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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report

on

Dehumidification of Air for Submarines and Closed Spaces in Ships - Design of Hoppers for Calcium Chloride or Other Desiccants.

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APPENDIX

ABSTRACT

This report describes the experimental work on several types of apparatus devised to make use of the solid desiccants described in previous reports to dehumidify closed spaces aboard ship. As a result of these experiments a simply constructed hopper using lump calcium chloride is recommended for the majority of uses. Incidental experiments proved that in a closed compartment there is much more water absorbed on the rusty walls than is contained in the air of the compartment and hence that the amount of desiccant required is greater than would be calculated from humidity tables and the volume of the space.

INTRODUCTION

(a) Authorization

1. This problem was authorized by Bureau of Engineering letter NP14(5-6-W8) of 12 July 1935.

(b) Statement of Problem

2. This report is a continuation of NRL Report No. P-1234 and NRL Report No. P-1277 and deals with the design of hoppers for exposing a desiccant in order to get the maximum speed of drying.

(c) Facts Bearing on the Problem

3. Although many types of apparatus have been invented for drying moving air, practically no work has been done on devices for drying static air. The Philadelphia Navy Yard uses wooden trays to contain the quicklime used for drying the double bottoms of decommissioned ships. However, the same method cannot be applied when using calcium chloride due to the fact that a solution is formed by the absorption of moisture by the calcium chloride. Where power is not available, or where fire hazard precludes the use of an electric motor, a fan or blower cannot be used. In these cases it is necessary to rely on the natural diffusion of the water vapor through the air, or on convection currents set up by the heat of absorption of water by the desiccant, to bring all the moisture laden air in contact with the drying agent.

(d) Theoretical Considerations

4. In designing hoppers it is desirable to use the heat of absorption of water by the calcium chloride to cause convection currents and thus increase the circulation of air over the desiccant. While a stack, acting as a draft promoter, would help in this respect, the increased height interferes with the use of the apparatus in small spaces. In spite of this difficulty, however, experiments were carried out involving the use of stacks.

(e) Original Work at this Laboratory

5. Very little work had been reported heretofore on this type of dehumidification. Various types of containers or hoppers were tried at this Laboratory in order to determine the fastest form which would be of relatively simple design. No apparatus employing blowers or other power equipment was tried. The effects of cloth wicks to expose the saturated solution, formed by absorption of moisture on the desiccant, to the air were studied. This saturated solution has a fairly good drying power, and by increasing the surface of it exposed to the air, it was hoped to speed up the drying process.

6. To determine what percentage of the total moisture in a container was absorbed on the walls of the container a large steel tank simulating a ship compartment was first saturated with water vapor, and then dried by means of calcium chloride.

METHODS

(a) Types of Hoppers Studied

7. In order to determine the most efficient types of hoppers to use, small scale hoppers were first constructed and from the most promising of these, full scale models were built. The dimensions of the latter were such that they could be moved through the man holes of ships, and would fit in the smaller closed compartments found on destroyers and other small vessels. Following is a list of the hoppers used:

Type SA - See Plate 1. This hopper consisted of a conical wire screen container for the desiccant, with a sheet metal container below to catch the solution formed by the absorption of water. It was constructed of thin tin-plated iron.

Type SB - See Plate 2. This hopper differed in design from Type SA in that the desiccant chamber was of smaller diameter, and a stack was provided below this chamber to increase the draft.

Type SC - See Plate 3. This hopper contained four wire screen trays arranged one above the other with a vessel below for catching the solution formed. A sheet metal sleeve fitted snugly around the trays so that only the top and bottom were open.

Type SD - This type of hopper was identical with Type SC except that six grams of wicking were suspended from the lower tray. The wicking was made in the form of strips (about 1/2" x 3") of Turkish toweling. The purpose of the wicking was to expose a greater surface of the saturated solution to the air.

Type SE - This type was identical with Type SD except that the sleeve surrounding the trays was of wire screen instead of sheet metal.

Type SF - This hopper was identical with Type SC except that the sleeve surrounding the trays was of wire screen instead of sheet metal.

Type A - See Plates 4 and 7. This was a full sized hopper constructed of galvanized iron, and similar to Type SA. It could be used with or without a stack and with or without wicks.

Type B - See Plates 5 and 8. This was a full sized hopper resembling Type SC. It consisted of three removable trays made with bottom and sides of wire screen, and top open. These trays fitted in a holder with a container below for the solution.

Type C - See Plates 6 and 8. This hopper consisted of several trays suspended vertically above a container for the solution. The fronts and backs of the trays were made of wire screen, and the trays were removable from the suspending rack. Four of the pads had a thickness of 1/2-inch and three were of one-inch thickness.

Type D - This was similar to Type A (Plate 4) except that the distance between the upper and lower containers was 12 inches instead of 6 inches. It could be used with or without a stack and with or without wicks.

Type E - This hopper was similar to Type D except that the distance between the two containers was 24 inches instead of 12 inches.

(b) Methods of Determining Efficiencies

8. The small scale hoppers (Types SA, SB, SC, SD, SE) were compared one against the other running under similar conditions. A known weight of calcium chloride was placed in the upper container, and the hopper was weighed from time to time as the calcium chloride absorbed water.

9. A similar procedure was carried out in the case of hoppers of Types A, B and C. Type A was used as a standard, and the other hoppers were compared with it. In the case of hoppers of Types D and E, a known weight of calcium chloride was added to the upper container, but the apparatus was not weighed after that. Instead the solution which had formed from absorption of the water was weighed. In each case two different hoppers were compared simultaneously. The calcium chloride used in all of the hoppers was either commercial granular material or in the form of lumps of about two to three inch diameter.

(c) Methods of Testing Wicking Materials

10. Small pieces of various cloth were tested as to their relative absorbing powers by immersing them either partially or wholly in water, and weighing the amount of water absorbed. The dimension and weights of the samples were known. The rate of evaporation was also studied.

(d) Determination of Water Absorbed on the Walls of a Rusty Container.

11. Consideration of the conditions existing in a closed ship compartment with rusty walls indicates that a large amount of water may be absorbed on the walls of the compartment. To make dehumidification effective, this absorbed water would have to be removed. To determine the amount of this absorbed water the following experiment was made. An old oil storage tank was first saturated with water vapor and then dried by means of calcium chloride in a small hopper. The tank was made of iron and was 49x46x28-1/2 inches in dimensions. The inside was somewhat rusty. The humidity of the contained air was measured from time to time by drawing a known volume of the air through a previously weighed calcium chloride tube, and noting the increase in weight. The hopper containing the calcium chloride used for drying the tank was weighed at intervals to determine the amount of water absorbed.

DATA OBTAINED

(a) Data on Efficiency of Hopper

12. In the first data obtained no record was kept of the gain

in weight of the calcium chloride, the solution which was formed being alone considered. These data show the effect of stacks and wicks on the hoppers. The data are tabulated in Table 1.

TABLE 1

Effect of Stacks and Wicks on Efficiency of Hoppers

Run	Type of Hopper	Stack	Wicks	Wt. of $CaCl_2$ (grams)	Granular or Lump	Ratio of Water to $CaCl_2$	Per Cent Water in Solution
I	A	-	-	2300	G	0.08	51
I	A	+	-	8200	L	0.17	51
I	A	-	-	9400	L	0.07	51
II	A	-	-	7500	L	0.11	51
II	A	+	-	9100	L	0.16	51
III	A	+	*	9800	L	0.40	51
III	A	+	-	11100	L	0.41	52

* Wool and hygrometer wicking.

In the following runs approximately equal weights of lump calcium chloride were used:

Run	Type of Hopper	Stack	Wicks	Weight of Solution Formed	Per Cent of Water in Solution
IV	D	+	Hygrometer	1810	60
IV	E	+	Hygrometer	1560	67
V	E	+	Muslin	1560	55
V	E	+	Hygrometer	1675	62
VI	E	+	Muslin	1760	60
VI	E	+	Hygrometer	1960	62
VI	E	-	Muslin	1720	61
VII	E	+	Muslin	1530	59
VII	E	-	Muslin	1300	61

13. The other data on the efficiency of various types of hoppers are all presented in the form of curves, shown on Plates 9 to 13, inclusive. Plate 9 shows the results obtained with the small scale hoppers. In these cases the speed of drying seems to be roughly proportional to the surface of the calcium chloride exposed, and the effect of drafts appear to be negligible. Types SA and SF are the most efficient of these small scale hoppers, and full sized models of these types were constructed (Types A and B).

14. Plate 10 compares lump calcium chloride with granular calcium chloride in a Type A hopper. The lumps were approximately two to three inches in diameter. It will be noted that initially the lump calcium chloride is faster than the granular, then the rate falls off rapidly, and

finally increases very rapidly to the point where the granular calcium chloride has absorbed one-half its weight of water. The reasons for this behavior are as follows. Perfectly dry calcium chloride is a slower dehydrating agent than the monohydrate ($CaCl_2.H_2O$), containing 14% water. Due to the small surface exposed in the lump form, as compared with that of the granular, the surface of the lump becomes coated with a layer of the monohydrate before the surface of the granular does. The rate of water absorption by the lump form then increases rapidly with respect to the granular. However, when the surface of the granular form has become coated with a layer of the monohydrate, its rate increases markedly, causing a drop in the relative rate of the lump form. This proceeds until the granular form begins to cake from the absorbed water, when the rate of absorption by the granular form decreases again due to decreased surface and prevention of air circulation among the granules. Thus the lump form of calcium chloride is a more rapid drying agent than the small granular form.

15. Plate 11 compares granular magnesium chloride with granular calcium chloride in a Type A hopper. The magnesium chloride is a commercial product sold by the Dow Chemical Co. of Midland, Michigan. The results of this experiment are in accord with the results given in NRL Report No. P-1277. The use of magnesium chloride as a desiccant is discussed in that report.

16. Plate 11 also compares the Type B hopper with the Type A form. The results show that the Type B form is 20% to 30% faster than the Type A hopper when using granular calcium chloride.

17. Plate 12 shows the effects of wicks on the rate of absorption of water by calcium chloride in the Type A hopper. The wicks serve to expose a greater surface of the solution formed to the air to be dried. As this saturated solution has drying properties it was hoped that the rate of absorption would be increased. In Plate 12, Type A hoppers with two different types of wicks are compared with a Type A hopper without wicks. One hopper had muslin wicks suspended in a circle below the screen container, about 12 inches long by 1/2 inch wide. The other hopper had shredded cellulose (Kotex) wicks wrapped in cheesecloth about 3/4 inch in diameter by 10 inches long. In both cases the rate of absorption was decreased by the wicks. This was probably due to the decreased circulation of air through the screens and around the solid calcium chloride.

18. Plate 13 compares the Type C hopper with the Type A hopper. In one case the Type C hopper had four 1/2 inch and three one-inch pads suspended from the rack, and in the other case two one-inch pads. Granular calcium chloride was used in both Type C hoppers and in the standard Type A hopper. The Type C form is much faster than the Type A, or any other hopper tried. With two one-inch pads it is about 70% faster than the standard hopper.

(b) Data on Wicks

19. Several types of wicks were studied in an attempt to find the most efficient one for exposing the saturated solution to the wet air. This was done by hanging samples of the various materials above

a calciumchloride solution with about 1/4 inch of the bottom immersed in the solution. In a second experiment the solution was poured over the samples and they were then allowed to drain. In a third experiment the cloths were soaked over night in the solution and then allowed to drain for an hour. In all cases the gain in weight was noted. Finally the wet samples were allowed to stand in the air for a few hours, and the loss in weight noted, to determine the rate of evaporation. Table 2 gives the results.

Table II.

Tests on Wicks.

Material	Density	Dimension	Weight	Water per unit weight				Water per unit volume.			
				A*	B*	C*	D*	A*	B*	C*	D*
"Kotex"	0.073	4 x 1"	0.177	4.26	12.75	18.0	9.80	0.312	0.930	1.31	0.60
Hygrometer Wick	0.28	4 x 3/4"	0.477	2.72	3.72	3.99	0.51	0.762	1.040	1.12	0.97
Flannel	0.26	4 x 1"	0.525	2.29	4.99	5.45	1.48	0.596	1.299	1.42	1.03
Turkish Towel	0.19	4 x 1"	0.771	2.74	4.64	5.76	2.72	0.520	0.881	1.09	0.58
Knit String	0.24	4 x 1"	0.620	0.123	0.74	1.03	0.08	0.030	0.178	0.25	0.23
Wool Blanket	0.29	4 x 1"	1.100	0.706	1.49	3.64	1.38	0.204	0.432	1.06	0.66

* A – End of material dipping in solution.
B – Solution poured over material.
C – Materials soaked in solution and drained.
D – Solution allowed to evaporate from materials.

20. In considering materials for wicks the water per unit volume is of greater importance than the water absorbed (or evaporated) per unit weight. This is due to the fact that only a limited volume of material can be hung under the screen, and the weight of the material is negligible. Under these conditions flannel appears to be the best material.

(c) Data on Quantity of Water Absorbed by Rusty Iron

21. As previously described in paragraph 11 a large iron tank was first saturated with water vapor and then dried with calcium chloride. The tank was 46x49x28-1/2" in dimensions and had a volume of 37.18 cubic feet, and a surface area of 68.87 square feet. It was provided with a door (6x11") that was screwed tightly to the tank, and sealed with a rubber gasket. A small opening, which was normally closed, was used to withdraw a sample of the air for the determination of moisture. The sample withdrawn had a volume of about 1 liter which amounted to about 0.1% of the total volume of air in the container.

22. At the start of the experiment the temperature of the air in the container was 72°F. and the relative humidity was 95%. This amounted to 18.5 grams of water vapor in the air of the container. The experiment was carried on for four weeks, the humidity and the amount of water removed being measured every few days. At the end of the four weeks, the relative humidity had dropped to about 20% at 75° F., and the amount of water removed amounted to 349.9 grams. The amount of water remaining in the air was 4.1 grams. Thus the amount of water removed from the air was $18.5 - 4.1 = 14.4$ grams. The water removed from the walls of the container was $349.9 - 14.4 = 335.5$ grams, or over twenty-three times that taken from the air. Thus the quantity of water absorbed per square foot of surface amounted to $335.5/68.87 = 4.87$ grams which is equal to about 0.17 ounce per square foot.

23. The change in relative humidity of the air in the container was plotted against the quantity of water removed from the walls of the container. This is shown in Plate 14. The flat portions in the curve indicate the existence of possible hydrates of iron oxide.

CONCLUSIONS AND RECOMMENDATIONS

24. The conclusions may be summarized as follows:

(a) Lump calcium chloride is a faster drying agent than granular calcium chloride.

(b) The Type A hopper is the simplest and cheapest type to build.

(c) The Type B hopper is slightly faster than the Type A.

(d) There is a notable improvement in the rate of absorption in the Type C hopper.

(e) Wicks in conjunction with the Type A hopper decrease the rate of water removal.

(f) Stacks in conjunction with the Type A hopper increase the rate of water removal.

(g) Far more water may be absorbed on the walls of a closed space than is contained in the enclosed air. This may be the principal factor in attempting to dry such a closed space.

25. The following recommendations are made:

(a) If lump calcium chloride can be purchased as cheaply as the granular form, it should be used in preference to the latter.

(b) That where speed of drying is not paramount, the Type A hopper without wicks or stack be used. Although the stack increases the rate of water removal, its height precludes the possibility of using it in cramped quarters such as double bottoms, and thus detracts from the usefulness of the hoppers.

(c) Where speed of drying is of great importance Type C hopper should be used.

(d) It should be borne in mind that in drying a closed space, several times the amount of desiccant necessary to remove the water from the air should be used. This excess desiccant is necessary to take care of the absorbed water coming off of the walls.

SUMMARY

26. This report deals with the various types of hoppers which can be used to contain the desiccants used for drying closed spaces. It discusses the efficiency of several different designs, and considers the use of lump or granular form drying agent. The report also deals with an investigation into the amount of water absorbed on the walls of a rusty iron enclosure.

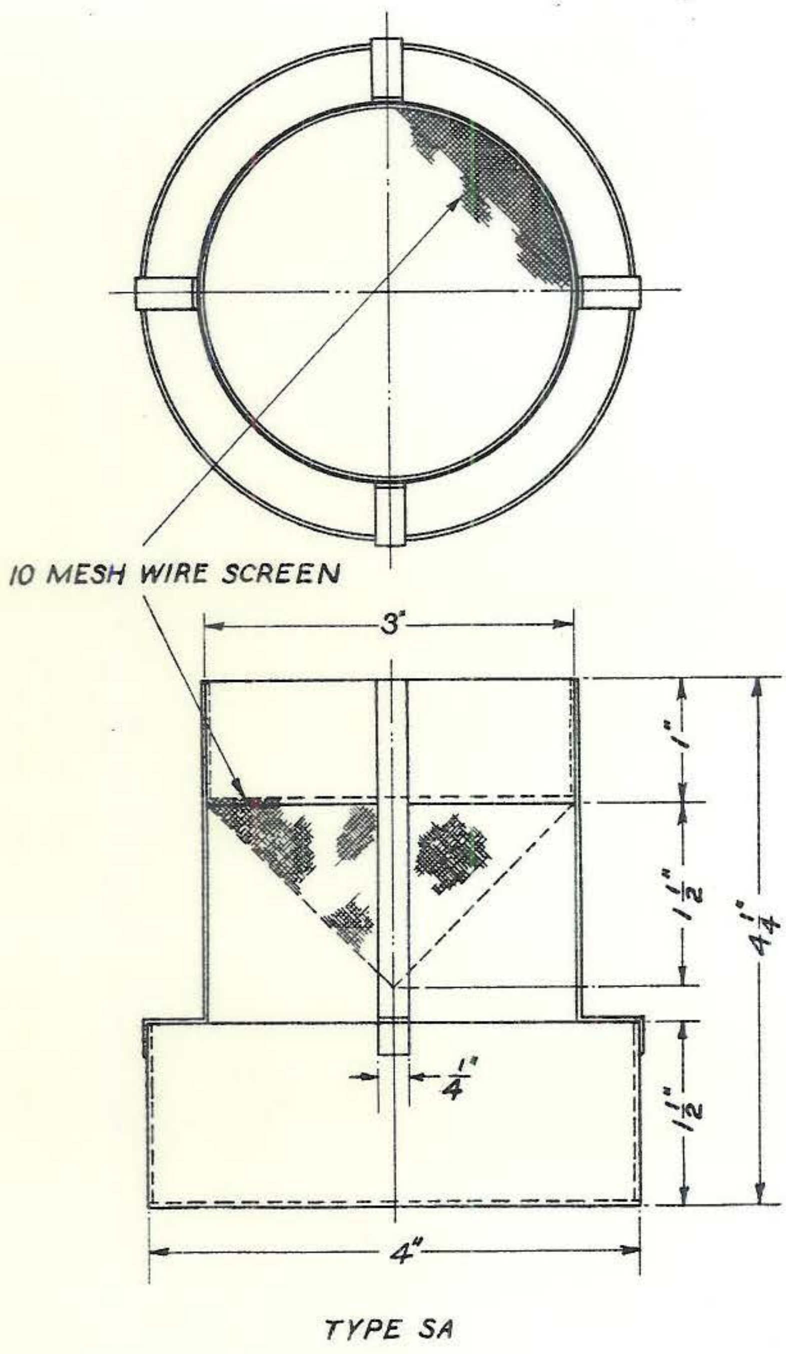
Appendix I.

This appendix gives all the measurements made in this Laboratory for this report.

Run No.	Type of Hopper	Date of start (1935)	Time of Run (hrs.)	Initial Temp. (°F)	Initial R.H. (%)	Wt. of $CaCl_2$ (gms.)	Stack	Wicks	Final Temp. (°F)	Final R.H. (%)	Wt. of Sol'n. formed (gms.)	% H_2O in sol'n.	Wt. H_2O absorbed (gms)
I	A	7/1	20	82	69	2300	-	-	82	55	350	51	180
I	A	7/1	20	82	69	8200	+	-	82	55	2700	51	1390
I	A	7/1	20	82	69	9400	-	-	82	55	1350	51	695
II	A	7/2	22	83	55	7500	-	-	82.5	48	1560	51	795
II	A	7/2	22	83	55	9100	+	-	82.5	48	2780	51	1418
III	A	7/3	115	82	51	9800	+	wool and hygrometer	82	45	8870	51	4510
III	A	7/3	115	82	51	11100	+	-	82	45	7580	52	3945
IV	D	7/10	18	84	62	-	+	Hygrometer	83	69	1810	60	1080
IV	E	7/10	18	84	62	-	+	Hygrometer	83	69	1560	67	1055
V	E	7/11	16	87	64	-	+	Muslin	85.5	70	1560	55	855
V	E	7/11	16	87	64	-	+	Hygrometer	85.5	70	1675	62	1038
VI	E	7/15	17	84	66	-	+	Muslin	83	62	1760	60	1055
VI	E	7/15	17	84	66	-	+	Hygrometer	83	62	1960	62	1215
VI	E	7/15	17	84	66	-	-	Muslin	83	62	1720	61	1050
VII	E	7/16	16	84.5	56	-	+	Muslin	82.5	65	1530	59	900
VII	E	7/16	16	84.5	56	-	-	Muslin	82.5	65	1300	61	793

Run No.	Date of Start (1935–36)	Type of Hopper	Weight of $CaCl_2$ (gms)	Ratio $H_2O/CaCl_2$													
VIII				16.5	40.5	64.5	166.5 hours										
	9/30	SA	47.8	0.079	0.146	0.236	0.515										
	9/30	SB	46.2	0.043	0.080	0.102	0.182										
IX				20.5	44.5 hours												
	10/1	SC	114.5	0.079	0.144												
X				18	147 hours												
	10/7	SD	100.0	0.050	0.295												
	10/7	SE	100.0	0.058	0.315												
XI				23	53	120.5	166.5 hours										
	10/15	SA	66.1	0.101	0.174	0.409	0.506										
	10/15	SF	66.4	0.089	0.158	0.464	0.570										
XII				23	65.5	144	191	307	352	427.5	600	695	815	956	984	1008	1104 hr
	1/16	A	1792	0.045	0.141	0.179	0.183	0.215	0.219	0.244	0.309	0.325	0.405	0.438	0.476	0.506	0.529
	1/16	B	3212	0.050	0.168	0.213	0.222	0.264	0.282	0.308	0.398	0.438	0.510	0.559	0.625	0.644	0.682
XIII				50	95	170.5	343	438	558	699	727	751	847	1087	1417	1781	2453 hr
	1/27	A	2320*	0.030	0.072	0.110	0.218	0.263	0.332	0.377	0.414	0.435	0.474	0.659	0.896	1.125	1.445
	1/27	A	2595	0.020	0.045	0.071	0.145	0.175	0.229	0.266	0.295	0.316	0.339	0.516	0,770	0.967	1.211
XIV				43	65	161	185	240	401	521	600	hours					
	4/13	A	3420 gran.	0.064	0.091	0.133	0.148	0.171	0.257	0.436	0.490						
	4/13	A	3410 lump	0.069	0.113	0.127	0.139	0.160	0.328	0.768	0.861						
	4/13	C 7 pads	5370	0.186	0.270	0.372	0.402	0.445	0.684	1.012	1.080						
XV	5/11			23	47	71	96	167	191	215	263	343	528	936 hours			
		A(no wick)	930	0.199	0.468	0.694	0.720	0.930	1.098	1.200	1.231	1.311	1.399	1.79			
	5/11	A(Kotex)	955	0.157	0.403	0.597	0.613	0.797	0.968	1.031	1.074	1.152	1.248	1.71			
	5/11	A(Muslin)	930	0.145	0.430	0.661	0.662	0.855	1.042	1.124	1.150	1.231	1.301	1.69			
XVI				25	49	73	98	169	193	217	265	345	530	938 hours			
	5/11	C (2-1" pads)	2110	0.144	0.346	0.510	0.545	0.761	0.931	1.022	1.093	1.263	1.462	1.76			
	5/11	A	2110	0.083	0.197	0.306	0.332	0.462	0.557	0.607	0.644	0.740	0.910	1.64			

*Magnesium chloride.



TYPE SA

PLATE I

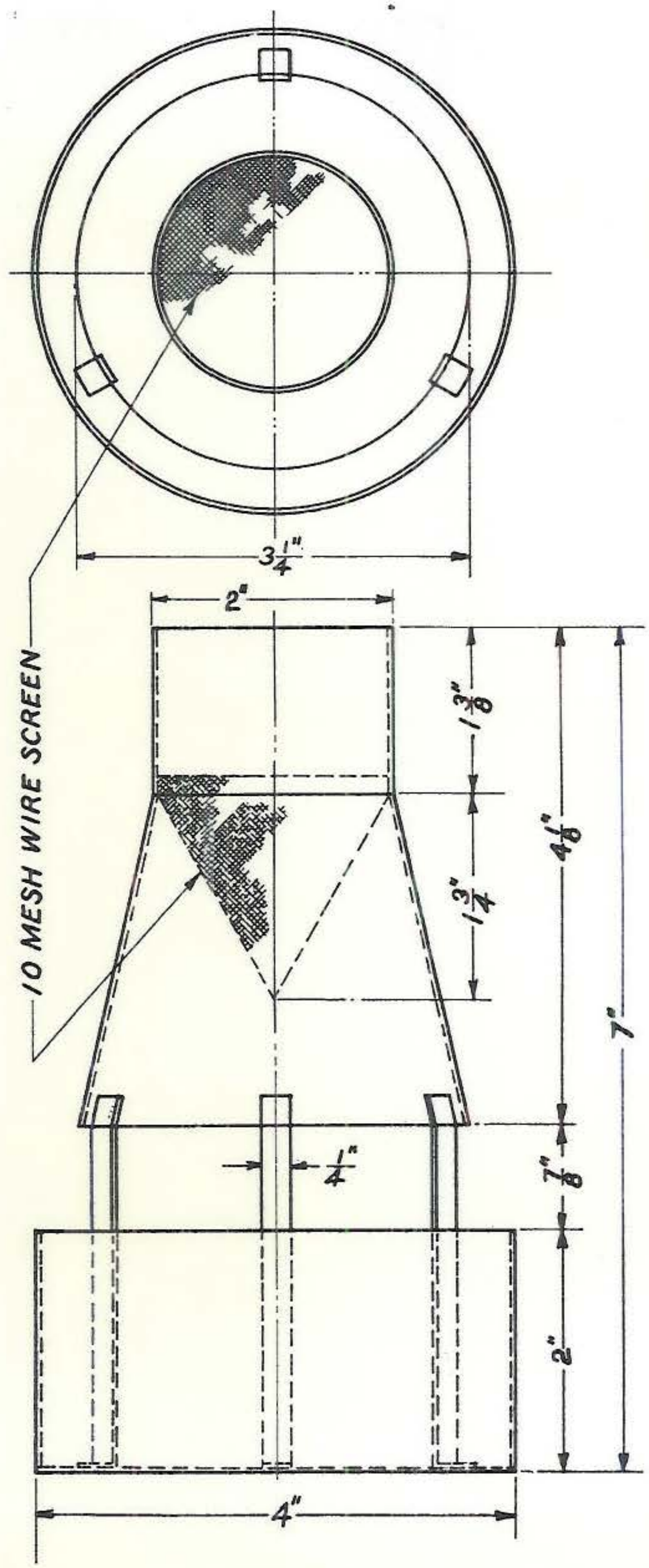


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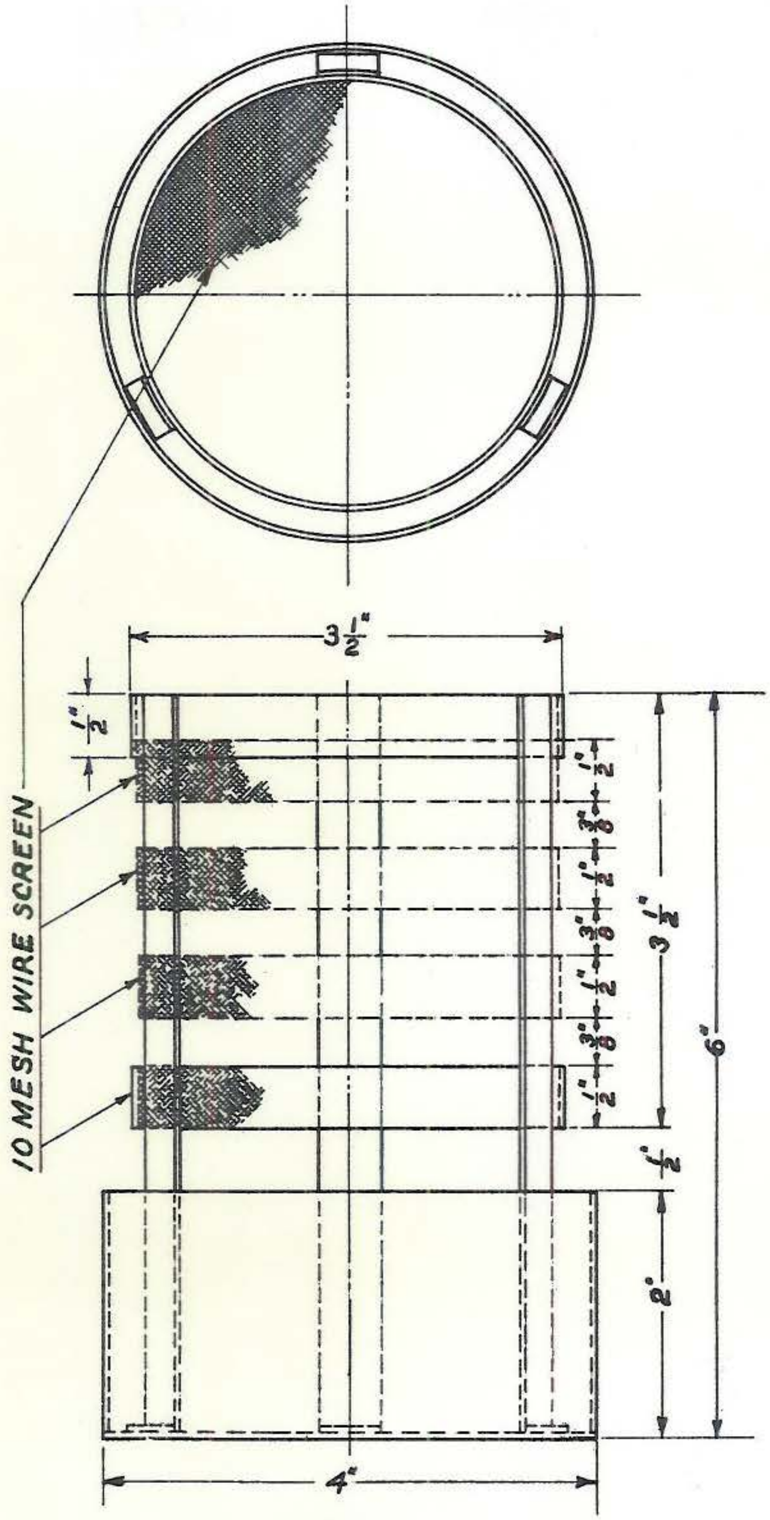
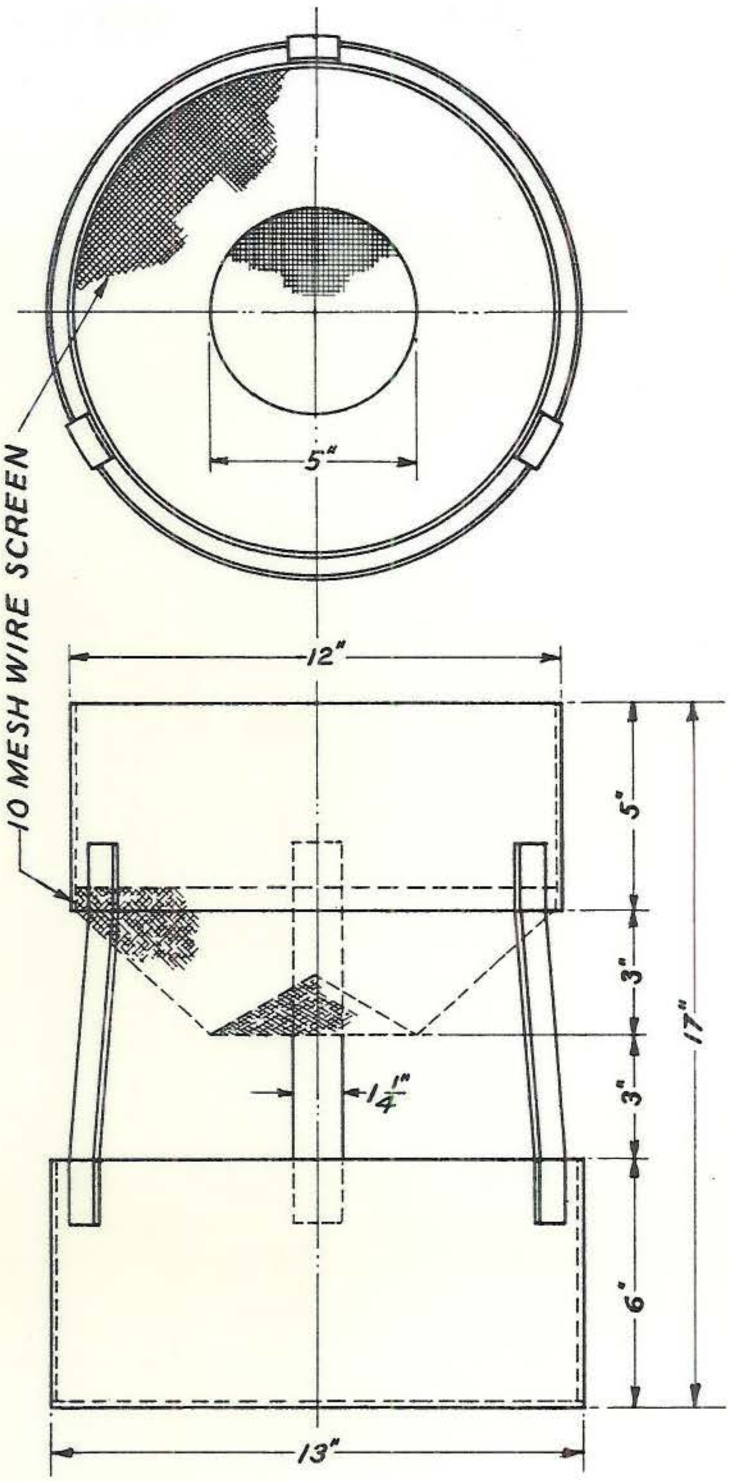
PLATE 2



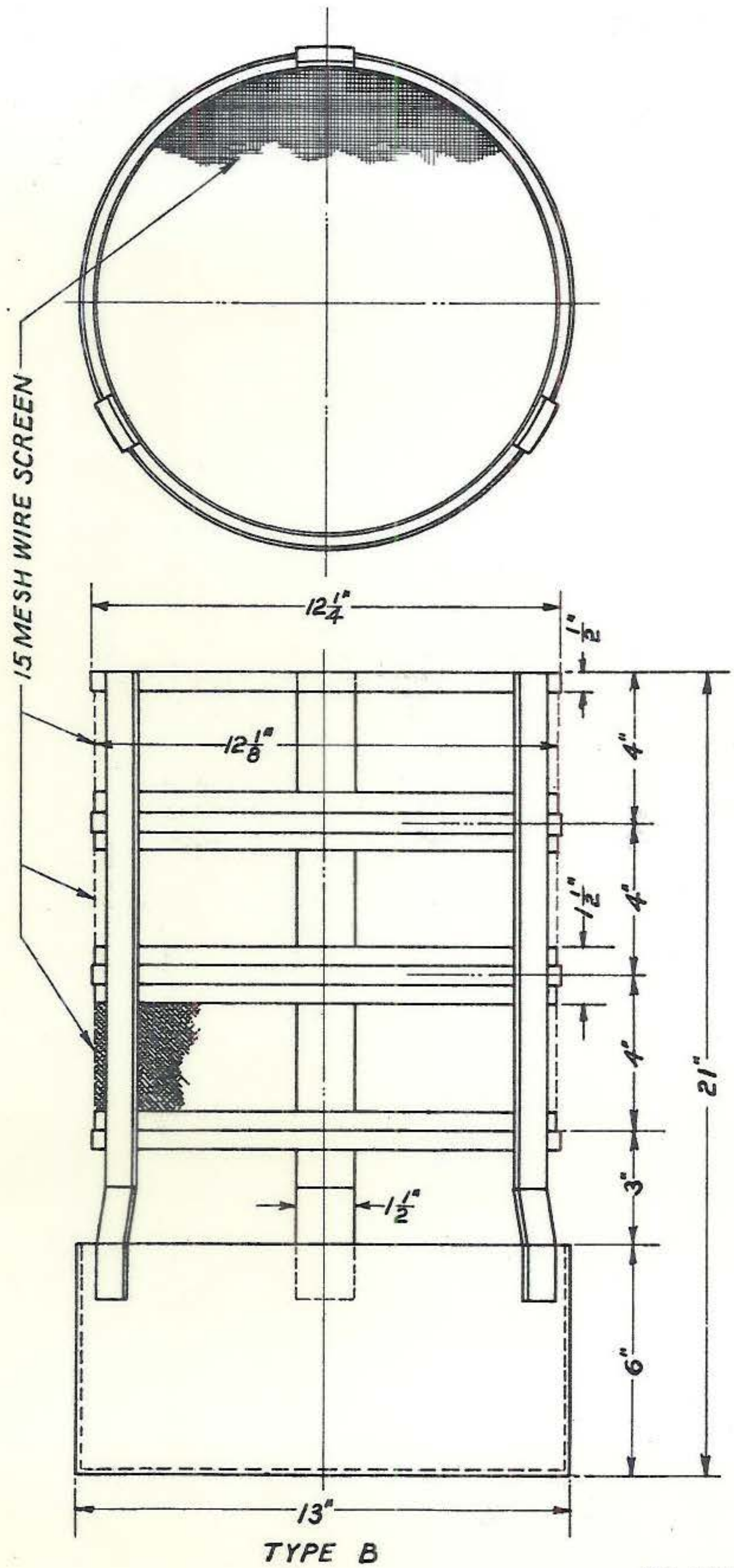
TYPE SC

PLATE 3



TYPE A

PLATE 4



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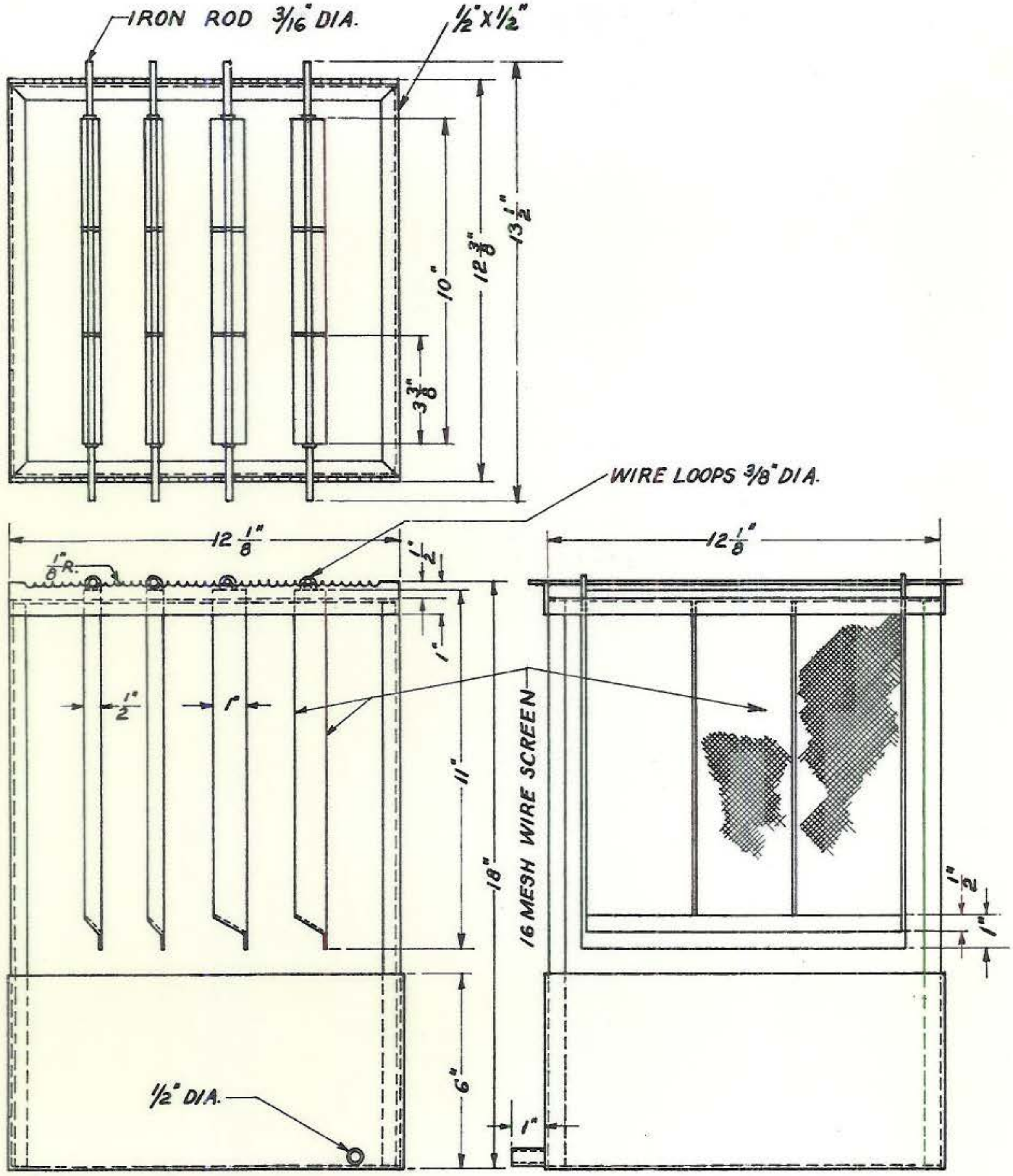
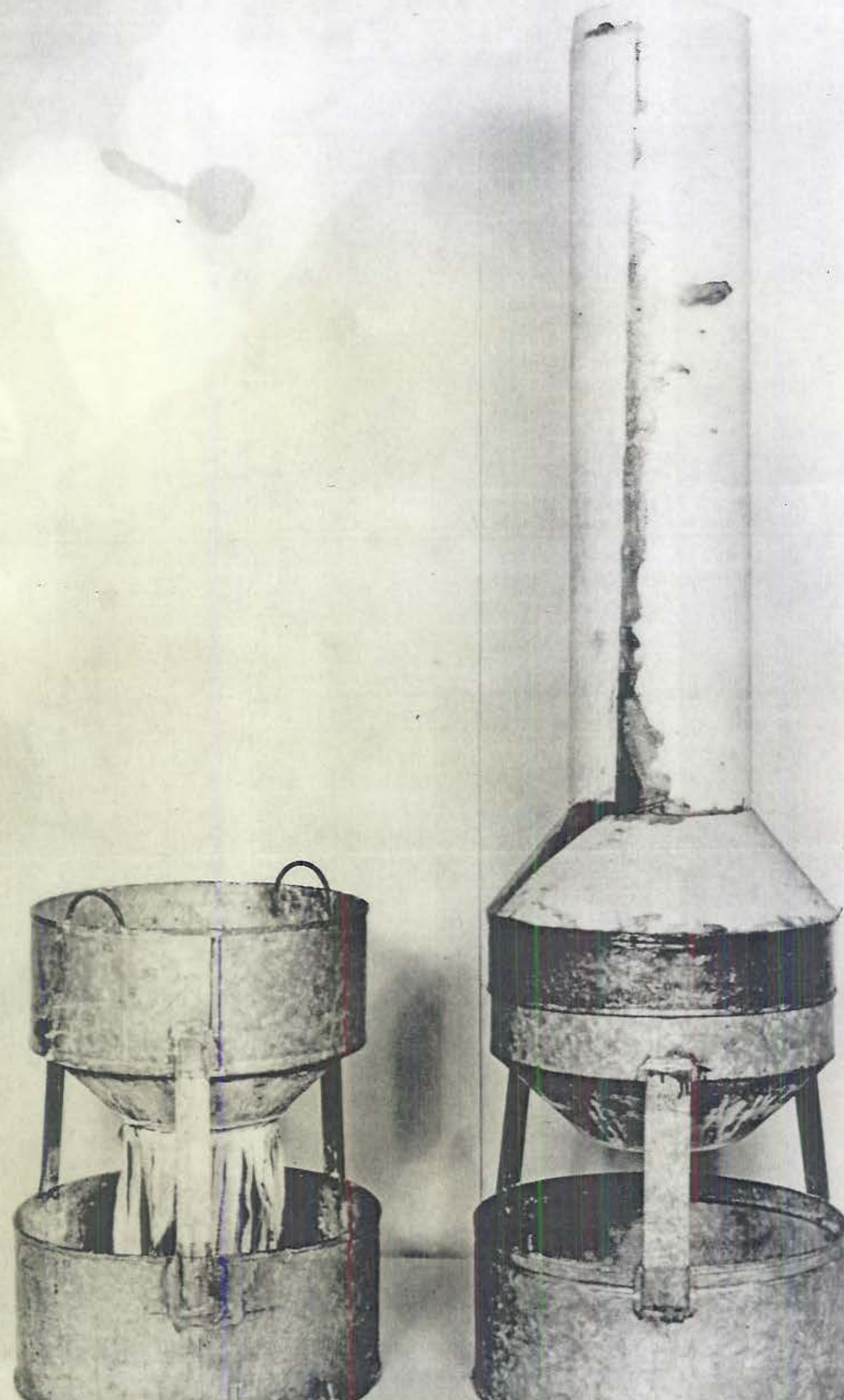


TYPE C

PLATE 6



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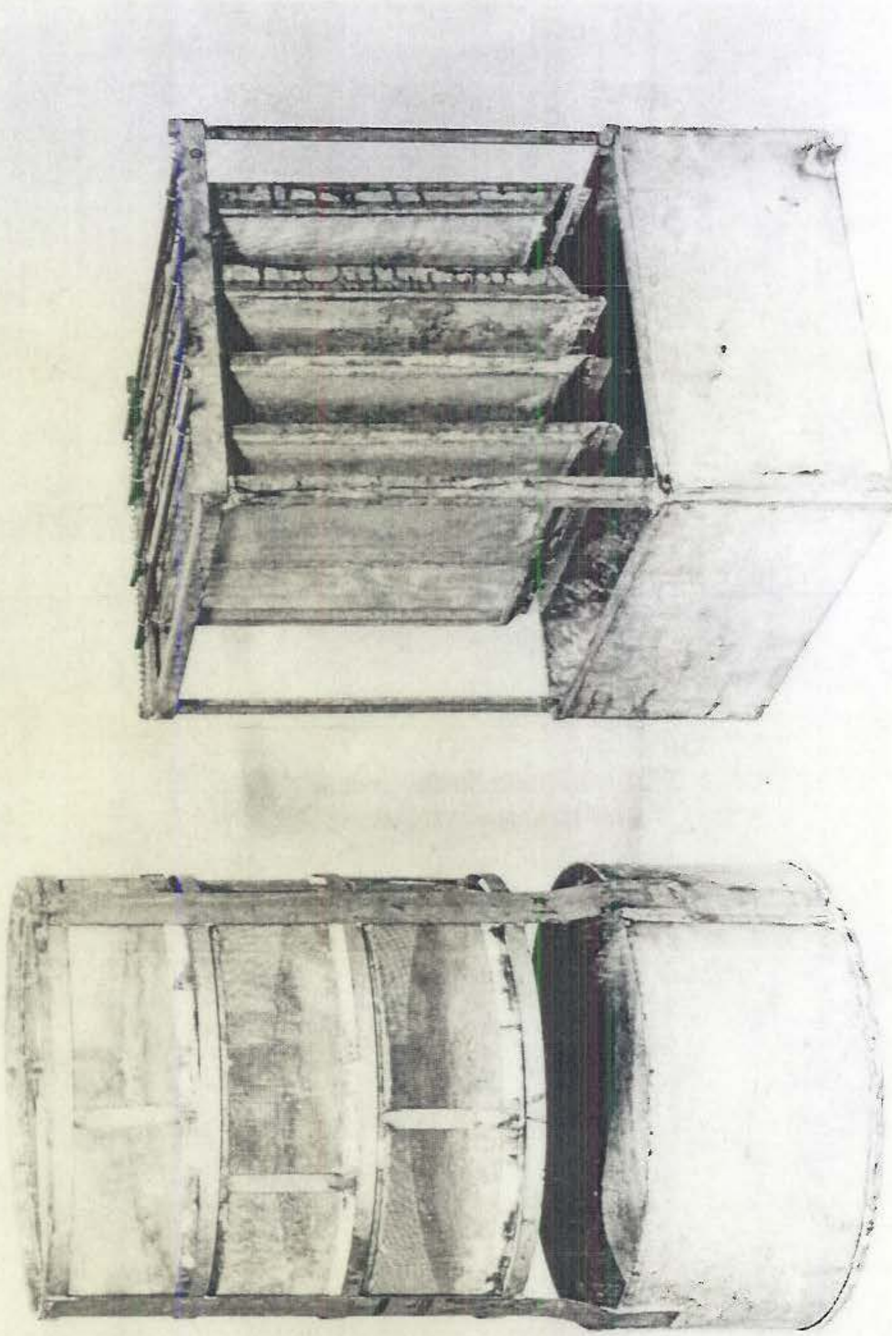
Type A with wick Type A with stack



Type B

Type C

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Plate 8

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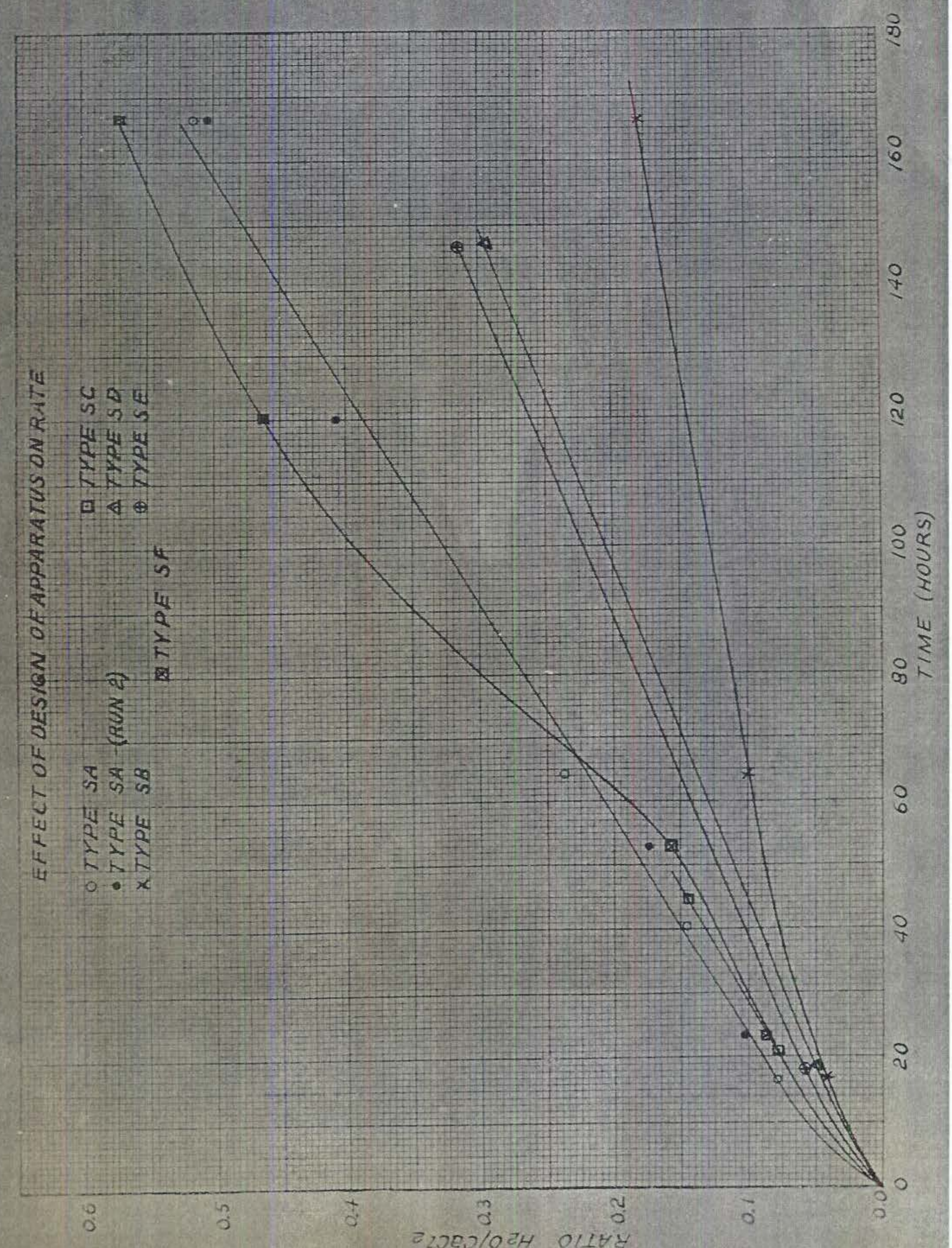
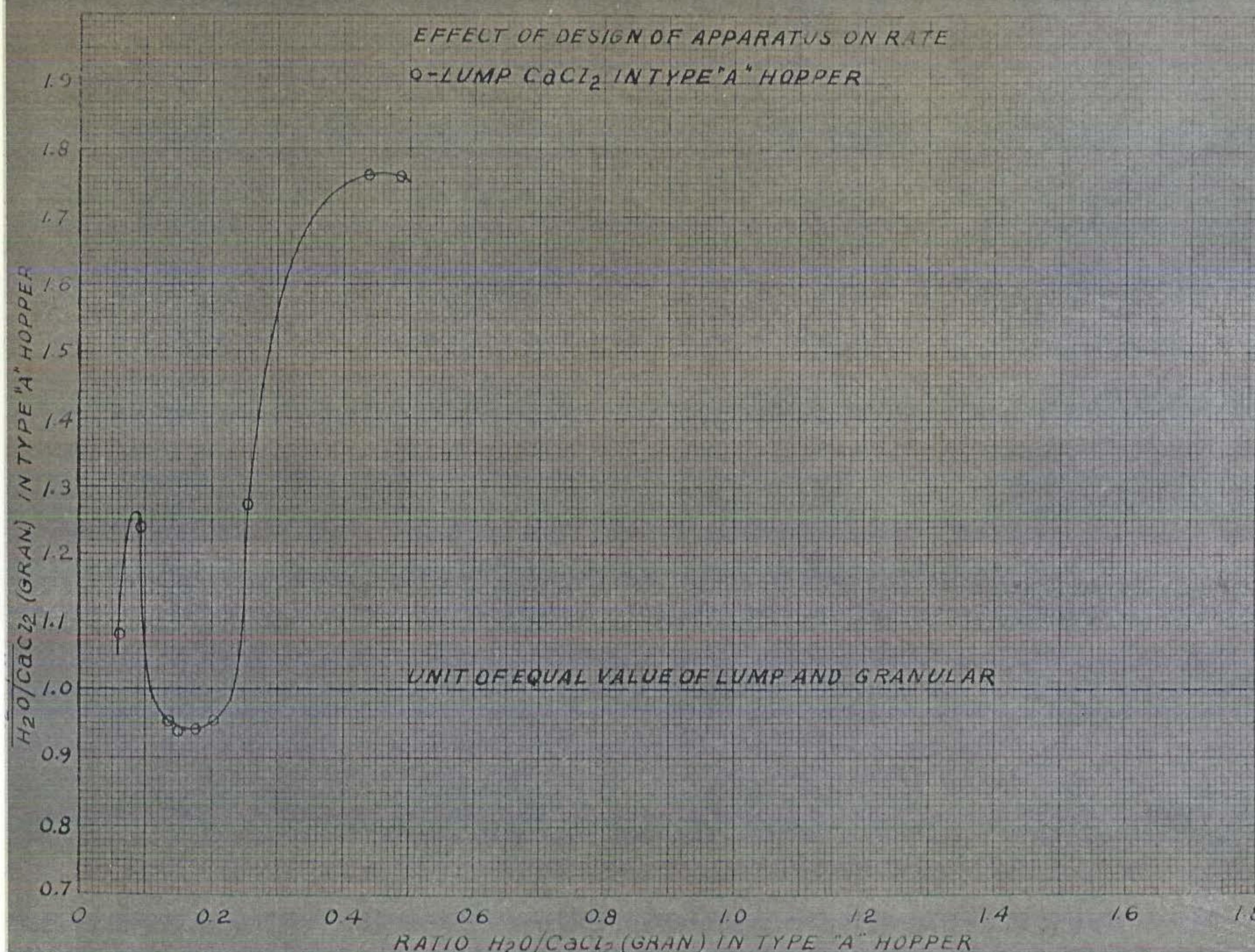
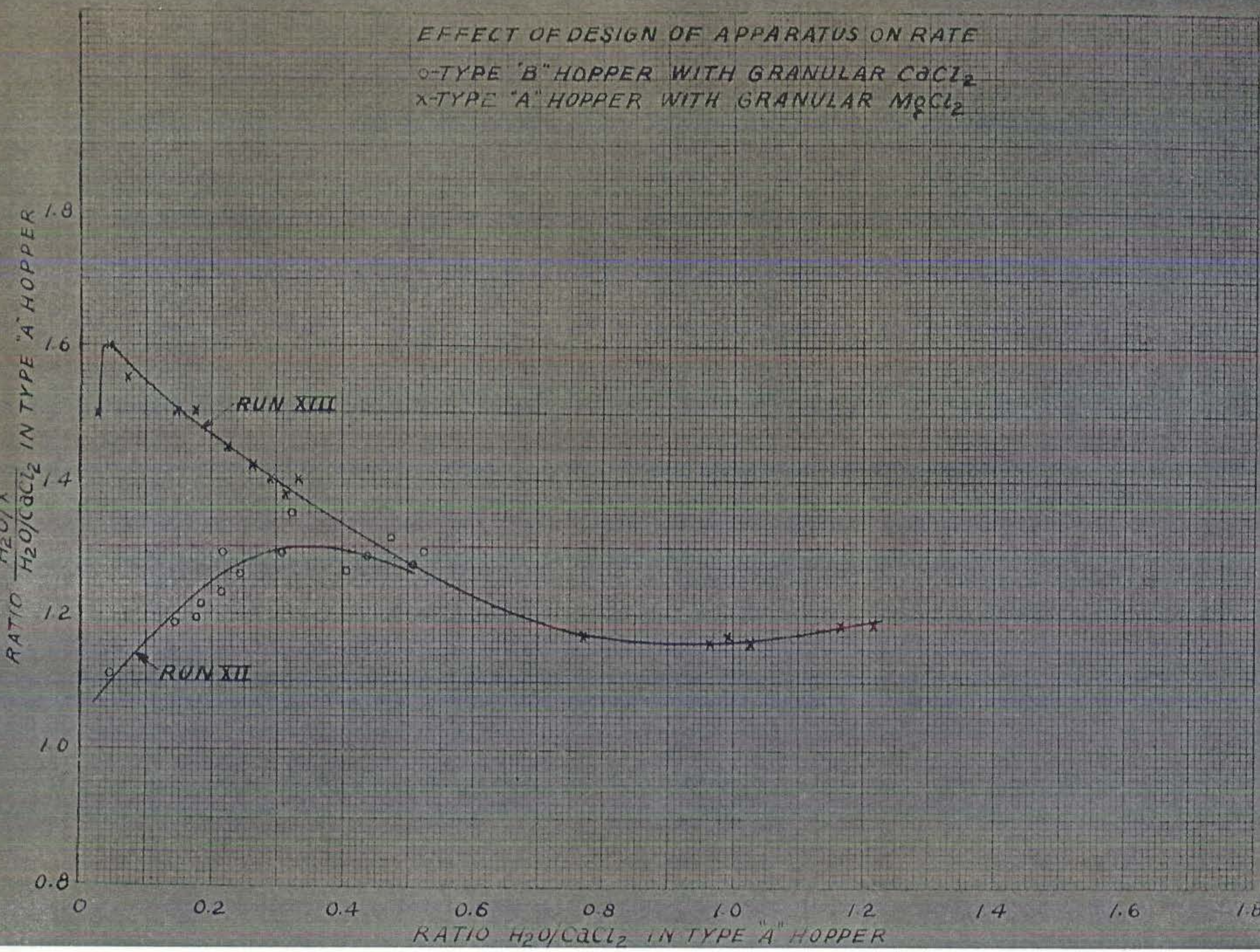
BELLEVUE D.C.

DATE





EFFECT OF DESIGN OF APPARATUS ON RATE
o-LUMP $CaCl_2$ IN TYPE "A" HOPPER
UNIT OF EQUAL VALUE OF LUMP AND GRANULAR
$H_2O/CaCl_2$ (GRAN) IN TYPE "A" HOPPER
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
RATIO $H_2O/CaCl_2$ (GRAN) IN TYPE "A" HOPPER



EFFECT OF DESIGN OF APPARATUS ON RATE
o-TYPE "B" HOPPER WITH GRANULAR $CaCl_2$
x-TYPE "A" HOPPER WITH GRANULAR $MgCl_2$
RUN XIII
RUN XII
RATIO $\frac{H_2O/x}{H_2O/CaCl_2}$ IN TYPE "A" HOPPER
RATIO $H_2O/CaCl_2$ IN TYPE "A" HOPPER
0.8
1.0
1.2
1.4
1.6
1.8
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

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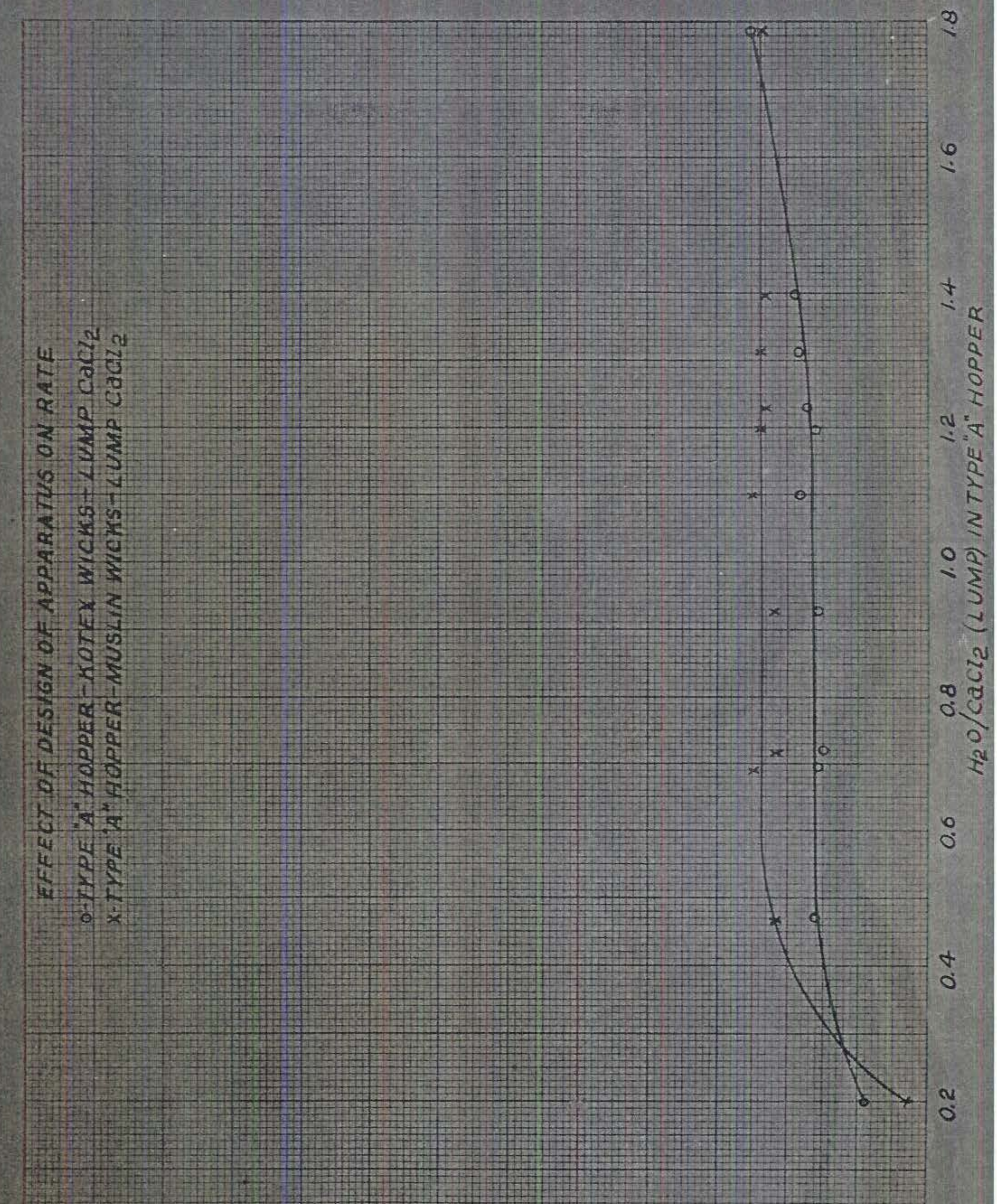
DATE



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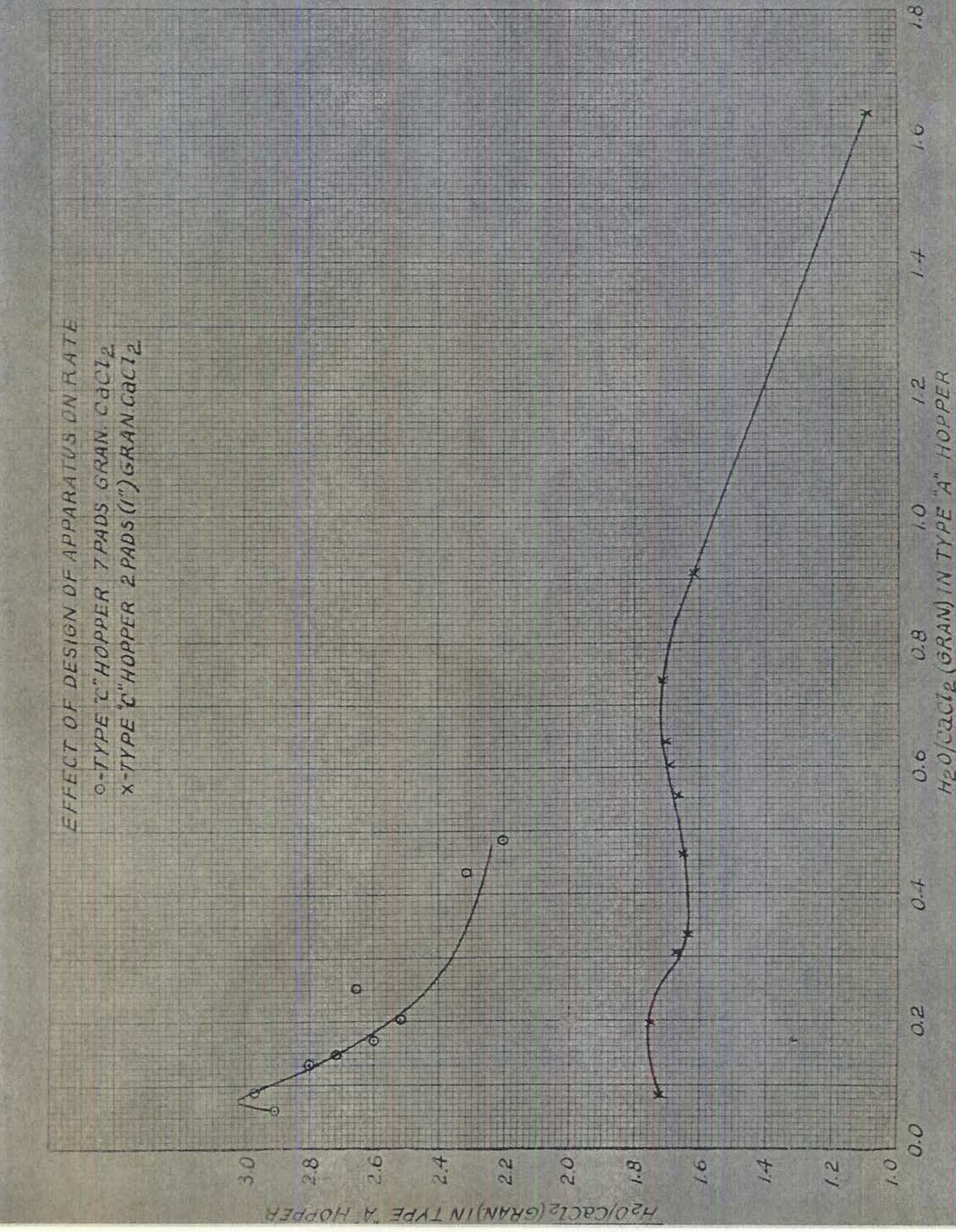

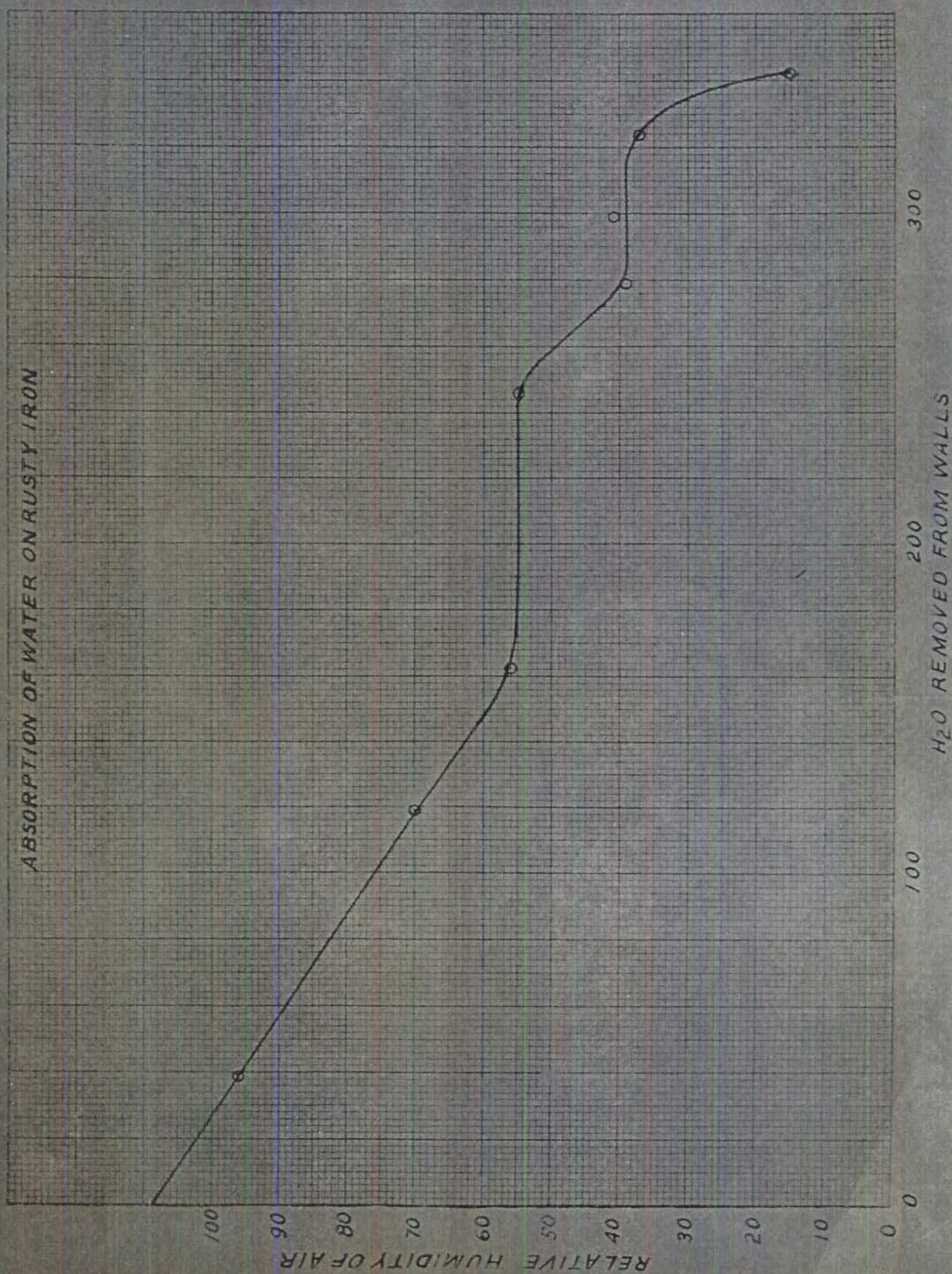
ABSORPTION OF WATER ON RUSTY IRON
RELATIVE HUMIDITY OF AIR
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
H_2O REMOVED FROM WALLS