Analyses of Some Local Material as a possible cooling pad in Active Evaporative Cooling System

*Ndukwu M. C[1], S.I. Manuwa[2], O. J. Olukunle[2], I. B. Oluwalana[3]

1. Department of Agricultural and Bio Resources Engineering, College of Engineering and Engineering Technology, Michael Okpara University of Agriculture Umudike, P.M.B 7267 Umuahia Abia State, Nigeria
2. Department of Agricultural Engineering, School of Engineering and Engineering Technology Federal University of Technology Akure, P.M.B. 704 Akure, Ondo State, Nigeria.
3. Department of Food Science and Technology, School of Agriculture and Agricultural Technology Federal University of Technology Akure, P.M.B. 704 Akure, Ondo State, Nigeria.

*Email: (ndukwumcu@gmail.com)

Abstract

The usefulness of some local material as cooling pads in evaporative cooling system was analyzed at a constant speed of 3, 4 and 4.5m/s. Four different pad materials made up of charcoal, palm fruit fiber, shredded latex foam and jute fiber were studied. Palm fruit fiber recorded the lowest storage temperature value of 19.1 at 4.0 m/s. Generally average temperature difference of 0.5 - 18.3 ^{0}C between the draft air and the storage space of the cooler was obtained for the four tested pads. The average relative humidity for the four pads were 63 -91% at 4.5 m/s, 60 -90 at 4.0 m/s and 57 – 70 at 3.0 m/s.

Keywords: **palm fiber, jute fiber, charcoal, latex foam, temperature difference**

1. Introduction

Adequate storage of fruits and vegetables prolongs their usefulness, checks market gluts, provide a wider selection of fruits and vegetables, helps in orderly marketing and will increase the financial gain to the producer by reducing subsequent losses. For fresh market produce, any method of lowering the temperature and increasing the relative humidity of the storage environment (or decreasing the vapour pressure deficit (VPD)) between the commodity and its environment relative to the ambient will Suppress enzymatic degradation and respiratory activity (Ndukwu 2011). It will also slow water loss, reduce the rate of growth of decay-producing micro-organisms (molds and bacteria), slow the pace of ethylene production (a ripening agent) and other metabolic activities (Katsoulas et al., 2010, Boyette et al., 2010). Post-harvest storage of fruits and vegetables is one of the major problems in tropical countries, which has resulted in estimated 25–30% loss of perishable commodities annually at various levels after harvesting (Jain 2007). CISRO, (2013) presented a wide range of storage temperature and relative humidity for different fruits and vegetables. This includes those with short shelf life of less than a week like the leafy vegetables and those with long shelf life of up to three months like apples. Several methods have been used to preserve fruits and vegetables in tropical country like Nigeria and they include, night air ventilation, the use of ice and underground (root cellars, field clamps, caves) or high altitude storage, (FAO, 2003). However, compression refrigeration remains popular but it has been reported that several tropical fruits and vegetables cannot be stored in the domestic refrigerator for too long due to their susceptibility to chilling injury, colour changes and rapid deterioration once removed from the refrigerator (Olusunde et al., 2009). The chlorofluorocarbon (CFCs) and hydro chlorofluorocarbon (HCFCs) refrigerants used in compression refrigeration systems are partly responsible for ozone layer depletion, which exacerbates global warming (Xuan et al., 2012). Compression refrigeration systems also consume 75% more power than evaporative cooling systems (Palmer 2002). Apart from this, the cost of compression refrigerators is beyond the reach of low-income earner in the rural areas. In view of the deep concerns on above mentioned, social, energy and global environment issues, researchers have been making great efforts to develop energy efficient air conditioning storage technologies and explore environmentally friendly alternative refrigerants. FAO since 1983, has advocated, a low cost storage system based on the principle of evaporative cooling for the storage of fruits and vegetable, which is simple, and relatively efficient. The basic principle relies on cooling by evaporation. When water evaporates, it draws energy from its surroundings, which produces a considerable cooling effect. Evaporative cooling occurs when air, that is not too humid, passes over a wet surface (humidifier). The movement of the air can be passive i.e. when the air flows naturally through the pads or active with fans or blowers. The driving force for heat and mass transfer between air and water is the temperature and partial vapor pressure differences. Water is the working fluid in evaporative cooling thus it is environmentally friendly (Xuan et al., 2012). Several materials have been used to provide the wet surface for air water contact. The major characteristic of these materials is that they were able to hold water and allow air to pass through. Several humidifier tested under different climates include metal pads, cellulose pad, hessian pads, CELdek, GLASdek, PVC pad, porous ceramic pad, wood shaven, jute, rice straw; excelsior of pine, fir, cotton wool. Others are luffa , cedar, red wood, spruce, plain and etched glass fibers, copper, bronze, galvanized screening ,vermiculite, perlite, palm leaf, expanded paper and woven plastic (Al- Sulaiman, 2002; Wei and Geng, 2009; Olusunde et al., 2009; Darwesh et al., 2009; Jain, 2007; Xuan et al., 2012; Manuwa and Odey, 2012). Despite the use of these pads several efficient and cheaper alternatives remain. In addition, most of these materials were evaluated under the temperate climate unlike the tropical climate with high solar load and high humidity most part of the year. The few pads used in the tropical environment especially Nigeria were evaluated using passive cooler which limits its performance to areas with constant natural moving air (Ndirika and Asota , 1994; Anyanwu, 2004; Ndukwu, 2011; Manuwa and Odey, 2012). With increasing market for active evaporative cooling systems, and the effort by researchers to adapt their performance to specific region, there is the need to investigate the possibility of using local materials as cheaper alternative cooling pads. In addition, characterize their performances in other to establish their effectiveness for storing fruits and vegetables for long or short shelf life in a tropical environment.

2. Materials and Methods

The research was done at Federal University of Technology Akure, Ondo state. The state can have maximum daily temperature of about 45^{0}C, in some time of the year and humidity of up to 93%. This represents a high solar load and a very high humidity.

2.1 Pad preparation and loading

The materials used for the test evaluation were charcoal (figure 1); palm fruit fiber (figure 2) shredded latex foam (figure 3) and jute (figure 4).


Figure 1: charcoal figure 2: palm fruit fiber


Figure 3: shredded latex foam figure 4: jute fiber

Water holding capacity and bulk densities of the material used in the humidification were presented in table 1. The thickness of each pad was 30mm. The latex foam was shredded into a 1cm cube shape while the jute fiber was cut into 30 x 33cm dimension. Charcoal and palm fiber was loaded in the shape they were obtained from the source. The compartment were the humidifiers were installed consist of the pad holder which confines the humidifier inside its chamber, the screw and nut assembly to close the pad holder firmly. It also consist of the humidifier chamber were the humidifiers are loaded and a perforated stopper to avoid sagging of the humidifiers and also allow water to pass through.

Table1: Physical Properties of Evaluated humidifiers

humidifier	Moisture Content(% db)	Bulk density (Kg/m^3)	Water holding Capacity (Kg of water /Kg of solid)
Palm fruit fiber	0	47.8	2.05
Jute fiber	0	89.8	2.1
charcoal	10.3	267	0.5
Latex foam	0	7.7	15.1

Source : Manuwa and Odey 2012 and current work

2.2 Description of the prototype evaporative Cooler

The evaporative cooler (Figure 5) used for the test is made up of 0.24 m^3 hexagonal shaped storage housing structure mounted on a steel frame with stainless wire partitions for storing of fruits and vegetables. The cooler wall is made of mild steel plate, fiberglass and aluminum. Three suction fan of 20 cm swept diameter controlled through a rheostat at and delivering maximum air flow rate of **0.5m^3/s were** mounted adjacent the pad holder for each of the three compartments using the frame and held with a bolt and nut assembly. The fans move the draft air through the wet porous media into the storage chamber. To provide for the exhaust air, which is one of the conditions for evaporative cooling, the conditioned air passes through two vents. The vents open to the atmosphere through vent holes. Directly at the bottom of this housing is a plastic 20 L water storage tank for storage of water. A 0.37 KW electric water pump lifts the water from the bottom tank through a PVC pipe to 20L upper plastic water tank.

Figure.5: schematic active evaporative cooling system

Water from the upper tank sprays at the top edges of the pads, and distributes further by gravity and capillarity before it drains into a trough under the pad holder.

2.3 Transient test.

Experimental tests were undertaken with latex foam, jute, charcoal and palm fruit fiber at three air velocities of 4.5, 4.0 and 3.0 m/s to study the effectiveness of the material in lowering the temperature and increase the humidity of the storage space . The evaporative cooler performance tests were undertaken with no produce to establish its transient response to variations in prevailing weather conditions. The test was done between January and February 2013. This period presented the extremes of temperature within the period. During this period, there was rain for some days of the week, which presented very high ambient relative humidity of 80%. In addition, the period presented extreme low humidity of 28% and very high temperature of 45^0C. The materials were tested for three different air velocities of 3, 4 and 4.5 m/ s at a pad thickness of 30mm and a parking density of 20 – 25Kg/m^3. Once the pad is in place, the control valve of the upper water tank was opened to a constant water flow rate of 10 cm^3/s. The water sprays at the top edges of the pad, and distributes further by gravity and capillarity and drains into a trough under the pad holder to the bottom tank. The water was re-circulated back by the water pump for half an hour. The first speed of 3.0 m/s was set with the rheostat and the fan switched on. K-type thermocouple with an accuracy of ±0.1^0C, through the hot wire terminals was inserted into the cooling chamber and connected to an Omega® data logger (model HH1147). One of the terminals was covered with cotton wool soaked inside the water to measure the wet bulb temperature (Anyanwu 2004). The air speed of the fan was measured with vane microprocessor (AM-4826) digital anemometer (±0.1m/s). ABS digital temperature and humidity clock (±0.1^0C and 1.0%) was positioned outside to record the temperature and humidity of the ambient. Two analogue thermometers were inserted inside the two tanks to measure the water temperature. The data were logged every one hour starting from 0900hrs to 1800hrs local time. The relative humidity of the cooler was obtained using the Heatcraft HDPsyChart computer program

3 Results and Discussion

3.1 Temperature drop inside the cooler

There was variation in the daily weather data generated during the experiment. During the period of the test, the dry bulb temperature outside the cooler ranged from 24.4 – 36.8 ^{0}C while the wet bulb temperature ranged from 18.8 – 28.8 ^{0}C. In addition, the relative humidity ranged from 30 – 76 %. Several temperature and relative humidity data was recorded during the period of the test for each pad material used. However for easy assimilation of the results, the data observed for a typical day were presented. Figure 6 – 8 shows the temperature difference between the inside of the storage space and outside the cooler at the various air speeds used.

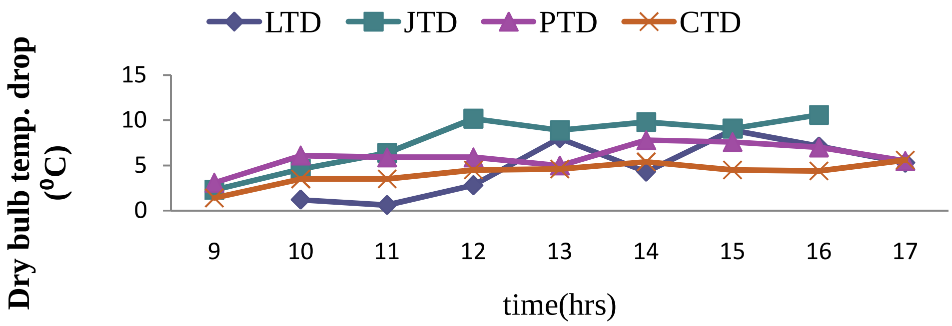

Figure 6: Periodic drop in Temperatures at 3 m/s for the four cooling pads

LTD is the latex foam temperature difference , JTD is the Jute fiber temperature difference PTD is the Palm fiber temperature difference , CTD Charcoal temperature difference.

Figure 6 showed that at a lower speed of 3m/s, the various pad material can bring down the temperature of the draft air passing through it into the storage space to a range of 0.5 to 12^{0}C. Higher temperature difference was comparatively observed as from 12 noon local time when normally the temperature of the outside air warms up and tries to dip in the evening. However this is a function of the weather condition as shown by 1300hrs for palm fruit fiber and 1400hrs local time for shredded latex foam. The higher temperature difference in the noon period showed that the pads were able to extract enough heat from the incoming air to maintain a relatively stable temperature for the storage space although the outside temperature is increasing. Generally jute fiber maintained a higher temperature difference than the rest of the pads at this lower speed.

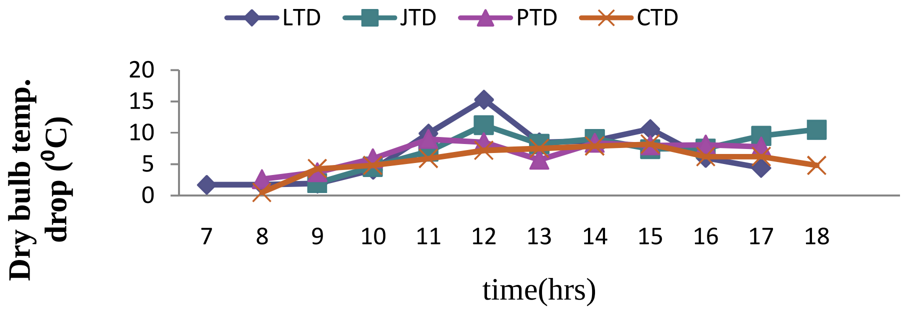

Figure 7: Periodic drop in Temperatures at 4.0 m/s for the four cooling pads

At the air speed of 4.0m/s, the temperature reduction ranged from 1 to 18^{0}C as shown in figure 7. Higher temperature difference was also observed in the noon period. However shredded latex foam gave a higher temperature difference in the noon period compared to others. For 4.5m/s the maximum temperature difference recorded was 11^{0}C as shown in figure 8. Higher temperature difference was observed for charcoal compared to others at 4.5m/s. Generally air speed of 4.0m/s showed a higher drop in temperature followed by 3 and 4.5m/s. It can be suggested that lower temperature difference observed at a speed of 4.5m/s might be because of short resident time of the incoming air moving across the pad into the storage space. Palm fruit fiber which was tested as a new pad consistently performed well at all

speed

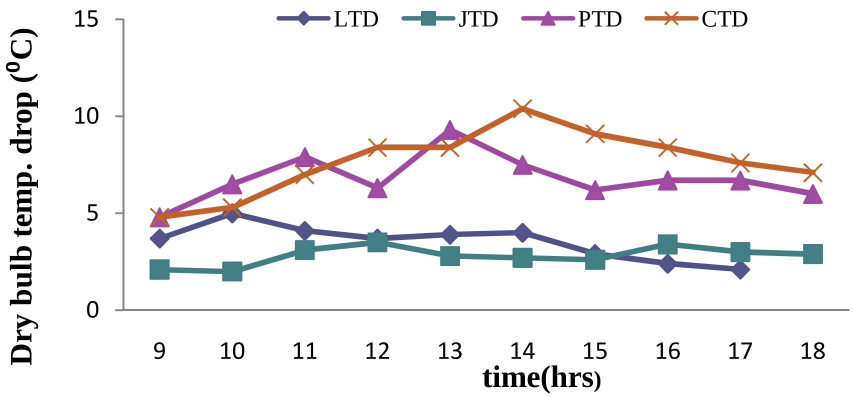

Figure 8: Periodic drop in Temperatures at 4.5 m/s for the four cooling pads

In the analysis of evaporative cooler performance by most researchers (Xuan et al 2012, Jain 2007), the ability of the pads to drop the storage space air dry bulb temperature closer to the wet bulb of the outside air is seen as a good parameter to access and compare their performance in direct evaporative cooling. This is because, the weather condition continuously changed during the period of the test. Therefore the temperature and relative humidity of the air moving across the pad into the cooler cannot be constant but varies with the weather condition. Jute fiber and palm fiber was able to drop the dry bulb temperature of the cooler storage space closer to the wet bulb temperature of the outside air at 4.5m/s as shown in figure 8. In addition, shredded latex foam, jute and palm fruit fiber was able to drop the dry bulb temperature of the cooler closer to the wet bulb temperature of the shade at 4.0 m/s and 3.0 m/s as shown in figure 6 and 7.

The maximum mean temperature difference calculated between the cooler storage space dry bulb and outside air wet bulb were 0.4, 1.5, 1.3 and 4 ^{0}C for latex foam, jute fiber, palm fruit fiber and charcoal respectively at 4.0 m/s. Also at 3.0 m /s, their values were 0.4, 2, 1.6 and 3.2 ^{0}C for latex foam, jute fiber, palm fruit fiber and charcoal respectively. This shows that jute; palm fruit fiber and shredded latex foam can lower the temperature, closer to the wet bulb temperature of the outside air at a lower speed. Charcoal consistently performed less well than the three other pads and this might be because of its low water holding capacity. On the average, the pad materials dropped the storage temperature relative to the wet bulb temperature of the outside air better at 4.0m/s. All the materials showed a good performance in terms of temperature drop for the three speed used. The minimum temperature of the cooler storage space for the four pads ranged from 19.6 – 24 ^{0}C at 4.5 m/s ^{0}C. Also at 4.0 m /s, it ranged from 19.1 - 24.9, while 3.0 m/s showed 20.8 - 26.8 with palm fruit fiber having the lowest value of 19.1 at 4.0 m/s. Generally these values are a function of the solar load and relative humidity at the period of the test. More heat energy will be extracted from air that is not too humid. Despite the high temperature of the tropical environment, the pads were able to hold the cooler temperature within the storage temperature of most fruits and vegetables. Jain (2007) obtained a storage period of two weeks for tomato at a temperature of 20-23^{0}C while Ndukwu (2011) obtained a storage time of 19 days for tomato at average storage temperature of 25^{0}C.

3.2 Relative humidity of the storage space

High humidity and low temperature are the conditions that favour storage of fruits and vegetables. The amount of increase of the relative humidity of the four pads at different speed is shown in figure 9 – 11 for the three speeds tested. Comparatively jute fiber showed a better humidification than the rest material tested. Better humidification was shown by the various materials in the afternoon than in the morning or evening period. Looking at the plot of humidity changes for the three speeds in figure 9 -11, 4.0m/s gave a higher value than the rest speed tested.

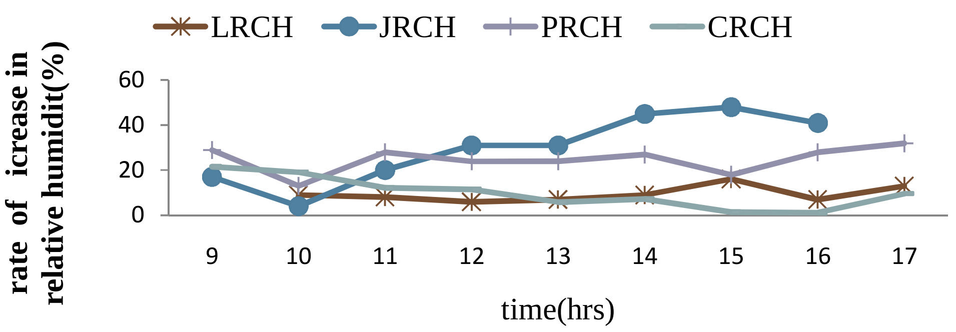

Figure 9: Periodic rate of increase in relative humidity at 3 m/s for the four cooling pads

LRCH is the rate of increase of humidity for latex foam, JRCH is for jute fiber, PRCH is for palm fiber, and CRCH is for charcoal

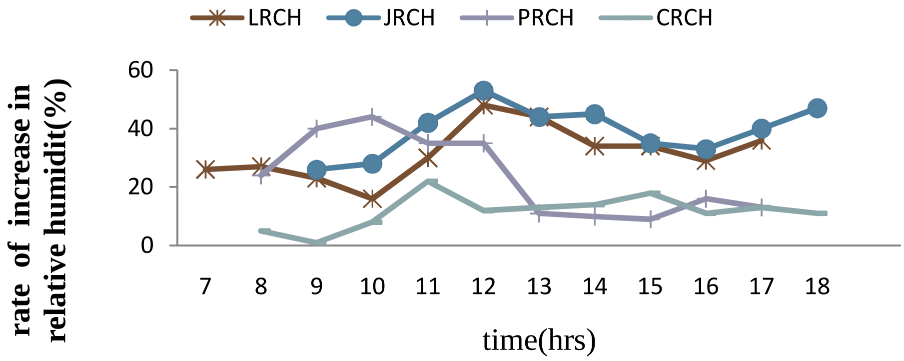

Figure 10: Periodic rate of increase in relative humidity at 4.0 m/s for the four cooling pads

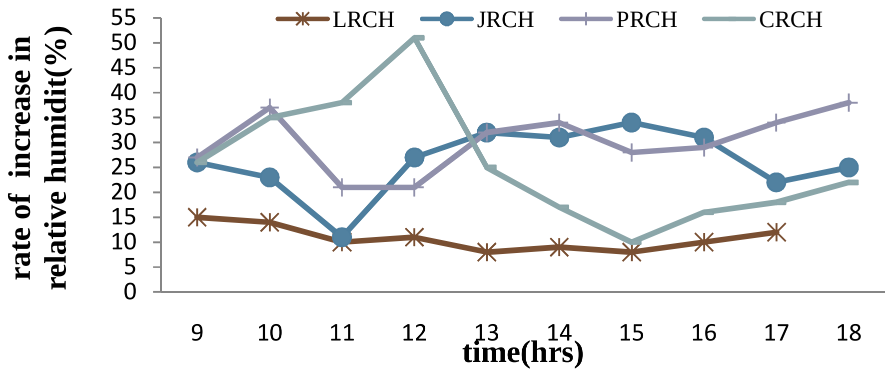

Figure 11: Periodic rate of increase in relative humidity at 4.5 m/s for the four cooling pads

The daily environmental relative humidity ranged from 30 -73% during the test. From table 2, latex foam showed increase in relative humidity of 12 % and 9 % at 4.5 and 3 m/s respectively. This development was also observed for charcoal, which showed an average increase in relative humidity of 12 and 18% at 4 and 3 m/s respectively. These values were lower than jute and palm fruit fiber at the same test condition, which consistently showed a good relative humidity change. The change in humidity shows the extent the pad materials can raise the humidity of the cooler. Palm fruit fiber did better at 4.5m/s while jute performed well at 4.0m/s. Jute fiber on the average showed a better humidification at all speed than three other pads.

However, the extent to which the material can raise the relative humidity is also a function of the relative humidity of the incoming air, the water holding capacity and the parking density of the pads. Xuan et al., (2012) noted that 100% relative humidity was not achievable in direct evaporative cooling systems because 100% saturation is impossible. This is because most of the pads are loosely packed, and the process air can easily escape between the pads without sufficient contact with the water. In addition, the contact time between air and water is not long enough which results that heat and mass transfer is insufficient (Manuwa and Odey 2012).

On the average the relative humidity for the four pads were 63 -91% at 4.5 m/s, 60 -85 at 4.0 m/s and 57 – 70 at 3.0 m/s. Lower relative humidity observed at 3.0 m/s for the four pad materials might be because, the speed of the fans was not powerful enough to drive enough moisture into the cooler.

3. Conclusion

From the analysis of the results obtained from the tests, Jute fiber and palm fiber was able to bring the dry bulb temperature of the cooler closer to the wet bulb temperature of the outside air at 4.5m/s. Shredded latex foam, jute and palm fruit fiber was able to bring the dry bulb temperature of the cooler closer to the wet bulb temperature of the outside air at 4.0 m/s and 3.0 m/s. On the average, the pad materials brought the storage temperature relative to the wet bulb temperature better at 4.0m/s. All the materials showed a good performance in terms of temperature difference for the three speed used except charcoal which comparatively performed poorly at all speeds. The minimum temperature of the cooler for the four pads ranged from 19.6 – 24 ^{0}C at 4.5 m/s ^{0}C; 19.1 - 24.9 at 4.0 m /s, while 3.0 m/s showed 20.8 - 26.8 with palm fruit fiber having the lowest value of 19.1 at 4.0 m/s. On the average the relative humidity for the four pads were 63 -91% at 4.5 m/s, 60 -85 at 4.0 m/s and 57 – 70 at 3.0 m/s. Lower relative humidity was observed at 3.0 m/s for the four pad materials. The various pads used were able to drop the temperature of the draft air up to 0.6 - 18.3 ^{0}C. Despite the high tropical solar load, the pads were able to hold the cooler temperature within the storage temperature of most fruits and vegetables. The order of performance of the four pads is palm fiber, jute, shredded latex foam and charcoal.

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