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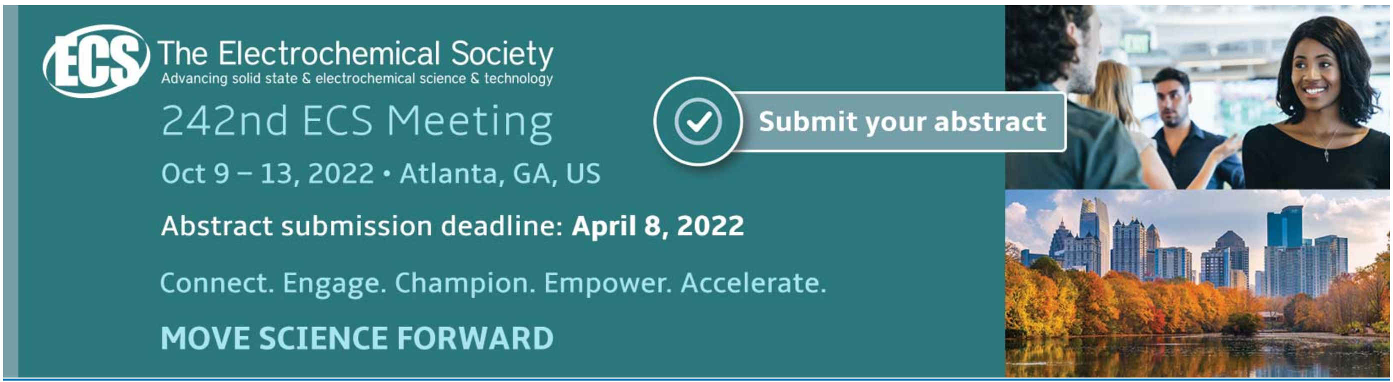

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Experimental Analysis of Evaporative Cooling Water in Porous Clay Vessels Under Varying Ambient Conditions

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Abstract
Due to the ability of clay vessels to store and retain water below ambient temperature, it has become a basic commodity for water storage among the rural dwellers in the Sub-Sahara region and as an alternative to other cooling/refrigerating system. It therefore, becomes necessary to study and determine how effective and efficient porous clay pot serves as evaporating coolers. Evaporative cooling of water in six different porous clay vessels was studied under varying ambient conditions. In this study, water was stored in six porous clay vessels of different sizes and volumes. The weight, relative humidity, and ambient temperatures of water content in the porous clay vessels were measured bihourly from 12 noon to 8 pm for a period of 7 days. The result of the study revealed that the mass loss is affected by several factors such as ambient temperature, the surface area of the vessel, porosity and thickness of the vessel. From this study, pots with small water holding capacity (Pots D and E) experienced the fastest rate of evaporation. The relative humidity was based on the condition of the environment. This study concludes that energy demand can be minimized by applying evaporative cooling concept in households, offices, and industries. Thus, this paper provides an insight towards ways of conserving energy demand for cooling as there is no requirement of electricity to run the system. Hence, extensive usage of these sorts of cooling systems helps in providing greener environment

Keywords: Relative humidity, dry bulb temperature, wet bulb temperature, clay pot, evaporative cooling

1. Introduction

Evaporative cooling is an age long procedure of cooling an object or a system without fully employing any means of energy. There is a temperature exchange mainly by convection between the fluid and the surface in contact. The surface can be air or the vessel in which the fluid occupies. The relevance of this method of cooling becomes necessary due to the depletion of the ozone layer by the escape of flue gasses to the atmosphere from energy equipment [1-3]. Temperature differential plays a factor in the evaporation of water. The wet-bulb temperature, as compared to the air dry-bulb temperature, is the measure of the potential for evaporative cooling when considering water evaporating into the air. A typical wet and dry bulb thermometer is shown in Figure 1. The greater the difference between the two temperatures, the greater the evaporative cooling effect [4-8]. Before the advent of modern technology, man has always strived for survival and sought solutions to identified challenges. Such a solution has improved generations in terms of application. One of these several solutions is the evaporating cooling process of water in clay vessels [9-11]. Evaporative cooling is a unique technology that transports cool air to the dwellers plus the reduction in carbon emissions and energy demand [12-13]. Evaporative cooling enables the environment to cool while increasing the moisture level of the environment [14]. It has found application in HVAC, industrial equipment cooling, amongst others [15-17]. Appreciable evaporative cooling can be enjoyed in localities were high dry bulb temperature (≥32ºC) occur simultaneously with low wet-bulb temperature (<24ºC) for an extended period.

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The prime objective of this study is to experimentally investigate the rate of evaporation of water from six clay pots of different surface areas under variable ambient temperature.

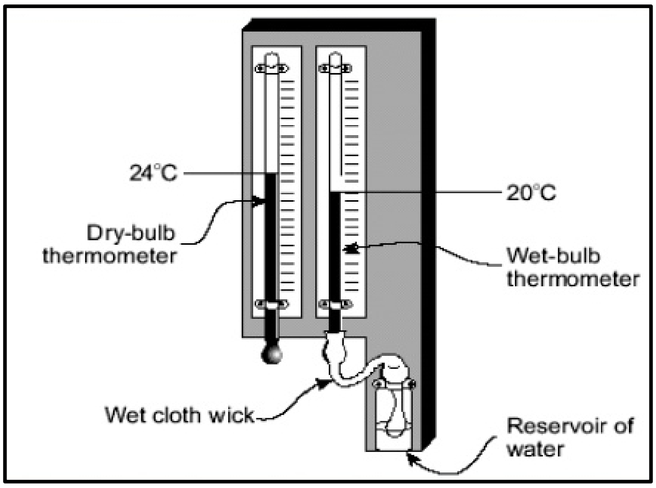

Figure 1: Schematic Diagram of Hygrometer [4]

2. Experimental Set-up

The items employed in this study are wooden stand, six clay pots, wick, weight scale, scissors, stopwatch, distilled water, seven wet bulb-dry bulb thermometer and thread. Figure 2 shows the experimental set up for this study.

The wooden stand acts as a foundation upon which the clay pots will be placed it also has been constructed to allow the hanging of the hygrometers (wet bulb-dry bulb thermometers). The clay pots are to house the water (working fluid) it also is one of the primary purposes of our experiment, which is to study the evaporative cooling of water in clay vessels under varying ambient conditions. The wick is the primary tool for allowing the passage of water from the clay pot to the various hygrometers through upward capillary movement. The weight scale was used in taking the mass loss of water due to the evaporation of water and slippage of water through clay pots pores. Scissors were used to trim and cut the wick to the required shape and length. The Stopwatch was used in measuring the bihourly time durations of the 8-hour experimental daily duration. Distilled water was used as basis of working fluid. Seven (7) wet bulb-dry bulb thermometer was used in taking the bihourly temperature readings of the water as well as ambient readings. The thread was used in fastening the wick to the probes of the wet bulb and dry bulb thermometers, to hold them in place securely.

This experiment consecutively carried out for three days. Readings were taken at 8 hours interval and a total of 56 hours used for the experimentation. Detailed description of the experimental procedure is presented as follows: First, the empty clay vessels were weighed. Each pot was filled to its brim with water. The pots were weighed with water. The mass of water in each pot was determined by subtracting the mass of the empty pot from the mass of pot filled with water. Then the hygrometers wick was placed in distilled water to wet them and enhance their rate of capillary movement because water with dirt particles will affect the rate of capillary movement through the wick. The wicks of the hanged hygrometers were

placed in the water to take initial readings before final reading is taken at the end of every bihourly time duration, i.e., 2 pm (initial reading) to 4 pm (final reading). Also, bihourly mass loss readings are taking by weighing the clay pot with a weight scale. The process of bihourly readings is also applied for the taking of the relative humidity, average cooling rate, and evaporative cooling rate. For our relative humidity, cooling rate, and evaporative cooling rate, the use of formulas was applied in achieving their values.

Figure 2: Experimental Setup

Table 1 shows the surface areas of the pots used in this experimental set-up.

Table 1: Surface Areas of Pots used for the Experimental Set-up

POTS A-F	Pot A	Pot B	Pot C	Pot D	Pot E	Pot F
Surface Area (m^2)	0.01018	0.01053	0.0085540	0.0053099	0.0080435	0.022905

3. Mathematical Analysis

Mathematical models used in this study are presented as follows:
Surface area is given by:

$$\text{Area}=\text{A} = \frac{\pi d^2}{4} \quad (1)$$

Average Evaporative Cooling rate is given by:

$$\frac{Q}{A} = \frac{(Mi-Mf)hfg}{7200A} \quad (2)$$

Average Cooling rate is given by:

$$\frac{Q}{A} = \frac{I}{2(MI-Mf)} \times Cpw \times \frac{Ti-Tf}{7200A} \quad (3)$$

Bi hourly Relative Humidity is given by:

$$\text{Bi hourly Relative Humidity} = Td - Tw \quad (4)$$

Bi hourly Mass Loss is given by:

$$\text{Bi hourly Mass loss} = Mi - Mf \quad (5)$$

Specific Heat Capacity is given by:

$$Cpw = 4.179\frac{kJ}{kg} \quad (6)$$

4. Results and Discussion

4.1 Average Mass Loss

Figure 3 shows the average mass loss readings for each clay pot. The average mass loss readings were taken bihourly for 8 hours daily for seven days. At day 1, there was (0.015, 0.1962, 0.0044, 0.001066, 0.00134, and 0.00048) kg mass loss for pot A-F against the control which are quite insignificant and an indication of the effectiveness of the pots in retaining water for a long hour. However, pot F retains the fluid most compared to other pots. The elemental make-up, microstructure and the closeness of the pores in the structure are responsible for the minimal fluid escape. Heat transfer depends the change in temperature, the mass of the system, and the substance and phase of the substance.

A wide surface area influences heat transfer rate and the eventual cooling of the water. From Figure 1, Pot F possesses the widest surface area, an indication of the most effective cooling pot and a significant heat transfer by both conduction and convection leading to evaporative cooling.

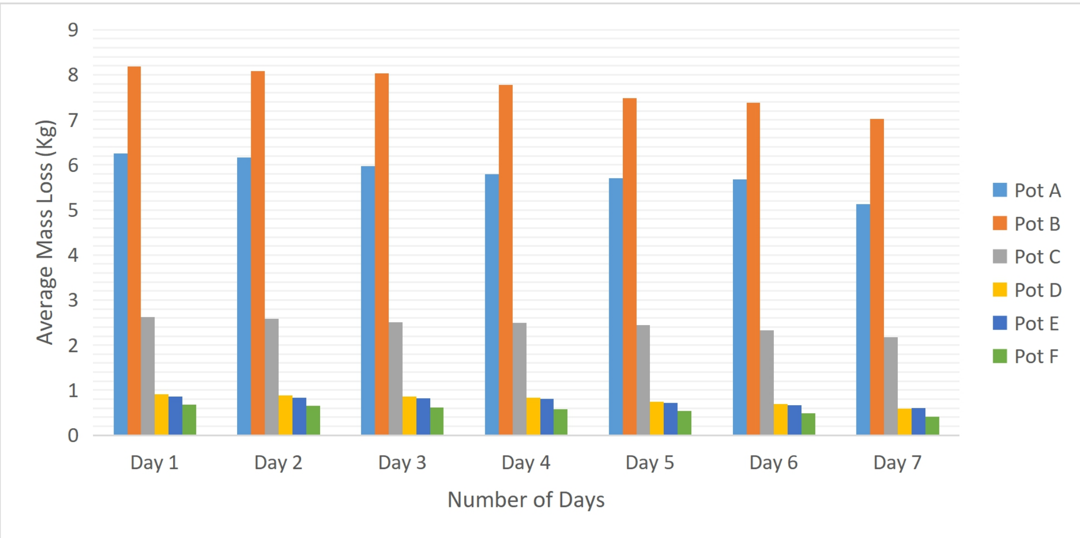

Figure 3: Average Mass Loss with Number of Days

4.2 Average Relative Humidity

Relative humidity (RH) expresses the amount of moisture in the atmospheric air. RH and temperature varies inversely. Thermal comfort level is determined by the relative humidity. RH ≤25% feel uncomfortably dry, while RH ≥ 60% feel uncomfortably humid. RH ≥70% can cause mould and corrosion and accelerate deterioration of interior surfaces, while low RH can cause paint cracking and wood shrinkage. In this study, the Relative Humidity was measured using the Humidity chart where the differential value of the Dry bulb and Wet bulb was read against the Dry bulb temperature value on the Humidity Chart. The average humidity taken for seven days is in Figures 4. From day 1, Pots A, C and F had increment in RH by 0.7, 0.6 and 5.6 % while pots B, D and E decreased by 2.1, 0.58 and 2 % respectively. All the pots possess high RH for the first three days. The high RH is an implication of low evaporation which is due to a very humid atmosphere.

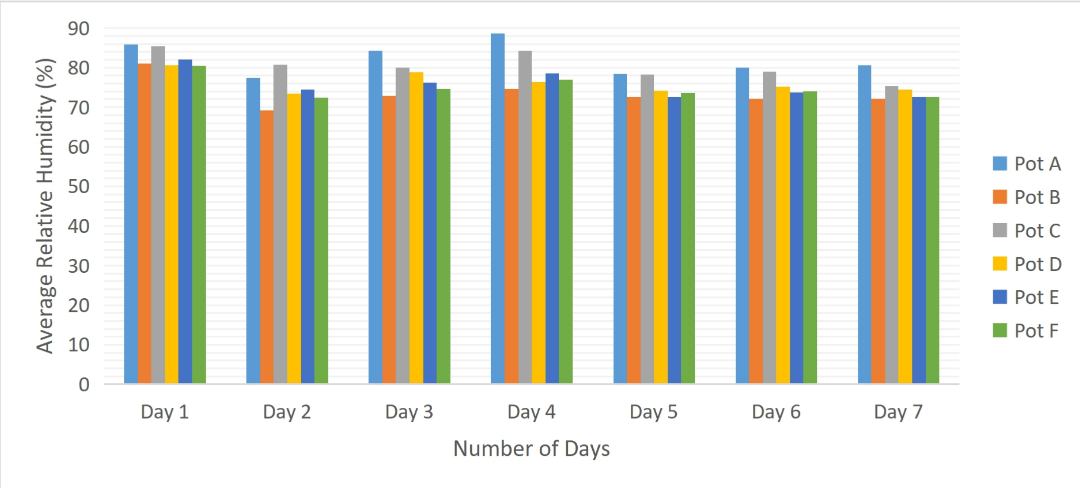

Figure 4: Average Relative Humidity with Number of Days

4.3 Average Enthalpy

Enthalpy is the amount of internal energy within a system combined with the product of its pressure and volume. It is also the amount of heat in air. In the HVAC industry, enthalpy process is assumed to be at constant pressure thus, the change in enthalpy is equal to the heat absorbed or released. The purpose of an HVAC system is to transfer heat, which is a form of energy. When the temperature of a system increases, the kinetic and potential energies of the atoms and molecules in the system increase. Thus, the internal energy of the system increases, which means that the enthalpy of the system increases – this is true under constant pressure or constant volume. From Figures 10-13, Pots A-F all had positive enthalpy values from days 1-3. The positive enthalpy values indicate an endothermic reaction and the complete absence of combustion which is null in this experiment. A marginal cooling takes place in pots except pot E due to minimal increment in the enthalpy values as enthalpy is a function of temperature rise.

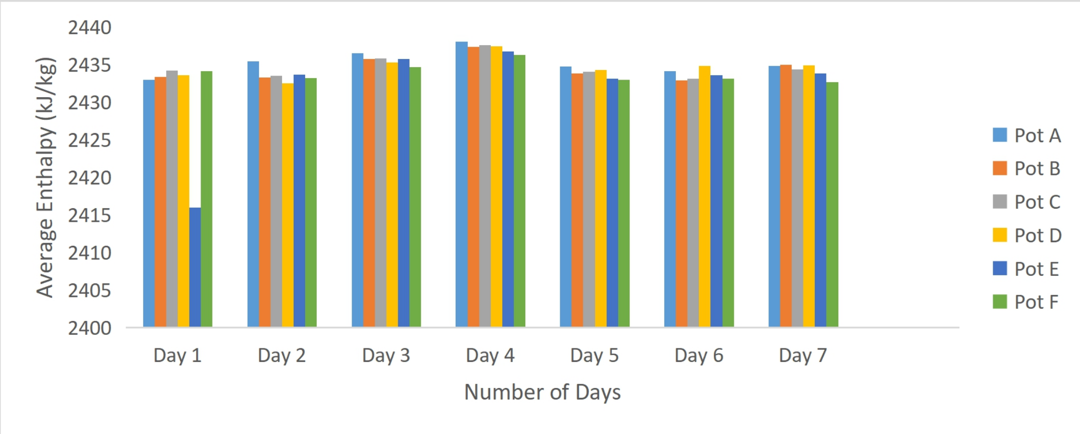

Figure 5: Average Enthalpy with Number of Days

4.4 Average Evaporative Cooling Rate

Figure 6 presents the average evaporative cooling rate for the six pots within seven days. Pot A shows a gradual decrease in the average evaporation from Day 1 to Day 7 with initial and final average evaporative cooling of 0.0215kJ/m^2 and 0.0183 kJ/m^2 respectively. Pot D has the same changes as pot A but experienced a high average evaporative cooling. It is observed that there exists relationship between the enthalpy, temperature and evaporation rate. Thus, the higher the temperature, the higher the enthalpy and evaporative cooling rate. From Figures 6, pot B has a significant high evaporative cooling compared to other pots, an indication of effective thermal comfort in application.

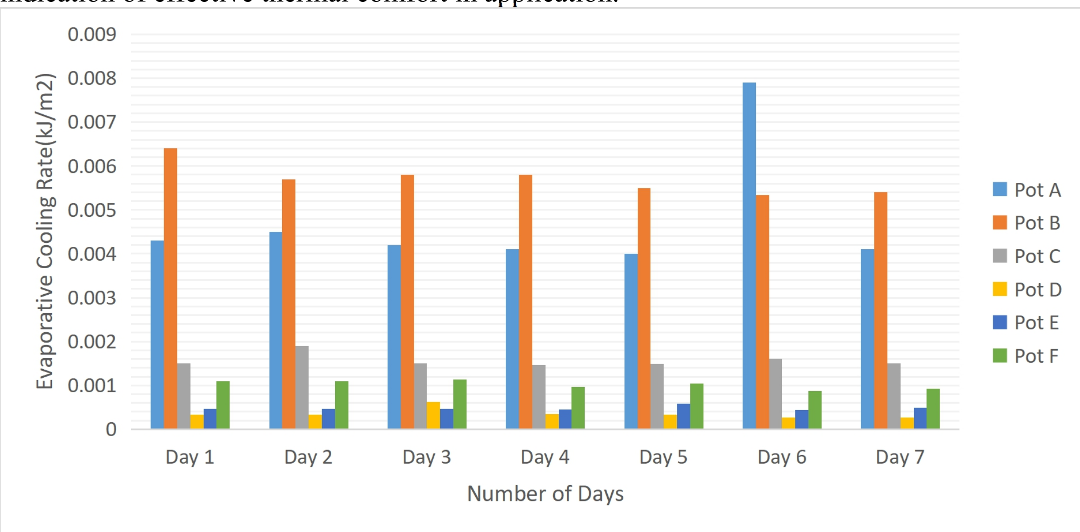

Figure 6: Average Evaporative Cooling Rate with Number of Days

5. Conclusions

In this study, experimental analysis of cooling capacity of six different porous clay vessels (A to F) with different sizes and dimensions was carried out to examine the evaporative cooling of water under varying ambient temperatures with emphasis on rate of mass loss, relative humidity, average cooling rate. The result revealed that. there was mass loss in all the six pots with pot (B) experiencing higher mass loss due to its wide surface area. Considering porosity level, it was observed that water in Pots (D) and (E) gave the highest mass loss.

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