DEVELOPMENT AND VALIDATION OF A MINI AUTOMATIC REFRIGERATOR FOR FRESH FRUITS AND VEGETABLE STORAGE

Tanko Bako[1*], Rotimi Emmanuel[2], Innocent Alex[3]

1, Department of Agricultural and Biosystems Engineering, Taraba State University, Jalingo, Nigeria
2, Department of Agricultural and Bio-Environmental Engineering Technology, Federal Polytechnic, Bali, Taraba State, Nigeria
3, Department of Electrical and Electronics Engineering, Taraba State University, Jalingo, Nigeria
Email: engbako@gmail.com Tel: +234 7064190523

ABSTRACT: Fruits and vegetables are vital agricultural produce for human consumption worldwide. Post-harvest losses of vegetables and fruits often occur due to lack of proper preservation methods. This study aimed to develop, and validate a mini automatic refrigerator specifically for storing fresh fruits and vegetables. The automatic mini refrigerator after construction has an estimated volume of 126,678.24 cm^3 equivalent to 127 Litres Component of Refrigeration unit consist of Compressor, Condenser Coil, Expansion Valve, Evaporator Coil, R600a Refrigerant and Digital Thermostat. The digital thermostat has a Temperature measurement range of -50 to 110 °C and accuracy of plus, or minus 0.2 °C, giving it the ability to store fruit and vegetable at a temperature range 0 to12 °C. The system runs on a 220- 240 Voltage power supply, 0.95 Ampere and 120 Watts while the rated frequency is 50 Hz. The choice of all materials selected for this work was done on the basis of their local availability, affordability. The refrigerator's performance was evaluated based on its cooling capacity, coefficient of performance (COP), and cooling rate. Results showed a cooling capacity of 735 W, COP of 1.61, and cooling rate of 15.33 W, indicating moderate to good efficiency. The refrigerator's effectiveness in maintaining optimal temperature and humidity levels makes it a valuable asset for reducing post-harvest losses and improving food security. This innovation has practical applications in reducing food waste, enhancing produce quality, and providing economic benefits for farmers and suppliers, particularly in rural or remote areas with limited access to electricity.
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KEY WORDS: Fruits; Vegetables; Performance; Temperature; Refrigeration

1.0 INTRODUCTION

Inadequate storage facilities have been identified as the major cause of heavy losses to farmers in many parts of the world especially in developing countries. This have resulted to serious waste of foodstuff and increased cost to the farmers. In the developing countries such as Nigeria, the estimate loss from inadequate storage is 45-50% of the production level of the farm produce (Orji, 2013).

Fruits and vegetables are vital agricultural produce for human consumption worldwide. They are rich in vitamins and minerals such as carotene (pro-vitamin A), Ascorbic acid, Riboflavin, Iron, Iodine and Calcium. However, most fruits and vegetables are not only seasonal, they are highly perishable. Producers suffer huge economic losses due to inadequate and inefficient storage methods (Chandy, 2016). Storage is of great importance because not all the harvested vegetables or crops in general may be used immediately after harvest. Some methods of preservation of fruits and vegetables include storage in ventilated sheds, at low temperatures, use of evaporative cooling systems, waxing and chemical treatment amongst others (Olosunde, 2006). The bulk of post-harvest loss of fruits and vegetables in developing countries is due to the lack of proper storage facilities. Refrigerated cool stores are the best method of preserving fruits and vegetables but they are expensive to buy and run (Odesola and Onyebuchi, 2009). There is therefore an interest in simple low-cost, low power alternatives by developing countries (Udayanga *et al.*, 2015).

Storage is defined as the process of keeping parts of the crop produced during the season of abundant production to ensure its availability during the off-production period. Cold storage is defined as the storage of perishable food, fruits, vegetables etc. in an artificially cold environment (Udayanga *et. al*, 2015).

Perhaps the most widely known domestic's item for food storage is the refrigerator which is commonly used for preserving foodstuffs, fruits, and vegetable at low temperature. Cold storage extends the shelf life and the marketing of fruits and vegetables, avoiding food glut, and reducing transport bottle necks during the peak period of production. It therefore aids the control and minimization of spoilage and integrates cold chain network from the point of harvest to the point of purchase (Muhammad, *et al*., 2012). Post-harvest losses of vegetables and fruits often occur due to factors like poor handling, inadequate storage facilities, transportation issues, and lack of proper preservation methods. In many cases, insufficient cold storage, improper packaging, and delays in transportation contribute to spoilage, reducing the overall quality and quantity of the produce before it reaches consumers. Improved post-harvest management practices can help mitigate these losses.

One common problem in fruit and vegetable storage in Nigeria is inadequate infrastructure, leading to challenges such as unreliable electricity, temperature fluctuations, and limited access to modern storage facilities, affecting the overall quality and shelf life of farm produce. Lowering the temperature of fresh produce retards metabolic activities and extends shelf life. Cooling retards microbial activity and arrests pathogen proliferation that produces decay. A cold storage system for fruits and vegetables is significant for preserving freshness and extending shelf life. It helps slow down the ripening process, reduces spoilage, and maintains nutritional content. Cold storage prevents the growth of microorganisms, preserving quality from harvest to consumption, crucial for minimizing food waste and ensuring a consistent supply of produce.

A cold storage system is vital for local farmers' markets as it enables farmers to store and prolong the freshness of their produce. This ensures a steady and diverse supply of fruits and vegetables, allowing markets to offer a wider selection to consumers throughout the year. Cold storage helps farmers manage inventory, reduce waste, and maintain the quality of their products, contributing to the market's sustainability and supporting the local agricultural economy. The basic aim of this research study is to develop and validate a mini automatic refrigeration system for storage of fresh fruits and vegetable using available local materials. The objectives of the work are;

i. To develop a mini automatic refrigerator for fresh fruits and vegetable storage using locally available materials.
ii. To evaluate the performance of the developed mini automatic refrigerator for fresh fruits and vegetable storage.

2.0 MATERIALS AND METHODS

2.1 Design Conception

i. Capacity of the refrigerator: 127 liters.
ii. Temperature range: 0°C to 12°C (273k to 283K).
iii. Thermostat Temperature sensor control range: -50 to110 ° C (±0.2 °C).
iv. Insulation: Polyurethane foam: to be placed between the outer and inner all of the cooling system (40-50 mm).
v. Shelf layout: Not adjustable for this system.
vi. Compressor: Hermetic compressor type with rating of 1/4 HP, 120W and 50Hz.
vii. Evaporator: Copper wire tube type.
viii. Condenser: Air-cooled type of condenser.

2.2 Design Consideration

Gas selection: Most widely used refrigerators are those which use a liquefiable vapour as refrigerants. Based on the operation of the refrigerator being a cyclic process, properties such as temperature (°C), pressure (bar), specific enthalpy(kJ/kg),specific entropy (kJ/kg .k), specific volume (m^3/kg) were put into the consideration. Isobutane (R-600a) which is a hydrocarbon refrigerant used in various refrigeration applications, including domestic and light commercial refrigeration units, was selected based on the fact that it has minimal ozone depletion potential.

Construction materials: In order to reduce cost of construction, aluminum and mild steel were chosen for construction of the body of the refrigerator.

2.3 Design Analysis

Refrigerator capacity: Volume (cm^3) = Length × Width × Height (1)

Volume = 40.40 × 40.20 × 78 = 126,678.24 cm^3 = 0.127 m^3

Total product holding capacity: $M = \rho \times V$ (2)

Where, V = device chamber volume (m^3), ρ = product bulk density (kg/m^3).

Cooling load calculation: $Q = \frac{m \times \Delta T \times Cp}{3600}$ (3)

Where; Q = Cooling load (kW), m = Mass of stored produce (kg) = Density of produce × volume of refrigerator = 650 kg/m³ × 0.127 m^3 = 82.55 Kg, ΔT = Temperature difference (K) = (12°C + 273) K = 285K (difference in storage temperature for carrot and Avocado), Cp = Specific heat capacity of produce (J/Kg.K) = 3940 J/kg·K. Q = 25.75 kW

Coefficient of performance (COP): $\mathrm{COP} = \frac{\text{Refrigerating Effect}}{\text{Compressor Work Input}}$ (4)

R600a Properties at -12°C Evaporating Temperature: Enthalpy (h_1): 229.4 kJ/kg, Enthalpy (h_2): 274.8 kJ/kg, Enthalpy (h_3): 183.2 kJ/kg = h_4 (throttling process).
Assuming mass rate, m = 0.1 kg/s
Refrigerating effect = (h_1 - h_4) (5)
Refrigerating effect = (229.4 - 183.2) × 0.1 ≈ 4.62 kW
Compressor work input = (h_2 - h_1) (6)
Compressor work input = (274.8 - 229.4) × 0.1 ≈ 4.54 kW
COP = 1.02

Refrigeration Capacity (RC) $= \frac{Q}{\mathrm{COP}}$ (7)

Where; RC = Refrigeration capacity (W), COP = Coefficient of performance (dimensionless). RC = 25.24 kW

Compressor Power (P) in Watt: $P = \frac{RC}{\mathrm{COP} \times \eta}$ (8)

Where; P = Compressor power (kW), RC = Refrigeration capacity (kW), η = Compressor efficiency assume value, 0.8 (dimensionless). P = 30.93 kW.

Energy Consumption: $E = P \times t$ (9)

Where; E = Energy consumption (kW hr), t = Operating time (hr). E = 30.93 kW hr.

2.4 Description of the Mini Automatic Refrigerator

The refrigerator (Plates 1) is a rectangular shaped storage housing structure of 550 mm length, 430 mm width and 660 mm height, mounted on a steel frame with stainless wire partition for storing of fruits and vegetables. The refrigerator consists of a door made with aluminum metal sheet, lagging material (polyurethane foam insulation) and rectangular pipe, cooling chamber (evaporator made with copper wire-and-tube type and shelves made with mild steel), external refrigeration component (condenser and compressor), Digital temperature control thermostat and power cable. The body of the refrigerator consist of the internal frame work made of rectangular metal pipe, lagging material (polyurethane foam) and aluminum sheet (as exterior and interior cover material).

Plate 1: The Mini Automatic Refrigerator

2.5 Evaluation of the Refrigerator

The following parameters was considered during the evaluation process: condenser and evaporator temperature, cooling capacity.

2.5.1 Temperature difference

Temperature readings were taken three times at a given interval during the test period to monitor and determine change in temperature cold reservoir (evaporator) in degree Celsius (^{0}C) and hot reservoir (condenser) in degree Celsius (^{o}C) and also for difference between the inside temperature and the outside temperature. A mercury in bulb thermometer is used for monitoring of change of temperature.

2.5.2 Cooling capacity

Cooling Capacity (Watts) = Total Volume of the Refrigerator in litres × Temperature Difference between Inside and Outside the Refrigerator in °C × 0.293 (10)

Where; Total volume is the internal volume of the refrigerator, including shelves and compartments and Temperature difference is the difference between the inside temperature and the outside temperature.

2.5.3 Coefficient of performance

This is measured in the refrigerator as follows (Kumar and Kumar 2020).

$$\text{COP} = \frac{T_E}{(T_C - T_E)} \quad (11)$$

Where; T_E = Temperature of the cold reservoir (evaporator) in (°C), T_C = Temperature of the hot reservoir (condenser) in (°C).

2.5.4 Cooling rate

$$\text{Cooling Rate (Q) in (Watts)} = \frac{(\text{COP} \times \text{P})}{T_C - T_E} \quad (12)$$

Where; COP = Coefficient of performance, P = Power input to the compressor (Watts), T_C = Condenser temperature (°C), T_E = Evaporator temperature (°C).

3.0 RESULTS AND DISCUSSION

3.1 Cooling Capacity

The cooling capacity of a refrigerator is the amount of heat that can be removed from the cold side per unit time (Kumar *et al*., 2018). Cooling capacity refers to the rate at which a refrigerator can remove heat from the stored produce, typically measured in Watts (W) or British Thermal Units per hour (BTU/h). Results in Table 1 indicates that the cooling capacity of the mini refrigerator ranged from 447 W to 967 W with mean value of 735 W. According to Kumar *et al*. (2020), a cooling capacity of 735 W is suitable for small to medium-sized storage applications. Llopis *et al*. (2015) documented that refrigerators with cooling capacities between 500-1000 W are commonly used for storing perishable items. Benefits of a good cooling capacity include; maintains optimal temperature range (0-5°C or 32-41°F) for fruits and vegetables, prevents rapid spoilage and bacterial growth and extends shelf life of stored produce.

Table 1: Cooling Capacity of the Refrigerator

Time Interval (min)	Volume in Litres	Inside Temperature (^{0}C)	Ambient Temperature (^{0}C)	Temperature Difference (^{0}C)	Cooling Capacity (Watt)	Average Cooling capacity (Watt)
5	127	19	31	12	447	735
10	127	12	31	19	707	
15	127	9	31	22	819	
20	127	5	31	26	967	

3.2 Coefficient of Performance

The coefficient of performance (COP) is a measure of the efficiency of a refrigeration system, defined as the ratio of the heat removed to the work input" (Llopis *et al*., 2015). Results in Table 2 indicates that the COP of the Refrigerator for Storage of Fresh Fruits and Vegetables ranged from 0.95 to 2.4 with an average value of 1.61. COP is a measure of refrigeration efficiency, calculated as the ratio of cooling capacity to power input. The Coefficient of Performance (COP) of 1.61 for a refrigerator storing fresh fruits and vegetables indicates moderate to good efficiency (Singh *et al*., 2020). According to Llopis *et al.* (2015), COP range of 1.5-3.5 is considered moderate to high efficiency for commercial refrigeration systems (Llopis *et al.*, 2015).

Table 2: Coefficient of Performance of the Refrigerator

Time Interval (min)	Evaporator Temperature T_E (^0C)	Condenser Temperature T_C (^0C)	T_C- T_E (^0C)	COP	Average COP
5	24	34	10	2.4	1.61
10	22	35	13	1.69	
15	21	36	15	1.4	
20	19	39	20	0.95	

3.3 Cooling Rate

Cooling Rate (Q) in (Watts) depends on the Coefficient of performance, Power input to the compressor (Watts), Condenser temperature (°C) and Evaporator temperature (°C) (Kumar and Kumar, 2020). Result in Table 3 indicates that the cooling rate varied from 5.7 W to 28.8 W having mean value of 15.33 W. For refrigerator storing fresh fruits and vegetables, cooling rate of 15.33 W indicates moderate cooling capacity (Singh *et al*., 2020). Wang *et al*. (2017), stated that cooling rates between 10-20 Watts are suitable for small to medium-sized storage applications.

Table 3: Cooling Rate of the Refrigerator

Time Interval (Min)	T_C- T_E (^0C)	Power Input (Watts)	COP	Cooling Rate	Average Cooling Rate (W)
5	10	120	2.4	28.8	15.33
10	13	120	1.69	15.6	
15	15	120	1.4	11.2	
20	20	120	0.95	5.7	

4.0 CONCLUSION

This research project focused on the development and validation of an automatic mini refrigerator specifically made for storing fresh fruits and vegetables. The refrigerator's performance was validated based on its cooling capacity, coefficient of performance (COP), and cooling rate. The results showed that the refrigerator achieved a cooling capacity of 735W, COP of 1.61, and cooling rate of 15.33W. These values indicate that the refrigerator is efficient and effective in maintaining the quality of fresh fruits and vegetables. The study successfully demonstrated the development and validation of a mini automatic refrigerator for storing fresh fruits and vegetables. The results obtained from validating the refrigerator's performance indicate its potential for practical applications. The refrigerator's efficiency and effectiveness in maintaining the quality of fresh produce make it a valuable asset for reducing post-harvest losses and improving food security. Future studies can focus on optimizing its performance and exploring the use of alternative refrigerants.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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