May 9th, 1918.

COOLING OF CONDENSING WATER BY TOWERS AND SPRAYING.

By E. W. MARRIOTT.

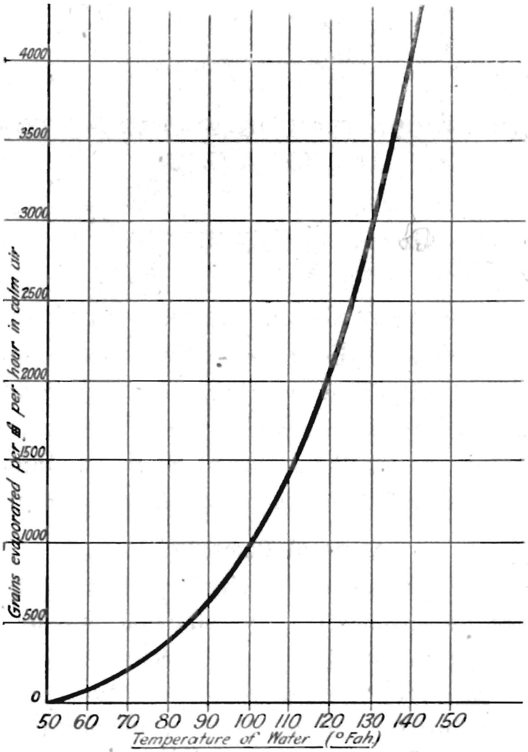
I have been asked by our President to put together some notes on the cooling of condensing water, as I have had an opportunity of comparing the efficiencies of both Tower and Spray Cooling Systems under identical weather conditions at one of the Colonial Sugar Refining Company's mills, situated in the humid zones of the tropics.

General Remarks.

The cooling of water under either system is effected in three ways, by evaporation, by radiation, and by convection, that is, by contact with the cold air. During cold weather most of the heat is lost by radiation and convection, but during the hot weather by evaporation.

The laws governing radiation, convection, and the amounts of cooling produced by evaporation are given in text books and scientific papers; some of them are of a complex nature, and as far as I have been able to make use of them, of little value in determining the amount of cooling which might be expected. The difficulty lies in fixing the values relating to atmospheric conditions. However, some experiments made by Box, given in his "Treatise on Heat," showing the rate of evaporation with increasing temperatures, and the effect of the wind on the rate of evaporation, are of special interest.

In figure I. I have plotted the results of his experiments and the rate of evaporation with increasing temperature—



CURVE SHOWING THE EFFECT OF THE TEMPERATURE OF WATER ON THE RATE OF EVAPOPORATION IN CALM AIR AT 52° FAH & 85° HUMIDITY.

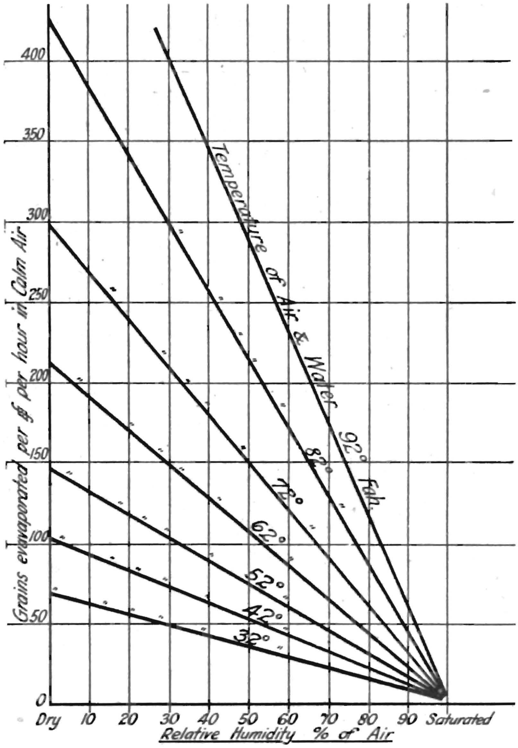
$E = \{243 + (3{\cdot}7 \times t)\} \times (V - v)$. Box p. 152.

Fig. 1.

from which it will be seen that the hotter the water to be cooled the greater the amount of evaporation, and therefore the greater the temperature drop to be expected, though the drop is by no means directly proportional.

To show the effect of the wind, Box exposed a small vessel partly filled with water to winds varying in strength from a fresh breeze to a gale, and found that the increased rate of evaporation was in the ratio of 1.0, 4.4, 8.8, 12.4, with calm air, a fresh breeze, a strong wind, and a gale respectively.

The effect of the state of dryness of the air on the amount of evaporation for various temperatures is shown in figure II.:—

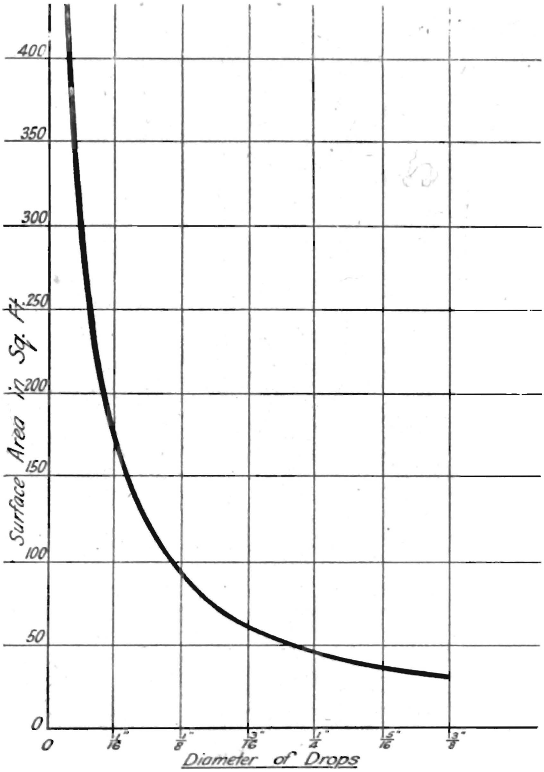


CURVE SHOWING THE AMOUNT OF EVAPORATION AT ORDINARY TEMPERATURES WITH AIR IN DIFFERENT STATES OF DRYNESS

$R = (F - f) \times 378$. Box p. 142.

Fig. 2.

And, since the amount of cooling, whether by evaporation, radiation or convection, is so dependent on the surface area of water exposed, a curve shown in figure III. illustrates how rapidly the surface area increases as the smallness of the drops or the fineness of the sprays increases:—

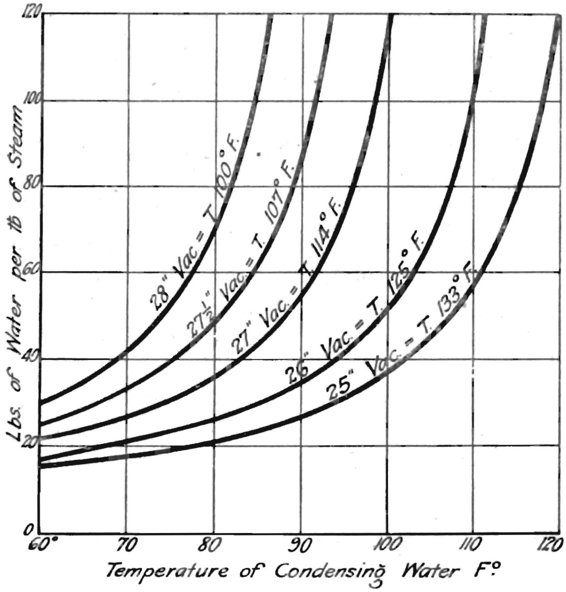


CURVE SHOWING THE RATE OF INCREASE IN THE SURFACE AREA EXPOSED AS A GALLON OF WATER IS DIVIDED INTO DROPS OF DECREASING DIAMETER.

Fig. 3.

Quantity of Water.

Where condensing waters are circulated, no matter what cooling system is adopted, their temperatures will, in most cases, be above that of the atmosphere, so I have added another curve, figure IV., showing the quantity of water required for the ordinary conditions met with in practice:—



Formula $W = \frac{H - T_2}{T_2 - T_1}$

W = Lbs. water per ℔. steam condensed.
H = Total heat of steam reckoned from zero to the temperature equivalent to vacuum required.
T_1 = Initial temperature of water.
T_2 = Final " " " and reckoned 5° below equivalent temperature of vacuum.

QUANTITY OF WATER FOR BAROMETRIC CONDENSERS.
Fig. 4

For reasons other than economy in fuel, high vacuua in evaporating plants are aimed at in sugar factories. It will be seen that with condensing water above atmospheric temperature, the quantity required very quickly assumes large proportions.

Tower.

Fifteen years ago the C.S.R. Company erected at one of its sugar mills a Forced Draft Cooling Tower, from which very good results were obtained, provided it was worked within its capacity and kept in a good state of repair. For any further increase, once a tower has reached its capacity for a given set of conditions, it loses its flexibility, and expensive addition, probably greater than required at the time, is necessary. If the maintenance is high this addition makes a bad position worse, for whether a tower is worked at its full capacity or not the maintenance is the same.

Maintenance.

The Company's experience is that the maintenance of the tower is high. I cannot give the actual figures since it was built. In any case, figures, unless corrected to some standard cost of material and wages, are useless, but I can tell you that all the timber work has been renewed at least once, most of it twice, and some of it several times, and at the present time the whole of it would need renewing or rebuilding in other material. There is now over 50,000 super. feet of timber in the structure, so members can figure for themselves the cost of repairs. The maintenance of the engines driving the fans and of the pumps is of course normal, but that for the fans is higher than might be expected. The blades have to be repaired or renewed every year. The distributing system, whether of the rotary type or flumes with wire edges, need constant attention. A description of the tower and plant is given later.

Disadvantages of Towers and Advantages of Spray Cooling.

This high maintenance bill and want of flexibility led to the spray cooling system being investigated, for, other than the pumps, the maintenance of such a system should be practically nil.

The spray system will generally be found to have two other main advantages over a cooling tower. They are:—

(1) Lower first cost.

(2) If forced draft is used in the tower a saving, generally reckoned at 50 per cent., in the power required for operation.

The main disadvantage is the space required, this being considerably in excess of that required for the tower.

Description of Towers.—Structure.

In 1903 a tower of the forced draft type was installed. It consisted of one rectangular tower 14ft. x 28ft. x 30ft. high, divided into two compartments 14ft. square, the lower 9ft. of the casing being of concrete, and the upper 21ft. of wood. The grid was made of 6 x 1 hardwood (N.S.W.) boards, standing on edge, spaced 6in. centres, alternate layers at right angles, not staggered, and with a total height of 17ft. from the top of the concrete. In this structure there was some 15,000 super. feet of timber.

Pumps.

Two plunger pumps, one 15in. x 12in. x 18in. and the other a duplex 16in. x 14in. x 15in., delivered the water to the top of each compartment, where it was distributed over the grids by means of rotary distributors, the quantity flowing to each compartment being regulated by butterfly valves to give equal cooling in each.

Fans.

Air was supplied by two 70in. Sirocco fans, propeller type, one for each compartment, delivering into the bottom, and thus giving counter current effect. The fans and distributors being driven by a pair of 10in. x 12in. cross coupled engines.

Trials.

In Tables I., II., III. are given the results of some trials of this plant. Each set of figures is the average of about 20 observations taken during the course of a day:—

TABLE I.

Two 70″ Fans.					Water Temperatures			Air Temperatures.		
Test No.	R.P.M.	Cu ft of air per fan per min.	Deliv'ry Pres're. Inches water	I H.P. of Engin's	Inlet °F.	Outlet °F.	Temp Drop	Inlet °F.	Hum'ty %	Outlet °F
1	250	37500	$\frac{1}{8}$ bare	14·5	117	89	28	77	79	—
2	275	42250	$\frac{1}{8}$	16·0	117	87	30	80	72	—
3	300	43000	$\frac{3}{16}$	19·0	111	84	27	81	72	100
4	325	46750	$\frac{1}{4}$ bare	22·0	117	84	33	78	74	100
5	350	52600	$\frac{1}{4}$	26·0	115	85	30	82	68	103
6	375	56256	$\frac{1}{4}$ full	33·0	118	81	37	77	74	95
7	410	60000	$\frac{5}{16}$	35·0	115	85	30	80	65	99

Water, 47,000 gallons per hour.

Wind: Vel. 10 to 25 miles per hour, N.E., N.N.E., S.S.E.

Sky: Cloudy, dull, bright, showery.

TABLE II.

Teet No.	Two 70″ fans.	Water Temperatures			Air Temperatures.		
	R.P.M.	Inlet °F.	Outlet °F.	Tem. drop	Inlet °F.	Hum'ty. %	Outlet °F.
1	250	116	89	27	76	78	106
2	275	114	83	31	80	72	102
3	300	117	82	35	79	66	102
4	325	116	83	33	81	68	101
5	353	115	78	37	78	69	95
6	375	115	75	40	76	73	100
7	400	113	79	34	77	72	97

Water, 50,000 gallons per hour.

TABLE III.

Test No.	Two 70″ fans.	Water temperature.			Air temperature.		
	R.P.M.	Inlet °F.	Outlet °F.	Tem. drop	Inlet °F.	% Hum'ty.	Outlet °F.
1	250	120	96	24	81	69	118
2	275	122	98	24	84	77	121
3	300	119	95	24	83	78	119
4	325	121	93	28	81	76	112
5	350	119	91	28	81	83	113
6	375	122	93	29	84	80	110
7	400	122	92	30	84	79	101

Water, 65/70,000 gallons per hour.

The following year the cooling plant was duplicated. The boards in the grid were spaced 4in. centres, with a view to obtaining a finer subdivision of the water. The fans were run at 250 r.p.m.

Figure V. shows an external view of the Towers.

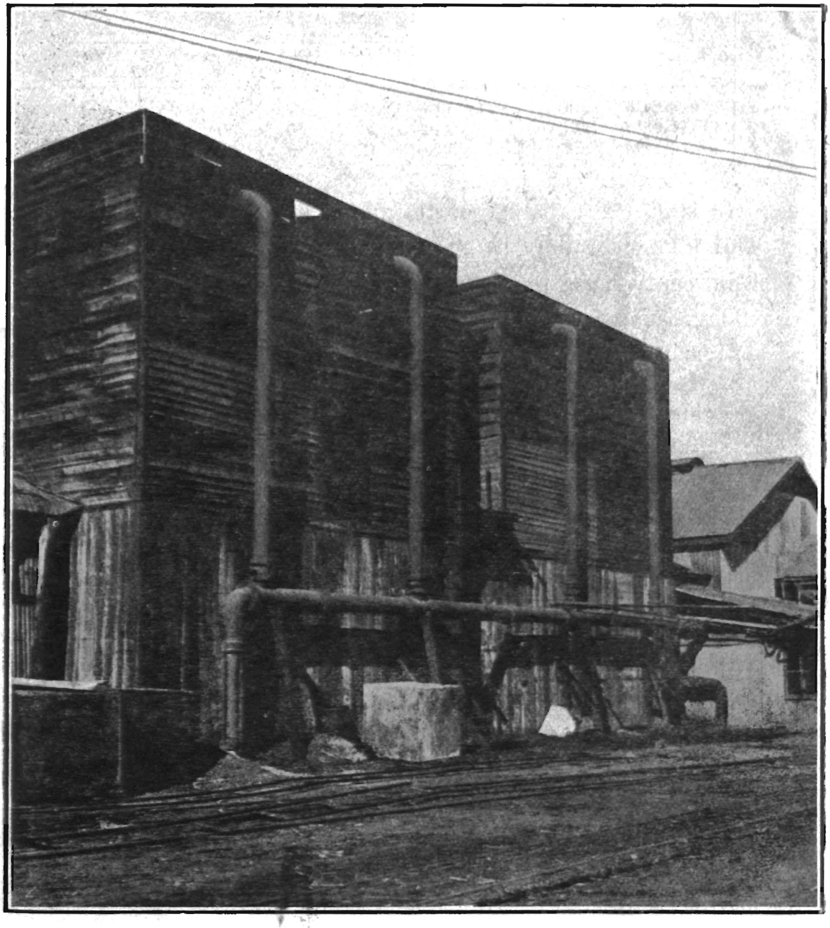


Fig. 5.

Table IV. gives the results of some special trials during the next two years. The figures given in (1) and (2) are each the averages of 150 observations taken over a week, and those in (3) of 100 observations taken over 5 days.

TABLE IV.

Test No.	Water	Four 70° Fans		Water temperature.			Air temperature.		
	Gallons per hr.	R.P.M.	I.H.P.	Inlet ° F.	Outlet °F.	Temp. Drop.	Inlet ° F.	% Humidity.	Outlet % F.
1	90000	250	46	115	88	27	81	83	103
2	95/100000	275	—	116	96	20	90	84	94
3	95/100000	290	—	115	97	18	86	84	—

In 1906 the capacity of the plant was again increased. The plunger pumps were replaced by a Ruston Proctor 10in. centrifugal pump, and two of the 70in. fans by two 100in. fans of the same make and type. The larger fans delivering more air for less power.

Table V. gives the results of some special trials.

TABLE V.

Water, 135,000 gallons per hour.

Test No	2·70° & 2 100″ Fans			Water temperature			Air temperature		
	100″ Fans. R.P.M.	70″ Fans R P.M.	I H P. of Engines.	Inlet ° F.	Outlet ° F.	Temp. Drop.	Inlet ° F.	Humidity %	Outlet ° F.
1	170	250	35	115	89	26	83	80	109
2	182	280	40	118	90	28	9[illegible]	81	104

In the years following the alterations made were restricted to the motive power, except that the 6in. x 1in. boards were notched into each other an inch to provide a better method of keeping them in place, and two of the rotary distributors were replaced with wooden flumes having weir edges. In Table VI. the average cooling effect obtained for each year up to 1915 is given. The figures given represent the average of a large number of observations. Generally one set of observations was made each shift of 8 hours, that is, three sets per day, for six days per week throughout the whole season. I find it impossible to give the average quantity of water passed through the tower; the figures given must be taken as approximate:—

TABLE VI.

Year.	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915
Number of weeks	25	29	29	27	28	24	23	29	17	23	29	21	17
Quantity of water Galls. per hour	45/75030	90000	95/100000	125/130000	125/130000	125/130000	125/130000	125/130000	125/130000	125/130000	125/130000	125/130000	125/130000
Temp're. of water Inlet ° F ...	123·5	127·8	118·0	116·8	110·3	110·0	115·8	113·0	116·0	119·0	118·0	114·0	121·0
Temp're. of water Outlet ° F ...	95·9	92·4	90·5	88·6	88·9	90·6	95·3	96·0	95·0	92·0	96·0	96·0	99·0
Temp're. drop °F	27·6	35·4	27·5	28·2	21·4	19·4	20·5	17·0	21·0	27·0	22·0	18·0	22·0

At first sight there appears to be a big variation in the efficiency. Evaporation probably is the greatest factor in the amount of cooling effected, and remembering Box's experiment, shown in Fig. I, it will be seen in Fig. IV, where the temperature drops have been plotted as ordinates and the corresponding inlet temperatures as abscissae the variations from the mean curve, except for the years 1906, 1907 and 1915, are remarkably small; over such a long period variations in atmospheric conditions and efficiency of the plant must have occurred. For 1906 and 1907 the temperature drops are high, and, apart from anything else, we know the plant for these years was in good order, whereas in 1915 the drop is low, and we know the plant to have been in a bad state of repair.