J. Sci. Engr. Tech. 3(2), 460 - 470, Oct. 1996.

EFFECT OF DRAUGHT ON EVAPORATIVE COOLING IN EARTHENWARE POTS

J. A. Olorunmaiye
Department of Mechanical Engineering,
University of Ilorin
Ilorin, Nigeria.

ABSTRACT

An earthenware pot filled with water was exposed to draughts of 8.9 km/h and 15.7 km/h, at different times, from a fan. Water temperature, room air dry-bulb temperature and relative humidity and mass of water left in the pot were measured hourly or bihourly. Water temperature depressions up to 106% of wet bulb depression and water cooling rates up to 146 W per square metre surface area of the pot were obtained.

INTRODUCTION

The only form of cooling of drinking water commonly enjoyed in rural areas, which have no electricity, in many developing countries is evaporative cooling in earthenware pots filled with water. As the water seeps out of the porous pot, some of it evaporates and thereby cool the pot and its content. If the climate is dry and the pot is kept in shade outdoors on a windy day, the water in the pot is cooled to a temperature which lies considerably below ambient temperature.

Evaporataive cooling finds considerable application in desert climates. Before the development of vapour absorption and vapour compression refrigerators, porous earthenware jars were in much demand to keep drinking water coll through the process of evaporation.

An interesting application of porous earthenware jars for space cooling is done in traditional Middle Eastern architercture. The pots containing drinking water are arranged in the duct conducting trapped wind into the underground room (basement) so that the evaporation of the water seeping out cools both the air blowing past the pots and the water in the pots (1). Unit the early 1940's small earthenware evaporative coolers were used extensively in Europe to cool butter and cheese (2).

In some places, earthenware pots for drinking water are normally kept indoors where the air is still. In his experimental investigation of cooling of water in earthernware pots kept in quiescent air, Olorunmaiye reported water temperature depression below room dry bulb temperature up to 72% of wet bulb depression and water cooling rates up to 18 W per square metre of pot surface area, at Ilorin in the month, of December (3). He also found that the rate at which water seeps out of the pot in quiescent air is much higher than the rate of evaporation; after 108 hours, 30% of the initial mass of water had collected in the plastic bowl in which the pot was placed (3).

The earthenware pot is sometimes kept outdoors in a shade where it is exposed to draught. The work reported here is an extension of the work referred to above, to study the effect of draught on evaporative cooling in earthenware pot.

EXPERIMENTAL PROCEDURE

An earthenware pot of mass 3.062 kg, capacity of 4.686 litres and an external surface area of approximately 0.165 m^2 was obtained from a pottery yard at Okelele, Ilorin (Fig 1). The pot was filled nearly to capacity with water and put in a plastic bowl having a height which was much smaller than that of the pot so that the pot was not screened from room air. The plastic bowl was there to collect excess water seeping out of the pot which did not evaporate. A plastic plate was used to cover the pot so that mass transfer out of the pot occurred only through the wall of the pot.

The pot was exposed to draught from a KDK A. C. Electric desk fan type E40DK having 40 cm diameter fan blade rotating at 900 rpm (lowest blade speed), at a distance 1. 5m from the pot. The air speed at this distance from the fan was found to be 8.9 ± 1.9 km/h. Due to the frequent occurrence of unannounced electric power supply interruptions in the country, efforts were made to note the time power failure occurred when the fan could not work.

The pot, the plastic bowl in which it was put, the plastic cover and the water contained in them were weighed bihourly form 8.00 a.m. to 8.00 p.m. from December 14 to 17, 1993, at Ilorin (latitude 8°26' N and longitude 4°29'E). Room air temperature and relative humidity, water temperatures in the pot near the top, middle land bottom were also measured bihourly. By 4.00 p.m. on the fourth day, the water had dried out in the pot and the measurements were stopped. Due to electric power failure, the fan did not operate for 18 hours from the fourteenth hour, for 28 minutes in the fifty-ninth hour and for 5 minutes in the seventy-sixth hour.

In another set up, the pot was exposed to draught for 12 hours (8.00 a.. to 8.00 p.m.) on January 12, 1994, from the fan mentioned above. In this case, the blades rotated at 1300 rpm (highest fan blade speed) also at a distance of 1.5m from the pot, giving an air speed of 15.7 + 1.9 km/h. For this experiment, the measurements mentioned above were taken hourly. due to electric power failure the fan was off for 8 minutes in the sixth hour and for 9 minutes in the seventh hour of the experiment.

Engineering Laboratory Equipment analytical balance having serial number 51395 made in Hertfordshire, England was used. The mass measured, could be read to the nearest half of a gramme. The accuracy was checked using STANTON beam balance weights.

Water temperatures were measured using a type K (Chromel-Alumel) hand-held thermocouple probe having a 30 cm length, 6.5 mm diameter stainless steel sheath. The probe was connected to model 873F thermometer readout meter. Both probe and readout device were made by OMEGA ENGINEERING INC., Stamford, Connecticut, U.S.A. This makes it particularly suitable for this work.

Room air temperature was measured using A. J. COPE & SONS LTD. total immersion mercury-in-glass thermometer. Relative humidity in the room was measured using BRANNAN THERMOMETERS REGD. DSGN. No. 917158 sling hygrometer. Distilled water was used to wet the wick of the wet bulb thermometer to prevent soluble salts and dirt particles form accumulating on it and a adversely affect rate of evaporation and capillarity in the wick.

The rotational speeds of the fan blades were measured using type 1214B DAWE Stroboscope. The air speeds of the draught from the fan were measured with model W1208/2 CASELLA kilometres cup anemometer/wind vane.

RESULTS

The results obtained for the pot exposed to a draught of 8.9 km/h are shown (Table 1). The values of depression of water temperature (T_W) below room air dry bulb temperature (T_{rm}) divided by the corresponding values of room air wet bulb depression, i.e., $(T_{rm} - T_W)/(T_{rm} - T_{wb})$ are shown in the last column of Table 1. Using this parameter instead of $(T_{rm} - T_w)$ enables us to compare the cooling effect of the pot on different days in different seasons and at different locations having different relative humidity and ambient air distributions. Figure 2 shows plots of this parameter versus time of day on the first day for the cases when the pot was exposed to draught of 8.9 km/h and 15.7 km/h. Also shown in Figure 2 for the purpose of comparison is the result for the case when the pot was in quiescent air obtained earlier (3).

Figure 3 shows the variations of room wet and dry bulb temperature and water temperature in the pot with time of day for the case when the pot was exposed to a draught of 15.7 km/h. The reduction mass of water in the pot and plastic bowl with time of day for the first day are shown for the draughts of 8.9 km/h and 15.7 km/h (Fig. 4.). Also shown is the result for the case when the pot was kept in quiescent air (Fig. 4).

The evaporative cooling rate during a two hour period per unit surface are of the pot was calculated using the formula

$$\dot{Q}_1 = (m_i - m_f)\, h_{fg} / (7200\, A_s). \qquad (1)$$

The average cooling rate in W/m^2 during a two hour period, for the water left in the pot was calculated using the following formula

$$\dot{Q}_2 = C_p\, (m_i + m_f)\, (I_i - I_f) / (14400\, A_s). \qquad (2)$$

In deriving the formula in equation (2), it was assumed that both the mass of water left and average water temperature vary linearly with time over the 7200's time interval. The cooling rates $\dot{Q}_1$ and $\dot{Q}_2$ calculated for the two cases when the pot was exposed to draught are shown in Table 2.

Anywhere we have dash sign in the columns for Q_2 it means that the average water temperature in the pot remained constant or increased during the two hour period.

Since increases in the wetted surface are exposed to air increases the cooling effect, cooling rates per unit surface area were calculated in this work rates per unit surface area were calculated in this work rather than just cooling rates, to eliminate the effects of size of the pot from the experimental results.

DISCUSSION OF RESULTS

It can be seen that the water temperature depression increased on the first day and peaked after 8 hour, 6 hours and 4 hours for the pot in quiescent air and for the cases when it was exposed to draughts of 8.9 km/h and 15.7 km/h respectively (Fig. 2). The normalized water temperature depression hovered around one after its value had peaked for the cases when the pot was exposed to draught. This can be seen after 34 hours (Fig. 2 and Table I.). The relatively low values of 0.87 and 0.86 in the 76th and 78th hour in was because the water level had become very low in the pot and the plastic bowl in which the pot was placed was screening the lower part of the pot from the draught (Table II).

When the normalized water temperature hovers around one, it means that the water temperature remains approximately equal to room wet bulb temperature within limits of experimental error. Although the occasional drop of water temperature below room air wet bulb temperature is within limits of experimental error, it is a real effect. It must be remembered that the cooling of water in the pot is an unsteady heat and mass transfer problem since the factors causing it are varying. The times when water temperature below wet bulb temperature of room air had increased from a lower value to a higher value and water temperature also increased but at a much slower rate due to thermal inertia of the pot and water, making the amplitude of oscillation of water temperature to be much less than that of room air wet bulb temperature. Hence, water temperature lower than wet bulb temperature were observed when readings were taken. This is well illustrated in the values of wet bulb and water temperature from 4 to 6, 8 to 10, 48 to 50, and 58 to 60 hours (Fig. 3 and Table I).

The reduction of mass of water with time due to evaporation is approximately linear (Fig. 4). The rate of evaporation increased with air velocity of the draught as expected. The rate of evaporation for the cases in which the pot was exposed to draught was an order of magnitude higher than when it was quiescent air reported in the earlier work.

Normally a portion of the latent heat of evaporation is obtained from the pot and the water in it while the rest is taken from the surrounding air. With the water and the external surface of the pot kept below room air dry bulb temperature, there will be a transfer of heat form the warmer surroundings to the pot by convection and radiation. When the average temperature of the water is constant, the rate of heat transfer to the pot balances the rate of loss of energy due to evaporation of water from the external surface of the pot. This is similar to what happens when the wet bulb thermometer reading reaches a steady value. When the water temperature rises, it means that the gain of heat from the surroundings is greater than the evaporative cooling experienced by the pot during the time interval.

The air speeds of the draughts form the fan are comparable to wind speeds observed for many Nigerian cities. From their analysis of wind data of seventeen years for many cities in Nigeria, it was found that Nigeria is a region of calm, with light winds which stay most of the time below 18.5 km/h (4). From statistical analyses of meteorological data it has been found than wind velocity varies much more with time and over space than ambient temperature, solar radiation and ambient humidity (5). Therefore, it is not expected that a pot placed outdoors will have steady draught for extend periods like in the experiments reported in this paper. The water temperature in that case is expected to be between the results obtained for quiescent air reported earlier and hose for pot exposed to draught reported here (3). On very windy days, the water temperature and this cooling would be obtained relying entirely on a renewable source of energy-wind energy.

With the present high cost of energy and possibility of further increases in energy cost, the use of renewable energy such as wind energy to obtain draught and the natural evaporative cooling due to diurnal variations of dry bulb temperature and relative humidity as a result of the rising and setting of the sun, will become more and more attractive.

CONCLUSION

The effect of draught on earthenware pots is to increase the rate of evaporation from their surfaces and thereby enhance the cooling rate of water in the pots. If the pot is kept outdoors in the shade on a windy day, the water temperature can approximately attin wet bulb temperature in four to six hours.

ACKNOWLEDGMENT

The author is grateful for the assistance of Mr. M.M. Bello in the experimental work.
Thanks to Civil and Mechanical Engineering departments of University of Ilorin for providing the equipment and instruments use for this work. This work was supported by University of Ilorin Senate Research Gant No. 8:16:505.

Table 1: Bihourly Room Air Temperature and Relative Humidityt, Mass and Temperature of Water Stored in an Earthenware Pot Exposed to Draught form a fan having 440 cm Blade Rotating at 900 rpm at a Distance of 1.5 m from the Pot (Air Speed = 8.9 ± 1.9 km/h)*

TIME (HOURS)	MASS OF WATER IN POT & PLASTIC (kg)	ROOM AIR DRY BULB TEMP t (°C)	AVERAGE WATER TEMP., t_w (°C)	RELATIVE HUMDITY OF ROOM AIR (%)	ROOM AIR WET BULB TEMP., t_{wb} (°C)	$\frac{T_{rm} - T_w}{t_{rm} - T_{wb}}$
0	4.785	26.0	23.0	35.5	16.0	0.30
2	4.606	26.0	17.4	22.0	13.5	0.69
4	4.426	27.0	15.4	26.0	14.7	0.94
6	4.254	28.4	15.9	27.5	16.5	1.05
8	4.034	29.0	16.4	26.0	16.3	0.99
10	3.059	28.8	16.7	30.0	17.0	1.03
12	3.698	28.2	16.9	29.5	16.7	0.98
24	3.426	25.6	19.7	43.5	17.5	0.73
26	3.404	26.2	19.9	37.5	16.8	0.67
28	3.369	27.5	20.2	34.5	17.0	0.70

Table 1 (contd.)

TIME (HOURS) *	MASS OF WATER IN POT & PLASTIC (kg)	ROOM AIR DRY BULB TEMP., T (°C)	AVERAGE WATER TEMP., T_w (°C)	RELATIVE HUMDITY OF ROOM AIR (%)	ROOM AIR WET BULB TEMP., T_{wb} (°C)	$\frac{T_{rm} - T_w}{T_{rm} - T_{wb}}$
30	3.331	28.5	20.5	30.0	16.0	0.68
32	3.288	28.6	20.6	33.0	17.6	0.73
34	3.102	28.4	18.4	35.0	18.0	0.96
36	2.928	28.2	18.4	34.0	17.5	0.92
48	2.117	26.7	19.9	53.0	19.7	0.97
50	2.016	27.0	20.3	55.5	20.5	1.03
52	1.908	28.1	20.7	49.0	20.2	0.94
54	1.762	29.5	20.1	37.0	19.2	0.91
56	1.608	29.2	19.9	41.0	19.6	0.97
58	1.470	29.0	19.9	41.0	19.5	0.97
60	1.360	29.0	20.1	47.0	20.6	1.06
72	0.730	27.0	21.6	60.0	21.2	0.93
74	0.651	27.7	22.4	64.0	22.4	1.00
76	0.523	28.5	21.6	49.0	20.6	0.87
78	0.401	29.4	21.6	44.0	20.4	0.86
80+	0.282	-	-	-	-	-

* **Fan operation schedule: Due to electric power failure, the fan did not operate during the following time intervals: 13h 50 min. - 31h 55min, 58h 24 min - 58h 52 min, and 75h 20min - 75h 25 min.**

+ **The pot was empty. Water of mass 0.057 kg was found in the plastic in which the pot was put. This remaining part of the mass recorded in the table wa in the porous wall of the pot.**

Table II: Evaporative and Water Cooling Rates On the First Day Of Experiment In Each Case.

	POT EXPOSED TO DRAUGHT OF 8.9 km/h			POT EXPOSED TO DRAUGHT OF OF 15.7 km/h		
	EVAPORA-TIVE COOLING RATE	WATER COOLING RATE	$\dot{Q}_2/\dot{Q}_1$	EVAPORA-TIVE COOLING RATE	WATER COOLING RATE	$\dot{Q}_2/\dot{Q}_1$
TIME OF DAY	$\dot{Q}_1$, W/m^2	$\dot{Q}_2$, W/m^2		$\dot{Q}_1$, W/m^2	$\dot{Q}_2$, W/m	
8.00 - 10.00	369.64	92.52	0.25	376.81	146.04	0.39
10.00 - 12.00	373.06	31.82	0.09	416.04	38.46	0.09
12.00 - 14.00	356.71	-	-	383.40	2.94	0.01
14.00 - 16.00	456.04	-	-	428.96	-	-
16.00 - 18.00	362.63	-	-	408.16	-	-
18.00 - 20.00	333.55	-	-	383.12	-	-

Fig. 1. The experimental pot placed beside a 30cm ruler

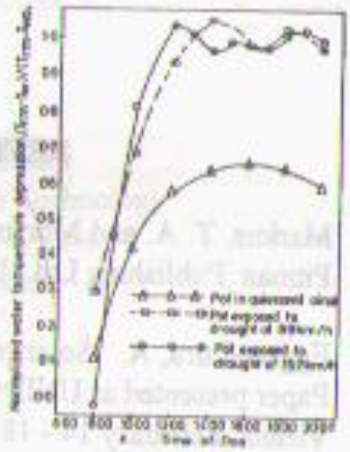

Fig. 2. Variation of water temperature with time of day on the first day for each case

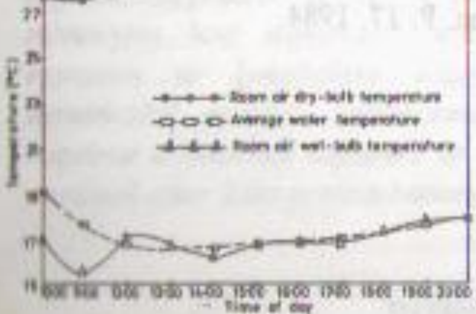

Fig. 3. Room air dry and wet-bulb temperatures and average water temperatures for pot exposed to draught of 15.7km/h.

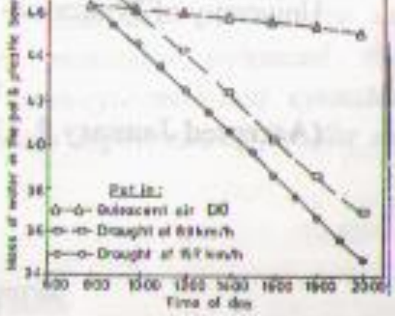

Fig. 4. Reduction of mass of water with time due to evaporation

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(Accepted January 9 1995.)