University of Louisville

ThinkIR: The University of Louisville's Institutional Repository

Electronic Theses and Dissertations

1945

The absorption of carbon dioxide with a semi-plant scale packed tower.

Lewis P. Aker 1902-1981
University of Louisville

Follow this and additional works at: <https://ir.library.louisville.edu/etd>

Part of the [Chemical Engineering Commons](#)

Recommended Citation

Aker, Lewis P. 1902-1981, "The absorption of carbon dioxide with a semi-plant scale packed tower."
(1945). *Electronic Theses and Dissertations*. Paper 1863.
<https://doi.org/10.18297/etd/1863>

This Master's Thesis is brought to you for free and open access by ThinkIR: The University of Louisville's Institutional Repository. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of ThinkIR: The University of Louisville's Institutional Repository. This title appears here courtesy of the author, who has retained all other copyrights. For more information, please contact thinkir@louisville.edu.

UNIVERSITY OF LOUISVILLE

THE ABSORPTION OF CARBON DIOXIDE
WITH A SEMI-PLANT SCALE PACKED TOWER

A Thesis

Submitted to the Faculty
of the Graduate School
of the University of Louisville
in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF CHEMICAL ENGINEERING

Department of Chemical Engineering

by

Lewis P. Aker

1945

THE ABSORPTION OF CARBON DIOXIDE
WITH A SEMI-PLANT SCALE PACKED TOWER

Lewis P. Aker

Approved by the Examining Committee:

Director _____

February, 1945

CONTENTS

	Page
List of Tables	iii
List of Figures	iv
Abstract	v
Introduction	1
Theoretical	3
Apparatus	9
Analytical Techniques	18
Data and Results	23
Literature Cited	32
Appendix	35
Acknowledgments	54
Vita	56

LIST OF TABLES

Table No.	Title	Page
1	Tabulation of Data	24
2	"Theoretical" Variation of Transfer Coefficient with Temperature	25
3	Water Meter Calibration Data	40

LIST OF FIGURES

No.	Title	Page
1	Absorber	11
2	Absorber Details	13
3	Flow Diagrams	15
4	Transfer Coefficient Variation with Water Rate	28
5	Transfer Coefficient Variation with Temperature	30
6	Transfer Coefficient versus Gas Rate	31
7	Calibration of Water Flow Meter	41

ABSTRACT

Carbon Dioxide is absorbed in water, using a semi-plant scale absorber consisting of a 17 ft. length of 16" O.D. pipe and packed with 3" spiral tile, stacked. Air is recirculated and CO₂ added to the air stream at the absorber inlet. Louisville city water is used as the absorbing medium. Construction details of the absorber are described. Water rates vary between 2,550 lb./ (hr.) (sq.ft.) and 13,510 lb./ (hr.) (sq.ft.) and gas rates vary between 61 and 240 lb./ (hr.) (sq.ft.). Transfer coefficients ($K_L a$) are found that have considerably higher values than would be expected from the work of other investigators. The equation for the transfer coefficient shows a variation proportional to the 0.85 power of the water rate

$$K_L a = .166 (L_S)^{.85}$$

No trend of transfer coefficient is found with varying gas rate. Most of data is obtained at 83° F. with a few runs at lower temperatures. The trend of the coefficient with temperature is in the expected direction.

INTRODUCTION

The field of absorption, which is primarily the removal of a gaseous constituent or constituents from a gas stream by a liquid stream, has been covered extensively in the published literature. The majority of the published data, however, has been obtained by using small scale apparatus, and from such data the performance of large scale equipment has been predicted. The publication of actual data from plant scale equipment is rare (1). This condition is probably due to two factors. The first factor is that industrial equipment designers and operators prefer to keep their data to themselves, and the second factor is the difficulty, financial and physical, of constructing and operating plant-scale or semi-plant scale equipment in an educational institution.

While it is probable that design data based upon small scale equipment are applicable to equipment of any size, it is felt that there is need for more data on plant scale or semi-plant scale apparatus. Consequently, when it was found possible to construct and operate a semi-plant scale absorption tower, this work was attempted.

The packing available was three inch spiral tile and the tower a sixteen foot length of sixteen inch pipe. The system decided upon was the system carbon dioxide-water, mainly for reasons of convenience.

THEORETICAL

In the absorption or desorption of a gaseous constituent into or from a liquid phase, the most successful theory has been the so called "two film" theory. This theory was suggested by Whitman (2,3) and has proved to be very useful in absorber design.

This two-film theory states that the principal resistance to mass transfer is the existence of two films of stagnant fluid with respect to one another, one on each side of the gas-liquid interface, and through which mass-transfer must take place by diffusion alone. The thicknesses of both the liquid and gaseous films are considered to be functions of the state of agitation of their respective phases. The concept is entirely analogous to the usual treatment of heat-transfer problems involving fluid phases.

The driving force which causes the mass transfer is the concentration difference, for the component in question, between the main body of the liquid and the interface and/or the partial pressure difference between the main body of the gas and the interface.

The following general equation expresses the relation between the mols transferred per unit area, the driving force and the resistance.

$$-\frac{d N_A}{d A} = \frac{C_1 - C_L}{r_L} = \frac{p_G - p_1}{r_G} \quad (1)$$

It is noted that the resistance r includes not only the resistance of the film but also the resistance from

the body of the fluid to the fluid film, although the major portion of the resistance is in the film.

In engineering calculations, however, the reciprocal of the resistance, known as the transfer coefficient is generally used.

$$k_G = 1/r_G \quad \text{and} \quad k_L = 1/r_L$$

$$- \frac{dN_A}{dA} = k_L (C_i - C_L) = k_G (p_G - p_i) \quad (\text{II})$$

It is assumed that at the true interface the two phases are always in equilibrium (4). This means that p_i is in equilibrium with C_i and that p_i is a function of C_i .

It is rather difficult to evaluate the transfer coefficients for the individual phases, so overall coefficients are used very extensively in engineering design.

$$- \frac{dN_A}{dA} = K_L (C^* - C_L) = K_G (p_G - p^*) \quad (\text{III})$$

Either overall coefficient (K_G or K_L) may be used in any particular instance. In the case of very soluble gases the major portion of the resistance is in the gas film so that K_G is usually used. Where the solubility of the gas is low, the liquid film controls and K_L is usually used.

For the system carbon dioxide-water, the major resistance (5) is in the liquid film and thus the liquid basis overall coefficient is indicated as the basis for calculation.

As equation III is valid only for an infinitesimal

portion of an absorption tower, it is not applicable until it can be evaluated over the whole system by graphical integration or other means.

Where concentrations of the solute gas are low in both the gaseous and liquid phases, it is very convenient to use the calculation system of Gilliland (6). In this system, the liquid concentrations are expressed as X , the mols of solute per mol of solute-free solvent, and the gas concentrations as Y , the mols of solute in the gas phase per mol of solute-free gas ($Y = P_A/P - p_A$). The liquid rate through the apparatus is expressed as L , the mols of solute-free liquid per hour and the gas rate is expressed as G , the mols of solute-free gas per hour.

In using this system, the "operating line" of an absorber, plotted in terms of X and Y is a straight line. (see Equation VI) Also, the equilibrium curve for systems following Henry's law will be a straight line when plotted on the same coordinates.

In such a case, the integration of the driving force from top to bottom of the tower becomes a simple mathematical calculation.

In any given crossection of an operating absorption tower, with steady rates of flow, the amount of solute absorbed by the liquid must equal the amount given up by the gas.

$$GdY = LdX \quad (IV)$$

If we consider the gas and liquid concentrations

at the top of the tower to be represented by X_2 and Y_2 , and the concentrations at the bottom of the tower to be represented by X_1 and Y_1 , integration of equation IV between the bottom and top of the tower (allowable under steady condition)

$$G(Y_1 - Y_2) = L(X_1 - X_2) \quad (V)$$

Also integration between the top of the tower and any cross-section of the tower where concentrations are X and Y produce.

$$G(Y - Y_2) = L(X - X_2) \quad (VI)$$

From these conditions, with steady flow, Y must be linear in X .

Expressing equation III in terms of X and Y

$$- \frac{dN_A}{dA} = K_{LX} (X^* - X) = K_{GY} (Y - Y^*) \quad (VII)$$

In this equation K_{LX} is K_L expressed in terms of X instead of c and K_{GY} is K_G expressed in terms of Y instead of p . X^* represents liquid concentration in equilibrium with the body of the gas and Y^* gas concentration in equilibrium with the body of the liquid.

If " a " represents the interfacial area of contact between gas and liquid in square feet per cubic foot in the absorber and S represents the cross-sectional area of the absorber, then

$$dA = aSdl$$

where l represents the height of the tower. Also

$$\begin{aligned} - dN_A &= LdX \\ - \frac{dN_A}{dA} &= \frac{LdX}{aSdl} \end{aligned} \quad (VIII)$$

Combining equations VII and VIII,

$$- dN_A = LdX = K_{LX} aS (X^*-X)dl \quad (IX)$$

Integrating equation IX between top and bottom of the tower,

$$L(X_1 - X_2) = K_{LX} aSl (\Delta X)_{av} \quad (X)$$

where $(\Delta X)_{av}$ is the logarithmic mean of the driving forces at the top and bottom of the tower.

Equation X is applicable only if the equilibrium curve, plotted in X and Y, is a straight line over the range in which it is involved so that the value of (X^*-X) is linear with respect to the distance from the top of the tower.

Since the system carbon dioxide-water follows Henry's Law (7) and since carbon dioxide is not very soluble in water, all data in this work have been calculated in terms of $K_{LX}a$ using equation X and then recalculated to K_La for comparison with other work.

APPARATUS

As shown in figure 1, the absorption tower is constructed of a length of 16 inch O.D., 3/8 inch wall, steel pipe. One end (the bottom end) is "bull-headed" with an "orange peel" weld, the other end swedged down to standard 6 inch pipe and flanged. At the bottom of the tower are welded two flanged 4 inch pipe openings, at right angles to each other for gas inlet and liquid outlet. Six inspection and packing openings are spaced along the length of the tower and consist of short standard 6 inch pipe nipples welded into the shell, flanged, and closed with companion flanges. The gas outlet at the top is a flanged 4 inch standard pipe welded to the swedged portion of the shell and placed as high as possible. At the lower end, just above the gas inlet opening, a grid is welded inside the shell to support the packing. The tower is supported at the bottom by a ring of 12 inch pipe and at the top by a clamp attached to the building framework. Attached to the liquid outlet is a seal pot made of 12 inch pipe, closed on both ends, with a 4 inch inlet and outlet.

The packing consists of 3 inch, corrugated spiral rings which are ceramic cylinders, three inches in diameter and three inches high (about), with a spiral web in the center. These rings are packed in the tower, 19 to a layer, with the axes all parallel to the axis of the tower. The arrangement of an individual layer is shown in figure 2. In each successive layer of packing, the axis of each individual tile in the outer circle is placed above the edge of a tile in the layer below, as shown by the dotted circles in the packing

Figure 1, ABSORBER

crossection of figure 2.

The height of the packing is 158 $\frac{3}{8}$ inches, consisting of 51 layers, 19 tile to a layer, making a total of 969 individual units.

Perry (8) gives the following data for 3 x 3 corrugated spiral rings.

	% Free Space	Surface sq.ft./cu.ft.	Wt.#/ cu.ft.	Units/ cu.ft.
Dumped	72	22	40	48
Stacked	64	29	53	63
Sherwood & Holloway (9)				
Dumped				48
Stacked	59	42		62
Butcher (10)				
Stacked	64	29	53	64

In this case with 1.27 square feet crossection and packing height of 158 $\frac{3}{8}$ inches, there are 16.77 cu.ft. of packing or 57.8 units/cu.ft.

Several tile were measured and examined by W. F. Durbin (11) and gave an average of 0.443 sq.ft. of surface per unit. This gives a surface area of the packing of 25.6 sq.ft./cu.ft.

The inner surface of the tower is 52.5 sq.ft. from the top of the packing to the supporting grid. Surface area of the grid is assumed to be 2 sq.ft. Total area for absorption, dry, is 483.5 sq. ft. or 28.83 sq.ft./cu.ft.

Cross-section of Tower Packing

Bottom View

Side View

Liquid Distributor

Figure 2

ABSORBER DETAILS

The liquid distributor at the top of the tower is a "christmas tree" made up of five sections of standard $1/2$ inch pipe, each section having the ends welded closed and a short, threaded, nipple welded at right angle in the center. The middle section is 14 inches long, the sections on either side of the middle are 12 inches long, and the outside sections are 6 inches long. Each section has a series of holes, $1/8$ inch in diameter, and spaced 1 inch apart, making a total of fifty $1/8$ inch holes with a total area of 0.613 sq. in. The liquid line entering the tower is standard $1\ 1/4$ inch pipe which is reduced to 1 inch pipe just before entering the "Christmas tree", which, in addition to the sections described is composed of a 1 inch cross, two $3/4$ inch tees, two $1/2$ inch elbows, various bushings, short nipples and unions. The assembly is shown in figure 2.

The flow-meter for the gas (inlet) consists of a 1.125 inch, sharp edged orifice in a 4 inch standard pipe flange, with throat connections.

The liquid flowmeter consists of a 0.703 inch sharp edged orifice in a standard 2 inch pipe flange, with throat connections.

The orifices for both flow meters were made from $1/8$ inch stainless (18-8) steel plate.

The gas to be treated was forced thru the tower with a 4-A Roots Acme blower. No liquid pump was used as the liquid was Louisville city water and the pressure avail-

Figure 3, Flow Diagrams

able gave sufficient capacity without a pump.

A six cu.ft. "meter-prover", borrowed from the Louisville Gas and Electric Company was used as a carbon dioxide storage holder on a few of the runs. Solid carbon dioxide was placed in a one gallon can equipped with a press lid to which was attached a hose connected to the "holder". As the carbon dioxide vaporized it passed into the "holder" and was withdrawn at atmospheric pressure into the gas stream during the run.

In the rest of the runs a pressure vessel equipped with a safety valve and a gas pressure regulator was used as as a generator. The vessel was filled with solid carbon dioxide, the lid bolted on and the gas pressure regulator used to hold a constant gas pressure of a few inches of water at the outlet of the vessel.

A one-tenth cubic foot wet test meter and a small flowmeter, consisting of a $13/64$ inch orifice in $9/16$ inch I.D. copper tubing, were used to measure the gaseous carbon dioxide entering the tower.

In the first series of runs (Runs 1 to 3 inclusive), the setup indicated in top flow diagram of figure 3 was used. The air pump was connected directly into the bottom of the tower and the gas outlet from the top of the tower was connected to the suction side of the pump with the gas flowmeter between the tower outlet and the pump inlet. Gaseous carbon dioxide, after passing the wet test meter, was introduced

into the gas stream at the suction side of the pump.

It was intended, with this layout, to introduce carbon dioxide at a constant rate until equilibrium was established within the tower, at which time the absorption rate would equal the rate at which the carbon dioxide was being added. Under these conditions, therefore, it should only be necessary to measure the carbon dioxide concentration of the gas leaving the tower, and the concentrations of the liquid entering and leaving the tower. These assumptions were the basis of the calculations in this series of runs.

The remainder of the runs were made with the apparatus arranged as shown in the lower flow diagram in figure 3. The change in layout was necessitated by a change in location of the equipment. In runs 4 to 17 tests were made on liquid entering and leaving the tower and on the gas entering and leaving.

In all runs, Louisville city water was passed through the tower at various rates, air was pumped at various rates and gaseous carbon dioxide passed into the gaseous stream at the tower inlet. The range of the variations was limited by the range of the manometer available for the liquid flowmeter and by the capacity of the Roots blower.

ANALYTICAL TECHNIQUES

The first technique used in analyzing the gaseous phase was to fill with water an ehrlenmeyer flask, fitted with a two hole stopper and glass tubes, and displace the water with the gas to be tested. First the inlet of the flask was closed with a clamp and then the outlet, leaving the gaseous sample at atmospheric pressure. As soon as possible after sampling, 10 ml of a standard barium hydroxide solution was introduced with a pipette, by releasing both inlet and outlet clamps on the sample flask and draining the pipette into the flask thru the tube leading to the bottom of the flask. Both openings were then closed and the flask shaken for five minutes. Then the stopper was removed, the stopper and tubes washed with freshly boiled and cooled distilled water, all washings being caught in the sample flask. The excess of barium hydroxide was titrated with standard hydrochloric acid, using phenolphthalein as indicator. From the volume of the flask, the barometric pressure, the temperature of the room, the titration and a blank titration, the percentage of carbon dioxide in the sample was calculated. For the calculation, the volume of the flask, minus 10 ml, was used as the sample volume.

This technique gave accurate results (presumably) but was too time consuming and was used on runs 1 and 2 only.

On all runs except runs 1 and 2, a single pipette "Orsat" type gas analysis apparatus was used, consisting of a burette and leveling bottle and a contact pipette filled with

40% potassium hydroxide. Water was used as the confining medium in the burette.

The first technique used for determining the carbon dioxide concentration in the liquid phase was used in runs 1 to 3 only. The sampling tube was held near the bottom of a 300 ml B.O.D. bottle and several times the volume of the bottle was permitted to flow before the sampling tube was removed. The stopper was immediately inserted after sampling. As soon as possible after sampling, the stopper was removed and 25 ml of a standard barium hydroxide solution were added with a pipette. The tip of the pipette was lowered nearly to the bottom of the bottle, drained and then slowly removed. The stopper was replaced, the bottle rotated to mix the sample and reagent, and then the whole sample dumped into a large flask, which had been previously swept out with CO_2 -free air, and the excess of barium hydroxide titrated with standard hydrochloric acid. The volume of the bottle, minus 25 ml, was considered the volume of the sample. A blank titration was made on a similar sample of freshly boiled and cooled distilled water. This method was also discarded as being too time-consuming although it should give quite accurate results.

On runs 4 and 5, and on several runs not reported, a testing system for the liquid phase was adopted and which proved to be generally unsuccessful. A relation (12) between the pH, free CO_2 and the alkalinity of water, was found which seemed to be made to order for speed and accuracy as a

glass-electrode pH meter of the best industrial type was available. All that appeared to be necessary was to test inlet and outlet for pH and make an occasional alkalinity titration. From the relation,

$$\text{pH} = \log_{10} \left[(.1938)(10^7) \frac{(\text{alkalinity as ppm CaCO}_3)}{\text{Free CO}_2 \text{ in ppm}} \right]$$

the free CO₂ could be readily calculated. This method may be good for approximate free CO₂ determinations, but data calculated from this relation gave negative driving forces at the bottom of the tower in most instances.

Runs 4 and 5 are also the only runs in the series in which the air from the outlet of absorber was not led to the air pump inlet. In these two runs the air from the room was taken into the air-pump suction and the air leaving the absorber discharged into the room.

On the remainder of the runs a modification of the standard (13) water-laboratory titration for free CO₂ was used. A 100 ml pipette was connected to the sampling tube and the water allowed to flow through the pipette until several hundred milliliters had passed through it. The pipette was then disconnected, adjusted to the mark and the sample transferred to a 300 ml flask which contained almost enough standard sodium hydroxide solution (as determined by a previous titration) to react with the free CO₂ in the sample. The tip of the pipette was led below the surface of the standard solution when transferring the sample. Then phenolphthalein was added and the titration completed by adding standard sodium hydroxide

solution until a faint permanent pink was attained. This method does not completely correct for the interference of the CO_2 in atmosphere but should give the difference in free CO_2 between the inlet and outlet waters fairly accurately.

DATA AND RESULTS

Run #	Water Temperature °F	Water Meter Differential inches of Mercury	Water Rate #/hr.	L _S Water Rate #/(hr)(sq.ft)	L mols/hr.
1	51	9.06	9,510	7,490	528
2	53	1.05	3,235	2,550	180
3	65	4.1	7,020	5,520	390
4*	54	4.4	6,620	5,210	368
5*	54	13.85	11,750	9,250	653
6	83	4.2	6,475	5,090	360
7	83	12.3	11,080	8,720	615
8	83	29.55	17,170	13,510	953
9	83	2.4	4,890	3,850	272
10	83	1.05	3,240	2,550	179.9
11	83	8.35	9,120	7,180	507
12	83	20.15	14,250	11,220	791
13	83	14.90	12,190	9,600	667
14	83	23.07	15,180	11,930	843
15	83	29.18	17,080	13,430	947
16	83	11.65	10,780	8,500	598
17	83	5.7	7,540	5,930	418

* On these two runs, the air leaving the absorber was not recirculated.
Air pump inlet received air from the room.

TABLE 1

X_2	X_1	$L(X_1 - X_2)$	Air Temperature		Air Meter Differential inches of Water
Mols CO_2 <u>Mol Water</u> $\times 10^5$	Mols CO_2 <u>Mol Water</u> $\times 10^5$	Mols CO_2 <u>hr.</u>	In $^{\circ}\text{F}$	Out $^{\circ}\text{F}$	
.894	7.33	.034	71	51	9.83
.88	11.67	.0194	68	53	9.3
.45	13.01	.0489	66	65	15.45
.02	1.48	.00538	86	54	16.8
.02	1.57	.0100	86	54	16.8
.08	4.82	.0171	93	83	13.2
.08	4.66	.02815	93	83	13.1
.08	4.37	.0409	92	83	13.0
.08	4.34	.0116	93	83	13.2
.08	4.82	.00852	93	83	13.2
.04	4.40	.0221	94.5	83	9.7
.04	3.71	.0290	96	83	9.65
.04	4.57	.0302	104	83	4.75
.04	3.61	.0301	115	83	2.93
.04	3.58	.0335	116	83	1.89
.04	4.56	.0270	118.5	83	1.44
.04	4.87	.0202	123	83	1.42

TABULATION OF DATA

Air Rate	G	Y_1	Y_2	$G(1-Y_2)$	K_{LX}^a
#/hr	Mols/hr of CO ₂ free air	$\frac{\text{Mols CO}_2}{\text{Mol Air}}$	$\frac{\text{Mols CO}_2}{\text{Mol Air}}$	$\frac{\text{Mols CO}_2}{\text{hr.}}$	$\frac{\# \text{ mols}}{(\text{hr})(\text{cu.ft})(\Delta X)}$
242.5	7.31	.1031	.0984	.034	53.7
238.5	6.81	.162	.159	.020	25.6
313	8.08	.236	.229	.057	61.15
305	10.52	.0194	.0183	.011	51.8
305	10.52	.0225	.0204	.0221	73.6
275.5	8.35	.1021	.0994	.0225	60.8
274	8.4	.0950	.0916	.0285	127.0
273.5	8.45	.0917	.0863	.0455	159.2
275.5	8.51	.0882	.0863	.01618	48.5
275.9	8.44	.0974	.0951	.0194	41.8
235.1	7.26	.0902	.0872	.0218	95.0
233.3	7.36	.0763	.0708	.0405	144.8
163	5.01	.0963	.0901	.0310	112.8
126	4.01	.0754	.0659	.0380	147.3
101	3.21	.0811	.0664	.0471	129.0
88.2	2.73	.0989	.0854	.0368	98.6
87.5	2.69	.1011	.0921	.0242	83.5

$$\frac{K_{La} \cdot 3.46 \frac{\text{#mols}}{(\text{hr})(\text{cu.ft})}}{K_{LXa} \frac{\text{#mol}}{(\text{cu.ft})}} (K_{LXa}) \left(\frac{10,000}{L_S} \right)^{.85}$$

186	68.8
88.5	82.0
212	101
179	90.1
255	78.6
210	108
440	142.5
552	123.3
168	109
145	134
329	129.8
501	131.3
390	116.7
510	126.8
447	100.5
345	113.2
289	130.7

TABLE 2
 "THEORETICAL" VARIATION OF TRANSFER COEFFICIENT
 WITH TEMPERATURE

Temperature in °F	Viscosity in Centipoises μ_x	(Viscosity) ^{3/2} (in Centipoises)	Calculated value of $(K_{LX^a})_{10,000}$
83	.830	.764	121
80	.861	.799	116
75	.917	.876	106
70	.978	.965	96
65	1.045	1.07	86.5
60	1.12	1.18	78
55	1.21	1.33	69.5
50	1.31	1.50	61.6

Note: Value of $(K_{LX^a})_{10,000}$ for 83°F taken from curve of figure 4, other values calculated as follows $(K_{LX^a})_{10,000}$
 $= (121) \frac{.764}{(\mu_x)^{3/2}}$

A summary of the data is shown in table 1. The material balances are none too good in many of the runs as shown by comparison of the values of $L(X_1 - X_2)$ and $G(Y_1 - Y_2)$. As a slight error in the measurement of the concentration of CO_2 in the gas phase would make a large error in $G(Y_1 - Y_2)$, in the calculations where poor agreement was obtained the value of $L(X_1 - X_2)$ was used as being considered the more reliable.

On all runs the value of $K_{LX}a$ was calculated by the methods of Walker, Lewis, McAdams and Gilliland (6) and then recalculated to the usual K_La by multiplying by the factor $62.3/18$ as $K_{LX}a$ is expressed as $\text{lb.mols}/(\text{hr.})(\text{cu.ft.})(\text{lb.mols}/\text{lb.mol})$ and K_La as $\text{lb.mols}/(\text{hr.})(\text{cu.ft.})(\text{lb.mols}/\text{cu.ft.})$. For the liquid phase used (water) the ratio $\text{cu.ft.}/\text{lb.mol}$ is $62.3/18$.

In figure 4, the values of K_La are plotted as well as data obtained by others (14). The solid line represents the data obtained at 83°F and the equation of the line is

$$K_La = .166(L_S)^{.85} \quad (\text{XI})$$

Assuming from this equation that the value of $K_{LX}a$ is proportional to the .85 power of L_S , it should be possible to reduce all figures for $K_{LX}a$ to the basis of a common water rate so as to study the effect of temperature. The value of $K_{LX}a$ at a water rate of $10,000 \text{ lbs.}/(\text{hr.})(\text{sq.ft.})$ is the final column of figures in table 1, and is listed as $(K_{LX}a)_{10,000}$

$$(K_{LX}a)_{10,000} = K_{LX}a \left[\frac{10,000}{L_S} \right]^{.85} \quad (\text{XII})$$

These values of $(K_{LX}a)_{10,000}$ are plotted in figure 5 for all those runs not made at 83°F, all the runs at 83°F being represented by a single composite point. This composite point was obtained by taking the value of K_La at 83°F from the curve in figure 4 and reconvertng this value to $K_{LX}a$ by multiplying by 18/62.3.

According to walker, Lewis, McAdams and Gilliland (15), diffusivity in the liquid phase is approximately proportional to the inverse three-halves power of the viscosity. Since the transfer coefficient is proportional to the diffusivity, when the liquid film thickness is uniform, as it would be with a uniform liquid velocity, at constant temperature, then the value of K_{LX} or $K_{LX}a$ should be proportional to the inverse three-halves power of the viscosity.

Taking as the initial point the composite point for runs 6 to 17 in figure 5, points for a "theoretical" curve for the variation of $K_{LX}a$ with temperature were calculated and listed in table 2, and plotted in figure 5.

It will be noted that the trend of $K_{LX}a$ follows this "theoretical" curve fairly well, indicating that the variation of the transfer coefficient with temperature is probably a function of liquid viscosity.

In figure 6, the values of $(K_{LX}a)_{10,000}$ at 83°F are plotted against the gas rate so as to ascertain any trend due to gas rate. No such trend is noted so that it may safely be said that this work indicates that there is no noticeable effect on the transfer coefficient due to variation in the

Figure 4, Transfer Coefficient Variation with Water Rate

gas rate. The most noteworthy feature of the data for $K_L a$ in figure 1 is the very high values obtained in this work compared with that of other observers. The only explanation that comes to mind is that the careful stacking of the tile used in this work may be at least a partial cause.

It is recommended that further data with this same apparatus be made by other observers so that the values may be either corroborated or discredited.

By making series of runs at several seasons of the year the temperature may be chosen at will over the range of city water temperatures, which will vary from 40° in late winter to 85° in late summer. These temperatures vary slowly and tend to remain fairly constant for several days at a time.

Figure 5, Transfer Coefficient Variation with Temperature

Figure 6, Transfer Coefficient versus Gas Rate

LITERATURE CITED

Literature Cited

- (1) Sherwood, T.K., "Absorption and Extraction", 1st Edition, page 170, McGraw-Hill, 1937
- (2) Whitman, W. G., Chem. & Met. Eng., 29, 147, (1923)
- (3) Whitman, W. G., Ind. Eng. Chem., 16, 1215, (1924)
- (4) Walker, W.H., Lewis, W.K., McAdams, W.H. and Gilliland, E.R., "Principles of Chemical Engineering", Third edition, page 450, McGraw-Hill, 1937
- (5) Ibid, page 452
- (6) Ibid. Chapter XV
- (7) National Research Council, "International Critical Tables", 1st Edition, volume III, page 260, McGraw-Hill, (1928)
- (8) Perry, J.H., "chemical Engineers Handbook", 2nd Edition, page 1200, McGraw-Hill, 1941
- (9) Sherwood, T.K., and F.A.L. Holloway, A.I.Ch.E. Trans., 36, 57, (1940)
- (10) Butcher, C.H., "The Industrial Chemist", compiled by Sherwood (1), page 133
- (11) Durbin, W.F., Private Communication
- (12) The Permutit Co., Private Communication, quoting as references J.A.W.W.A. 30, #1, 105 (1938) and J.A.W.W.A. 31, #1, 51, (1939)
- (13) American Public Health Assn., "Standard Methods of Water Analysis", 8th Edition, page 69, American Public Health Assn., New York, 1936
- (14) Sherwood, T.K., "Absorption and Extraction", 1st Edition, figure 69, page 182, McGraw-Hill, 1937

Literature Cited (Cont.)

- (15) Walker, W.H., Lewis, W.K.; McAdams, W.K.; and Gilliland, E.R., "Principles of Chemical Engineering", 3rd Edition, page 447, McGraw-Hill, 1937
- (16) Perry, J. H., "Chemical Engineers Handbook", 2nd Edition, page 848, McGraw-Hill, 1941

APPENDIX

LIST OF SYMBOLS

		<u>Units</u>
A	Area of interface	sq.ft.
a	Area of interfacial surface per unit volume	sq.ft./cu.ft.
C _i	Concentration of solute in liquid at interface	lb.mols/cu.ft.
C _L	Concentration of solute in the main body of the liquid	lb.mols/cu.ft.
C*	Liquid concentration in equi- librium with the main body of gas	lb.mols/cu.ft.
G	Lb.mols of solute-free gas per hr.	lb.mols/hr.
K _G	Overall transfer coefficient expressed in terms of gas partial pressure	lb.mols/(hr.) (sq.ft.)(atm)
K _L	Overall transfer coefficient, expressed in terms of liquid concentration	lb.mols/(hr.)(sq.ft.) (lb.mols/cu.ft.)
K _{GY}	Overall transfer coefficient, expressed in terms of Y	lb.mols/(hr.)(sq.ft.) (unit ΔY)
K _{GX}	Overall transfer coefficient, expressed in terms of X	lb.mols/(hr.)(sq.ft.) (unit ΔX)
k _G	Transfer coefficient for the gas phase	lb.mols/(hr.)(sq.ft.) (atm)
k _L	Transfer coefficient for the liquid phase	lb.mols/(hr.)(sq.ft.) (lb.mols/cu.ft.)

LIST OF SYMBOLS (CONT.)

		<u>Units</u>
$(K_{LX}^a)_{10,000}$	K_{LX}^a recalculated to a liquid flow of 10,000 lb/sq.ft.	lb.mols/(hr.)
	$K_{LX}^a \left[\frac{10,000}{L_S} \right]^{.85}$	(cu.ft.)(lb.mols/ lb.mol)
L	Lb.mols of solute-free liquid per hr.	lb.mols/hr.
L_S	Lb. liquid per hr. per sq.ft. cross-section of tower	lbs./(hr.) (sq.ft.)
l	Height of tower in feet	ft.
N_A	Rate of transfer of component A	lb.mols/hr.
P_i	Partial pressure of solute at the interface	atm.
P_G	Partial pressure of solute in body of the gas	atm.
p^*	Partial pressure of solute gas in equilibrium with main body of the liquid	atm.
P	Total pressure	atm.
r_L	Resistance to mass transfer in the liquid, from the body of the liquid to the interface	(hr.)(sq.ft.) (lb.mol/cu.ft.)/ lb.mol
r_G	Resistance to mass transfer in the gas, from the body of the gas to the interface	(hr.)(sq.ft.) (atm)/lb.mol
S	Crosssectional area of tower	sq.ft.
X	Concentration of solute in liquid	lb.mols/lb.mol

LIST OF SYMBOLS (CONT.)

		<u>Units</u>
Y	Concentration of solute in gas	lb.mols/lb.mol
X*	Equilibrium value of X corresponding to Y	lb.mols/lb.mol
Y*	Equilibrium value of Y corresponding to X	lb.mols/lb.mol.
$(\Delta X)_{av}$	Logarithmic mean driving force	

CALIBRATION OF WATER METER

The water meter consists of a .703 inch sharp-edged orifice in a standard 2" pipe (2.067" I.D.), with throat connections.

Using the basic equation of the A.S.M.E. Special Research Committee on Fluid Meters (13)

$$w = CYA_2 \sqrt{\frac{2 g_c (p_1 - p_2) \rho_1}{1 - \beta^4}}$$

where

- w Weight rate of discharge in lb.mass/sec
- C Coefficient of discharge (no dimensions)
- Y Expansion factor (no dimensions)
- A_2 Crossectional opening of discharge area in sq.ft.
- g_c Dimensional constant 32.174 (lb.mass)(ft.)/
(lb.force)(sec)²
- p_1, p_2 Pressures at upstream and downstream pressure taps
respectively in lb. force/sq.ft.
- ρ_1 Density at upstream temperature and pressure in lb.
mass/cu.ft.
- β Ratio (for circular openings) of diameter of con-
striction to diameter of upstream pipe

$$C = .61$$

$$\rho_1 = .62.35$$

$$Y = 1$$

$$A_2 = \left(\frac{.703}{12}\right)^2 \left(\frac{3.14}{4}\right) = .0026955 \text{ sq.ft.}$$

$$^2 g_c = 64.34$$

$$\beta = \frac{.703}{2.067} = .3401 \quad \beta^4 = .01338 \quad 1 - \beta^4 = .98662$$

$$w = \sqrt{p_1 - p_2} \quad (.61)(.002955) \sqrt{(64.34)(62.35)/.98662}$$

$$= \sqrt{p_1 - p_2} \quad (.10432)$$

If $p_1 - p_2$ is expressed in inches of mercury under water, expressed as h

$$w = \sqrt{\frac{h(12.6)}{12} 62.3} \quad (.10432) = .844\sqrt{h}$$

$$w \text{ in \#/hr} = (3600)(.844) \sqrt{h} = 3038 \sqrt{h}$$

This is the "theoretical" curve in figure 7.

TABLE 3

WATER METER CALIBRATION DATA

Time	#Water Weighed	Manometer Reading	# Water/hr.
30 seconds	36#	1.87 inches Hg.	4320
30 seconds	53.5	4.1 " "	6420
30 seconds	28.25	1.2	3390
30 seconds	91.5	11.6	10980
30 seconds	121	20.9	14520
30 seconds	137.5	26.0	16500

The data of Table 5 are plotted in figure 7.

The calibration curve so obtained is

$w \text{ in \#/hr.} = 3160 \sqrt{h}$, 4% higher than the theoretical curve.

Figure 7, Calibration of Water Flow Meter

GAS FLOW METER

No calibration was made of this meter which consists of a 1.125" sharp edged orifice in a standard 4" pipe glange, throat connections.

The same formula (13) is used in computing flow thru this meter as in the case of the water meter

$$w = CYA_2 \sqrt{\frac{2g_C(p_1-p_2)\rho_1}{1-\beta^4}}$$

$$C = .61 \text{ (for } Re_o \text{ above 30,000)}$$

$$Y = \frac{1-(p_1-p_2)}{(p_1^k)} \left(.41 + 0.35 \beta^4 \right) = \frac{1-(p_1-p_2)}{(p_1)} .2943$$

$$A_2 = \text{Area of orifice} = \frac{(1.125)^2}{(12)} \frac{(II)}{(4)} = .006903 \text{ sq.ft.}$$

$$g_C = 32.174$$

$$\beta = \frac{D_o}{D_1} = \frac{1.125}{4.026} = .2794 \quad \beta^4 = .006095$$

$$1 - \beta^4 = .9939$$

$$w = Y \sqrt{(p_1-p_2) \rho_1} \quad (.61)(.006903) \sqrt{\frac{64.34}{.9939}}$$

$$= .03388 Y \sqrt{(p_1-p_2) \rho_1}$$

If h is differential pressure in inches of water at 20°C

$$w = Y \sqrt{h \rho_1} \sqrt{5.19} (.03388) = .07718 Y \sqrt{h \rho_1}$$

#/second.

This formula used in calculating gas flow.

CALCULATIONS ON RUN #1

Gas samples, leaving absorber

Volume of Sample	Ml Ba(OH) ₂	Ml .107 N HCl	% CO ₂
522.3-10	10	1.3	8.76
510.5-10	10	0.3	9.25
520.8-10	10	0.3	9.08
521.6-10	10	1.6	<u>8.76</u>
		Ave.	8.95 %

26.75 ml .10003 N NaOH (standardized against B of S benzoic acid) required 25.10 ml of HCl. NF of HCl .107.
 10 ml of Ba(OH)₂ required 35.4 ml of .107 N HCl.

Water samples, leaving absorber

Volume of Sample	Ml Ba(OH) ₂	Ml .107 N HCl	Ml .107 N HCl equiv. to CO ₂	CO ₂ in sample gCO ₂ /ml
530.5-50	50	170.8	37.0	.0001735
344 -25	25	74.3	29.6	.000219
336 -25	25	84.8	19.1	<u>.000145</u>
			Ave.	.0001792 gCO ₂ /ml

25 ml of baryta water required 103.9 ml of .107 N HCl

Water sample, entering absorber

337 -25	25	101.05	2.85	.0000216 gCO ₂ /ml
---------	----	--------	------	-------------------------------

Air Meter

Average differential 9.83" H₂O, upstream static
 9.2" H₂O = .68" Hg.

Average air temperature 21.5°C , Barometric pressure $29.40''$ Hg.

Water temperature 10.5°C

Assume entering air to be saturated with water vapor at 10.5°C
partial pressure of water at $10.5^{\circ}\text{C} = 9.521$ mm Hg.

$$\% \text{ water vapor in air} = \frac{(9.521)(100)}{(25.4)(29.4)} = 1.27\%$$

	%	Mol Wt.	
Water Vapor	1.27	18	.228
CO ₂	8.95	44	3.96
Dry Air	89.78	29	<u>26.05</u>
			30.238 Ave. mol wt. of

gas passing thru meter. Will use 30.2

$$w = .07718 Y \sqrt{h p_1}$$

$$Y = \frac{1 - (p_1 - p_2) \cdot 2943}{(p_1)} = \frac{1 - \left(\frac{9.83}{(30.08)(13.6)} \right) \cdot 2943}{(p_1)} = .993$$

$$p_1 = \frac{(30.2)(29.4 \cdot .68)}{(359)(29.92)} \cdot \frac{(273)}{(294.5)} = .0785$$

$$w = (.07718)(.993) \sqrt{(9.83)(.0785)} = .0674 \text{ \#/sec} = 242.5 \text{ \#/hr.}$$

$$\text{Total mols gas/hr} = \frac{242.5}{30.2} = 8.03$$

$$(8.03)(.9105) = 7.31 \text{ mols CO}_2\text{-free gas/hr} = G$$

Water Meter

Average differential = 9.06" Hg under water

Water flow = $3160 \sqrt{9.06} = 9510 \text{ \#/hr.}$

Mols/hr = $\frac{9510}{18} \times 528 \text{ mols/hr} = L$

$X_1 = (.0001792) \frac{18}{44} = .0000733$

$X_2 = (.0000216) \frac{18}{44} = .00000894$

$X_1 - X_2 = .00006436$

$L(X_1 - X_2) = (528)(.00006436) = .034 = G(Y_1 - Y_2)$

$Y_2 = \frac{8.95}{91.05} = .0984$

$Y_1 = \frac{.034}{7.31} + .0984 = .1031$

From I.C.T. data

At 10.5°C $K = p_a = \frac{(.8056)(10^6)}{X_a}$

where K = Henry Law constant for CO_2

p_a = Partial pressure of CO_2 in mm Hg.

X_a = mol fraction CO_2

Total pressure = 30.08" Hg = 764 mm

$p_a = (764) \frac{.1031}{1.1031} = 71.3 \text{ mm Hg. where } Y_1 = .1031$

$X_a = \frac{71.3}{(.8056)(10^6)} = (8.85)(10^{-5}) = X_1^*$

$X_1^* - X_1 = (8.85 - 7.33)(10^{-5}) = (1.52)(10^{-5})$

$$p_a = \frac{(764)(.0984)}{1.0984} = 68.5 \text{ mm Hg, where } Y_2 = .0984$$

$$x_a = \frac{68.5}{(.8056)(10^6)} = (8.49)(10^5) = x_2^*$$

$$x_2^* - x_2 = (8.49 - .89)(10^5) = (7.60)(10^5)$$

$$\Delta x_{lm} = \frac{(7.6 - 1.52)(10^5)}{2.303 \log_{10} \frac{(7.6)}{(1.52)}} = (3.775)(10^5)$$

$$L(x_1 - x_2) = dN = K_{LX^a} \Delta x_{lm}$$

$$K_{LX^a} = \frac{.034}{(13.2)(1.27)(3.775)(10^5)} = 53.7$$

CALCULATIONS ON RUN #4

Gas Meter

Average differential 16.8 inches of water, air temperature 30°C
barometer 29.0

$$w \text{ in \#/sec} = .07718 \ Y \ \sqrt{h \rho_1}$$

$$Y = 1 - \frac{(p_1 - p_2)}{\left(\frac{p_1}{\rho_1}\right)} .2943 = 1 - \frac{(16.8)}{((30.24)(13.6))} .2943$$

$$= .988$$

$$\rho_1 = \frac{(30.24)(273)(29.0)}{(29.92)(303)(359)} = .0736 \text{ \#/cu.ft.}$$

$$w = (.07718)(.988) \sqrt{(16.8)(.0736)} = .0847 \text{ \#/sec}$$

$$= 305 \text{ \#/hr.}$$

$$\text{mols/hr.} = G = \frac{305}{29} = 10.52$$

(In this run, air passing thru meter is practically CO₂-free)

Water Meter

Average differential 4.40 inches of mercury under water. Water temperature 12°C.

$$w = 3160 \sqrt{4.40} = 6,620 \text{ \#/hr.}$$

$$\text{mols/hr.} = L = \frac{6620}{18} = 368$$

Water Analyses

Inlet water, pH 8.24, alkalinity 40 ppm as Ca CO₃

$$\text{pH} = \log_{10} \left[(.1938)(10^7) \frac{\text{Alkalinity as Ca CO}_3}{\text{Free CO}_2 \text{ in ppm}} \right]$$

$$8.24 = \log_{10} \left[(.1938)(10^7) \frac{40}{\text{CO}_2} \right]; \text{CO}_2 = \frac{(.01938)(40)}{\text{antilog}.24}$$

$$.45 \text{ ppm}$$

Outlet water, pH 6.33, alkalinity 40 ppm as CaCO_3

$$\text{CO}_2 = \frac{(1.938)(40)}{\text{antilog}.33} = 36.2 \text{ ppm}$$

$$X_1 = \frac{(36.2)(18)}{(44)} 10^{-6} = (1.48)(10^{-5})$$

$$X_2 = \frac{(.45)(18)}{(44)} 10^{-6} = (.0184)(10^{-5})$$

$$X_1 - X_2 = (1.462)(10^{-5})$$

$$L(X_1 - X_2) = (368)(1.462)(10^{-5}) = .00538$$

Gas Analyses

Inlet air 1.9% CO_2

$$Y_1 = \frac{1.9}{98.1} = .01938$$

Outlet air 1.8% CO_2

$$Y_2 = \frac{1.8}{98.2} = .01833$$

$$Y_1 - Y_2 = .00105, G(Y_1 - Y_2) = (10.52)(.00105) = .011$$

Since it is felt that the material balance on the water end is the better, Y_1 and Y_2 are recalculated on that basis.

$$L(X_1 - X_2) = G(Y_1 - Y_2) = .00538$$

$$Y_1 - Y_2 = \frac{.00538}{10.52} = .000512$$

$$Y_1 + Y_2 = .01938 + .01833 = .03771$$

$$2 Y_1 = .03822, Y_1 = .0191$$

$$Y_2 = .0186$$

$$\text{at } 12^\circ\text{C K} = \frac{p_a}{X_a} = (.8455)(10^{-6}) \text{ from International Critical Tables}$$

where K = Henry's Law constant for CO_2

p_a = partial pressure of CO_2 in mm of Hg.

X_a = mol fraction CO_2 in solution

Total pressure 29.0 inches Hg. = 737 mm

$$p_a = \frac{(737)(.0191)}{1.0191} = 13.81 \text{ mm (where } Y_1 = .0191)$$

$$X_a = \frac{13.81}{(.8455)(10^6)} = (1.645)(10^{-5}) = X_1^*$$

$$X_1^* - X_1 = (1.645 - 1.48) 10^{-5} = (.165)(10^{-5})$$

where $Y_2 = .0186$

$$p_a = \frac{(737)(.0186)}{1.0186} = 13.45 \text{ mm}$$

$$X_a = \frac{13.45}{(.8455)(10^6)} = (1.572)(10^{-5}) = X_2^*$$

$$X_2^* - X_2 = (1.572 - .018)(10^{-5}) = (1.554)(10^{-5})$$

$$\Delta X_{1m} = \frac{(1.554 - .165)(10^{-5})}{2.3 \log_{10}(1.554/.165)} = (.62)(10^{-5})$$

$$K_{LX}^a = \frac{.00538}{(13.2)(1.27)(6.2)(10^6)} = 51.8$$

CALCULATIONS ON RUN #6

Gas Meter

Average differential 13.2 inches of water, gas temperature 93° F.

Gas entering meter saturated with water vapor at 83° F, and containing 9.4% CO₂ (dry basis). Barometer 29.63 inches = 753 mm Hg.

Total pressure upstream $29.63 - \frac{13.2}{13.6} = 30.60$
inches Hg = 776 mm Hg.; vapor pressure of H₂O at 83° F = 1.13" H₂O.

Composition of Gas

	%	Mol wt.	$\frac{(\text{Mol})(\%)}{100}$
Water Vapor	(100)(1.13/30.60) = 3.69	18	0.675
CO ₂	(.9631)(9.4) = 9.05	44	3.93
Dry Air	(.9631)(90.6) = 87.20	29	<u>25.35</u>
Ave. Mol Wt. 30.005 (use 30.0)			

$$w \text{ in \#/sec} = (.07718)(Y) \sqrt{h \rho_1}$$

$$Y = 1 - \frac{(p_1 - p_2)}{p_1} (.2943) = 1 - \frac{(13.2)}{((30.6)(13.6))}$$

$$(.2943) = .989$$

$$\rho_1 = \frac{(30.6)(492)(30.0)}{(29.92)(533)(359)} = .0761 \text{ \#/cu.ft.}$$

$$w = (.07718)(.989) \sqrt{(13.2)(.0761)}$$

$$= .0765 \text{ \#/sec} = 275.5 \text{ \#/hr.}$$

$$\text{mols/hr.} = \frac{275.5}{30.0} = 9.18$$

$$\text{mols CO}_2\text{-free gas/hr.} = (.9095)(9.18) = 8.35 = G$$

Water Meter

Average differential 4.2 inches of mercury under water.

$$w \text{ in \#/hr.} = 3160 \sqrt{4.2} = 6,475 \text{ \#/hr.}$$

$$\text{mols/hr.} = 6,475/18 = 360 = L$$

Gas Analyses
(Orsatt with water as confining medium)

	Entering Tower	Leaving Tower
	9.85%	9.65%
	9.55	9.15
	<u>9.5</u>	<u>9.40</u>
Average	9.63	9.40

Water Analyses

100 ml samples titrated to phenolphthalein endpoint using standard NaOH, 1 ml = .956 mg CO₂, standardized against Bureau of Standards benzoic acid.

Entering Tower		Leaving Tower	
Titration, ml of NaOH	ppm CO ₂	Titration ml of NaOH	ppm CO ₂
.2	2 ppm	12.3	
		12.15	
		<u>12.2</u>	
	Ave.	12.22	118 ppm

$$x_1 = 118 \frac{(18)(10^{-6})}{(44)} = (4.82)(10^{-5})$$

$$x_2 = 2 \frac{(18)(10^{-6})}{(44)} = (.08)(10^{-5})$$

$$x_1 - x_2 = (4.74)(10^{-5})$$

$$L(X_1 - x_2) = (360)(4.74)(10^{-5}) = .01708$$

$$Y_1 = \frac{(9.63)(.9631)}{100 - (9.63)(.9631)} = .1021$$

$$Y_2 = \frac{(9.4)(.9631)}{100 - (9.4)(.9631)} = .0994$$

$$Y_1 - Y_2 = .0027$$

$$G(Y_1 - Y_2) = (8.35)(.0027) = .0225$$

Recalculating Y_1 & Y_2 on basis of material balance
in liquid phase

$$L(X_1 - X_2) = G(Y_1 - Y_2) = .01708$$

$$Y_1 - Y_2 = \frac{.01708}{8.35} = .002045$$

$$Y_1 + Y_2 = .1021 + .0994 = .2015$$

$$2 Y_1 = .20355$$

$$Y_1 = .1018$$

$$Y_2 = .1018 - .00205 = .0997$$

$$\text{At } 83^\circ\text{F} = 28.3^\circ\text{C}$$

$$K = \frac{p_a}{X_a} = (1.353)(10^6)$$

where K = Henry's Law constant, p_a = partial pressure of CO_2 in mm of Hg, and X_a = mol fraction of CO_2 in liquid phase.

$$\text{where } Y_1 = .1018 \quad p_a = \frac{(753).1018}{1.1018} = 69.5$$

$$x_a = \frac{69.5}{(1.353)(10^6)} = (5.13)(10^{-5}) = x_1^*$$

$$x_1^* - x_1 = (5.13 - 4.82)(10^{-5}) = (.31)(10^{-5})$$

$$\text{where } Y_2 = .0997 \quad p_a = \frac{(753)(.0997)}{(1.0997)} = 68.1$$

$$X_a = \frac{68.1}{(1.353)(10^6)} = (5.02)(10^{-5}) = X_2^*$$

$$X_2^* - X_2 = (5.02 - .08)(10^{-5}) = (4.94)(10^{-5})$$

$$\Delta X_{1m} = \frac{(4.94 - .31)(10^{-5})}{2.3 \log \frac{(4.94)}{(.31)}} = (1.672)(10^{-5})$$

$$K_{LX}^a = \frac{.01708}{(13.2)(1.27)(1.672)(10^{-5})} = 60.8$$

ACKNOWLEDGMENTS

This is to acknowledge the help and assistance of Dr. R. C. Ernst in direction of this work.

This study would not have been possible without the help of the Louisville Gas and Electric Company whose donation of the absorber shell and packing are hereby acknowledged.

Acknowledgments are also due Dr. E. E. Litkenhaus, Dr. G. C. Williams and Mr. Wilson R. Barnes for their kind advice and suggestions.

VITA

FATHER'S NAME: Preston T. Aker (Deceased)

MOTHER'S NAME: Florence Lee Aker (Deceased)

DATE OF BIRTH: June 17, 1902

PLACE OF BIRTH: Smithville, Missouri

ELEMENTARY SCHOOLS: Smithville, Missouri public school
Thomas Hart Benton School, Kansas
City, Mo., Graduated, 1916

HIGH SCHOOL: Central High School, Kansas City, Mo.
Graduated 1920

UNIVERSITIES: University of Missouri 1920-21
University of Illinois 1922-26
B. S. in Ch. E. 1926

EMPLOYED BY: Louisville Gas & Electric Co. 1926 -
Title: Chemical Engineer

FIELDS OF SPECIALIZATION: Water conditioning, corrosion pre-
vention, boiler water conditioning.
Manufactured and Natural gases.

MAJOR WORK DONE AT UNIVERSITY OF LOUISVILLE UNDER:

Dr. R. C. Ernst

Dr. G. C. Williams

Dr. E. E. Litkenhaus