, 2N Sodium hydroxide

Amount of resin (gms/400mls solution)	Enhancement factor		
	Water	1N NaOH	2N NaOH
0	1	1	1
5	0.64	0.74	0.77
10	1.73	1.85	2.159
15	2.33	2.67	2.85
20	0.6	0.69	0.73
25	0.38	0.466	0.53

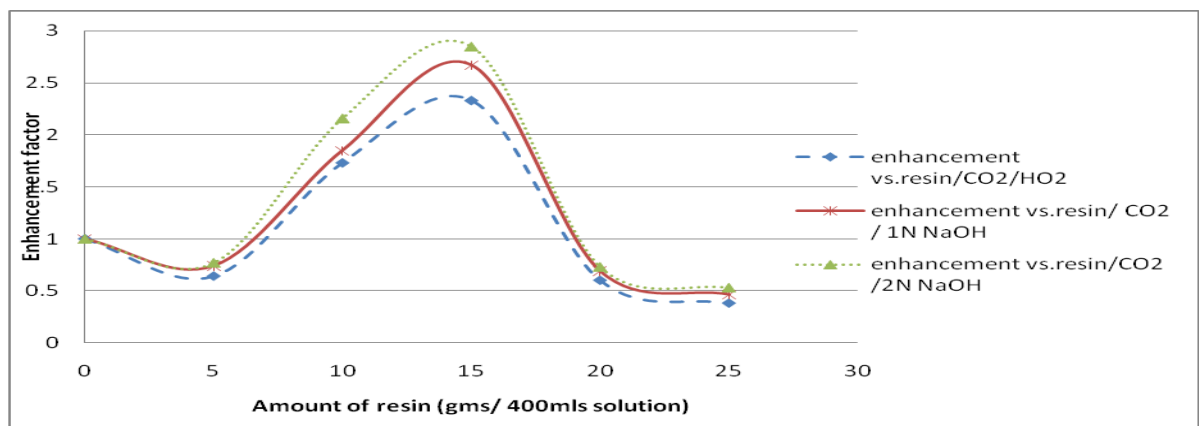


Fig (3.1): enhancement versus resin particulates added to CO2 /water, CO2 / 1N NaOH and CO2 / 2N NaOH systems



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 3, May 2015

The figure shows a decrease at the beginning and an increase at maximum and then a decline. At the loading of 0.01125gm/ml minimum values were observed for 0.61 for distilled water, 0.7 for 1N NaOH and 0.71 for 2N NaOH. There the particulates are occupying part of the interphase; this is followed by an increase.

The plots show an increase of the enhancement with the particulate hold up to a maximum at the loading of 0.035 gm/ml maximum values were observed 2.395 for distilled water, 2.7 for 1N NaOH and 2.9 for 2N NaOH. Hence the optimum amount to be added is the value of 0.035 gm/ml.

This is in agreement with previous studies [1, 4 and 11] that the fine particulates provide another route to mass transfer as the solute may be taken by the particulates, leading to a steeper concentration gradient around the interface causing this observed enhancement.

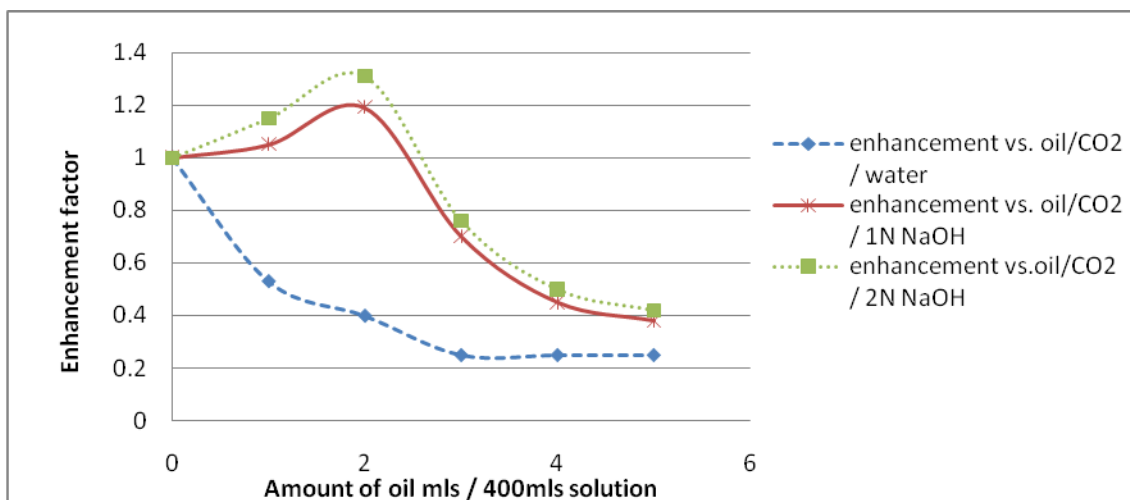
After the maximum value a gradual decrease is observed with increase of particulate loading, the rate falls further to very low values that showed that the particulates are now having a negative effect retarding the rate of mass transfer. This is explained that the particles are occupying part of surface hence reducing the interfacial area. Particulates may also affect the interfacial tension and viscosity of the reacting solution.

**Effect of inert liquid (oil) droplets**

The effect of oil on absorption rate of carbon dioxide into distilled water and 1N, 2N Sodium hydroxide are reported in table (3.2) and plotted in figure (3.2).

**Table (3.2) the effect of oil on absorption rate of carbon dioxide into distilled water and 1N, 2N Sodium hydroxide**

Amount of oil (gms/400mls solution)	Enhancement factor		
	Water	1N NaOH	2N NaOH
0	1	1	1
1	0.53	1.05	1.15
2	0.399	1.19	1.31
3	0.25	0.7	0.76
4	0.25	0.45	0.50
5	0.25	0.38	0.42



**Fig (3.2): enhancement versus Oil Droplets added to CO<sub>2</sub> / water, CO<sub>2</sub> / 1N NaOH and CO<sub>2</sub> / 2N NaOH systems**

From the figure (3.2) it is noticed that the addition of oil decreases transfer rate for pure water drastically. This decrease starts from the beginning falling to 0.25 at 3 gm/400ml loading and remaining constant thereafter. Addition of oil is expected to affect the physicochemical properties of the resulting mixture. The oil droplets are



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 3, May 2015

immiscible in water and decrease the absorption rate. Different amounts of oil were added to the 1N and 2N aqueous solutions of sodium hydroxide. For the reacting system an opposite effect occurred with the increase of the factor up to a maximum. 1.32 for 0.0045 for 2N NaOH and 1.2 for 0.0045 for 1N NaOH. After the 2 ml loading the enhancement parameter declines, this maybe attributed to oil phase accumulating at the interface decreasing the area available for mass transfer and also its depressing effect on the interfacial tension. Thus the chemical reaction affects the transfer processes and as the strength of the NaOH increases the factor increases.

#### IV. CONCLUSION

From the above results, the effect of micro-fine resin particulates on the rate of absorption of carbon dioxide into distilled water, 1N and 2N sodium hydroxide aqueous solutions has been investigated. It has been shown that the presence of the inert micro fine resin particulates decreases the mass transfer rate initially followed by an increase to a maximum and then a decline. This retardation in mass transfer rate is attributed to the reduction of the interfacial area available to mass transfer as the solid phase started to exert its bulk effect.

The addition of oil decreases transfer rate for pure water drastically. This decrease starts from the beginning falling to a low loading and remaining constant thereafter. Here again the oil droplets that are immiscible with water decrease the interfacial area. When different amounts of oil were added to the 1N and 2N sodium hydroxide aqueous solutions-for this reacting system- an opposite effect occurred with the increase of the factor up to a maximum and then the enhancement parameter declines.

#### ACKNOWLEDGEMENT

The authors wish to thank the College of graduate studies scientific research, of Karary University, for their support. This research is made in partial fulfillment of the requirements for the degree of Ph.D. in Chemical Engineering at Karary University.

#### REFERENCES

- [1] Alper, E. editor, Mass Transfer with Chemical Reaction in Multiphase Systems, vol. 2, Three Phase Systems, ASI Series, Martinus Nijhoff Publishers, The Hague, 1983.
- [2] Astarita, G., Mass Transfer and Chemical Reaction, Elsevier, Amsterdam, 1966.
- [3] Clegg, G.T. and Mann, R. 'A penetration model for gas absorption with first order chemical reaction accompanied by large heat effects', Chem. Eng. Sci. v 24, pp. 3 21-329, 1969.
- [4] Mehra, A., "Heterogeneous Modeling of Gas absorption in Emulsions", Ind. Eng. Chem. Res., v 38, pp. 2460-2468, 1999.
- [5] Mehta, V.D. and Sharma, M.N., "Mass transfer in mechanically agitated gas-liquid contactors", Chem. Eng. Sci., v 26, pp.461-479, 1971.
- [6] Mustafa, H.M. and El Amin I.H.M, "The enhancement factors for the absorption of carbon dioxide into aqueous solutions of sodium phenoxide", J.Eng.Sci, King Saud Univ., v14 (2) pp183-196, 1988.
- [7] Quicker, C. et'al, "Effect of fine activated carbon particles on the rate of carbon dioxide absorption", A.I.Ch.E. J. v.33, pp. 871-875, 1987.
- [8] Sharma, M.N., "perspective in gas-liquid reactions", Chem EngSci, v 38, pp. 21-28, 1983.
- [9] Venugopal, B.V. and Mehra, A., "Gas absorption accompanied by fast chemical reaction in water-in-oil emulsion", Chem. Eng. Sci., v 49, n.19, pp. 3331-3336, 1994.
- [10] Vinke, H. et'al, "Enhancement of the gas-absorption rate in activated slurry reactors by gas-adsorbing particles adhering to gas bubbles", Chem. Eng. Sci., v 48, n.12, pp. 2197-2210, 1993.