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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on

Water Recovery in Lighter-Than-Air-Craft;
Study of the Properties of Granular Silica Gel.

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A B S T R A C T

This report considers studies of the properties of granular silica gel in relation to its use for the recovery of water from the atmosphere to compensate for the consumed weight of fuel on lighter-than-aircraft. In it are studied the processes of adsorption of water from the air, the reactivation of the saturated gel and sundry properties of granular silica gel which may affect its use for this purpose.

AUTHORIZATION

1. This problem was authorized by Bureau of Aeronautics Project Order No. 164/34 of 26 June 1934.

STATEMENT OF PROBLEM

2. Certain disadvantages in the water recovery apparatus of the type used on the AKRON and the MACON have led the Bureau of Aeronautics to consider the possibility of using other methods for water recovery. Among these is the use of granular silica gel to adsorb water from the atmosphere. The problem studied in this report is to consider the significant engineering properties of granular silica gel to obtain engineering data which will permit the Bureau of Aeronautics to appraise the feasibility of the use of silica gel for water recovery in lighter-than-air-craft.

KNOWN FACTS BEARING ON THE PROBLEM

3. The use of silica gel to adsorb vapors from gases, especially air, has been widely studied in chemical laboratories. Most of the data which have been published are concerned with adsorption under static conditions and practically no work has been done on the rate of adsorption. Considerable work has been done on methods of preparing silica gel and of reactivating the used material.

4. Silica gel is a commercially available substance obtained by the chemical interaction of a soluble silicate, of which "water glass" is typical, and an inorganic acid such as sulphuric. The hydrosol of silicic acid formed in the reaction "sets" in a definite time to a jelly-like mass. This mass is carefully washed with water, the temperature of which is carefully controlled, to free it from excess acid and salts and then is dried, crushed, sized and heat treated at a definite temperature. The resulting produce is a hard, glassy, granular material, light in weight and highly porous, its internal structure being made up of an enormous number of tiny capillary tubes whose diameter are about 4×10^{-7} cm. Its properties indicate that 1 cubic inch of silica gel contains, roughly, 50,000 square feet of pore surface.

5. The enormous internal surface in the shape of fine capillaries attracts most vapors and condenses them as liquid in the pores or capillaries.

6. The increasing use of silica gel for air conditioning has led the manufacturers of air conditioning equipment, such as the Silica Gel Corporation of Baltimore and the Bryant Furnace Company of Cleveland, to study the engineering aspects of the adsorption of water by silica gel and its reactivation by direct contact with hot flue gases. Most of these data are held as commercially confidential by the respective companies. Owing to the nature of the usual air conditioning installations, however, most of this engineering data is not applicable to the present problem. These companies do, however, have extensive knowledge of diverse properties of silica gel which affect the feasibility of using it aboard aircraft. Silica gel has been studied by the Zeppelin Company at its Friedrichshafen plant. The method used there was one employing silica gel powder of very fine mesh. It is understood that the experiments were abandoned.

THEORETICAL CONSIDERATIONS

7. The theoretical factors which have a bearing on this problem can be considered in the following subdivisions: (a) the adsorption processes, (b) the reactivation processes, and (c) the incidental properties of silica gel.

Adsorption Processes

8. The total amount of water which a given sample of gel can adsorb depends on the weight of the gel, the temperature and the humidity only under static conditions. When ordinary air is passed through a given layer of silica gel, the rate of adsorption of water vapor from that air depends upon (a) the grain size of the gel, (b) the thickness of the layer, and (c) the velocity of the air as well as (d) the temperature and (e) humidity of the air. To obtain the engineering data necessary to decide the feasibility of this system, the effect of all these theoretical factors must be taken into consideration.

Reactivation Processes

9. In reactivating a given sample of gel upon which water has been adsorbed, the amount of water which can be recovered depends on the amount of gel and the amount of water which has been adsorbed, but the rate at which water can be recovered from a given sample of silica gel in the reactivation process depends upon (a) the temperature of the silica gel, (b) the particle size, and (c) the rate at which the water vapor is removed from the immediate vicinity of the gel particles. The engineering data relating to the reactivation process necessary to determine the feasibility of this system must determine the relation between these variables.

Incidental Properties of Silica Gel

10. The suitability of silica gel would further depend upon a variety of incidental characteristics which include:

(a) The purity of the silica gel.
(b) The method of preparation.
(c) The past history of the gel.
(d) The aerodynamic characteristics of the granules.
(e) Thermal characteristics of silica gel.
(f) The disintegration of the gel particles with age.
(g) The abrasive nature of the gel and its effect upon apparatus.
(h) Powdering of gel resulting in loss.
(i) Weight and space characteristics of the necessary equipment.
(j) The effect of impurities from the atmosphere or activating medium.
(k) The effect of contact with liquid water, as from rain or snow.
(l) Health hazards.

NARRATIVE OF ORIGINAL WORK DONE AT THIS LABORATORY

11. The significant properties of silica gel were studied at this Laboratory by obtaining a variety of samples of silica gel from the manufacturer and studying the processes of adsorption and reactivation.

METHODS

(a) Preparation of Materials

12. The silica gel used in these experiments is a standard commercial product of the Silica Gel Corporation and was obtained directly from that corporation. The Silica Gel Corporation supplied the following representative analysis showing the impurities in an average commercial gel.

Chemical Analysis

Total residue	0.2 to 0.5%
Iron and aluminum, as oxides	0.1 to 0.3%
Net residue as sodium sulphate	0.1 to 0.2%
Acidity, as H_2SO_4, less than	0.05%
Silica Gel	Remainder

The gel as received was slightly stained a yellowish brown color by the decomposition products of the traces of wood fibres which had become mixed with the gel from the wooden equipment used in manufacture. Samples having the following grain size were used:

2-4	Tyler's	Sieve	Series
4-6	"	"	"
6-8	"	"	"
8-10	"	"	"
8-20	"	"	"

The 8-20 gel is a widely used commercial product and is composed chiefly of 9-10 grain size.

The Adsorption Process

13. Prior to a test of the adsorption characteristics of a gel sample, the sample was activated by heating. The gel supplied by the company had been activated by heating in a furnace for three hours at 600°F in a moving air stream. Following an adsorption test, the gels were completely activated in furnaces constructed at this Laboratory at temperatures less than 700°F (usually at 600°F).

14. The adsorption of water by the various samples of silica gel was determined by placing a weighed sample in one of two types of adsorbing pads (Plates 1 and 2). The weight of water adsorbed was determined by the increase in weight following the adsorption of water. These adsorption pads were fitted into the duct system shown in Plate 3. In this, B is an electrically driven blower forcing atmospheric air at a constant rate through the duct D containing the pads. The duct system was so constructed that four adsorption pads could be placed in the air stream simultaneously; when this was done, one pair of pads was in series and another pair in parallel with the first.

15. The adsorption pads were constructed with a framework of galvanized iron. The silica gel was retained by tinned copper screening (16 wires per inch) soldered to the frame. The pads were carefully braced, as

shown, to minimize bulging which would result in the maldistribution of air flow through the pads and also increase the weight of the gel. The larger pads had a cross-section of .90 sq.ft., while the smaller ones were of .105 sq.ft.

16. The adsorption pads were so fitted into the duct that they could be removed rapidly for weighing and provision was made to insure that there be no significant leakage past the edges of the pads nor to the outside of the ducts. The experimental runs were timed with an interval timer. The weight of the pads before and after adsorption were determined on chemical laboratory balances. As a check upon this measured adsorption of water, the samples were dried in an oven and the weight of water loss determined.

17. The humidity of the incoming air was determined at intervals with a calibrated standard U.S. Weather Bureau sling psychrometer and, as a check, by calibrated wet and dry bulb thermometers located in the moving air stream. The temperature of the air was measured by calibrated thermometers placed just in front of the gel. The rates of air flow through the gel beds were measured in three independent ways: (a) by a calibrated Pitot-Venturi tube, (b) for the higher velocities with a Pitot-static tube and (c) with thin-plate, sharp-edged orifice meters. The back pressure developed by the air flowing through the gel pads was measured with a U-tube water manometer.

The Reactivation Process

18. The actual projected use of the silica gel water recovery scheme requires that the silica gel be reactivated by heat supplied by the hot exhaust gases from the engines and that the water driven out of the gel by this heat be condensed and added to the ship's ballast. Two possible methods of effecting this suggest themselves:

(a) Direct Method -- The hot exhaust gases may be blown through the water-laden silica gel after which the hot exhaust gases enriched with water would pass through condensers where the water vapor would be condensed out.

(b) Indirect Method -- The water-laden silica gel would be heated in an oven-like heat interchanger, the heat being supplied by the hot exhaust gases. From this oven the water vapor would pass to a small air-cooled condenser.

19. Ascertaining the feasibility of using each of these two methods would require that the following engineering data be determined:

(a) Direct Method

(1) The rate of water extraction from a gel bed by the hot gases.
(2) The energy consumed in forcing the exhaust gases through the gel bed.
(3) The condenser surface required to condense the water.

(b) Indirect Method

(1) The rate of water loss from heated silica gel.
(2) The rate of heat transfer through a mass of silica gel.
(3) The condenser area required.

20. Commercial experience in reactivation of silica gel with hot flue gases suffices to show that the rate of water loss from silica gel by direct heating is ample to make the process feasible and hence no laboratory experiments on this were made. The indirect method was studied by heating the moisture-laden silica gel in metal crucibles.

DATA OBTAINED

(a) Curves or Plots of Data

21. The data obtained for the adsorption process are in part graphically summarized in Plates 4 to 9. Under various combinations of temperature and humidity, measurements on the effect of gel size, air velocity, bed thickness and heat treatment on the rate of water vapor adsorption by silica gel (from air at 760 mm Hg) are tabulated in Tables 1 to 6. Some data concerning the reactivation process are given in Plate 10. The water vapor adsorption under static conditions is given in Plate 11 and the back pressure generated by air flowing through beds of silica gel is given in Plate 12. Flow sheets illustrating possible complete water recovery processes (under rather favorable conditions) are given in Plates 13-17 inclusive. Calculations similar to those involved in the flow sheets but for a variety of conditions are summarized in Table 7.

(b) Data in Tabular Form

22. The data are condensed into Tables 1 to 6.

(c) Probable Errors

23. The data contained in this report are considered to be sufficiently accurate for the purpose in view.

(d) Data on Incidental Characteristics of Silica Gel

24. The following data on the incidental properties of silica gel which may affect decision as to the feasibility of using it are given.

(1) Purity. The adsorption characteristics of silica gel depend upon its purity. More important, the life under high temperature reactivation is also affected by the purity. The present product of the Silica Gel Corporation contains enough impurities so that high temperature (about 1000°F) reactivation shortens the life considerably. Professor W.A. Patrick (inventor of the method of manufacturing silica gel) unofficiall advises that the use of a more highly purified gel might prove economically profitable in a water recovery installation owing to the longer life obtainable.

(2) The Method of Preparation. The methods of preparing the gel have been carefully studied by the Silica Gel Corporation and it is believed that corporation would supply the most suitable material. For an additional cost of perhaps 20 cents a pound, a more highly purified material could be supplied which could be heated to considerably higher temperatures without destruction.

(3) Past History of the Gel. The adsorbing power of the gel depends greatly upon its past history. Heating to too high temperatures impairs the adsorbing power. The effect of the temperature or heat treatment on the adsorbing power is shown in Plate 18 and Table 5. The impairment of adsorbing power depends on the temperature to which the gel has been heated in excess of 600°F and is independent of the time which it is exposed to that temperature. The effect of high temperature is much more serious in impairing the adsorbing power at low humidities than at high (Table 5). Commercial experience in reactivating silica gel with hot flue gases shows that the pick-up of black deposits contained as impurities in the flue gases does not seriously impair the adsorbing power (under static conditions) even if the silica gel becomes black, provided the carbon content of the deposited organic matter does not exceed 0.5% of the gel weight.

(4) Aerodynamic Characteristics of the Granules. The power loss in forcing air through beds of silica gel in water recovery apparatus is a significant factor. In commercial air conditioning apparatus the usual rate of air flow is 50 c.f.m. to minimize this factor. The horsepower required for passage of the air over silica gel beds is given in Plates 4 to 9 and Table 7 and is shown in the flow sheets of Plates 13-17 inclusive.

(5) Thermal Characteristics of Silica Gel. The adsorption process requires that the heat generated by the condensation of water in the gel be dissipated; this requires that an excess of air be used to cool the gel during the adsorption part of the cycle. Further, this limits the speed of the adsorption process since the low heat conductivity of the gel particles limits the speed with which this heat can be removed. Analogously, the speed of the activation phase is limited by the low heat conductivity of the gel granules -- the rate of heat flow to the innermost portion of a granule being low even if the activating temperature is high.

(6) Disintegration of the Gel Particles with Age. Commercial experience with air conditioning apparatus gives some data on the life which might be expected from silica gel under the conditions which obtain in those installations. After a period of four years' operation, it is reported that one industrial air drying installation employing granular silica gel in stationary beds required a replacement of 10 percent of the original weight.

(7) The Abrasive Nature of the Gel. Silica gel is very abrasive and tends to destroy any apparatus in which it is used. The Silica Gel Corporation finds it necessary to employ wood apparatus to handle it in the dry state. The destruction of water recovery apparatus would be a serious economic factor which would have to be considered.

(8) Powdering of Gel. The repeated handling of the silica gel required in airship water recovery apparatus would abrade the granules and powder the gel. This would result in loss of gel and in possible deleterious effects such as those experienced on the experimental installation of the Zepplin Company.

(9) Weight and Space Characteristics of Necessary Equipment. The weights of silica gel which would be required for a given rate of pick-up are given in Table 7 and Plates 4, 5 and 6, but these weights do not include the equipment for containing the gel. The weight and space characteristics can only be decided by at least preliminary design of equipment.

(10) Effect of Impurities from the Atmosphere or Activating Medium. Under the conditions which would normally obtain on an airship, impurities from the atmosphere would be insignificant. If activation were by direct heating, the effect of the lead and bromine compounds, etc., would have to be considered as would the effect of the tarry materials in the exhaust.

(11) The Effect of Contact with Liquid Water as from Rain or Snow. Experiment and commercial experience show that silica gel granules are ruptured if they come in contact with liquid or solid water. An airship installation would have to make provision for preventing the rain and snow from coming into contact with the gel beds.

(12) Health Hazards. It is known that exposure to silica induces the pathological condition called silicosis. It is not known whether this condition can be induced by repeated exposure to silica gel, though employees of the Silica Gel Corporation exposed daily for several years to air heavily laden with silica gel dust have reported no trouble. The possibility of a health hazard from this should, however, be recognized.

(e) Example of Use of Above Data.

25. To illustrate the use of the data considered above, a typical engineering calculation may be made.

Water required for ballast - 1000 lbs./hr.
Outside air - 70°F Relative humidity - 45%
Silica Gel - 8-20 Tyler Mesh (1" thick gel beds, density 3.2 lbs./sq.ft./in.)
Air flow - 170 cu.ft./sq.ft./min.
1 cycle per hour
Exposure time - 30 minutes
Activation time - 30 minutes
From graph
.192 lbs. water/lb.gel/exposure
5200 lbs. silica gel required
hence
2600 lbs. gel in furnace always
2600 lbs. gel in air duct always
812 sq.ft. gel bed in air duct
Power to move air through gel bed in air duct 812 x .0418 = 34.0 H.P.

Heat required for water removal at 600°F
for silica - 5200 x 104.5 = 543,000 B.T.U.
for water 1,289,600 B.T.U.
Total heat required for water removal
at 600°F 1,832,600 B.T.U.

CONCLUSIONS AND RECOMMENDATIONS

(a) Facts Established

26. The rate of adsorption of water vapor from air has been determined for a number of sizes of granular silica gel over a wide range of humidity, temperature and air speed.

27. The effect of a number of incidental properties of silica gel and the feasibility of using it for water recovery has been collected.

28. Data concerning the reactivation process have been obtained.

29. Heat balances for the processes have been determined.

30. The adsorbing power of silica gel in water vapor under static conditions is independent of temperature and dependent only upon the relative humidity.

31. The percent of water adsorbed by commercial silica gel (per unit weight of active gel) under static conditions is equal to the relative humidity divided by 2.

32. When silica gel is heated above 600°F, the loss in adsorbing power is determined by the temperature alone to which it has been heated.

33. When heat treatment has impaired the adsorbing power of silica gel, the impairment is greater at low humidities than at high.

(b) Opinions

34. It is considered that should the Bureau of Aeronautics contemplate the use of silica gel water recovery apparatus, a decision will have to be made between the use of granular silica gel and the use of powdered silica gel as was proposed for the GRAF ZEPPELIN. It is felt that it may be easier to overcome the deficiencies which have been disclosed in the laboratory operation of the GRAF ZEPPELIN installation than it would be to design a satisfactory granular gel apparatus. Perfection of the powdered gel installation would require principally a study of dust-collecting devices to prevent loss of the gel.

(c) Recommendations

35. If the Bureau of Aeronautics considers that the use of granular silica gel for water recovery holds promise, it is recommended that prior to design of the apparatus the following studies be made:

(a) The rate and efficiency of heat transfer from hot exhaust gases by direct and indirect contact with moisture-laden silica gel.
(b) The abrasive effects of silica gel on the equipment.
(c) The abrading effects of repeated handling on silica gel.
(d) The effect of repeated exposures to exhaust gases on silica gel.
(e) The corrosive effects of continued exposure to exhaust gases on the equipment.
(f) The feasibility of using a highly purified gel.

SUMMARY AND DISCUSSION

(a) Summary

36. This report contains a summary of experiments to illustrate the more important factors which determine the rate of water vapor adsorption from air by silica gel including (1) the temperature of the air, (2) the relative humidity of the air, (3) the rate of air flow, (4) granular size of the silica gel, (5) thickness of gel bed, (6) heat treatment. It also considers a variety of incidental properties of silica gel which may affect its suitability.

APPENDIX I.

Difference in Heat Content of Water Adsorbed in Silica Gel (at 77°F) and in the Vapor State (at 600°F).

It is assumed that the heat content of water adsorbed in silica gel is the same as in the liquid state.
H as used here indicates heat content.

Liquid $H_{212°} - H_{77°}$		135.2 B.T.U./lb.
Vaporization at 212°F	H_{212}	969.7 B.T.U./lb.
Gas $H_{600} - H_{212}$		184.7 B.T.U./lb.

Total Difference H_{600} (gaseous water) $- H_{77}$(adsorbed water) =

1289.6 B.T.U./lb.

References:
Thermodynamics, Lewis and Randall, McGraw Hill, New York (1923).
Handbook of Chemistry and Physics, Chemical Rubber Co., Cleveland, (19[illegible]).

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APPENDIX II

(No copies of Appendix II of this report are available at this time. If and when a copy can be obtained it will be tipped in this place)

APPENDIX III

Heat Content of Exhaust Gases (300°F - 1300°F)

Outside air at 45°F, 25% relative humidity

	by volume	by weight
assume composition of air	21.00%	23.37% oxygen
	78.73	76.46% nitrogen
	0.27%	.17% water

Assume average composition of gasoline to conform to formula C_7H_{15} (15.16% hydrogen, 84.86% carbon).

Complete combustion (to CO_2 and H_2O) per pound of gasoline requires 14.9 pounds of air resulting in the following weights of gases, each weight of gas possessing the noted differences in heat content between 300°F and 1300°F.

	Gas	Weight lbs.	Heat Content (300°F to 1300°F) B.T.U.
	H_2O	1.39	652
	CO_2	3.11	684
	N_2	11.40	2,830
Total	Exhaust gas	15.9	4,166 B.T.U./lb. of gasoline

APPENDIX IV

Weight of Water Per Pound of Silica Gel Delivered by Fresh Outside Air (1" Thick Gel Beds, Density of Silica Gel 3.2 lbs./sq.ft./in. This is the amount delivered, but not all is adsorbed.)

Temperature 90°F
Rate of Air Flow 170 cu.ft./sq.ft./min.

Exposure time (min.)	Relative Humidity 25	45	75	100
10	.280	.50	.84	1.12
15	.420	.76	1.26	1.68
20	.560	1.01	1.68	2.24
30	.84	1.51	2.52	3.36

Temperature 90°F
Rate of Air Flow 65 cu.ft./sq.ft./min.

Expos. time (min.)	Relative Humidity 25	45	75	100
10	.107	.193	.321	.428
15	.161	.289	.481	.642
20	.214	.386	.642	.856
30	.321	.578	.963	1.28

Temperature 70°F
Rate of Air Flow 170 cu.ft./sq.ft./min.

Expos. time (min.)	Relative Humidity 25	45	75	100
10	.152	.273	.455	.606
15	.228	.410	.683	.909
20	.304	.546	.910	1.212
30	.456	.819	1.365	1.818

Temperature 70°F
Rate of Air Flow 65 cu.ft./sq.ft./min.

Expos. time (min.)	Relative Humidity 25	45	75	100
10	.058	.104	.174	.232
15	.087	.156	.261	.348
20	.116	.208	.348	.464
30	.174	.312	.522	.696

Temperature 45°F
Rate of Air Flow 170 cu.ft./sq.ft./min.

Expos. time (min.)	Relative Humidity 25	45	75	100
10	.0645	.116	.193	.258
15	.0967	.174	.290	.387
20	.129	.232	.386	.516
30	.194	.348	.579	.775

Temperature 45°F
Rate of Air Flow 65 cu.ft./sq.ft./min.

Expos. time (min.)	Relative Humidity 25	45	75	100
10	.025	.044	.074	.099
15	.037	.067	.111	.148
20	.049	.089	.147	.197
30	.074	.133	.221	.296

TABLE 1.

EFFECT OF GEL SIZE
Density Active Silica Gel 3.2 lbs/sq.ft./in.
See Plate 12 for Pressure Drops.

Run No.	Pad Thickness, Inches	Temp. °F	Relative Humidity %	Air Flow cu.ft./sq.ft. min.	Mesh Size	Total Time of Exposure, Min.	Water Adsorbed, Percent of Active Gel
13-53b	1	57.5	40	65	4-6	15	5.3
						30	8.9
						45	11.4
						60	16.2
13-53b	1	57.5	40	65	6-8	15	7.5
						30	12.1
						45	14.8
						60	16.8
13-35b	1	65	34	65	6-8	15	6.2
						30	9.3
						87	13.7
13-35b	1	65	34	65	4-6	15	5.4
						30	8.4
						87	13.1
13-49a	1	67	32	65	2-4	15	3.6
						30	6.0
						70	9.5
13-49a	1	67	32	65	4-6	15	4.9
						30	7.9
						70	11.8
13-49b	1	81	33	63	6-8	15	6.6
						30.5	9.7
13-49b	1	81	33	63	8-10	15	8.0
						30.5	10.9
13-53a	1	62	34	67	8-10	15	6.7
						30	10.6
						67	13.8
13-53a	1	62	34	67	6-8	15	5.9
						30	9.5
						67	12.6
13-17a	1	76	27	191	2-4	10	3.7
						20	6.1
						41	8.6
13-17a	1	76	27	191	8-10	10	6.8
						20	9.4
						41	10.6

Table 1, Sheet 2.

Run No.	Pad Thickness, Inches	Temp. °F	Relative Humidity %	Air Flow cu.ft./sq.ft./min.	Mesh Size	Total Time of Exposure, Min.	Water Adsorbed, Percent of Active Gel
13-17b	1	78	24	190	8-10	10	7.1
						20	8.5
						40	8.5
13-17b	1	78	24	190	2-4	10	4.2
						20	5.9
						40	7.0
13-19a	1	83	14	185	8-10	10	4.3
						30	5.6
13-19a	1	83	14	185	6-8	10	3.9
						30	6.0
13-19b	1	82	15	185	4-6	8	3.1
						40	6.2
13-19b	1	82	15	185	6-8	8	3.7
						40	6.5
13-21a	1	60	45	194	4-6	10	7.4
						20	12.4
						60	21.4
13-21a	1	60	45	194	6-8	10	9.0
						20	14.5
						60	23.0
13-21b	1	57	36	189	4-6	10	6.2
						20	9.7
						30	12.2
						82	16.3
13-21b	1	57	36	189	2-4	10	4.5
						20	7.2
						30	9.4
						82	13.8
13-29a	1	47	67	178	8-10	10	12.2
						20	19.6
						30	25.7
13-29a	1	47	67	178	2-4	10	6.7
						20	11.5
						30	16.4
13-29b	1	49	39	178	8-10	10	7.4
						20	12.5
						30	15.1
						80	19.2
13-29b	1	49	39	178	4-6	10	5.1
						20	9.3
						30	12.0
						80	17.8

Table 1, Sheet 3.

Run No.	Pad Thickness, Inches	Temp. °F	Relative Humidity %	Air Flow cu.ft./sq.ft./min.	Mesh Size	Total Time of Exposure, Min.	Water Adsorbed Percent of Active Gel
13-31	1	49	41	175	8-10	10	7.5
						20	11.7
						30	14.0
13-31	1	49	41	175	6-8	10	6.3
						20	10.4
						30	12.9
13-35	1	61	40	173	6-8	15	11.4
						30	14.8
						98	15.5
13-35	1	61	40	173	2-4	15	6.7
						30	9.7
						98	13.2
13-55	1	67	31	66	2-4	15	3.88
						30	5.64
13-55	1	67	31	66	2-4	15	3.93
						30	5.59
Remarks on above runs:	Both mesh sizes of gel from same well mixed batch. Subsequent heat treatment identical.						
11-83	1	59	48	168	6-8	10	8.0
						20	13.1
						30	16.8
11-83	1	59	48	168	2-4	10	4.8
						20	8.8
						30	12.2
11-87	1	56	47	168	6-8	10	8.5
						20	12.9
						30	15.9
						80	21.4
11-87	1	56	47	168	8-20	10	11.7
						20	17.0
						30	19.2
						80	23.0
10-37	1	83	74	172	8-20	10	22.4
						20	32.9
						30	38.8
						80	37.3
10-37	1	83	74	172	4-6	10	15.5
						20	25.4
						30	31.0
						80	38.0

Table 1, Sheet 4.

Run No.	Pad Thickness, Inches	Temp. °F	Relative Humidity %	Air Flow cu.ft./sq.ft./min.	Mesh Size	Total Time of Exposure, Min.	Water Adsorbed, Percent of Active Gel
11-5	1	76	79	168	2-4	10	12.2
				168		20	21.6
				168		30	28.4
				355		90	40.5
11-5	1	76	79	168	4-6	10	15.3
				168		20	26.4
				168		30	33.4
				355		90	44.4
11-91	1	54	42	168	2-4	10	4.3
	Activated at 600°F for 3 hrs.			"		20.5	7.1
	(Never heated above 600°F)			"		30.5	8.9
				341		65.5	17.5
11-91	1	54	42	168	4-6	10	4.9
	Activated at 700°F for about			"		20.5	8.3
	10 hrs.			"		30.5	10.9
				341		65.5	18.8
11-89	1	54	43	168	6-8	10	7.0
	Activated at 600°F for 3 hrs.					20	10.6
	(Never heated above 600°F)					30	12.8
						120	18.7
11-89	1	54	43	168	4-6	10	5.7
	Activated at 700°F for about					20	8.3
	10 hrs.					30	11.0
						120	18.6

Remarks on Runs 11-83 through 11-5:
Activated at 600°F for 3 hours. Neither gel heated to temperatures in excess of 600°F. Both gels made in same manner, but separately.

Remarks on Runs 11-91 & 11-89: Both gels made in same manner, but separately.

TABLE 2.

EFFECT OF AIR VELOCITY
Density Active Silica Gel 3.2 lbs./sq.ft./in.
See Plate 12 for Pressure Drops.

Run No.	Pad Thick-ness, Inches	Temp. °F	Relative Humidity %	Air Flow cu.ft. / Sq.ft. min.	Mesh Size	Total Time of Exposure, Min.	Water Adsorbed Percent of Active Gel
14-7	1	46	50	212	6-8	15	13.8
						30	18.9
						80	26.4
14-7	1	46	50	150	6-8	15	11.7
						30	16.7
						80	24.4
14-11a	1	62	42	237	6-8	15	11.0
						30	16.8
						98	21.1
14-11a	1	62	42	170	6-8	15	10.0
						30	15.6
						98	21.0
14-11b	1	67	47	171	6-8	15	13.0
						30	18.9
14-11b	1	67	47	123	6-8	15	11.2
						30	16.9
14-13a	1	63	53	230	6-8	17.5	15.9
						30	20.7
						95	27.7
14-13a	1	63	53	166	6-8	17.5	14.0
						30	18.6
						95	27.0
14-13b	1	53	30	304	6-8	15	8.7
						30	11.3
14-13b	1	53	30	180	6-8	15	7.1
						30	10.0
14-13c	1	51	38	162	6-8	15	7.8
						28.25	11.1
14-13c	1	51	38	96	6-8	15	5.3
						28.25	8.8
14-15a	1	55	29	246	8-20	16	10.4
14-15a	1	55	29	179	8-20	16	9.4
14-15b	1	53	58	236	6-8	15	15.3
14-15b	1	53	58	168	6-8	15	12.9
14-17a	1	77	40	394	6-8	15	14.9
						35	17.7
14-17a	1	77	40	142	6-8	15	11.1
						35	15.5
14-17b	1	71	50	170	6-8	15	14.4
						30	20.8
14-17b	1	71	50	61	6-8	15	7.8
						30	12.9

Table 2, Sheet 2.

Run No.	Pad Thickness, Inches	Temp. °F	Relative Humidity %	Air Flow cu.ft./sq.ft./min.	Mesh Size	Total Time of Exposure, Min.	Water Adsorbed, Percent of Active Gel
14-19a	1	69	69	181	6-8	15	21.4
						30	31.4
14-19a	1	69	69	65	6-8	15	10.0
						30	16.8
14-19b	1	57	47	178	6-8	15	11.2
						30	16.6
						45	18.6
14-19b	1	57	47	72	6-8	15	7.8
						30	12.0
						45	14.5
14-21a	1	74	25	178	6-8	15	6.6
						30	7.6
14-21a	1	74	25	68	6-8	15	4.4
						30	6.2
14-21b	1	71	49	97	6-8	15	10.7
				97		30	16.0
				246		80	17.9
14-21b	1	71	49	38	6-8	15	4.9
				38		30	9.3
				97		80	17.1
14-23a	1	61	28	76	6-8	15	5.4
						30	8.3
						55	11.0
14-23a	1	61	28	45	6-8	15	3.1
						30	5.4
						55	9.1
14-23b	1	55	33	172	6-8	15	7.6
						31	11.3
						46.5	12.9
14-23b	1	55	33	75	6-8	15	4.7
						31	8.0
						46.5	10.1

Table 3, Sheet 2.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
9-65	0.5	83	65	81	8-20	10	15.8
						20	22.4
						30	26.3
						40	30.3
	1.0	83	65	81	8-20	10	10.5
						20	17.1
						30	21.0
						40	25.0
	1.5	83	65	81	8-20	10	8.8
						20	14.0
						30	18.0
						40	21.7
9-73	0.5	81	65	168	8-20	10	21.1
						20	29.0
	1.0	81	65	168	8-20	10	17.1
						20	25.0
	1.5	81	65	168	8-20	10	14.5
						20	22.4

Note: In runs 9-61 to 9-73, incl. (only), the adsorbing capacity of the gels used was about 80% of that of regular commercial gel.

TABLE 4.

DISTRIBUTION OF WATER IN GEL BEDS
Density Active Silica Gel 3.2 lbs./sq.ft./in.
See Plate 12 for Pressure Drops

Run No. (1)	Description of Gel Bed (2)	Temp. °F (3)	Relative Humidity % (4)	Air Flow cu.ft./sq.ft./min. (5)	Mesh Size (6)	Total Time of Exposure, Min. (7)	Water Adsorbed, Percent of Active Gel (8)
14-7	Front half of 2-inch pad	47	50	150	6-8	15	11.7
						30	16.7
						80	24.4
	Rear half of 2-inch pad	47	50	150	6-8	15	5.1
						30	9.3
						80	18.9
14-11a	Front half of 2-inch pad	61	42	170	6-8	15	10.0
						30	15.6
						98	21.0
	Rear half of 2-inch pad	61	42	170	6-8	15	5.5
						30	10.9
						98	20.0
14-11b	Front half of 2-inch pad	67	46	123	6-8	15	11.2
						30	16.9
						53	21.3
	Rear half of 2-inch pad	67	46	123	6-8	15	6.2
						30	10.8
						53	17.9
14-13a	Front half of 2-inch pad	63	53	166	6-8	17.5	14.0
						30	18.6
						95	27.0
	Rear half of 2-inch pad	63	53	166	6-8	17.5	8.0
						30	12.1
						95	23.3
14-15a	Front half of 2-inch pad	55	29	179	8-20	16	9.4
	Rear half of 2-inch pad	55	29	179	8-20	16	4.2
14-15b	Front half of 2-inch pad	53	58	168	6-8	15	12.9
	Rear half of 2-inch pad	53	58	168	6-8	15	6.3
9-61	Front 2/3 of 1.5" pad	86	65	168	8-20	10	15.8
						20	23.7
	Front 1/3 of 1.5" pad	86	65	168	8-20	10	21.0
						20	28.9
	Rear 2/3 of 1.5" pad	86	65	168	8-20	10	9.2
						20	15.8
	Rear 1/3 of 1.5" pad	86	65	168	8-20	10	7.9
						20	15.8

Table 4, Sheet 2.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
9-65	Front 2/3 of 1.5" pad	82	64	81	8-20	10	10.5
						20	17.1
						30	21.0
						40	25.0
	Front 1/3 of 1.5" pad	82	64	81	8-20	10	15.8
						20	22.4
						30	26.3
						40	30.3
	Rear 2/3 of 1.5" pad	82	64	81	8-20	10	5.3
						20	9.2
						30	13.1
						40	17.1
	Rear 1/3 of 1.5" pad	82	64	81	8-20	10	5.3
						20	9.2
						30	13.1
						40	15.8
9-73	Front 2/3 of 1.5" pad	81	65	168	8-20	10	17.1
						20	25.0
	Front 1/3 of 1.5" pad	81	65	168	8-20	10	21.1
						20	29.0
	Rear 2/3 of 1.5" pad	81	65	168	8-20	10	10.5
						20	18.4
	Rear 1/3 of 1.5" pad	81	65	168	8-20	10	10.5
						20	18.4

Note: In runs 9-61 to 9-73, incl. (only), the adsorbing capacity of the gels used was about 80% of that of regular commercial gel.

TABLE 5.

EFFECT OF HEAT TREATMENT
See Plate 12 for Pressure Drops

Run No. (1)	Pad Thickness, Inches (2)	Temp. °F (3)	Relative Humidity % (4)	Air Flow cu.ft./sq.ft. min. (5)	Mesh Size (6)	Density Active Gel lbs./sq.ft. inch (7)	Total Time of Exposure, Min. (8)	Water Adsorbed, Percent of Active Gel (9)	Remarks (10)
10-59	1	83	73	168	8-20	3.2	10	25.3	Regular run of commercial gel activated at 600°F for 3 hrs.
							20	35.8	
							30	41.0	
							50	44.7	
	1	83	73	168	8-20	4.6	10	17.3	Gel saturated and activated about 10 times. Temperatures during activation unknown. Final activation at about 800°F. Both gels prepared in same manner, but separately.
							20	26.6	
							30	31.5	
							50	34.5	
11-25	1	78	44	168	8-20	3.2	10	14.7	Regular run of commercial gel activated at 600°F for 3 hrs.
							20	19.4	
							30	20.9	
							90	22.5	
	1	78	44	168	10-14	4.6	10	5.3	Gel saturated and activated 300 times. Temperatures during activation unknown. Final activation at about 700°F for about 2 hrs. Both gels prepared in same manner but separately.
							20	7.4	
							30	8.9	
							90	10.5	
11-49a	1	77	42	168	4-6	3.5	50	16.5	Saturated 27 times; activated rapidly 27 times at about 700°F. Slight oil stain. Final activation at 650°F for 2.5 hrs.
	1	81	42	168	4-6	3.2	50	17.9	Never heated above 600°F for more than 3 hrs. Both gels prepared in same manner but separately.

Table 5, Sheet 2.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11-49b	1	76.5	59	352	4-6	3.5	105	34.9	Saturated 27 times; activated rapidly 27 times at about 700°F; slight oil stain. Final activation at 650°F for 2.5 hrs.
	1	76.5	59	352	4-6	3.2	105	38.3	Never heated above 600°F for more than 3 hrs. Water adsorbed determined by loss in weight at 720°F (20 hrs.). Both gels prepared in same manner but separately.
11-53	0.5	58	40	168	8-20	3.3	10 20 30 50	12.3 16.9 20.0 19.3	Regular run of commercial gel. Activated at 700°F for 137 hrs. Above percentages based on weight gains. After 50 min. exposure, the loss in weight on drying at 700°F (16 hrs.) was 17.1%.
	0.5	58	40	168	8-20	3.2	10 20 30 50	15.6 18.8 20.3 19.5	Regular run of commercial gel. Activated at 600°F for 3 hrs. Above percentages based on weight gains. After 50 min. exposure the loss in weight on drying at 700°F (16 hrs.) was 22.6%. Both gels prepared in same manner but at different times.
11-59a	0.5	81	44	168	8-20	3.2	60	27.4	Activated at 600°F for 3 hrs. (only heat treatment).
	0.5	81	44	168	8-20	3.6	60	16.4	Activated at 945°F for 144 hrs. Water adsorbed determined by loss in weight at 945°F (16 hrs.). Both gels wei parts of a single well mixed batch which had never been heated in excess of 600°F.
11-59b	0.5	75	66	168	8-20	3.2	135	45.7	Activated at 600°F for 3 hrs. (only heat treatment).
	0.5	75	66	168	8-20	3.6	135	36.4	Activated at 945°F for 144 hrs. Water adsorbed determined by loss in weight at 700°F. (20 hrs). Both gels were parts of a single well mixed batch which had never been heated in excess of 600°F.

Table 5, Sheet 3.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11-59c	0.5	81	44	168	8-20	3.2	60	26.2	Regular run of commercial gel.Activated at 600°F for 3 hrs.
	0.5	81	44	168	8-20	4.6	60	11.2	Gel saturated and activated 300 times. Temperatures during activations unknown. Water adsorbed determined by loss in weight at 945°F (16 hrs). Both gels prepared in same manner but separately.
11-59d	0.5	75	66	168	8-20	3.2	135	45.4	Regular run of commercial gel. Activated at 600°F for 3 hrs.
	0.5	75	66	168	8-20	4.6	135	21.6	Gel saturated and activated 300 times. Temperatures during activation unknown. Water adsorbed determined by loss in weight at 700°F (20 hrs.). Both gels prepared in same manner but separately.
11-59e	0.5	81	44	168	8-20	3.2	60	27.4	Regular run of commercial gel. Activated at 600°F for 3 hrs.
	0.5	81	44	168	8-20	3.2	60	26.2	Regular run of commercial gel. Activated at 600°F for 3 hrs. Water adsorbed determined by loss in weight at 945°F (16 hrs.). The gels were delivered to N.R.L. in separate containers.
11-59f	0.5	75	67	168	8-20	3.2	135	45.7	Regular run of commercial gel. Activated at 600°F for 3 hrs.
	0.5	75	67	168	8-20	3.2	135	45.4	Regular run of commercial gel. Activated at 600°F for 3 hrs. Water adsorbed determined by loss in weight at 700°F (20 hrs.). The gels were delivered to NRL in separate containers.
11-111	0.5	54	20	174	8-12	4.6	123	3.25	Gel saturated and activated 300 times. Temperatures during activation unknown.
	0.5	54	20	174	8-20	3.2	123	9.9	Regular run of commercial gel. Activated at 600°F for 3 hrs. Water adsorbed determined by loss in weight at 700°F (16 hrs.) Both gels prepared in same manner but separately.

Table 5. Sheet 4.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11-121a	0.5	70	21	202	6-8	3.3	15	3.1	Activated at 975°F for 10 hrs.
							60	3.5	
	0.5	70	21	202	6-8	3.3	15	2.8	Activated at 975°F for 60 hrs.
							60	3.1	Prior to above treatments, both gels were parts of a single well mixed batch which had never been activated at temperatures in excess of 600°F.
11-121b	0.5	47	50	197	6-8	3.3	166	17.5	Activated at 975°F for 10 hrs.
	0.5	47	50	197	6-8	3.3	166	15.7	Activated at 975°F for 60 hrs.
									Percents adsorbed determined by loss in weight at 600°F (6 hrs.). Prior to above treatments, both gels were parts of a single well mixed batch which had never been activated at temperatures in excess of 600°F.
11-121c	0.5	71	21	202	6-8	3.2	60	7.9	Activated at 575°F for 14 hrs.
	0.5	71	21	202	6-8	3.3	60	3.5	Activated at 975°F for 10 hrs.
									Prior to above treatments, both gels were parts of a single well mixed batch which had never been activated at temperatures in excess of 600°F.
11-121e	0.5	71	21	202	6-8	3.2	60	8.2	Activated at 600°F for 3 hrs. (Only heat treatment.
	0.5	71	21	202	6-8	3.2	60	7.9	Activated at 575°F for 14 hrs. (Had been heated 600°F for 3 hrs., then saturated, and then activated as above.)
									Prior to above treatments, both gels were parts of a single batch delivered to N.R.L. in a single container.
11-121d	0.5	47	50	197	6-8	3.2	166	22.4	Activated at 575°F for 14 hrs.
	0.5	47	50	197	6-8	3.3	166	17.5	Activated at 975°F for 10 hrs.
									Percents adsorbed determined by losses in weight at 600°F (6 hrs.). Prior to above heat treatments, both gels were parts of a single well mixed batch which had never been activated at temperatures in excess of 600°F.

Table 5, Sheet 5.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11-121f	0.5	47	50	197	6-8	3.2	166	22.6	Activated at 600°F for 3 hrs. (Only heat treatment)
	0.5	47	50	197	6-8	3.2	166	21.8	Activated at 575°F for 14 hrs. (Had been heated to 600°F for 3 hrs., then saturated, and then activated as above.) Prior to above treatments, both gels were parts of a single batch delivered to NRL in a single container.
11-123a	1	52	58	181	6-8	3.2	15	13.5	Activated at 575°F for 14 hrs.
							30	20.2	
	1	52	58	181	6-8	3.3	15	8.7	Activated at 975°F for 10 hrs.
							30	13.6	Prior to above treatments, both gels were parts of a single batch which had never been activated at temperatures in excess of 600°F.
11-123b	1	54	55	185	6-8	3.2	15	15.1	Activated at 575°F for 14 hrs.
							30	24.4	
							56	26.9	
	1	54	55	185	6-8	3.3	15	9.1	Activated at 975°F for 60 hrs.
							30	16.1	Prior to above treatments, both gels were parts of a single well mixed batch which had never been activated at temperatures in excess of 600°F.
							56	18.8	
11-133	1	47	37	181	4-6	3.4	15	6.0	Saturated 27 times; activated rapidly 27 times at about 700°F; slight oil stain. Final activation at 570°F for 5 hrs.
							54	14.2	
	1	47	37	181	4-6	3.2	15	6.65	Never heated above 600°F for more than 3 hrs. Saturated once. Final activation at 570°F for 5 hrs.
							54	16.5	Both gels prepared in same manner but separately.
11-147	1	70	21	173	6-8	3.2	10	5.6	Both gels from same container and originally well mixed. Activated at 500-560°F for 6 hrs.
							20	7.7	
							77	7.6	
	1	70	21	173	6-8	3.2	10	5.0	Activated at 680-700°F for 6 hrs.
							20	7.0	
							77	7.0	

TABLE 6.

MISCELLANEOUS DATA
Density Active Silica Gel 3.2 lbs./sq.ft./in.
See Plate 12 for Pressure Drops.

Run No. (1)	Pad Thick-ness, Inches (2)	Temp. °F (3)	Rela-tive Humid-ity % (4)	Air Flow cu.ft./sq.ft./min. (5)	Mesh Size (6)	Total Time of Expos-ure, Min. (7)	Water Adsorbed, Percent of Active Gel (8)
9-77	1	89	51	168	6-8	10	12.1
						20	17.9
						30	21.8
						40	23.6
						50	24.3
						60	24.3
9-89	1	90	51	168	4-6	10	8.8
						20	14.2
						30	16.9
						40	18.9
9-97	1	85	60	168	6-8	5	8.5
						15	17.7
						25	23.4
						35	26.9
						45	30.5
						55	34.0
						65	36.5
						75	37.2
9-113	1	80	72	168	4-6	5	7.9
						10	12.8
						20	21.0
						30	27.2
						40	32.7
				354		50	39.0
						60	41.4
9-135	1	79	74	168	6-8	5	11.5
						10	18.2
						20	27.0
						30	33.8
				354		50	43.2
						60	44.0
9-159	1	80	76	168	6-8	5	10.0
						10	16.6
10-15	1	83	75	168	4-6	5	7.7
						10	13.5
						20	21.3
						30	29.0
				354		50	39.3
						70	40.6
10-35	1	81	80	172	6-8	10	15.0
11-9	1	84	61	168	4-6	10	14.1
						20	21.1
						30	26.7
						70	32.4

Table 6, Sheet 2.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
11-13	1	70	59	168	4-6	10	11.9
						20	18.9
						30	23.1
						90	32.9
11-17	1	74	53	168	4-6	10	9.7
						20	15.3
						30	18.0
						90	26.4
11-21	1	67	69	168	4-6	10	10.9
						20	19.2
						30	24.6
						80	31.5
11-29	1	72	65	168	8-20	10	20.8
						20	30.7
						30	36.1
						90	40.0
11-33	1	75	60	168	4-6	30	21.9
11-33a	1	71.5	65	168	4-6	30	24.0
11-33b	1	81	60	168	4-6	30	23.0
						45	25.6
11-33c	1	76	59	168	4-6	30	21.9
11-33d	1	71	69	168	4-6	30	25.5
11-33e	1	69	81	168	4-6	30	29.0
11-35a	1	77	72	168	4-6	10	14.1
						20	20.5
						30	25.6
						40	30.7
11-35b	1	73	78	168	4-6	10	12.8
						20	21.8
						30	28.2
						40	33.3
11-35c	1	72	69	168	4-6	10	12.0
						20	20.3
						30	26.9
						40	30.4
						50	33.2
11-41a	1	81	50	168	4-6	10	9.7
						20	14.4
						30	16.7
11-41b	1	67	58	168	4-6	10	9.3
						20	15.0
						30	18.8
						40	20.8
11-41c	1	71	39	168	4-6	10	6.5
						20	9.8
						30	12.4
11-41d	1	72	37	168	4-6	10	7.1
						20	10.3
						30	11.9
11-43a	1	65	51	168	4-6	10	7.5
						20	11.9
						30	15.0
						40	17.5

Table 6, Sheet 3.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
11-43b	1	59	63	168	4-6	10	8.8
						20	13.7
						30	17.5
						40	20.9
11-43c	1	67	53	168	4-6	10	8.6
						20	15.0
						25	17.0
11-43d	1	72	42	168	4-6	10	7.6
						20	11.4
						32	13.6
11-45a	1	72	46	168	4-6	10	7.8
						20	12.8
						30	17.9
						40	18.7
11-45b	1	66	54	168	4-6	10	8.7
						20	16.2
11-45c	1	69	65	168	4-6	10	11.2
						20	16.7
						30	23.2
						40	24.2
11-49a	1	77	40	168	4-6	10	8.0
						20	11.9
						30	14.2
						50	16.8
11-57	1	74	61	168	8-20	10	25.0
						20	34.4
						32	37.5
						52	37.5
						115	39.1
11-97	1	40	36	339	2-4	10	5.0
						20	7.9
						170	16.0

TABLE 7.

WATER RECOVERY BY GRANULAR SILICA GEL

Weight and Size (1" thick beds) of Silica Gel Beds, Heat and Power Required for Recovery of 1000 pounds of water per hour from atmospheric air.

Temp. °F (1)	Relative Humidity % (2)	Mesh Tyler (3)	Air Flow cu.ft. sq.ft. min. (4)	Time of Exposure, Min. (5)	Cycles per hour (6)	Total Weight of Silica Gel (7)	Size of all beds in duct, sq.ft. (8)	Power to move outside air thru gel beds in duct (9)	Minimum heat for water removal at 600°F, B.T.U./hr. (10)
45	25	8-20	170	10	3	6,410	1002	41.8	3,299,600
45	25	8-20	170	20	1.5	10,100	1580	66.0	2,874,600
45	25	8-20	170	30	1	11,620	1815	76.0	2,504,600
45	25	6-8	170	30	1	13,150	2050	39.0	2,662,600
45	25	6-8	65	30	1	16,950	2640	2.7	3,061,600
70	45	8-20	170	20	1.5	3,770	589	24.6	1,880,600
70	45	8-20	170	30	1	5,200	812	34.0	1,832,600
70	45	6-8	170	30	1	5,920	925	17.6	1,907,600
70	45	6-8	65	30	1	8,770	1370	1.4	2,206,600
70	45	6-8	170	15	2	4,000	625	11.9	2,125,600
70	75	8-20	170	30	1	3,060	478	19.8	1,609,600
60	40	6-8	170	30	1	6,410	1000	19.0	1,960,600
60	40	6-8	237	30	1	5,950	930	48.5	1,911,600

Note: Approximately 4,200,000 B.T.U. are available in the exhaust gases of 1,000 lbs. gasoline (C_7H_{15}) between 1300°F and 300°F. Times of exposure and of activation are equal.

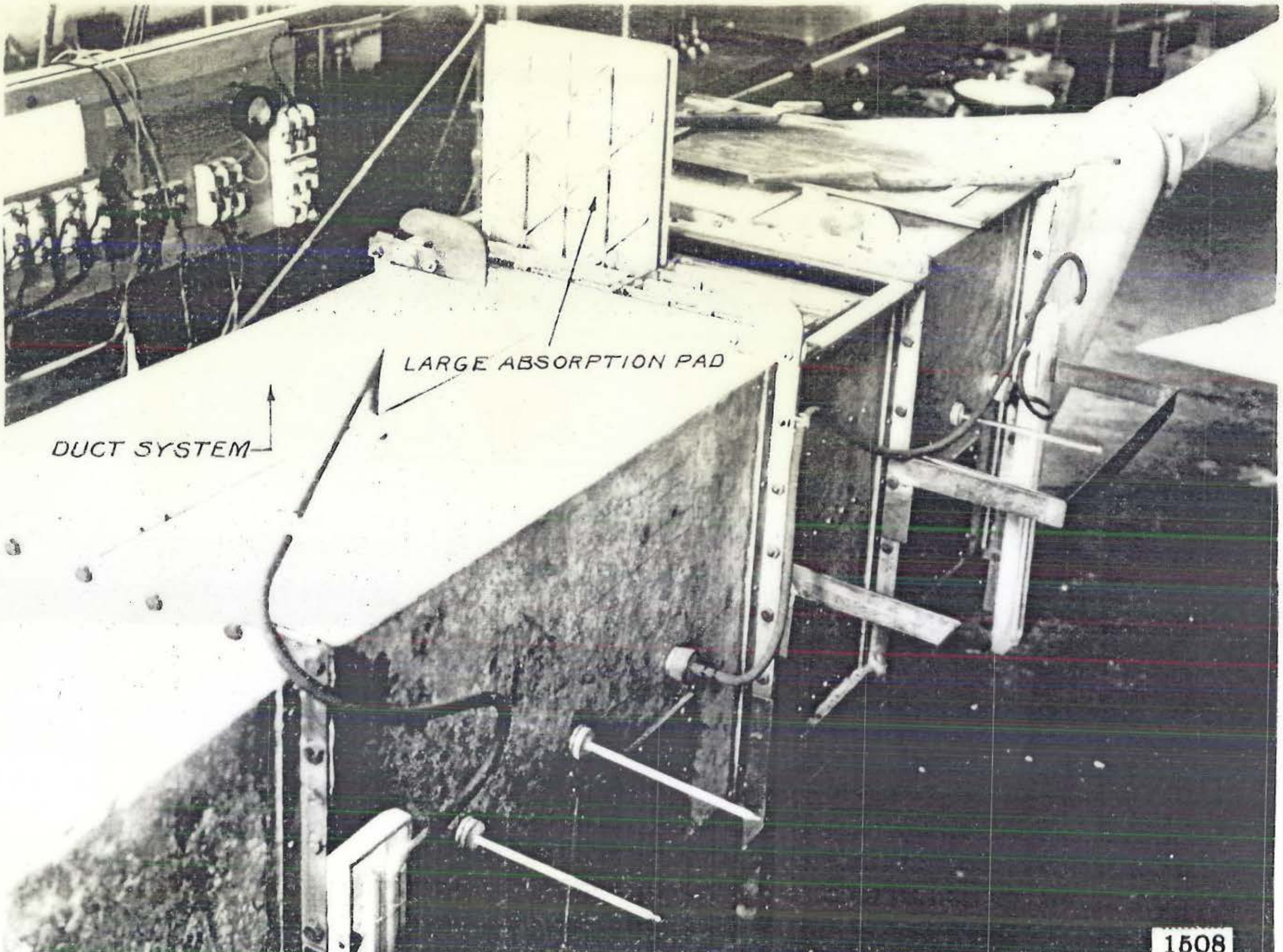
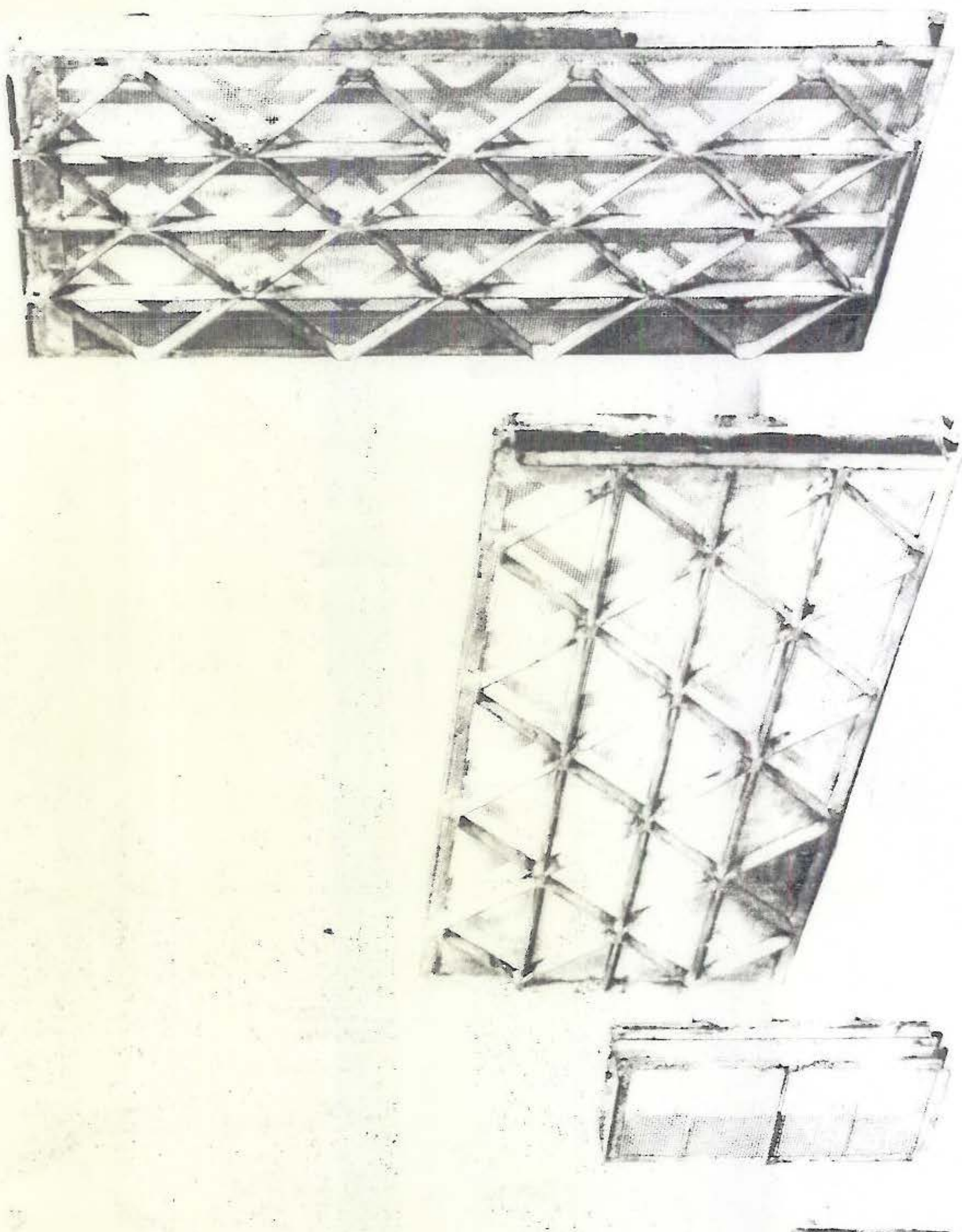
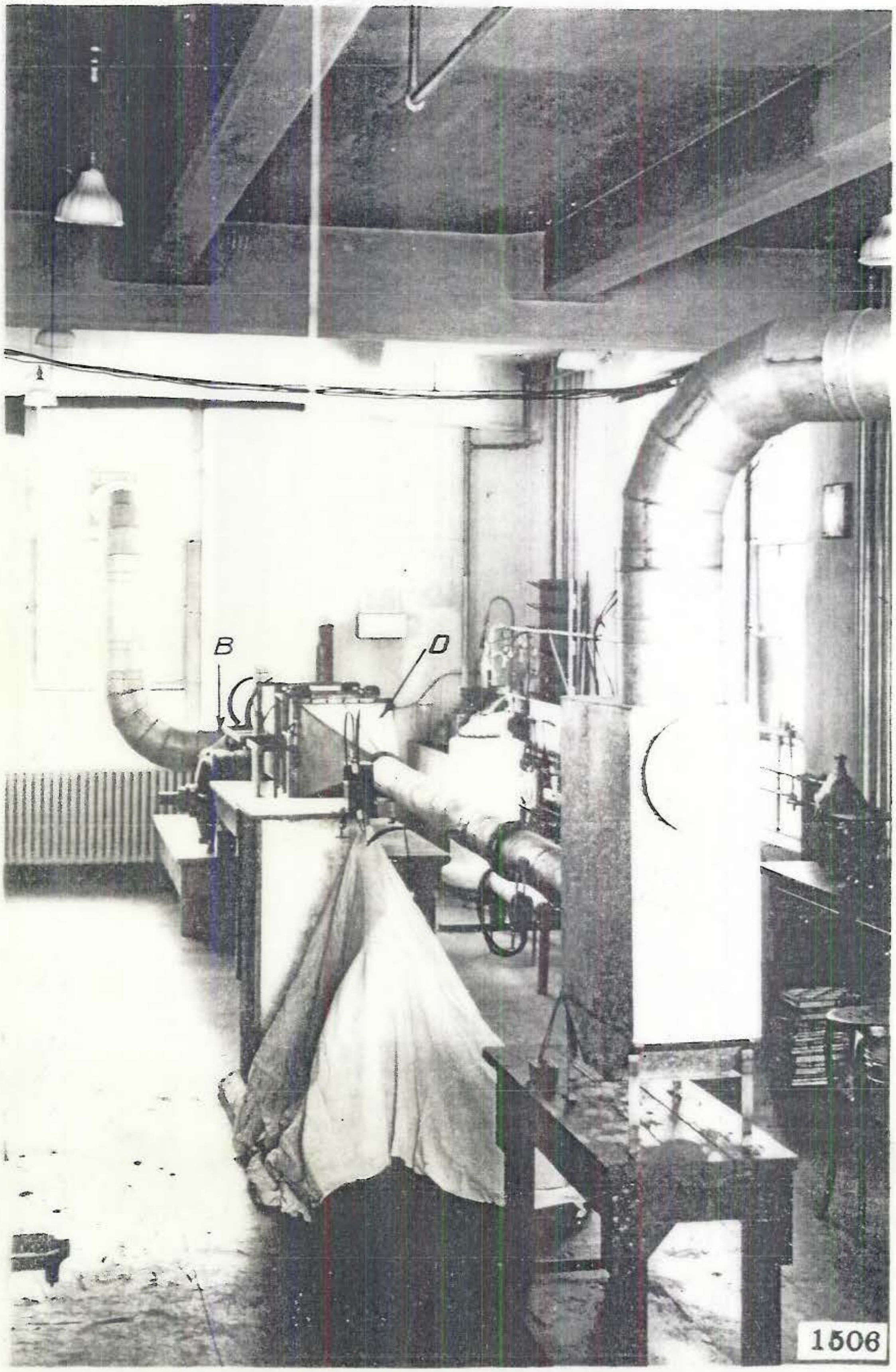


PLATE 1



1766

PLATE 2



NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON D.C.

PLATE 3

GRAPHIC SUMMARY

WATER VAPOR ABSORPTION FROM AIR BY GRANULAR SILICA GEL
(1" THICK BEDS) AT 25% RELATIVE HUMIDITY. AIRFLOW 170 CU. FT./SQ. FT./MIN.
DENSITY ACTIVE SILICA GEL 3.2 LBS./SQ. FT./IN.

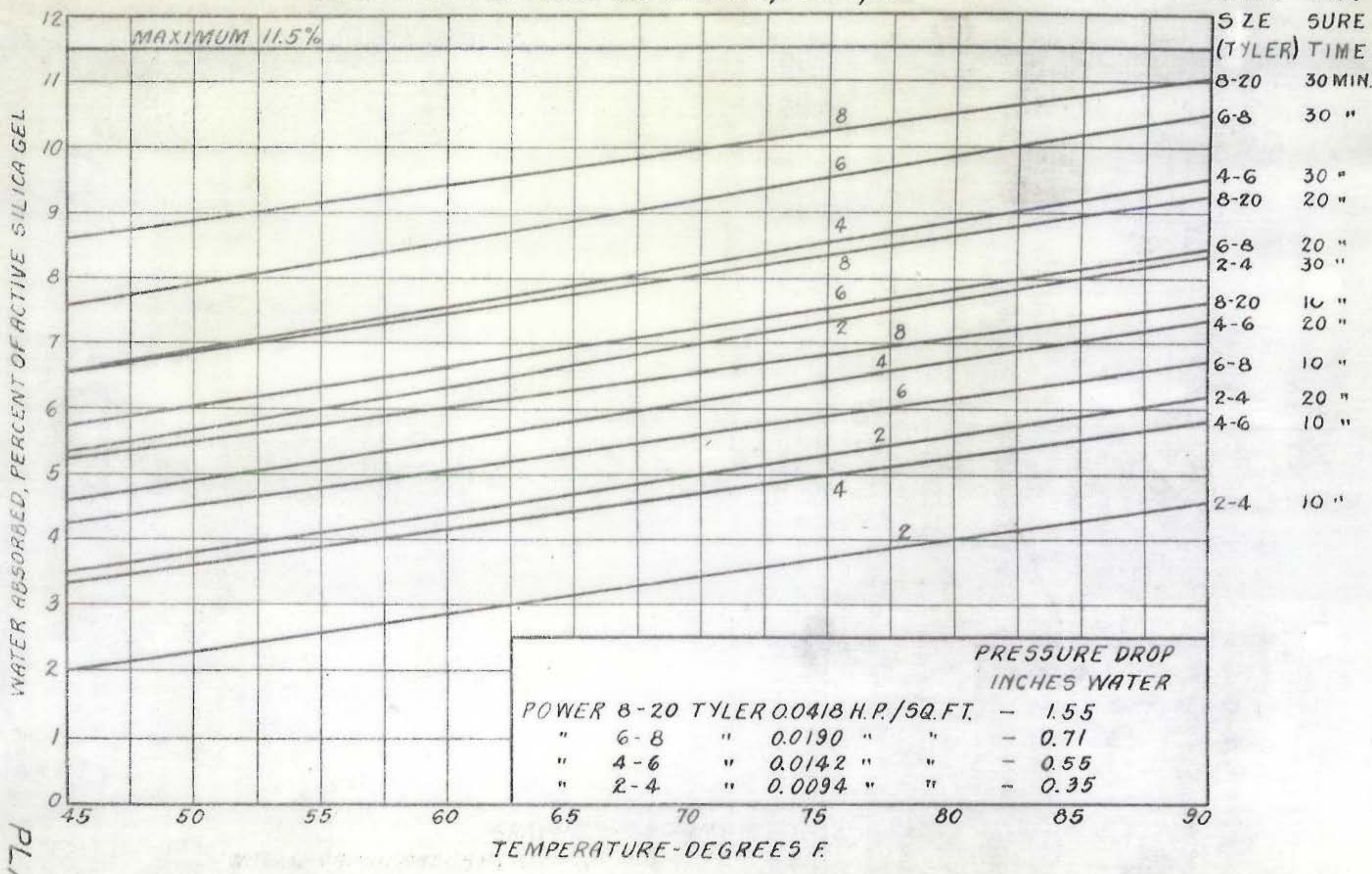


PLATE 4

GRAPHIC SUMMARY

WATER VAPOR ABSORPTION FROM AIR BY GRANULAR SILICA GEL (1" THICK BEDS) AT 45% RELATIVE HUMIDITY. AIRFLOW 170 CU.FT./SQ.FT./MIN. DENSITY ACTIVE SILICA GEL 3.2 LBS./SQ.FT./IN.

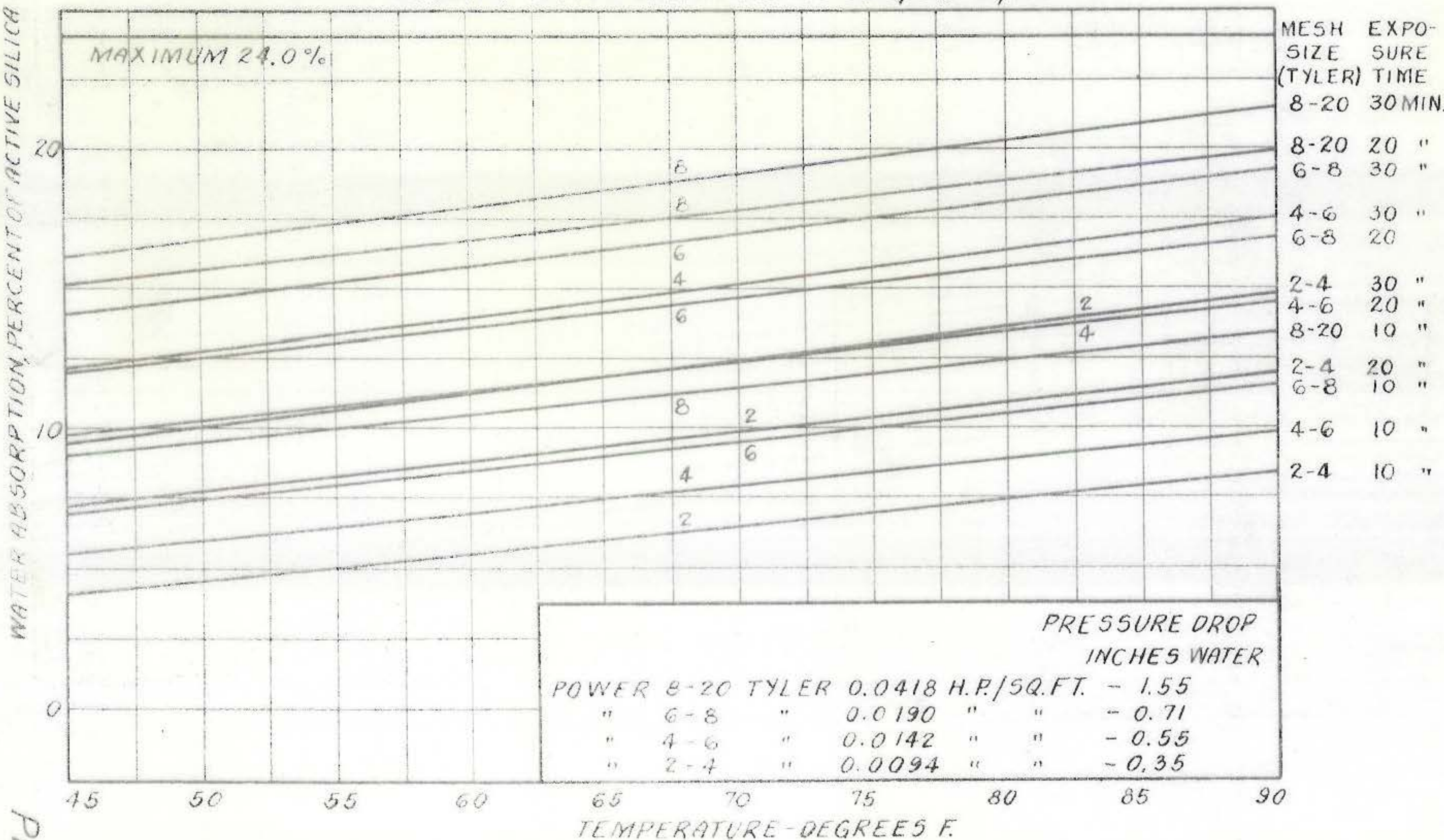


PLATE 5

GRAPHIC SUMMARY

WATER VAPOR ABSORPTION FROM AIR BY GRANULAR SILICA GEL
(1" THICK BEDS) AT 75% RELATIVE HUMIDITY. AIR FLOW 170 CU.FT./SQ.FT./MIN.
DENSITY ACTIVE SILICA GEL. 3.2 LBS./SQ.FT./IN.

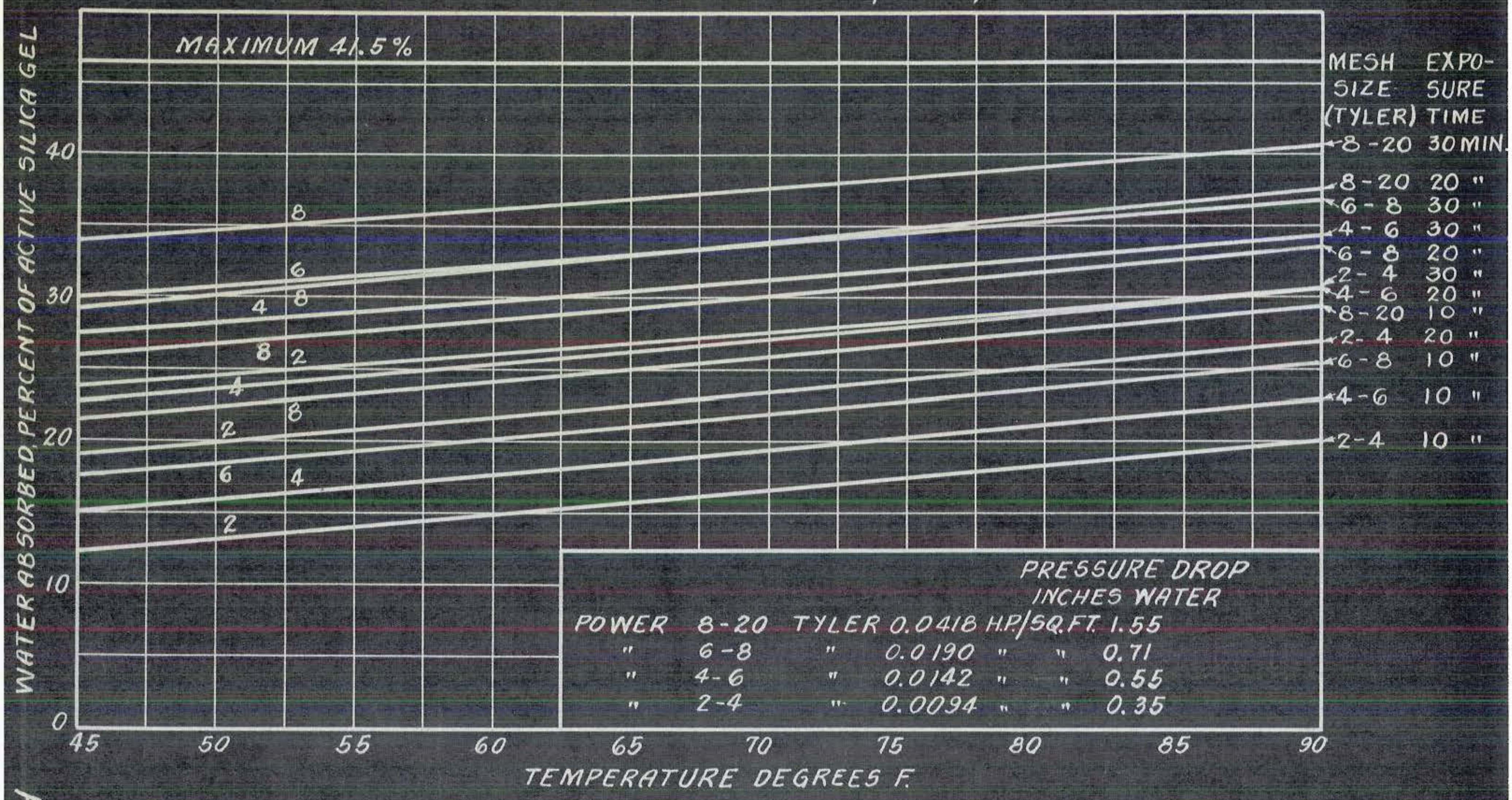


PLATE 6

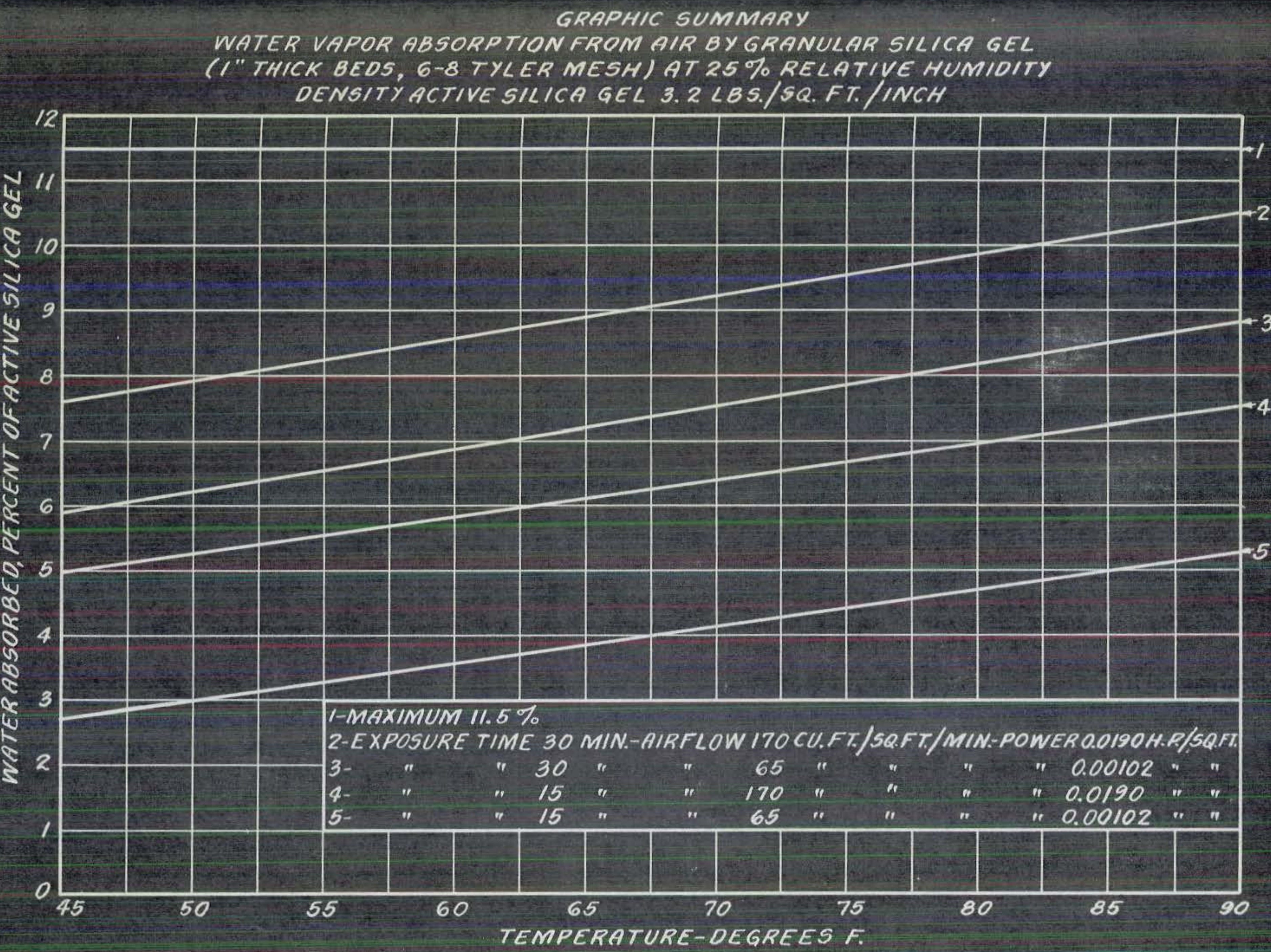

GRAPHIC SUMMARY
WATER VAPOR ABSORPTION FROM AIR BY GRANULAR SILICA GEL
(1" THICK BEDS, 6-8 TYLER MESH) AT 25% RELATIVE HUMIDITY
DENSITY ACTIVE SILICA GEL 3.2 LBS./SQ. FT./INCH
WATER ABSORBED, PERCENT OF ACTIVE SILICA GEL
TEMPERATURE-DEGREES F.
0
1
2
3
4
5
6
7
8
9
10
11
12
45
50
55
60
65
70
75
80
85
90
1
2
3
4
5
1-MAXIMUM 11.5%
2-EXPOSURE TIME 30 MIN.-AIRFLOW 170 CU.FT./SQ.FT./MIN.-POWER 0.0190 H.P./SQ.FT.
3- " " 30 " " 65 " " " " 0.00102 " "
4- " " 15 " " 170 " " " " 0.0190 " "
5- " " 15 " " 65 " " " " 0.00102 " "

PLATE 7

GRAPHIC SUMMARY
WATER VAPOR ABSORPTION FROM AIR BY GRANULAR SILICA GEL
(1" THICK BEDS, 6-8 TYLER MESH) AT 45% RELATIVE HUMIDITY
DENSITY ACTIVE SILICA GEL 3.2 LBS./SQ.FT./INCH

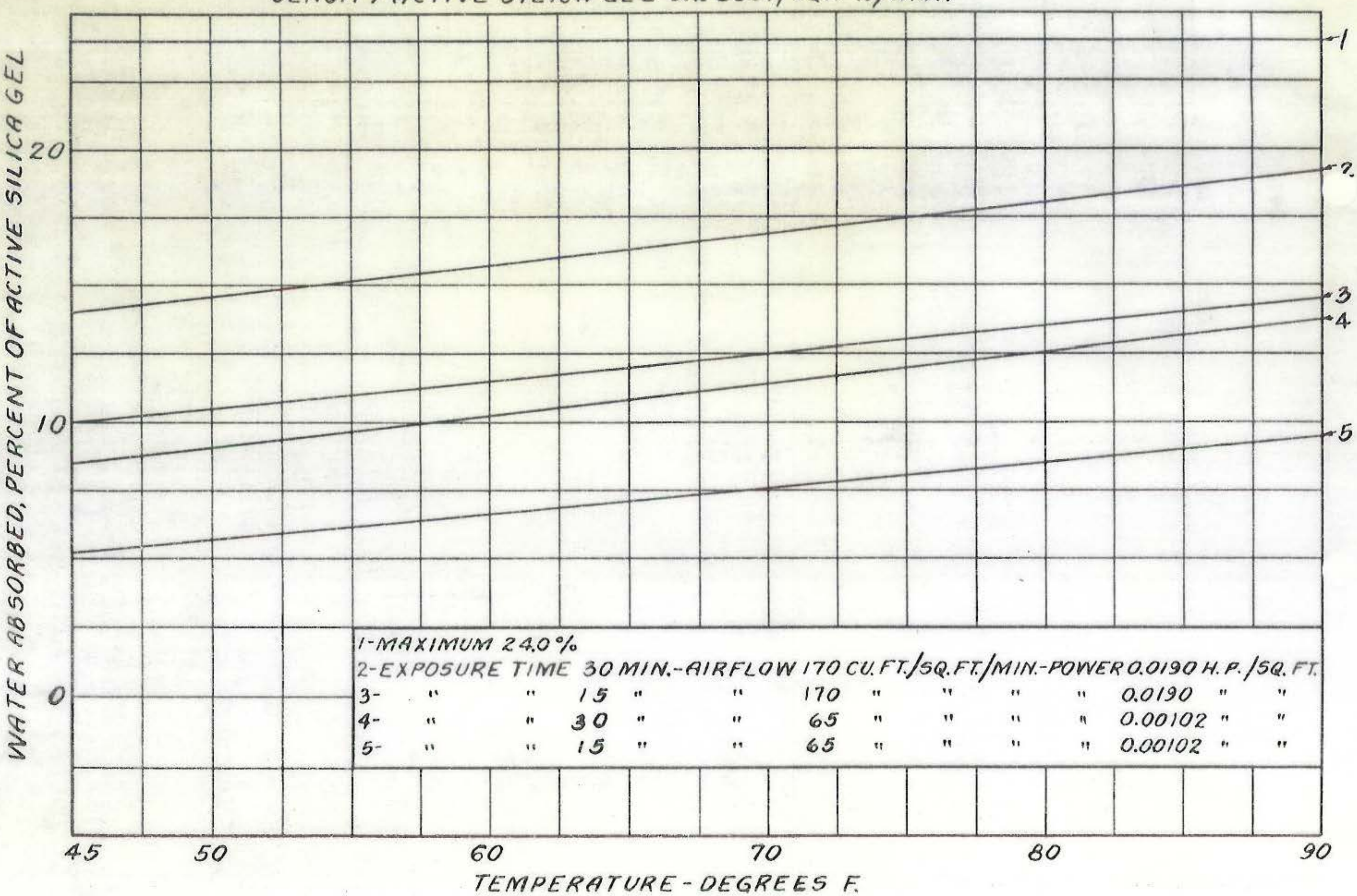


PLATE 8

GRAPHIC SUMMARY
WATER VAPOR ABSORPTION FROM AIR BY GRANULAR SILICA GEL
(1" THICK BEDS, 6-8 TYLER MESH) AT 75% RELATIVE HUMIDITY
DENSITY ACTIVE SILICA GEL 3.2 LBS./SQ.FT./INCH

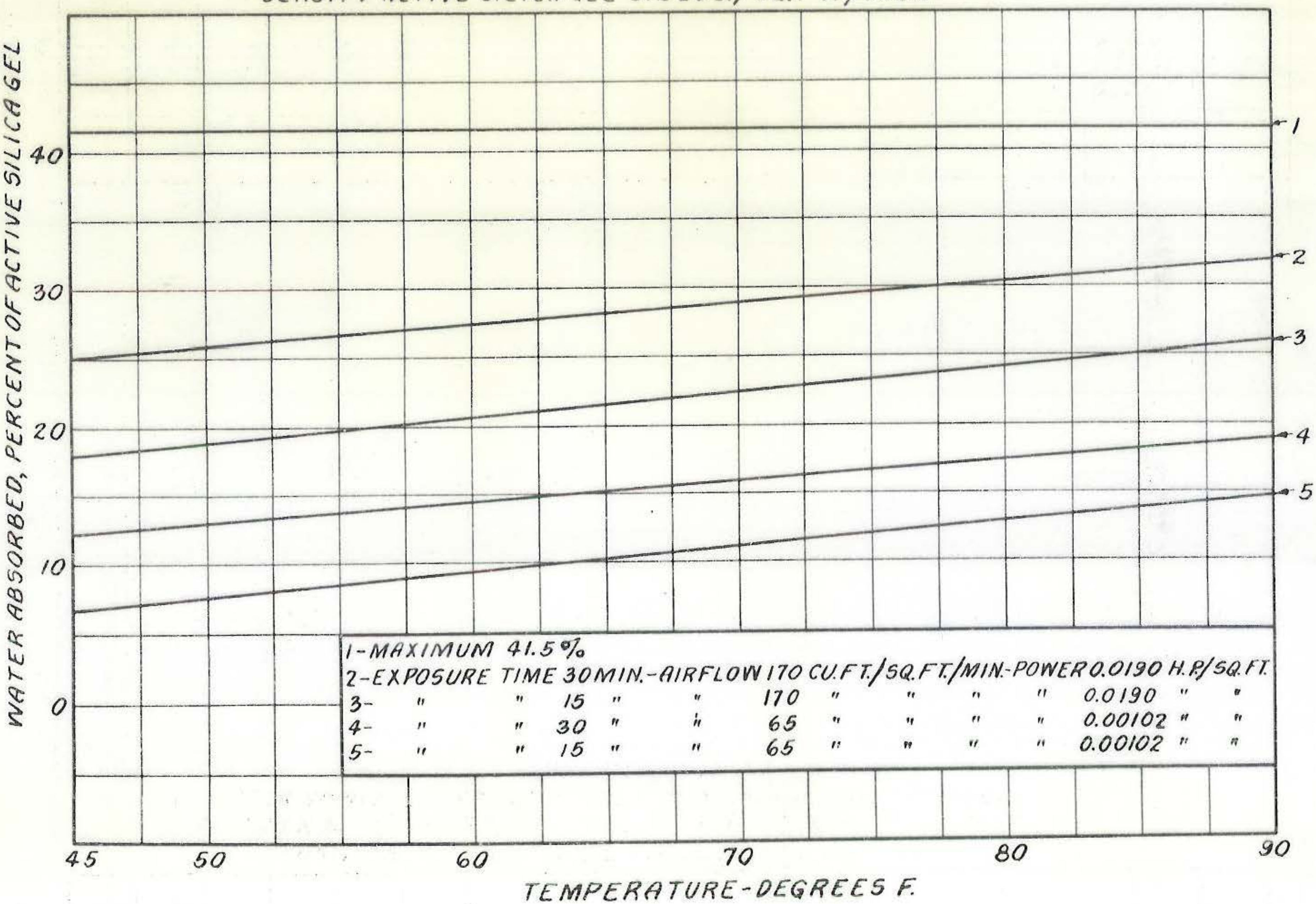


PLATE 9

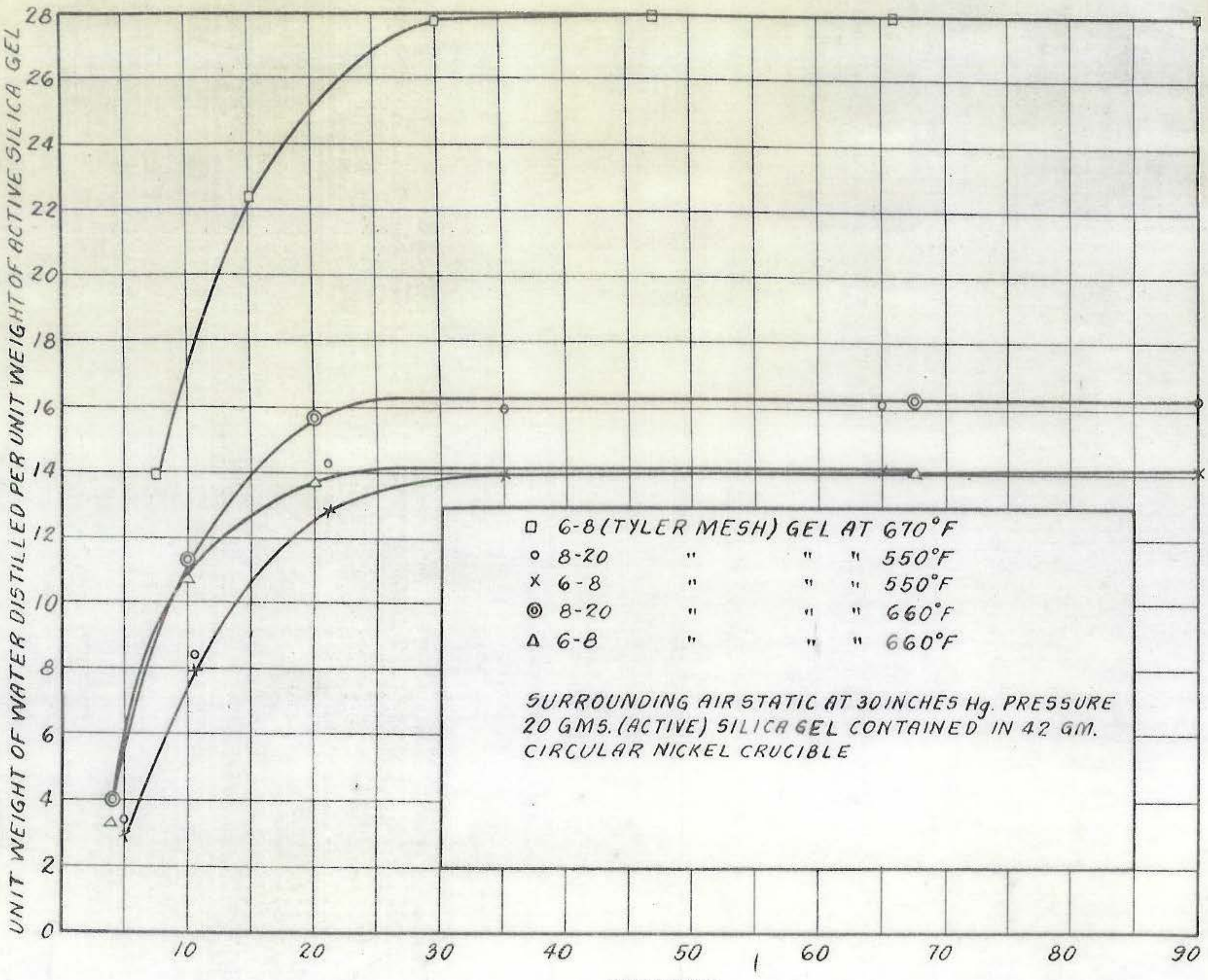

UNIT WEIGHT OF WATER DISTILLED PER UNIT WEIGHT OF ACTIVE SILICA GEL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
10
20
30
40
50
60
70
80
90
□ 6-8 (TYLER MESH) GEL AT 670°F
○ 8-20 " " " 550°F
× 6-8 " " " 550°F
◎ 8-20 " " " 660°F
△ 6-8 " " " 660°F
SURROUNDING AIR STATIC AT 30 INCHES Hg. PRESSURE
20 GMS. (ACTIVE) SILICA GEL CONTAINED IN 42 GM.
CIRCULAR NICKEL CRUCIBLE

PLATE 10

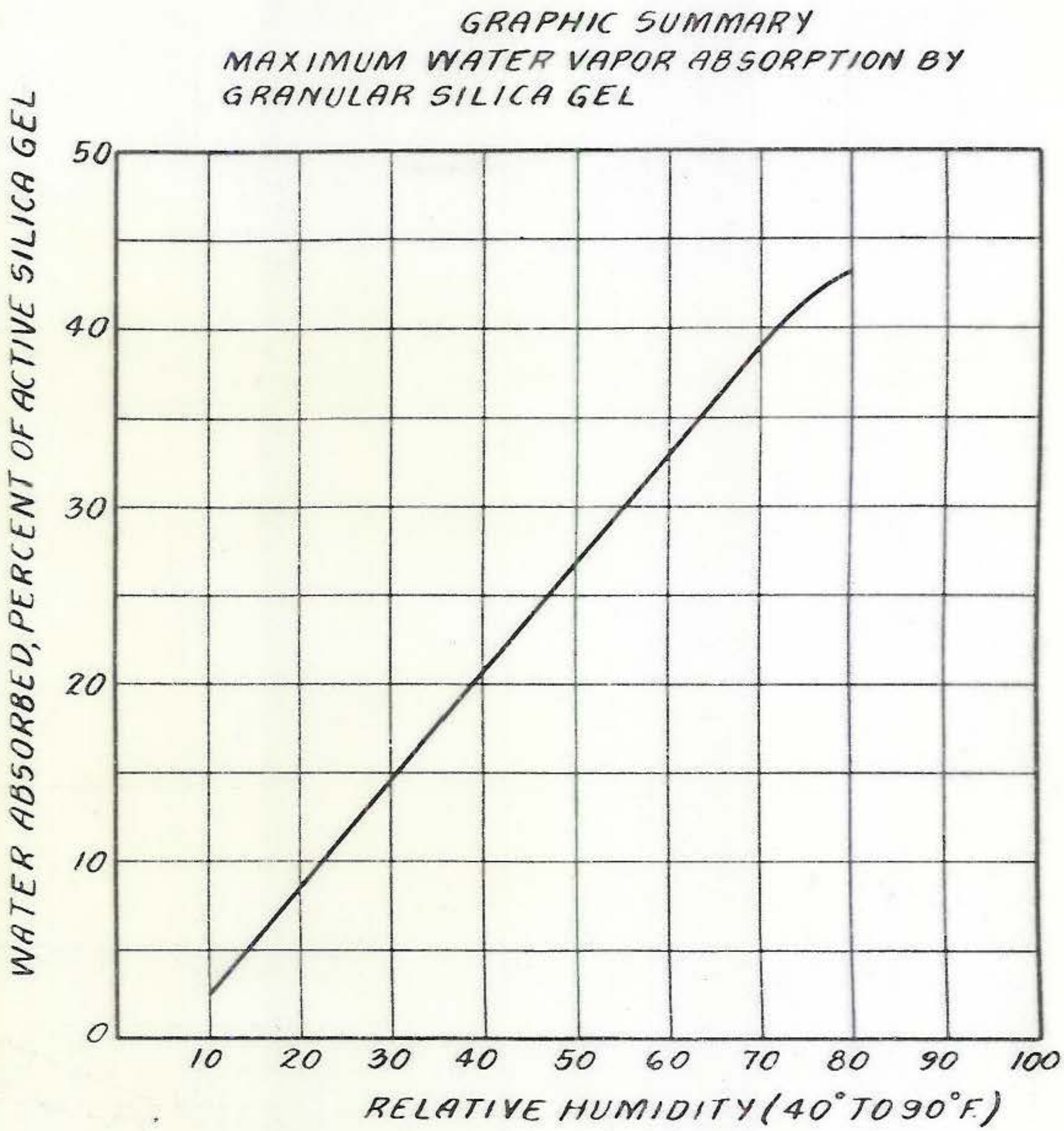

GRAPHIC SUMMARY
MAXIMUM WATER VAPOR ABSORPTION BY
GRANULAR SILICA GEL
WATER ABSORBED, PERCENT OF ACTIVE SILICA GEL
50
40
30
20
10
0
10 20 30 40 50 60 70 80 90 100
RELATIVE HUMIDITY (40° TO 90° F.)

PLATE II

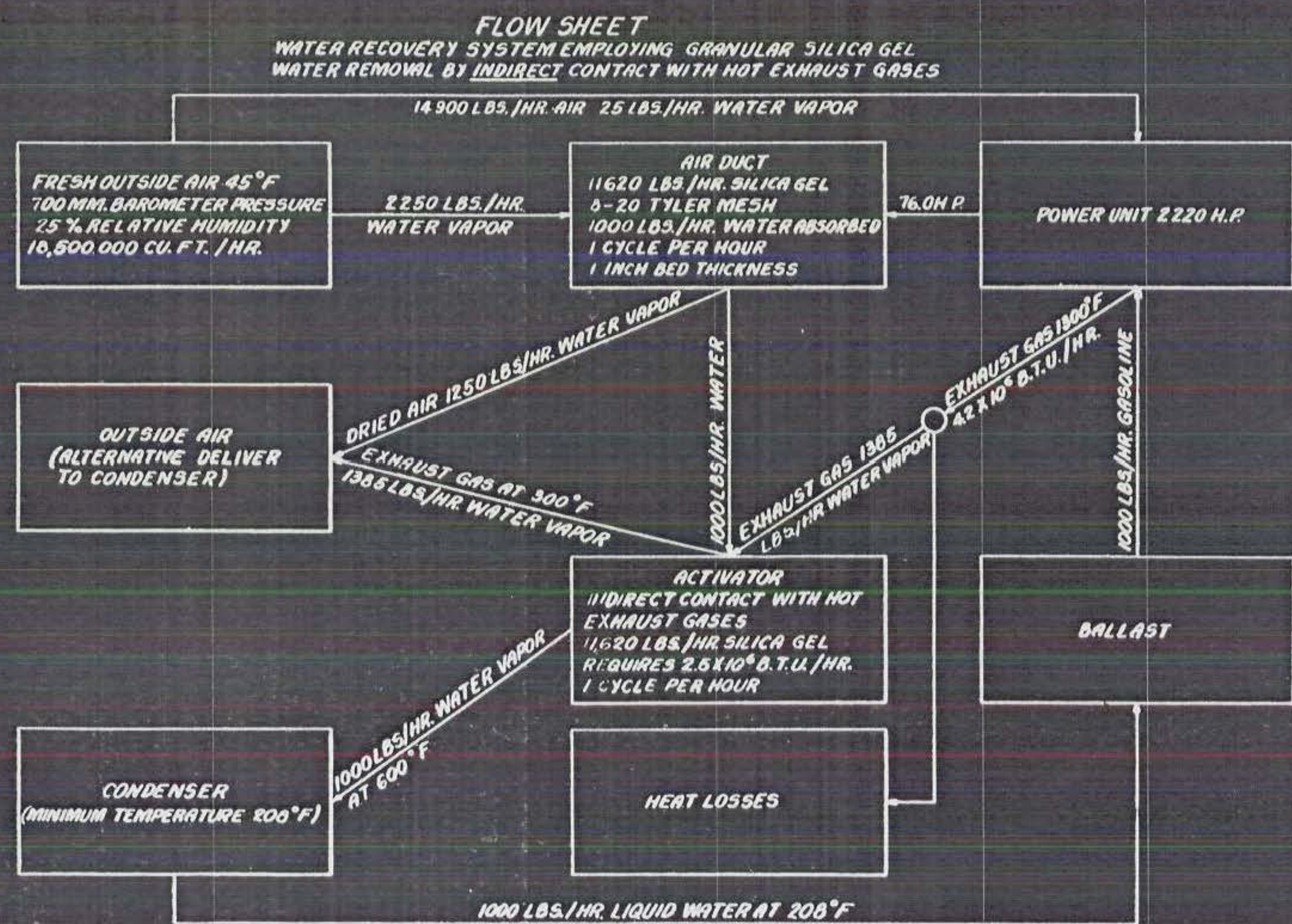

FLOW SHEET
WATER RECOVERY SYSTEM EMPLOYING GRANULAR SILICA GEL
WATER REMOVAL BY INDIRECT CONTACT WITH HOT EXHAUST GASES
14 900 LBS./HR. AIR 25 LBS./HR. WATER VAPOR
FRESH OUTSIDE AIR 45°F
700 MM. BAROMETER PRESSURE
25 % RELATIVE HUMIDITY
10,500,000 CU. FT. /HR.
2250 LBS./HR.
WATER VAPOR
AIR DUCT
11620 LBS./HR. SILICA GEL
8-20 TYLER MESH
1000 LBS./HR. WATER ABSORBED
1 CYCLE PER HOUR
1 INCH BED THICKNESS
76.0 H.P.
POWER UNIT 2220 H.P.
DRIED AIR 1250 LBS/HR. WATER VAPOR
OUTSIDE AIR
(ALTERNATIVE DELIVER
TO CONDENSER)
EXHAUST GAS AT 300°F
1385 LBS./HR. WATER VAPOR
1000 LBS./HR. WATER
EXHAUST GAS 1385
LBS/HR WATER VAPOR
EXHAUST GAS 1300°F
4.2 X 10⁶ B.T.U./HR.
1000 LBS./HR. GASOLINE
ACTIVATOR
INDIRECT CONTACT WITH HOT
EXHAUST GASES
11,620 LBS./HR. SILICA GEL
REQUIRES 2.5 X 10⁶ B.T.U./HR.
1 CYCLE PER HOUR
BALLAST
1000 LBS./HR. WATER VAPOR
AT 600°F
CONDENSER
(MINIMUM TEMPERATURE 208°F)
HEAT LOSSES
1000 LBS./HR. LIQUID WATER AT 208°F

PLATE 13

FLOW SHEET

WATER RECOVERY SYSTEM EMPLOYING GRANULAR SILICA GEL
WATER REMOVAL BY DIRECT CONTACT WITH HOT EXHAUST GASES

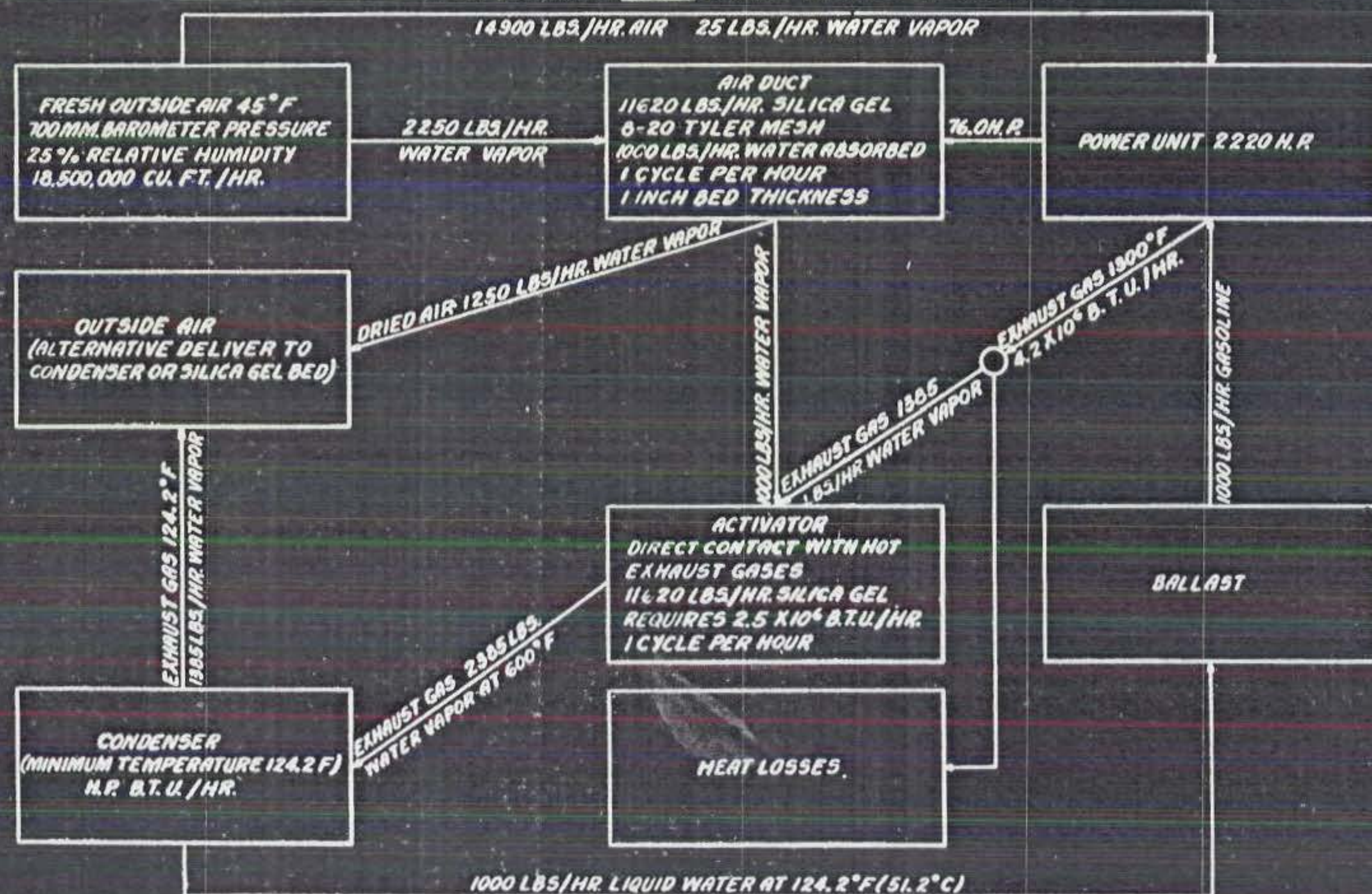


PLATE 14