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Preliminary Design and Testing of an Evaporative Cooler

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Abstract: **The dependency of the existing designs of evaporative coolers on electricity for operation is a severe limitation for their usage in Nigeria due to challenges associated with electricity provision. Consequently, devices that are either energy independent or raw energy dependent will provide a more reliable option. The present work is aimed at harnessing raw solar radiation for cooling. A range of designed and fabricated prototype evaporative coolers were employed for which analysis were conducted to study the effect of varying certain parameters against a controlled condition. Attempt was made to utilize the device such that a temperature drop low enough to effectively preserve perishables without employing external energy sources, pumps or converters was attained. The performance evaluation yielded a temperature drop of at least 6 °C from the ambient. Potentially, this device shall be suitable for the preservation of perishable edibles.**

Keywords: **Solar radiation, evaporative cooling, temperature drop, ambient temperature.**

1. BACKGROUND

Unlike conventional refrigerators and central air conditioners that works by removing humidity out of the air, evaporative coolers cool air by filtering it through water thereby lowering its temperature (port-a-cool.com). Using evaporative cooling for lowering the temperature of ambient air and improving the relative humidity of a cooling chamber had been in practice for time immemorial in the form of 'pot-in-pot" coolers (Watt, 1997). The general features of a typical pot-in-pot evaporative cooler is as depicted in Figure 1.0.

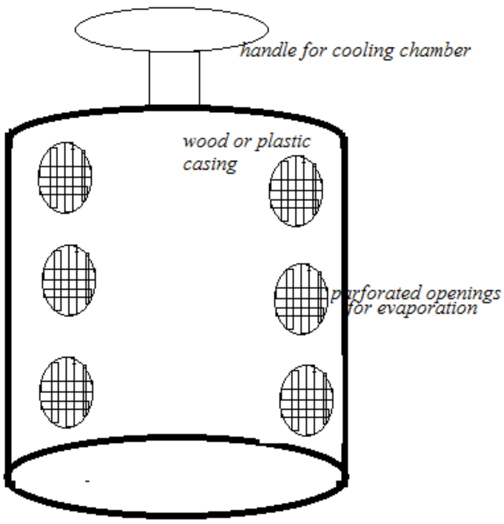

Figure 1.0 General features of pot-in-pot refrigerator

Applications of solar radiation had remained an active research field especially in the temperate regions of the world (Otterbein, 1996). The preservation of perishable foods is usually achieved via refrigeration which is limited by electricity availability. Several researchers (Dagtekin *et al.*, 2011; Fouda and Melikyan, 2011; Kulkarni and Rajput, 2011; Jain, 2007; Beshkani and Hosseini, 2006; Camargo *et al.*, 2005; El-Dessouky *et al.*, 2004; Dowdy and Karbash , 1987; Dowdy *et al.*, 1986; Kulkarni and Rajput, 2013) had attempted to explore evaporative phenomena for cooling purposes.

To attain this, various control parameters were studied and their effect on cooling rate. Direct contact with farmers and sellers of vegetables and fruits has shown skepticism on the effectiveness of this method in preservation of products in a tropical environment like Nigeria (Ndukwu and Manuwa, 2015).

1.1 Evaporative Cooling

Evaporative cooling is a thermodynamic process resulting from adiabatic saturation of air. When water evaporates it draws energy from its surroundings, which produces a considerable cooling effect. The driving force for heat and mass transfer between air and water is the temperature and partial vapor pressure differences (Xuan *et al.*, 2012). Due to the humidity difference of the incoming air in contact with water, water absorbs the heat from the incoming air, thereby lowering its temperature and increasing its humidity. The sensible heat from the air is then converted to the latent heat and the water uses it to evaporate (Watt, 1963).

2. AIM AND OBJECT1VES

This study was aimed at design and fabrication of a cooler that utilizes raw solar-radiation-based evaporation for cooling.

Specific Objective

1. To fabricate a range of simple prototype models without employing external energy sources, pumps or converters.
2. To study the effect of varying a range of parameters on the temperature drop.
3. To evaluate the performance of a simple evaporative cooler that can provide significant temperature drop.

Limitations

1. Nature of material and its effect on the evaporative cooling rate
2. Lag-cage dimension and its effect on the evaporative cooling
3. Air velocity and its effect on the cooling efficiency
4. Fluid mass flow rate inconsistency

3. MATERIALS

The materials deployed for experimental set up and measurements are: thermometer, stopwatch, polished wood, external caliper, empty iron tins (milk and paint), water, scissors, hammer, measuring tape, saw, foam, buttemut, thread and needle, nails, sharp sand, mud sand.

4. METHODOLOGY

4.1 Cooling Chamber

The cooling chamber is made of' an empty iron tin of either milk or paint. The iron tins used were not customized but adopted as manufactured by their respective factories. The iron tins were used because they are both made from metallic material whose conductivity is a necessary ingredient for effective cooling due to its efficient heat transfer property.

4.2 Casing

The casing was achieved by coupling 8 narrow pieces of (1.5 x 1.6) cm polished wood held firmly together using nails to construct rectangular cages of dimensions (25.5x14.3) cm, (27.6x16.l) cm and (32.2x21.0) cm for smallest, medium and biggest case sizes respectively. The built wooden skeleton were then wrapped with the flexible *butternut* to form a rectangular enclosure with an opening at the top.

4.3 Lagging

The lagging of the space between he cooling chamber and the outer casing was performed in order to provide a medium that will perform the dual function of moisture retention and evaporation surface provision. Three main materials were used to achieve lagging of the evaporative cooler namely: soil (Sharp sand and mud soil), foam and butternut. The dimensions of the lag cages were of the range: 9 m to 2.4 cm. The lagging density was not specified but stuffed reasonably.

5. EXPERIMENTATION

5.1 Procedure

i. Pure tap water was used to fill the cooling chambers of six evaporative coolers and two empty iron tins of milk and paint types for control experimentation purposes.

ii. The ambient environmental temperature, the initial temperature for each of the cooling chambers and the controlled iron tins were read using laboratory liquid-in-glass thermometer.

iii. The evaporative coolers were then soaked with pure water until the lagging and casing materials were completely saturated.

iv. The evaporative coolers and control iron tins were then, kept in a shed for a period of one hour after which the cooling chamber temperatures were read and recorded. The ambient temperature and that of the control iron tins were also read and recorded.

v. Steps iii) and iv) were repeated at an interval of one hour to obtain four additional readings.

6. RESULTS

Summary of materials used for lagging and cooling chamber are presented in Table 4.1. The temperatures (^oC) measured at intervals of 1 hour are presented with corresponding ambient temperatures. The starting time of this Procedure was 01:40 pm Sunday, 19th June, 2016 (rainy session in Niger State, Nigeria). This experiment was conducted in the vicinity of Niger State Polytechnic Zungeru TetFund Complex behind the polytechnic's main Library. Summary of results obtained is presented in table 6.1.

Table 6.1: Materials and Temperature summary

Lag Material	Time (m)	$T_0/^oC$ (33.2_{amb})	$T_1/^oC$ (32_{amb})	$T_2/^oC$ (29_{amb})	T_3 $/^oC$ (26_{amb})	$T_4/^oC$ (29_{amb})
Sharp sand	0	29	28.9	29	28.3	29
Mud soil	60	29	28.2	28.2	28	28
buttemut	120	29	28.3	28.3	28	28.3
buttemut	180	29	28.0	28.0	27.4	27.4
foam	240	29	28.3	28.0	28.0	28.0
buttemut	300	29	27.9	27.4	27.2	28.0

The temperature drop presented in Table 6.1 is given by equation 6.1.

$$Temperature\ Drop = T_4 - T_o \qquad 6.1$$

A measure of the temperature fluctuation with corresponding evaporative cooler (EC) number is depicted in Figure 6.1. T_0 to T_3 ate acronyms for measured temperatures at 0 to 3 hours respectively while the numbers in parenthesis gives the ambient temperatures at time of measurement.

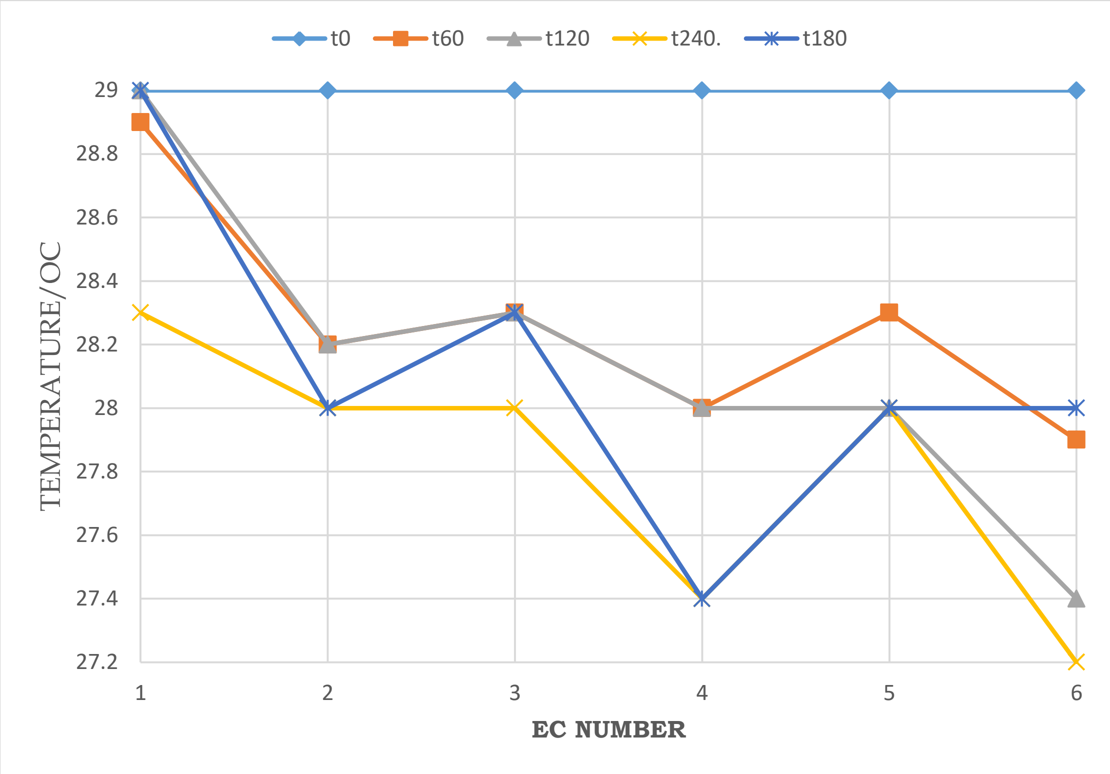

Figure 6.1: Temperature-time trends

The trend shows an unsteady but consistent drop of temperature with time in all the cases for all material types. The unsteady trend could be as a result of temperature reset arising from exchange of heat between the already cooled chamber and the introduced higher temperature water used in re-wetting. However, there is a more noticeable temperature drop in the T_{240} curve compared to T_0, T_{60} , T_{120} and T_{180} This could be as a result of i) prolonged cooling and ii) lower ambient temperature. The actual effect of the achieved cooling can be calculated by subtracting the minimum temperature value in the T_{240} curve in presented in Figure 6.1, from the maximum of the control experiment presented in Figure 6.2.

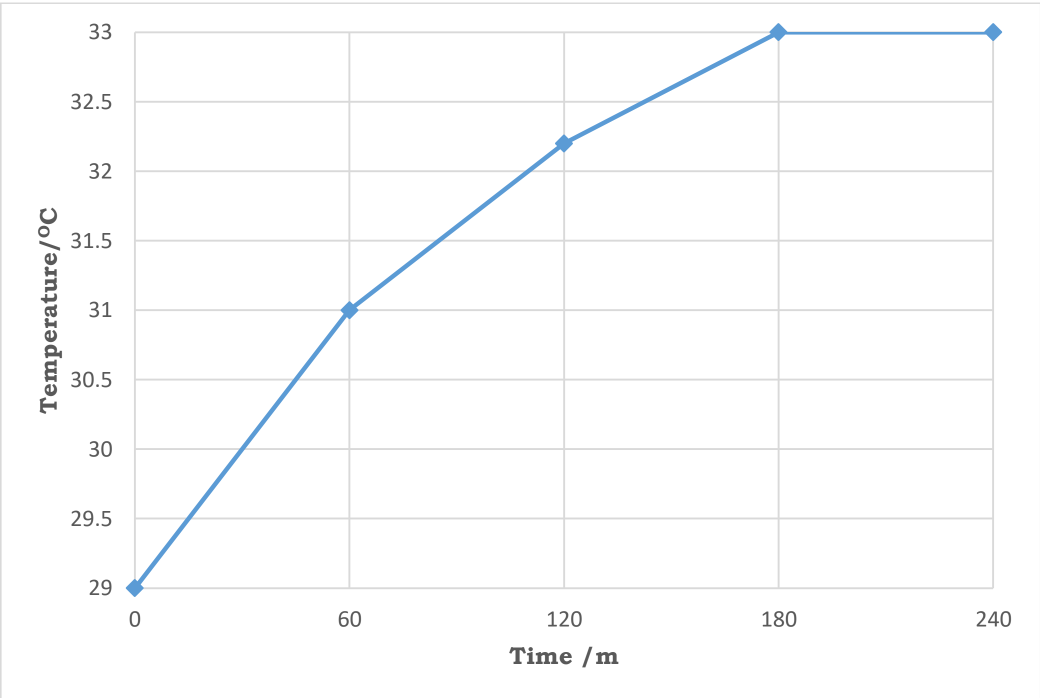

Figure 6.2: Temperature-time trend for control

This implies that a cooling of about 5.8 ^{o}C was attained through the utilization of the evaporative cooling devices as presented in equation 6.2.

$$Actual\ cooling\ attained = 33 - 27.2 = 5.8^{o}C \qquad 6.2$$

7. CONCLUSION

Evaporative cooling via raw solar radiation had been exploited to successfully achieve temperature drop that is substantial enough to attest to the viability of this methodology for effective cooling.

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