Development of clay evaporative cooler for fruits and vegetables preservation

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Abstract: An evaporative cooler was developed with clay and other locally available materials. The performance of cooler was evaluated in terms of temperature drop, evaporative effectiveness and cooling capacity. The result showed that the evaporative cooler can reduce the daily maximum ambient temperature from 32-40℃ to 24 - 29℃ i.e. a temperature reduction of up to 10℃ and increase the relative humidity of incoming air from 40.3% to 92% for the storage chamber. The cooling efficiency ranged from 20%-92 % with a maximum cooling capacity of 1207 W. The cooling capacity and effectiveness of the cooler was higher during the day between the period of 12 -16 h local time when harvesting and selling of farm produce is done. The evaporative cooler was able to preserve freshly harvested tomato for 19 days before visible colour changes and mould spotting appeared and the weight drastically reduced

Keywords: Cooling efficiency, cooling capacity, evaporative cooler, enthalpy, vapour pressure, ambient

Citation: Ndukwu Macmanus Chinenye. 2011. Development of clay evaporative cooler for fruits and vegetables preservation. Agric Eng Int: CIGR Journal, 13(1): CIGR MS No.1781.

1 Introduction

In Nigeria and other countries of the world vegetables and fruits are important food items that are widely consumed because they form an essential part of a balanced diet. Fruits and vegetables are important sources of minerals and vitamins especially A and C. They also provide carbohydrates and protein, which are needed for normal healthy growth (Abdul, 1989; Salunkhe and Kadam, 1995; Adetuyi et al 2008; Olusunde et al, 2009). In developing countries like Nigeria, agriculture constitutes the bulk of the informal sector of the economy. It is reported that among the various types of activities that can be termed as agriculturally based, fruit and vegetable processing are among the most important (FAO 1995). However the farmers are not getting enough value for their product due to weak infrastructure, poor transportation, and perishable nature of the crops, which results in substantial economic losses. During the post-harvest glut, the loss is considerable and often some of the produce has to be fed to animals or allowed to rot. According to Ndirika and Asota, (1994), the damage that occurs in some bio products is primarily by loss of moisture, change in composition and pathological attack.

An aspect to consider when handling fruits and vegetables is the temperature and relative humidity of the storage environment. For fresh harvested produce, any method of increasing the relative humidity of the storage environment (or decreasing the vapour pressure deficit (VPD) between the commodity and its environment) will slow the rate of water loss and other metabolic activities (Katsoulas et al., 2001). This will slow both the respiratory processes and activities of micro-organisms (pathogens) which are the most destructive activity during storage of fruits and vegetables (Barre et al, 1988). Although, refrigeration is very popular but it has been observed that several fruits and vegetables, for example banana, plantain, tomato etc. cannot be stored in the

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Received date: 2010-09-29 **Accepted date:** 2011-03-28

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domestic refrigerator for a long period as they are susceptible to chilling injury (Shewfelt, 1994; Olusunde et al. 2009). Apart from this, the epileptic power supply and low income of farmers in the rural communities' makes refrigeration expensive.

FAO (1983) advocated a low cost storage system based on the principle of evaporative cooling for storage of fruits and vegetables, which is simple, and relatively efficient. The basic principle relies on cooling by evaporation. However sometimes when evaporative cooling system is used in preservation, it is used with shade on top (Kittas et al 2003).

Different designs of evaporative coolers have been reported in literature for the preservation of fruits and vegetables (Redulla, 1984a; FAO 1986; Roy 1989; Thompson and Scheureman 1993; Acedo 1997, Noble 2008). The design ranges from straw packing house to some sophisticated design. FAO (1986) reported that the packing houses of typical evaporative coolers are made from natural materials that can be moistened with water. Wetting the walls and roof first thing in the morning which is tedious creates conditions for evaporative cooling of the packing house. The major problem of these structures is the constructing material which deteriorates quickly and is susceptible to rodent attack. Redulla (1984 b) presented an evaporative cooler for preservation of fruit and vegetable which complements natural air with forced air to cool small lots of produce. Redulla (1984 b) also showed some other evaporative cooler which he called drip coolers and can be constructed from simple material such as burlap and bamboo. They operate solely through the process of evaporation without the use of fan. These coolers are cumbersome and have the same problem of the packing house.

Acedo (1997) developed two simple evaporative coolers with jute bag and rice husk as the cooling pad in the Philippines for cooling and storage of vegetables. He prevented decay by washing the product first in the chlorinated water. Jain (2007) presented a two stage evaporative cooler for fruits and vegetable which incorporated a heat exchanger. This design is expensive but he could only achieve a storage life of 14 days for tomato. Anyanwu (2004) developed a porous wall (pot in pot) evaporative cooler for preservation of fruits and vegetables. He got a storage life of less than four days (93 hours) on tomato. In this research work, an evaporative cooler with locally sourced materials for the construction was developed and evaluated. The evaporative cooler fabricated with mud (clay) directly excavated from the swamp is not electricity dependent will help farmers and marketers of fruits and vegetables to be able to store and preserve efficiently their products.

2 Materials and methodology

2.1 Principle of Evaporative Cooling System

The principle underlying evaporative cooling is the conversion of sensible heat to latent heat. The warm and dry outdoor air is forced through porous wall or wetted pads that are replenished with water from the cooler's reservoir. Due to the low humidity of the incoming air some of the water evaporated. Some of the sensible heat of the air is transferred to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapour and diffuses into the air (Watt,1986). Evaporation causes a drop in the dry-bulb temperature and a rise in the relative humidity of the air.

In a direct evaporative cooler (DEC), the heat and mass transferred between air and water decreases the air dry bulb temperature (T_b) and increases its humidity, keeping the enthalpy constant (adiabatic cooling) in an ideal process. The minimum temperature that can be reached is the wet bulb temperature (T_w) of the incoming air.

2.2 Design Consideration

The following were design considerations

1) The evaporative cooler was designed with locally available material to reduce cost.

2) The shape of the cooler is a cuboids (to provide large surface area for air movement) placed under a shade, to reduce the ambient heat.

2.3 Description of the Evaporative Cooling Systems

The evaporative cooler is made up of double jacket walls. The inside wall is a cuboids (60 cm long × 52 cm wide × 85 cm deep) shaped clay (mud) storage structure with partitions for storage of fruits and vegetables. The outside wall is also a cuboid (75 cm long × 67 cm wide × 100 cm deep) with a 15 cm gap separating it from the inside wall. The mud was excavated from a nearby stream and before the casting of the structure; it was mixed thoroughly with water to increase its plasticity. Mud was chosen because of its low conductivity of heat and is abundantly available. It is also very cheap. The wall was first reinforced with bamboo sticks and casted on a mud floor 30 cm thick. At the front is a cooling pad (42 cm long × 8 cm thick and 85 cm deep) made of wood shaven stacked in between perforated (pin hole) bamboo stick 42 cm long and 0.4 cm thick to prevent sagging .

The walls of the cooler were double jacketed to reduce the heat transfer by conduction. The top of the structure is covered with an aluminium foil (75 cm long × 67 cm × 85 wide) because of its high heat reflectivity. The foil contains pin holes (2.5 mm in diameter) for the exhaust air. Through a natural convection by the help of buoyancy the air passes through the wet cooling pad into the storage chamber. Inside the storage chamber, the air picks up heat from fruits and vegetables and the temperature rises due to respiration of the product. To provide for the exhaust air which is one of the conditions for evaporative cooling, the conditioned air passes in a vertical flow direction and exit through the exhaust air opening back to the environment. Directly at the bottom of this compartment is an opening for water dripping down from the pads to drain away easily. A 6 litre filled water bucket was used to manually circulate water to the cooling pad through perforated water trough located directly on top of the cooling pad as shown in Figure 1.

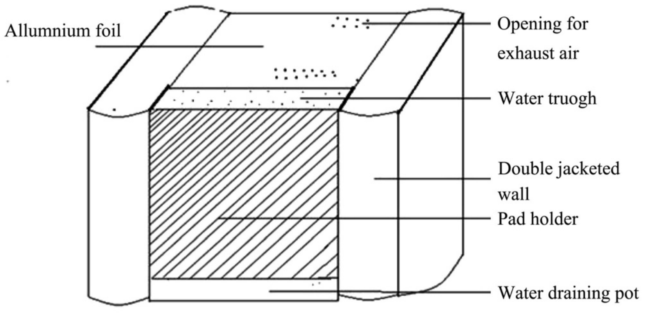


Figure 1 Schematic direct evaporative cooler

Figure 2 A prototype developed mud (Clay) evaporative cooler

2.4 Experimental Procedure and Evaluation

The experimental evaporative cooler was located under a tree. This has the advantage of reducing considerably the effects of direct solar radiation on the test facility and exposing it to open air flow. The cooler was positioned facing the most frequent direction of the wind. The cooling pad was wetted three times a day, in the morning (7.am), afternoon (12 noon) and evening (4.p.m) with a 6 litre bucket full of water. Experimental tests were undertaken with cooler loaded with produce and without produce in place. The no load test was done to establish its transient response to variations in prevailing weather conditions in terms of temperature reduction between the ambient and the cooler storage chamber and change in relative humidity before storage of tomatoes began. Load tests were conducted to determine the length of storage of the fruits and vegetables in the cooler before spoilage. A control test in which the same product inside the evaporative cooler was exposed to open air conditions under a shade was used to evaluate the cooler effectiveness in preservation of the fruits and vegetables. Control test samples were weighed every two days to determine the weight loss and the colour was examined under the full day light to determine the colour changes and presence of mould. Fresh mature tomatoes not completely ripe, obtained from the Michael Okpara University of Agriculture Students Experimental farm were used for the tests. A measurement of temperature and relative humidity was taken at intervals of two hours for all the tests conducted starting from 6hrs to 22 hrs local time. The wet and dry bulb temperatures inside the cooler were monitored with two digital thermometers fixed permanently on top of the cooler with the bulb carefully lowered into the cooler chamber through a hole made at the centre of the top aluminium cover. Ambient wet and dry bulb temperatures were measured with the digital thermometers with a reading accuracy of ±0.1℃. The relative humidity was also monitored with a hygrometer with a reading accuracy of ±0.1%. However the air flow rate from the outside into the cooler was not determined. These measurements provided the general trend of the prevailing conditions within the cooler.

Three tests were conducted each month starting from September to December 2009. The cooler was evaluated on the temperature drop between the ambient and the storage environment of the evaporative cooler, change in relative humidity between ambient and storage environment, cooling capacity and efficiency. The parameters monitored or calculated were; relative humidity, dry and wet bulb temperatures, vapour pressure, dew point and enthalpy. Also evaporative cooling chamber relative humidity, dry and wet bulb temperatures, vapour pressure, dew point temperature and enthalpy was also determined. The cooling efficiency is calculated as follows (Lertsatitthanakorn et al. 2006):

$$\eta = \frac{Tdb - Ts}{Tdb - Tw} * 100 \qquad (1)$$

Yun (2008) provided an algorithm for calculating the cooling capacity of direct evaporative cooler as follows

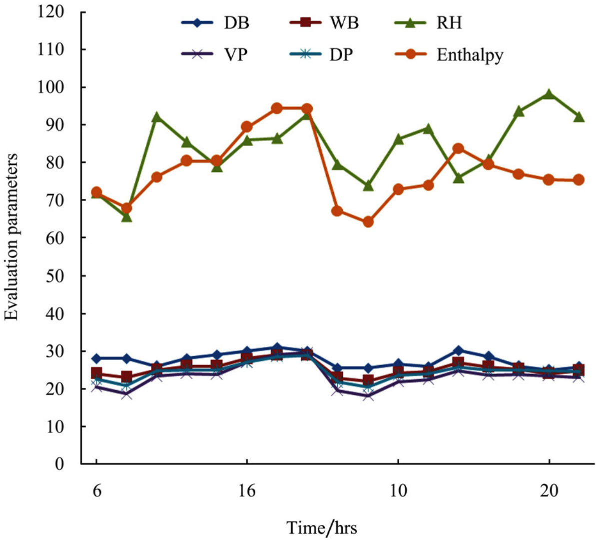
$$Colcap = 1.08 * Q * (T_s - \eta[T_{db} - T_w]) \qquad (2)$$

Where, T_{db} = dry bulb temperature of ambient air, ℃; T_w = wet bulb temperature of the ambient air, ℃; T_s = temperature of cold air, ℃; Q = air flow rate, m^3/s; η = evaporative effectiveness, %.

The enthalpy of the air, dew point and the vapour pressure was determined from the psychometric chart and psychometric equation.

3 Results and discussion

The results showed that the evaporative cooler can reduce the daily maximum ambient temperature from 32–40℃ to 24–29℃ i.e. a temperature reduction of up to 10℃ and increase the relative humidity of the air from 40.3% of the ambient to 92% of the storage chamber. Figure 3 and 4 presents a variation of all the measured parameters and time for a typical two consecutive days reading (9 and 10 th December) for the storage chamber and the ambient. The enthalpy of air for the storage chamber has a maximum value of 94.46 KJ/KJDA, while the vapour pressure ranged from 18.1–29 mmHg. Enthalpy is lower than the ambient which has a maximum value of 92 KJ/KJDA. The cooler was able to bring the wet bulb temperature of the ambient (24–27℃) closer to the temperature of the storage chamber (24–29℃). The ambient dry bulb temperature observed throughout the period was 32–40℃, while the relative humidity ranged from 40.3%–68.5% between 12–16 hour local time when most of the harvesting and selling of farm produce is done. At this high temperature period the cooler temperature averaged 25℃ while the relative humidity ranged from 76%–86%. The figures also revealed the closeness of the ambient and cooler storage chamber as from 18–6 hours local time which results in low cooling efficiency. This implies that no meaningful cooling can be achieved at this period although temperatures at this period remain considerably low with a high relative humidity. Also Figure 4 presents cooling efficiency and cooling capacity as a function time.



Note: DB = Dry bulb temperature, ℃; WB = Wet bulb temperature, ℃; RH = Relative humidity, %; VP = Vapour pressure, mmHg; DP = Dew point temperature, ℃; Enthalpy, J

Figure 3 Periodic changes in Temperatures, relative humidity, vapour pressure, dew point temperature and enthalpy for the storage space of the evaporative cooler

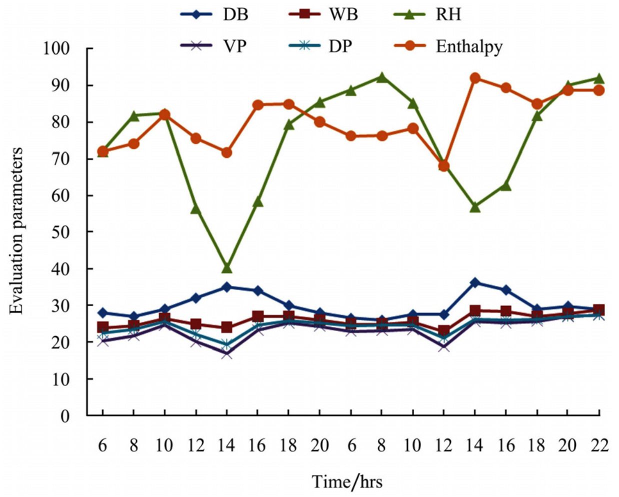
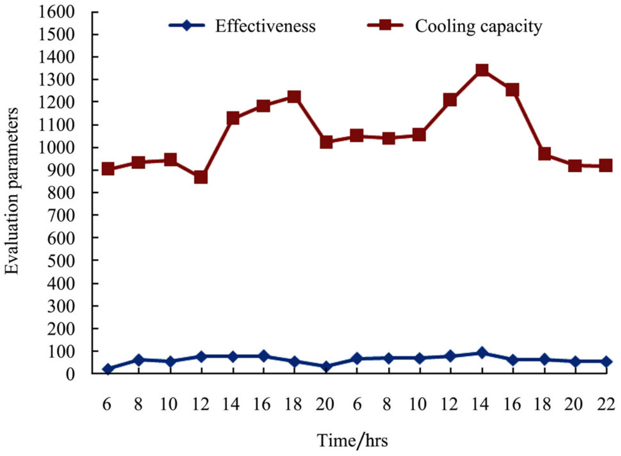


Figure 4 Periodic changes in Temperatures, relative humidity, vapour pressure, dew point temperature and enthalpy for the ambient of the evaporative cooler

The cooling efficiency ranged from 20%–92% while the cooling capacity ranged from 870–1 207 W as shown in Figure 5. The results also showed that the higher cooling efficiency and cooling capacity was achieved at a higher temperature and low relative humidity, this agreed with the work of Jain (2007). At the above prevailing conditions the mud evaporative cooler was able to preserve freshly harvested tomatoes for 19 days and can be seen by the weight loss in Figure 6. Though proximate food analysis was not carried out to ascertain the quality of the nutritional composition of the tomato after 19 days, however visible colour changes and mould spots started to appear on the tomatoes after this time when examined under full day light. The results clearly indicate that the evaporative cooler may be conveniently used for preservation of vegetables and fruits since the temperature depression for cooling application are in the range of 2–12℃ reported in literature (Anyanwu 2004).



Note: Effectiveness, %; Cooling capacity, W

Figure 5 Periodic changes in cooling capacity and efficiency

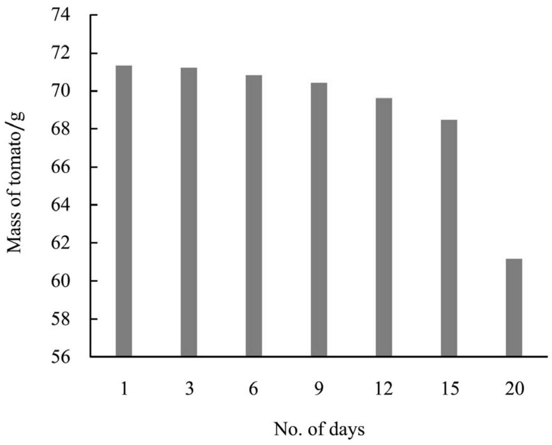


Figure 6 Mass changes of samples of tomatoes as it deteriorates (g)

4 Conclusions

A mud evaporative cooler was developed with the local available materials. The cooler was able to drop the ambient temperature to 10℃ and increase the relative humidity of incoming air from 40.3% to 92% for the storage chamber. The cooling capacity and efficiency was higher between 12−16 hrs local time when harvesting and selling of farm produce is done and much cooling required. The evaporative cooler was able to preserve freshly harvested tomato for 19days.

Acknowledgements.

Appreciation is extended to the year three students 2006/2007 admission set of the Michael Okpara University of Agriculture Umudike for their assistance in taking the readings of the evaluation data throughout the research period.

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