Absorption of Carbon Dioxide in a Centrifugal Absorber by Mono- and Diethanolamine Solutions[1]

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The carbon dioxide concentration in a closed circuit increases upon the respiration of the inhabitants. The rate of carbon dioxide generated by an adult is almost 0.95 mol. per hour, that is, about 25 l. at 30°C under atmospheric pressure.[2]

The effects of the continuous exposure of carbon dioxide on humans have been much investigated. The results may be summarized by saying that the activities of people are considerably reduced when more than three percent of carbon dioxide is present.[3] It is, therefore, indispensable to install a carbon dioxide removal plant and an oxygen generator in a closed circuit when the duration of stay is long.

Solutions of ethanolamines and potassium carbonate are used as regenerative carbon dioxide absorbents, since they absorb carbon dioxide at room temperature and expel the carbon dioxide at a high temperature of about 140°C.[4]

We have constructed new centrifugal absorbers for the removal of carbon dioxide in a closed circuit, using regenerative ethanolamine liquids as absorbents.

The present paper will report on the effects of such variable conditions as the gas flow rate, the liquid flow rate, the composition of the liquid, rotor revolutions per minute, and rotor design on the mass transfer coefficients of the absorbers.

Experimental

Apparatus and Procedure. — On the carbon dioxide absorber, it is advisable to increase the frequency of contacts between carbon dioxide and the liquid. Therefore, a centrifugal-type absorber, which has a large liquid surface,[5] was used with some modifications.

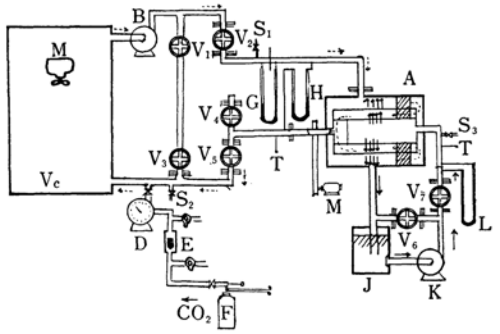

Fig. 1. Experimental arrangement of apparatus.

Figure 1 shows the arrangement of the experimental apparatus. A closed chamber Vc, has a volume of about 3.8 m³. A motor M rotates a perforated rotor of a centrifugal absorber A. The rotating rotor tangentially sprays absorbing liquid, which is introduced by a pump K from a tank J. The liquid flow is controlled by a flowmeter L, and valves, V_6 and V_7. When the carbon dioxide concentration of the closed chamber becomes 1.5 to 3.0%, the gas is introduced to the liquid-spraying space by a blower B. The gas flow rate and the carbon dioxide concentration are controlled by flowmeters D, E, G, and valves V_1, V_2, V_3, and V_5, A cylinder F feeds in carbon dioxide. The gas samples collected from the inlet S_1, and the outlet S_2 are analyzed for CO_2 by a CO_2 analyzer.

The Determination of the Carbon Dioxide Content in a Liquid.—Carbon dioxide in a liquid was determined according to the method of Reed and Wood,[6] which measures volumetrically the carbon dioxide evolved on the addition of sulfuric acid to the sample.

Results and Discussion

Part 1.—There exist a number of variables which effect the over-all mass transfer coefficient, $K_G a$, as defined by Eq. 1:

$$K_G a = \frac{G_M}{VP}\int_{p_2}^{p_1}\frac{\mathrm{d}p}{p-p^*} \tag{1}$$

where

G_M = average rate of gas flow (l./sec.)
V = volume of absorbing space (l.)
P = total pressure of gas flow (atm.)

1) A part of this report was presented at the Autumn Meeting of the Chemical Society of Japan, 1962.

2) R. G. Oliver and F. C. Riesenfeld, Closed Circuit Respiratory Systems Symposium, WADD Technical Report 60—574, 96 (1960).

3) Karl E. Shaefer, *Aerospace Medicine*, **32**, 197 (1961).

4) A. L. Kohl and F. C. Riesenfeld, " Gas Purification," McGraw-Hill, N. Y. (1960), p. 8.

5) T. Takamatsu, T. Takahashi, S. Shiga and H. Shoji, *Chemical Engineering of Japan (Kagaku Kogaku)*, **22**, 561 (1958).

6) R. M. Reed and W. R. Wood, *Trans. Am. Inst. Chem. Engrs.*, **37**, 363 (1941).

TABLE I. CENTRIFUGAL CARBON DIOXIDE ABSORBER

Type D_e	Dia. of stator D_S, cm.	Dia. of rotor D_R, cm.	Cross sectional area of absorbing space S_A, cm²	Length of absorbing space cm.	Volume of absorbing space V, l.	Characteristics of openings	Number of cylinder
I	18	10	176	7	1.232	dia. 0.8 mm. N_h, 128	1
II	18	10	176	7.5	1.320	dia. 0.8 mm. N_h, 960	1
III	ca. 28	D_{R1} 18 D_{R2} 10	1023.4	9.5	9.722	dia. 0.8 mm. N_h, 3840	2
IV	55	D_{R1} 40 D_{R2} 18	2110	30	63.300	#1. Slit #2. Screen #3. Conical perforated plates	2 Packed Packed
V	55	D_{R1} 43 D_{R2} 33 D_{R3} 23 D_{R4} 10	2190	57	124.800	perforated aluminum plate dia. 0.5 mm. N_h, 90/cm² plate	4

p = partial pressure of CO_2 in absorbing space (atm.)
p_1 = partial pressure of CO_2 in influent-gas flow (atm.)
p_2 = partial pressure of CO_2 in effluent-gas flow (atm.)
p^* = partial pressure of CO_2 in equilibrium with an amine solution[7] (atm.)

For this report the effects of the following factors on the transfer coefficient were investigated:

Absorbent: monoethanolamine (MEA) and Diethanolamine (DEA) (A)
Solvent: water and glycerol (S)
Concentration of absorbent (N, mol./l.)
Concentration of carbon dioxide in the liquid (M, mol. CO_2/mol. amine)
Liquid flow rate (L, l./sec.)
Initial concentration of carbon dioxide in gas stream (P_1, atm.)
Revolution rate of rotor (R_n, r.p.m.)
Gas flow rate (G, l./sec.)
Number of openings of the rotor (N_h, —)
Type of rotor (D_e, —)

Table I shows the dimensions of the rotors. Tables II and III show the experimental conditions and results.

The Effect of Revolution. — The relation between the number of revolutions per minute of a rotor and the transfer coefficients, K_Ga, calculated according to Eq. 1, were studied in runs No. 1 to 6. The transfer coefficient dependence on the gas velocity is shown in Fig. 2.

The transfer coefficient, K_Ga, increases with the number of revolutions per minutes. When the number of revolutions is less than 1×10^3 r.p.m., the increase in gas velocity hardly changes the transfer coefficient, or even decreases it. The decrease may be explained as occuring because the gas stream goes unreacted through the absorbing space near the stator as a result of the insufficient density of liquid, as the revolution rate is small. When the number of revolutions is more than 1×10^3 r.p.m., the transfer coefficient rises with the gas velocity.

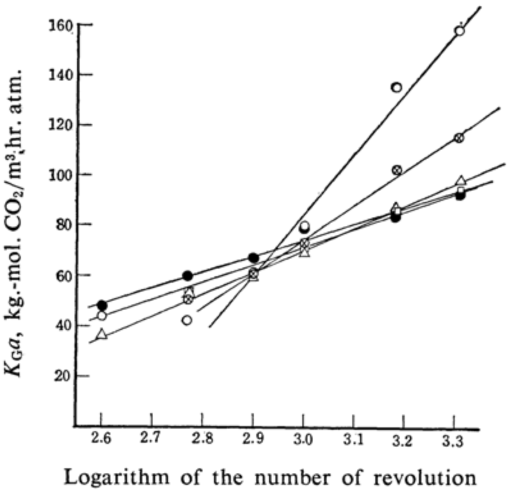

Fig. 2. Relation between coefficient and $\log R_n$.
Gas velocity: ● 4.6, □ 7.0, △ 9.5, ⊗ 18.5, ○ 38.0 cm./sec.

The Concentration of DEA.—Run No. 10 was carried out under the same conditions as No. 7 except for the normality.

Comparing the transfer coefficients with the normality (N) and kinematic viscosity (μ), we obtained:

$$K_Ga \propto \frac{N}{\mu^{0.5}} \qquad (2)$$

7) J. W. Mason and B. F. Dodge, ibid., 32, 27—48 (1936).

TABLE II. OPERATION VARIABLES AND EFFICIENCY (PART 1)

Run	A	S	N mol./l.	M mol. CO_2/mol. amine	L l./sec.	Liquid temp. °C	G l./sec.	P_1 atm.×100	Rotor type	R_n r.p.m.	E ×100	K_Ga kg.-mol. CO_2/m³ hr. atm.
1	D[a]	W[a]	1.0	0.0	(39—43)[b]	20	(4.6—38)[b]	0.5	I	2000	62—16.0	94—159
2	D	W	1.0	0.0	(39—43)	20	(4.6—38)	0.5	I	1500	58—15.5	84—136
3	D	W	1.0	0.0	(39—43)	20	(4.6—38)	0.5	I	1000	54—9.4	79—79
4	D	W	1.0	0.0	(39—43)	20	(4.6—38)	0.5	I	800	50—7.4	68—62
5	D	W	1.0	0.0	(39—43)	20	(4.6—38)	0.5	I	600	46—5.1	60—43
6	D	W	1.0	0.0	(39—43)	20	(4.6—38)	0.5	I	400	39—7.2	48—45
7	D	W	1.52	0.1105	0.35 (73)	20	1.86—4.10 (10.56—23.2)	3.2—1.71	II	2000	43.9—25.6	122—137
8	D	W	1.25	0.0613	0.35	20	6.63—8.39 (37.7—47.7)	1.375—3.20	II	2000	18.4—16.95	174—177.1
9	D	W	1.24	0.020	0.100	20	1.96—7.25 (11.13—41.2)	1.5—3.5	II	2000	39.2—12.4	116—108
10	D	W	3.25	0.0477	0.350	20	2.04—47.34 (11.58—268.5)	1.73—2.98	II	2000	56.0—4.5	190—214
11	D	W	3.5	—	0.550	20	8.0—30.4 (45.4—172.8)	2.45—2.83	II	960	20.1—5.33	203—190
12	D	W	3.5	0.085	0.350	20	1.74—7.69 (9.89—43.7)	1.79—2.505	IIa	960	44.7—18.55	117—179
13	D	W	3.5	0.094	0.350	20	1.43—8.25 (8.12—46.8)	1.83—2.58	IIb	960	49.2—14.45	71—86
14	D	W	3.5	0.093	0.350	20	2.05—10.51 (11.42—60.2)	2.05—2.50	IIc	960	45.2—22.25	91—128
15	M[a]	W	7.6	0.017	0.350	20	1.75—8.11 (9.93—46.1)	2.025—2.54	IId	960	75.2—43.4	277—526
16	M	W	7.6	0.017	0.540	20	2.05—8.22 (11.65—46.6)	2.03—2.59	IId	960	75.8—47.1	416—592
17	M	W	7.6	0.021	0.580	20	2.05—9.57 (11.63—54.3)	2.19—2.605	IIe	960	79.1—48.8	363—724
182	M	W	9.80	0.00	0.200	35.0	7.18	2.80—0.0	III	800	75.0	134
183	M	W	8.36	0.00	0.212	31.5	7.20	2.98—0.0	III	800	69.2	116
184	M	W	6.24	0.00	0.200	28.4	7.15—7.30	3.00—0.0	III	800	60.5	92
185	M	W	4.30	0.00	0.200	28.2	7.15	3.02—0.0	III	800	55.0	79
186	M	W	0.45	0.00	0.200	30.5	7.15	2.30—0.0	III	800	35.2	64

TABLE II. (Continued)

Run	A	S	N mol./l.	M mol. CO_2/mol. amine	L l./sec.	Liquid temp. °C	G l./sec.	P_1 atm.×100	Rotor type	R_n r.p.m.	E ×100	K_Ga kg.-mol. CO_2/m^3, hr. atm.
187	M	W	9.80	0.095	0.200	33.0	7.15	2.83—0.0	III	800	75.9	150
188	M	W	9.75	0.197	0.212	37.5	7.20	2.80—0.0	III	800	56.7	88
189	M	W	9.76	0.279	0.205	37.0	7.15	2.65—0.0	III	800	43.2	59
190	M	W	9.77	0.330	0.212	34.5	7.15	2.70—0.20	III	800	28.3	35
191	M	W	9.67	0.375	0.200	30.4	7.10	2.85—0.40	III	800	22.9	28
192	M	W	9.69	0.425	0.210	29.3	7.20	2.85—0.78	III	800	15.7	18

a) D=DEA, M=MEA, W=Water, G=Glycerol.
b) Data in parentheses are velocities of liquid or gas flow, cm./sec.
IIa: Type II absorber reduced the number of openings half by taping the opening lines radially arrounded the cylinder on every other line.
IIb: Type II absorber increased both the length of the cylinder to 11.5 cm. and the number of opening rows to 19.
IIc: Type IIb cylinder surrounded with an stainless steel 50-mesh screen.
IId: Type II cylinder surrounded with an 50-mesh screen.
IIe: Type II cylinder, modified with 32 small blades to scatter the sprayed liquid. Blade dimension was 0.8×7×130 mm.

TABLE III. OPERATION VARIABLES AND EFFICINCY (PART 2)

Run	A	S	N mol./l.	M mol. CO_2/mol. amine	L l./sec.	Liquid temp. °C	G l./sec.	P_1 atm.×100	Rotor type	R_n r.p.m.	E ×100	K_Ga kg.-mol. CO_2/m^3 hr. atm.
1	M[a]	W[a]	(4)[c] 3.72	2.19×10^{-3}	(5)[c] 5	22.0	(125)[c] 125	(1.0)[c] 1.005	IV3	(500)[c] 510	24.0	80
2	M	W	(7) 7.08	3.16×10^{-3}	(5) 5	26.0	(125) 118	(2.0) 2.12	IV3	(500) 520	28.3	90
3	M	W	(7) 7.07		(7) 7	23.0	(90) 94.2	(1.0) 0.955	IV3	(400) 400	43.5	125
4	M	W	(10) 10.4	12.1×10^{-3}	(3) 3	29.0	(55) 55	(1.0) 1.005	IV3	(500) 520	48.9	85
5	M	W	(10) 10.4	14.5×10^{-3}	(4) 5	27.0	(35) 35.3	(2.0) 1.98	IV3	(400) 400	65.1	86
6	M	W	(13) 13.5	9.0×10^{-3}	(3) 3	28.5	(55) 55.8	(2.8) 2.76	IV3	(500) 510	62.0	123

TABLE III. (Continued)

Run	A	S	N mol./l.	M mol. CO_2/mol. amine	L l./sec.	Liquid temp. °C	G l./sec.	P_1 atm.×100	Rotor type	R_n r.p.m.	E ×100	K_Ga kg.-mol. CO_2/m³ hr. atm.
7	M	W	(13) 12.8	16.3×10^{-3}	(5) 5	25.0	(35) 33.7	(1.0) 0.99	IV3	(400) 400	66.6	86
8	M	W	(4) 4.26	6.08×10^{-3}	(7) 7	25.0	(90) 86.5	(2.8) 2.893	IV3	(400) 400	45.1	119
9	M	W	(4) 4.29	11.2×10^{-3}	(3) 3	22.0	(35) 34.3	(1.0) 1.02	IV1	(400) 400	50.0	55
10	M	W	(7) 7.30	9.0×10^{-3}	(5) 5	29.0	(55) 56	(1.0) 1.005	IV1	(500) 500	67.0	140
11	D[a]	W	(6) 6.05	1.62×10^{-3}	(5) 5	27.0	(125) 124	(2.8) 2.82	IV1	(400) 400	7.45	22
12	D	W	(4) 3.97	0.97×10^{-3}	(7) 7	33.0	(55) 54.3	(2.0) 2.04	IV1	(400) 400	46.5	75
13	D	W	(3) 3.42	0.775×10^{-3}	(5) 5	27.0	(35) 35.6	(2.8) 2.76	IV1	(500) 500	44.6	48
14	D	W	(5) 5.70	1.16×10^{-3}	(3) 3	25.0	(90) 90.1	(2.0) 1.995	IV1	(500) 500	11.2	25
15	M	G[a]	(13) 13.0	0.0	(7) 7	33.0	(125) 120.5	(1.0) 1.035	IV1	(500) 510	74.6	351
16	M	G	(10) 10.05	4.26×10^{-3}	(5) 5	29.5	(90) 90.8	(1.0) 0.990	IV1	(400) 400	34.8	89
17	M	W	(13) 12.7	15.5×10^{-3}	(5) 5	24.5	(90) 88.3	(2.0) 2.04	IV2	(400) 400	55.2	165
18	M	W	(10) 10.45	16.1×10^{-3}	(7) 7	26.0	(125) 122.5	(2.8) 2.85	IV2	(500) 510	53.6	271
19	D	W	(6) 6.75	7.15×10^{-3}	(3) 5	25.0	(90) 93.1	(1.0) 0.966	IV2	(500) 500	19.3	46
20	D	W	(4) 4.36	4.45×10^{-3}	(5) 5	25.5	(35) 34.3	(1.0) 1.02	IV2	(500) 500	44.8	48
21	D	W	(3) 3.54	4.06×10^{-3}	(7) 7	24.5	(55) 56.4	(1.0) 0.975	IV2	(400) 400	38.5	64
22	D	W	(5) 5.53	3.48×10^{-3}	(5) 5	26.0	(125) 126	(1.0) 0.99	IV2	(400) 400	18.2	58
23	M	G	(7) 6.92	2.5×10^{-3}	(3) 3	26.0	(35) 35.4	(2.8) 2.775	IV2	(400) 410	31.9	31

TABLE III. (Continued)

Run	A	S	N $\frac{\text{mol.}}{\text{l.}}$	M $\frac{\text{mol. } CO_2}{\text{mol. amine}}$	L $\frac{\text{l.}}{\text{sec.}}$	Liquid temp. °C	G $\frac{\text{l.}}{\text{sec.}}$	P_1 atm.×100	Rotor type	R_n r.p.m.	E ×100	K_Ga $\frac{\text{kg.-mol. } CO_2}{\text{m}^3 \text{ hr. atm.}}$
24	M	G	(4) 4.65	4.75×10^{-3}	(5) 5	29.0	(55) 54.7	(2.0) 2.010	IV2	(500) 510	15.65	21
25	D	W	(3) 3.63	6.07×10^{-3}	(3) 3	24.0	(125) 121.4	(2.0) 2.058	IV3	(400) 400	14.7	45
26	D	W	(3) 3.60	8.71×10^{-3}	(5) 5	24.5	(90) 91.0	(1.0) 0.99	IV3	(500) 510	20.0	47
27	D	W	(4) 4.08	7.08×10^{-3}	(5) 5	25.0	(90) 88.6	(2.8) 2.82	IV3	(500) 510	22.5	52
28	D	W	(4) 4.36	10.7×10^{-3}	(3) 3	25.0	(125) 122.2	(1.0) 1.02	IV3	(400) 420	26.2	86
29	D	W	(6) 6.56	10.4×10^{-3}	(5) 5	30.0	(55) 54.5	(1.0) 1.01	IV2	(400) 400	31.7	48
30	D	W	(6) 6.52	14.3×10^{-3}	(7) 7	28.0	(35) 35.3	(2.0) 1.986	IV2	(500) 510	51.4	77
31	D	W	(5) 5.50	7.33×10^{-3}	(7) 7	25.0	(35) 35.9	(1.0) 0.975	IV2	(500) 520	54.0	64
32	D	W	(5) 5.52	8.60×10^{-3}	(5) 5	26.0	(55) 54.4	(2.8) 2.82	IV2	(400) 400	28.0	43
200	M	G	12.65	$7-280\times10^{-3}$	5		125.0	2.80	IV2	500		218—
501	M	W	9.65	39×10^{-3}	5	22.0	98	0.90—1.02	V	500	60	107
502	M	W	12.5	30×10^{-3}	5	24—30	98	1.03—1.10	V	500	70	139
503	M	W	5	0.0	5	22—25	98	1.0	V	510	47	74

a) D=DEA, M=MEA, W=Water, G=Glycerol
c) Data in parentheses are settled levels of factors.

The Number of Openings. — In run No. 7 a type II absorber was used, which had 960 openings, while type I had 128 while it had 960 in run No. 10 and 448 in No. 12.

Figure 3 compares the coefficients of No. 7 and No. 1, and No. 10 and No. 12. If the variation in $K_{G}a$ with normality is taken into account, it may be concluded that the increase in the openings does not necessarily increase the transfer coefficient.

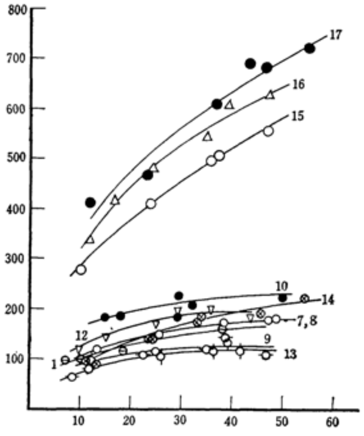

Fig. 3. Relation between gas velocity and coefficient.

The Type of Rotor.—Run No. 14 was taken in order to determine the increase in the centrifugal force on a liquid. When it is compared with No. 13 (Fig. 3), the favorable effect of the 50-mesh stainless screen can be observed.

In the runs Nos. 15, 16 and 17, MEA liquid was used. The liquid flow rate effected the transfer coefficient.

The small effect of the gas velocity on the coefficient, $K_{G}a\sqrt{S_A/G}$, as shown in Fig. 4, indicates that the rate-determining step is substantially the diffusion of carbon dioxide in the gas stream.

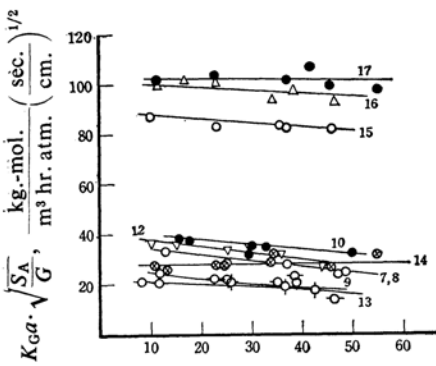

Fig. 4. Relation between $K_{G}a\sqrt{S_A/G}$ and coefficient.

Concentration of MEA. — In runs No. 182 to No. 186, a closed chamber was used. Assuming that the efficiency, E, of the absorber remains constant and that the mixing in the chamber is perfect, the following differential equation can be derived by considering the mass valance in the system:

$$g_{A}\mathrm{d}t - GEp\mathrm{d}t = V_{C}\mathrm{d}p \tag{3}$$

When $p=p_0$ at $t=0$, and $p=p_1$ at $t=t$, the solution of Eq. 3 is:

$$p_1 = p_0 \exp\left(-\frac{GE}{V_C}t\right) + \frac{g_A}{GE}\left\{1-\exp\left(-\frac{GE}{V_C}t\right)\right\} \tag{4}$$

$$E = (p_1 - p_2)/p_1$$

where p_0 is the initial partial pressure (atm.) of carbon dioxide in the closed chamber; p_1 is the partial pressure (atm.) of carbon dioxide in the closed chamber at time t (sec.); p_2 is the partial pressure of carbon dioxide at the outlet of the absorber; V_C is the volume of the closed chamber (l.); g_A is the rate at which carbon dioxide is added to the closed chamber (l./sec.), and G is the rate of gas flow (l./sec.).

The concentrations of the MEA liquids applied were 9.8, 8.3, 6.2, 4.1 and 0.45 normal. The variation in the carbon dioxide concentration in the chamber with the time is given

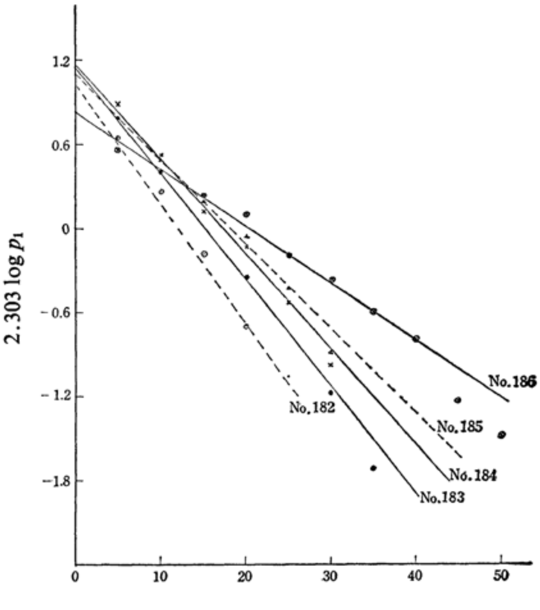

Fig. 5. Variation of CO_2 concentration with time in the closed chamber.

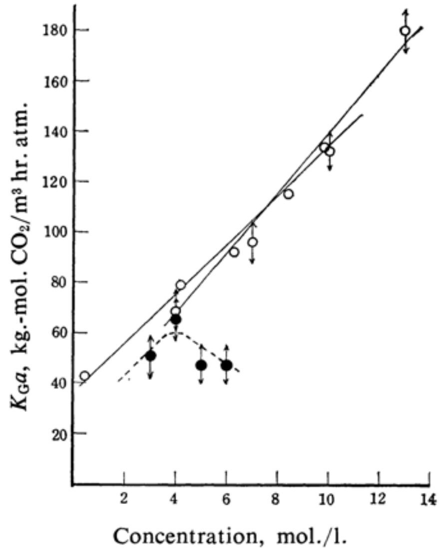

Fig. 6. Relation between liquid concentration and coefficient.

○ Nos. 182—186, MEA

↕○ Part 2, MEA ↕● Part 2, DEA

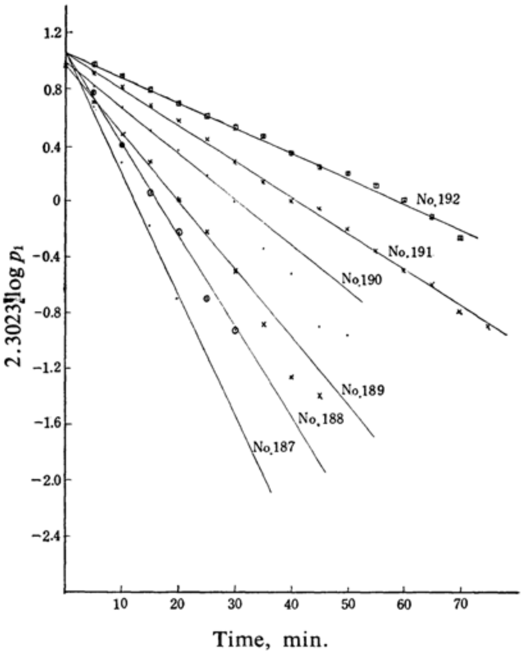

Fig. 7. Variation of CO_2 concentration with time in a closed chamber.

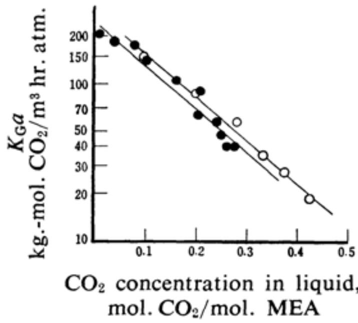

Fig. 8. Relation between CO_2 concentration in liquid and coefficient.

○ No. 187—No. 192 ● No. 200

in Fig. 5. From Eq. 4, where g_A is zero, the efficiencies of the absorber, E, and the transfer coefficients, K_Ga, were calculated.

Figure 6 shows that the transfer coefficient increases linearly with the concentration of the MEA solution.

Goodridge[8] described a similar relation between the absorption rate and the concentration.

From the lines of Fig. 5, the efficiency of the absorber can be seen to be independent of the concentration of carbon dioxide in the gas stream. The assumption for Eq. 3 was, therefore, sound.

The Concentration of Carbon Dioxide in a Liquid.—In runs No. 187 to No. 192, the closed chamber was used again. The concentrations of carbon dioxide in the liquid were 0.095, 0.197, 0.279, 0.330, 0.375 and 0.425 mol. CO_2/mol. MEA.

Figure 7 shows the relation of the carbon dioxide concentration in the chamber to the time. The efficiencies of the absorber and the transfer coefficients were calculated according to Eq. 4. In Fig. 8 the effect of the carbon dioxide concentration in a liquid on the transfer coefficient is plotted. From the slope, the following equation has been obtained:

$$K_Ga \propto e^{-6.56M} \qquad (5)$$

Part 2. — In Part 1, carbon dioxide absorption behavior was studied with a small centrifugal absorber (rotor dimensions: ca. 10 cm. in diameter × 7.5 cm.). These investigations into the process of absorption with a chemical reaction have distinguished the effects of several factors on the transfer coefficient. However, effects of these factors on the transfer coefficient were deduced from experiments in which a certain factor was varied while the others were kept constant. We have thus manufactured a centrifugal absorber of a large scale (rotor dimensions: ca. 55 cm. in diameter × 30—57 cm.; Table I, types IV and V).

The experimental design of the orthogonal table[9] is shown in Table III, where settled

8) F. Goodrige, *Trans. Faraday Soc.*, **51**, 1703 (1955).

9) G. Taguchi, "Method of Experimental Design," Maruzen Book Co., Tokyo (1962).

levels are in parentheses, along with the experimental values and the results. The other experimental procedures were the same as in Part 1.

It was possible to adjust the actual levels of the factors to the settled levels within ±5% deviation. The main effects of each factor are calculated and plotted according to the usual method[9] in Figs. 9 to 12. The arrows shows the range of experimental error.

The dependence of the transfer coefficient on the concentration of the MEA solution is shown in Fig. 6, indicating the same tendency as in Part 1.

Figure 6 shows also the relation between the concentration of DEA and the transfer coefficient.

In both liquids, MEA and DEA, the transfer coefficients show substantially the same magnitude up to a concentration of about four normal. When the normality increases more than 4 N, the transfer coefficient of DEA decreases because the viscosity influences the coefficient, as was stated in Part 1.

Equation 2 is verified by the fact that the $K_G a \mu^{0.5}/N$ for 3, 4, 5 and 6 N DEA solutions with kinematic viscosities of 3.5, 5.6, 10 and 20 c. s., are 31.8, 38.5, 30.0 and 36.0 respectively.

Certainly, the influence of viscosity depends upon the centrifugal force produced by the revolution. The transfer coefficients are plotted against the gas flow rate in Fig. 9. The coefficient increases with the gas flow rate in the MEA system, indicating that the rate-controlling step is still in the gas film, while it changed little in the DEA system, indicating that the step there has been shifted to that in the liquid film.

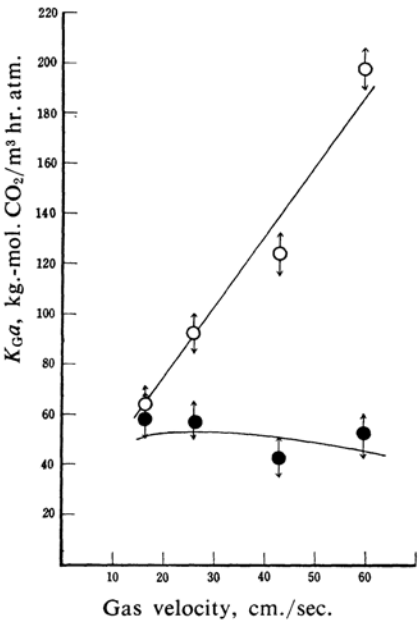

Fig. 9. Relation between gas velocity and coefficient.

○ MEA   ● DEA

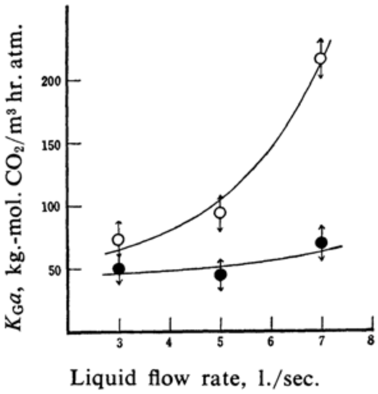

Fig. 10. Relation between liquid flow rate and coefficient.

○ MEA   ● DEA

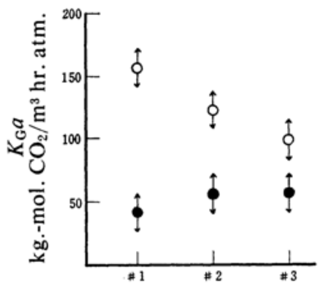

Fig. 11. Relation between type of rotor and coefficient.

♯1 Slit, unpacked   ♯2 Screen, packed,
♯3 Conical perforated plate, packed

○ MEA   ● DEA

In Fig. 10 the transfer coefficient increases considerably with the MEA liquid flow rate, but only slightly with the DEA liquid flow rate. Figure 11 shows the effects of the differences of rotors on the transfer coefficient. Generally, it is advantageous to choose a packed rotor when the absorbing liquid is viscous and the liquid flow rate is small.

Figure 12 shows the dependence of the transfer coefficient on the solvent, the revolution rate of the rotor, and the initial concentration of carbon dioxide in the gas stream.

The differences between water and glycerol have hardly any effect on the transfer coefficient. As for the revolution rate and the carbon dioxide concentration, tendencies

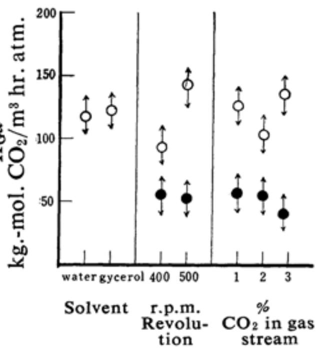

Fig. 12. Effects on coefficients of solvent, revolution rate, and CO_2 concentration in gas stream.

○ MEA ● DEA

similar to those in Part 1 were observed. Additionally, the concentration of carbon dioxide in MEA glycerol solutions affected the transfer coefficient in the same manner as in Part 1 (Fig. 8, Table III, No. 200).

Runs No. 501 to 503 in Table III were obtained with a large, modified centrifugal absorber which had a rotor (55 cm. in diameter ×57 cm.) comprised of four perforated aluminum cylinders.

The length of the absorbing space, the number of cylinders, and especially the number of openings were increased. From a comparison between No. 501 and Nos. 5 and 16, between No. 502 and Nos. 7 and 17, and between No. 503 and Nos. 8 and 9, it may be concluded that the increase in the number of both openings and cylinders has little effect on the mass transfer coefficient.

Summary

After a description of a centrifugal carbon dioxide absorber, the effects of variables on the mass transfer coefficient of the absorber have been reported. For the experimental conditions examined, the following conclusions may be arrived at:

(1) When the rate-determining step is gas diffusion, the MEA and DEA liquid of the same concentration have the same mass transfer coefficient as long as the effect of viscosity is negligible.

(2) The transfer coefficient increases linearly as the concentration of an MEA aqueous solution increases.

(3) The relation between the coefficient and the concentration of a viscous DEA aqueous solution is given as:

$$K_Ga \propto N/\mu^{0.5}$$

(4) The relation between the coefficient and the concentration of carbon dioxide in a MEA liquid is given as:

$$K_Ga \propto e^{-6.56M}$$

(5) So long as the gas diffusion is the rate-determining step, the coefficients for two solvents, water and glycerol, differ little.

(6) The coefficient for MEA increases greatly with the liquid flow rate; however, the coefficient for DEA increases only a little.

(7) The coefficient is initially in direct proportion to the square root of the gas flow rate.

(8) The efficiency of the centrifugal absorber remains constant even if the carbon dioxide concentration in the gas stream changes from 3 to 0.2%.

(9) The coefficient is in direct proportion to the logarithm of the rotor revolutions per minute.

(10) Slight modifications, except for packing on the rotor, with the aim of increasing the surface area of a liquid do scarcely anything to improve the absorber.

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