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THE DAVID W. TAYLOR MODEL BASIN

AERODYNAMICS LABORATORY

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THE DESIGN AND PERFORMANCE OF AN AIR-DRYING SYSTEM FOR A SUPERSONIC WIND TUNNEL

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SUMMARY

This report describes the design data used and the subsequent observed performance characteristics of an air-drying system designed to provide an average of 1,100,000 cubic feet of air per day dried to a dew point of -15°F or lower for an intermittent supersonic wind tunnel. The data presented show that the performance of such an air-drying system can be predicted with sufficient accuracy.

INTRODUCTION

The air-drying system described is an integral part of the David Taylor Model Basin Supersonic Wind Tunnels facility. Funds for its design and construction were authorized by the Navy Bureau of Aeronautics under Project Order 415-47.

Dry air is required in supersonic wind-tunnel testing in ordér to eliminate errors in the aerodynamic measurements that would otherwise be caused by the condensation of water vapor as the air expands in the Laval nozzle. This air-drying system was designed to provide testing air for the

18- by 18-inch Intermittent Supersonic Wind Tunnel, and two smaller channels, whose dewpoint should not exceed -15°F for an average 8-hour days' operation under peak atmospheric humidity conditions (midsummer). This design allows two shift operation for most of the year. Each channel draws atmospheric air through the drying system and discharges it into a vacuum sphere from which it is pumped into the atmosphere.

The chief advantage of this type of air-drying system, in which all testing air is dried as used, rather than recirculated from a dry-air storage vessel, is the complete absence of oil vapor in the testing air. This type of system requires a large quantity of desiccant although a dry-air storage vessel and extensive oil-removing equipment which are required for the recirculating type system are not needed.

Silica gel was chosen as the desiccant because the most data on its performance characteristics were available. The water vapor which has been adsorbed by silica gel may be driven off by heating, a process called regeneration. The adsorption-regeneration cycle may be repeated indefinitely without deterioration of the silica gel.

DESIGN CRITERIA

The mass of air to be dried is a maximum at the lowest 18-inch channel supersonic Mach number, i.e. 1.22, and is about 101 pounds per second at an atmospheric pressure of 30 inches of mercury and temperature of 95°F. A given mass flow of air determined an amount of silica gel required to dry the air by two separate considerations. The first of these was the allowable velocity of the air through the silica gel bed, as determined by the allowable pressure drop; the second was the total amount of water vapor to be removed by the silica gel between regenerations. The consideration yielding the greater amount of silica gel was necessarily chosen. The volume flow of air through the 18-inch channel, corresponding to the mass flow of 101 pounds per second, is 1410 cubic feet per second.

Figure 1, part of which was taken from Reference 1, shows the pressure drop through silica gel as a function of the velocity of the air for a 12-inch thick bed of silica gel. Reference 1 dictated that the thickness of the silica gel should be at least 12 inches to prevent the air from ''blowing'' a free path through the silica gel. An arbitrary allowable drop of 1½ inches of mercury was established and a preliminary design analysis indicated that the ducting could be built economically to withstand this pressure. Since the values of Figure 1 from Reference 1 did not extend to a pressure drop of 1½ inches of mercury, an empirical equation was applied to the values. This equation could then be extended, and a curve describing the equation is shown on Figure 1. From this curve an allowable velocity of the air through the silica gel bed of 4½ feet per second was established.

This velocity, divided into the maximum volume flow of air, gave the required area of silica gel, 12 inches thick, as 313 square feet; the total volume of silica gel as 313 cubic feet; and the total weight of silica gel, at 45 pounds per cubic foot, as 14,085 pounds. It will be shown later that the empirical equation of Figure 1 yielded a slightly conservative pressure drop.

According to Reference 1, silica gel will adsorb up to about 45 percent of its own weight under static conditions. Less is known about adsorption by silica gel under conditions of relatively high velocity flow, but the Davison Chemical Corporation recommended that the dynamic adsorptive capacity of silica gel be assumed as no more than 8 percent by weight.

Given the maximum mass flow in pounds of air per second and the allowable adsorptive capacity of the silica gel, the weight of silica gel required was further governed by the amount of moisture to be removed from the air and by the total length of running time in an 8-hour operating period.

Taylor Model Basin weather records for the previous 5 years were consulted from which Figure 2 was constructed, showing the average annual variation of absolute humidity and the variation of absolute humidity on a typical midsummer day. From this data a value of 0.014 pound of water vapor per pound of dry air was established as the average peak absolute humidity. This value, multiplied by the maximum mass flow of air, indicated a maximum water vapor weight of 1.414 pounds per second to be removed. The residual water vapor in air at -15°F dewpoint (0.0005 pounds per pound) is negligible.

The maximum length of running time in an 8-hour day was computed from the observed running time to pumping time ratios for the 18-inch channel. This total running time is shown as a function of the length of each run in Figure 3. From this curve an average value of 780 seconds of running time per 8-hour day was chosen. This 780 seconds of total running time, multiplied by the previously determined 1.414 pounds of water vapor per second, gave a maximum weight of about 1100 pounds of water vapor to be removed between regenerations. This latter value, divided by the silica gel adsorptive capacity of 0.08, by weight, indicated a requirement for 13,800 pounds of silica gel. This weight required was about equal to that determined by the allowable velocity of the air through the silica gel, i.e. 14,085 pounds. Since the allowable velocity of the air through the silica gel is independent of atmospheric humidity conditions, it became the major consideration. The total amount of water vapor to be removed became of secondary importance since its requirements are comparable only under worst humidity conditions. In addition, as it will be shown later, over 1000 pounds of water vapor can be removed only under midwinter atmospheric conditions without exceeding the -15°F dewpoint allowed.

PLANS

The air-drying system was constructed in the basement of the Supersonic Wind Tunnels Building, below the three channels, as shown in Figure 4. The silica gel bed area was arbitrarily increased to 320 square feet to allow for the supporting structure. In order to accommodate this area in the allotted space it was divided equally into two parallel beds, 24 feet long and 6 2/3 feet high.

Normal dry air operation is effected by opening Dampers 1, 3, and 4. For testing in which undried air is permissible, such as subsonic testing, Dampers 1 and 2 are opened. A combination of Dampers 2, 3, and 4 may be opened for controlling the humidity.

The air intake extends upward to well above ground level. Three screened and louvered vertical openings admit outside air to the intake. The inside of these openings is also covered by replaceable fiber-glass filters to protect the silica gel from oil and dust.

The silica gel is 3 to 8 mesh and is contained on the sides by 10 mesh, 0.020 wire diameter stainless steel screens. These screens are supported by vertical and horizontal stringers which transfer the air load, and silica gel weight load, to the floor and ceiling structure. The resulting free area of silica gel is 303 square feet. The silica gel extends 10 inches above the screen to accommodate settling. The silica gel was treated before purchase to reduce ''dusting'' to a minimum. The initial filling of the 360 cubic feet of silica gel beds required 15,450 pounds.

The drying system ducting is principally of welded steel construction, the sub-atmospheric pressure portion consisting of 1/8-inch steel plate, reinforced by channels.

REGENERATION

The electro-mechanical system for regenerating is shown diagrammatically by Figure 5. It consists, chiefly, of an axial-flow fan to circulate the regenerating air, an electrical heater to heat this air, a water cooling coil to cool this air, ducts to direct the air to the inner and outer chambers, and controls.

Regeneration is accomplished by a heating cycle and a cooling cycle, as indicated by Figure 5. These cycles are automatic, once started, being controlled chiefly by thermoregulators. During the heating cycle the hot air supply to the inner chamber is maintained at about 350°F by regulating one eighth of the heating coils. The heating cycle is stopped when the temperature of the air leaving the silica gel rises to about 250°F. These temperatures are approximately those recommended by Reference 1. The cooling cycle is stopped when the temperature of the silica gel is reduced to about 100°F.

During the heating cycle the hot moisture-laden air is expelled to the atmosphere through Dampers 3 and 4. All dampers are closed during the recirculating cooling cycle. It is important to note that the flow of cooling air is reversed so that residual moisture is adsorbed by the outer face of the silica gel beds. Initially,cooling air flowed in the same direction as the heating air. The moisture trapped in the ducting at the end of the heating cycle was thus adsorbed by the inner face of the silica gel beds and was sufficient to raise the initial dewpoint over 20°F.

Regeneration heat must be supplied to meet the following requirements:

a. to bring the ducting up to temperature

b. to bring the silica gel up to temperature

c. to make up the heat lost through the insulated ducting

d. to make up the heat lost in the discharged air

e. to liberate the adsorbed moisture

The first two of these requirements are about constant, the third varies with time, the fourth varies with time and the atmospheric temperature, and the fifth varies with the amount of adsorbed moisture. A summation of these heat requirements indicated that 168 kilowatts would be necessary to accomplish the heating cycle in 6 hours. The final installation had 192 kilowatts.

PERFORMANCE

Test data, such as the atmospheric pressure, temperature, anddewpoint, and the testing air stagnation pressure, temperature, and dewpoint, are accurately recorded at frequent intervals during routine testing operations. Other data, such as the amount of moisture adsorbed, are used only to estimate whether regeneration is required one night or the next, and are computed from averaged conditions. Those performance curves which are dependent upon this type of data thus show some scatter. The data points shown were carefully selected as being typical of the performance under average routine conditions.

DRYING - The measured pressure drop of the air flowing through the silica gel is shown by Figure 1, slightly less than that predicted.

The dewpoint of the testing air is chiefly dependent upon the amount of moisture adsorbed since the last regeneration, the temperature of the silica gel, and the rate of flow. Figure 6 shows the effects of the amount of moisture and the temperature. These data, obtained at flow rates of 3.7 to 5.3 cubic feet per minute per pound of silica gel, exhibit characteristics similar to those shown in Reference 1, obtained at a flow rate of 0.8 cubic foot per minute per pound of silica gel. The increased flow rate at a given temperature causes the curve to break at a lower percent of adsorption.

The temperature rise of air passing through silica gel is chiefly dependent upon the amount of moisture removed from the air. Figure 7 compares measured values with the curve computed from Reference 1, which states, ''In practice, the temperature rise in the dehydrated air caused by the adsorption heat is approximately 10°F for each grain of moisture removed per cubic foot of air at atmospheric pressure.''

This drying system was designed to provide dry testing air for one 8-hour days' operations when the atmospheric humidity is 0.014 pounds of water vapor per pound of dry air. The percentage of operating days after which regeneration is required is shown as a function of the atmospheric humidity in Figure 8. Of chief significance is the indication that less than a full days' operation can be accomplished with dry air if the atmospheric humidity exceeds about 0.015 pounds of water vapor per pound of dry air.

REGENERATING - Temperatures at various positions in and near the silica gel beds are recorded at intervals during regeneration to provide a performance check. Figure 9 is a typical plot of these temperatures. Note how the temperature of the air leaving the silica gel (circles) levels off while moisture is being liberated at a constant rate, then rises rapidly when practically all of the moisture has been released. A similar typical outlet air temperature curve may be found in Reference 1. Temperatures within the gel bed also show this leveling-off characteristic, the duration of the levelling-off being indicative of the amount of water vapor adsorbed by the silica gel at that depth. The relative temperature levelling-off times from several regeneration records are shown as a function of silica gel depth by Figure 10a. From this curve Figure 10b was constructed showing the percent of total moisture adsorbed as a function of silica gel depth. This curve indicates that the 12 inch depth recommended by Reference 1 to prevent ''blowing'' adsorbs about

99 percent of the water vapor from the air flowing through the silica gel at the flow rates previously given.

The time required for the regeneration heating cycle varies, chiefly, with the amount of moisture adsorbed and the temperature of the atmospheric (heater supply) air. This variation is shown by Figure 11 for two approximate temperatures.

The time required for the regeneration cooling cycle depends, chiefly, upon the amount of cooling water circulated through the coil, as shown in Figure 12. A considerable reduction in the total quantity of cooling water used may be effected whenever additional regeneration time can be tolerated. The cooling water temperature is approximately 67°F the year around. Figure 9 also shows that about one hour of cooling time may be eliminated by cooling only to about 140°F.

The silica gel settled in its beds for about the first year. This required 1450 pounds (about 10 percent) as make-up. The make-up due to dusting is apparently negligible, since there has been no evidence or erosion on models or nozzles, such as would be caused by silica gel particles.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
December 1951

REFERENCES

1. ''Silica Gel, Its Use as a Dehydrating Agent'' by Frank C. Dehler, The Davison Chemical Corporation, Baltimore 3, Maryland.

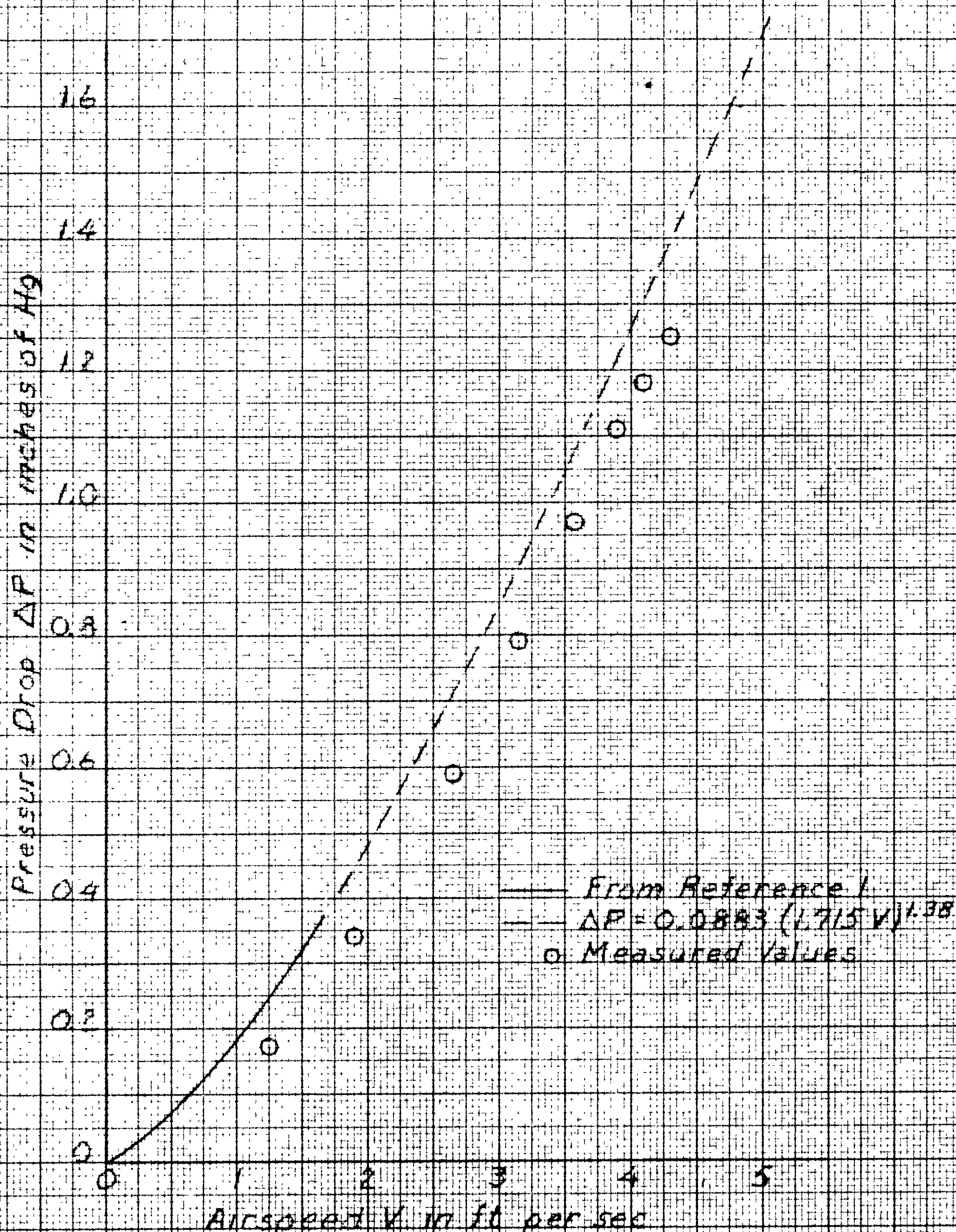

Figure 1 - Pressure Drop Through Silica Gel Bed 12 Inches Thick

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FIGURE 1

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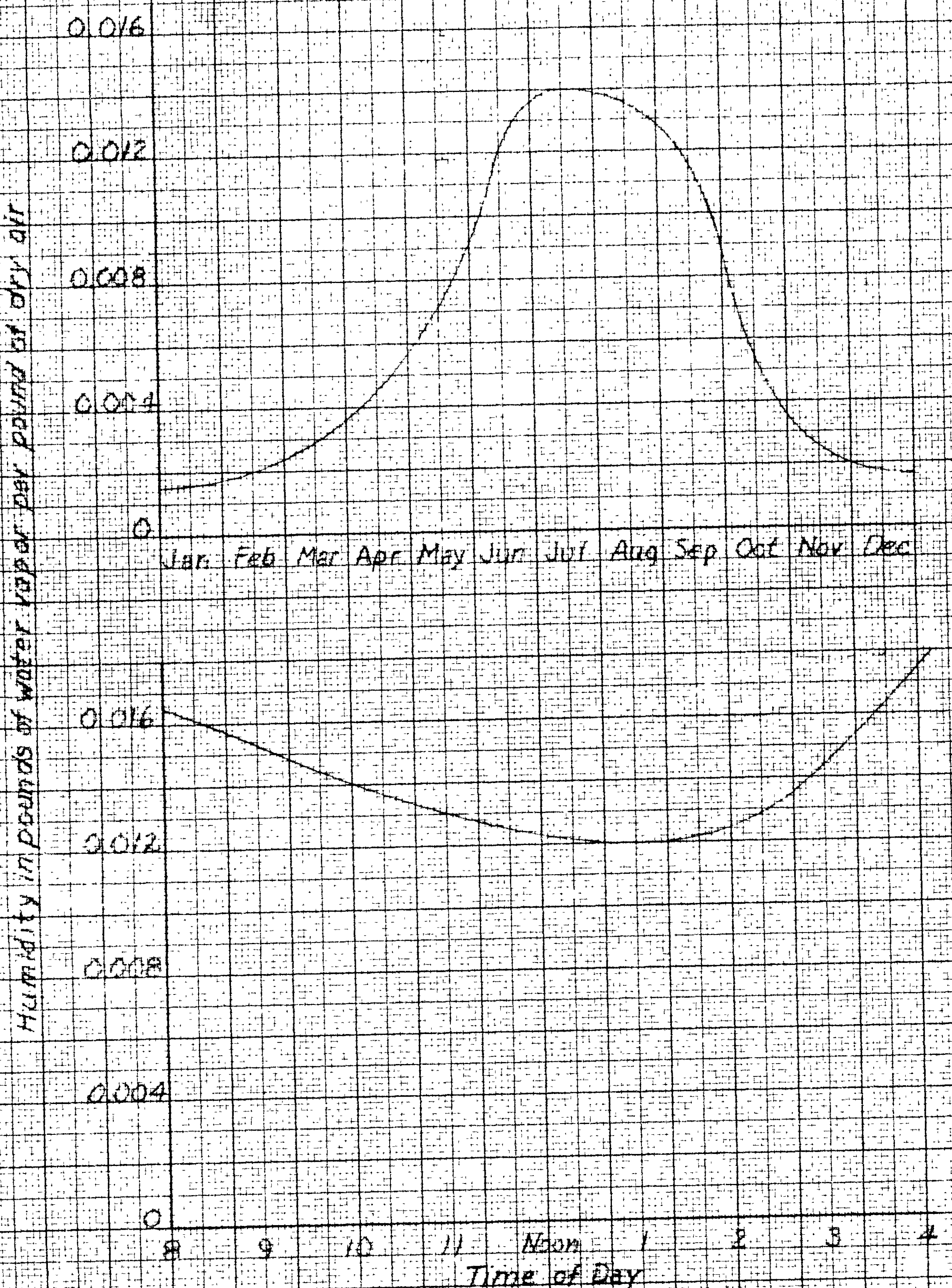

Figure 2 - Typical Average Annual and Midsummer Daily Variation of Absolute Humidity at DTMB

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FIGURE 2

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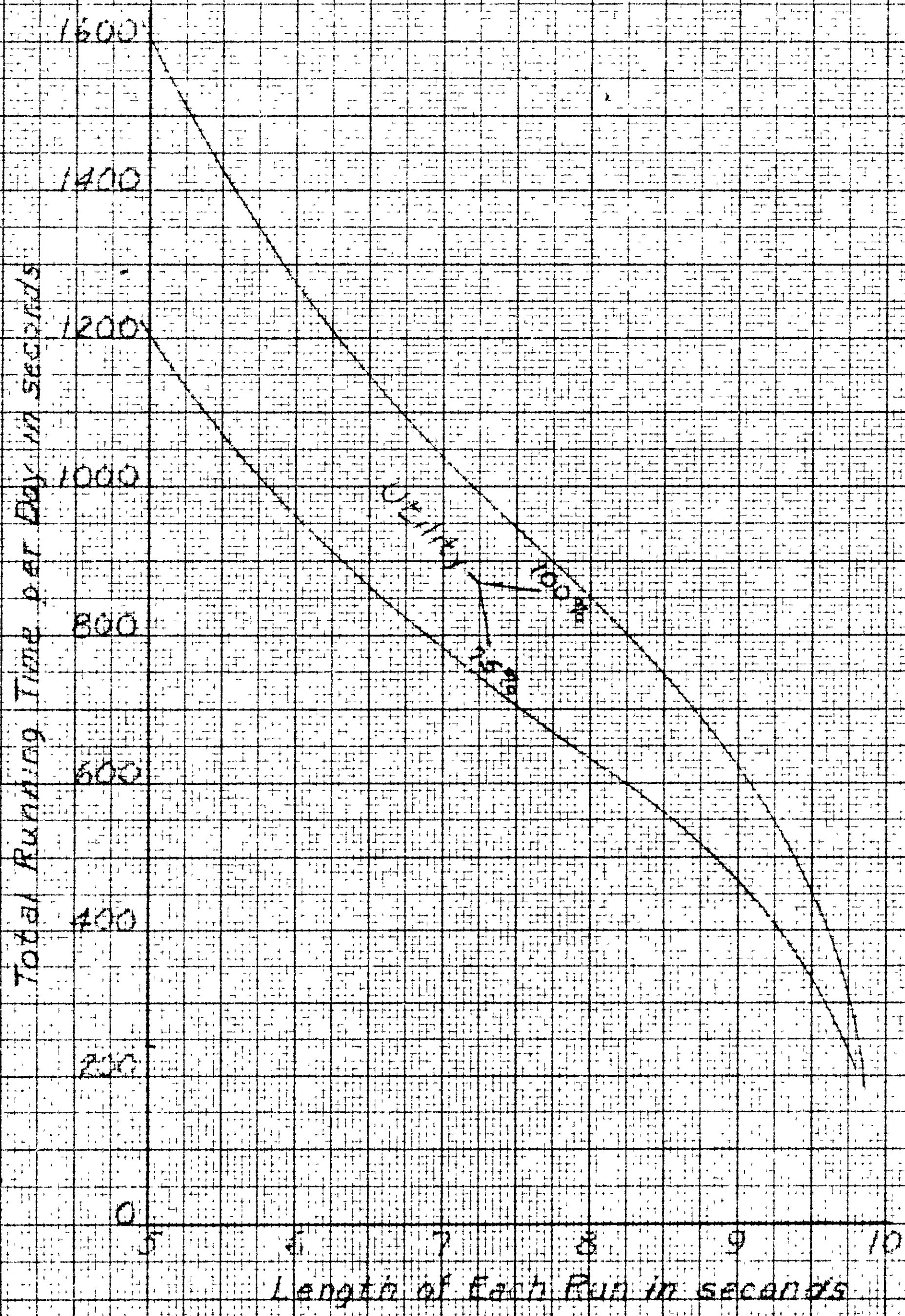

Figure 3 - Total Running Time per 8-Hour Day

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FIGURE 3

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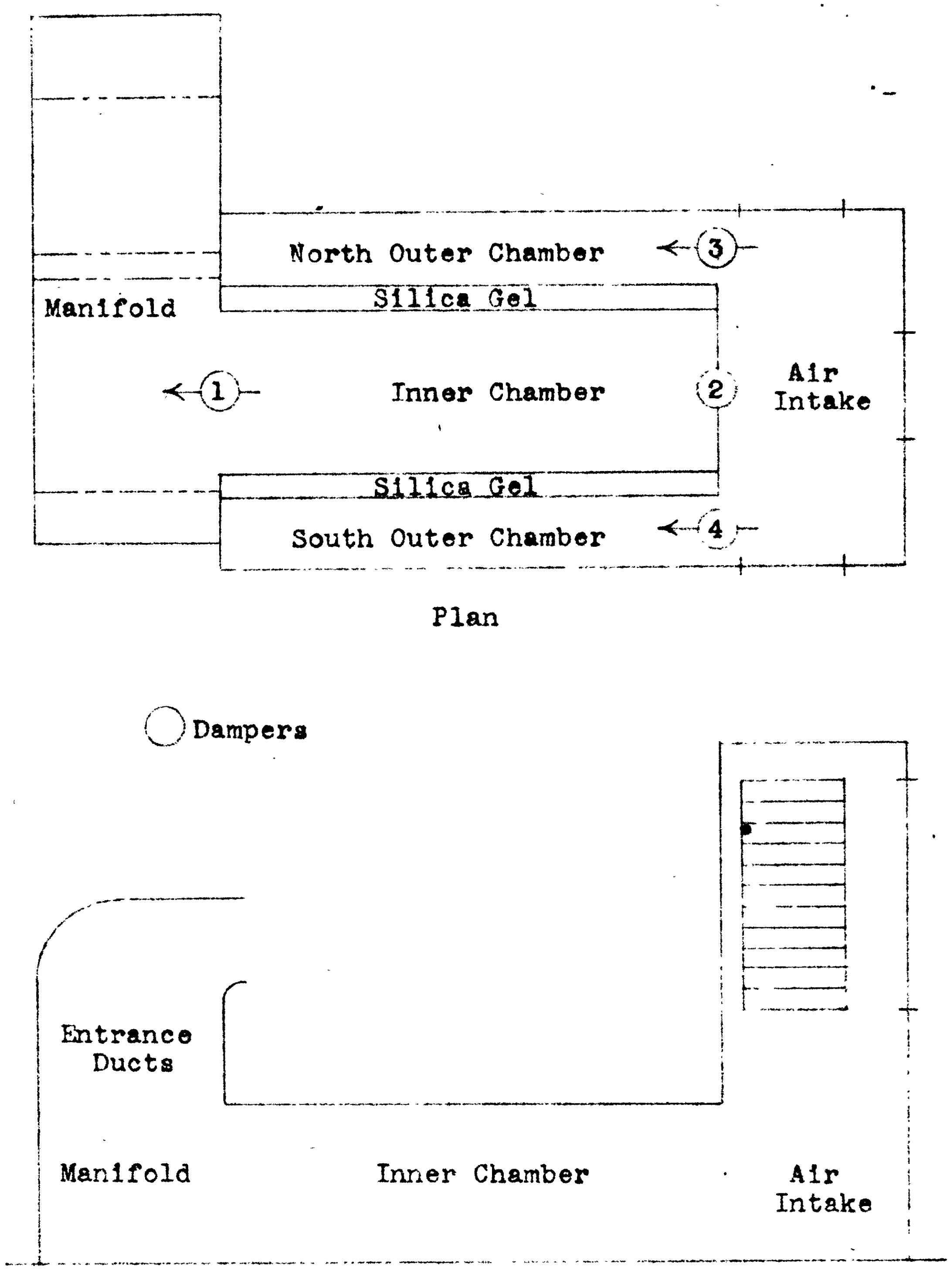

Figure 4 - Diagram of Air-Drying System

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FIGURE 4

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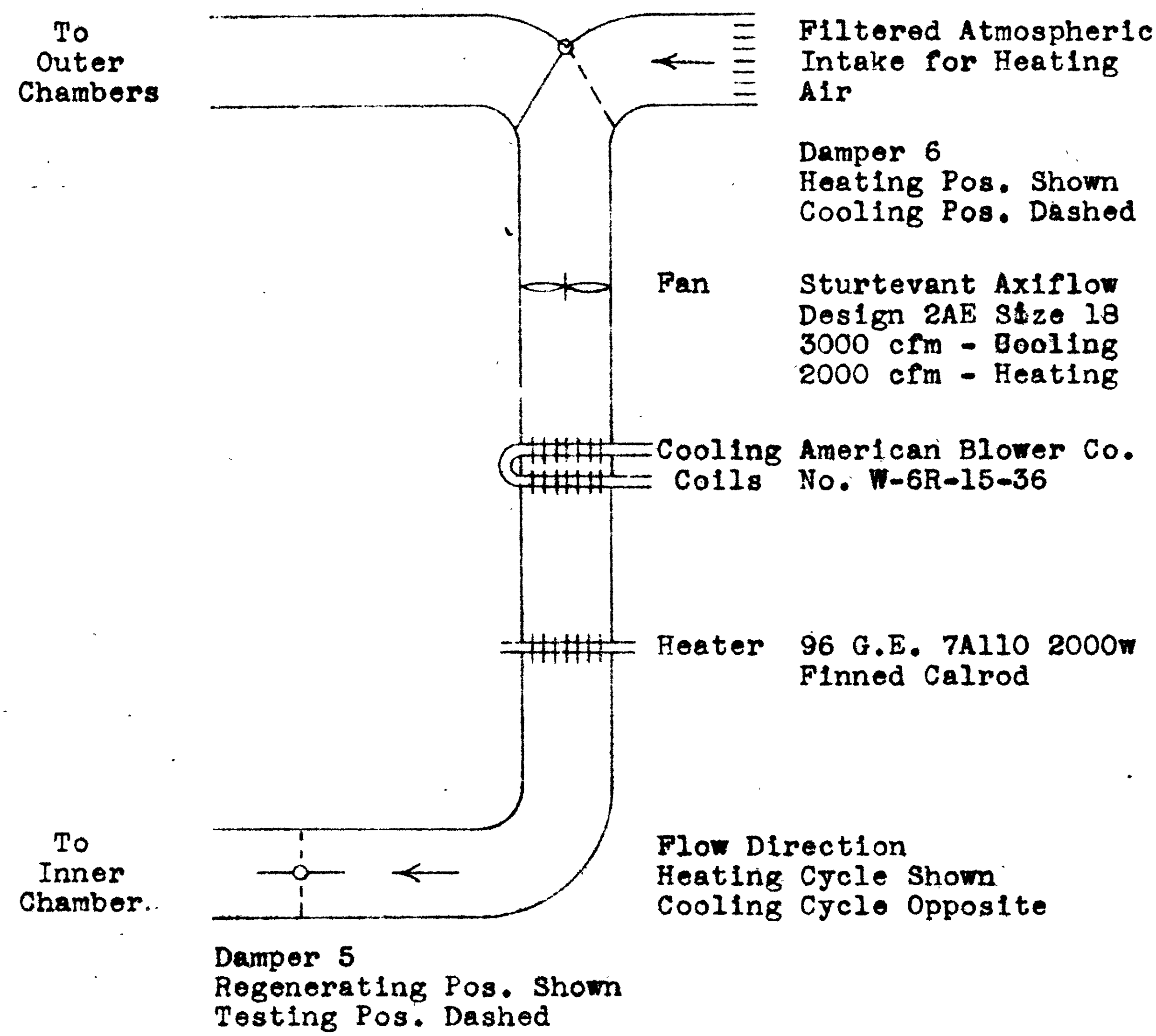

Figure 5 - Schematic Diagram of Regeneration System

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FIGURE 5

AERO 311

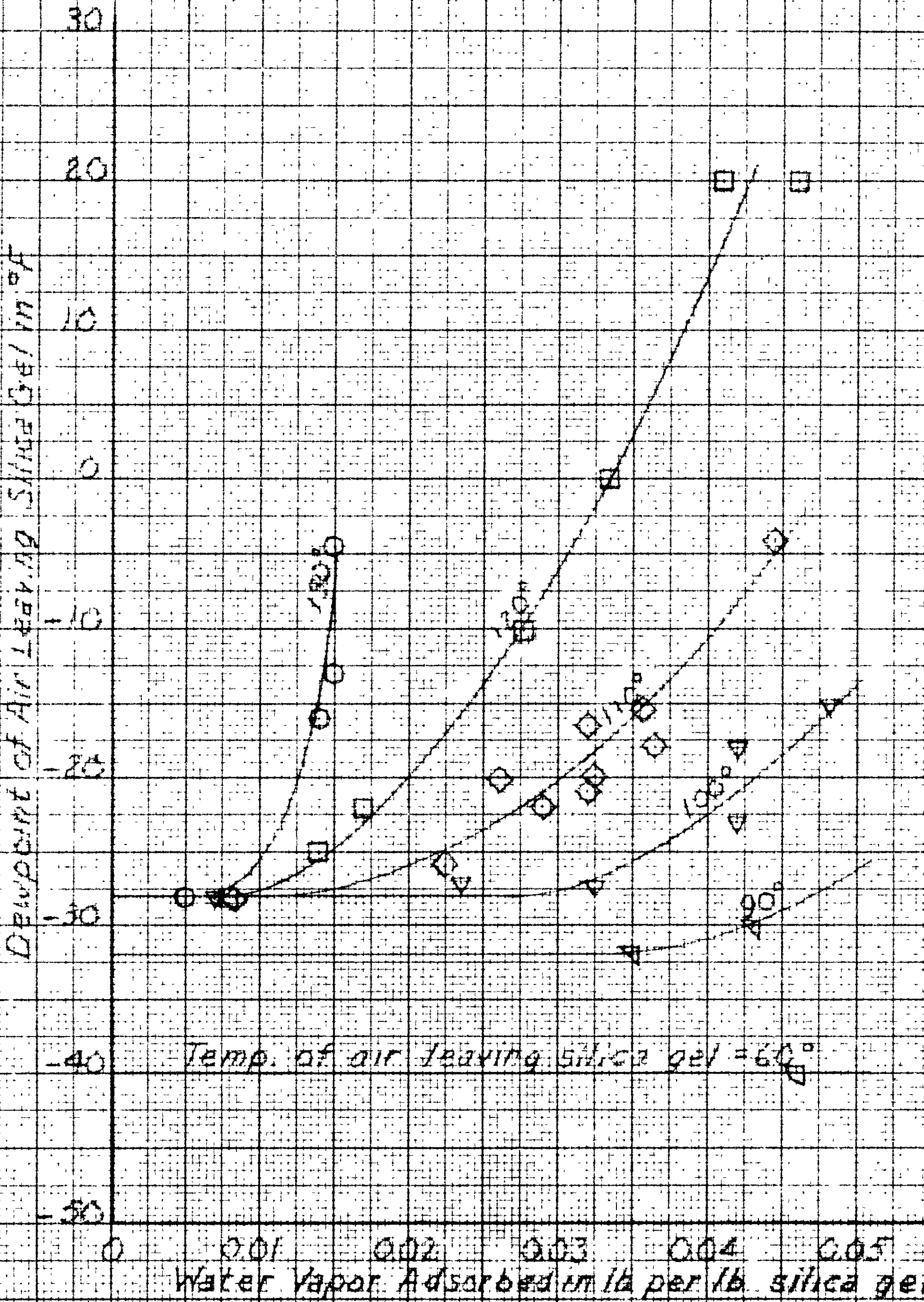

Figure 6 - Dewpoint of Air Leaving Silica Gel

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FIGURE 6

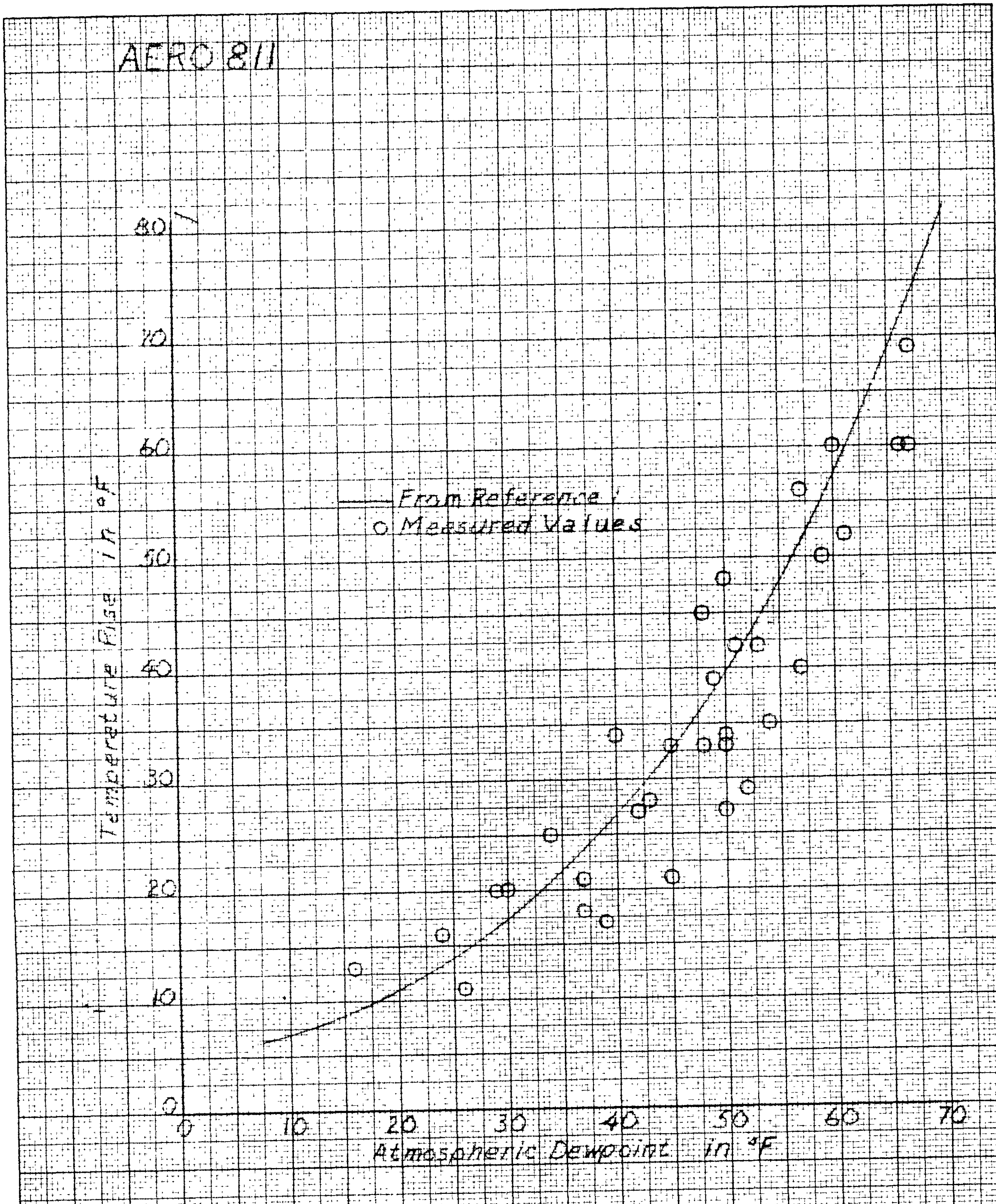

Figure 7 - Temperature Rise of Air Passing Through Silica Gel

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FIGURE 7

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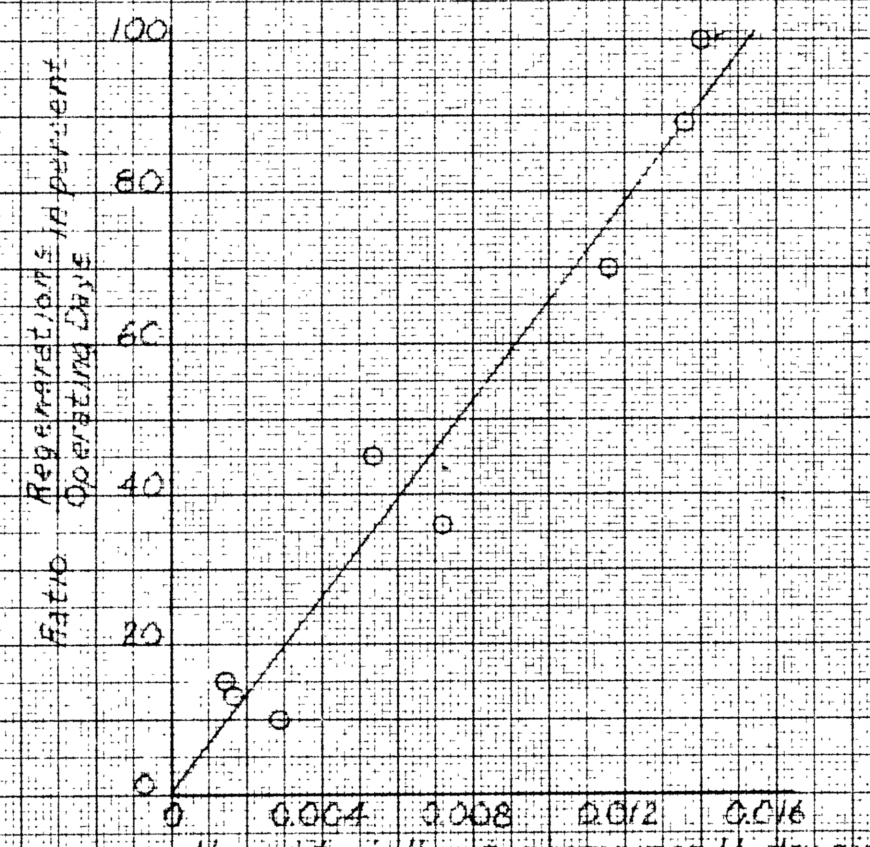

Figure 8 - Percentage of Operating Days After Which Regeneration is Required

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FIGURE 8

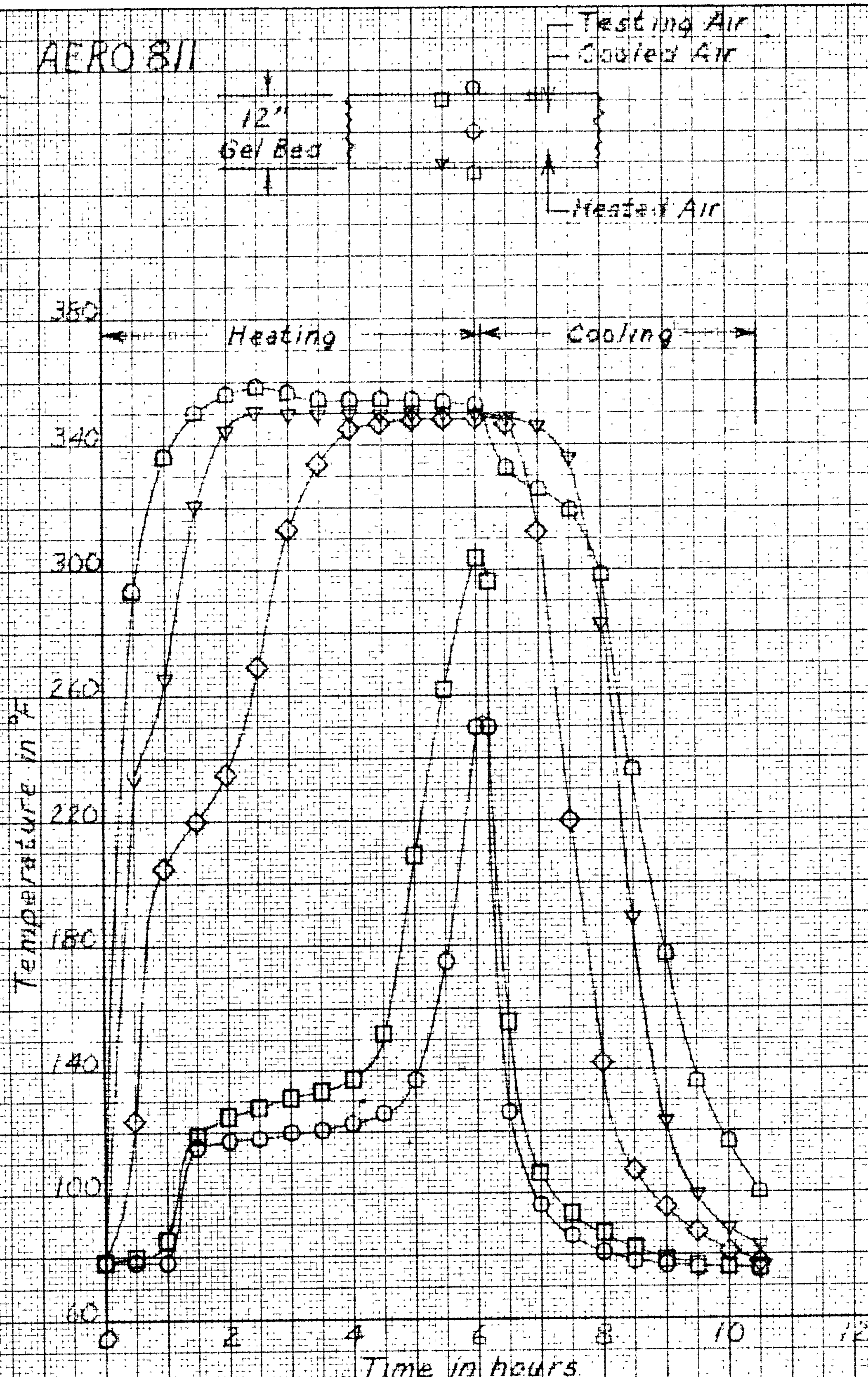

Figure 9 - Typical Regeneration Temperatures

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FIGURE 9

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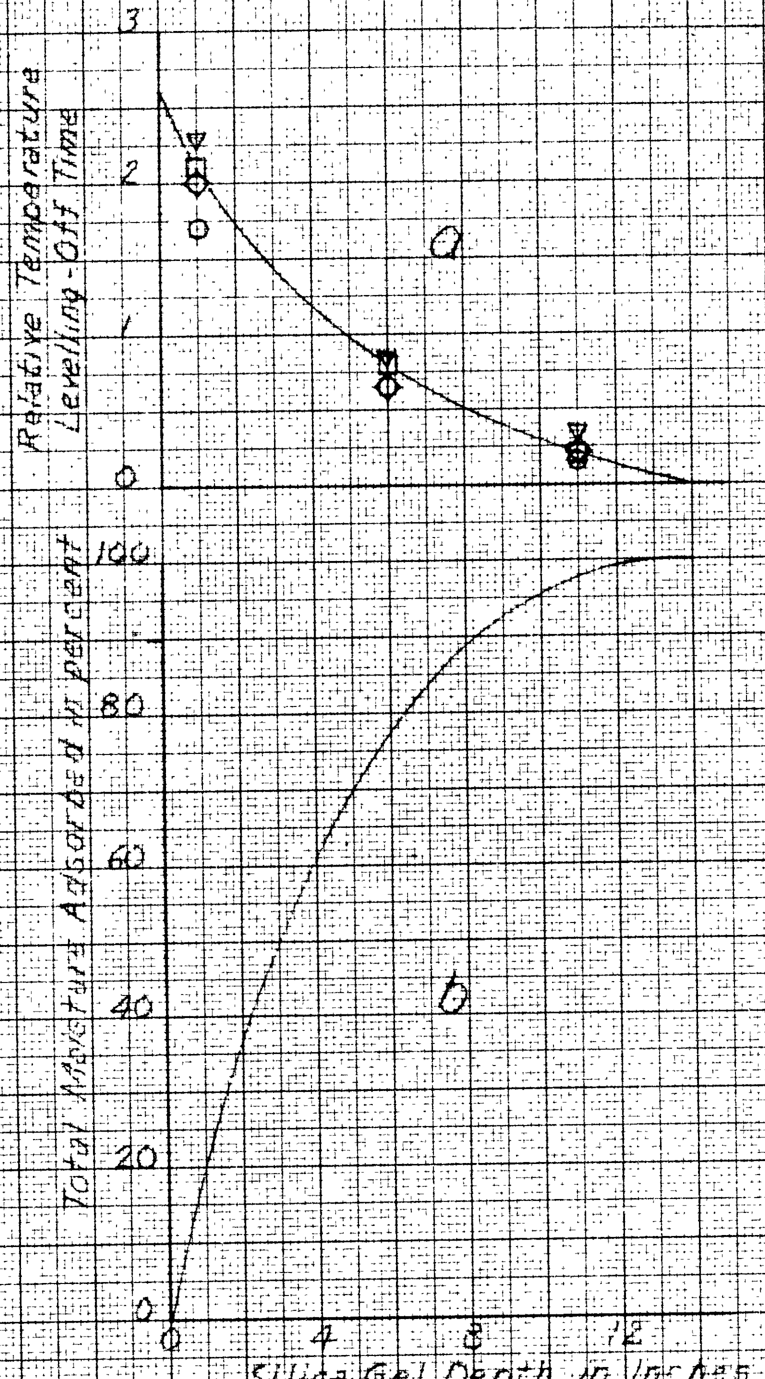

Figure 10- Variation of Adsorption with Depth of Silica Gel

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FIGURE 10

AERO 811

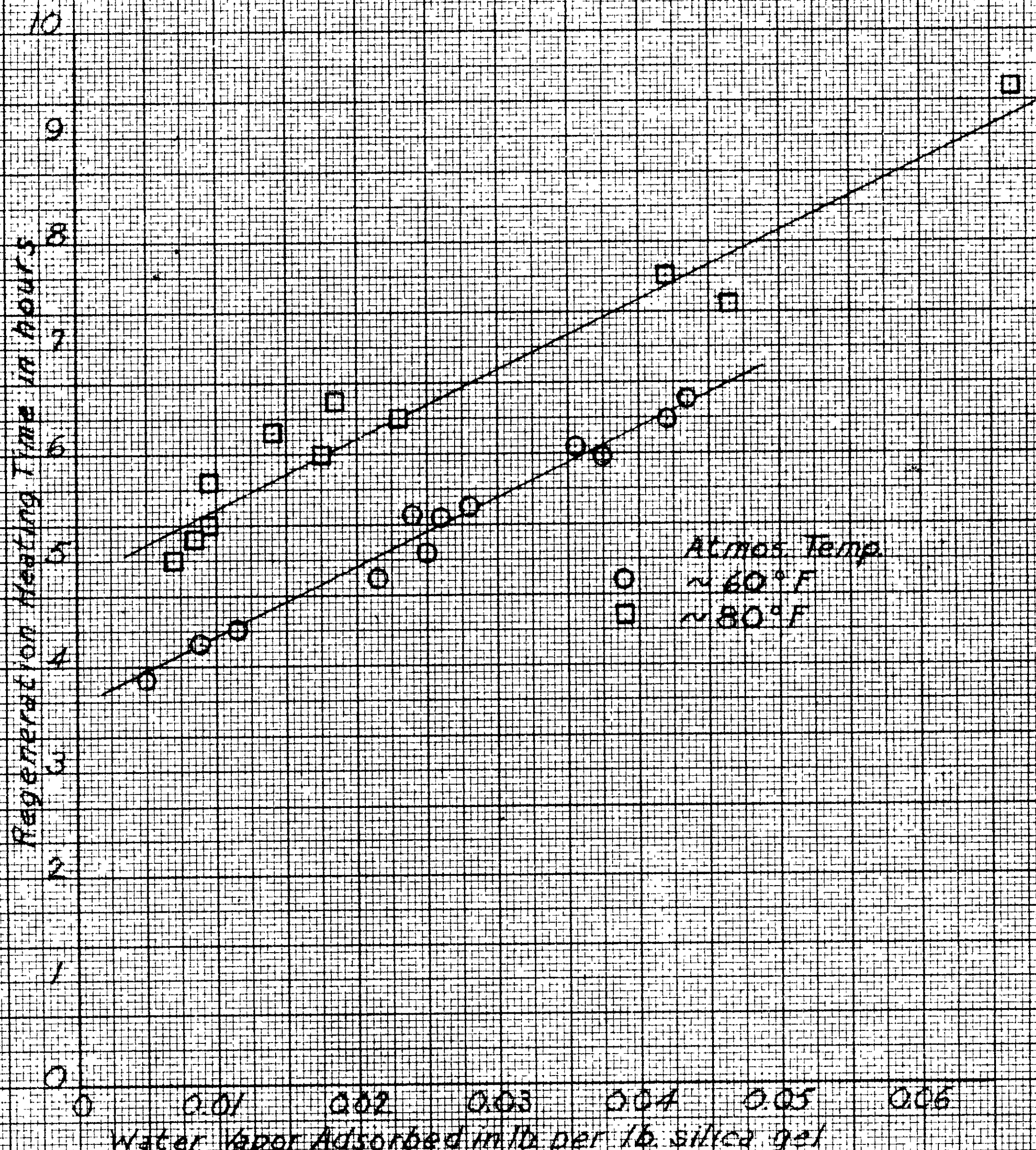

Figure 11- Regeneration Heating Time

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FIGURE 11

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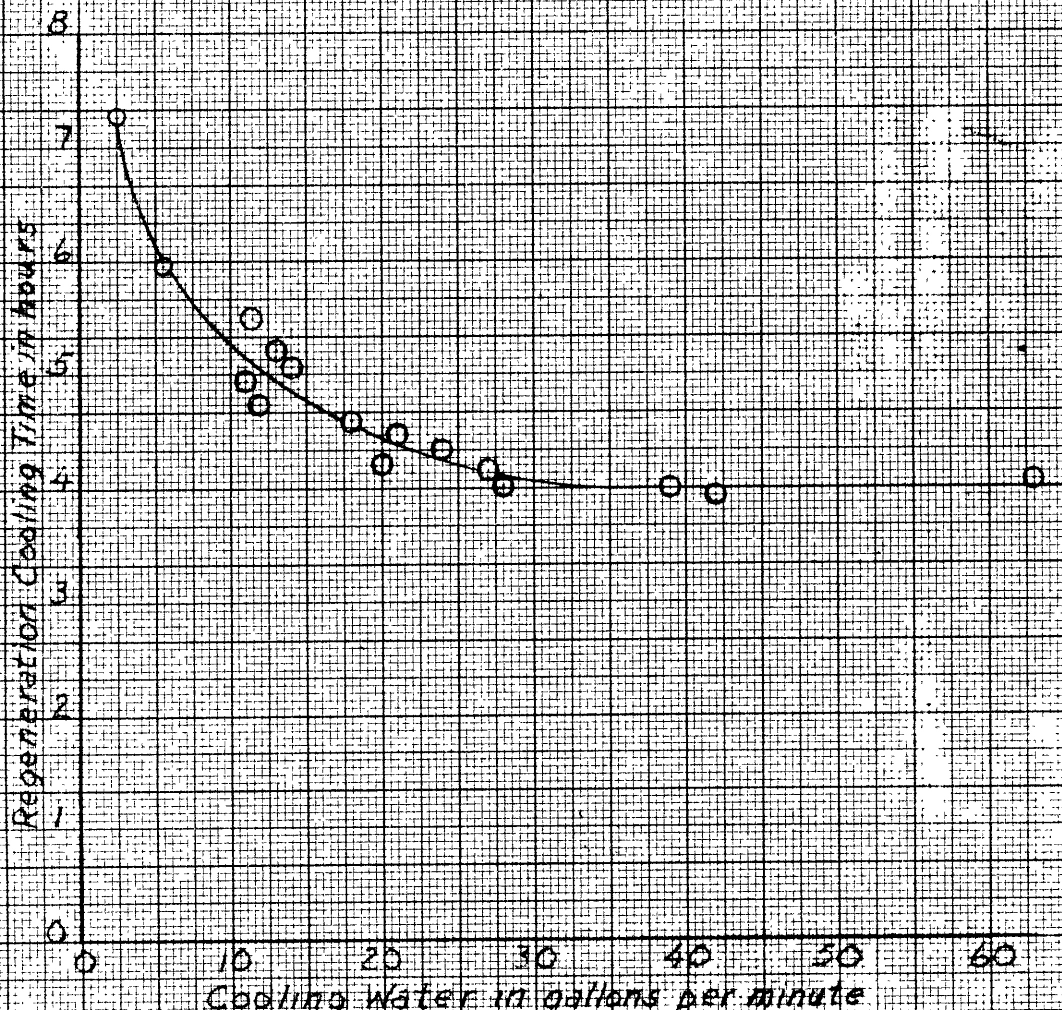

Figure 12 - Regeneration Cooling Time

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FIGURE 12