Development and Performance Evaluation of Pot-in-pot Cooling Device for Ilorin and its Environ

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Abstract

Pot-in-pot cooling device is basically a food cooler that utilizes the effect of evaporative cooling for its intrinsic mechanism to preserve drugs, fruits and vegetables in hot and dry climate. The performance of the cooler was examined in this experiment when the lining media was changed from sand to charcoal and sawdust as well as considering the meteorological data of Ilorin. The cooling effects of three pots of the same geometry bearing different lining media were compared. The pots were set up and observed for 59 days from 8:00 am to 6:00 pm and the performances were recorded. The device performs well under a low relative humidity. The lining media, that holds water necessary for evaporative cooling is the primary factor that was used to determine the performance of the pot-in-pot cooling device in this research. It was found that the three inner temperatures for the three lagging materials were significantly different. Under all three conditions Charcoal (mean efficiency of 75 %) provides better results than sand (mean efficiency of 66 %) and sawdust (mean efficiency of 58 %).

Keywords

Evaporative cooling, Efficiency, Pot-in-pot, Preservation, Ilorin

1. Introduction

As the problem of energy persists in Nigeria and Africa at large and the high cost of energy, especially in cooling system, for food storage being not economically friendly, there is a need to explore other sources of

energy such as wind, water and solar. Several simple practices are useful for cooling and enhancing storage system efficiency wherever they are used, especially where energy savings may be critical, like in the developing nations. Mechanical refrigeration commonly used in the developed nations is, however, energy intensive and expensive, and involves considerable initial capital investment requiring uninterrupted supplies of electricity which are not always readily available (Basediya et al., 2013). Therefore, the pot-in-pot device is a good cooling mechanism especially in the tropical region with less humidity and reasonably high reception of sun ray that is in localities where reasonable low wet-bulb temperature (21°C and below) occurs intermittently with high dry -bulb temperature (32°C and above) for extended period of time (Manuwa & Odey, 2012).

The pot-in-pot cooling device is invented in Africa which operates by the principle of evaporative cooling. According to Science in Africa, each device can store 12kg of vegetables, keeping them fresh for up to 20 days while costing less than 2USD to produce (Elkheir, 2002). The cooler is made of a porous outer earthenware pot with wet sand or other lining materials as its lining media and contains an inner pot within which the food or other items to be cooled is placed - the evaporation of the outer liquid draws heat from the inner pot cooling any substance within it. Rinker (2014) reported that this simple technology requires only a flow of relatively dry air and a source of water.

Earthen pots of various shapes and sizes are sold in many local markets in Nigeria and it is well known that water stored in earthen pots cools down below ambient temperature due to evaporative cooling (Olorunmaiye, 1994). Pot-in-pot cooling has had the multiple helpful influences on the population that uses them outside the simple ability to preserve food for longer periods of time and diminishing instances of food-related disease (Oluwasola, 2011).

Sanders (2013) opined that evaporative coolers are a neat idea and when used in the correct environments, they can provide much needed cooling for very little cost. It is however safe to make expectations reasonable as they very rarely manage to keep temperatures as cool as the modern refrigerators. Warmer temperatures and less storage space are part of the trade-off for their low cost and simplicity. But to maximize the

effectiveness of the pot-in-pot cooling device, the rate of evaporation must be increased. To properly investigate the technology, it is important to quantify the effects of Relative Humidity, air flow and Area available for Evaporation (Richard, 2010).
Manuwa and Odey (2012) noted that most of the research publications on evaporative cooling are from the temperate regions of the world whose climatic conditions are quite different from those of tropical countries. Harris (1987) recorded that the wet-bulb temperature prevailing in an area is one of the important limitations in evaporative cooler performance. It is only in localities where reasonable low wet-bulb temperature (21 °C and below) occurs intermittently with high dry-bulb temperature (32 °C and above) for extended period of time that evaporative cooling was successful. Apart from the general requirements for the efficient operation of an evaporative cooling system, the efficiency of an active evaporative cooler depends on the rate and amount of evaporation of water (Wiersma, 1983; Dzivama, 2000) from the lining media.

For direct evaporative cooling, the direct saturation efficiency, ε, measures in what extent the temperature of the inner pot of the evaporative cooler is close to the wet-bulb temperature of the ambient temperature. The saturation efficiency is calculated using the model reported by (Harris, 1987):

$$\varepsilon = \frac{T_{e,db} - T_{l,db}}{T_{e,db} - T_{e,wb}} \quad (1)$$

where ε = direct evaporative cooling saturation efficiency (%), $T_{e,db}$ = entering air dry-bulb temperature (°C), $T_{l,db}$ = leaving air dry-bulb temperature (°C), $T_{e,wb}$ = entering air wet-bulb temperature (°C)

The rate of evaporation is the key to cooling performance in these devices; however, the amount of energy removed during evaporation matters a lot, so faster evaporating liquids would support improved performance if energy is removed in the process. The pot-in-pot cooling device is capable of keeping foods and drugs at a temperature lower than the ambient air temperature. How much lower though? How many degrees Centigrade or Fahrenheit lower and under what ambient

conditions? Several literatures states that evaporation brings about a drop-in temperature of several degrees, cooling the inner pot and extending the shelf life of the perishable food inside. Brooke (2009) affirmed that without using any power, temperatures stay at 6 °C.

A lot of disparate designs of evaporative cooling gadgets have been accounted for in writings in literature for extending the shelve life of fruits and vegetables (Redulla, 1984; Roy, 1989; Acedo, 1997; Noble, 2008; Anyanwu, 2004; Ndukwu, 2011). The design ranges from straw packing house to some sophisticated design.

Acedo (1997) researched cooling pads such as jute bag and rice husk in the development of evaporative cooler in the Philippines for cooling and storage of vegetable. Anyanwu (2004) also developed a porous wall (pot in pot) evaporative cooler where he got a storage life of less than four days (93hours) on tomato. Jain (2007) incorporated a heat exchanger in a two-stage evaporative cooler for fruits and vegetable where a storage life of 14 days for tomato was achieved with the simple design. Ndukwu (2011) developed a mud evaporative cooler with local available materials. The ambient temperature was able to be dropped to 10 ^{o}C and an increase in the relative humidity from 40.3% to 92% of incoming air for the storage chamber. The evaporative cooler was able to preserve freshly harvested tomato for 19 days (Ndukwu, 2011).

Liberty *et al.* (2013) developed and evaluated evaporative cooler fabricated with locally sourced materials. From the previous research works done vis-à-vis the need for a storage system for the preservation of fruits and vegetables, which is not expensive and can be commercialized, it is obvious that there is need to further develop/improve the existing works (Olosunde *et al.* 2009). In this research work, an effort was made to evaluate the performance of several lining materials experimentally. A special setup was designed to evaluate the performance of the three widely available materials chosen due to their abundance and low cost. The chosen lining materials are Sand, Sawdust and Charcoal.

The pot-in-pot cooler saves money, after the initial purchase, there is no running cost, it needs no fuel as sunlight is the fuel it needs, and sunlight is abundant, inexhaustible and always free. It is completely quiet, no

noise, no fumes, no pollution and gives real energy independence. The pot-in-pot cooler has no moving parts and therefore no wear and tear and has minimal cost of material. This device will help in preservation of foods and drugs most especially in the rural areas.

This paper is therefore aimed at considering other alternatives to sand for the operation of the cooling device. Readily available, inexpensive and easy to handle materials are therefore examined. The specific objectives of this paper are to:

(i) Determine the top efficiency of the pot-in-pot cooling device by changing the lining media (sand, saw dust and charcoal);
(ii) Compare the data collected from the experiment to know the viability of the device in Ilorin.

2. Methodology

2.1 Place of Study

The study was carried out in the month of January and February 2014 in Ilorin, the capital city of Kwara State Nigeria. Ilorin is located on latitude 80 10'N and longitude 40 35'E marking a divide between the southern forest Zone and the Northern grassland of Nigeria. The climate is therefore tropical wet and dry characterized by a distinct wet and dry season with a mean annual temperature of about 26.80 °C with five

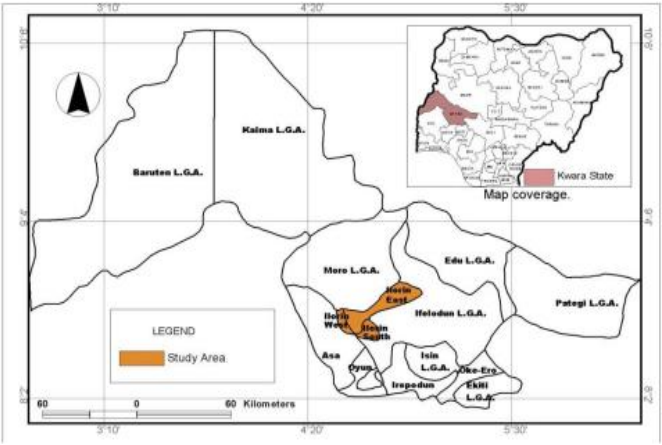


Figure 1: Figure 1: Map of Kwara state showing the study area (Inset: Map of Nigeria) (Olorunfemi & Raheem, 2013)

hours average daily sunshine Figure 1 shows a map of Kwara state showing Ilorin.

2.2 Materials

The success of the pot-in-pot cooling device is dependent on the surrounding conditions due to the reliance on natural evaporative cooling, in order to quantify the effect of the lagging materials on the performance of the pot-in-pot cooling device in Ilorin. Meteorological data (Ambient Temperature, Relative Humidity and Wind Speed) of Ilorin were obtained from Nigeria Meteorological Agency (NIMET).

Ventilated Space*:* The experiment was set up in a dry, ventilated space for the water to evaporate effectively towards the outside.

Evaporative Coolers: The experiment uses two clay pots, one larger than the other, made from earthenware clay. In whole there were six pot-in-pot cooling devices made for the project with the size of the inner pot kept constant at a diameter of 0.25m and 3 outer pots of $0.22m^2$ surface area employed. A wetted towel was used as the lid for the inner pot, to reduce the effect of sensible heat that could be gained from solar radiation.

Lining materials: Sand is often used because it is inexpensive, and it has a large surface area. The most important features are that it holds lots of water and provides surface area for evaporation. Charcoal can be made from anything containing carbon. Traditionally wood has been the raw material used to make charcoal. Wood consists of three main components: cellulose, lignin and water. These compounds are composed almost entirely from atoms of hydrogen, oxygen and carbon. Charcoal is made by removing the hydrogen and oxygen in the wood while leaving just the carbon.

The Lining materials investigated include:

(i) River Sand, sieved with a laboratory test sieve of 850 micro-metre aperture sizes;
(ii) Sawdust, collected from the Sawmill in Sawmill area in Ilorin; and
(iii) Charcoal (wood) crushed and used in no definite sizes;

Measuring Devices; The measuring devices used in the investigation include:

(i) Digital thermometers which were used to record the various temperatures
(ii) A clock was used to record the time interval

Water: Water is the most practical liquid to use for evaporation. It is readily available, and it removes a large amount of heat per kilogram of evaporation as compared to other liquids. For practical coolers, it is really the only liquid that makes sense (Sanders, 2013). So, water was used to drive the process.

2.3 Test Procedure

The tests were carried as described below to establish the transient response of the cooler to variations in prevailing weather conditions in terms of temperature reduction between the ambient and the cooler storage chamber and change in relative humidity. Further analyses were carried out to determine the differences in the temperatures inside the pot based on the lagging material. The hypotheses stated are as follows:

$$H_0: \mu_i = \mu \quad (2)$$

for all i, with i =1,2,3

$$H_1: \mu_i \neq \mu \quad (3)$$

for at least one i, with i=1,2,3

where μ_i represents the mean temperature inside pot i and i stands for each pot of the various experiment. Analysis of Variance (ANOVA) (Yandell, 1997) was used to test hypotheses stated above. P-value, obtained from the ANOVA, was used to determine which of the two hypotheses is to be accepted. The decision rule is given as: Reject H_0 if p-value is less than 0.05.

2.3.1 Comparison of the Cooling Effect with Different Lining Media

Sand, sawdust and charcoal were placed in the bottom of the 3 large pots respectively forming a layer of approximately 5cm in depth. The smaller pots were then placed on top of the sand, sawdust and charcoal respectively and centred in the large pot (the pots were set to the same level). The remaining spaces between the pots were then filled with

sand, sawdust and charcoal respectively. The small pots were covered with wet towel to prevent hot air from entering the storage chamber. Water is then added to make the lining media moist. The pot-in-pot cooling device operates passively if the sand remains moist. Digital thermometers with reading accuracy of ±0.1 °C were used to obtain the temperatures of the inner pots.



Figure 2: Comparison of the cooling effect with different lining media

2.3.2 Evaluations of Efficiency

Efficiency (E) as an important criterion to judge the evaporative cooling system is calculated as a temperature difference ratio (ASHRAE, 1992). The efficiency of the evaporative media was calculated by

$$\varepsilon = \frac{T_{Amb} - T_{in}}{T_{Amb} - T_{wet}} \quad (4)$$

where T_{in} = Temperature of the inner pot (°C), T_{Amb} = Dry Bulb Temperature (°C), T_{Wet} = Wet Bulb Temperature (°C), ε = Efficiency of the evaporative media (%)

3. Results and Discussion

3.1 Variation of Temperature inside and outside the Evaporative Cooling Systems

Figure 3 shows the variation of dry-bulb temperature versus time inside and outside the coolers. The daily temperature readings within each

cooler depend on ambient conditions. There was significant difference ($p < 0.05$) in each case between the temperature observed inside the coolers and the ambient temperature. Maximum temperature outside the coolers was observed at about 16.00 hours for all the tests. The lowering of the dry-bulb temperature which was clearly observable in the curves is a measure of the effectiveness of the experimental setup depending largely on the lagging material, area available for evaporation and height under the same ambient condition.

The ANOVA test done on the lagging material produced p-values of 8.321e-06, since the p-values for the test done is clearly less than 0.05, H_1 will be accepted. Therefore, the conclusion is that the mean temperatures in the inner pots for the three lagging materials (charcoal, sand and sawdust) are significantly different from each other. Because of the conclusion reached, a pair wise comparison is needed to determine the difference comparing each pair e.g. charcoal and sawdust, sand and charcoal, sand and sawdust.

Tukey HSD test (Yandell, 1997) was used for this purpose. The decisions are also reached based on the p-values obtained from the test. The pair compared, and the corresponding p-value is as follows:

For the lagging material; Sand and Sawdust is 0.0338509, Sand and Charcoal is 0.0068541 and Sawdust and Charcoal is 0.0000048. Since the three p-values are less than 0.05, it can be concluded that the inner temperature for all the three-lagging material are significantly different from each other.

3.2 Variation of Temperature Drop inside the Evaporative Cooling Systems

This phase was aimed at recording the air condition inside the evaporative cooling system and atmospheric air condition simultaneously. The comparison of both readings showed if there was any significant difference between them. The parameters of interest were temperature and relative humidity. The temperature changes in the cooler was measured and recorded hourly. A digital thermometer was used. 59 replicates of the experiments for each experimental arrangement were carried out and the average temperature and relative humidity were reported. The ability of the various lining material used in

this project to support evaporation by easily giving up water under sunlight impact was tested and charcoal was found to have the greatest ability, closely followed by river sand and the poorest of the three was saw dust as shown in Figure 3.

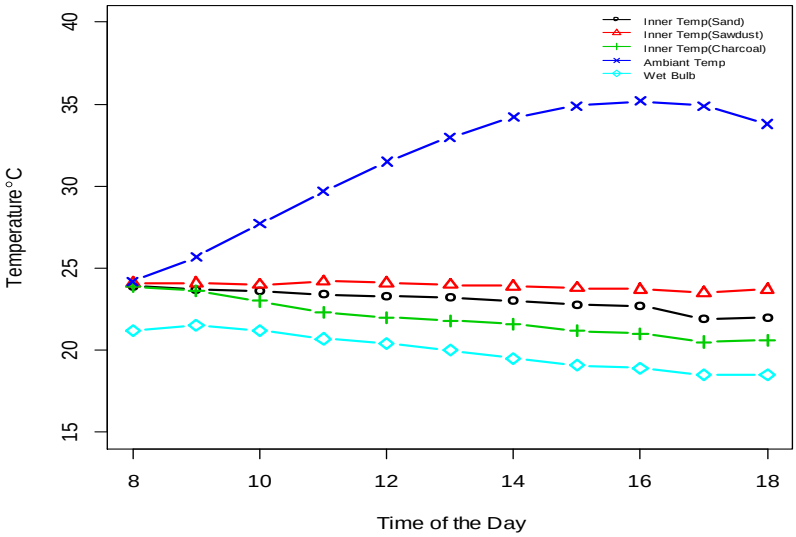


Figure 3: Comparison of sand, sawdust and charcoal as lining media

3.3 Cooling Efficiency of the Evaporative Cooling System

Many researchers (Harris, 1987; Olorunmaiye, 1996; Al-Sulaiman, 2002; Lertsatitthanakorn, Rerngwongwitaya, & Soponronnarit, 2006; Dagtekina, Karacab, & Yıldızb, 2009; Ahmed, Abaas, Ahmed, & Ismail, 2011; Xuan, Xiao, Niu, Huang, & Wang, 2012) have estimated cooling (saturation) efficiency of direct evaporative cooling system using equation (4).

The values of depression of the temperature within the inner pots (T_{in}) below the ambient temperature (T_{amb}) divided by the ambient wet bulb depression i.e. (T_{amb} - T_{in})/ (T_{amb} – T_{wb}). Using this parameter instead of temperature difference (T_{amb} - T_{in}) enables us to compare the cooling effect of the pot on different days in different locations having different relative humidity and ambient air distributions (Olorunmaiye, 1996)

Table 1 - Comparison of the Efficiency of lining media

Time of Day	Average of reading										
	Inner Temperature T_{in} (°C)			Ambient Temp	Wet bulb Temp	Relative Humidity	Wind Speed	$T_{Amb} - T_{wet}$	$\varepsilon = (T_{Amb} - T_{in})/(T_{Amb} - T_{wet})$ (%)		
	Sand	Sawdust	Charcoal	(°C)	(°C)	(%)	(m/s)	(°C)	Sand	Sawdust	Charcoal
8.00	23.9	24.1	23.9	24.2	21.2	63.3	2.4	3.0	0.10	0.03	0.10
9.00	23.7	24.1	23.6	25.7	21.5	78.4	3.1	4.1	0.46	0.36	0.51
10.00	23.6	24.0	23.0	27.7	21.2	68.4	4.2	6.5	0.63	0.57	0.72
11.00	23.4	24.2	22.3	29.7	20.7	59.0	3.9	9.0	0.70	0.61	0.82
12.00	23.3	24.1	22.0	31.5	20.4	52.3	3.6	11.1	0.74	0.67	0.86
13.00	23.2	24.0	21.8	33.0	20.0	46.8	3.8	13.0	0.76	0.69	0.86
14.00	23.0	23.9	21.6	34.2	19.5	42.5	2.9	14.6	0.76	0.70	0.86
15.00	22.8	23.8	21.2	34.9	19.1	40.0	3.4	15.8	0.77	0.70	0.87
16.00	22.7	23.7	21.0	35.2	18.9	38.5	3.1	16.3	0.77	0.71	0.87
17.00	21.9	23.5	20.5	34.9	18.5	38.1	3.2	16.4	0.79	0.70	0.88
18.00	22.0	23.7	20.6	33.8	18.5	40.8	3.2	15.3	0.77	0.66	0.86

The efficiency of the pot-in-pot cooling devices increases as the relative humidity, a measure of the content of water that is held in the air at a specific temperature, of the environment decreases as shown in Figure 4.

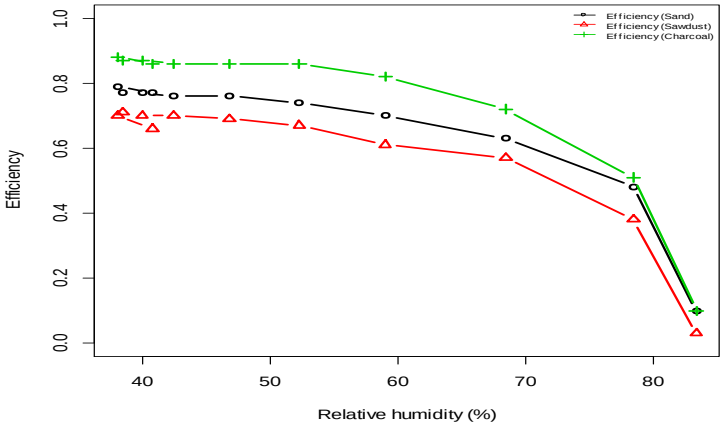


Figure 4: Efficiency vs relative humidity (%) for different lining media

It is observed that the efficiency of the cooling device increases with time. There is a noticeable increase in the efficiency from morning to noon time. After noon, there is no significant change in the efficiency of the device. This is due to the fact that the relative humidity is lower at this time and the device performs optimally at this point when harvesting is mostly done in the farms and cooling is much needed. Evidently, the pot-in-pot cooling device is only effective in environments with a low relative humidity as such environment will evaporate moisture readily and as shown in Figure 5.

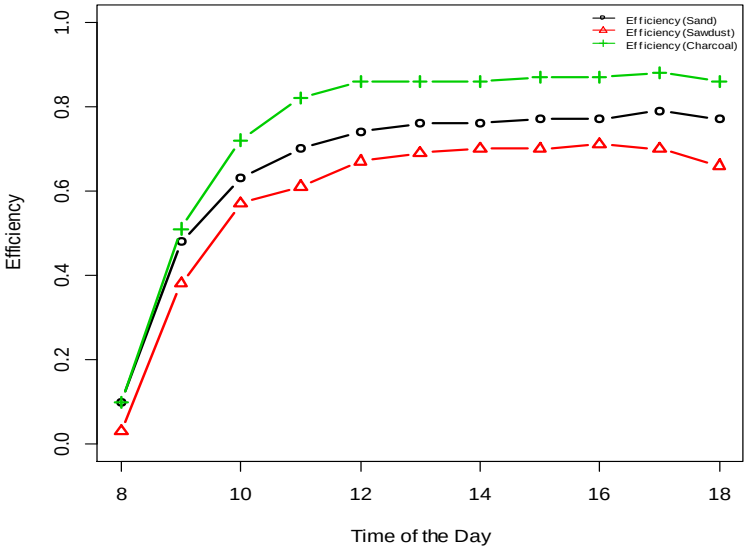


Figure 5: Efficiency Vs time of day for different lining media.

There is a positive relationship between the temperature in the pots and relative humidity. As the relative humidity increases, the temperature inside the cooling chamber also increases. This confirms the conclusion made when comparing the relationship between relative humidity and efficiency of the device. This is shown in Figures 6.

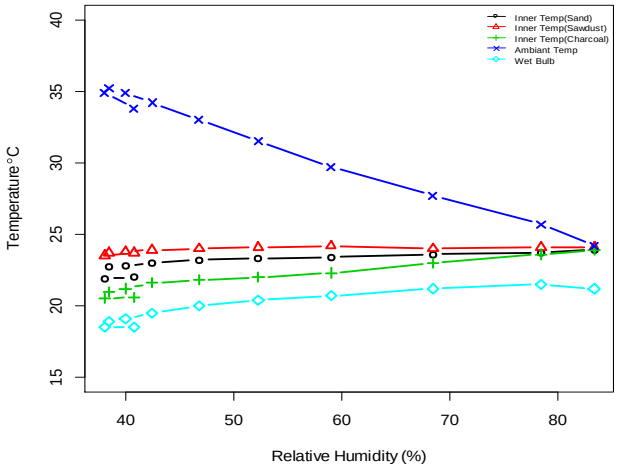


Figure 6: Graph of Temperature (^{o}C) Vs Relative Humidity (%) for different lining materials

4. Conclusions

A parametric analysis concerning the performance of a pot-in-pot cooling device has been performed. The lining material is a primary factor that was addressed to analyse the performance of the pot-in-pot cooling device as demonstrated by the research. The mean efficiencies of the device were found to be 66%, 58% and 75% for the various lining materials; sand, sawdust and charcoal respectively. This demonstrates that charcoal is the best lining media to power the pot-in-pot cooling device. The performance of these lining material is better when compared favourably with those reported by other researchers. elsewhere. It is hoped that this project will be able to address the issues of food storage in Sub Saharan West Africa as part of a sustainable approach. The device is simple and inexpensive. It can operate without any additional heat source or Solar collector and can be constructed from locally available materials.

5. Recommendation

A 'load tests' to determine the effectiveness of the coolers is highly recommended and a detailed conduction model to analyse heat transfer and mass diffusion mechanisms within the various layers would aid in identifying factors limiting performance and how they can be addressed.

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