THE COOLING OF WATER FOR POWER PLANT PURPOSES

by

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1 9 2 8

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This paper presents the results of an experimental investigation into the conditions governing the cooling of the condensing water at the University of Tennessee power plant by means of a spray pond. It involves determining the efficiency of the cooling process under varying conditions of pressure at the spray nozzle, the height of sprays above the pond surface, the temperature of the water to be cooled, and the power required to circulate the water.

In condensing plants where a plentiful supply of circulating water is not available, some means must be provided for cooling this water so that it can be used over and over again. Two devices are in use: the cooling tower, and the spray pond.

The action of the cooling tower depends mainly on the giving up of heat by the hot water to the air. The tower is usually a high structure, square or circular in section, with its interior filled with some sort of baffle-work designed to break up the water into fine sheets or sprays. The hot water is delivered to the top of the tower, while a strong current of air is injected into the tower at the base by means of a forced draft fan. The air and water comes into intimate contact within the tower. By this method the water is cooled and the air is heated. The cooled water from the tower is collected in a basin at the foot from which the condenser water is taken.

The action of the spray pond depends on the cooling of water by evaporating part of it, and thus taking from what was left the heat of vaporization necessary to do the evaporating. Conduction and convection were not relied upon for cooling. This effect is present, also, to a small extent in any cooling tower as some of the water evaporates and carries away heat in the form of steam.

Cooling in the modern spray pond is accomplished, by spraying the hot water through nozzles designed to break the water up into very fine particles, thus aiding the evaporation tendency. A great deal of experimental work has been carried on in this country in the perfection of these nozzles. At the present time there are several different designs on the market, all of which apparently give good results.

Sprays are arranged in rows and placed a certain distance apart, depending upon the system employed. Theoretically, the farther we place the sprays apart the better the cooling. In practice we are limited in this respect to the space available and the cost of the pond. These spray heads are attached to the main pipe line either in clusters of five or six, or alone. The row of sprays are generally placed closer together than the nozzles in a single row. This arrangement is supposed to create a draft between the rows and thus produce better cooling. The general direction of the air is upward, however, and this consideration would seem to be somewhat theoretical.

The purpose of the work here discussed is to ascertain by means of the spray pond, the conditions governing the cooling of the water at the University of Tennessee power plant. This involved determining the efficiency of the cooling process under varying conditions of pressure at the spray nozzle, the temperature of the water to be cooled, the power applied to the pumps and the height of sprays above pond.

This experiment was made on the pond shown in Figure I which is part of the power plant equipment of the University of Tennessee at Knoxville. The pond is 40' long and 34' wide and was designed to cool the condensing water of a 500 K. W. Westinghouse turbine fitted with a surface condenser. The water was sprayed through 4 Klein invalute nozzles and two Themas adjustable nozzles. A motor driven centrifugal pump with a 6" suction and discharge sends the water through the condenser tubes and to the spray heads as shown in Figure I.

The pressure at the nozzle was in all cases measured by a pressure gauge connected on one of the pipes, on which a nozzle is located. The humidity was taken every hour by the use of a wet and dry bulb sling psychrometer. The amount of water circulated was measured by the aid of water tight doors and storage tanks.

The efficiency E of a spray pond may be expressed as the ratio between the cooling actually produced, (T_1-T_2), and that which would have resulted from cooling the water down to the wet bulb temperature Tw. Thus

$$E = \frac{T_1-T_2}{T_1-Tw}$$

Where T_1 and T_2 are the temperatures of the water before and after spraying. A perfect spray cooling device would be one capable of subdividing the water so that evaporation would take place at Tw.

The loss due to evaporation varies with weather conditions: initial temperature of water, pressure at nozzle, and with humidity. Data obtained from the Yarnell Waring Co. shows that 2% to 2½% per hour represents fairly well the average loss of water, but in this particular case this loss exceeded these figures enormously, due to the peculiar construction of the pond.

The power required to circulate the water is shown in Figure II as watts per gallon, per minute per degree of cooling from varying initial temperatures. By the use of this curve the power required to circulate the water in a given case can be estimated to cover specified temperatures and capacity. The equation used in this computation is:

$$P = \left(\frac{100}{T_1}\right)^{3.23}$$

Here P equals power of pump motor in watts per gallon per minute per degree Fahrenheit of cooling, T_1 is initial temperature of the water to be cooled, degrees Fahrenheit. (Not absolute Temperature).

*The height of spray nozzles above the surface of the pond has a very important effect upon the cooling of the water. Experience has shown that the nozzle should be kept as low as possible. At first this was not done because it was thought that the long path of the water through the air would result in correspondingly greater cooling. This is not the case in actual practice as it has been proven from reliable experiments that a loss of 8^0 and sometimes 12^0 has occurred from such practice. The reason for this according to (C. C. Thomas) is that a given pump, placed in a certain relation to the surface of the pond, will deliver a smaller amount of water to a high level, than to a lower level, and this smaller amount will leave the condenser at a higher temperature than did the larger amount of water; second, with a given amount of power at the pump, less energy will be available for breaking up the water if the nozzle is placed high than if it is placed low, and it appears that minute subdivisions of the water is more important than is a long path through the air.

Another factor which affects the efficiency of a spray pond to a considerable extent is the depth of water employed. Of course, the more shallow the pond the greater will be the area exposed to radiation and conduction in proportion to the body of water. This would seem to be an asset but experience has shown, however, that a deep pond is more desirable, when possible, because of the lag in temperature between day and night made possible by the smaller surface exposed to the heat of the sun and the larger body of water. The pond will cool down considerably during the night and will not rise to as high a value during the day in the deep pond. This lag will keep the average temperature of the pond during the twenty-four hours several degrees below the average for the shallow pond. This is a decided gain. On the other hand the deep pond costs more to build and the designer must strike a balance between the interest on his investment and the gain to be realized by the lower temperature of the water. Practice and all available data shows that a pond should be from three to six feet in depth to give good results.

In conclusion it is of interest to consider some other methods of cooling water and to compare the results with those obtained from spray ponds. The simplest method is to discharge the water through a single pipe line to a pond of sufficient area, so that the water will be cooled by contact with the atmosphere on the surface of the water. Such a pond must be very large in order to obtain satisfactory results, and in order to reduce the area required it is necessary to add some device by which additional contact of the water with the atmosphere is obtained. The most completely controlled means for cooling water in large quantities is found in the force-draft cooling tower, which is particularly effective because of the regularity with which an air current is brought into contact with water spread out and dropping from properly arranged surfaces. The cost of installation and operation of a forced-draft tower, however, is very much greater than for a spray pond. The newly developed spray head provides for control of the system in a manner which, while somewhat less complete than in the case of a cooling tower, yields results which compare very favorably with those of the tower.

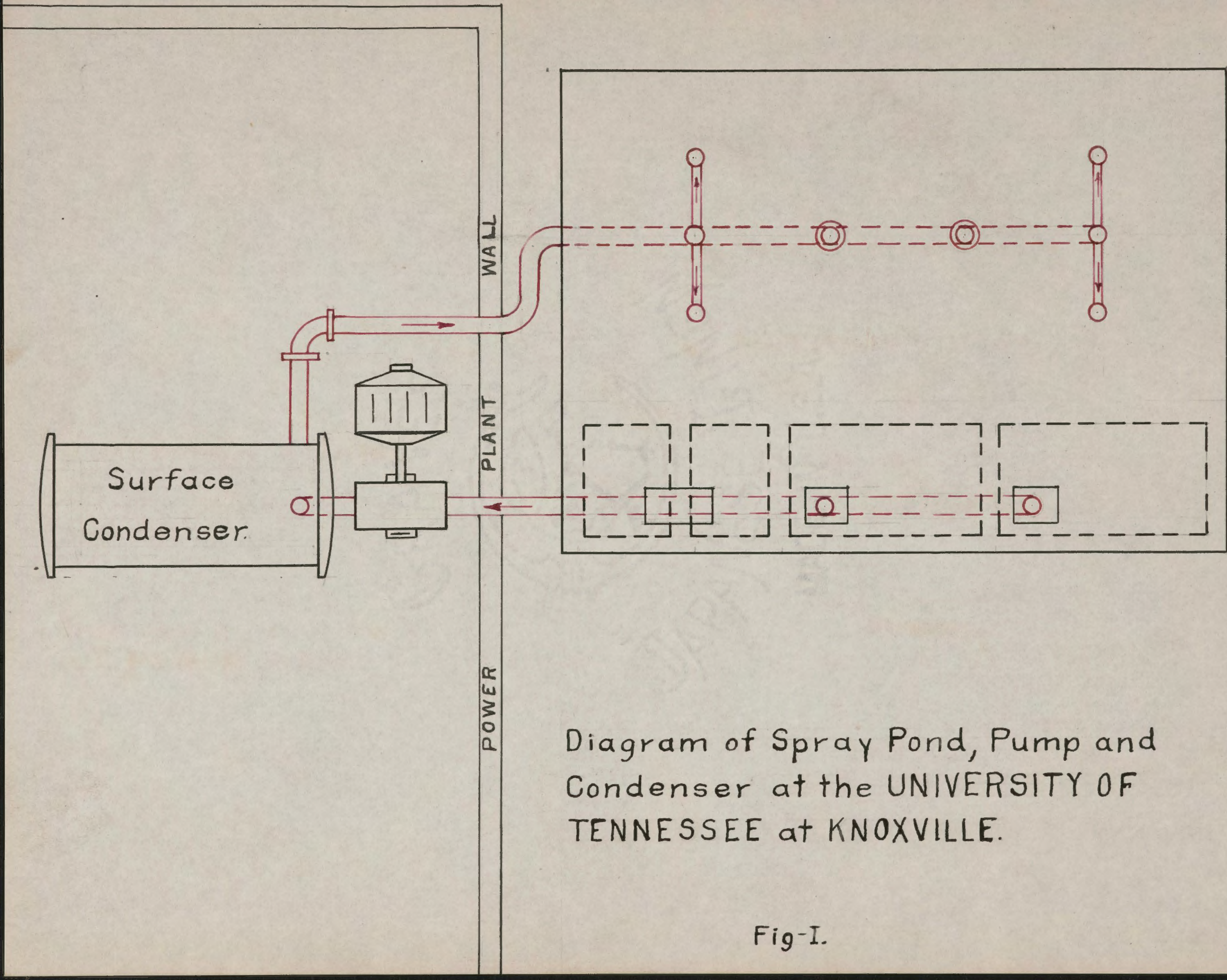
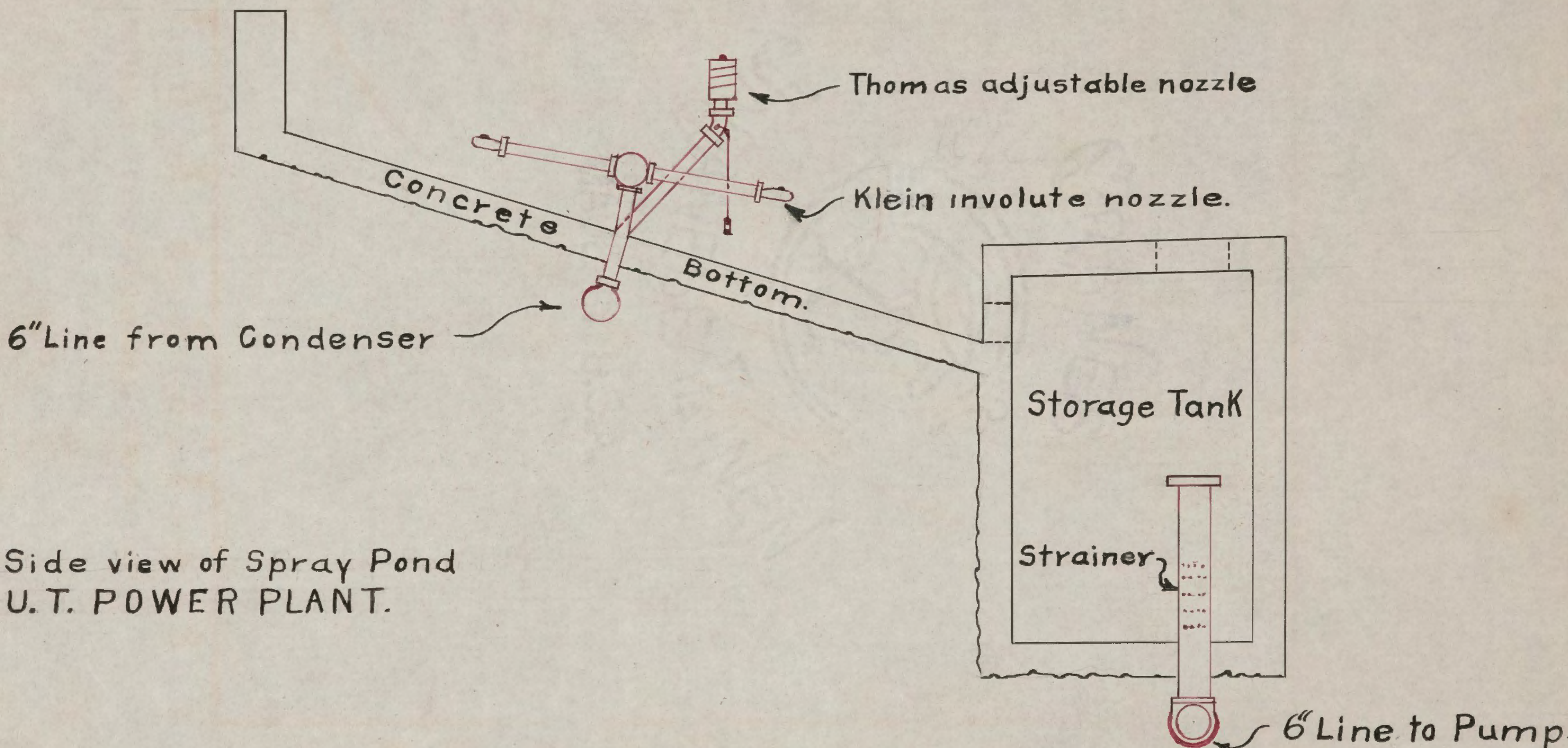


Diagram of Spray Pond, Pump and Condenser at the UNIVERSITY OF TENNESSEE at KNOXVILLE.

Fig-I.



Side view of Spray Pond
U. T. POWER PLANT.

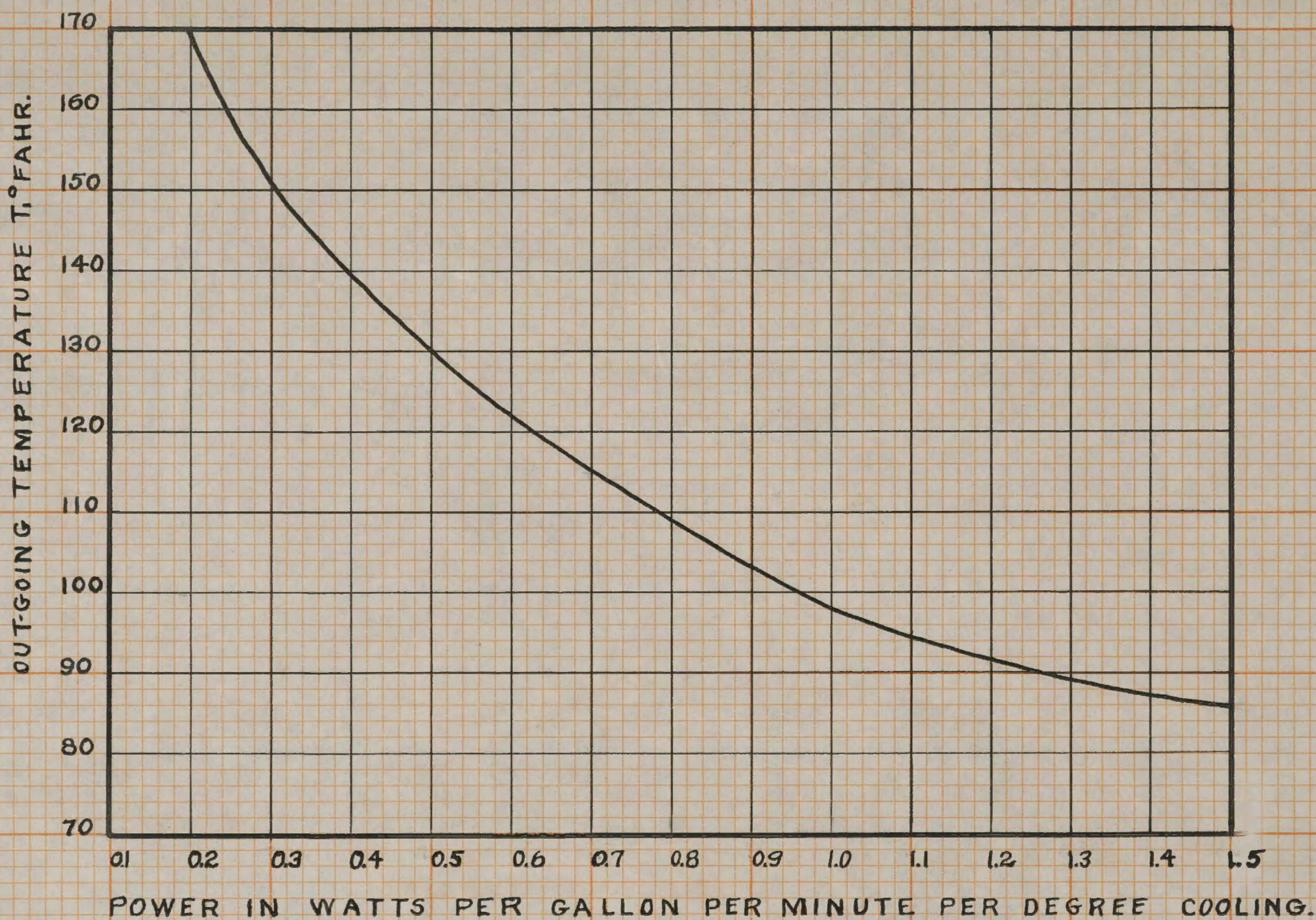
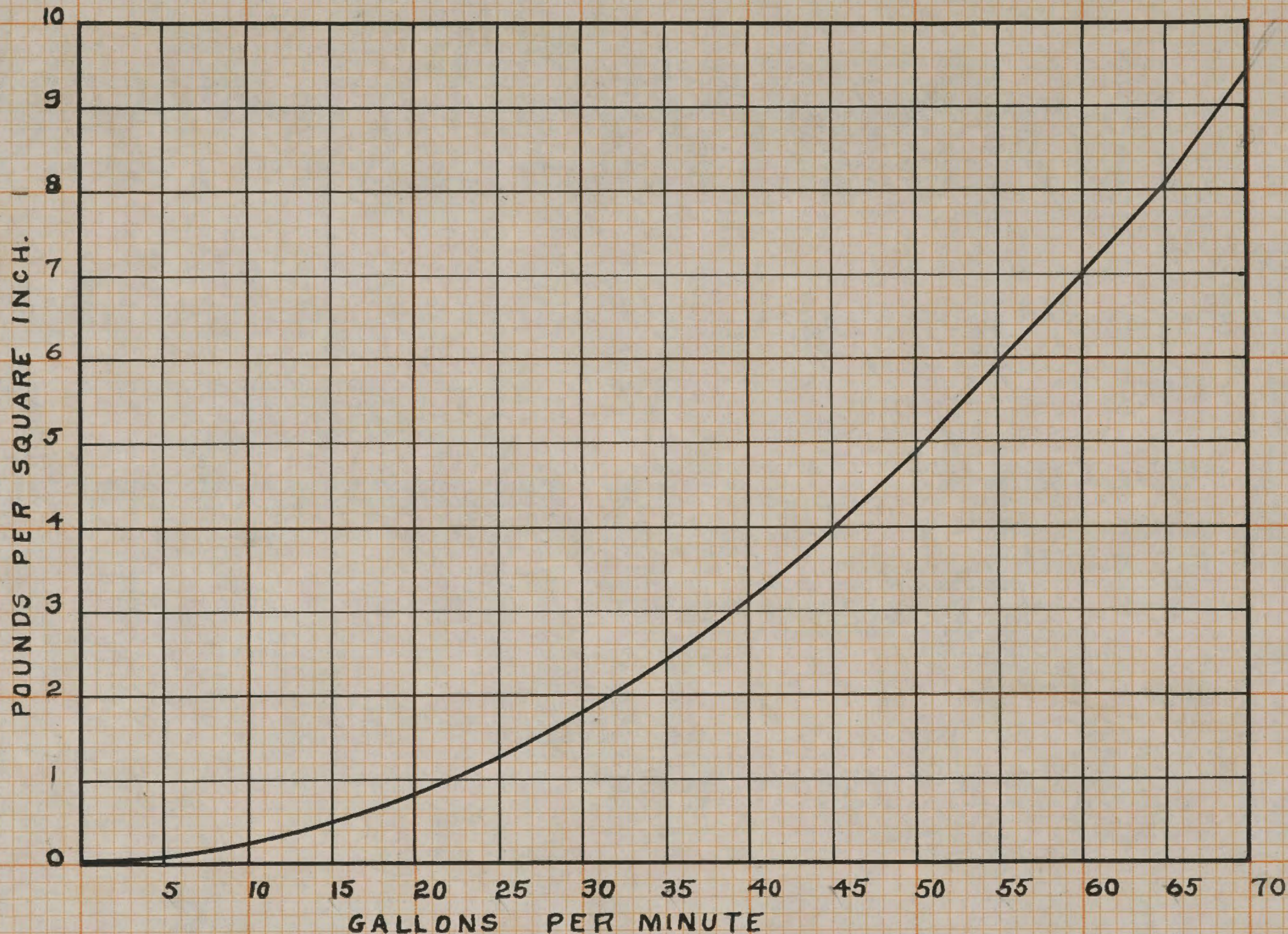
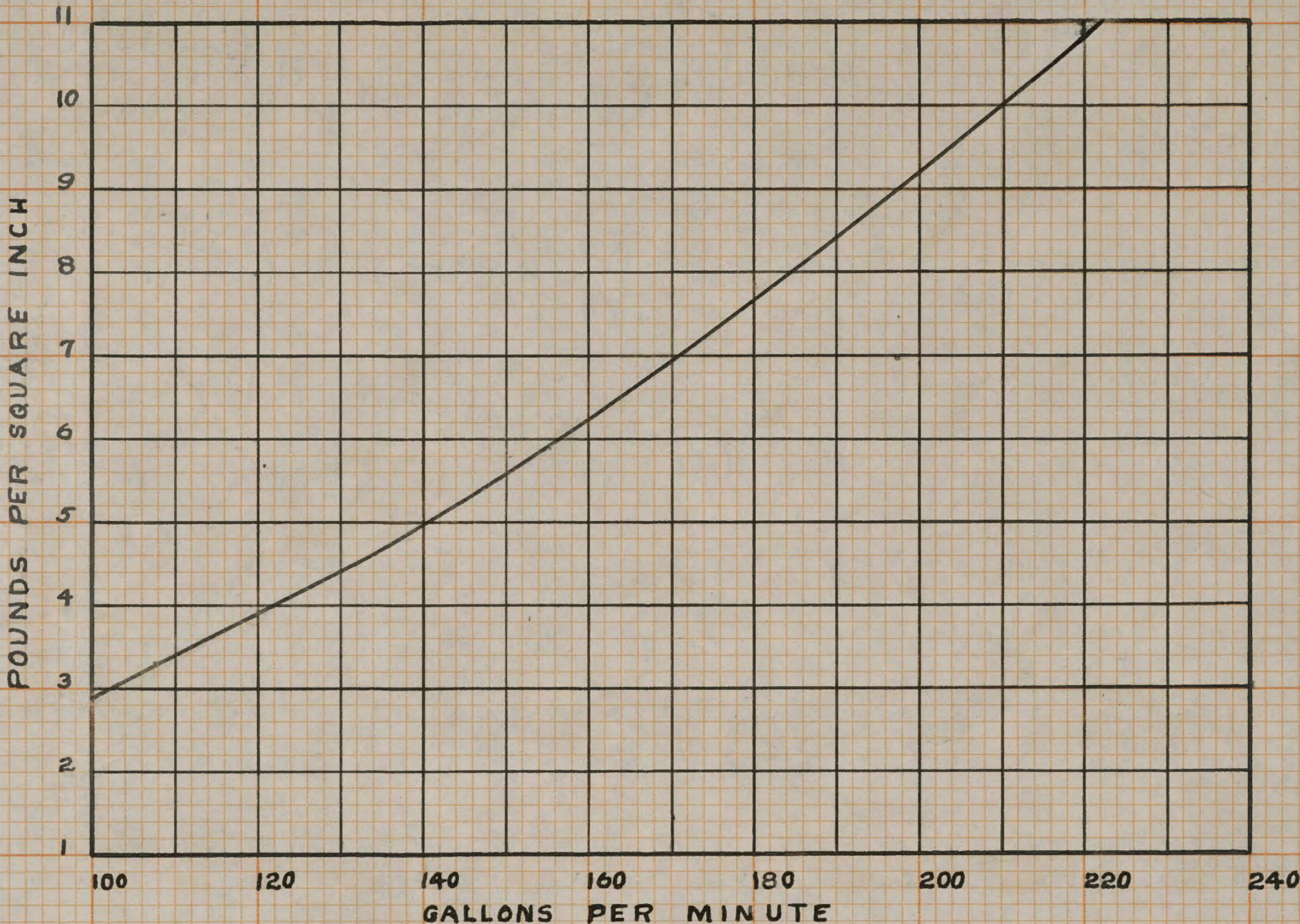

170
160
150
140
130
120
110
100
90
80
70
OUT-GOING TEMPERATURE T, °FAHR.
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
POWER IN WATTS PER GALLON PER MINUTE PER DEGREE COOLING.

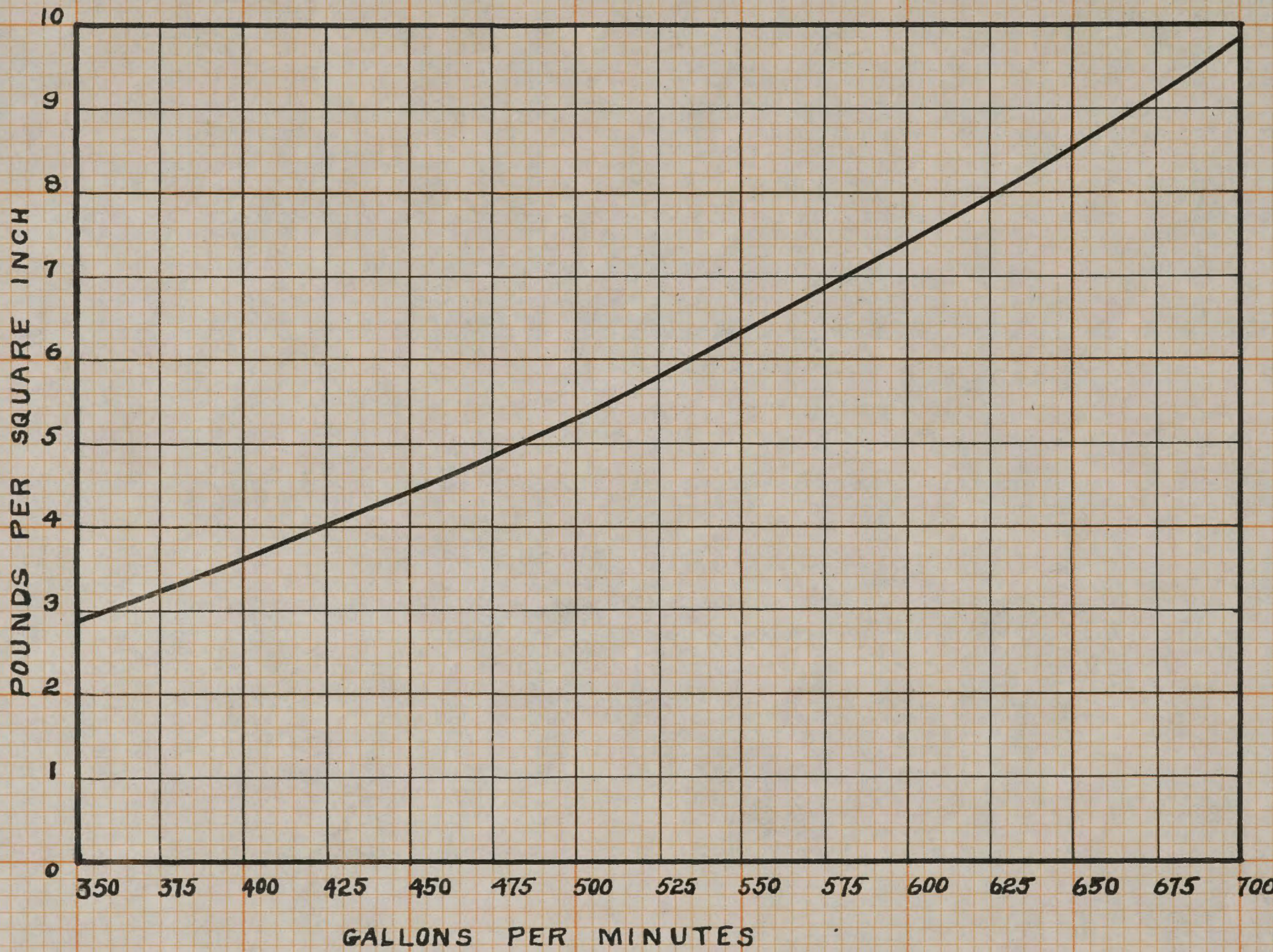
Fig-2.



AMOUNT OF WATER 2½" Klein INVOLUTE NOZZLE SPRAYED at DIFFERENT PRESSURES



AMOUNT OF WATER 2½" "THOMAS ADJUSTABLE" SPRAYED AT DIFFERENT PRESSURES



TOTAL AMOUNT OF WATER SPRAYED IN GALLONS PER MINUTE AT THE DIFFERENT PRESSURES.

INDEX FOR READING CHARTS

T = Temperature of air.
Tw = Temperature of wet Bulb.
T_1 = Temperature of water before spraying.
T_2 = Temperature of water after spraying.

V = Vacuum in inches.

$T_1 - T_2$ = Number of degrees water is cooled in pond.

$$E = \frac{T_1 - T_2}{T_1 - Tw} = \text{Efficiency of Spray Cooling.}$$

$$P = \left(\frac{100}{T_1}\right)^{3.23} = \text{Power required to circulate the water}$$

as watts per gallon per minute per degree of cooling from varying initial Temperature. (C. C. Thomas)

H = Humidity in percent.

L = Load in K. W.

C = Condensate Temperature.

TEST 1a

Weather Cool and Cloudy

Date 4/30/28

Pressure 4# gage

	Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
	9	86	68	55	99	88	11	60	$26\frac{1}{4}$	116
	10	81	68	55	99	88	11	60	$26\frac{1}{4}$	121
	11	86	64	56	100	89	11	57	$26\frac{1}{4}$	119
	12	70	62	56	100	89	11	52	$26\frac{1}{4}$	118
Average		$80\frac{3}{4}$	$65\frac{1}{2}$	$55\frac{1}{2}$	$99\frac{1}{2}$	$88\frac{1}{2}$	11	57.2	$26\frac{1}{4}$	118.5

$$E = \frac{99\frac{1}{2} - 88\frac{1}{2}}{99\frac{1}{2} - 55\frac{1}{2}} = \frac{11}{44} = 25\%$$

$$P = \frac{(100)}{(99.5)}^{3.23} = 1.0165$$

Test 2a

Weather Rain

Date 4/30/28

Pressure 5# gage

Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
1:30	68	60	61	99	89	10	85	26	120
2:30	120	59	58	100	90	10	75	24	149
3:30	155	59	57	102	90	12	75	24	150
4:30	130	64	57	103	92	11	64	$24\frac{1}{4}$	144
Average	118.2	$60\frac{1}{2}$	58.2	101	$90\frac{1}{4}$	$10\frac{3}{4}$	75	$24\frac{1}{2}$	140.7

$$E = \frac{101 - 90\frac{1}{4}}{101 - 58.2} = \frac{10.75}{42.8} = 24.5\%$$

$$P = \left(\frac{100}{101}\right)^{3.23} = .9684$$

Test 3a

Weather Fair and Cool

Date 5/1/28

Pressure 6# gage

	Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
	7	65	60	56.5	100	88	12	73	$26\frac{1}{4}$	118
	8	67	62	57	101	89	12	72	$26\frac{1}{4}$	119
	9	86	65	59	104	93	11	70	$26\frac{1}{2}$	120
	10	92	70	58.5	104	93	11	40	26	121
Average		77.5	64.2	57.7	$102\frac{1}{4}$	90.7	$11\frac{1}{2}$	63.7	$26\frac{1}{4}$	$119\frac{1}{2}$

$$E = \frac{102.25 - 90.7}{102.25 - 57.7} = \frac{11.50}{45.55} = 25.6\%$$

$$P = \frac{(100\ )^{3.23}}{(102\frac{1}{4})} = .926$$

Test 4a

Weather Fair and Cool

Date 5/1/28

Pressure 7# gage

Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
12	82	70	60	100	89	11	50	$26\frac{1}{4}$	118
1	82	70	61	100	89	11	52	$26\frac{1}{4}$	118
2	86	75	60	102	90	12	40	$26\frac{1}{4}$	119
3	88	74	59	102	90	12	40	$26\frac{1}{4}$	120
	$84\frac{1}{2}$	$72\frac{1}{4}$	60	101	89.5	11.5	45	$26\frac{1}{4}$	$118\frac{3}{4}$

$$E = \frac{101 - 89.5}{101 - 60} = \frac{11.5}{41} = 28.1\%$$

$$P = \frac{(100)}{(101)}^{3.23} = .9684$$

Test 1b

Weather Fair and Clear

Date 5/2/28

Pressure 7# gage

Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
7	80	68	55	98	85	13	42	$26\frac{1}{4}$	119
8	88	68	55	98	85	13	42	$26\frac{1}{4}$	119
9	87	69	56	99	85	14	42	$26\frac{1}{4}$	120
10	85	72	56	99	85	14	34	$26\frac{1}{4}$	122
	85	$69\frac{1}{4}$	$55\frac{1}{2}$	$98\frac{1}{2}$	85	$13\frac{1}{2}$	40	$26\frac{1}{4}$	120

$$E = \frac{98\frac{1}{2} - 85}{98\frac{1}{2} - 55\frac{1}{2}} = \frac{13.5}{43} = 31.4\%$$

$$P = \frac{(100\ )}{(98.5)} = 1.05$$

Test 2b

Weather Fair and Clear

Date 5/2/28

Pressure 6# sq. in. gage

Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
11	88	73	53	100	85	15	23	26	123
12	70	74	53	100	86	14	23	26	122
1	78	75	55	101	86	15	24	$26\frac{1}{4}$	119
2	78	75	56	101	87	14	27	$26\frac{1}{4}$	119
	78.5	$74\frac{1}{4}$	$54\frac{1}{4}$	$100\frac{1}{2}$	86	$14\frac{1}{2}$	$24\frac{1}{4}$	26 1/8	120.7

$$E = \frac{100\frac{1}{2} - 85}{100\frac{1}{2} - 54\frac{1}{4}} = \frac{14.5}{46.25} = 31.4\%$$

$$P = \left(\frac{100}{100.5}\right)^{3.23} = 0.983$$

Test 3b

Weather Fair and Clear

Date 5/2/28

Pressure 5# gage

Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
3	80	76	53	101	88	13	23	26	123
4	92	77	53	101	89	12	23	25 7/8	130
5	95	76	54	103	90	13	23	$25\frac{1}{2}$	132
6	100	76	56	105	93	12	25	25 7/8	130
	91.7	$76\frac{1}{4}$	54	$102\frac{1}{2}$	90	$12\frac{1}{2}$	23.7	25 4/5	$128\frac{3}{4}$

$$E = \frac{102\frac{1}{2} - 90}{102\frac{1}{2} - 54} = \frac{12.5}{48.5} = 25.7\%$$

$$P = \left(\frac{100}{102.5}\right)^{3.23} = 0.921$$

Test 1c

Weather Fair and Warm

Date 5-3-28

Pressure 5# sq. in. gage

Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
9	62	66	58	110	95	15	67	$25\frac{1}{2}$	122
10	75	71	59.5	118	100	18	50	25 7/8	140
11	82	75.5	59.5	120	103	17	39	$26\frac{1}{4}$	141
12	76	80.5	59	118	103	15	29	$26\frac{1}{4}$	136
	$73\frac{3}{4}$	$73\frac{1}{4}$	59.0	$116\frac{1}{2}$	$100\frac{1}{4}$	$16\frac{1}{4}$	$45\frac{1}{2}$	26	$134\frac{3}{4}$

$$E = \frac{116\frac{1}{2} - 100\frac{1}{4}}{116\frac{1}{2} - 59} = \frac{16.25}{57.5} = 28.5\%$$

$$P = \left(\frac{100}{116.5}\right)^{3.23} = .6104$$

Test 2c

Weather Fair and Warmer

Date 5/3/28

Pressure 4# gage

Time	L	T	Tw	T_1	T_2	T_1-T_2	H	V	C
1	60	84	62	122	107	15	23	$25\frac{3}{4}$	132
2	68	85	63	124	110	14	24	$25\frac{3}{4}$	134
3	70	86	63	126	110	16	25	25	136
4	80	88	64	126	111	15	27	$25\frac{1}{4}$	142
	69.5	$85\frac{3}{4}$	63	$124\frac{1}{2}$	$109\frac{1}{2}$	15	$24\frac{3}{4}$	$25\frac{1}{2}$	136

$$E = \frac{124.5 - 109.5}{124.5 - 63} = \frac{15}{61.5} = 24.4\%$$

$$P = \left(\frac{100}{124.5}\right)^{3.23} = 0.4926$$

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Brayton, H. M.

2 : Binks Spray Equipment Company,

Spray Cooling Towers.

3 : Yarnall Waring Company,

Spray Cooling.

4 : Spray Engineering Company,

Spraco System.

The data recorded in this experiment gave exceedingly low results which can be contributed to many causes. This pond deviates in every way from standard practice and violates all previous experimental work accomplished in this particular field. The spray system in general depends upon evaporation and suitable storage for its effect. In this particular pond the storage is entirely removed and the evaporation is hindered by the poor location of the pond itself, which is cut off from the moving air currents by the plant on one side and a high bank on another. Although this is quite a hindrance, it is what must be expected and overcome in actual practice. There were no grounds available for a pond and a cooling tower of sufficient size could not be constructed at a reasonable cost without maring the appearance of the surrounding terrace which in this particular case would not be justified. Conditions of this nature, although not of the same type, may occur in any installations and therefore must be met in some similar way.

Another cause which contributed to the low efficiencies was the way in which the nozzles were crowded. This crowding prevented a thorough circulation of the air and caused what is known as "hot spots" in the system. Where ever "hot spots" are present no cooling takes place thus affecting the entire system by gradually raising the temperature of the initial state of the water. This does not affect to any great degree the effect of the temperature T_1-T_2, but does continue to raise both to a point where the desired results cannot be obtained.

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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