

DESIGN AND FABRICATION OF A PASSIVE EVAPORATIVE COOLING SYSTEM FOR FRUITS AND VEGETABLES STORAGE

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ABSTRACT

A multipurpose passive evaporative cooler was designed, constructed and its performance evaluated by determining the adiabatic efficiency. The multi-purpose passive evaporative cooling system consists of three compartments whose outer and inner cooling chambers were made of galvanize steel. The interspace was filled with sandy loam. The cold storage system for fruits and vegetables was based on the water cooling system to cool the storage chamber. Water is supplied from the storage tank to a pipe with a gate valve attached to this pipe. As the valve is opened, water flows through the distribution pipe networks placed over the soil allow in a constant flow of water through into soil. The water leaves the system through the outlets created underneath the housing. This process is continuous; as the water moves out, it carries along the heat present inside the cooling chamber hence lowering the temperature and at the same time increasing the relative humidity in the storage chamber. During the test period with fresh bananas, the average temperatures of 24.5°C and 28.8°C were obtained for the multi-purpose evaporative cooler and the ambient respectively. Also average relative humidity of 88.87% and 69.41% were obtained for the multi-purpose evaporative cooler and the ambient respectively. The cooling efficiency of the evaporative cooler was 55%.

Key words: Passive, cooling chamber, banana, storage and humidity

1. INTRODUCTION

The cold storage of nearly all food, fresh or processed is beneficial to the retention of quality. Unrefrigerated fruits and vegetables usually deteriorate rapidly and loss its food value for man. If similar fruits and vegetables are held temporarily in cold storage, metabolic processes are retarded but the net result is a longer period in which the food is acceptable for man.

Fruits have not been given a pride of place in the diet of Nigerians. The main reasons for neglect are ignorance of the nutritive values of most fruits which abound in our environment. Other reasons include the rising cost of fruits, problems of storage of perishables and that of distribution. The limitation of the nutritional values and economic importance of fruits and vegetables in Africa in general and West Africa in particular was reported by Osagie and Eka (1988). Though tropical fruits are generally poor sources of proteins and lipids, they provide notable amounts of amino acids (tryptophan, methionine, lysine), ascorbic acid (and other organic acids such as malic and tartaric acid), carotenes and peptic substances, as well as more complex polymers such as lignin. Vegetables have little or no calorific value, but are very important as supplementary nutrients in addition to the main food. The latter which usually consists of cereals and tuber furnish 70% or more of the total calories and the major nutrient requirements. They are poor in vitamins and mineral elements which are readily supplied by fruits and vegetables (Macrae *et al.*, 1997).

The important features of environment which influence longevity of fresh produce and which are amenable to control are temperature, relative humidity and composition of the atmosphere

surrounding the produce. Temperature has the greatest effect on storage life and is conveniently the most readily controlled. Humidity is not readily controlled but can have a considerable effect on deterioration. It does not only regulate the rate of water loss but also influence the physiological activities of the fruits. According to Richard and Priester (1986), too low humidity in storage cause shrinking and water loss and too high humidity promotes the growth of moulds possible agents of product spoilage. However, the preservation of most fresh produce is enhanced by cooling such produce to the most suitable temperature immediately after harvest. This is because low temperature depresses both the physiological activity of vegetable tissues themselves and any microorganisms capable of causing spoilage; hence storage life is then extended.

Rockland and Nishi (1980) stated that the agricultural crops and their products are hygroscopic in nature and when exposed to the environment, their moisture content will either increase or decrease until they equilibrate with the environment. During storage, moisture content of stored produce is altered by prevailing temperature and relative humidity of the environment. Okunola and Igbeka (2000) ascertained that the effect of dynamic process of water movement during the storage of crops or crop products require considerable attention for optimum storage qualities. The storage and shelf life of most vegetables are extended if they are cooled rapidly within 10 hours to below 5°C and store just above freezing (Oyeniran, 1988). The bacteria and moulds that can cause spoilage in fruits and vegetables produce grow at a slower rate when temperature is low (Oyeniran, 1988).

Banana is a staple food of several African tribes in many countries across the world including Nigeria. The commonest cultivated types in West Africa are the *Musa sapientum* and *Musa cavendishi*. The former grows to a height of 5 to 6 metres and it is characterized by the compactness of the branch. The latter are the dwarf varieties and they normally attain the height of 150-240cm. The fruit has thinner skin and fingers often stand at right angles to the peduncle.

The best technical method of preserving some perishable crops is through the use of refrigerator, which supplies low temperature and high relative humidity space for perishable crops. However, because refrigerator is rather complex, energy intensive and expensive to purchase and maintain, its application for fresh perishable crops storage is thus not feasible under the prevailing socio-economic status of the rural dweller in Nigeria. This therefore necessitates the need to develop an alternative, inexpensive, an easy to operate and maintain cooling system that does not need electricity for preserving the various types of fruits and vegetables produced by several small scale farmers.

Evaporative cooler works on the principle of cooling resulting from evaporation of water from the surface. The cooling achieved by this device also results in high relative humidity of the air in the cooling chamber from which the evaporation takes place relative to the ambient air. The atmosphere in the chamber therefore becomes more conducive for fruits and vegetables storage (NSPRI, 1990) as reported by Owuye (1998). This research is aimed at design and fabrication of a passive evaporative cooling system for fruits and vegetables storage.

2. MATERIALS AND METHODS

2.1 Design Calculations

2.1.1 Calculation for Flow Rate/ Discharge through the Pipe

The velocity of flow is calculated from the relation.

$$v = \sqrt{2gh} \quad (1)$$

where g = acceleration due to gravity, 9.8 m/s^2

h = differential height of water in the pipe

Area of the pipe is also calculated from the relation.

$$A = \pi / 4d^2 \quad (2)$$

where d = diameter of the pipe (0.0127m)

2.1.2 The Discharge Rate, Q

When the valve is half opened, the discharge is calculated as:

$$Q = V_w / t \quad (3)$$

where

V_w = total volume of water in the tank = 40000 cm^3

t = elapse time = 132 seconds

$Q = 3.03 \text{ m}^3/\text{secs}$

2.1.3 Calculation for Rate of Flow through the Outlet Perforated Pipe

The discharge rate (Q_p) through the perforated pipe networks was calculated as:

$$Q_p = Q / n \quad (4)$$

where

n = number of perforations on the pipe = 26

Q is the discharge rate.

$Q_p = 303.03 / 26 = 11.6550 \text{ cm}^3/\text{s}$

2.1.4 Calculation of Pressure or Friction Loss in Pipes

Pressure loss or loss of head may be caused by friction between the moving particles of a fluid and the interior surfaces of a pipe. When a pressure loss occurs in a straight pipe, it is usually classed simply as *friction loss*. Friction or pressure loss in pipes can be calculated from;

$$P_f = 4fV^2l / 2D \quad (5)$$

where P_f = pressure loss

D = diameter of the pipe (m), 0.0127m

L = total length of the pipe networks (6.12m)

V = velocity of flow in the pipes (4.011m/s)

f = friction coefficient = 0.0006

Putting the above values in equation 5 above.

$$P_f = 3.403J$$

2.1.5 Calculation for Friction Loss in Fittings

A greater pressure loss per unit of pipe length may be caused by the excessive friction between particles in the eddy currents following special fittings in which case the term *shock loss* is usually used. Four types of fittings were used in this application and these are the elbow joint

(90° standard), the tee joint, union connector and the gate valve. Each of them has its own friction loss factor otherwise known as *Ks factor* which are standard for a particular fitting. The *Ks* factor for the tee joint, elbow joint, gate valve and union connector are 1.5, 0.74, 0.13 and 0.5 respectively.

Friction loss in fittings can be calculated as shown below;

$$Fr = K_s V^2 / 2 \quad (6)$$

where fr is the friction loss in fittings

and K_s is the standard for each type of fittings

2.1.6 Calculation for the Capacity of the Main Cooling Chamber

The length, breadth and height of each cooling chamber are 0.45m, 0.45m and 0.40m respectively.

The volume of each cooling chamber is calculated as;

$volume = length \times breadth \times height$

$$= 0.45 \times 0.45 \times 0.40 = 0.81\text{m}^3$$

Total capacity of the three cooling chambers = $0.81 \times 3 = 0.243\text{m}^3$

where Q = rate of heat transfer, w

K = thermal conductivity = $0.28 \text{ m}^{-1\text{s}^{-10}\text{C}^{-1}}$

dT = temperature difference between the inside and the outside = 9°C

$A = 0.18\text{m}^2$

dr = thickness, m of plywood = 0.0015m

$$Q = 30.24\text{W}$$

Heat transfer through the galvanized sheet using equation 8 above,

2.1.7 Heat Transfer Calculations

The rate of heat transfer from the plywood to the soil and finally to the cooling chamber can be calculated from the relation,

$$Q = Kadt / dr$$

where Q = rate of heat transfer, w

K = thermal conductivity = $0.28 \text{ m}^{-1\text{s}^{-10}\text{C}^{-1}}$

dT = temperature difference between the inside and the outside = 9°C

$A = 0.18\text{m}^2$

dr = thickness, m of plywood = 0.0015m

$$Q = 30.24\text{W}$$

Heat transfer through the galvanized sheet using equation 8 above,

$$Q = Kadt / dr$$

K = thermal conductivity = $45 \text{ m}^{-1\text{s}^{-10}\text{C}^{-1}}$

$A = 0.18\text{m}^2$

$dr = 0.001\text{m}$

$$Q = 72.90\text{W}$$

Heat transfer through the lagging material (sandy loam) using equation 8 above,

$$Q = Kadt / dr$$

K = thermal conductivity = $0.00245 \text{ m}^{-1\text{s}^{-10}\text{C}^{-1}}$

$A = 0.18\text{m}^2$

$dr = 0.1\text{m}$

$$Q = 0.03969\text{W}$$

$$\text{Total Heat Transferred} = 30.24 + 72.900 + 0.03969 = 103.17969\text{W}$$

2.2 Description of the Passive Evaporative Cooler and Its Principle of Operation

This passive evaporative cooler is a special type that has three separate chambers and can be used to store three different types of produce at a time. Water is supplied from the storage tank to a pipe with a gate valve attached to this pipe. As the valve is opened, water flows through the distribution pipes placed over the soil to allow for constant supply of water into the soil. The water leaves the system through the outlets created underneath the housing (Figure 1). The out flow rate is lower to allow for more water retention in the soil. This process is continuous; as the water moves out, it carries along the heat present inside the cooling chamber, hence lowering the internal temperature (heat) of the storage chamber of the cold storage system. The cooling achieved by this device resulted in high relative humidity of the air in the chamber, from where the evaporation takes place relative to ambient air. This system also allows for evaporation of water through the surface of soil and as a result the chamber becomes more conducive for fruits and vegetables storage (NSPRI, 1990) as reported by Owuye (1998).

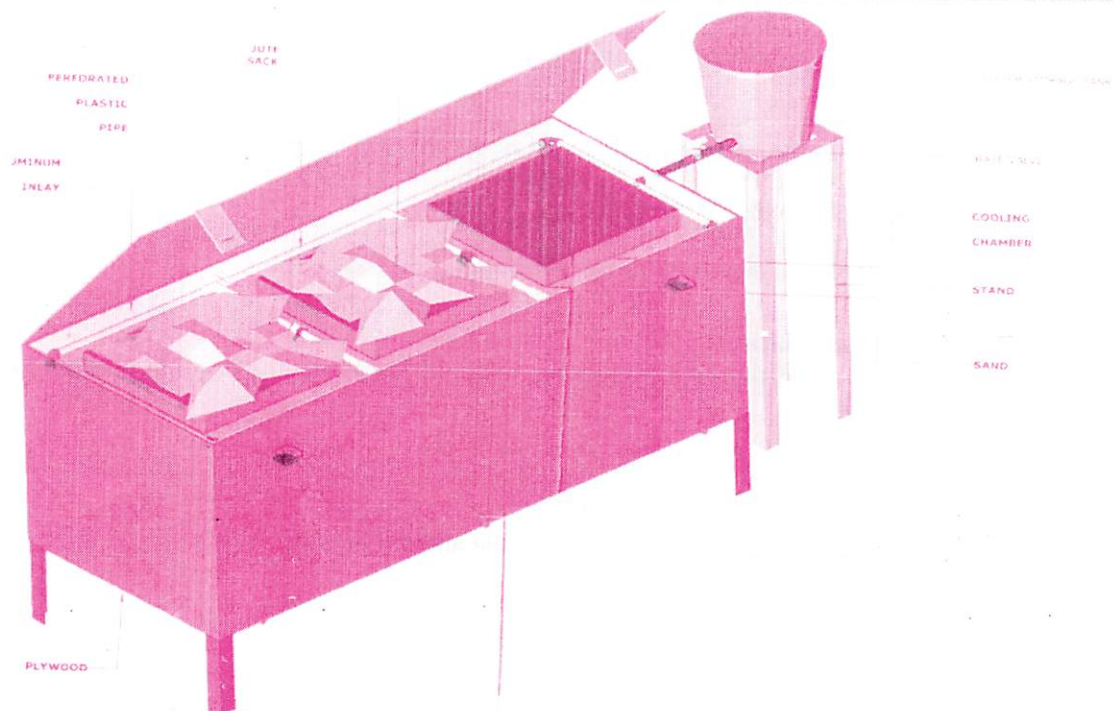


Figure 1: Isometric View of the Multi-Purpose Passive Evaporative Cooling Structure

2.2.1 Collection of Fresh Fruits and Determination of Temperature and Relative Humidity
 Forty (40) pieces of matured fresh bananas were obtained from Ago Market in Ilorin and were stored for two weeks inside the passive evaporative cooler. The temperature and relative humidity of the fruit and vegetables stored in the different packaging materials were measured daily at 8.00am, 12 noon and 6.00pm and compared with the ambient using a digital thermometer and a relative humidity measuring instrument (Testo 625 Compact instrument).

2.2.2 Determination of Soil Moisture Content of Evaporative Cooler (Initial and Final)
 A dry clean can was weighed (W_1) and known weight of the soil sample was placed in the can and weighed (W_2). The sample with the can was then dried in an oven at 110°C for about 48 hours during which a constant weight was obtained (W_3). The percentage moisture content (wet basis) in the soil sample is calculated as follows;

$$\text{Percentage Moisture Content} = \frac{W_2 - W_3}{W_2 - W_1} \quad (9)$$

2.2.3 Sieve Analysis
 About 700g of the soil sample was weighed into an aluminium pan using a balance after which it was transferred in the upper test sieve which is fixed to the mechanical shaker to shake it for a minimum of 10 minutes. Finally, the weight of the soil sample in each of the sieve was obtained and this was used to determine the soil type.

2.2.4 Determination of Coefficient of Soil Permeability (K) Using Constant -Head Permameter

The calculation of the coefficient of permeability was then obtained by using of Darcy's law,
 $K = \frac{QL}{Aht}$ (11)

where

Q = Total quantity collected in time t = $13.5\text{cm}^3/\text{secs}$

Hydraulic head $h/l = 0.25$

t = 17.3 secs

A= Cross - sectional area of the sample= 1.3cm²
 Substituting these values in equation 11 above,
 K=0.245cm/sec.

2.3 Testing the Performance of the Evaporative Cooling System

2.3.1 Storage of Banana

After the design and construction of the evaporative cooler forty (40) pieces of matured fresh bananas were obtained from Ago Market in Ilorin and were stored for two weeks inside the passive evaporative cooler. The evaporative cooler was tested to evaluate the degree to which the cooler could achieve cooling by evaluating the on-load efficiency. This efficiency was obtained by using the digital thermometer to measure the temperature of the air leaving the cooler and the temperature of the thermometer. The performance of the evaporative cooling system was evaluated using the formula;

$$\text{Efficiency } (\epsilon) = \frac{DB_{on} - DB_{off}}{DB_{on} - WB_{on}} \times 100 \quad (12)$$

where DB_{on} = dry bulb temperature of the air entering the cooler = 30°C

DB_{off} = dry bulb temperature of the air leaving the cooler = 24.5°C

WB_{on} = wet bulb temperature of the air entering the cooler = 20°C

Substituting these in equation 9 above,

$$\text{Adiabatic Efficiency} = \frac{30 - 24.5}{30 - 20} \times 100 = 55\%$$

2.3.2 Assessment of the Sensory Characteristics of Stored Banana

The stored bananas were still fresh, very firm with good taste and also maintaining their initial good appearance until after 11th day of storage. There was no sign of deterioration and the samples were still green in colour. First ripening was noticed after the 11th day of storage. None of the samples got deteriorated and they still have normal banana flavor at the end of storage period.

3. RESULTS AND DISCUSSION

3.1 Temperature and Relative Humidity of Stored Banana in the Passive Evaporative Cooler

The summary of the results of the temperature and relative humidity is presented in Table 1 below. The effectiveness of the passive evaporative cooler for storing banana is a function of both temperature drop and relative humidity rise achieved in the storage chamber. The storage chamber recorded lower temperature when compared with the ambient. This could be attributed to the cooling effect of the evaporative cooler. The wetting of the jute pads and the evaporation of water in the soil also helped in reducing the temperature.

Table 1: Daily Temperature and Relative Humidity of Stored Banana

Storage Period (Days)	Temperature/ Relative Humidity Storage Chamber		Temperature/ Relative Humidity Ambient	
	°C	%	°C	%
1	24.0	88.0	28.7	69.5
2	22.5	89.5	28.7	73.0
3	23.9	90.0	28.6	70.0
4	24.6	87.0	28.4	65.5
5	23.3	89.5	30.1	71.5
6	24.7	89.5	29.9	68.0
7	23.9	88.0	29.0	65.0
8	24.0	88.5	28.5	68.5
9	24.8	89.5	29.8	65.0
10	23.2	88.0	27.5	68.0
11	23.5	89.5	28.5	73.0
12	24.5	90.0	30.0	65.0
13	23.7	89.5	29.5	71.5
14	24.3	88.5	28.1	69.5
Average	24.5	88.87	28.82	69.41

3.2 Soil Parameters

The initial and final moisture content of the soil sample used were 21.8% and 87.1% respectively and the soil type according to soil class chart is sandy loamy. The average value of the coefficient of permeability of the soil (K) obtained from three runs was 0.245cm/sec. The summary of measured parameters of the passive evaporative cooler is presented in Table 2.

Table 2: Summary of Measured Parameters of the Passive evaporative Cooler

Parameters	Experimental Value
Soil Type	(80% sand, 12% silt, 8% clay) (Loamy Sand)
Soil Moisture Content Before Wetting	21.8%
After Wetting	87.1%
Permeability	0.245cm/s

4. CONCLUSION

This research focused on the design and construction of a multi-purpose passive evaporative cooler for the storage of fruits. Based on the findings above, the multipurpose evaporative cooling system is appropriate for storage of bananas and is recommended for use by both small and large scale producers of bananas and other fruits and vegetables.

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