SOME NOTES ON THE HYPERBOLIC COOLING TOWER AT MAIDSTONE

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This is a short paper which will deal with the construction, theory and performance of the hyperbolic cooling tower at Maidstone. Frequently we are asked how effective the cooling is and how much evaporation takes place in the tower. The theoretical and actual figures will be included for comparison.

Construction

Essentially the cooling tower is a chimney open all round at the bottom and standing in a pond of water. In the lower section, wooden slats are arranged so as to present the maximum surface area of water to be cooled, to the cooling air. The air flow is caused by a density difference between the heated air in the tower and the surrounding air. The height of the tower above the water level is 100 feet and its diameter at the base is 75 feet. The neck of the tower at 85 feet above water level is 36 feet and the diameter at the top is 38 feet. Water to be cooled is pumped up a central column to which pipes equipped with sprayers radiate from the centre in a horizontal direction to the circumference with the water sprayers pointing vertically upwards. Beneath this level (18 feet above pond water level) the wooden slats form the tower stack over which the water cascades, presenting a large surface area to the cooling air.

The whole construction of the shell of the tower is reinforced concrete. The inclined columns at the base which form a series of "A" frames and also form the opening for the air inlet to the tower are 9 inch octoganal in section. These columns support the main 9-inch circular beam on which the reinforced shell is sprung. The shell thickness tapers fairly rapidly to 4 inches in thickness which is then constant to the top except for the top capping. Being hyperbolic in section, all the main reinforcing bars are straight and inclined slightly off the vertical. It was constructed by using creeping formers bolted in place with spacers to ensure that a uniform thickness of shell was obtained. After the shuttering had been removed the holes left by the spacers were filled with grouting to prevent air short-circuiting the tower stack. The tendered price for the tower was £12,000 in 1948 but the whole construction of tower, reinforced concrete pump-house and 24-inch supply and delivery piping to the factory cost £23,000 when completed.

The following quantities were used:

2,800	cu. yards of excavations
620	cu. yards of concrete of which the shell accounted for 203.6 cu. yards.
37½	tons of reinforcing material
2,300	cu. feet of timber in the cooling stack
396	Asbestos cement water sprayers

(The above quantities refer to total of tower and pump-house.)

Theory

The design of the tower was prepared by Messrs. Mouchel and Partners of London with Messrs. Kanthack and Partners of Johannesburg as consultants. The specified duty of the tower is to cool 300,000 gallons of water per hour from 120°F to 95°F when the atmospheric dry bulb temperature is 70°F and the relative humidity is 65 per cent which corresponds to a wet bulb temperature of 63°F.

It is as well to explain at the outset that not all the hot water from the sealing wells is passed through the tower. At peak factory some 600,000 gallons of water per hour are pumped into the condensers, half of which is re-circulated through the cooling tower, the other half finding its way back to the river via the main drain. The cooled water is mixed with an equal quantity of river water and the final temperature is therefore below the temperature of that of the exit water from the tower.

It can be proved mathematically that the water can be cooled to the temperature of the wet bulb thermometer, that is, to a temperature below that of the atmospheric air (depending on the relative humidity). To achieve this theoretical result would involve enormous capital expenditure and is therefore impractical. It can also be proved that with practical applications the rate of cooling per square foot of ground occupied by the natural draught cooling tower is three to four times less than that of the ordinary spray pond and it is not affected to any marked extent by conditions of wind. At Maidstone the space available was one of the prime reasons for utilising a hyperbolic tower in place of a spray pond.

The cooling of the water is effected by evaporation and by convection, both functions being greatly increased by presenting as large a surface area of water as possible to the cooling air. This as mentioned before, is achieved by the timber stack inside the tower. In the appendix of this paper, calculations can be found for the standard conditions as specified by the designers. One assumption has been made to arrive at the results, and that is that the exit air temperature at the top of the tower is 100°F and the water humidity is 100 per cent. The following results are obtained by calculation:

1. Quantity of air required to cool 5,000 gallons of water per minute from 120°F to 95°F at air temperature of 70°F with relative humidity of 65 per cent is 31,400 lbs per minute. (Slide rule calculation.)

2. Volume of air per minute at 70°F is 438,000 cubic feet.
3. Velocity at neck of tower 438 feet per minute (approximately 5 miles per hour.)
4. Percentage evaporation of water to be cooled is 1.99 per cent.
5. Percentage cooled by evaporation to total cooling is 80.3 per cent.

As stated all the above figures are theoretical, and to be expressed in scientific figures they refer to dry air.

Comparison of actual figures obtained.

Periodic checks are made on the performance of the cooling tower and the following temperatures are observed:

(*a*) Temperature of water entering tower
(*b*) Temperature of water leaving tower
(*c*) Temperature of water entering factory
(*d*) Temperature of river water
(*e*) Temperature of air on dry bulb
(*f*) Temperature of air on wet bulb.

Taking some readings at random during November and December, which are obviously the months in which the worst conditions can be expected, we find that on one day only, did the temperature of water entering the tower reach 120°F. On that day, 1st December, 1953, the temperature was 120.1°F and it was cooled down to 91.8°F with a dry bulb temperature of 77°F and relative humidity of 91 per cent. By comparison of temperature of the water pumped to the factory (89.6°F) and the river water (82.4°F), we find that 3.27 times as much water was passing through the tower than was being added from the river or alternatively 76.7 per cent of the total. It is reasonable to assume that at that particular time (6.30 p.m.) the full flow of 300,000 gallons per minute was flowing through the tower. Here we have a result far above the specified accepted duty.

The average figures for December read as follows:

Dry Bulb temperature = 77.6°F
Wet Bulb temperature = 74.1°F
Giving a Relative humidity of 86 per cent
Temp. of water entering tower = 102.7°F
Temp. of water leaving tower = 88.4°F
Giving a temperature drop of 14.3°F
Temp. of river water = 76.2°F
Temp. of water to factory = 84.7°F

Signifying that 69.9 per cent of water entering factory passes through the cooling tower.

For November the figures read:

Dry bulb = 74.0°F Wet bulb = 70.7°F
Relative humidity = 84 per cent
Temp. entering tower = 103.9°F
Temp. leaving tower = 89.4°F
Temp. drop = 14.5°F
Temp. of river water = 74.3°F
Temp. entering factory = 86.7°F

Showing that 82.1 per cent of water entering factory had been through the cooling tower.

December—
Average dry bulb temp. for 10 yrs. = 76.4°F
Average wet bulb temp. for 10 yrs. = 68.7°F
Average humidity = 67 per cent

November—
Average dry bulb temp. for 10 yrs. = 74.4°F
Average wet bulb temp. for 10 yrs. = 66.9°F
Average humidity = 66 per cent

From the above figures it would seem that the year 1953 ended up with very high relative humidities.

Appendix

To find weight of air required to cool 50,000 lb. water from 120°F to 95°F with dry bulb temperature of air 70°F and relative humidity 65 per cent. (Wet bulb = 63°F.)

We will symbolise various data:

p = true partial pressure of water vapour in mixture
p^1 = saturation pressure at wet bulb temperature
t = dry bulb temperature
t^1 = wet bulb temperature
p_m = total pressure of mixture

First formula:

$$p = p^1 - 0.000367 p_m \left(t - t^1\right)\left(\frac{t+1539}{1571}\right) \quad \ldots \quad (1)$$

Substituting figures we get

$p = 0.50$ in Hg

Thus weight of water vapour per lb. of air mixture is given by:

$$w^1 = 0.622 \frac{p}{p_m - p} = 0.622 \frac{0.50}{30 - 0.50} = 0.0105 \text{ lbs.}$$

For air at 100°F and Relative Humidity, from formula (1) we get

$p = 1.9$ inches Hq

$$wa^1 = 0.622 \frac{1.9}{30 - 1.9} = 0.0421 \text{ lbs./16 of mixture}$$

Water evaporated per lb. of mixture = 0.0346 lbs.

Now where—

Wa = weight of air in lb./min.
W = weight of water in lb./min.
h_1 = heat content of water entering tower
h_2 = heat content of water leaving tower
H_1 = heat content of vapour mixture entering tower
H_2 = heat content of vapour mixture leaving tower

Then—

$$Wa = \frac{W(h_1 - h_2)}{H_2 - H_1 - (wa^1 - w^1)W_2} \quad \ldots \quad (2)$$

The values for the heat content of vapour mixture are obtained from the formula:

$$H = 0.24\,(t - 32) + w^1(1059.2 + 0.45t) \quad \ldots \quad (3)$$

for example—

$$H_2 = (0.24 \times 68) + 0.0481\,(1059.2 + 0.45 \times 100) = 62.86$$

$$Wa = \frac{50000 \times 25}{62.86 - 20.66 - 0.0316 \times 63}$$

= 31,400 lb. of dry air per minute

$$\text{Volume} = Wa \frac{t + 460}{D \times P \times 33.49} \quad \ldots \quad (4)$$

where—

D = weight of gas in lb. per cu. foot

P = absolute pressure in lb. per sq. inch

$$= 31,400 \times \frac{530}{0.0807 \times 14.7 \times 33.49}$$

= 438,000 cu. feet per minute

$$\text{Velocity} = \frac{\text{Volume per minute}}{\text{cross-section area}} = \pm 438 \text{ ft./minute.}$$

REFERENCES

(1) Ferrel Psychrometric formula.
(2) and (3) Heat-Power Engineering—Barnard, Ellenwood and Hirshfeld.
(4) Useful Tables—Babcock & Wilcox Ltd.

The President said that these papers gave us information such as we had never had before and should be valuable to people who wished to erect cooling towers.

Mr. Main wanted to know if the comparative costs could be given.

Mr. Trewren said the cost of the cooling tower at Rossburgh was £15,000.

Mr. Main considered therefore that it was much cheaper than the Maidstone tower.

Mr. Gunn gave the cost of the Maidstone tower.

Mr. Main pointed out that the cedar slats deteriorated much faster than a concrete tower.

Mr. Trewren stated that the guaranteed life of a tower was twenty years.

Mr. Leclezio said it was interesting to compare the cooling efficiencies of the two towers. One thus arrived at a figure of 50 per cent at Maidstone as compared with 70 per cent at Huletts.'

Mr. Gunn said it was admitted that induced draught fan cooling towers were more efficient than the hyperbolic tower. This again was more efficient than the spray pond, but the cost of maintenance had to be taken into consideration. Furthermore with the hyperbolic tower no power was required to force air through.

Mr. Seymour enquired about the current consumption in the induced draught fans and he asked if they were variable speed fans.

Mr. Trewren said that the fans were run at full capacity requiring 40 h.p. He pointed out that during the winter the motors ran at half speed almost continuously and 10 h.p. was negligible as far as the Refinery requirements were concerned.

Mr. Walsh enquired what the depth of the water was in the ponds and pointed out that in the ordinary spray pond a head of only fifteen feet or so was required whereas in the cooling towers a considerable amount of power was required to raise the water to the top of the towers.

Mr. Trewren said that for most of the water passing through the cooling tower at Rossburgh pumps were not required.

Mr. Dick said that in designing the Maidstone tower a relative humidity of 66, as supplied from the Experiment Station, was used whereas at Rossburgh the relative humidity was 72. He wanted to know if there was so much difference in Durban, say, as compared with Maidstone as this factor was of great importance in designing equipment. He wanted to know from Mr. Gunn what was an actual expected figure for the worst conditions and not an average figure of relative humidity at Maidstone.

Mr. Gunn pointed out that the figures for relative humidity were misleading because those given for Maidstone were taken in November and December whereas at Rossburgh they were taken in April and May. Mr. Gunn said that the design of the tower was carried out by Messrs. Mouchel & Partners who were quite happy to take a figure supplied by a place twelve miles away.

Mr. Du Toit said that the relative humidity at Mount Edgecombe would be different from Durban, but there should not be much difference between Mount Edgecombe and Maidstone. He did not know when the figures were taken. He asked if they were taken at midday.

Mr. Gunn said the figures taken were average ones taken at 8 a.m. and 1 p.m. The figures taken at Maidstone were taken at 6 a.m., 1 p.m. and 6.30 p.m.