Original Research Article

Design and fabrication of a DC pump evaporative cooling system

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Abstract
The design, fabrication and evaluation of an evaporative cooling system was carried out. The system was cabinet was constructed with 1 mm thick aluminum sheets and jute wetted by water flowing by gravity through a series of perforated 25mm diameter pipes from a 60-liter capacity reservoir located at the top of the storage system. The cooler has 4 trays. A 0.5 horse power pump was installed for pumping water to the overhead reservoir. As evaporation took place, the temperature in the system dropped drastically from 24.6 to 30.5°C and the relative humidity in the cooling chamber increased to 97.5% compared to ambient relative humidity value of 58.9%. However, the testing of the evaporative cooling system shows that the tomatoes can be stored for an average of five (5) days with negligible changes in weight, color, firmness and rotting as compared to ambient condition which started rotting after four (4) days. The average cooling efficiency was 87.6%.

***Keywords**:* evaporative cooling, storage, relative humidity, weight loss, tomato.

1.0 Introduction

In Nigeria, the deterioration rate of fruits and vegetables is very high and detrimental to the income of farmers and marketers across the country. Post-harvest losses in fruits and vegetables are estimated at 5%-20% in developed countries and 20%-50% in developing countries [9]. In Nigeria, post - harvest losses in fruits and vegetables amount to 35%-45% of the annual production [6]. Postharvest loss includes food loss across the food supply chain from harvesting of crop until its consumption [3]. Postharvest losses can broadly be categorized as weight loss due to spoilage, quality loss, nutritional loss, seed viability loss, and commercial loss [5].

Evaporative cooling is the process by which the temperature of a substance is reduced due to the cooling effect from evaporation of water. The conversion of sensible heat to latent heat causes a decrease in the ambient temperature as evaporated water provides useful cooling. This cooling effect has been used on various scales from small space cooling to large industrial applications [7]. In developing countries, Storage has been observed to pose a greater threat to fruits and vegetables because information on the storage temperature, humidity requirements and the length of time they can be kept without a decline in market value is either inadequate or unknown to those who need the information [5]. Deterioration of fruits and vegetable during storage largely depends on temperature [12]. Therefore, the best way to extend the shelf life of fruits and vegetable is by controlling the temperature [1].

Evaporative cooling system can be constructed from locally available materials using unskilled labour, thereby making the cost affordable for the resource poor small-holder farmers [7]. Evaporative cooling units are, thus, suitable for application in most rural areas in Nigeria [2]. The main objective of this study was to evaluate the performance of an evaporative cooling system powered by DC pump for storing vegetables and fruits.

2.0 Materials and Methods

2.1 Design Considerations

Different design factors were taken into consideration. These are as follows.

2.1.1 Durability

The materials used for the construction of evaporative cooling were chosen that they may last for longer period before any sign of damage may be noticed.

2.1.2 Strength

The strength of construction materials is depending on the load that the system will carry and this is very essential.

2.1.3 Corrosiveness

Evaporative cooling parts must be prevented from moisture as to prevent corrosion of the system. This is achieved by painting the iron parts.

2.1.4 Availability

This is one of the most important factors to be considered when selecting materials. The materials must be readily available at low cost to ease the construction work and maintenance. In respect of the above fact, the materials used in the production of this system were sourced for locally in Owode Onirin market in Lagos, Nigeria.

2.2 Design Analysis and Fabrication

2.2.1 Design of Front and Rear Sides of the Storage System

The design of the rear side of the system was achieved using Equation (1);

$A_r = H_r \text{ x } L_r$

Where; A_r= Area of rear side,

L_r = Length of rear side,

H_r = Height of rear side

A_r = 0.5 x 0.7

A_r= 0.35m^2

2.2.2 Design of Left- and Right-Hand Sides of the Storage System (Pad Area)

The design for the left side of the storage system was done using Equation (2);

$A_l = H_l \text{ x } B_l$

Where; A_l = Area of left side of the storage system,

H_l = Length of left side of the storage system,
B_l= Breadth of left side of the storage system.
A_l= 0.5 x 0.5
A_l= 0.23m^2
Similarly, the right-hand side of the system has the same design with the left side of the system.

2.2.3 Design of Top of the Storage System

The design for the top of the storage system was done using Equation (3);
$A_t = L_t$ x B_t
Where; A_t= Area of top of the storage system,
L_t= Length of top of the storage system
B_t = Breadth of top of the storage system,
A_t = 0.5 x 0.5
A_t= 0.25m^2

2.2.4 Design of Reservoir Seat

The design for the reservoir seat was also done using Equation (4);
$A_s = L_s$ x B_s
Where; A_s = Area of reservoir seat,
L_s = Length of reservoir seat,
B_s= Breadth of reservoir seat
A_s = 0.5 x 0.5
A_s = 0.25m^2

2.2.5 Volume of the Storage System:

The storage system is designed to have four trays, each tray carries 3kg.The capacity of the storage system was determined using Equation (5);
$V_c = L_c \times B_c \times H_c$
Where; V_c= Volume of the storage system,
L_c= Length of the storage system,
B_c = Breadth of the storage system,
H_c = Height of the storage system
V_c= 0.5 x 0.5 x 0.3
V_c = 0.075m^2

2.2.7 Selection of Cooling Pad

The efficiency of an evaporative cooler depends on the rate and amount of evaporation of water from the cooling pad. This is dependent upon the air velocity through the pad thickness and the degree of saturation of the pad, which is a function of the water flow rate wetting the cooling pad [4]. In this work, Jute type of cooling pad of 0.06 m thickness was selected for an efficient performance of the evaporative cooling system as it has good water holding capacity, high moisture content, and percentage dry basis, high bulk density reported [8].

3.0 Construction of the Evaporative Cooler

Angle iron and iron sheets were measured, cut and assembled to form a rectangular storage chamber with the left-hand side left open for the insertion of jute pad according to specifications of the design. The angle irons and sheets were assembled by welding. The storage chamber was divided into three shelve using mesh wire. An opening of 10mm radius was made near the bottom of the reservoir tank which has a volume of 20 liters; a PVC pipe of 20mm diameter was inserted in opening, T-joint, and elbow joint was used to connect the pipe networks together using Pvc gum to hold the pipe in position and a valve was also used at the end of the pipe network to stop water flow. A 0.5hp DC pump were used to lifts water of 50 liters from the bottom tank through a 25cm diameter PVC pipe to the overhead tank as water passing through the pad drains back to the bottom tank with floater switch. The pipes were assembled so that a single pipe runs over the jute pad area; the pipe is perforated at equal interval to create opening for free flows over the jute pad when the control valve is opened. A 40mm diameter PVC pipe was divided into two halves with a half connected at the bottom of the storage system at the side were the jute pad is inserted so it collects the excess water that drips off from the jute pad.

4.1 Performance evaluation of the Evaporative Cooling system

4.1.1 No Load Test of the Evaporative Cooling System

A no-load test of the system was conducted at Engineering section, Farm mechanization unit, Federal College of Freshwater Fisheries Technology, New Bussa, to see the effect of the evaporation that is expected to take place whether the process is effective or not in order to determine its efficiency before being loaded with the vegetables that will be stored. This was achieved by taken temperature difference and the relative humidity of the system relative to the ambient condition.

4.1.2 Flow Rate

The flow rate of water from the reservoir was determined through the use of a digital stop watch to monitor the time it takes to collect a certain volume of water by the water collector at the bottom of the cooling system.

4.1.3 Load Test of the Evaporative Cooling System

The load test of the evaporative cooling system was subjected to the following:

i. Temperature and Relative Humidity Measurement

The temperature and relative humidity were determined. Both the temperature of the evaporative cooling system and that of ambient were determined. The temperature and humidity readings were taken using digital Hygrometer at an interval of four hours for seven days.

ii. Physiological Weight Loss

The differences in weight of the tomatoes stored in both the ambient and in the cooler condition for seven days were estimated and this was done for seven days. The percentage weight loss was estimated using Equation (6) as given by [4].

Percentage Weight loss = $\frac{W1-W2}{W1}$ x 100

iii. Color Changes and Firmness

The changes in color of the ripe tomatoes (Roma variety) were noted both in the cooler and in the ambient condition in conjunction with the physiological weight loss. The color changes observed was based on the physical appearance of the vegetable [4]. The physical texture of the tomatoes was examined and noted. The difference in the firmness was also noted after storing the vegetables in the evaporative cooling system and in ambient condition.

5.0 Results and Discussions

5.1 Cooling Efficiency

The cooling efficiency of the evaporative cooling system was calculated when loaded with tomatoes and Table-1 shows the result of the cooling efficiency of the preservation chamber with the tomatoes. The result showed that the average cooling efficiency of the system was 92.5%, this shows that the evaporative cooling system was very effective and hence it will increase the shelf life of fresh tomatoes.

Table. 5.1. Cooling efficiency of cooler for seven days.

Days	1	2	3	4	5	6	7	Average
Efficiency(%)	80.0	85.4	88.7	92.5	89.3	84.2	82.7	92.5

5.2 Reservoir Discharge Rate

The discharge rate of the system was determined by measuring the volume of water collected at the bottom of the cooling system per hour. Therefore, the discharge rate of the system is 4 liters per hour.

5.3 Testing of Evaporative Cooler

The evaporative cooler was subjected to both no load and load tests and tomato (Roma variety) was selected in carrying out these experiments.

5.3.1 No Load Test of Evaporative Cooler

The test was achieved by testing the system without uploading tomatoes in order to ascertain whether there is temperature drop and increase in relative humidity as compared to that of ambient environment.

5.3.2 Load Test of the Evaporative Cooling System

The evaporative cooling system was loaded with 3kg of Roma variety of tomatoes with the same quantity kept under ambient condition. The temperature Dry bulb (DB) and Wet bulb (WB), relative humidity (RH) of both the system and ambient condition were monitored throughout the experiment and assessment of the physiological weight loss, color change and firmness of tomatoes were carried out. The load test result (daily temperature and relative humidity) of the system were shown in Table 5.2 and the result was then averaged and presented in Table 5.3. It was observed that the temperature difference between the ambient and cooling system ranges from 6 °C to 10 °C which was in conformity with that reported by Mogaji and Fapetu (2011) who gave ranges of temperature difference as 5 to 10 °C. It was observed that there is increase in the system relative humidity in relation to that of the ambient and this increase ranges from 13% to 55% as presented in Table 5.2.

Table. 5.2. Daily temperature and relative humidity for seven days

DAY 1

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(⁰C)	WB(⁰C)	RH(%)	DB(⁰C)	RH(%)
9:00am	20	13	45	12	89
1:00pm	23	18	63	14	82
5:00pm	27	27	61	18	75

DAY 2

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(ºC)	WB(ºC)	RH(%)	DB(ºC)	RH(%)
9:00am	18	11	35	12	70
1:00pm	24	19	57	15	78
5:00pm	28	22	47	23	81

DAY 3

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(ºC)	WB(ºC)	RH(%)	DB(ºC)	RH(%)
9:00am	16	10	41	15	88
1:00pm	23	17	55	20	83
5:00pm	28	21	51	13	81

DAY 4

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(ºC)	WB(ºC)	RH(%)	DB(ºC)	RH(%)
9:00am	18	11	45	12	78
1:00pm	23	19	49	15	82
5:00pm	26	24	58	16	90

DAY 5

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(ºC)	WB(ºC)	RH(%)	DB(ºC)	RH(%)
9:00am	18	13	45	14	71
1:00pm	23	18	62	16	80
5:00pm	27	27	59	20	75

DAY 6

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(ºC)	WB(ºC)	RH(%)	DB(ºC)	RH(%)
9:00am	18	11	43	12	78
1:00pm	25	15	46	16	80
5:00pm	21	20	58	11	90

DAY 7

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(ºC)	WB(ºC)	RH(%)	DB(ºC)	RH(%)
9:00am	19	13	50	11	89
1:00pm	23	18	62	16	90
5:00pm	26	21	70	18	82

Table. 5.3. Average temperature and relative humidity readings for both ambient condition and the evaporative cooling system.

TIME	AMBIENT CONDITION			COOLER CONDITION	
	DB(ºC)	WB(ºC)	RH(%)	DB(ºC)	RH(%)
1	23.33	19.33	56.33	14.67	82
2	51.33	37.33	107.66	34.67	175
3	48.33	34	49	16	84
4	22.33	18	50.67	14.33	83.33
5	22.67	19.33	55.33	16.67	75.33
6	21.33	15.33	49	13	82.67
7	22.67	17.33	60.67	15	87

5.4 Physiological Weight Loss of Tomatoes

Table 5.4 shows the results of physiological weight loss and percentage of weight loss of tomatoes while Figure-4 to 8 shows the daily weight loss during the experiment. These results revealed that the weight loss of tomatoes in the evaporative cooling system ranged from 1.7 to 5.7g per day while that of ambient system at open space ranges from 9.3 to 18.6g per day while and the percentage of weight loss of tomatoes in evaporative cooling system and ambient ranged from 0.05 to 0.18% and 0.30 to 0.60% per day respectively. However, the evaporative cooling system with mean 3.98g gave the less loss of weight as compared to the ambient condition with mean 13.95g gave the highest loss of weight.

Table. 5.4. Physiological weight measurement of tomatoes.

Days after storage	Weight loss of tomatoes in evaporative system (g)	Weight loss of tomatoes in ambient condition (g)
1	1.5	2.45
2	1.92	3.12
3	2.04	3.57
4	2.7	4.03
5	3.06	4.49
6	3.87	4.83
7	4.23	5.42

Figure 1: Tomatoes stored in evaporative System

Figure 2: Tomatoes stored in open area

Figure 3: Tomatoes stored in an evaporative system

Figure 4: Tomatoes stored in an evaporative system.

Plate 1: Evaporative system front

Plate 2: Water Distribution Network

5.5 Colour Change

During the testing period, the color changes of the tomatoes were monitored for both samples kept under ambient and evaporative cooling system. The color changes of tomatoes stored under ambient condition was very obvious from the third day of storage. By the sixth day, the color changed from yellowish red to a deep red color while some turned reddish black. It was also observed that the tomatoes stored in the evaporative cooling system still retained their color after six (6) days with no color changes noticed in most of the tomatoes.

5.6 Firmness

The change in the firmness of the tomatoes was much noticed because of their spherical shape. The tomatoes stored in the evaporative cooler still retained its firmness but those stored in the ambient have started losing their firmness after the third day and after the sixth day most of the tomatoes have started rotting. It is based on this background that the use of evaporative cooling system for storing fresh tomatoes is significant and cannot be over emphasized.

6.0 Conclusions

An evaporative cooling system was designed and fabricated for preservation of fresh vegetables. The system was tested using tomatoes (Roma variety). The evaluation of the system was carried out to ascertain the average drop in the temperature during the no-load test where the temperature recorded ranged from 13.75 to 14.75 °C. The cooling efficiency of the cooler was estimated both on load and a no-load condition and ranged from 71 to 90.6% with an average of 83%. The tomatoes were stored both in cooling system and in ambient condition in order to deduce the effectiveness of the system, physical phenomenon such as the system relative humidity, weight loss, color and firmness of tomatoes were taking into consideration. The percentage weight loss of the tomatoes was much in the ambient (0.30 to 0.60%) compared to those stored in the cooler (0.05 to 0.18%). The color changes observed in the tomatoes stored in the ambient (deep red to reddish black) was greater compared to the ones stored in the evaporate cooler (yellowish red to red). The loss of firmness was also very obvious in the tomatoes stored under ambient as compared to evaporative cooling system. However, the testing of the evaporative cooling system shows that the tomatoes could be stored for an average of six (6) days without rotting compared to that of ambient which started rotting after three (4) days. Hence, it was concluded that farmers, house holders and tomatoes processing factories should adopt the use of an evaporative cooling system for the preserving of fresh tomatoes as this increases the shelf life of tomatoes and the system is affordable.

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