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Design, Construction and Testing Of a Freeze Dryer for Vegetables

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Abstract: *Drying of vegetables by farmers in Benue State Nigeria has not been very successful due to unavailability of appropriate drying technologies such as a freeze dryer. Farmers no longer produce in large quantity due to fear of wastage which also results to labour lost. The main purpose of this study was to evolve a better way of drying vegetables for longer shelf live. The study designed, constructed and evaluated the performance of the freeze dryer. Digital thermometer, vacuum gauge and stop-watch were used to determine the freezing temperature, freeze drying vacuum pressure and freeze drying time. Tomato, pepper and okra were tested on the freeze dryer and were freeze dried at a temperature of -2℃, -1.5℃ and -1.4℃ and vacuum pressure of -29inHg, -24inHg and -22inHg, the freeze drying time was 20hours, 10hours and 10hours respectively. 0% moisture content was achieved with the aid of the vacuum as moisture does not exist in a vacuum space. The freeze dried products were able to regain their freshness when reconstituted with water. It has been recommended among others that farmers should be encouraged to use freeze dryer for drying tomato, pepper and okra.*

Keywords - *Freeze drying, Pressure, Refrigeration, Sublimation, Temperature, Vacuuming, Vegetables.*

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I. Introduction

One of the basic needs of human beings is food, People and animals need to eat food to survive, grow and stay healthy and strong. In an effort to produce food, people engage in various agricultural activities for the purpose. These agricultural endeavours result into production of food items for local consumption and trade. However, farmers in Africa, Nigeria and Benue state in particular have problems of preservation and storage of agricultural products when produced in abundance. The lack of adequate preservation facilities of food produces, especially vegetables, leads to a lot of wastages of the produce. This preservation problem, therefore, discourages farmers as their efforts seem wasted and they cannot get profit for their labour but rather incur losses.

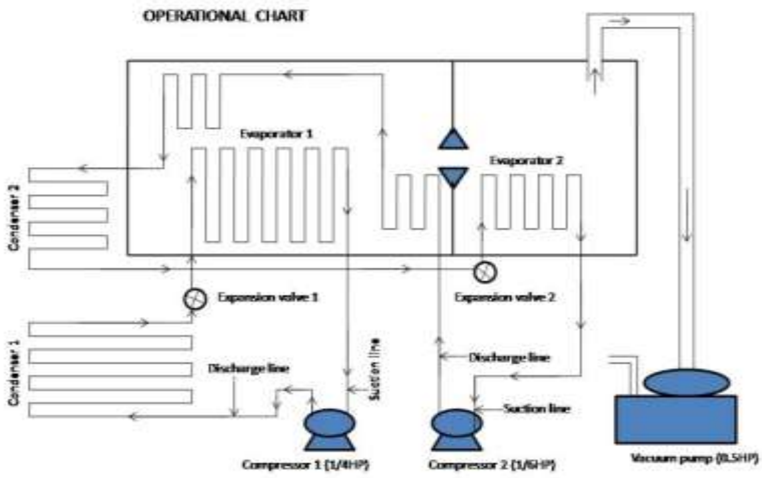
Drying, a process of moisture removal in controlled manner is practiced for preserving food products [1]. The process removes moisture required for the growth of microorganisms and prevent vegetables and other farm produce from spoilage. The moisture is removed to a safe level that does not affect important qualities of the commodity. Africa, Nigeria and Benue farmers in particular use the traditional "sun drying" and also smoking methods for most of the agricultural produce [2]. There are many disadvantages and problems associated with the process of sun drying. It lacks controllability on the drying conditions. Often, the drying process is very slow and can be interrupted by unfavourable weather conditions, it also requires constant supervision of the process since the produce has to be protected from rain and predators [2]. He further expressed that the chances for contamination due to dust, dirt and insect infestation are high under open sun drying. Similarly, smoking which is used leads to contamination of the product with smoke. It is also expensive since a lot of wood need to be used. It is also a long process. As a result, the dried product is of poor quality. Therefore, it is necessary to introduce improved technology such as a freeze drying to upgrade the quality and thereby overcome the problems of traditional sun drying and wastage of agricultural produce.

Freeze drying is a method of drying product by sublimation, using low temperature and reduced pressures [3]. It is widely used in different fields, such as food and pharmaceuticals manufacturing, in particular when the product can be damaged by the high temperatures of other drying procedures and when the process must be carried out in sterile conditions [3]. Freeze drying was first carried out by Altmann, who freeze-dried parts of organs in 1890 [3]. In 1932, Gersh designed an effective vacuum plant for freeze-drying of histological preparations with the help of the diffusion pump just invented by Gaede at that time [3]. The goal of freeze drying is to produce a substance with good shelf stability and which is unchanged after reconstitution with water, although this depends also very much on the last step of the process: the packaging and conditions of storage [3].

This study designed and constructed a freeze dryer for drying tomato, pepper and okra. The freeze dryer is incorporated with a refrigeration system and a vacuuming system. This is very important in order to ensure that tomato, pepper and okra are preserved by freeze drying and quality is maintained. The results obtained here and the concept will be used by fabricators to produce freeze dryers for farmers and home use in order to control post-harvest losses of tomato, pepper and okra in Nigeria and Africa at large.

II. Concept

Fig. 1 Operational diagram of the freeze dryer



The freeze dryer has two chambers, two compressors, two condensers, two evaporators and a vacuum pump. Vegetables are frozen and dried in the first chamber; the vacuum used for drying is generated from the second chamber which also serves as ice condenser. It has two stages of operations; freezing and vacuuming. During freezing, compressor 1, condenser 1 and evaporator 1 are in operation; this enables fast freezing to take place. And during vacuuming, vacuum pump, compressor 2, condenser 2 and evaporator 2 are in operation; this create a very fast sublimation and vacuum which causes drying to take place.

III. Materials And Methods

3.1 Design of the Freeze Dryer

The freeze dryer was design to meet the requirements for drying tomato, pepper and okra. Based on the material layer thickness in a tray and bulk density of the fresh produce, the tray area was determined. The freeze dryer has two chambers; the freezer/drying chamber and the vacuum chamber. The specifications of the freeze dryer and trays are given below. There were three trays in the freezer/drying chamber.

Width of the freeze dryer = 1000 mm
Height of the freeze dryer = 1100 mm
Depth of the freeze dryer = 800 mm

3.1.1 Chamber 1

Height = 600 mm
Width = 600 mm
Depth = 800 mm
Compressor size = 1/4HP
Condenser size = 1/4HP
Evaporator size = 1/4HP

3.1.2 Chamber 2

Height = 600 mm
Width = 300 mm
Depth = 800 mm

Compressor size = 1/6HP
Condenser size = 1/6HP
Evaporator size = 1/6HP
Vacuum Pump = 1/4 HP

3.1.3 Trays
Width = 450 mm
Length = 600 mm

3.2 Design Analysis
3.2.1 Heat gain through the freeze dryer walls
Considering 50mm thick insulation, 1mm thick galvanized sheet and 1mm thick aluminum from outer to inner surfaces respectively.

The overall heat factor (u) = $\frac{1}{1/h_i + x/k \cdots + 1/h_o}$ [4] (1)

X = wall thickness = 0.05 m (50 mm), 0.001 m (1 mm), and 0.00 m (1 mm)
K = thermal conductivity of wall materials = 0.029 (polystyrene), 205(Aluminum sheet) and 314 (Galvanized sheet).
h_i = 6 (inside surfaces)
h_o = 6 (outside surfaces)

Therefore, u = $\frac{1}{1/6 + 0.05/0.029 + 0.001/205 + 0.001/314 + 1/6} = \frac{1}{2.06}$ = 0.49 W/mK

Surfaces; cabinet 1 = 6surfaces, cabinet 2 = 6surfaces

3.2.2 Chamber 1
Dept (D) = 800 mm, Length (L) =600 mm, Height (H)=600 mm, insulation thickness = 50 mm

1. Area surface of front and back (A1) = 2 × H × L = 2 × 0.6 × 0.6 = 0.72 m^2
2. Area surface of sides (A2) = 2 × D × H = 2 × 0.8 × 0.6 = 0.96m^2
3. Area surface of top and bottom (A3) = 2 × D × L = 2 × 0.8 × 0.6 = 0.96 m^2

Total surface area of cabinet 1 = A1 + A2 + A3 = 0.72 + 0.96 + 0.96 = 2.64 m^2

The heat that will gain through walls of the cabinet 1 (Q) = $\frac{U \times A \times \Delta t}{x}$ [5] (2)

= $\frac{0.49 \times 2.64 \times (38 - (-30))}{0.05}$ = 1759.3 J = 1.7593 kJ

For condenser sizing, $Q_c = Q \times \frac{24\text{hr } (1440 \text{ min})}{\text{Desired runing time}}$ = 1.7593 $\times \frac{1440}{1200}$ = 2.11 kJ/min

3.2.3 Chamber 2
Dept (D) = 800 mm, Length (L) = 300 mm, Height (H) = 600 mm

1. Area surface of front and back (A1) = 2 × H × L = 2 × 0.6 × 0.3 = 0.36 m^2
2. Area surface of sides (A2) = 2 × D × H = 2 × 0.8 × 0.6 = 0.96 m^2
3. Area surface of top and bottom (A3) = 2 × D × L = 2 × 0.8 × 0.3 = 0.48 m^2

Total surface area of cabinet 1 = A1 + A2 + A3 = 0.36 + 0.96 + 0.48 = 1.8 m^2

The heat that will gain through walls of the cabinet 2 (Q) = $\frac{U \times A \times \Delta t}{x}$

= $\frac{0.49 \times 1.8 \times (38 - (-30))}{0.05}$ = 1199.5J = 1.1995 kJ

For condenser sizing, $Q_c = Q \times \frac{24\text{hr } (1440 \text{ min})}{\text{Desired runing time}}$ = 1.1995 $\times \frac{1440}{1200}$ = 1.44 kJ/min

3.2.4 Heat gain from products
Three products are selected for this study; tomato, pepper and okra.
Specific heat of tomato above freezing = 4.08kJ/kg K , specific heat of pepper above freezing = 4.08 kJ/kg K, specific heat of okra above freezing = 3.97 kJ/kg K

From equation Q1 = m×c1× (t1 – t2) [6] (3)
= 94.24 × 4.08 (20 – (-2)) =82.72 kJ.
From equation 2.4, Q2 = m×c1× (t1 – tf)
= 0.94 × 4.08 × 19 = 72.9 kJ.
From equation 2.5, Q3 = m×hif = 0.94 × 311 = 292.34 kJ.
From equation Q4 = m×c2× (tf – t3) [6] (4)
= 0.94 × 2.05 × (-9) = -17.34kJ

Therefore, the total heat that will be removed from products by the freeze dryer = $\frac{Q1 + Q2 + Q3 + Q4}{3600\,n}$ [5] (5)

$= \frac{82.72 + 72.9 + 292.34}{3600 \times 1440} = \frac{447.96}{5184000} = 0.00009$ kJ/min

The load for 3kg of product = 3 × 0.00009 = 0.0027 kJ/min

From equation 2.9, COP = $\frac{\text{refrigerating effect}}{\text{Work done}} = \frac{h1-h4}{h2-h1} = \frac{223.95-3.841}{270.99-223.95} = 4.68$

Therefore, the coefficient of performance (COP) = 4.68

The total heat to be remove by cabinet 1 condenser = product load + heat gain through insulated walls of cabinet 1 = 0.0027 + 2.11 = 2.1127 kJ/min

The total heat to be remove by cabinet 2 condenser = 1.44 kJ/min (cabinet 2 has no product)

Refrigeration effect

The refrigerating effect (RF) of the freeze dryer = h1 – h2 (at temperature of -30°C)
= 223.9 – 3.841= 220.059 kJ/kg

3.3 Components Sizing

The components were sized based on the heat load analysis; compressor 1 = 1/4HP, compressor 2 = 1/6HP, condenser 1 = ¼, condenser 2 = 1/6, Evaporator 1 = ¼, Evaporator 2 = 1/6 and Vacuum pump = 1/4HP

3.4 Freeze dryer evaluation

3.4.1 Freezing Temperature and Time Test

Temperature and time was measured using digital stop watch of four digits and digital thermometer. Time and temperature was recorded every two hours with samples taken out and observed until tomatoes, pepper and okra were completely frozen.

3.4.2 Vacuum and Time Test

Vacuum and time was measured using vacuum gauge of 0 to -30 inHg and four digits stop watch; time and vacuum pressure was recorded in twenty minutes interval until the ice was completely sublimed from the tomato, pepper and okra. No sample was taken until vacuum was achieved and at this point moisture was completely removed from the vegetables as moisture does not exist in vacuum (moisture content at 0%).

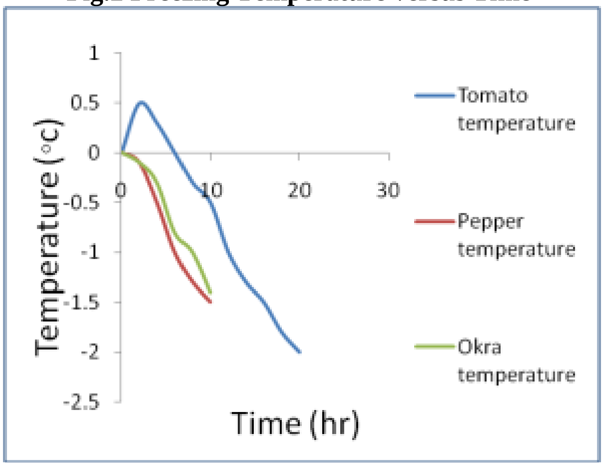
IV. Results And Discussion

The performance evaluation of the freeze dryer was done according to the freezing temperature, vacuum pressure and time for freeze drying tomato, pepper and okra.

4.1 Freezing Temperature and Time for Tomato, Pepper and Okra

The freezing temperature and time for tomato, pepper and okra is presented in "Fig.2" below.

Fig.2 Freezing Temperature versus Time

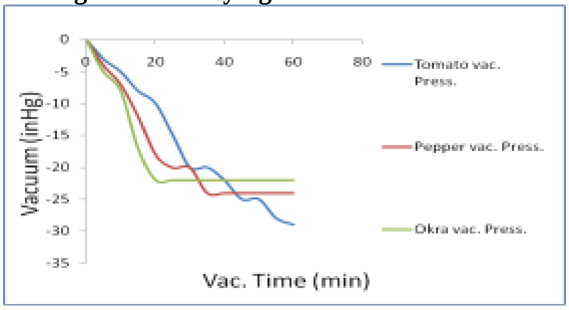


The Figure shows the temperatures achieved by the freeze dryer; Tomato was frozen at -2◦c within 20 hours, Pepper at -1.5◦c within 10 hours and Okra at -1.4◦c within 10 hours.

4.2 Vacuum Pressure and Time for Freeze Drying Tomato, Pepper and Okra

The vacuum pressure and time for freezing drying tomato, pepper and okra is presented in "Fig.3" below.

Fig.3 Freeze drying vacuum versus Time

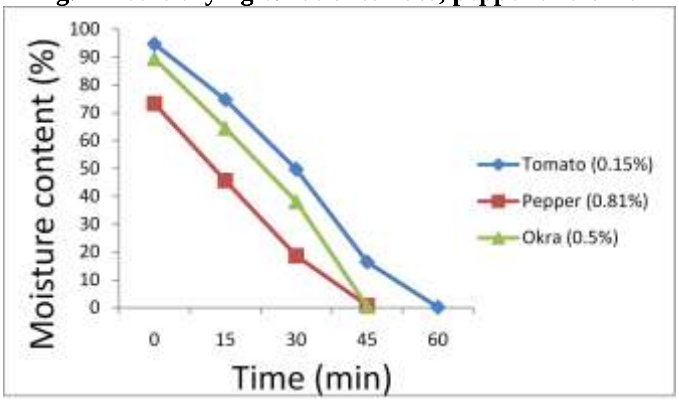


After freezing the vegetables, the pressure in the freeze dryer cabinet was lowered to vacuum and at a vacuum of -22 inHg, -24 inHg and -30 inHg okra, pepper and tomato were found to be dried with a moisture content of 0%

4.3 Moisture content

The achieved moisture content is presented in "Fig.4" below.

Fig.4 Freeze drying curve of tomato, pepper and okra



The moisture content of the vegetables decreases continuously with increase in vacuuming time.

V. Conclusions

The freeze dryer was designed, constructed and evaluated; tomato, pepper and okra were tested on the freeze dryer and major conclusions are as follows:

1. The freeze dryer is suitable for drying vegetables.
2. Tomato, pepper and okra can be freeze dried for longer period storage.
3. Tomato can be freeze dried at a temperature of -2◦c with a vacuum of -30 inHg; Pepper at -1.5◦c with a vacuum of -24 inHg; and Okra at -1.4◦c with a vacuum of -22 inHg.

VI. Acknowledgement

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