

Analysis of an Earthen Pot Water Cooler

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ABSTRACT

Heat and mass transfer analysis of an earthen pot water cooler has been done. The cooling process has been found to be only humidity controlled. A simple way of predicting temperature of water T_w , has been found. A correlation between the evaporation rate of water and relative humidity has been calculated. The Coefficient of Performance (CoP) of *matka* cooling is found to be ~ 0.2 . Subsequently the potential of using earthen pot cooler as a simple village refrigerator is explored.

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1. INTRODUCTION

Passive evaporative cooling is used extensively in nature for environmental conditioning [1]. Human beings have exploited this phenomenon in cooling water for drinking purposes. Throughout the ages and in different countries earthen pots have been used extensively in cooling potable water especially in hot dry climates [2]. Cooling of water in earthen pots is a very simple and cheap way of providing drinkable water and is still widely used in India. The earthen pots are made of fired clay and are porous. Evaporating water from the pores – akin to sweating, cool the remaining water. Average temperature of water (depending on place and time) can reach 18-20°C.

It is however felt that besides just providing a cheap way of cooling potable water, the earthen pot can also become a cost-effective refrigerator for rural areas. In villages, it is very common that certain products like milk after boiling have to be kept for 10-15 hours in the village before being transported to the centralized chilling plant or cold storage. During this time the life of the produce can be increased if it is kept in a relatively cool place (~ 18-20°C). In the absence of any refrigerators or coolers, extensive spoilage occurs, especially in hot climates. Thus there is a need to provide a cheap and reliable cooling system for temperatures in ~ 18-20°C range.

The extension of a water cooler to a low-cost refrigerator requires theoretical and experimental analysis of heat and mass transfer process of earthen pot. The purpose of this study is, therefore, to provide such an analysis.

2. EARTHEN POT CHARACTERISTIC

Four earthen pots (called *Matka*) locally produced were used in the present study. Earthen pots making is a cottage industry and each pot costs about \$ 0.5. These pots are made of 6:2:1 ratio (by weight) of clay; cow, horse or donkey dung; and ash respectively. It is mixed with water, and dough like consistency of mixture is spun on the potter's wheel to yield the spherical

shape (Figure 1). These pots are sun dried for about 1-2 hours and then baked for about 1-2 hours in an improvised oven. The fuel used for baking is farm waste like wheat stalks, bagasse, cotton stalks, etc. The time of baking allows the finished product to have enough strength to hold water, without fusing the clay together. Thus the pot maintains its porous structure.

The mixture ratio and the method of firing results in ~ 30% porosity for the pot. This porosity, which is a result of evolution of this technology through ages, has beneficial effects in the cooling process. The potable water contains salts and with water evaporating through the porous media, the salts are left behind. These salts have the tendency to clog the pores thereby reducing, and eventually stopping, the cooling process. The high porosity of the clay pot allows the water to come out easily thus effectively leaching the salts and maintaining salt free pores. The evaporation of water, therefore, takes place from a very thin layer around the surface of the spherical pot.

3. ANALYSIS

The energy transfer in the earthen pot with wind blowing across it can be essentially treated as heat and mass transfer through a porous media with forced convection. The nomenclature table gives the details of symbols. Thus an energy balance on water inside the pot yields.

$$UA(T_a - T_w) - m_{\text{evap}} h_{\text{fg}} = m_w c_{p,w} (dT_w/dt) + m_p c_{p,p} (dT_p/dt) \quad (1)$$

The amount of water evaporated m_{evap} can be calculated as follows [3] :

$$m_{\text{evap}} = h_m A (m_o - m_a) \quad (2)$$

The mass transfer processes in earthen pot results from moderate mass fraction difference between the water at outer layer and ambient and thus the mass transfer coefficient h_m can be calculated by heat and mass transfer analogy [3]. Thus

$$Nu_m = 2 + 0.3 Re_d^{0.6} Sc^{0.33}, Sc \geq 0.6 \quad (3)$$

where,

$$Nu_m = h_m d / \rho_a \nu \quad (4)$$

The mass fractions m_o and m_a at the surface and for atmosphere respectively can be calculated as follows [4].

$$m_o = (P_o M_w / RT_o) / \rho_o \quad (5)$$

and,

$$m_a = [(P_a X R.H. X M_w) / RT_a] / \rho_a \quad (6)$$

where,

$$\rho_o = [(P_o M_w) / RT_o] + [(P_{atm} - P_o) M_{air} / RT_o] \quad (7)$$

And,

$$\rho_a = [(P_a X R.H.) M_w] / RT_a + [(P_{atm} - P_a) X (R.H.)] M_{air} / RT_a \quad (8)$$

4. EXPERIMENTAL SET

The temperatures of inside and outside of pot and water were measured by 24 SWG copper-constantan thermocouples (Type T). The ambient temperature and humidity were measured by Hygrothermograph. The local wind data was taken by hand held precision anemometer.

The volume of the pots was measured by water displacement method and the surface area was measured by mapping it. The mapping technique was utilized because the thickness of clay pot was different at different places so that volume measurements would not have given accurate results of surface area. The porosity of the pot was measured after the conclusion of experiments. The measurements were conducted by noting the amount of air displaced by water when a small piece of clay pot was put in a measuring cylinder. Large number of such tests gave the average porosity. The porosity of various pots varied very little ($< 5\%$), testifying to the remarkable craftsmanship of local potters.

The experiments were run for 24 hr periods and since the cooling was in batchwise mode, the amount of water evaporated and leaked was replaced by measured quantity of water. Thus the pot was kept full all the time, and each pot was put on a stand in a bucket. This facilitated in measuring the amount of water leaked out. Thus the difference in the amount of water added and leaked out gave the amount of water evaporated.

5. RESULTS AND DISCUSSIONS

Figure 2 shows a typical temperature – time history of cooled water. It also shows the pot surface temperature – time history. As can be seen the outer surface temperature is always cooler (because of evaporation) than the ambient temperature. Thus the cooling process is only humidity controlled. Figure 3 shows the evaporation rate – time history. Also plotted in the figure is Equation 2. vs. time. The correlation between experimental and

calculated values is good thereby proving the humidity-controlled cooling process, and the maximum evaporation takes place around 16.00 hrs. when the relative humidity is minimum (Figure 2). Table 1 lists the property values used in Equation 2.

For a refrigerator or an air cooler working in continuous mode it is necessary to get an idea of the cooling process for various starting water temperatures. Figure 4 shows temperatures – time history for various starting temperature. In the early stages for water temperature greater than ambient, the cooling is very rapid. This is because the cooling is both temperature and humidity dependent. Thus the driving force is much greater than that in the humidity dependent one only.

For a designer it is necessary to know what the temperature of water under certain environmental conditions will be. Figure 5 shows the plot of ratio of T_w/T_a vs. relative humidity (driving force for evaporation). As the humidity increases there is less evaporation and subsequently T_w approaches T_a at 100% relative humidity. The same relationship between T_w/T_a and R.H. can also be obtained from equations 1-8. Thus it is easy to find the water temperature T_w by knowing relative humidity. The least-square curve fitting the data is :

$$(T_w/T_a) = 1 - 0.988 \exp (- 0.0377 \times \text{R.H.}) \quad (9)$$

It should be noted, however, that the temperature of water T_w found by above equation is valid for the geometry and other characteristics like porosity etc. of the earthen pot used in the present study. In order to generalize to any other pot of different geometry but same porosity it is necessary to plot the evaporation rate per unit area vs. relative humidity. Figure 6 shows such a plot. Also shown in this figure is the calculated values of evaporation rate from Equation 2. It is not difficult to see that with the existing technology available to the village potter, he can make different shapes and sizes of the pots but cannot change the composition. Changing

the composition (and thereby porosity) would entail changes in structure and baking methods. Thus Figure 6 represents a good estimate of the cooling rate for various pots made by existing methods. The linear regression analysis of the data gives the following:

$$E = - 0.004 \times R.H. + 0.505; (\text{kg}/\text{m}^2\text{-hr}) \quad (10)$$

For any pot, the designer can therefore calculate the amount of water evaporated and hence the cooling rate which subsequently gives the temperature of water – the item of interest.

In order to facilitate calculations, ambient temperature T_a vs relative humidity is plotted in Figure 7. Thus by just knowing the ambient temperature, relative humidity can be found and hence the cooling rate (Figure 6). It should be noted that the plot of T_a vs. R.H. is valid for particular location and season. Hence this plot is site specific and should be obtained first, before subsequent design be completed. Once this plot is, however, drawn then it is easier to find the cooling rate from Figure 6.

Based on the present study a small cooler is being tested in our laboratory. A small metallic container is put inside a modified earthen pot which is filled with water. Evaporating water cools the contents of the container.

6. CONCLUSIONS

Based on the present study the following conclusions can be drawn :

1. Earthen clay pot is a very cheap and simple water cooler.
2. Heat and mass transfer analysis of the earthen pot has been studied.
3. A simple way of predicting the cooling rate for such pots has been found (Equation 10).
4. The potential of using earthen pots as a simple village refrigerator is explored.

Table 1**Property values used in Equation 2.**

Wind velocity	2 kmph
Porosity of earthen pot	30%
Schmidt number for air-water mixture	0.61 [4]
Average diameter of pot, d	.3 m
Coefficient of Diffusion, D	0.1 m ² /hr [4]

NOMENCLATURE

A	Area of Earthen pot, m^2
$c_{p,w}, c_{p,p}$	Specific heats of water and earthen plot respectively, $KJ/kg^{\circ}C$
D_t	Diffusion coefficient of water in air m^2/hr
d	Diameter of earthen pot, m
E	Cooling rate of water (Equation 10), kg/m^2-hr
h_{fg}	Enthalpy of vaporization of water, KJ/kg
h_m	Mass transfer coefficient, $kg/m^2 hr$
M_{air}, M_w	Molecular weight of air and water respectively, $kg/mole$
m_a, m_o	Mass fraction for outside of pot and ambient respectively
m_{evap}	Amount of water evaporated kg
m_w	Amount of water in the plot, kg
Nu_m	Nusselt number for mass transfer
P_a, P_o	Partial pressure of water at T_w and T_o respectively, N/m^2
P_{atm}	Atmospheric pressure
R	Universal Gas Constant
Re_d	Reynolds Number
R.H.	Relative humidity, %
Sc	Schmidt number
T_a, T_w	Ambient and water temperature respectively, $^{\circ}C$
T_o	Outside temperature of pot, $^{\circ}C$
T_p	Average temperature of earthen pot, $^{\circ}C$
U	Overall heat transfer coefficient between T_a and T_w , $W/m^2 ^{\circ}C$

ρ_{av}	Average density of air-water mixture, kg/m^3
ρ_o, ρ_a	Density of air-water mixture at T_o and T_a respectively, kg/m^3

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The figures are given below.

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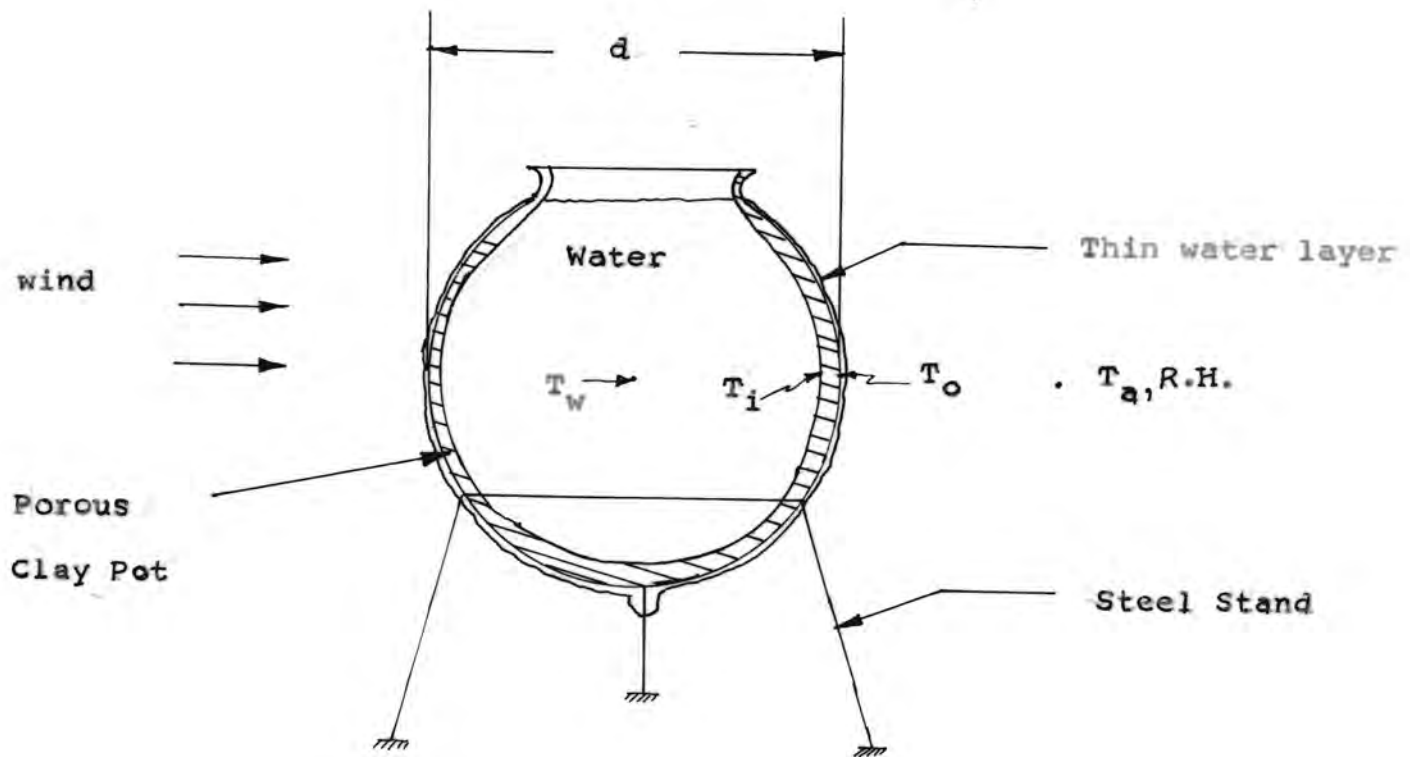


Fig 1. Schematic of Earthen Pot

Fig 2. Temperature - time History of water cooled

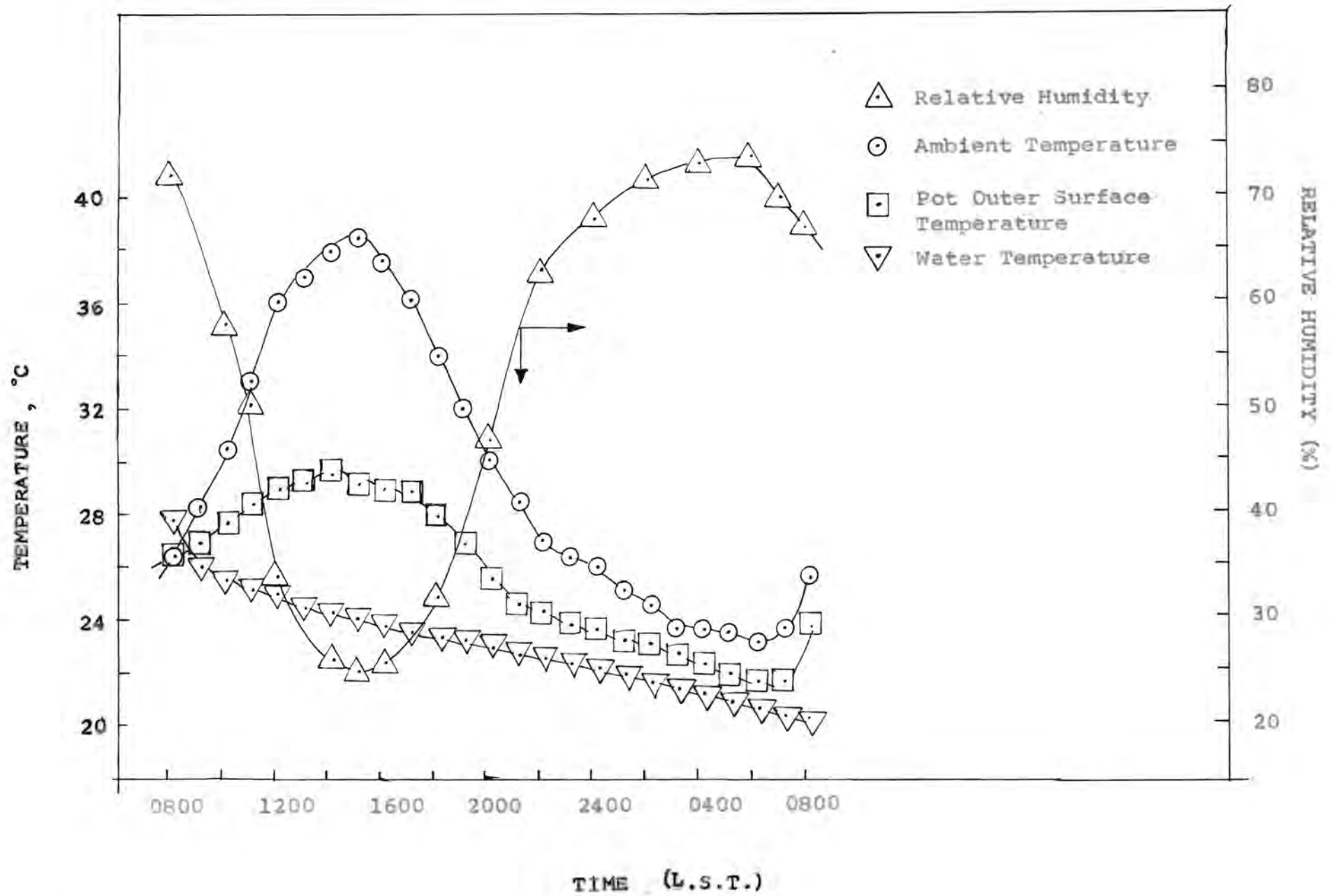


Fig 3. Evaporation of water -time history

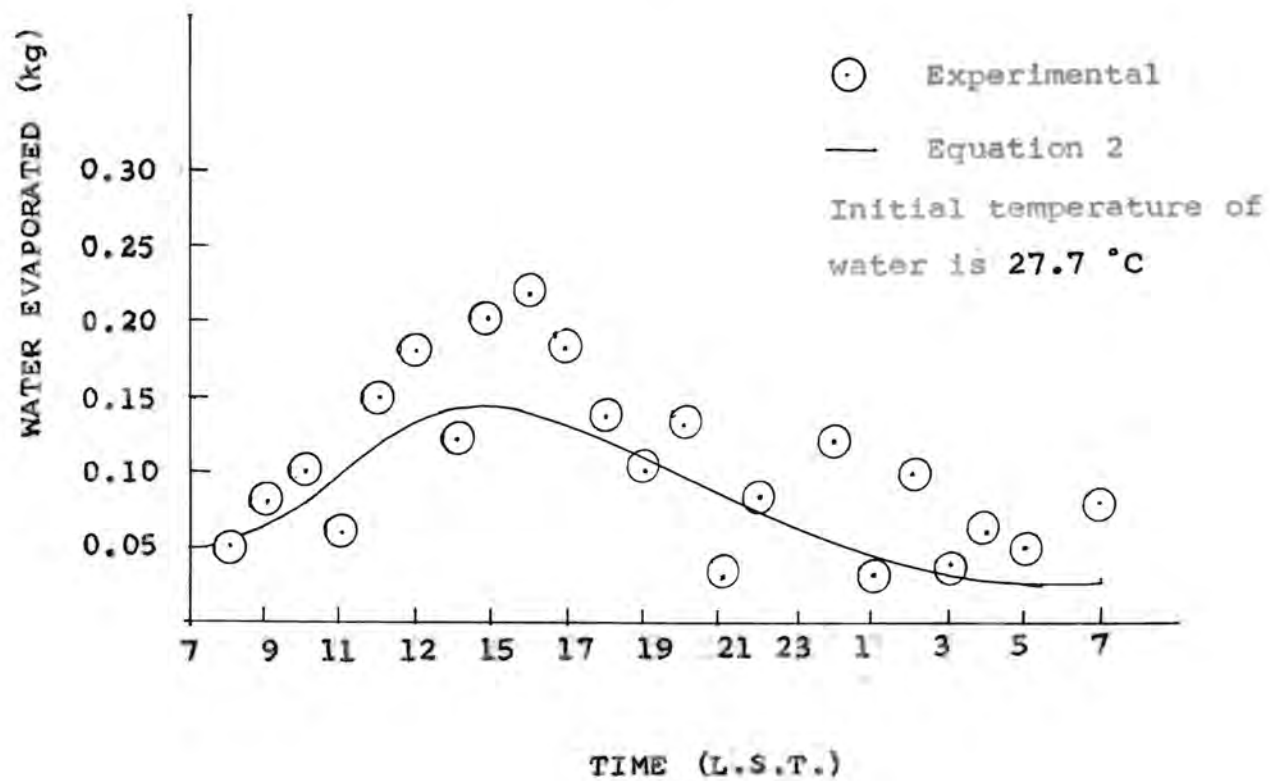


Fig 4. Cooling rate of water for various starting temperatures.

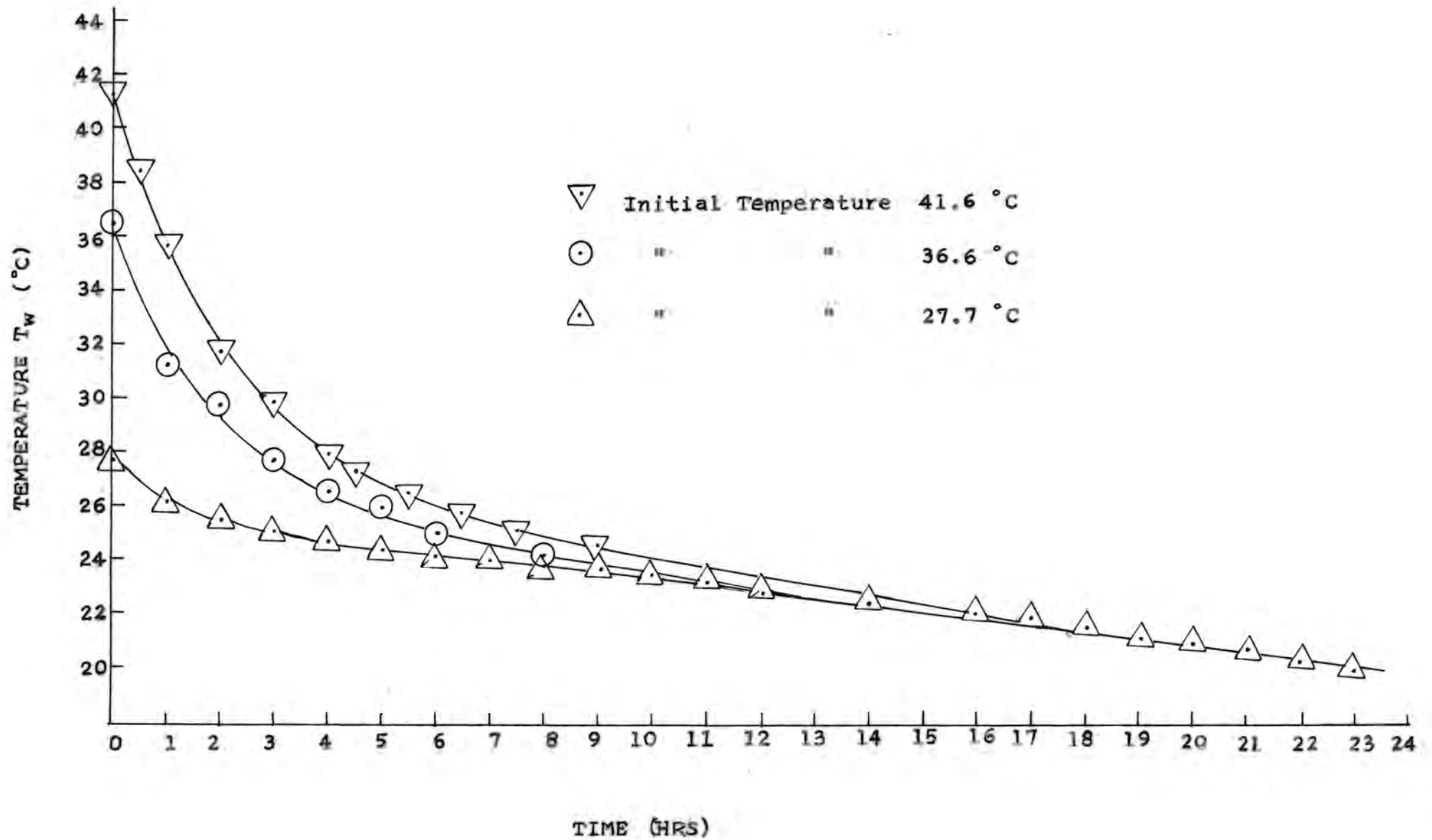


Fig 5. Plot of T_w/T_a versus Relative Humidity

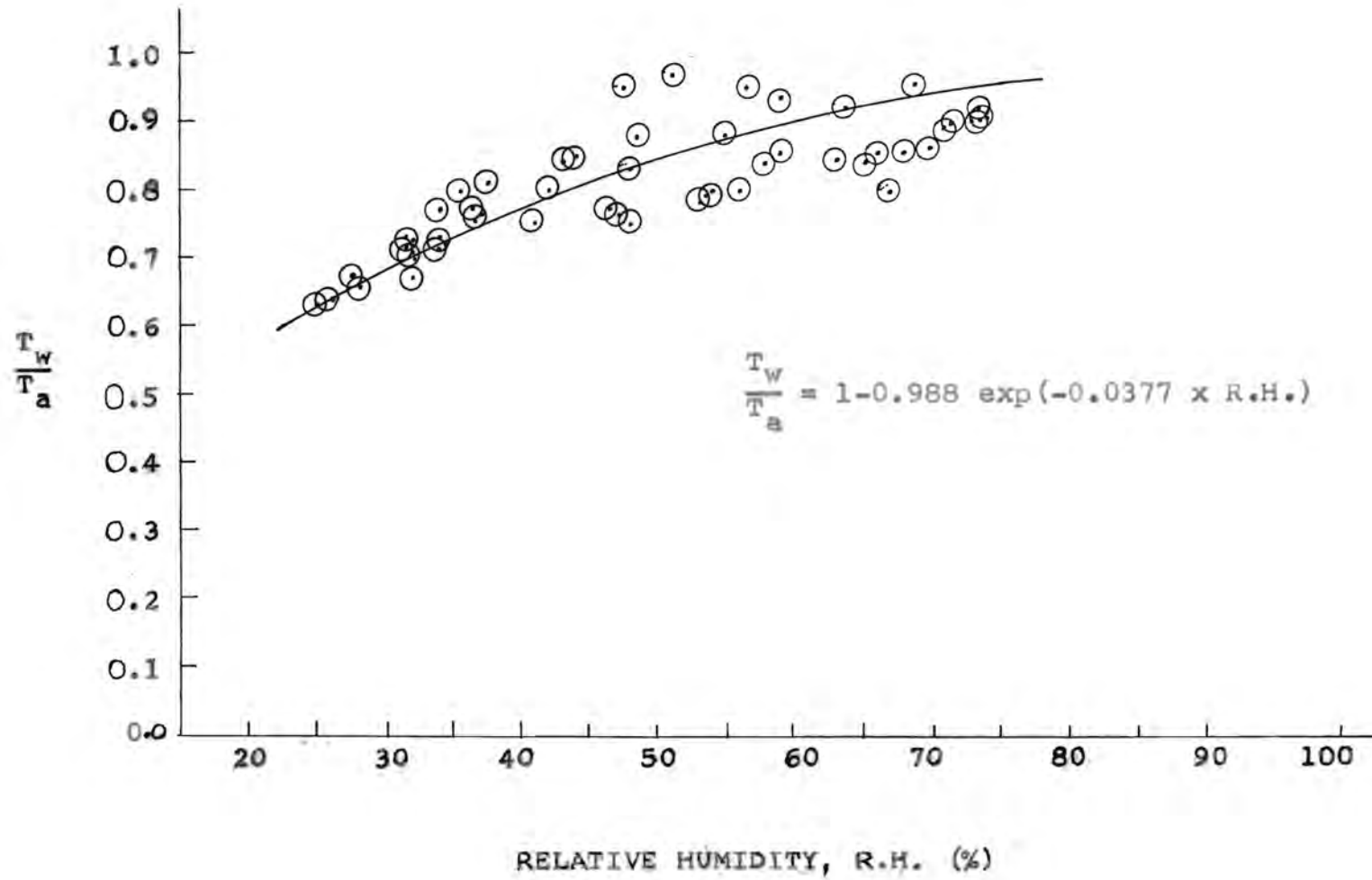


Fig 6. Evaporation Rate vs. Relative Humidity

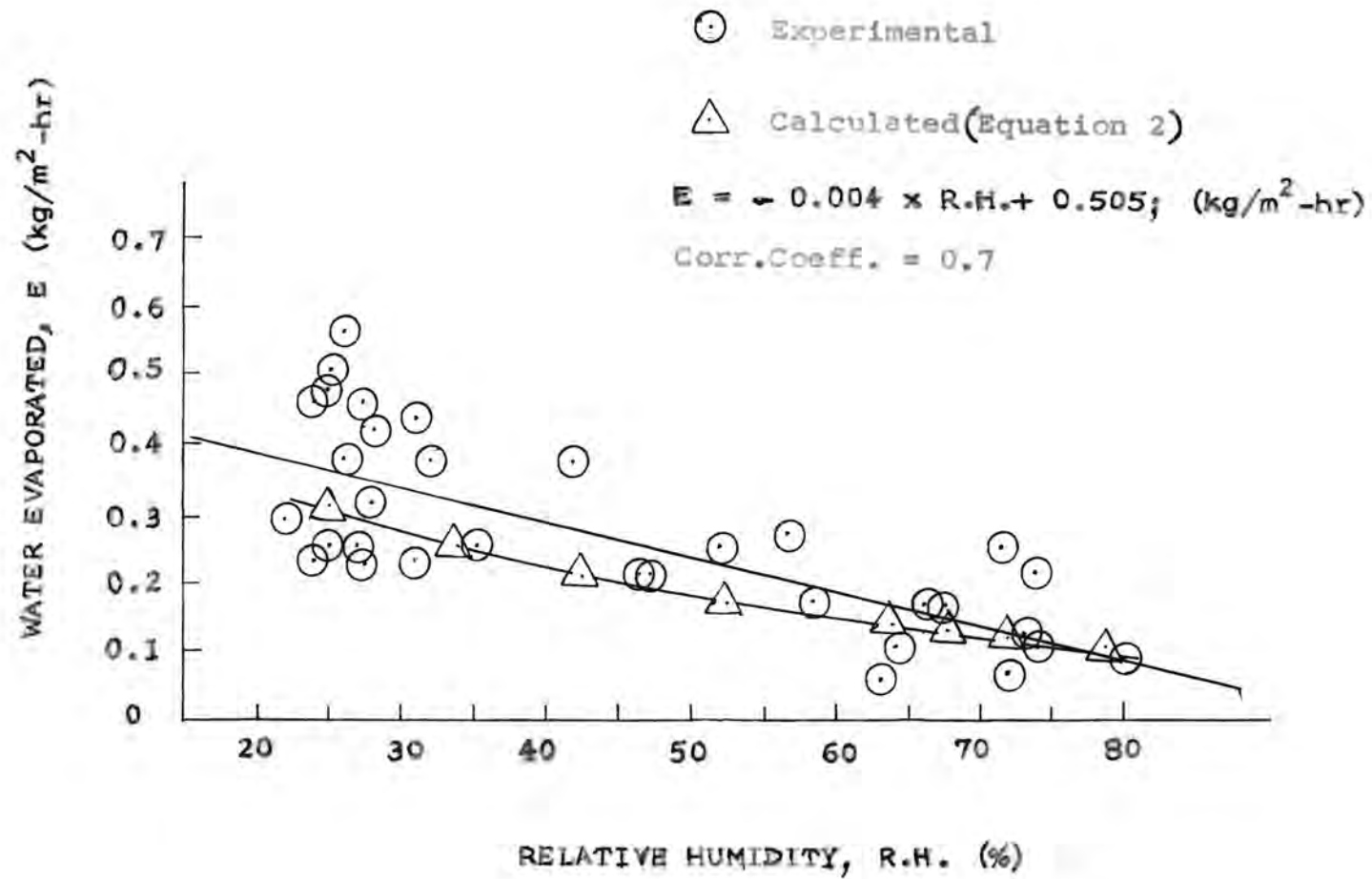


Fig 7.

Fig. 7. Relationship between ambient temperature and relative humidity

