The Effect of Surfactant Concentration on the Rate of CO_2 Absorption by Carbonate Solution in Packed Tower

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Abstract
Absorption of carbon dioxide from gaseous mixture (carbon dioxide, air) was studied by using Carbonate Solution (Na_2CO_3) in a counter-current packed column (7.5 cm id, 1.70 m height), packed with glass rashing rings of 1.8 cm i.d to a depth of 1.1 m.

The effect of Surfactant concentration (dodecyl benzene sulfuric acid sodium (DBS))(0.5, 1.5, 2.5gm/lit.), gas mass flux (0.05, 0.075, 0.1 kg/m^2.sec) and liquid mass flux (kg/m^2.sec) on the absorption rate of carbon dioxide and mass transfer coefficient was studied at constant carbonate concentration (0.3 kmol/m^3), inlet carbon dioxide concentration(0.08, Y_2=0.086 mol CO_2/mol air), ambient temperature and atmospheric pressure. The results show that the absorption rate tends to increase with increasing gas and liquid flow rate. Mass transfer coefficient (K_G.a) increases with increasing liquid flow rate and slightly change with increasing gas flow rate. Increasing surfactant concentration (decreasing surface tension) leads to decrease the absorption rate and mass transfer coefficient.

Keywords: Surfactant (DBS) , Absorption with chemical reaction, carbon dioxide, Carbonate Solution, Mass transfer Coefficient

تاثير تركيز المواد المقللة للشد السطحي على معدل امتصاص غاز ثنائي اوكسيد الكاربون بواسطة محلول الكاربونيت في الاعمدة المحشوة

الخلاصة
تم امتصاص ثاني اوكسيد الكربون من الهواء باستخدام عمود الامتصاص المحشو ذو جريان متعاكس, حيث كان العمود بقطر 7.5سم وارتفاع 1.7م محشو بحشوة زجاجية حلقية ذات قطر 1.8سم وارتفاع 1.1سم.

تم دراسة عدد من العوامل المؤثرة على معدل الامتصاص ومعامل انتقال الكتلة لغاز ثاني اوكسيد الكربون بوجود مادة شد سطحي انيونية (dodecyl benzene sulfuric acid sodium) (DBS) كمادة مقللة للشد السطحي, وهذه العوامل هي معدل جريان السائل والغاز وتركيز مادة الشد السطحي بثبوت تركيز محلول كاربونات الصوديوم عند 0.3 كيلومول/ م 3 وتركيز ثاني اوكسيد الكاربون الاولي (0.08, Y_2=0,086 مول ثاني اوكسيد الكاربون /مول هواء) وعند ضغط ودرجة حرارة الجو.

اظهرت النتائج بان معدل الامتصاص يزداد بازدياد معدل جريان الغاز والسائل. اما معامل انتقال الكتلة (K_G.a) يزداد بازدياد معدل جريان السائل ويتاثر قليلا بازدياد معدل جريان الغاز. زيادة تركيز المادة المقللة للشد السطحي (يقلل الشد السطحي) يؤدي الى تقليل معدل الامتصاص ومعامل انتقال الكتلة.

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Introduction

Removal of carbon dioxide from gaseous mixtures is of vital importance in the natural gas processing to reduce the costs of compression and transportation and in ammonia manufacture. Carbon dioxide removed from hydrogen stream, since it poisons the catalyst for the reaction between hydrogen and nitrogen.

In principle, many processes are employed for the removal of carbon dioxide, but the use of liquid solvents is economically attractive [(1)]. Water was employed as an absorbent in early processes, but has been largely replaced by reagent solutions that react chemically with dissolved carbon dioxide [(2)].

Aqueous solutions of ethanolamine such as MEA, DEA are widely used for the removal of carbon dioxide from gaseous streams. Potassium and sodium carbonate solutions are the most commonly employed chemical absorbents especially for bulk carbon dioxide removal, because of their low cost, large capacity, ease of handling and relative ease of regeneration[(3,4,5,6,7)]

Eillis et al [(8)], studied the absorption rates of carbon dioxide in a mixture of potassium carbonate and monoethanol amine and observed a significant rate promotion effect and the absorption rates were controlled by liquid.

Gents et al [(9)], studied the effect of adding an immiscible liquid phase on the gas absorption rate of carbon dioxide in carbonate-bicarbonate buffer solution catalyzed by sodium hydrochloride. They observed that the addition of 1-octanol and toluene caused an enhancement of mass transfer rate.

Zhao et al [(10)], studied the absorption of carbon dioxide in a bubble column with an anionic surfactant in the carbonate-bicarbonate buffer solution, They observed that the presence of surfactant decreases the individual mass transfer coefficient and absorption rate.

Sumin et al [(11)], studied the absorption of carbon dioxide in carbonate solution (K_2CO_3) n the presence of activated carbon particles and found that the absorption rate enhanced significantly , and the maximum enhancement factor 3.7 was observed.

The theory of gas-liquid absorption with chemical reaction is sufficiently established and known [(12)]. Film theory will be considered in the present work, which assumed that the mass transfer takes place by molecular diffusion through stagnant liquid layer [(13)]. When carbon dioxide is absorbed into carbonate solution, it reacts in this layer, the carbonate first reacts with water to generate hydroxyl ions which then react with carbon dioxide according to the following reaction in the ionic terms:

$$CO_3^{-2} + H_2O \Leftrightarrow HCO_3^- + OH^- \quad \ldots\ldots(1)$$

$$CO_2 + OH^- \Leftrightarrow HCO_3^- \quad \ldots\ldots(2)$$

The overall reaction is:-

$$CO_2 + CO_3^{-2} + H_2O \Leftrightarrow 2HCO_3 \quad \ldots\ldots(3)$$

The reaction (2) is slow [(14, 13)] and rate determining ,and the kinetics of the reaction have been determined to be second order [(15)].

Numerous experimental work have been carried out to study the effects of superficial gas and liquid velocities as well as the viscosity of the liquid phase, while the surface tension of the liquid phase are seldom investigated. Therefore the present work aimed to study the effects of surface tension of liquid phase on the absorption rate of carbon dioxide in carbonate solution (0.3 kmol/m^3) at ambient temperature and atmospheric pressure. An anionic surfactant (dodecyl benzene solfonic acid sodium (DBS)) used as surface tension modifier.

Experimental work

A schematic diagram of the experimental apparatus employed throughout this work is shown in Fig.(1).Absorption column is the principal parts of the apparatus used in the present work .It was constructed from (QVF) column of 7.5cm i.d. x 1.7 m height (of adequate ratio of column diameter to packing 8to1).The packed was made from a glass Rasching rings(20mm o.d.x 19mm i.d. x 20mm long),100cm height of packing was used. The packing support was a perforated stainless-steel with 64 holes of 0.9cm diameter.

The liquor (1,2.5,4 and 5.5 kg/m^2.sec) and gaseous(0.05, 0.075 and 1 kg/m^2.sec) mixture flow rates introduced at the top and bottom of the column respectively through the distributors were located at the top and bottom of the packed section. For the gases distributor a perforated ring type gas distributor was used of 18 holes, each hole is of 1mm diameter. This distributor had concentric copper ring with 9 cm diameter. The ring was a pipe of 1cm OD and length equal to its circumference.

The spent absorption discharge from bottom of the column through a pipe connected to a three way valve which is manually operated and the samples for the spent absorbent were taken from the column through this sampling device. The gases left the column at the top through a pipe to the atmosphere.

Gaseous flow rate and liquor flow rates were measured by a calibrated rotameters. Teflon cylindrical vessel of 0.1m^3 were used in the present work for the preparation of feed absorbent solution. The bottom of the vessel connected with rotary pump (type Mono pump) through three-way valve, for pumping the solution to the absorber. The outlet liquid from the bottom of the column that drawn to the drain.

Results and Discussion

Results:

Absorption rate of carbon dioxide into carbonate solution with anionic surfactant calculated from the material balance with chemical reaction as follows:

$$G' \frac{y_2}{1-y_2} + L_m C_B = G' \frac{y_1}{1-y_1} + L_m C_{B0} \quad ....(4)$$

CO_2 %removed = $y_2 - y_1$ ....(5)

Carbon dioxide absorbed "N"= CO_2 flux input $\times CO_2$ % removed ....(6)

$$Carbonate\ conversion(\%) = \frac{Carbonate\ reacted}{Carbonate\ input} \quad .....(7)$$

Overall mass transfer coefficient based on the gas phase (K_G.a) can be calculated as follows [16]:

$$k_G.a = \frac{G'}{PZ} Ln \frac{Y_2}{Y_1} \quad .... (8)$$

Table (1) presents the experimental results of carbon dioxide absorption.

Discussion

- **Effect of gas flow rate**:

Figs. (2, 3) show the effect of gas flow rate on the absorption rate and mass transfer coefficient at a given liquid flow rate and different surfactant concentration. It is clear that the absorption rate increases with increasing gas flow rate, while the mass transfer coefficient are slightly affected with the increasing gas flow rate. This merely confirms the fact, that the absorption of carbon dioxide is entirely controlled by the conditions in the liquid phase. These results are in agreement with the finding of Yih et al [17].

- **Effects of liquid flow rate:**

Figs. (4, 5 and 6) show the effect of liquid flow rate on the absorption rate of carbon dioxide in carbonate solution at a given gas flow rate and different surfactant concentration. Similar effect of liquid flow rate on mass transfer coefficient are shown in figure (7, 8 and 9).It can be seen that the absorption rate and mass transfer coefficient increases with increases liquid flow rate. This is due to increase in thickness of liquid layer on packing and so more liquid will be available to take up a given quality of carbon dioxide. Hence the concentration gradient of free carbon dioxide in the liquid will be greater, leading to increase the rate of absorption and mass transfer coefficient. These results are in agreement with previous finding of Zhao et al [10] and Yih et al [17].

- **Effect of surfactant concentration:**

Figs. (10-15) show the effect of surfactant concentration on absorption rate and mass transfer coefficient at a given gas flow rate and different liquid flow rate. It can be noticed from these figures that the absorption rate of carbon dioxide and mass transfer coefficient tends to decrease with increasing surfactant concentration. This reduction may be attributed to the effect of surface –active agent, which can reduce the interfacial moment when it occupies part of the surface of the packing, These result are in agreements with the previous findings of Zhao et al [10] and Vazquez et al [18]. Table (2) show the effect of surfactant concentration of the carbonate concentration.

Conclusions

The following points are concluded from the present work :

1. The presence of surfactant induced reduction of the absorption rate and mass transfer coefficient of carbon dioxide in carbonate solution.
2. Mass transfer coefficient and absorption rate of carbon dioxide will be increased with increasing the liquid flow rate.
3. Increasing the gas flow rate leads to slightly increase in the mass transfer coefficient.

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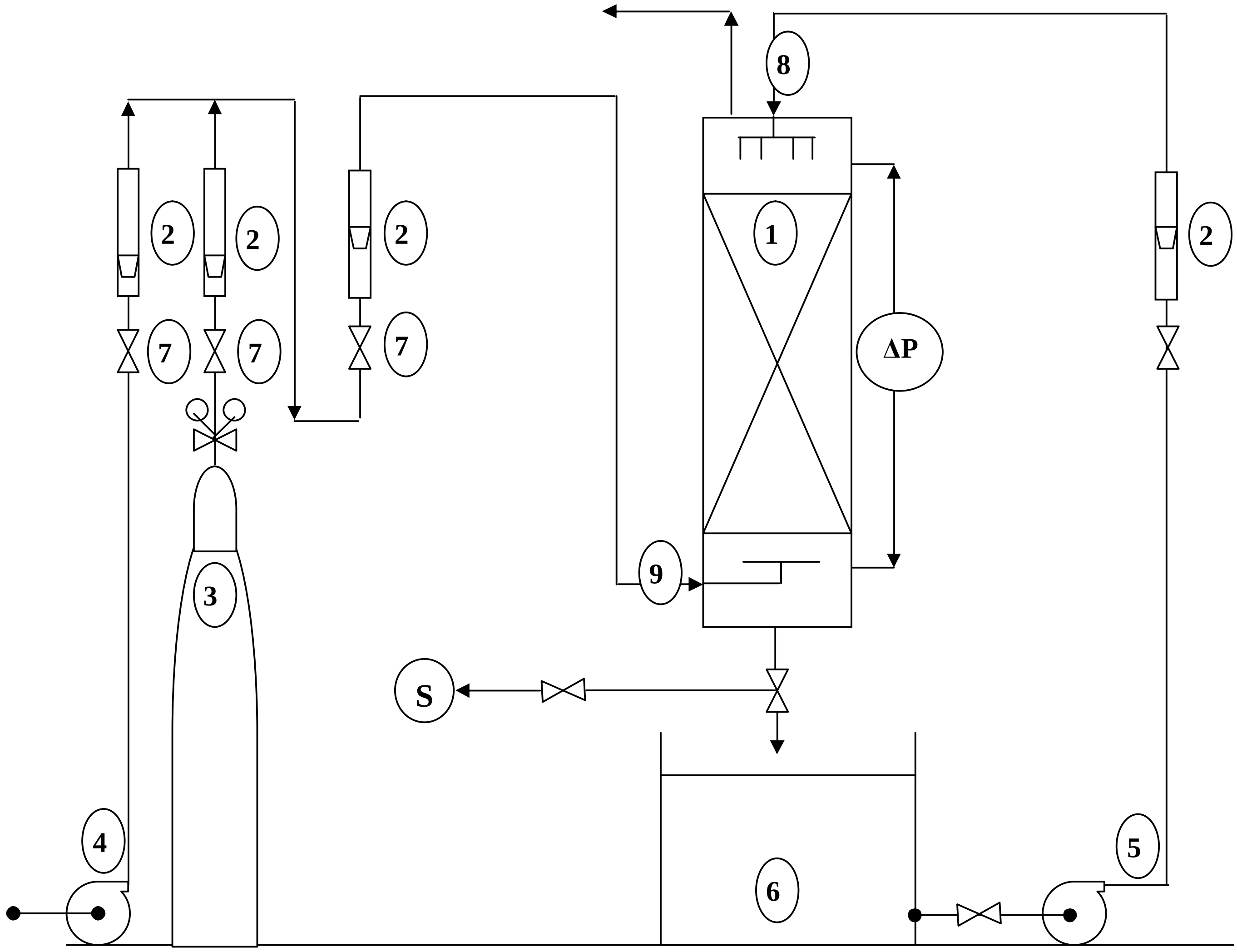
Table (1) Carbonatr conc.=0.3kmol/m^3, Inlet carbon dioxide conc.(y_2)=0.08, Y_2=0.0869 mol CO_2/mol air

Surfactant concentration (0.5 gm/liter)							
No.of exper.	L.flux (kg/m^2.sec)	G.flux (kg/m^2.sec)	Conv. %	y_1	Y_1	Absorption rate Kg/m^2.sec*10^4	K_G.a *10^4
1	1	0.05	45	0.055	0.0582	40.128	3.182
2	2.5	0.05	57	0.043	0.0449	50.204	4.461
3	4	0.05	63	0.037	0.0384	55.132	5.241
4	5.5	0.05	70	0.03	0.0309	60.808	6.306
5	1	0.075	39	0.061	0.0649	52.488	3.957
6	2.5	0.075	46	0.059	0.0571	61.336	4.914
7	4	0.075	51	0.049	0.0515	67.716	5.674
8	5.5	0.075	57	0.043	0.0449	75.196	6.691
9	1	0.1	30	0.071	0.075	54.12	3.829
10	2.5	0.1	37	0.063	0.067	66.44	4.944
11	4	0.1	43	0.057	0.061	76.56	5.991
12	5.5	0.1	48	0.0548	0.054	84.92	6.955
Surfactant concentration (1.5 gm/liter)							
13	1	0.05	40	0.061	0.0638	35.8864	2.723
14	2.5	0.05	49	0.051	0.0537	43.4676	3.582
15	4	0.05	58	0.042	0.043	51.0532	4.579
16	5.5	0.05	65	0.035	0.036	56.8084	5.526
17	1	0.075	30	0.071	0.0752	40.7	2.871
18	2.5	0.075	36	0.064	0.0683	48.576	3.582
19	4	0.075	47	0.053	0.0559	62.7	5.062
20	5.5	0.075	52	0.048	0.0504	68.948	5.842
21	1	0.1	24	0.076	0.082	44.44	2.957
22	2.5	0.1	30	0.071	0.072	54.12	3.829
23	4	0.1	39	0.061	0.0649	68.2	5.309
24	5.5	0.1	43	0.057	0.061	76.56	5.997
Surfactant concentration (2.5 gm/liter)							
25	1	0.05	33	0.067	0.0718	29.788	2.141
26	2.5	0.05	45	0.055	0.0582	40.128	3.185
27	4	0.05	54	0.046	0.0482	47.564	4.115
28	5.5	0.05	59	0.041	0.0427	51.832	5.713
29	1	0.075	25	0.075	0.0811	34.144	2.31
30	2.5	0.075	34	0.066	0.0706	46.024	3.33
31	4	0.075	43	0.057	0.0609	57.684	4.49
32	5.5	0.075	48	0.052	0.0548	64.064	5.21
33	1	0.1	20	0.081	0.0869	36.696	2.408
34	2.5	0.1	27	0.073	0.0787	49.148	3.385
35	4	0.1	38	0.062	0.0661	68.288	5.112
36	5.5	0.1	41	0.059	0.0626	73.568	5.635

Table (2) Surface tension of Carbonate Solution

Carbonate concentration (kmol/m^3)	Surfactant concentration (gm/lit.)	Surface tension (N/m^2)*10^3
0.3	0	69
0.3	0.5	67
0.3	1.5	64
0.3	2.5	62



1	2	3	4	5	6	7	8	9	S
Packed column	Rota meter	CO_2 Cylinder	Air Compressor	Liquid Pump	Feeding Tank	Needle valve	Liquid distributor	Gas distributor	Sample point

Figure (1) Schematic diagram of experimental apparatus.

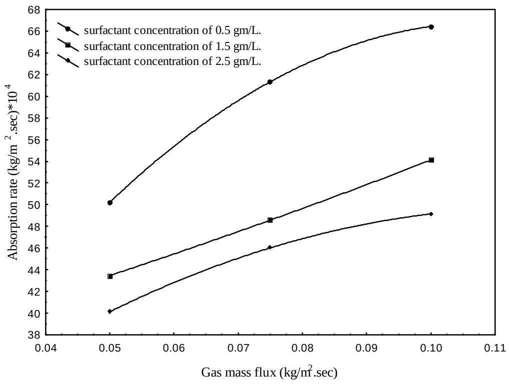


Fig.(2) Gas mass flux with Absorption rate with different surfactant concentration at liquid mass flux= 2.5 kg/m^2.sec

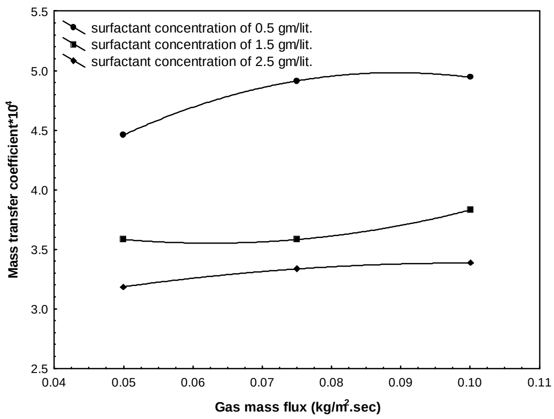


Fig.(3) Gas mass flux with Mass transfer coefficient with different surfactant concentration at liquid mass flux= 2.5kg/m^2.sec

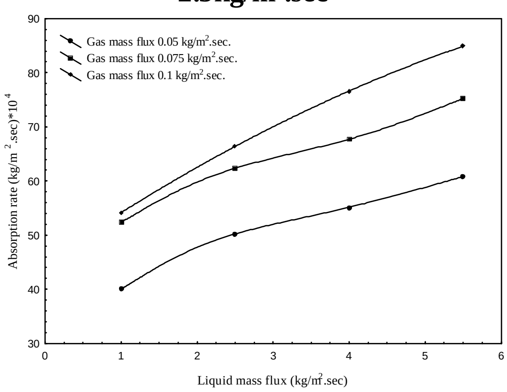


Fig.(4) Liquid mass flux with Absorption rate with different gas mass flux at Surfactant concentration =0.5 gm/lit.

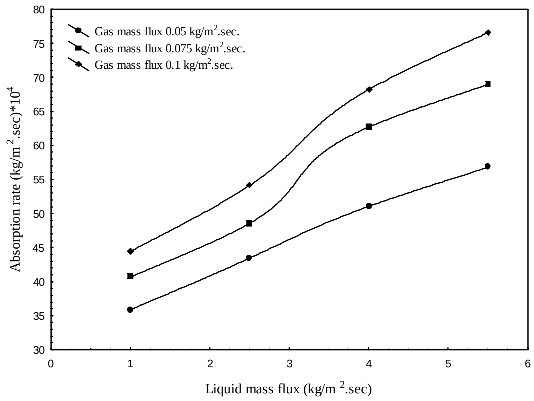


Fig.(5) Liquid mass flux with Absorption rate with different gas mass flux at Surfactant concentration =1.5 gm/lit.

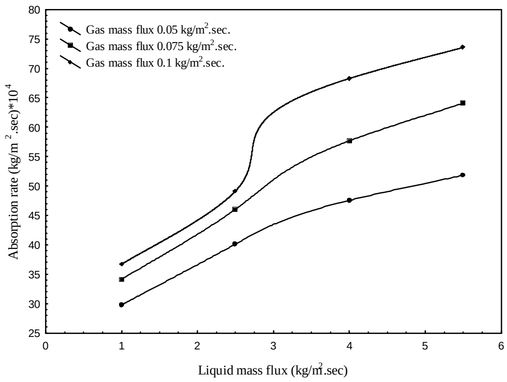


Fig.(6) Liquid mass flux with Absorption rate with different gas mass flux at Surfactant concentration =2.5 gm/lit.

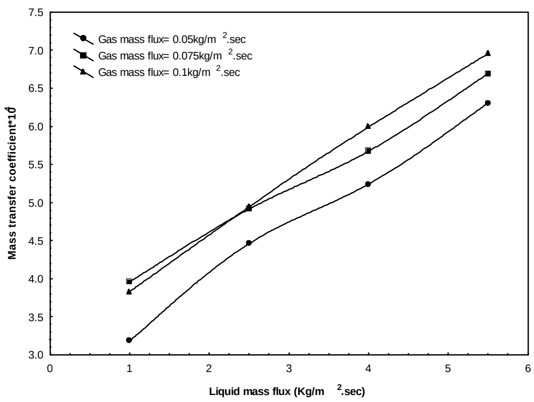


Fig.(7) Liquid mass flux with Mass transfer coefficient with different gas mass flux at surfactant concentration =0.5gm/lit.

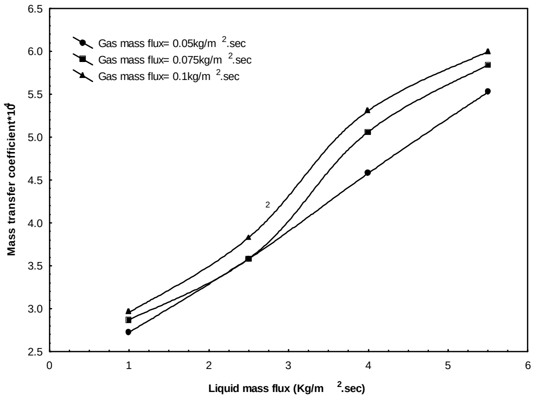


Fig.(8) Liquid mass flux with Mass transfer coefficient with different gas mass flux at surfactant concentration =1.5gm/lit.

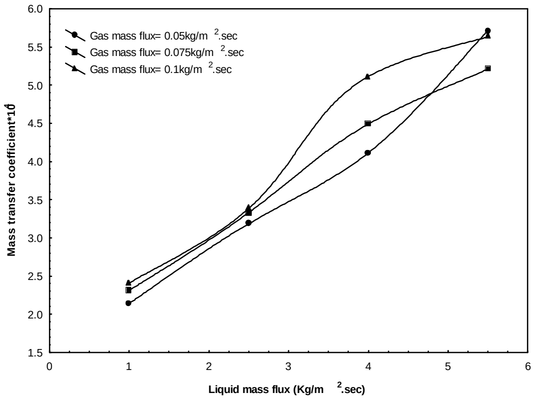


Fig.(9) Liquid mass flux with Mass transfer coefficient with different gas mass flux at surfactant concentration =2.5gm/lit.

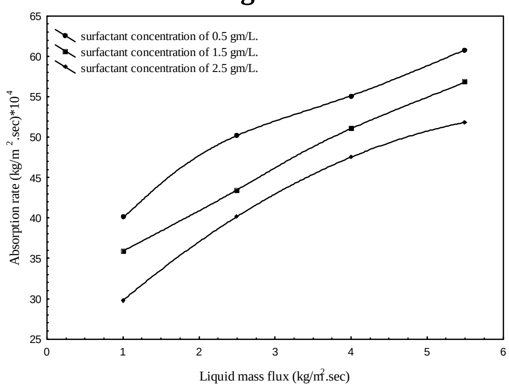


Fig.(10)Liquid mass flux with Absorption rate with different surfactant concentration at gas mass flux =0.05(kg/m^2.sec)

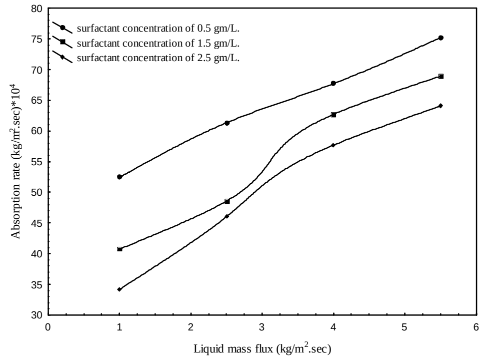


Fig.(11) Liquid mass flux with Absorption rate with different surfactant concentration at gas mass flux =0.075(kg/m2.sec)

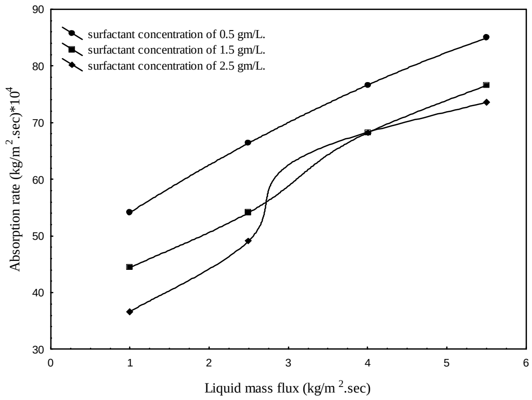


Fig.(12) Liquid mass flux with Absorption rate with different surfactant concentration at gas mass flux =0.1(kg/m2.sec)

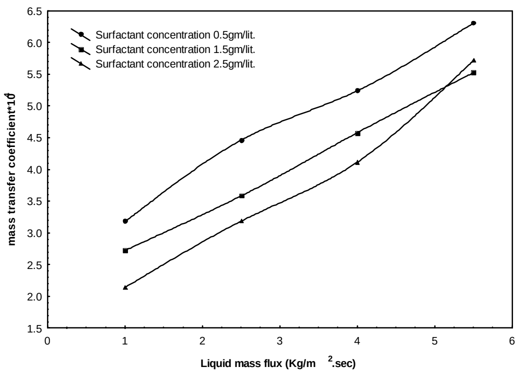


Fig.(13) Liquid mass flux with Mass transfer coefficient with different Surfactant concentration at gas mass flux = 0.05 kg/m2.sec

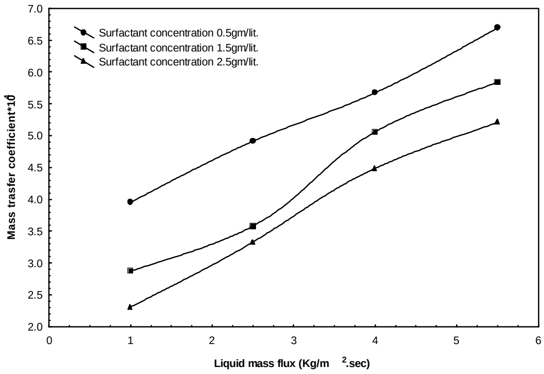


Fig.(14) Liquid mass flux with Mass transfer coefficient with different Surfactant concentration at gas mass flux = 0.075 kg/m2.sec

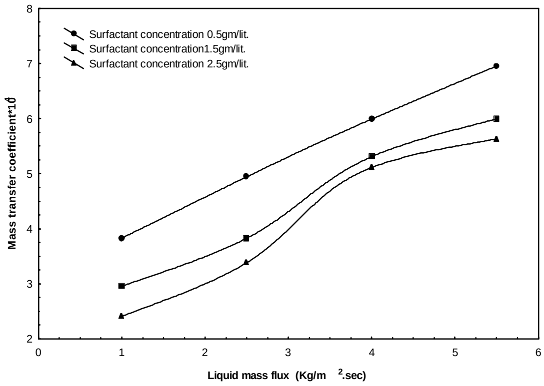


Fig.(15) Liquid mass flux with Mass transfer coefficient with different Surfactant concentration at gas mass flux = 0.1 kg/m2.sec

Nomenclature:

Symbol	Definition	Unit
N	Absorption rate	$Kg/m^2.sec$
$K_G.a$	Mass transfer coefficient	$Kg/m^2.sec$
L	Liquid mass flux	$Kg/m^2.sec$
L_m	Liquid flow	$Kmol/m^2.sec$
G	Gas mass flux	$Kg/m^2.sec$
G'	Inert gas flow(air)	$Kmol/m^2.sec$
P	Atmospheric pressure	atm
Z	Total height	m
Y_1	Outlet mole ratio	mole CO_2/mole air
Y_2	Inlet mole ratio	mole CO_2/mole air
y_1	Outlet mole fraction	mole CO_2/(mole air+mole CO_2)
y_2	Inlet mole fraction	mole CO_2/(mole air+mole CO_2)
C_{B0}	Initial carbonate concentration	$Kmol/m^3$
C_B	Final carbonate concentration	$Kmol/m^3$