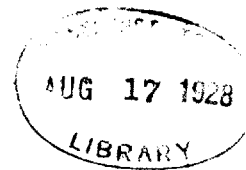


*Chem. Eng'g  
practice  
thesis  
1927*



AIR DRYING  
WITH  
CAUSTIC POTASH

A THESIS

submitted to the faculty of the  
Massachusetts Institute of Technology  
in partial fulfillment of the require-  
ments for the degree of Master of  
Science in Chemical Engineering Practice

by

Francis Graham Cunningham

Course X - A June, 1927



Very sincere thanks are due  
Mr. T. K. Sherwood for his  
assistance and supervision  
in connection with this thesis.

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1.

SUBJECT:

The drying, or partial drying  
of air, when blown through lump caustic  
potash.

OBJECT:

To study the absorption coeffi-  
cient of solid caustic potash when drying  
air, and to express the coefficient as a  
function of the superficial air velocity.

ABSTRACT

The absorption coefficient of solid caustic potash was studied over a superficial velocity range of from one-half to three feet per second and over a temperature variation of from 35° to 60° C. The overall coefficient  $K_a$  varied from 0.8 to 2.3. It was found that in this range velocity was controlling, the coefficient being expressed by the following equation:

$$K_a = 1.0U^{0.7}$$

where  $K_a = \frac{\#}{hr. /cu. ft. total vol. /min. Hg}$  pressure difference

and  $U =$  superficial air velocity in ft./sec. at the temperature of the air entering the tower.

Information is supplied so that the absorbing area and also the actual velocity through the tower filling may be readily calculated.

## INTRODUCTION

Air may be dried, or partially so, by dehumidification, compression, refrigeration, adsorption and absorption. Drying by absorption may be accomplished by using liquids such as  $H_2SO_4$ ; concentrated solutions of  $CaCl_2$  or caustic; or by blowing air through a tower filled with drying material in lump form. Of solid drying agents  $KOH$ ,  $CaO$ ,  $NaOH$ ,  $CaCl_2$  and soda lime are examples. Commercially  $KOH$  and  $CaO$  are used, especially  $KOH$ , as they can be obtained in a lump form very suitable for drying, the others cannot be bought in a form so well adapted for use as a tower filling, though on present evidence there seems to be no particular objection to them other than this.

At present this method of air drying is used mostly in the process of making liquid air, caustic being well adapted because it also removes  $CO_2$ . The dryness of the air is limited by the back pressure of the desiccant and cannot usually be made dry enough for use in this process by absorption alone. When necessary the last of the moisture is removed by refrigeration. Another possible but very undeveloped field for dry air is for use in blast furnaces. The high temperature of the melting zone, together with

the reducing condition, decomposes any moisture entering with the air with an absorption of heat and a reduction of temperature.

If this could be prevented and a higher temperature made available in the melting zone there would be an appreciable increase in the melting rate and therefore an increase in the capacity of the furnace since it is generally agreed that the melting capacity limits the output of the blast furnace. So far no data are available with which the capacity of such a drying tower might be predicted. This thesis is a study of the absorption coefficient and an attempt to find the relative importance of the variables affecting it. The absorption coefficient  $K_a$  is defined as the pounds absorbed per hour per cubic foot per millimeter pressure difference between the water vapor in the air and in the absorbing material and may be expressed by the equation:

$$\frac{w}{\theta} = K_a V \Delta p$$

where  $\frac{w}{\theta}$  is the absorption rate,  $V$  the total volume of the packed portion of the tower and  $\Delta p$  the driving force or difference in vapor pressure. This  $\Delta p$  is the logarithmic mean of the  $\Delta p$ 's at the

entrance and exit. It is evident that  $K_a$  depends on the particular apparatus and filling used in obtaining data. Results so obtained cannot be compared with results from other tests unless the absorbing area is known, from which  $K$  itself can be calculated. Since  $K$  is an important function of velocity it is well to know the actual velocity through the packing. Data are supplied whereby the results of this thesis can readily be put on a basis to compare them with the results of other tests.

Some work similar to this has been done on silica gel, \* mostly on a small scale and not of a nature to allow an absorption coefficient to be calculated. However, some data are given for a large size adsorber from which a  $K_a$  of about 0.35 at 0.5 feet per second has been calculated. These values are not comparable with the results of this thesis since neither the actual velocity through the gel nor the area of the adsorbing surface is known.

The superficial velocity is the velocity the air would have in passing through the tower if there were no packing in it. The actual velocity is the superficial velocity divided by the

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\* E.B. Miller, Chem. & Met. 23, 1155, 1219, 1251



fractional part of the total volume which is free volume. The total volume is the volume of the packing itself plus the free volume or voids. It is the product of the depth of packing and cross-sectional area of the tower.

PROCEDURE  
and  
DESCRIPTION OF APPARATUS

The apparatus consisted of an air blower delivering through a horizontal six-inch galvanized-iron pipe into which was set a one-inch sharp-edged orifice. After the orifice an elbow led the air into a vertical tower, also of 6" galvanized iron pipe, which contained the lump caustic. This tower was removable for convenience and contained a wire grid near the bottom to support the drying agent. Sampling points were provided at the orifice and at the top of the tower filling. After the first few runs a tube was inserted in the tower wall leading to a point in the center of the tower and about 1-1/8" above the grid at the bottom. This served as a thermometer well and also to take samples after each run with the air current off as a means of measuring the back pressure.

The pressure drop through the orifice was measured with a vertical water manometer for differences greater than 2" of water; otherwise an Ellison differential draft gage was used. Piezometer

rings were employed.

The moisture content of the air was determined by continuously abstracting a small amount during the whole run, passing it through  $P_2O_5$  and then measuring the air sample with a wet gas meter. The  $P_2O_5$  was contained in Midvale absorption bulbs and supported by glass wool to make the mass porous. When the moisture in the air was high a  $CaCl_2$  tube was put ahead of the  $P_2O_5$  in order not to decrease its efficiency too rapidly. After drying, the air was saturated by bubbling it through water before entering the wet meters. A slight suction on the exit end of the wet meters was necessary in order to draw the air through the system.

The drying material used was walnut size lumped caustic potash obtained from Innis, Speiden & Company, 41 Commercial Whard, Boston. With an average analysis as follows:

Total alkali as KOH	91.5%
KOH	88.8%
$K_2CO_3$	3.4%
K Cl	1.7%

the remainder probably being mostly water.

For the tests, pieces were selected with an approximate diameter of 1-1/4 inches. A comparison of the measured free volume with the free volume cal-

culated on the assumption that they were spheres shows the diameter to be 1.20 inches and this figure is used in calculating the area. The free volume was found to be 47% of the total volume of tower filled with packing and the area to be 31.7 sq. ft. per cu. ft. of total volume exclusive of wall area, or 39.7 sq. ft. per cu. ft. if the area of the wall surrounding the filling is added, the wall being a cylinder 6" in diameter. The free volume was determined (see page 29 ) by filling a 6" diameter beaker (the same diameter as the tower) with lumps to a known depth and barely covering them with kerosene. The volume of kerosene is the free volume while the total volume is calculated from the beaker dimensions. The number of lumps occupying this total volume was counted and the area calculated on the assumption that they were spheres of 1.20" dia. The volume calculated on this assumption checks with the volume obtained by actual measurement.

The material was placed in the tower and shaken somewhat to remove channels, the tower put in place and the blower started. The air velocity was kept constant for each run, a valve before the orifice being used to regulate the speed. In some runs steam

was admitted to the entrance of the blower along with the air to increase the humidity. About thirty minutes was allowed for the system to come to equilibrium during which time a saturated solution formed on the surface of the lumps, this effect being naturally greater at the bottom. Some of the ~~some of~~ the solution would run down the walls below the filling and had to be removed after the run.

Temperatures were taken of the air in the room, at the orifice, just above the bottom of the tower filling as before mentioned, and at the surface of the filling. The temperature of the room gave the temperature of the air passing through the meters. Samples were taken during the run of the air before and after it had passed through the filling.

Immediately after each run the back pressures were determined as follows: at the top by analyzing the air rising through the packing at very low velocity (0.1 ft./sec.) this air being assumed to have come to equilibrium with the top part of the filling. At the bottom the back pressure was obtained by closing the blower valve and sucking the air down through the filling with a laboratory vacuum pump (vel. = 0.01 ft./sec.) at the same time taking an air sample through the lower

sampling tube. The result of this analysis is assumed to be the back pressure at the bottom.\*

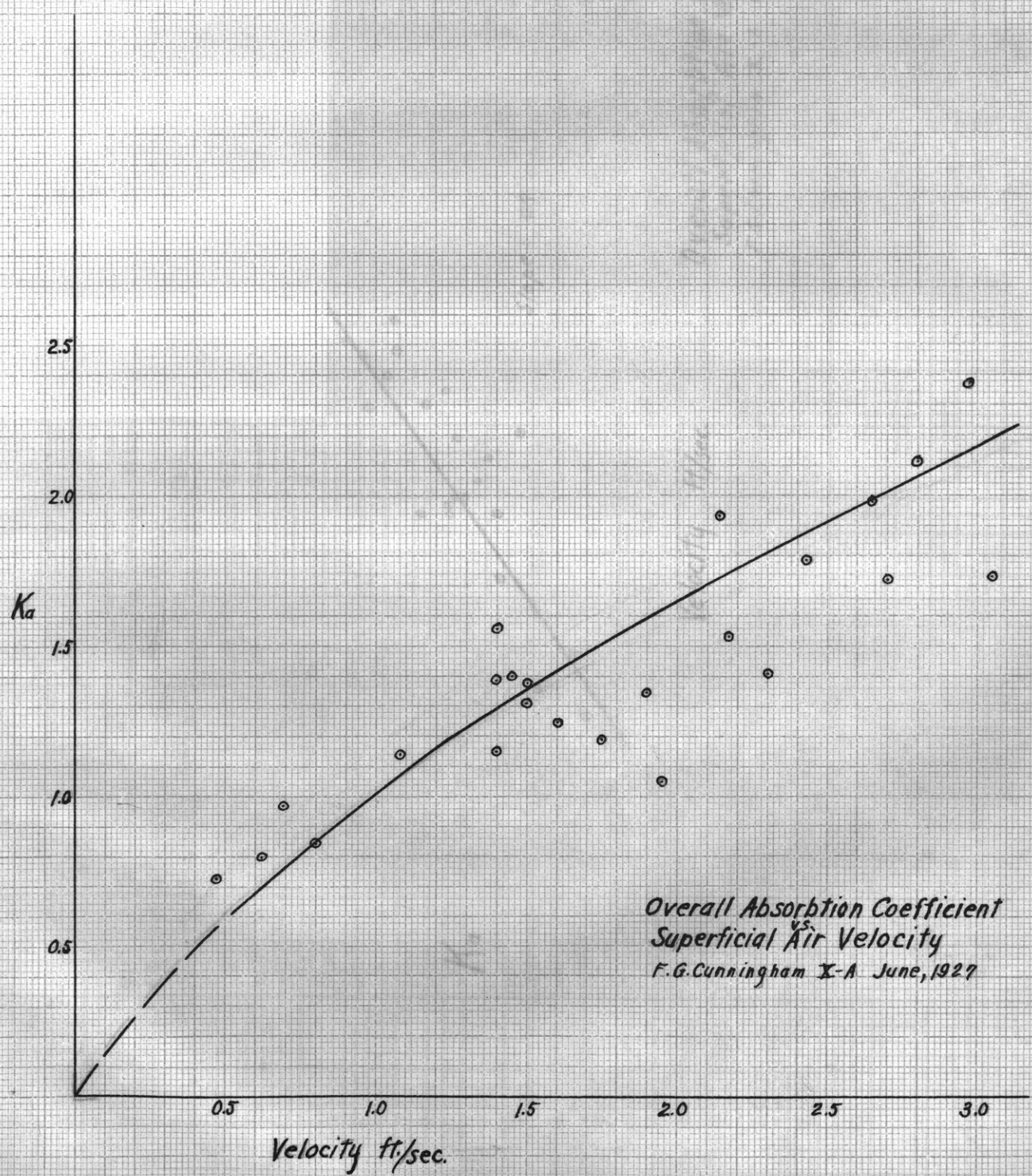
In all cases the distance from the sampling tube to the absorption bulb was kept as short as possible - never more than an inch - in order to obtain a true sample. All bulbs were weighed to 1/10 of a milligram, the increase in weight being considered as the moisture content of the sample. The readings of meter #2 had to be multiplied by a factor of .82 or .83, since it did not read directly in cubic feet. Analyses are accurate to about one per cent.

The depth of caustic in the tower was measured by difference from a fixed point at the top of the tower. These readings are accurate to about 1/4" which makes an error of 8% when the depth is 3" - the thinnest used.

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\* In some of the early runs the entrance back pressure was determined by taking the air sample through the lower sampling tube with the air current rising but since the air had only passed through an inch of filling before being sampled equilibrium was not nearly attained and these results have not been used in making the plots of back pressure.

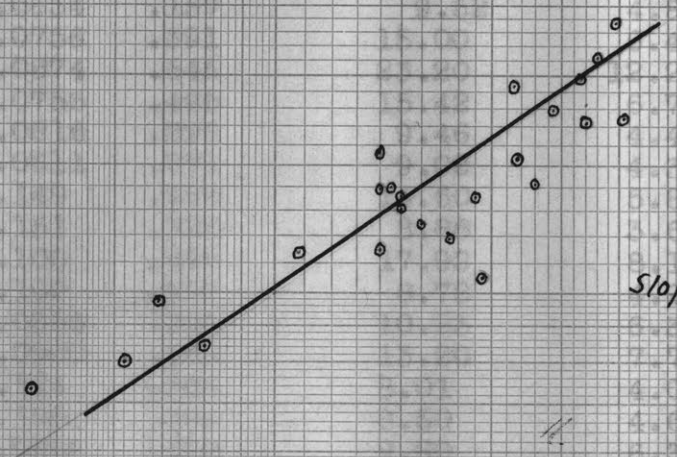
*Exp. 1000*  
*4/13/27*



*Overall Absorption Coefficient  
Superficial Air Velocity<sup>vs.</sup>  
F.G. Cunningham X-A June, 1927*

Run #	Vel. ft./sec.	Overall Absorption Coefficient	Superficial Air Velocity
19	1.27	0.25	1.27
14	1.42	0.28	1.42
5	1.83	0.35	1.83
10	1.85	0.35	1.85
3	1.88	0.35	1.88
9	1.90	0.35	1.90
8	1.90	0.35	1.90
7	1.90	0.35	1.90
10	2.00	0.38	2.00
11	2.00	0.38	2.00
12	2.00	0.38	2.00
13	2.00	0.38	2.00
14	2.00	0.38	2.00
15	2.00	0.38	2.00
16	2.00	0.38	2.00
17	2.00	0.38	2.00
18	2.00	0.38	2.00
19	2.00	0.38	2.00
20	2.00	0.38	2.00
21	2.00	0.38	2.00
22	2.00	0.38	2.00
23	2.00	0.38	2.00
24	2.00	0.38	2.00
25	2.00	0.38	2.00
26	2.00	0.38	2.00
27	2.00	0.38	2.00
28	2.00	0.38	2.00
29	2.00	0.38	2.00
30	2.00	0.38	2.00
31	2.00	0.38	2.00
32	2.00	0.38	2.00
33	2.00	0.38	2.00
34	2.00	0.38	2.00
35	2.00	0.38	2.00
36	2.00	0.38	2.00
37	2.00	0.38	2.00
38	2.00	0.38	2.00
39	2.00	0.38	2.00
40	2.00	0.38	2.00
41	2.00	0.38	2.00
42	2.00	0.38	2.00
43	2.00	0.38	2.00
44	2.00	0.38	2.00
45	2.00	0.38	2.00
46	2.00	0.38	2.00
47	2.00	0.38	2.00
48	2.00	0.38	2.00
49	2.00	0.38	2.00
50	2.00	0.38	2.00

$K_a$



Slope = 0.7

Velocity ft/sec.

Overall Absorption Coefficient  
 Superficial Air Velocity  
 F.G. Cunningham X-A June 1927



RESULTS

Run #	Vel. ft./sec.	Total Vol. cu.ft.	w/θ #absorbed/hr	Entrance Humidity MM. Hg	Exit Humidity Mm.Hg	log meanΔp	Ka
19	.47	.0674	.106	9.35	3.98	2.17	.73
14	.62	.106	.134	9.20	4.02	1.58	.80
6	.69	.0633	.287	16.15	6.50	4.68	.97
20	.80	.0634	.157	9.52	4.84	2.96	.84
5	1.08	.0756	.391	15.00	6.44	4.52	1.14
9	1.40	.0674	.645	23.20	12.20	8.35	1.15
8	1.40	.0755	.495	15.42	6.70	4.71	1.39
7	1.40	.0816	.298	9.46	4.42	2.33	1.56
10	1.45	.0611	.271	9.02	4.30	3.17	1.40
12	1.50	.149	.488	14.60	5.85	2.50	1.31
11	1.50	.151	.328	8.88	3.60	1.57	1.38
4	1.60	.100	.695	17.92	8.12	5.56	1.25
15	1.75	.102	.287	8.72	4.95	2.37	1.19
22	1.90	.0556	.305	10.23	6.38	4.05	1.35
17	1.95	.0900	.458	13.20	7.70	4.85	1.05
25	2.14	.114	.362	8.01	4.03	1.64	1.93
26	2.17	.106	.354	8.50	4.67	2.18	1.53
21	2.30	.0594	.329	9.80	6.37	3.94	1.41
27	2.43	.0939	.465	9.75	5.24	2.77	1.79
28	2.65	.0816	.462	9.60	5.25	2.86	1.98
18	2.70	.0700	.740	17.75	11.10	6.14	1.72
24	2.80	.0450	.471	11.62	7.59	4.95	2.11
13	2.97	.125	.618	9.50	4.52	2.09	2.37
16	3.05	.0960	.486	9.57	5.73	2.93	1.73

RESULTS

Used in Calculating  $\Delta p$

Run	Bottom temp.	Ent. back press.	$\Delta p_1$	Top temp.	Exit back press.	$\Delta p_2$
19	38 <sup>o</sup> C	3.40 Mm.Hg.	5.95	Mm.Hg. 42 <sup>o</sup> C	3.50 Mm.Hg	0.48 Mm.Hg
14	39	3.50	5.70	44	3.85	0.17
6	48	5.05	11.10	51	5.10	1.40
20	39	3.55	5.97	<del>51</del> 43	3.65	1.19
5	47	4.85	10.15	50	4.95	1.49
9	59	8.00	15.20	62	8.25	3.95
8	48	5.00	10.42	51	5.10	1.60
7	41	3.80	5.86	44	3.80	0.62
10	36	3.00	6.02	36	2.90	1.40
12	52	5.90	9.70	53	5.55	0.30
11	39	3.50	5.38	41	3.40	0.20
4	53	6.20	11.72	55	6.05	2.07
15	40	3.65	5.07	46	4.10	0.85
22	43	4.05	6.18	44	3.90	2.48
17	43	4.15	9.05	53	5.55	2.20
25	41	3.85	4.16	42	3.60	0.43
26	42	3.95	4.55	44	3.85	0.82
21	40	3.65	6.15	45	4.00	2.37
27	43	4.10	5.65	46	4.15	1.09
28	44	4.25	5.35	<del>53</del> 45	3.95	1.30
18	61	8.40	9.35	59	7.35	3.75
24	45	4.50	7.12	47	4.30	3.29
13	43	4.10	5.40	45	4.00	0.52
16	41	3.85	5.72	48	4.50	1.23

DISCUSSION

Considerable difficulty was encountered in measuring the back pressure since it was had to get a sample of air which had come to equilibrium. A fairly satisfactory method was finally evolved and has been described in the procedure. Inaccuracies in the analyses will introduce a larger error in  $\Delta p$  since this figure is obtained by difference between two much larger figures, especially the exit  $\Delta p$ . The back pressures at the entrance and exit have been plotted as functions of the temperature of the absorbing material at that point, and in calculating  $\Delta p$  the back pressure has been taken from the curve at the observed temperature, rather than using the back pressure measured for that run. Curve "A" gives the back pressure at the entrance, curve "B" at the exit. (p.28)

The back pressure at the bottom is probably that of a saturated solution of ~~KHO~~<sup>KOH</sup> and checks well with data from the literature\*. The curve of the exit back pressures falls below this perhaps because it represents the vapor pressure of a hydrate rather than

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\* R.J. Paranjpe, Jour. Ind. Inst. Sci. (2), p.59

a true saturated solution. An examination of the data from the poor runs shows that generally the observed back pressure did not check well with the curve. As an experiment these apparently poor runs were recalculated, using the observed back pressure. Better coefficients were usually obtained though sometimes they were much less satisfactory. On the whole it appears that most representative results are obtained by using the graphs of back pressure. It is possible that the temperature is not a true index of the back pressure though the  $\Delta p$ 's have been calculated on this assumption. For instance, the concentration of the solution which causes the back pressure may not be the same in two runs although the temperature is the same. A high absorption rate may prevent the film on the lumps from staying saturated and thus increase the back pressure. This is the same as saying that the liquid film has some effect. To show this, a plot has been made of  $1/K_a$  vs.  $1/u^{0.8}$ , which results in a relatively small positive intercept on the  $1/K_a$  ordinate showing that liquid film has little effect.

An error may possibly be introduced by the solution running down the wall below the screen which supports the packing; thus increasing the absorbing

area and giving a slightly high coefficient especially with a small volume of caustic, since then the area would be a larger proportion of the total absorbing area. To check this a plot was made of  $Ka/u^{0.7}$  vs volume which shows a slightly higher coefficient at low volumes, thus to some extent substantiating this theory. However, the points are so scattered that the results are not entirely conclusive.

Inconsistencies may be introduced if the absorbing area is not the same for a given volume due to the lumps arranging themselves differently in different runs. The figure obtained for this is subject to several errors which cannot be avoided.

It is suspected that channelling is responsible for some of the errors though this is hard to prove unless it is certain that all data are reliable.

Air velocity had the greatest effect on the coefficient. The superficial velocity has been used throughout, though the actual may be obtained by multiplying by 2.14. A plot has been made of  $Ka$  vs.  $u$  and an equation deduced from the curve

$$Ka = 1.0 u^{0.7}$$

the equality coefficient being unity.

To show the effect of temperature over the range studied ( $35^{\circ}$  -  $60^{\circ}$  C) a plot was made of  $K_0/\mu^{0.7}$  vs. T, which corrects for velocity. The points are too scattered to determine a line and the only conclusion that can be drawn is that these data do not show any high coefficients above  $52^{\circ}$  or  $53^{\circ}$  C.

### CONCLUSIONS

Caustic potash is a rapid absorbent, the first three or four inches of filling doing most of the work of absorption even at high absorption rates. The surface of the lumps rapidly becomes covered with a saturated solution, which has an appreciable vapor pressure, consequently the air is never thoroughly dried. The fresh caustic has a very low vapor pressure and should dry air to about 0.1% by weight but does not stay as effective as this for long.

The gas film is practically controlling which means that the air velocity is the important variable affecting the coefficient; in fact it can be expressed by the following equation:

$$K_a = 1.0U^{0.7}$$

Temperature has but little effect in the range studied (35° - 60° C).

The main sources of error in this investigation are due to equilibrium being very rapidly attained with a consequent low  $\Delta p$ , and possibly to channelling although it is difficult to get direct evidence of the latter.

RECOMMENDATIONS

In the event of any work being done in the future on this subject it would be well to design the apparatus so that the entering humidity and temperature would be controlled. Also a better means should be devised for measuring the back pressure.

Any excess solution forming in the tower could be prevented from running down the tower by slightly arching the grid so that the solution would run to the sides and providing a channel around the inside of the tower with a tap leading to the outside to remove it. An analysis of this solution might provide data whereby its vapor pressure might be determined. By not allowing any solution to escape from the tower the increase in weight could be noted which would furnish a material balance as a check on  $w/\theta$ .



APPENDICES

APPENDIX A

DATA

Run	Press. drop " H <sub>2</sub> O thru 1" orifice	Entering air analysis				Exit air analysis			Actual depth of packing
		wt. inc. of bulb	meter reading	temp. at both meters	temp. at sampling point	wt. inc.	meter reading	temp. at sampling point	
4	1.91	.2169g .1758 .2269 .3704 .4994	.466 <sup>H<sub>2</sub>O</sup> .358 <sup>cu. ft.</sup> .425 .715 1.033	27°C	33°C	.0532g .0535 .0650 .1413 .0370 .1108 .0845	.368H <sub>2</sub> O .256 <sup>cu. ft.</sup> .301 .626 .158 .490 .390	55°C	6 1/8"
5	.86	.2070 .2404	.493 .590	25	31	.0665 .0580 .0745	.370 .324 .431	50	4 5/8
6	.35	.1955 .2340	.446 .534	25	26	.0780 .0810 .0450	.457 .480 .258	51	3 3/4
7	1.43	.1750	.682	24	28	.0345 .0300	.303 .252	44	5
8	1.43	.3802	.903	24	27	.0750 .0457	.392 .253	51	4 5/8
9	1.43	.4555	.713	24	28	.1165 .0863	.354 .258	62	4 1/8
10	1.48	.1550	.630	22	24	.0380 .0205	.299 .175	37	3 3/4
11	1.53	.1235	.515	24	28	.0268	.303	42	9 1/4
12	1.53	.2735	.690	24 25	30	.0478	.258	54	9 1/8
13	6.60	.1927 .1942	.750 .772	26	32	.0410 .0187 .0409 .0431	.325 .153 .355 .365	46	7 5/8
14	.28	.1005	.411	27	33	.0375 .0240	.361 .226	45	6 1/2
15	2.23	.1792	.771	27	34	.0422 .0255	.348 .195	45	6 1/4

Run	Press. drop " H <sub>2</sub> O thru 1" orifice	Entering air analysis				Exit air analysis			Actual depth of packing
		wt. inc. of bulb	meter reading	temp. at both meters	temp. at sampling point	wt. inc.	meter reading	temp. at sampling point	
16	6.90	.1833g	.725 <i>cu. ft.</i>	28°C	34°C	.0553g	.390 <i>cu. ft.</i>	46°C	5 7/8"
17	2.78	.2610	.733	28	36	.0230	.144		5 1/2
18	5.55	.2003	.425	29	36	.0720	.374	51	
19	.17	.1082	.427	24	30	.0350	.173		4 1/4
20	.47	.1037	.402	24	31	.1015	.348	59	4 1/8
21	4.00			25	32	.0447	.417	42	3 7/8
22	2.70			25	32	.0792	.609	42	3 5/8
24	5.90	.1600	.515	27	32	.0995	.581	45	3 3/8
25	3.40	.1863	.864	25	32	.1340	.663	47	2 3/4
26	3.52	.2097	.916	25	32	.0242	.233	43	7
27	4.40	.1892	.720	25	33	.0287	.266		6 1/2
28	5.30	.2798	1.082	25	32	.0303	.249	44	5 3/4
						.0287	.229		
						.0256	.187	46	
						.0257	.182		
						.0492	.332	44	5
						.0343	.241		

DATA FROM EQUILIBRIUM RUNS

Run	Entrance			Exit			Calculated back pressure	
	True Temp.	wt. increase	meter reading	Temp.	wt. increase	meter reading	Entering	Exit
4	53°C			55°C	.0386g	.226 <i>cu. ft.</i>	<del>cu. ft.</del>	Mm. 6.41 Hg.
5	47			50	.0225	.167		5.04
6	48			51	.0248	.176		5.27
7	41			44	.0155	.164		3.52
8	48			51	.0290	.189		5.69
9	59			62	.0400	.172		8.59
10	35			37	.0134	.143		3.45
11	39			41	.0152	.166		3.42
12	52			53	.0305	.205		5.55
13	43			45	.0185	.177		3.94
14	39			44	.0285	.274		3.92
15	40			46	.0290	.249		4.39
16	42			48	.0150	.104		5.47
17	43			53	.0330	.195		6.44
18	61	.0248g	.115cu.ft.	59	.0308	.154	8.30Mm. Hg.	8.76
19	39	.0187	.203	42	.0170	.172	3.34	3.68
20	39	.0200	.200	43	.0195	.193	3.73	3.77
21	40	.0172	.152	45	.0165	.130	4.25	4.74
22	43	.0120	.107	45	.0168	.127	4.17	4.93
24	45	.0157	.106	47	.0160	.107	5.63	5.62
25	41	.0183	.200	43	.0241	.219	3.42	4.11
26	42	.0175	.161	44	.0195	.167	4.06	4.38
27	43	.0150	.147	46	.0205	.190	3.80	4.02
28	44	.0177	.152	45	.0193	.169	4.34	4.26

APPENDIX B

SAMPLE CALCULATIONS

Run #13 is calculated.

Data:

Pressure drop through one inch orifice- 6.60" H<sub>2</sub>O  
 Temperature at orifice (same as  
 temperature of entrance air sample) 32°C

Barometer -normal. In all runs the  
 atmospheric pressure was near enough  
 normal to be neglected

Distance from top of tower to top  
 of packing 16 $\frac{3}{4}$ "

Diameter of tower 6"

Temperature of both gas meters 26°C

Entering air samples:

2:15 to 2:35 P.M. weight increase  
 of bulbs .1927g

meter reading (#1 meter) .750 cu.ft.

2:35 to 2:55 P.M. wt.increase of  
 bulbs .1942g

meter reading (#1 meter) .772 cu.ft.

Exit Air samples:

2:15 P.M. to 2:25 P.M. weight  
 increase of bulb .0410g

meter reading (#2 meter) .325 cu.ft.

2:25 to 2:35 P.M. wt.increase .0187 g

meter reading #2 .153 cu.ft.

2:35 to 2:45 P.M. wt.increase .0409 g

#2 meter reading .355 cu.ft.

<u>2:45 to 2:55 P.M.</u> wt. increase	.0431 g.
#2 meter reading	.365 cu.ft.
Temperature at top surface of packing	45°C
Temperature of air at lower sampling point	41°C
Temperature of packing at lower sampling point	43°C



Equilibrium runs - air rising in both cases -  
samples taken simultaneously.

From lower sampling tube  
wt. increase of bulb .0349 g  
meter reading .230 cu.ft.

After rising through entire filling  
wt. increase .0185 g  
meter reading .177 cu.ft.

Calculation of superficial air velocity

Vel. through 1" orifice =  $.61\sqrt{2gh}$   $g = 32.2$

$h = \frac{6.60 \sqrt{1} \sqrt{623} \sqrt{359} \sqrt{305}}{12 \quad 29 \quad 273} = 474'$  air

$u = .61\sqrt{64.4 \times 474} = 106.6 \text{ ft./sec.}$

$U = \frac{106.6 \times 1}{36} = 2.97 \text{ ' /sec.}$  Superficial air velocity at 32° C

Calculation of total volume

Depth of packing  $23\frac{7}{8}'' - 16\frac{1}{4}'' = 7\frac{5}{8}'' = 7.63''$

Vol. =  $\frac{7.63 \pi (\frac{6}{2})^2}{1728} = .125 \text{ cu.ft.}$

Calculations of entering air analysis

Wt. increase .1927 g air sample .750 cu.ft. sat. at 26°C  
pp H<sub>2</sub>O vapor at 26° C = 25 mm, 760 - 25 = 735 mm Hg  
press. due to air alone

$$\frac{.750 \times 735}{760} \overset{\text{vol dry air}}{\Big|} \frac{273}{299} = .661 \text{ cu.ft. dry S.T.P.}$$

1 gram  $\text{H}_2\text{O}$  vapor =  $359/18 \times 454 = .0439$  cu.ft. S.T.P.

Vol. of  $\text{H}_2\text{O}$  vapor in sample =  $.0439 \times .1927 = .00846$  cu.ft.

S.T.P.

Total volume of sample =  $.661 + .00846 = .670$  cu.ft. STP

pp. in sample due to  $\text{H}_2\text{O}$  vapor =  $.00846/.670 \times 760 = 9.58$  Mm.Hg

All analyses are calculated in the same manner.

Entering air analyses 9.58 and 9.41 av. 9.50 Mm.Hg

Exit air analyses 4.74, 4.59, 4.34, 4.43 Mm.Hg. av. 4.52

Analyses at equilibrium

at top 5.94 Mm. Hg. (temp 45° C)

near bottom 5.70 Mm. Hg \* (temp 43° C)

Calculation of  $w/\theta$  # H<sub>2</sub>O absorbed per hour

$$w/\theta = \frac{2.97 \times 71 \times 9 \times 3600}{144} \times \frac{\frac{w \text{ g/hr. S.T.P.}}{305} \sqrt{273} \sqrt{9.50 - 4.52}}{760} \times \frac{0.01 \text{ H}_2\text{O S.T.P.}}{359} = 0.618 \text{ #/hr.}$$

Calculation of log mean  $\Delta p$

$\Delta p$  at entrance

entering humidity 9.50 Mm.Hg

back pressure at 43° C from

graph 4.10 " "

$$\Delta p_1 = 9.50 - 4.10 = 5.40 \text{ Mm.Hg}$$

$\Delta p$  at exit

exit humidity 4.52 Mm Hg

back press. at 45° C from graph 4.00 " "

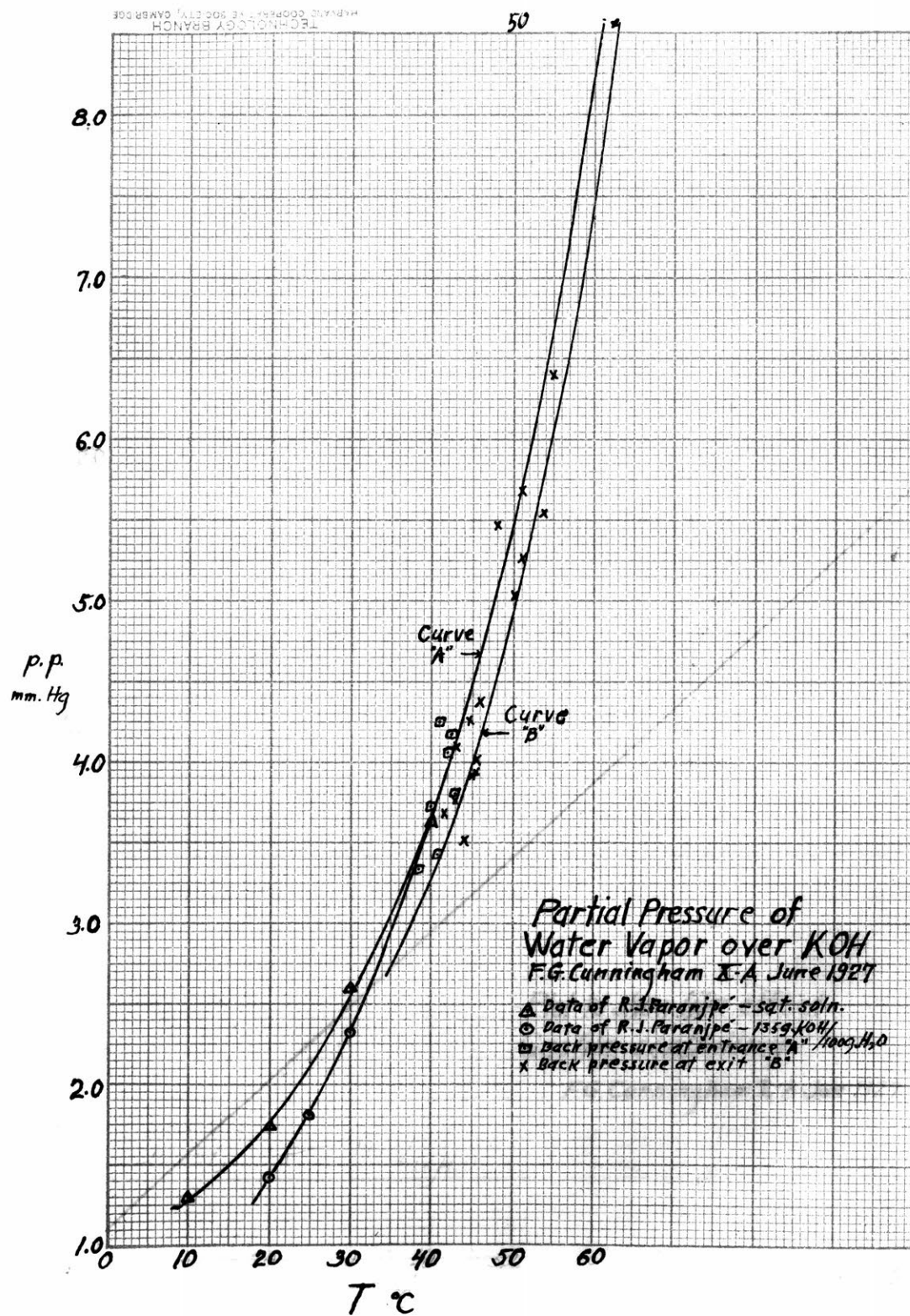
$$\Delta p_2 = 4.52 - 4.00 = .52 \text{ Mm.Hg}$$

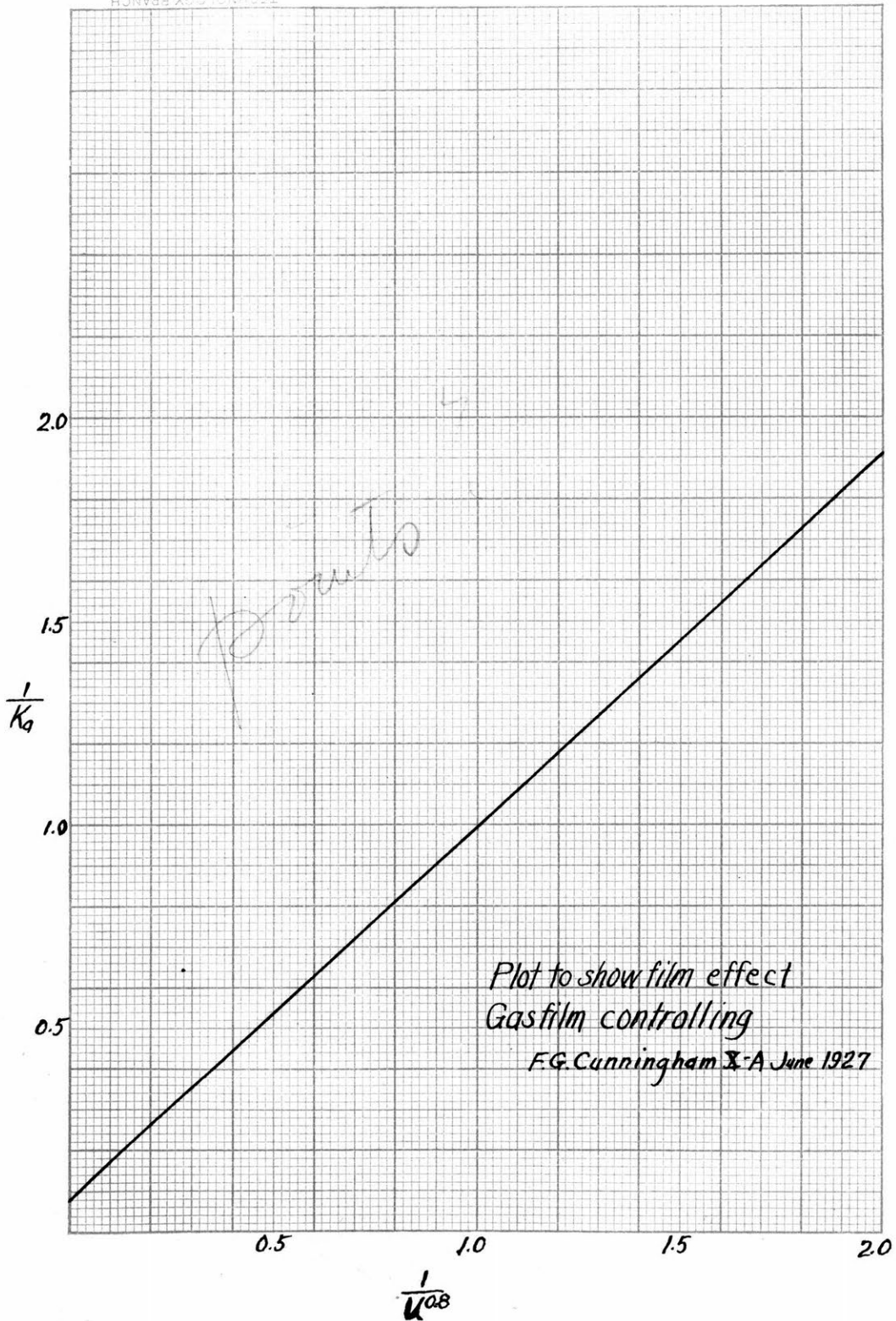
$$K_a = \frac{w}{\theta V \Delta p_{\log \text{ mean}}} = \frac{0.618}{.125 \times 2.09} = \frac{5.40 - .52}{2.3 \log \frac{5.40}{.52}} = 2.09$$

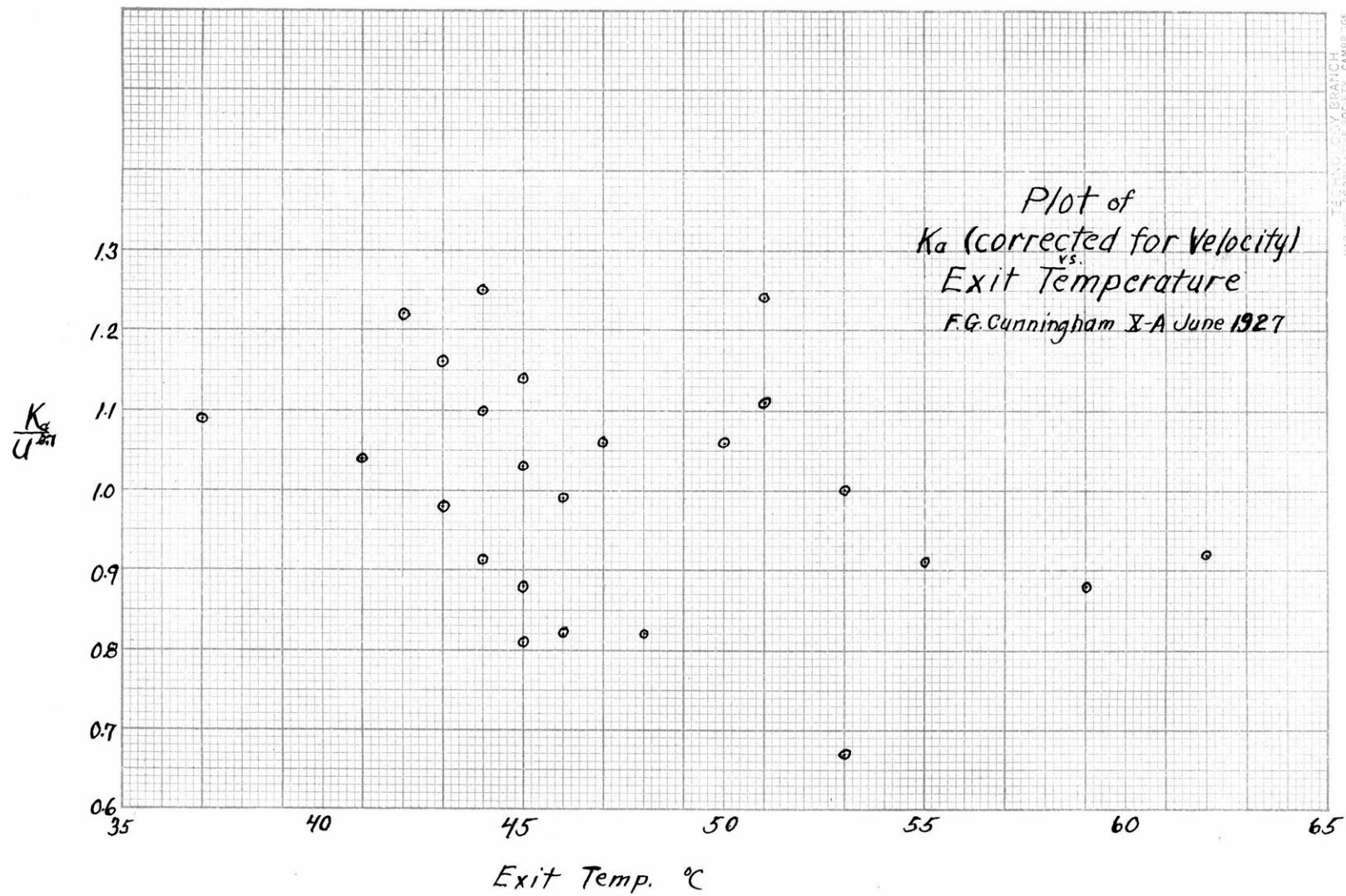
\*

The data for this result has not been included on the data sheet since it is certainly wrong. The true value as obtained from the plot is 4.10 Mm. which shows that the air had not attained equilibrium with the absorbent before being sampled. All bottom samples taken with the air rising are equally high and have been disregarded.

APPENDIX C







APPENDIX D



Free Volume and Area of Packing.

Data

Diameter of beaker used 6"

Volume to depth of 6-1/8" 0.100 cu.ft.

Free volume in this space as measured  
 by volume of kerosene required to  
 barely cover lumps 1320 cc = 0.0466 cu.ft.

Number of lumps in this space (lumps approx. 1 1/4" diam) = 101

Calculations

$$\% \text{ of free vol.} = \frac{\text{vol. of kerosene}}{\text{total vol.}} \times 100 = \frac{0.0466}{0.100} \times 100 = 47\%$$

Volume of lumps on assumption that they are  
 spheres 1.25" dia.

$$\frac{101}{.100} \times \frac{\pi(1.25)^3}{6 \times 1728} = .598 \text{ ft}^3/\text{ft}^3 \text{ compared with } .53 \text{ ft}^3/\text{ft}^3 \text{ obtained by measurement of free volume}$$

Solving for diameter which would make volumes equal

$$\frac{1010 \pi x^3}{6 \times 1728} = .530 \quad x^3 = 1.73 \quad x = 1.20" = \text{dia.}$$

Area on assumption that packing consists of spheres

$$\frac{1010 \pi (1.20)^2}{144} = 31.7 \text{ sq. ft. / cu. ft. total vol.}$$

~~31.7 sq. ft. / cu. ft. total vol.~~

Area of wall surrounding packing

$$\frac{6\pi \times 61.2}{12 \times 12} = 8.0^{\text{M}} \text{ft.}/\text{cu.ft. total vol.}$$

Total absorbing area if wetted wall is assumed

$$31.7 + 8.0 = 39.7 \text{ sq.ft.}/\text{cu.ft.}$$