A STUDY OF HEAT TRANSFER
IN A
BASKET TYPE EVAPORATOR

By

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INTRODUCTION

The purpose of this investigation is to determine the rate of heat loss by radiation[1] from the experimental basket type evaporator and the water condenser to the surroundings. Figure 7 shows the general layout of the entire evaporation set-up.

A heat balance of the evaporator and the condenser is necessary for determining the total heat lost by radiation to the surroundings. This heat balance comprises three different rates of heat transfer: (1) The total heat transferred to the boiling liquid by the entering steam; (2) the total heat transferred to the vapor from the boiling liquid; (3) the total heat transferred to the condenser cooling water by the vapor. The differences in these three rates of heat transfer will be taken to represent the rates of heat loss by radiation from the evaporator and condenser to the surroundings.

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1. For convenience, the word "radiation" appearing anywhere in the report actually means "radiation and convection combined", unless otherwise specified.

GENERAL SURVEY OF THE FIELD

Extensive work has been done in recent years on the quantity of heat lost by radiation from solids, liquids, and gases to the surrounding atmosphere, some of which is contradictory. However, the work in this field is practically negligible from the standpoint of radiation losses from single evaporators.

McMillan and Heilman have obtained data on heat losses by radiation from single horizontal pipes to air at room temperature.[1] Their results show an increase in the coefficient of heat transfer by radiation with an increase in the pipe diameter and the temperature difference.

Griffiths and Davis studied the variation of the average coefficient of heat transfer from heated vertical cylinders to the air with the height of the cylinders, and found little effect on cylinders over one foot tall. A further decrease in the height of the cylinder gave a large increase in the heat transfer coefficient.[2]

E. W. Kerr made accurate tests on a 9,000 square feet long tube quadruple effect evaporator, without insulation, used in the sugar industry, and found the performance to be 95 per cent of what it should have been as indicated

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1. McAdams, W.H., Heat Transmission, N.Y., McGraw-Hill Book Co., 1933, p. 252.
2. Ibid., pp. 241-244.

by a carefully calculated heat balance. It is believed, however, that in this particular case, the losses were much lower than the average, which would be about twice the figure.[3]

Equations for heat losses by natural convection from vertical cylinders, spheres, and plane surfaces are given by Rice and Heilman in an early report.[4]

There is reason enough for not applying the equations developed by these men to the experimental data of this investigation, because the arrangement of the apparatus is not simple enough to fulfill the conditions of the constants.

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3. Webre, A.L., Robinson, C.S., Evaporation, N.Y., Chemical Catalog Co., 1926, p. 235.
4. McAdams, W.H., Heat Transmission, N.Y., McGraw-Hill Book Co., 1933, p. 253.

GENERAL THEORY

In general discussions of the laws of radiation, laws are discussed which correlate wave lengths of maximum radiation with temperature, or energy of any particular wave length with temperature.[1] Since for the purposes of this investigation, all the radiant energy may be considered as heat, such discussions are of no significance here. This discussion is from the standpoint of the amount of heat transferred per unit area per unit of time from the hot body to the room.

The law governing the transfer of heat by radiation[2] is known as the Stefan-Boltzmann Law[3] and may be expressed as follows:

$$q_r = 0.172\ p\ A_r \left[\left(\frac{T_c}{100}\right)^4 - \left(\frac{T_o}{100}\right)^4\right]$$

where

q_r = rate of heat transfer from body to room in Btu./hr.

p = emissivity or relative blackness of the surface of the body.

A_r = radiating surface area in square feet.

T_c = temperature of the hot body in $^oF.$ absolute.

T_o = temperature of the room in $^oF.$ absolute.

Results calculated from this equation are used for compar-

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1. Webre, A.L., Robinson, C.S., Evaporation, N.Y., Chemical Catalog Co., 1926, pp. 25-26.
2. "Radiation" here means pure radiation without convection.
3. McAdams, W.H., Heat Transmission, N.Y., McGraw-Hill Book Co., 1933, p. 61.

ison with the experimental results.

The experimental results are calculated from the heat transfers which are based on the capacity equation:[4]

$$Q = UA\Delta T_a$$

where

Q = rate of heat transfer in Btu./hr.

U = overall heat transfer coefficient in Btu. per hour per square foot per ^{o}F. difference.

A = area of the heating surface in square feet.

ΔT_a = apparent temperature difference in ^{o}F. between the steam and the vapor.

From the calculated values of the rates of heat transferred, the rates of heat loss by radiation may be determined by difference:

$$Q_{r_1} = Q_s - Q_v$$

where

Q_{r_1} = rate of heat loss by radiation in Btu./hr. from an area A_{r_1} which is equal to the combined total surface areas of the evaporator shell, the entrainment separator, and the vapor pipe between them.

Q_s = rate of heat transfer in Btu./hr. based on the steam condensate.

Q_v = rate of heat transfer in Btu./hr. based on the vapor condensate.

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4. Badger, W.L., McCabe, W.L., Elements of Chemical Engineering, N.Y., McGraw-Hill Book Co., 1936, p. 196.

and

$$Q_{r_2} = Q_v - Q_w$$

where

Q_{r_2} = rate of heat loss by radiation in Btu./hr. from an area A_{r_2} which is equal to the combined total surface areas of the condenser shell, and the vapor pipe between the condenser and the entrainment separator.

Q_w = rate of heat transfer in Btu./hr. based on the temperature rise of the condenser water.

A hypothetical division of the total surface area of radiation is made just above the entrainment separator. The resulting areas are A_{r_1} and A_{r_2}, both of which are defined above (also see Figure 7). This division is justified by the fact that any entrainment in the separator will be returned to the evaporator (see Figure 7), while, at any point past the separator, entrainment and condensed vapors will pass on to the condenser.

For simplicity, the heat losses by radiation from the two areas will be expressed as factors of heat loss by radiation:

$$C_1 = \frac{Q_{r_1}}{A_{r_1}}$$

where

C_1 = factor of heat loss by radiation in Btu./hr per square foot.

and

$$C_2 = \frac{Q_{r2}}{A_{r2}}$$

where

C_2 = factor of heat loss by radiation in Btu./hr. per square foot.

In all ordinary cases of heat transfer in an evaporator, there are at least three resistances: the film resistance on the liquor side, the film resistance on the steam side, and the resistance of the metal wall through which the heat is being transferred. Where there is scale formation, this constitutes a fourth resistance. The overall coefficient of heat transfer is the reciprocal of the sum of all the resistances which may occur in a particular case.

The chief factors affecting the heat transfer are: steam pressure, non-condensible gases, quality and superheat in the steam, velocity and viscosity of the liquid.

Steam pressure will affect the heat transfer in an evaporator, since an increase in steam pressure with a corresponding increase in the boiling point of the liquid, will decrease the viscosity and give a better transfer of heat.

The removal of non-condensed gases can not be neglected in considering the transfer of heat. These gases are generally considered to be air which is present in the steam, the feed liquor, or air entering through leaks.

This air will increase the resistance to heat transfer.

Superheat of the steam effects both the apparent temperature drop and the quantity of heat transferred. However, the effect is very slight, since the specific heat of steam is about 0.48, and therefore the sensible heat exchange in becoming saturated would be practically negligible in comparison with the latent heat of condensation. The effect of superheat was not considered except as it influenced the heat balance. No correction was made for the initial higher Δt because the effect was transient.

With reference to the liquor side, an increase in velocity means in general an increase in heat transfer, or an increase in viscosity means a decrease in heat transfer, other factors remaining constant. Probably the velocity of the liquid is the major factor that controls the heat transfer from steam to boiling liquids. It is to be expected that with longer tubes a stronger pumping action may be generated. This led designers to use longer and longer tubes, but tubes over six feet long in this type of evaporator are rare, due to the difficulty of cleaning. The result of a layer of foreign material on the heating surface would greatly decrease the transfer of heat, since it acts as an additional wall to the transfer of heat.[5]

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5. McAdams, op. cit., pp. 187 and 301.

APPARATUS USED

The actual arrangement of the experimental evaporator and its accessories may be seen by observing Figures 8 and 9. These parts of the apparatus under question which serve as radiating surfaces are constructed of essentially the same material, and are coated with aluminum paint. Figure 7 shows an assembled drawing of the apparatus. A detailed description of the apparatus is now given here.

Basket Evaporator:

Shell: 3 sections, each 3/16" Pl. steel rolled to 20" O.D., height 30-3/4".

Steam Chest: 3/16" pl. - 16" O.D., height 28".

Tubes: 54 - 1" O.D. - 18 BWG copper, 1-5/8" between centers.

Deflector set on 3" standard - pipe 6" above top sheet.

Condenser: 6 pass - 6' long.

Tubes: 48-5/8" O.D. 20 BWG.

Manometers: 5 standard type.

One for feed orifice.

One for steam pressure.

One for vapor pressure.

One for condenser water orifice.

One for condenser water pressure drop.

Preheater for feed:

Tank 36" high - 23" diameter with closed steam coil.

Storage Tank: 78" high - 53" diameter.

Condensate Tanks: 4 - 60" high, 14" diameter.

Pumps:

One positive action Viking for pumping feed.

One centrifugal for pumping back to storage tank from condensate tanks.

One vacuum pumps for lowering boiling point of liquid to be evaporated.

DESCRIPTION OF THE METHOD USED

The data were obtained by two men operating the experimental evaporator. One man was placed at the main body of the evaporator in order to control the vapor and steam pressures and temperatures, the temperature of the inlet feed by control of the steam supply to the preheater, the liquid level around the basket of the evaporator, and the cooling water through the condenser. The other man was placed below at the condensate tanks in order to take the readings of the vapor condensate and the steam condensate. Manometers were used to obtain steam and vapor temperatures, since they were more accurate than thermometers and less sluggish. Steam from the University power house was throttled to the pressure corresponding to the temperature desired in the evaporator. This caused the steam to become superheated. The degree of superheat was measured with a thermometer placed in the steam inlet. Feed water was kept constant at 160° F.

A six pass tubular condenser was used as a source of vacuum supplemented by a vacuum pump to pull out the non-condensible gases. The volume of water through the condenser was obtained by measuring the pressure drop across a calibrated orifice. The temperature drop of the water through the condenser was measured with thermometers placed at the inlet and outlet of the condenser. The pressure

drop across the condenser was measured with a manometer. A small amount of sodium dichromate was put into the feed solution to minimize corrosion. Steam was bled through the steam chest to insure the best possible removal of non-condensible gases. The liquid level in the evaporator was controlled by hand since this was the only method available. Staggered readings were taken on the condensate tanks to enable one man to obtain all the readings in the unit time of the run and at the specified intervals. The steam condensate and vapor condensate were both used for heat transfer calculations, as well as the temperature rise across the condenser and the weight of water through it.

DISCUSSION OF OPERATION

In operating the evaporator on a given run, the following data were taken:

Steam temperature (varied from 210° F. to 248° F.).

Vapor temperature (varied from 176° F. to 228° F.).

Quantity of steam condensate.

Quantity of vapor condensate.

Steam inlet temperature (for getting superheat).

Feed inlet temperature (maintained at 160° F. approximately - for getting sensible heat).

Condenser water inlet temperature (varied from 58° F. to 86° F.).

Condenser water outlet temperature (varied from 115° F. to 190° F.).

Quantity of water through the condenser.

Pressure drop across the condenser.

The heat transfers, Q_S and Q_V, were calculated from the measured quantities of steam condensate and vapor condensate, respectively, per unit time of a run, taking into account small corrections of sensible heat, superheat, barometric pressure, etc. The heat transfer, Q_W, was calculated from the quantity of water passing through the condenser, and the temperature rise of this water.[1] From these calculated values of heat transfer, the heat losses by radiation may be determined.

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1. Sample Calculation Sheet No. 1, p. 40.

SOURCES OF ERROR

Some error might have been introduced in measuring the quantity of water passing through the condenser. The mercury level in the manometer varied considerably, and in addition to reading the pressure drop across the water line orifice, the water was weighed over a sufficient length of time. The outlet temperature of the condenser water was taken just as it came out of the condenser, and checked with a thermometer at the time of weighing.

The values for the radiating surface areas, A_{r_1} and A_{r_2}, are only approximately correct. No account was taken of the flanges in measuring these surface areas. This error affects only the factors of heat loss by radiation.

No account was taken of boiling point elevation due to hydrostatic head. The liquor level around the basket could not be kept constant, but varied approximately plus or minus one inch. The non-condensible gas vents on the steam condenser tanks had to be kept nearly wide open on runs of high steam pressures, because, without venting freely, the flow of the steam condensate was uneven and tended to come out in slugs. Even though the superheat of the steam was small, this was measured by the use of a thermometer. Thermometers were also used to check the temperatures calculated from manometer readings. Distilled water was used

in preference to city water in order to keep down scale formation.

The heat loss by natural convection would be increased considerably by disturbances from air currents in the room. However, the radiating surfaces are far from any doors or windows which would cause a variation of heat loss by convection due to air currents affecting vertical and horizontal bodies differently.

CORRELATION OF DATA

The calculated values of Q_s, Q_r, and Q_w (see Sample Calculation Sheet No. 1) are plotted as shown in Figures 1, 2, 3, and 4. Figures 1, 2, and 3 show the individual relationships between Q_s, Q_r, and Q_w, and Figure 4 shows all three relationships on one sheet. By definition earlier in this report, page 5, the heat loss by radiation from steam to vapor, Q_{r_1}, is the difference in heat transferred based on the steam condensate and vapor condensate. This value, which amounts to 45,000 Btu./hr., may be read directly from Figure 4 as shown. This radiation loss is constant since the lines are parallel. Similarly, the heat loss by radiation from vapor to the condenser water, Q_{r_2}, is the difference in the heat transferred based on the vapor condensate and the condenser water. This value is 30,000 Btu./hr., which is also constant because the lines are parallel. The factors of heat transfer by radiation are calculated as shown on Sample Calculation Sheet No. 2, and the results are practically the same, C_1 = 830 Btu. per hour per square foot, and C_2 = 825 Btu. per hour per square foot.

The values of heat transferred by radiation,[1] calculated from the Stefan-Boltzmann equation, do not compare favorably with the experimental results. Using an emis-

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1. "Radiation" here means pure radiation without convection.

sivity of 0.65 for the aluminum painted surface, the result for a hot body temperature of 176° F. and room temperature of 100° F. is 4,000 Btu./hr.[2] At a temperature of 226° F. for the hot body and 100° F. for the room, the calculated value is 7,700 Btu./hr. These values are based on the area, A_{r_1}, and correspond to the experimental value of 45,000 Btu./hr.

The results obtained in these runs do not indicate any significant change in heat loss by combined radiation and convection within the limits of temperature range that were used. For this reason, the total heat loss per unit area can be expressed as a factor, $C = Q_r/A_r$. Where the temperature drop between the radiating surface and the room influences the rate of total radiation, the corresponding factor would have been defined as a coefficient, $h_{rc} = Q_r/A_r\Delta T$.

Figure 5 shows the relation of the pressure drop and the flow of water through the condenser. An equation of this straight line may be written by determining the slope of the line plotted on logarithmic paper. The equation is:

$$W = K\Delta P^n$$

Evaluation of the constant gives the equation

$$W = 154\Delta P^{.515}$$

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2. See Sample Calculation Sheet N. 2, page 41.

where

W = pounds of water per minute

ΔP = pressure drop in pounds per square inch.

See sample calculations page 41 for method of calculating the constant K.

CONCLUSIONS

The conclusions drawn from this study are as follows:

1. The rate of heat transfer by combined radiation and convection is independent of the temperature within the range studied. The difference in temperatures between the vapor in the evaporator and the room varies from 76° F. to 126° F.

2. The factors of heat transfer by this total radiation are C_1 = 830 Btu. per hour per square foot, and C_2 = 825 Btu. per hour per square foot. These factors are expected to be very nearly the same since the emissivities of the radiating surfaces are the same. Furthermore, the radiating surfaces were far from any doors or windows which would cause a difference in factors due to air currents affecting vertical and horizontal bodies differently.

3. The heat loss by true radiation, calculated from the Stefan-Boltzmann equation, is 4,000 Btu./hr. at 176° F. vapor temperature and 100° F. room temperature. At a temperature of 226° F. of the vapor in the evaporator and the same room temperature, the calculated value is 7,700 Btu./hr. These values correspond with the experimental value of 45,000 Btu./hr., from which the conclusion can be made that approximately 85% of

the heat lost is by convection rather than by radiation.

4. An empirical equation is derived from the graph of Figure 5 for the pressure drop across the condenser:

$$W = 154\Delta P^{.515}$$

where

W = pounds of water per minute flowing through the condenser.

ΔP = pressure drop in pounds per square inch.

NOMENCLATURE

The nomenclature used in this paper is as follows:

Q = total heat transferred in Btu./hr.

U = overall coefficient of heat transfer in Btu./hr.

Δt_a = apparent temperature difference in $^{o}F.$ between steam and vapor.

q = rate of heat transfer in Btu./hr.

p = emissivity of the radiating surface.

A = surface area in square feet.

T_c = temperature of the hot body in $^{o}F.$ absolute.

T_o = temperature of the room in $^{o}F.$ absolute.

C = factor of heat loss by radiation in Btu. per hour per square foot.

Subscript r: applies to radiation.

Subscript s: applies to steam.

Subscript v: applies to vapor.

Subscript w: applies to water.

Subscript 1: applies to conditions between steam and vapor.

Subscript 2: applies to conditions between vapor and water.

W = flow of water through the condenser in pounds per minute.

ΔP = pressure drop across the condenser in pounds per square inch.

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Badger, W.L., McCabe, W.L., Elements of Chemical Engineering, N.Y., McGraw-Hill Book Company, 1936.

McAdams, W.H., Heat Transmission, N.Y., McGraw-Hill Book Company, 1933.

Webre, A.L., Robinson, C.S., Evaporation, N.Y., Chemical Catalog Company, 1926.

APPENDIX

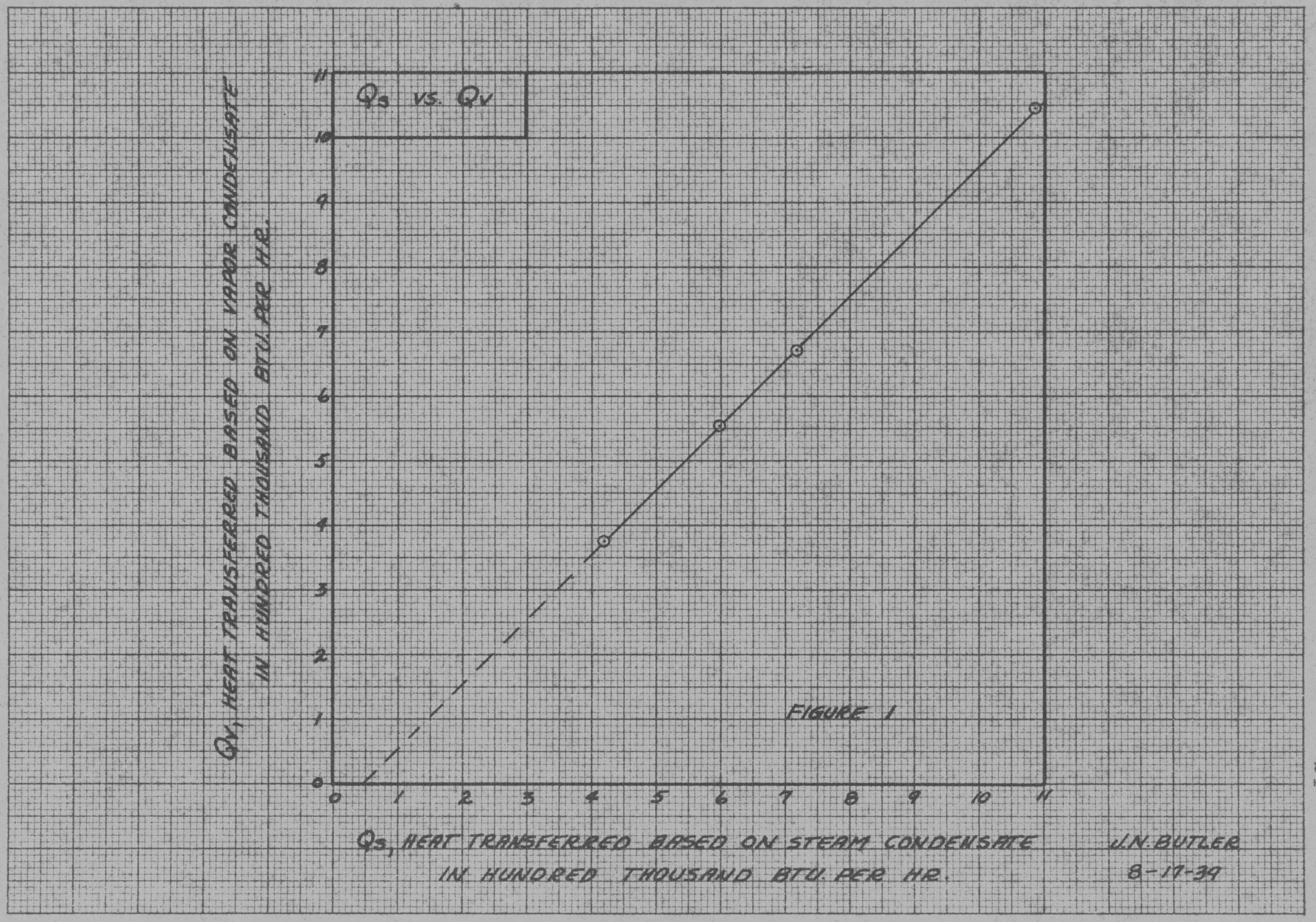

FIGURE 1

J.N. BUTLER
8-17-39

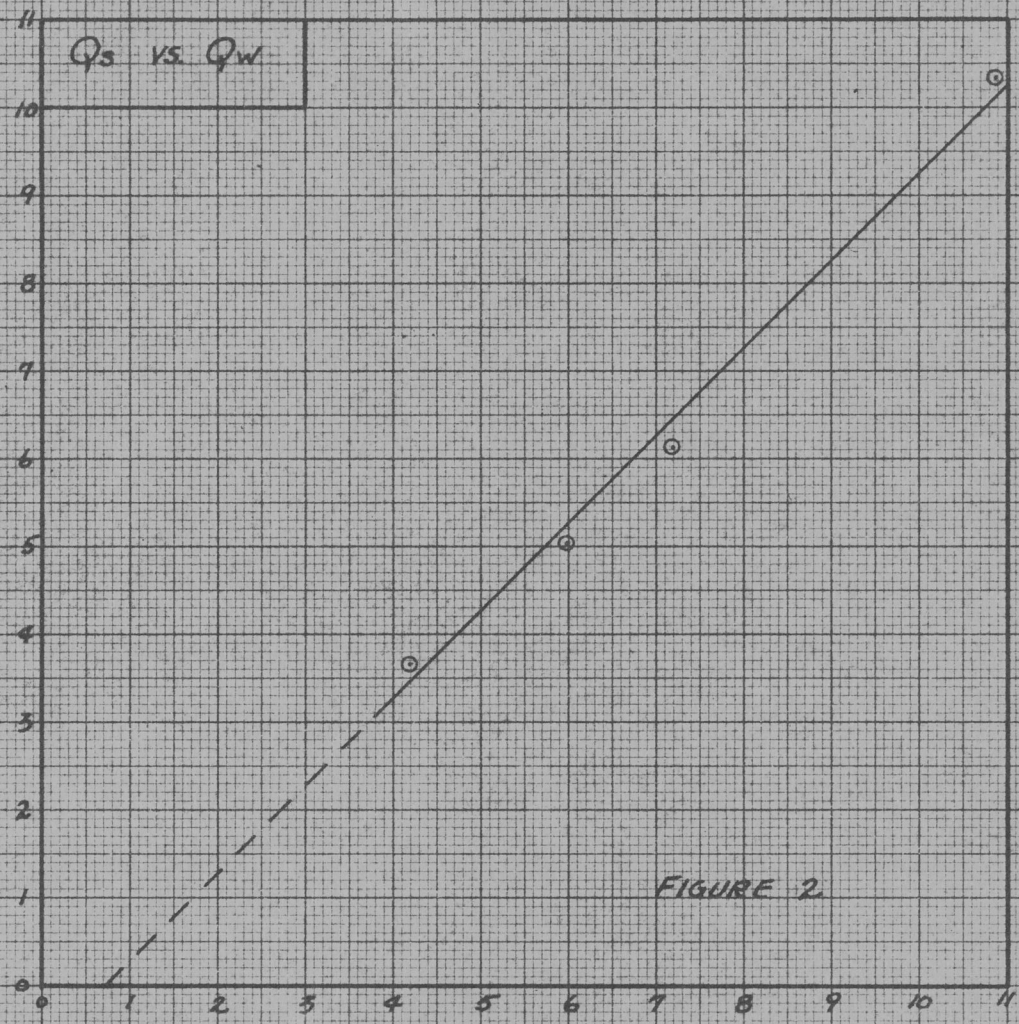

FIGURE 2.

J.N. BUTLER
8-17-39

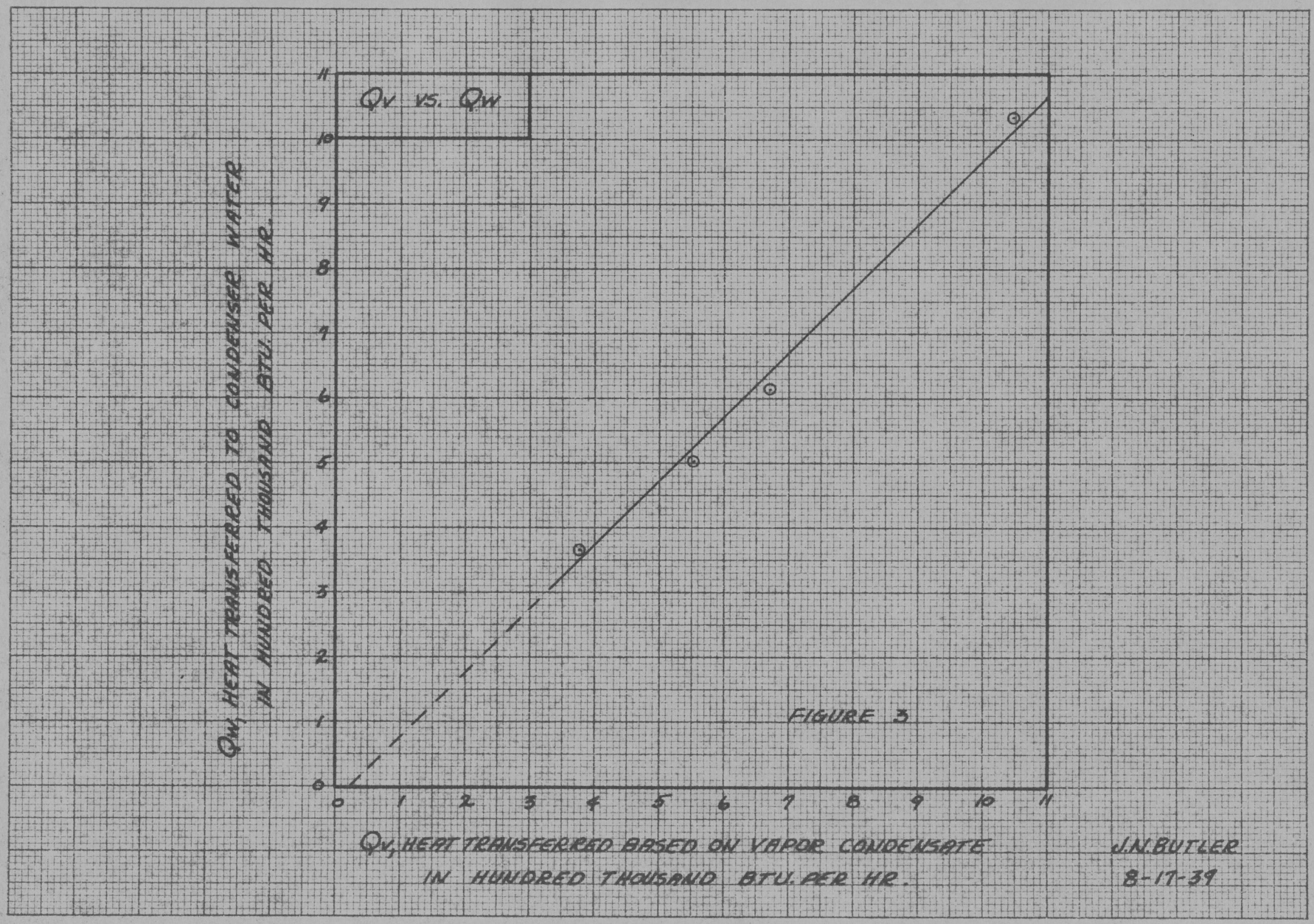
Q_V vs. Q_W
Q_W, HEAT TRANSFERRED TO CONDENSER WATER IN HUNDRED THOUSAND BTU. PER HR.
0
1
2
3
4
5
6
7
8
9
10
11
Q_V, HEAT TRANSFERRED BASED ON VAPOR CONDENSATE IN HUNDRED THOUSAND BTU. PER HR.
J.N. BUTLER
8-17-39

FIGURE 3

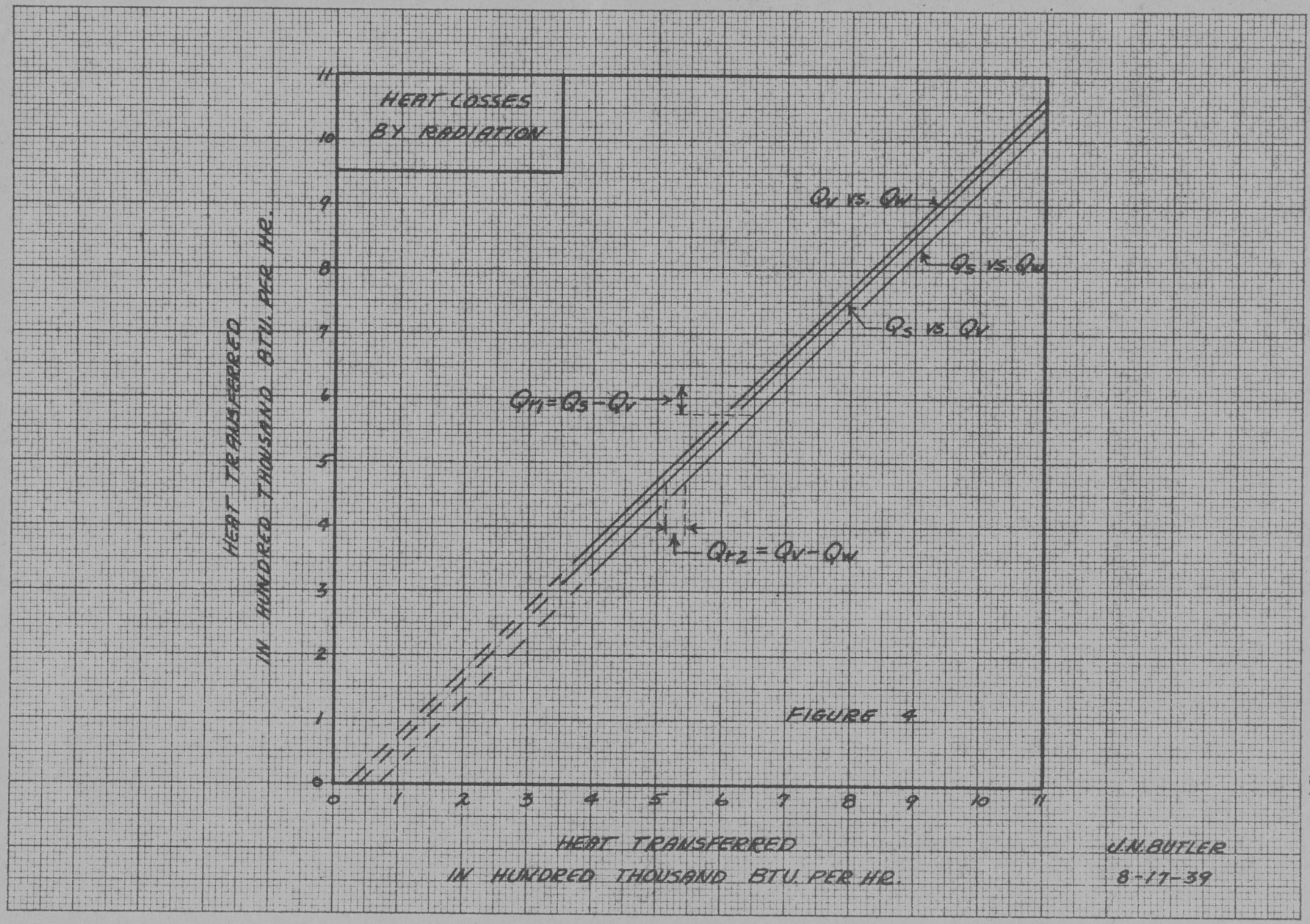

FIGURE 4

J.N. BUTLER
8-17-39

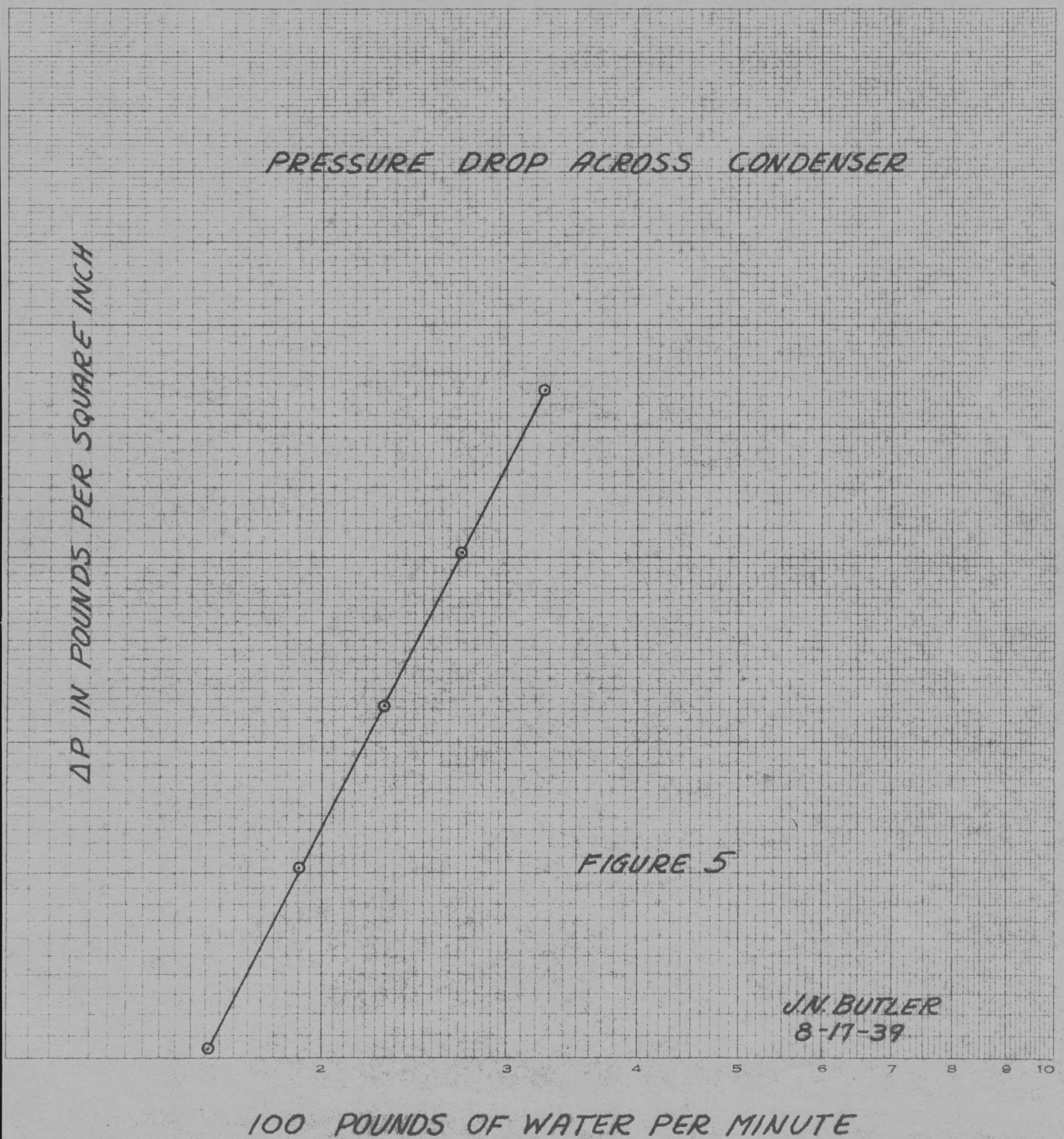
PRESSURE DROP ACROSS CONDENSER
ΔP IN POUNDS PER SQUARE INCH
J.N. BUTLER
8-17-39
2
3
4
5
6
7
8
9
10
100 POUNDS OF WATER PER MINUTE

FIGURE 5

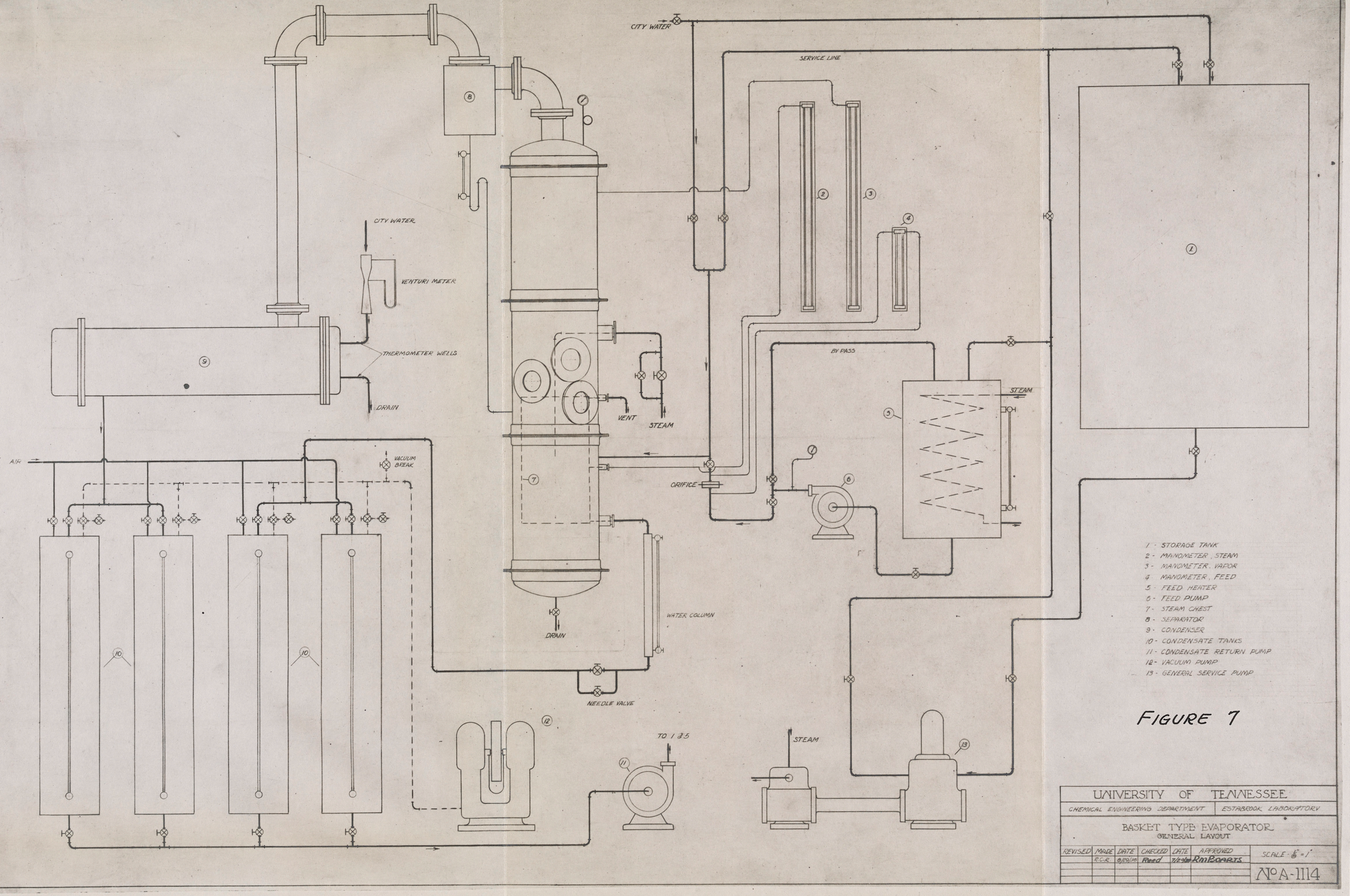

FIGURE 7

UNIVERSITY OF TENNESSEE
CHEMICAL ENGINEERING DEPARTMENT | ESTABROOK LABORATORY

BASKET TYPE EVAPORATOR
GENERAL LAYOUT

REVISED	MADE	DATE	CHECKED	DATE	APPROVED	SCALE
	R.C.R.	8/20/40	Reed	7/40	R.M. Roberts	1/8" = 1'

No. A-1114

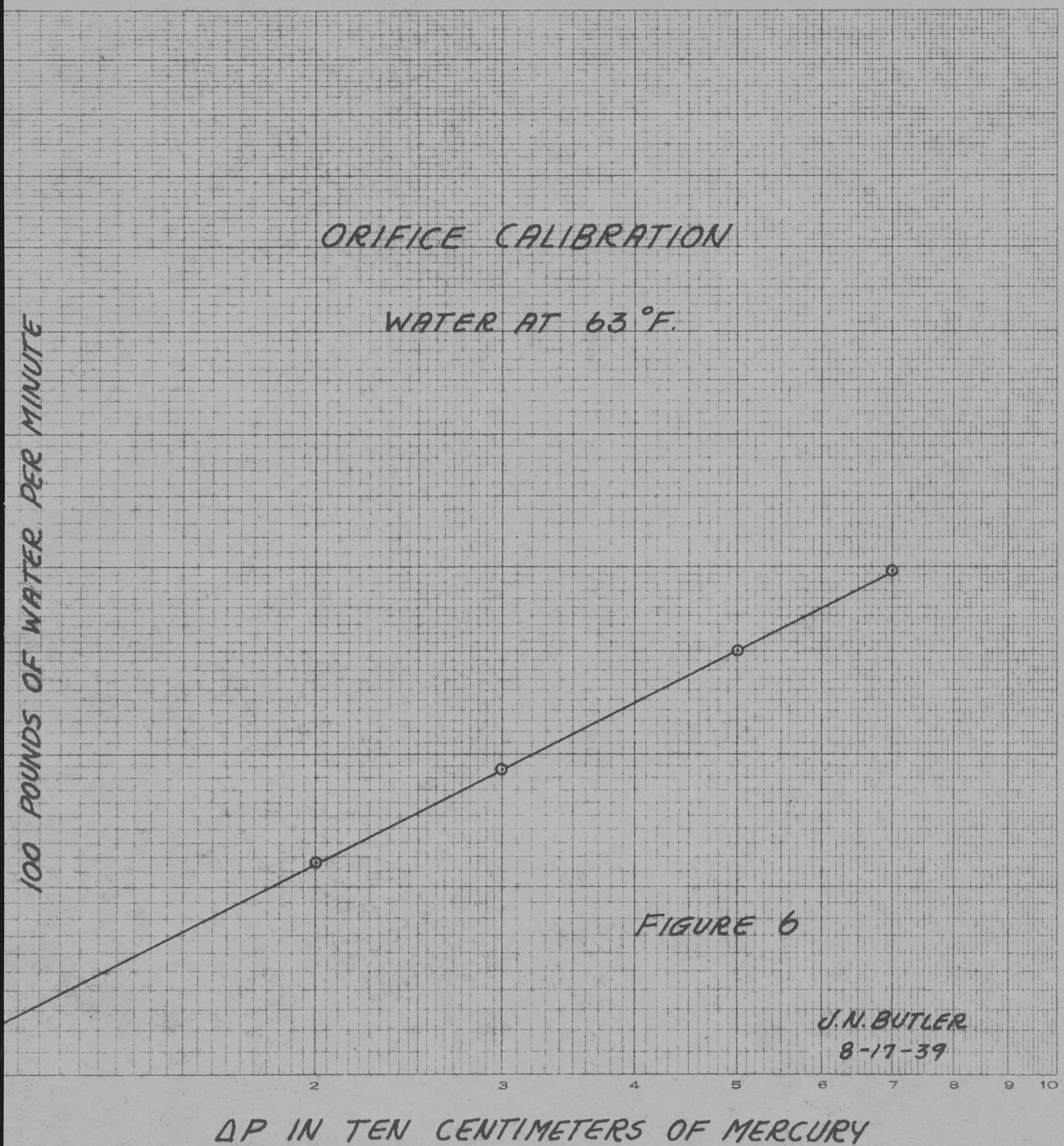
ORIFICE CALIBRATION
WATER AT 63 °F.
100 POUNDS OF WATER PER MINUTE
J.N. BUTLER
8-17-39
2
3
4
5
6
7
8
9
10
ΔP IN TEN CENTIMETERS OF MERCURY

FIGURE 6

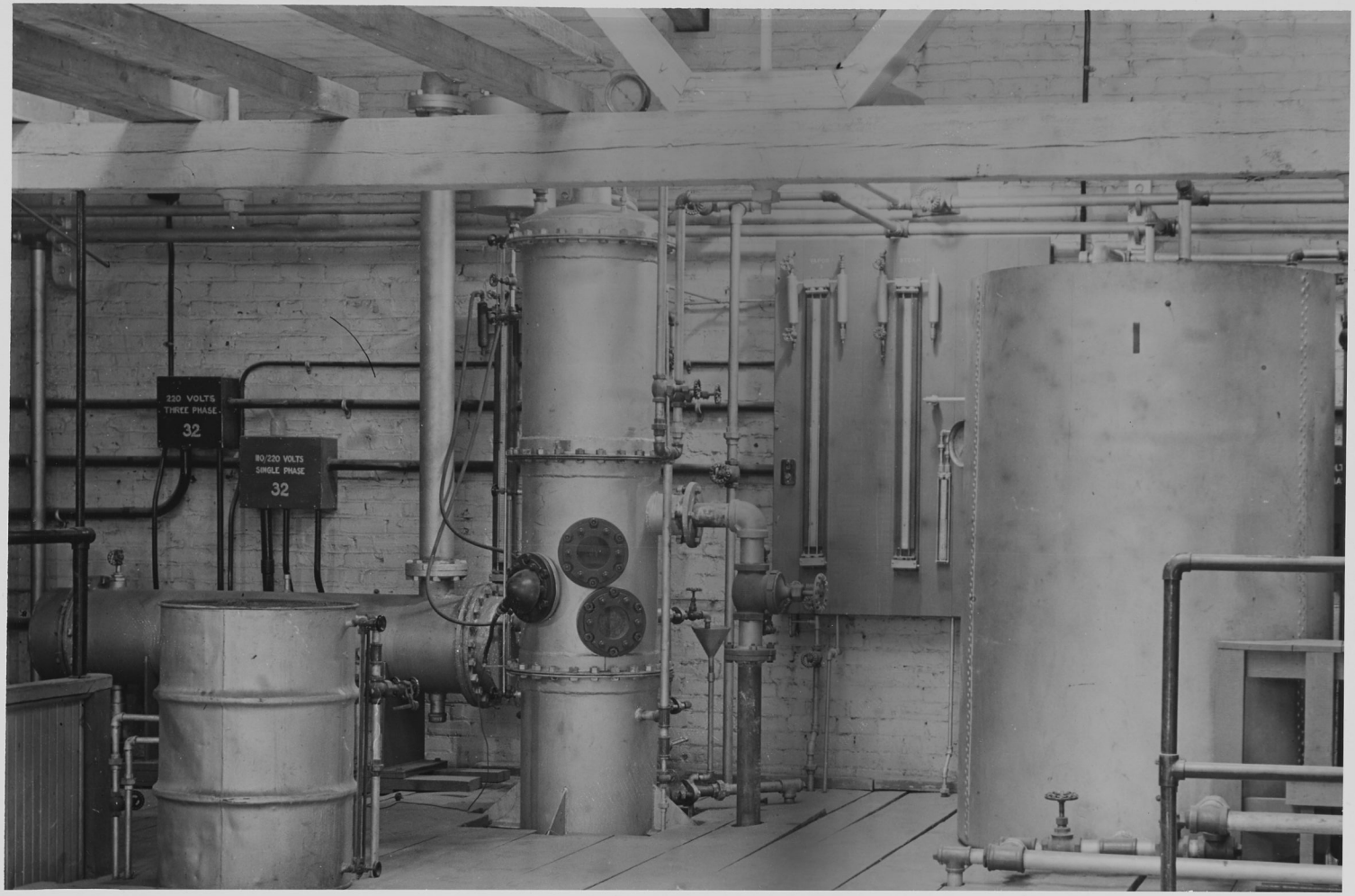

FIGURE 8



FIGURE 9

HEADINGS FOR TABLES

Steam temp. = steam temperature in basket in $^{o}F.$

Vapor temp. = vapor temperature in vapor space in $^{o}F.$

ΔT_a = apparent temperature difference in $^{o}F.$ between steam and vapor.

Steam temp. (inlet) = temperature of steam entering in $^{o}F.$

Steam cond. = steam condensate in centimeters collected in the condensate tanks.

Vapor cond. = vapor condensate in centimeters collected in the condensate tanks.

Cond. tanks = flow of water through condenser in lb./hr.

ΔT water = temperature difference in $^{o}F.$ between entering and leaving condenser water.

ΔP cond. = pressure drop across condenser in $lb./in.^2$

Q_s = total heat transferred based on steam condensate in Btu./hr.

Q_v = total heat transferred based on vapor condensate in Btu./hr.

Q_w = total heat transferred based on flow of water through the condenser and its temperature rise, in Btu./hr.

$Q_{r1} = Q_s - Q_v$, heat loss by radiation in Btu./hr.

$Q_{r2} = Q_v - Q_w$, heat loss by radiation in Btu./hr.

Observed $Q_{r1} = Q_s - Q_v$ from Figure 4, heat loss by radiation in Btu./hr.

Observed $Q_{r2} = Q_v - Q_w$ from Figure 4, heat loss by radiation in Btu./hr.

TABLE I

HEAT TRANSFER DATA FOR EXPERIMENTAL EVAPORATOR

Series	Run No.	Steam temp.	Vapor temp.	ΔT_a	Steam temp. (inlet)	Steam cond.	Vapor cond.	Cond. Water	ΔT water	ΔP cond.
1	4	210.4	176.4	34.0	284	128.5	121.6	9,760	72.5	0.99
1	18	227.2	177.2	40.0	250	181.3	165.4	21,960	47.5	4.45
1	12	218.7	177.0	41.7	326	162.4	158.2	15,130	69.0	1.95
1	14	228.2	178.7	49.5	320	202.4	186.7	17,460	66.5	6.74
1	17	247.4	178.7	68.7	320	297.7	288.3	31,120	55.0	8.92
1	15	247.5	178.7	68.8	320	302.3	289.3	32,400	53.5	9.07
2	3	211.1	177.0	34.1	220	60.1	52.6	5,640	77.0	0.33
2	4	227.3	177.0	40.3	232	89.8	76.6	7,540	62.0	0.62
2	5	247.6	177.0	70.6	250	139.1	125.2	14,090	59.0	1.82
3	9	247.7	177.3	70.4	254	206.2	189.7	21,960	52.5	4.06
3	8	227.6	178.2	49.4	234	138.8	124.4	13,080	58.0	1.59
3	7	211.7	178.3	33.4	216	76.6	65.8	6,990	60.5	0.48
4	4	258.0	178.3	69.7	270	347.6	320.1	45,840	42.5	16.40
4	14	227.2	177.2	50.0	254	241.0	226.7	27,360	50.0	5.65

TABLE I (Continued)

Series	Run No.	Q_s	Q_v	Q_w	Q_{r1}	Q_{r2}	Q_{r1} Obs.	Q_{r2} Obs.
1	4	800,800	757,400	708,000	43,400	49,400	45,000	30,000
1	18	1,090,000	1,042,000	1,047,000	48,000	1,000	45,000	30,000
1	12	1,023,200	986,300	1,030,000	36,900	43,700	45,000	30,000
1	14	1,259,000	1,140,000	1,160,000	119,000	-20,000	45,000	30,000
1	17	1,809,000	1,799,000	1,710,000	10,000	89,000	45,000	30,000
1	15	1,881,000	1,805,000	1,731,000	76,000	74,000	45,000	30,000
2	4	534,300	479,000	467,500	55,300	11,500	45,000	30,000
2	5	814,000	782,400	831,000	31,600	-48,600	45,000	30,000
3	9	1,209,6000	1,182,600	1,153,000	27,000	29,600	45,000	30,000
3	8	827,300	775,300	759,000	52,000	16,300	45,000	30,000
3	7	460,100	410,100	423,000	50,000	-12,900	45,000	30,000
4	4	2,055,500	1,996,100	1,950,000	59,400	46,100	45,000	30,000
4	14	1,449,100	1,411,600	1,368,000	37,500	43,600	45,000	30,000
	Mean	1,087,100	1,046,100	1,034,000	41,000	12,100		

TABLE I (Continued)

Series	Run No.	Steam temp.	Vapor temp.	ΔT_a	Steam temp. (inlet)	Steam cond.	Vapor cond.	Cond. water	ΔT water	ΔP cond.
4	10	211.5	195.6	14.9	284	50.9	46.2	3,660	73.5	0.13
1	23	211.0	195.2	15.8	248	46.7	43.9	3,923	68.0	0.02
4	7	211.5	195.6	15.9	284	56.9	50.3	4,560	66.5	0.10
2	8	211.4	195.1	16.3	242	23.6	20.2	2,255	55.0	0.06
3	4	211.7	195.0	16.7	246	28.5	24.8	1,627	82.0	0.02
1	8	227.0	196.0	31.0	276	129.7	122.8	8,910	83.0	0.81
3	5	227.6	196.4	31.2	232	88.5	75.5	5,910	75.0	0.35
1	3	227.0	195.1	31.9	264	125.8	111.3	7,435	90.5	0.56
4	11	227.6	195.6	32.0	236	156.9	136.5	11,850	67.5	1.25
2	7	227.3	195.1	32.2	232	56.4	48.1	4,020	75.0	0.15
1	11	239.7	195.0	44.7	326	198.3	186.2	13,200	86.0	1.74
1	10	247.4	196.3	51.1	310	230.9	216.2	16,290	83.0	2.43
4	9	247.6	195.6	52.0	254	269.0	236.7	22,560	62.5	3.93
3	6	247.6	195.6	52.0	256	152.7	138.5	11,650	71.5	1.22
2	6	247.6	195.1	52.5	250	99.8	86.5	6,955	75.0	0.39
1	16	247.2	194.5	52.2	320	221.0	209.0	15,990	79.0	2.50

TABLE I (Continued)

Series	Run No.	Q_s	Q_v	Q_w	Q_{r1}	Q_{r2}	Q_{r1} Obs.	Q_{r2} Obs.
4	10	305,000	289,900	269,100	15,100	20,800	45,000	30,000
1	23	285,600	275,700	267,000	9,900	8,700	45,000	30,000
4	7	340,900	315,600	303,500	25,300	12,300	45,000	30,000
2	8	144,000	127,000	124,000	17,000	3,000	45,000	30,000
3	4	173,800	155,500	133,500	18,300	22,000	45,000	30,000
1	8	787,100	763,700	739,000	23,400	24,700	45,000	30,000
3	5	525,900	473,900	444,000	52,000	29,000	45,000	30,000
1	3	761,200	698,400	672,000	62,800	26,400	45,000	30,000
4	11	930,200	825,100	799,000	105,100	26,100	45,000	30,000
2	7	334,800	302,500	306,000	32,300	3,500	45,000	30,000
1	11	1,224,000	1,166,000	1,135,000	58,000	36,000	45,000	30,000
1	10	1,430,000	1,344,600	1,351,000	85,400	-6,400	45,000	30,000
4	9	1,572,600	1,485,400	1,410,000	87,200	75,400	45,000	30,000
3	6	986,600	867,400	833,500	29,200	33,900	45,000	30,000
2	6	584,000	546,500	521,000	37,500	25,500	45,000	30,000
1	16	1,343,000	1,287,000	1,263,000	56,000	24,000	45,000	30,000
	Mean	718,690	670,410	612,290	48,280	58,120		

TABLE I (Continued)

Series	Run No.	Steam temp.	Vapor temp.	ΔT_a	Steam temp. (inlet)	Steam cond.	Vapor cond.	Cond. water	ΔT water	ΔP cond.
4	6	227.6	211.8	15.8	244	106.1	66.8	4,335	87.0	0.19
1	22	227.3	211.0	16.3	250	54.9	48.7	2,295	113.5	0.08
2	1	227.3	211.0	16.3	254	28.1	21.4	1,675	75.0	0.03
4	1	227.5	211.1	16.4	235	72.7	64.3	4,280	88.0	0.18
4	16	247.6	211.8	35.8	252	181.1	157.4	11,310	88.5	1.08
4	2	247.6	211.5	36.1	253	156.3	139.7	9,720	85.0	0.91
3	2	247.7	211.6	36.1	254	106.9	96.1	6,315	87.5	0.41
2	2	247.6	210.9	36.7	250	73.7	63.7	4,210	88.0	0.19
1	19	247.5	210.5	37.0	250	137.3	125.7	6,900	95.5	0.66
1	6	247.7	210.3	37.3	280	149.0	139.4	9,000	89.0	0.81
4	17	247.6	228.0	19.6	254	95.1	77.3	5,355	93.0	0.29
2	9	247.6	227.6	20.0	256	34.4	31.1	2,690	104.0	0.02
3	1	247.7	227.3	20.4	255	65.6	57.5	3,260	99.0	0.11
1	20	247.5	225.2	22.3	250	78.4	65.3	2,910	122.5	0.04
1	21	247.5	225.2	22.3	250	79.9	66.5	3,165	118.5	0.06

TABLE I (Continued)

Series	Run No.	Q_s	Q_v	Q_w	Q_{r1}	Q_{r2}	Q_{r1} Obs.	Q_{r2} Obs.
4	6	629,100	421,100	377,000	208,000	44,100	45,000	30,000
1	22	329,800	307,500	261,100	22,300	46,500	45,000	30,000
2	1	166,800	135,200	125,700	31,600	9,500	45,000	30,000
4	1	435,000	405,700	376,500	29,300	29,200	45,000	30,000
4	16	1,061,200	970,900	931,000	90,300	39,900	45,000	30,000
4	2	913,900	893,300	826,000	20,600	67,300	45,000	30,000
3	2	627,000	606,400	553,000	21,000	53,400	45,000	30,000
2	2	431,300	402,500	370,500	28,800	32,000	45,000	30,000
1	19	804,400	793,600	659,000	10,800	134,600	45,000	30,000
1	6	887,000	880,000	791,000	7,000	89,000	45,000	30,000
	Mean	598,140	553,980	502,110	44,160	51,870		
4	17	557,900	490,800	498,500	67,100	-7,700	45,000	30,000
2	9	224,700	192,500	280,000	27,200	-82,500	45,000	30,000
3	1	385,200	364,900	373,000	20,100	41,900	45,000	30,000
1	20	459,300	405,000	359,000	54,300	46,000	45,000	30,000
1	21	460,000	421,500	376,000	46,500	45,500	45,000	30,000
	Mean	418,880	375,940	367,300	42,940	8,640		

TEST ON BASKET EVAPORATOR

Sample Calculation Sheet No. 1

Series 2 — Date of Run 6/13/39
Run Number 6 — Room Temp. 91°F.

Steam		Vapor	
Steam press.R.side cm.Hg.	87.0	Vapor press.R. side cm.Hg.	38.6
Steam Press.l.side cm.Hg.	13.6	Vapor press.L.side cm. Hg.	59.0
Gage pressure cm. Hg.	73.4	Gage pressure cm. Hg.	-20.4
Barometric press. cm. Hg.	74.1	Barometric press. cm. Hg.	74.1
Absolute press. cm. Hg.	147.5	Absolute press. cm. Hg.	53.7
Steam temp. in basket °C.	119.7	Temp. in vapor space °C.	90.5
Steam temp. in basket °F.	247.6		
Temp. in vapor space °F.	195.1		
Delta T °F.	52.5		
Steam temp. (inlet) °F.	250.0		
L.H. steam cond. Btu./#	947.1	L.H. vapor cond. Btu./#	982.7
Super heat steam Btu./#	1.2	Sensible heat feed Btu./#	35.1
Heat available Btu./#	948.3	Heat transferred Btu./#	1017.8
Steam condensate cm.	99.8	Vapor condensate cm.	86.5
Log cm. steam cond.	1.9991	Log cm. vapor cond.	1.9370
Log factor*	0.7909	Log factor*	0.7909
Log heat available	2.9764	Log heat transferred	3.0077
Log total heat available	5.7664	Log total heat trans.	5.7376
Total heat avail.Btu./hr.	584,000	Total heat trans.Btu./hr.	546,500
A_{r1} radiating area sq.ft.	54.3	A_{r2} radiating area sq.ft.	36.4

Condenser		Orifice in water line	
Temp. cond. water out °F.	157	Pressure L. side cm. Hg.	54.0
Temp. cond. water in °F.	82	Pressure R. side cm. Hg.	42.8
Rise in temp. °F.	75	Delta H. cm. Hg.	11.2
Heat trans. to water Btu./hr	521,000	Wt.water (orifice)#/hr.	7,200
		Wt.water (scales) #/hr.	6,955

Drop across condenser

Pressure L. side cm. Hg.	49.2
Pressure R. side cm. Hg.	47.2
Delta H. cm. Hg.	2.0

$$* \text{ Factor} = \frac{0.253 \cdot 60.9 \cdot 3.0}{7.48}$$

where

0.253 = tank calibration in gal./cm.
60.9 = # water/cu.ft. at 165° F.
7.48 = gal./cu.ft.
3.0 = factor to convert 20 minute runs to hour runs.

Sample Calculation Sheet No. 2

Factor of heat transfer by radiation:

$$C_1 = \frac{Q_{r_1}}{A_{r_1}} = \frac{45{,}000}{54.3} = 830 \text{ Btu./hr.-ft.}^2$$

$$C_2 = \frac{Q_{r_2}}{A_{r_2}} = \frac{30{,}000}{36.4} = 825 \text{ Btu./hr.-ft.}^2$$

Heat loss by pure radiation from Stefan-Boltzmann Law:

$$q_{r_1} = 0.172 \; p \; A_{r_1} \left[\left(\frac{T_c}{100} \right)^4 - \left(\frac{T_o}{100} \right)^4 \right]$$

$$= 0.172 \cdot 0.65 \cdot 54.3 \left[\left(\frac{176-460}{100} \right)^4 - \left(\frac{100-460}{100} \right)^4 \right]$$

$$= 0.172 \cdot 0.65 \cdot 54.3 \cdot 656$$

$$q_{r_1} = 4{,}000 \text{ Btu./hr.}$$

Calculation of constant K:

$$W = K \Delta P^{.515}$$

$$220 = K \cdot (2.0)^{.515}$$

$$\log 220 = \log K - 0.515 \log 2.0$$

$$\log K = 2.3424 - 0.1550 = 2.1874$$

$$K = 154$$

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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