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Fabrication of a Freeze Dryer Using Locally Sourced Material

R.O.Bello [1] and Raji A.O.[2]
[1] Department of Agricultural and Bio-environmental Engineering
School of Engineering, Yaba College of Technology
[2] Department of Agricultural and Environmental Engineering
Faculty of Technology, University of Ibadan

Abstract
This study presents the design and construction of a freeze dryer system within a 330.2mm x 508mm x 457.2mm rectangular chamber, crafted from a 4mm galvanized metal sheet at the University of Ibadan, Nigeria. The chamber featured a dual-layer configuration with an inner and outer layer fortified by a 1.7mm x 1.7mm square gauge hollow pipe made of mild steel. This reinforcement aimed to prevent implosion, particularly during the dehydration phase of the freeze-dryer process.The system's design was used based on the specific heat capacity of relevant fruits and vegetables, including Pears, Tomatoes, and Carrots, each characterized by heat capacity values of 3.62KJ/kg^{o}C, 3.98KJ/kg^{o}C, and 3.79KJ/kg^{o}C, respectively. For the preservation of nutritional qualities during drying and subsequent reconstitution, products were initially frozen and then subjected to sublimation.Monitoring of key parameters within the chamber, such as dry-bulb and dew point temperatures, and relative humidity, was facilitated by a USB data recorder. While the chamber effectively achieved dry-bulb temperatures ranging from an initial 28°C to 1°C post-drying, and dew point temperatures from 20.8°C initially to -6.1°C post-drying, these temperatures remained below the target threshold of 5°C for optimal drying. This discrepancy may be attributed to potential leakages along welded portions of the chamber, impeding the product's transition to the desired dry state.Consequently, the final moisture content essential for safe storage of the dried product was not attained due to these challenges. Comparative analysis revealed lower temperatures (dry-bulb and dew point) and relative humidity in the freeze-dried product compared to imported counterparts. This discrepancy may be linked to the welding method employed in constructing the chamber, allowing air exchange between the chamber's interior and its surroundings.The freeze-drying process extended for 6 hours, resulting in a 1/10 reduction in the product's size when weighed.
Keywords: *Freeze dryer, Reconstitution, Implosion, Dehydration, Cooling*

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I. Introduction

A freeze dryer, also known as a lyophilizer, is a crucial piece of equipment in food processing industries and research institutes. Its significance arises from its wide range of applications and exceptional efficiency in operation. This equipment finds particular use as a food dehydrator, especially for products that are sensitive to traditional high-temperature drying methods, which can alter their nutritional composition. Unlike conventional dryers that employ extended drying periods at high temperatures, the freeze dryer operates on the principle of sublimation directly transitioning the product from a solid (ice) to a gaseous state. This sublimation process, characterized by low dehydrating temperatures, preserves the nutritional integrity of the food, including its original texture, flavor, and essential components (Soham, 2011).

Nigeria, with one of the largest economies in Africa, is predominantly associated with oil production, contributing about 5.6% of the gross domestic product (GDP) as of 2022. However, recent statistics show that the agricultural sector constituted a substantial portion of Nigeria's economy, accounting for approximately 30% of the GDP in the third quarter of 2022 (ITA, 2022). Fruits and vegetables hold a pivotal role within the agricultural sector, forming an integral part of a balanced human diet. Nevertheless, their high moisture content poses challenges to their shelf life, leading to significant value loss (Ndukwu, 2011). This results in substantial losses, especially during post-harvest periods, forcing part of the produce to be discarded or used as animal feed. Additionally, certain fruits and vegetables, such as tomatoes and bananas, require constant refrigeration to maintain their freshness, which is not always feasible for local farmers due to cost constraints and energy availability issues.

While various methods for drying and preserving food exist, such as sun drying, solar drying, and mechanical drying techniques like flash dryers, cabinet dryers, and rotary dryers, few of these methods effectively retain the nutritional quality of the food after drying. The loss of vital nutrients diminishes their suitability for drying sensitive products and their consumption. In the food processing industry, the focus extends beyond mere processing to maintaining the nutritional content of food products post-drying. Traditional methods like sun drying leave products vulnerable to unpredictable weather and contamination by animals and environmental factors, compromising their nutritional value. Meanwhile, most mechanical drying methods subject products to high temperatures, resulting in altered nutritional profiles. These methods can also impact the physical attributes of the product, such as shape, color, and texture, especially upon reconstitution for use.

In contrast, freeze-drying offers a comprehensive solution. It combines freezing and dehydration to preserve products, maintaining their nutritional values and physical properties, such as color, taste, flavor, and texture. The extended storage lifespan afforded by freeze drying significantly reduces food insecurity by minimizing post-harvest losses, particularly for fruits and vegetables prone to wastage during seasonal peaks.
Freeze drying carries several advantages, these include:

- It extends the shelf life of processed foods, reducing the need for frequent restocking.
- Transportation costs are lowered due to reduced product weight and increased shelf life.
- The process adds value to products, potentially leading to foreign exchange earnings.
- Reconstituted freeze-dried products closely resemble their fresh counterparts in terms of taste, texture, and flavor.
- Packaging freeze-dried products for the market is convenient and appealing.

This study aims to fabricate a freeze-drying system using locally sourced materials. The goal is to convert perishable fruits into storable forms, thereby minimizing wastage, enhancing food security, and ensuring the nutritional quality of the products. Freeze-dried products can be stored for extended periods without refrigeration and retain their original characteristics upon reconstitution. This research contributes to solving the issue of post-harvest losses and aligns with the World Health Organization's standards for food preservation.
The freeze-drying process involves several stages: the pretreatment stage to condition the product, the freezing stage to a very low temperature to halt microbial activity, the primary drying stage used to remove ice via sublimation under vacuum, and the secondary drying stage to eliminate bound water. This process ensures the preservation of the product's nutritional quality.

II. Materials and Method

2.1 Principle of Freeze DryerSystem

The freeze dryer operates through a two-fold process involving cooling and dehydration. In the initial step, the intended product is frozen within a chamber under extremely low temperatures. Subsequently, the product undergoes sublimation under vacuum-induced conditions, known as primary drying. This is followed by the controlled application of mild heat to eliminate residual bound water, a process referred to as secondary drying. Effective freeze drying requires the product's vapor pressure to be lower than that of the chamber environment, facilitating the drying process. Furthermore, pre-freezing the product at temperatures below 0°C before dehydration helps maintain the fundamental structure and shape of the dehydrated end product.

2.2Design Consideration

The following factors were taken into consideration in the design:

a) **Construction Material for the Chamber:** Selecting a corrosion-resistant material for constructing the chamber holds paramount importance. Corrosion resistance not only guarantees the system's longevity and durability but also safeguards the chamber from degradation caused by moisture and other environmental factors. Opting for locally available materials additionally contributes to cost-effectiveness, a crucial aspect of equipment design.

b) **Use of R134A Refrigerant:** The choice of refrigerant plays a pivotal role in designing refrigeration systems. R134A stands out for its recognized safety both for human consumption and the environment. Its economic feasibility and reliability make it an apt selection for cooling applications. Moreover, the simplicity of handling R134A offers the advantage of reducing the complexity of system maintenance and operation.

c) **Choice of Sample Product:** Deliberate selection of ripe and undamaged sample products significantly enhances the freeze-drying process. The quality and condition of the initial product wield substantial influence over the process's final outcome. Utilizing ripe and unblemished samples ensures the freeze-dried end product accurately mirrors the intended qualities and characteristics.

2.2.1 Design Calculation

Assumptions made in the design of the freeze dryer are as follows:

a.) One-dimensional heat transfer and mass flow were assumed, which occur normally to the interface and surface of the product.

b.) The thickness of the interface was assumed to be infinitesimal.

c.) The freeze-dried products were assumed to be of the same size and shape, meaning they were homogeneous.

d.) The frozen region was assumed to be homogeneous as well, characterized by uniform thermal conductivity, density, and specific heat. Additionally, it was assumed to contain a negligible proportion of dissolved gases.

e.) Heat transfer was assumed to occur at a constant temperature.

2.3 Description of the Freeze DryerSystem

The freeze-dryer designed within the scope of this study has a capacity of 15 kg, making it highly suitable for freeze-drying fresh fruits and vegetables. Its construction involves carefully selected components to ensure optimal performance and effectiveness.

A key component is a galvanized metal plate of 0.8 mm thick, measuring 330.2 mm x 508 mm x 457.2 mm. This plate forms the base of the rectangular chamber, designed to hold a total storage volume of 0.0194 m^3. To enhance insulation, the chamber interior is lined with a 25.4 mm layer of fiber material. This insulation helps regulate temperature and enhance operational efficiency.

To support the chamber's structural integrity, a hollow square pipe made of mild steel, measuring 1/8 inch square gauge (1.7 mm by 1.7 mm), is incorporated. This reinforcement is strategically placed to prevent implosion during the vacuuming process, ensuring the freeze dryer's safety and longevity.

For heat management during operation, a cooling fan is integrated with a capacity of 0.5 Amperes, 220 Volts, and 5 Watts. This fan performs a dual role, maintaining optimal operating temperatures for both the compressor and the condenser.

The chamber layout features four evaporator trays positioned above the product trays. These trays are serviced by evaporator coils spanning a total length of 7719.2 mm. Particularly, a 2000 mm expansion valve is installed to regulate refrigerant flow throughout the system. The compressor, supporting a robust capacity of 110 Watts, is responsible for the vital refrigeration process. Concurrently, the condenser, measuring 210 inches (53.4 mm) in length, is equipped with fins to enhance heat dissipation efficiency.

The operational procedures of the freeze-dryer revolve around the fundamental freeze-drying principle. Initially, the product undergoes freezing at temperatures below 0°C. Subsequently, the sublimation process begins, aided by a vacuum mechanism controlled by a fixed pressure gauge. An electric motor powers the vacuum pump, while controlled heat application at the start of the drying phase stimulates the dehydration process, further enhancing operational effectiveness.

For visual reference, Plate 1 offers a comprehensive side-view depiction of the fabricated freeze-dryer, providing insight into its structural configuration and design elements.

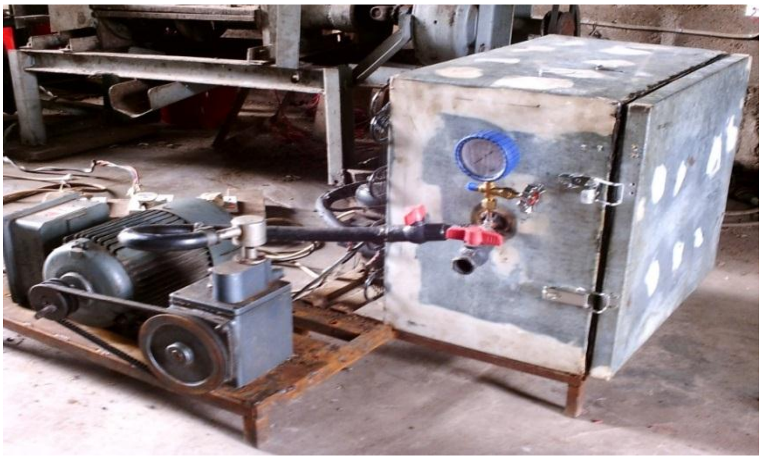

Plate 1: Illustration of The freeze dryer System

The design procedure and the system development

The freeze-dryer consists of three primary units: the Cooling Unit, the Dehydrating Unit, and the Heating Unit.

The chamber design

The calculation to show the range of cooling efficiency of two sample fruits with higher and lowerspecific gravity to know the size of compressor suitable for this design is as calculated as follows

Plate 2: Evaporator Coil laid under its tray with 9inches spacing

Rate of intake:

To achieve complete freeze-drying within an 8-hour working day period at a temperature of -20°C, a specific heat of 0.9 kcal/kg/°C is necessary for a product harvested at an initial temperature of 27°C. It's important to note that the freezing temperature range during the freeze-drying process falls between -5°C to -45°C.

Rate of intake= $\frac{M \, x \, T \, x \, C_a}{8 \, hrs}$x 2 (1)

M is the capacity of the chamber (15*kg*)

T is the temperature of the product from harvest (27^{o}C)

C is the specific heat capacity of the product (0.9kcal/kg/^{o}C)

Factor **2,**is a factor of safety.

$$= \frac{15 \times 27 \times 0.9}{8} \times 2$$
$$= \frac{729}{8} kcal/hrs$$
$$= 91.125 \; kcal/hrs$$

where 4.186kJ = 1 *kcal*

This now implies that, 381.449*kJ*/hrs= 105.9719J/s = 105.9719*Watt.* A 110-watt power-rated compressor will be chosen for this design instead.

Infiltration of External Air:

The ambient temperature is usually between 21^{o}C to 37^{o}C. Using an average temperature of 32^{o}C, relative humidity of 70%, and vapor pressure of -33.76*mbars*, being the vapor pressure of the environment

From the psychrometric chart, enthalpy (ΔH) in cooling the product to a temperature of 32^{O}C; H = 86.5kJ/kg = 20.7 *kcal*. 32^{o}C is the assumed atmospheric temperature of the surroundings where the freeze dryer will be placed.

Product Cooling: The total amount of sensible and latent heat to be removed in cooling a product is given by: where

$H = M\,[(C_a \times \Delta T_a) + h_l + (C_b \times \Delta T_b)]$ (2)

H - Total quantity of heat

M - Mass of product (*kg*) = 15 *kg*

C_a - Specific heat capacity above freezing point (for apple fruit)= 3.65kJ/kg^{o}C

C_b - Specific heat capacity below freezing point (for apple fruit)= 1.89 kJ/kg^{o}C

h_l - Latent heat of freezing = 280 kJ/kg

ΔT_a- Temperature decrease above freezing point= 32^{o}C

ΔT_b - Temperature decrease below freezing point= Let x represent this temperature.

Now, computing the values in the equation, we have:

H = 15[(3.65×32) + 280 + (1.89× x)] = 1752 + 27xkCal.

The celery fruit: was calculated asfollows(being the fruit with the highest specific heat capacity)

We have; $H = M\,[(C_a \times \Delta T_a) + h_l + (C_b \times \Delta T_b)]$

Where; H, M, C_a**,** $\Delta T_{a,}$ $h_{l,}$ $C_{b,}$ ΔT_b are definedas

C_a = 3.99 kJ/kg^{o}C

C_b = 0^{o}C

$\Delta T_{a,}$= 32^{o}C

$h_{l,}$ = 0 kJ/kg

$\Delta Ta = x^oC$
$H = 15[(3.99\times32) + 0 + (0\times x)] = 1915.2kJ$
The dairy products: are calculated thus (i.e. milk);
We have; $H = M[(C_a \times \Delta T_a) + h_l + (C_b \times \Delta T_b)]$
Where C_a is 3.75 kJ/kg^{o}C, C_b is 0^oC, $\Delta T_{a,} = 32^oC$, $h_{l,}$ is 0 kJ/kg and ΔTa is x^oC
$H = 15[(3.75\times32) + 0 + (0\times x)] = 1800kJ$
Meat products, bacon: are calculated thus;
We have; $H = M[(C_a \times \Delta T_a) + h_l + (C_b \times \Delta T_b)]$
$C_a = 1.5$ kJ/kg^{o}C,
$C_b = 1.07^oC$
$\Delta T_{a,} = 32^oC$
$h_{l,} = 64$ kJ/kg
$\Delta Ta = x^oC$
$H = 15[(1.5\times32) + 64 + (1.07\times x)]$
$H = 15[48+64+1.07x]$
$H = 1680 + 16.05x$ kJ
Where 'x' is the temperature to be determined inside the freeze-dryer.

Table 1: Values of energy for different product

Product	Amount of energy (kJ)
Apple	1752 + 27x
Celery	1915.2
Dairy (Milk)	1800
Meat, Bacon	1680+ 16.05x

From Table 2, the product with the highest amount of energy (i.e. Celery), 1915.2 kJ will be required by the evaporator to cool the product.
Specific Heat, $C_p = Q/m\Delta T$ (3)
C_p is the specific heat (kJ/kg^{o}C)
Q is the heat gained or lost from/to the environment (kJ)
M is the mass of the product (kg)
ΔT is the temperature difference between the ambient environment and the chamber (^{o}C). Specific heat is an essential part of the thermal analysis of food processing or the equipment used in heating or cooling products. It is a function of the moisture content, temperature, and pressure of the product being dried. Siebel (1892) gave the specific heat capacity of the product as:
$C_p=0.837+3.349X_w$ and
Charm (1978) gave $C_p = 2.093X_f + 1.256 X_s + 4.187 X_w$(4)
where:
X_w is the water content of the product (in fractions)
X_f is the fat content of the product (in fractions)
X_s is the solid content of the product (in fractions)
From Table 2 in the appendix, the water content (X_w) of fruits is between 87 to 95%. Now substituting the value of $X_w = 0.95$into Siebel equation ($\frac{95}{100}$);
We have $C_p = 0.837+3.349X_w$. Note that the highest water content (95%= 0.95) will be used for this design so that if a product with lesser water content is to be used in the future, the design will be able to perform the expected function compared to when the product of lower water content is chosen for the design.
Therefore,$C_p = 0.837+3.349\ (0.95)$
$= 0.837+ 3.18155$
$C_p = 4.01855$ kJ/kg^{0}C.
This implies that, the material of construction for the design should be of good thermal conductivity and that 4.01855kJ of energy will be required to remove every 1 kg mass of iced product by the condenser.
Heat gained or lost, $Q = C_p m\Delta T$.
Q =?
$C_p = 4.01855$ kJ/kg^{0}C b
m = 15kg

ΔT = 32-(x) = (32-x)^{0}C
This now implies, Q = 4.018855×15×(32-x) = kCal
This represents the heat gained or released to the environment by the evaporator.
where 'x' is as described above.
Conduction heat transfer: Thisrefers to the heat that flows through cold store surfaces, pipe insulation, and similar mediums. In many cases, this type of heat transfer is considered to remain constant.
Convective Heat Transfer:This occurs when air enters from outside mainly during the opening of the door for the passage of product to be dried. The parameters include; the size of the chamber and, the change in enthalpy between inside and outside air. The latter is affected by the existence of airlocks. It is usually given mathematically as:
Internal heat sources: The main sources here are the fan, motor, and circulating pumps.
Heat of respiration: The heat of respiration pertains to agricultural products, which are hygroscopic and essentially living organisms. These types of products gradually utilize their sugar or starch reserves, they emit heat. The heat of respiration varies based on factors such as the product's sugar content, variety, and temperature. Generally, this heat value falls within the range of 9 to 120 watts per ton (W/t). These values are often documented in tables for reference.
Compressor:A compressor is typically rated under saturated conditions at the suction. In the case of dry expansion systems, compressors might be rated at a specific level of superheating. However, in practice, there are instances where pressure drop and heat gain in the suction line are often overlooked or not fully considered.
Evaporator:The rating of an evaporator is typically linked to the temperature difference between the refrigerant and the cooled medium. In the context of designing the vacuum chamber, it's assumed that the chamber holds a pressure of 2 mmHg, which is intended to be extracted by a vacuum pump to initiate the drying process. To prevent the risk of the chamber collapsing inward due to external pressure surpassing internal pressure, it becomes necessary to reinforce the chamber. This reinforcement ensures the chamber's ability to withstand implosion during the commencement of the freeze-drying process.
From: 2mmHg = 266.6N/ mm^2
Pressure, P = F/A (5)
F = Force (N)
A = Area (m^2) = 0.0721m^2
We have: Force, F = Pressure (P) × Area (A)
Force = 266.6 ×0.072087456m^2 = 19.21851577 Newton
This implies that deflection, δ_c for uniformly distributed load $=\frac{5WL^3}{384EI}$(6)
W = Total Load (Newton, N) = wL
E = Modulus of Elasticity, 205,000N/mm^2 for stainless steel
L = Span of the chamber (0.268491074 m)
I = Moment of Inertia (m^4) = bd^3/12 (7)
b is the breadth of the chamber (=0.268491074m)
d is the depth of the chamber (=0.268491074m)
Moment of Inertia, I = $\frac{bd^3}{12}mm^4$
I = $\frac{0.268491074 \ \times 0.268491074}{12}$ = $4.330501192\times 10^{-4}\ m^3$
Therefore, by substituting W=wL;

The deflection, $\delta_c$can be written as:
$\delta_c = \frac{5\times(19.21851577 \text{ x } 0.268491074\ )\times 0.268491074^3}{384\times 205{,}000\times 4.330501192\times 10^{-4}}$= 1.464825897 x 10^{-5} m.
From this calculation, the design will be safe if the calculated deflection,$\delta_c\leq$. This now implies:
1.464825897 x 10^{-5} $m \leq \frac{0.268491074}{360}$
Therefore, since δ_c=1.464825897 x 10^{-5} $m\leq$ 7.458085389 x10^{-4} m, the design is safe from deflection.
To calculate the Bending Moment; M_B = Where W and L are as described above.
$M_B = \frac{19.21851577x\ 0.268491074\times 0.268491074}{8}$ = 0.17317674 Nm
Now, Bending Stress = $\frac{\text{BM}}{\text{MI}}$ (8)
BM = Bending Moment
MI = Moment of Inertia
$=\frac{0.17317674}{4.330501192\times 10^{-4}}$
M_B =399.8999938 N/m^3

2.4 Experimental Methods

The study involved three distinct fruits that were carefully selected to ensure they were free from any bruising. Before being transformed into pulp, these fruits were thoroughly washed to ensure their cleanliness. The initial sample underwent peeling, while the second sample had its seeds removed. Subsequently, all three fruits were individually ground in a household-type blender. Each sample was assigned an identification based on its color.In order to prevent corrosion and contamination of the samples, stainless steel material was utilized for loading the samples into the chamber. To maintain consistency and accuracy, three identical containers were employed to prepare equally sized samples for each of the fruits. These samples were visually documented and are displayed in Plates 3a, 3b, and 3c, respectively.



Plate3a: Mango Puree Plate 3b: Pear Puree Plate 3c: Tomato Puree

The physical and mechanical characteristics measured include the weight of the sample, before and after freeze drying, and the moisture content of each of the samples.
The individual weight of the samples was measured using an electronic precision balance whose reading is to one decimal point (TL-5000 model, Japan).The moisture content of the samples was determined before the freeze drying to determine the initial MC. This was done by the Oven-Dry method of moisture content determination as specified in the ASAE standard ASAE, (1986**).** Thesample was weighed before the commencement of the experiment and recorded as the "wet weight of the sample", dried to a constant weight at a temperature of not greater than 103^{o}C, and recorded as the "dry weight of the sample".
The moisture contentwas then calculated using the equation;

$$\%W = \frac{Ww - Wd}{Wd} \times 100 \; .$$

W= percentage of moisture in the sample,
Ww= weight of wet sample (grams),
$Weight$ of dry sample (grams).
The computed moisture content of the sample was calculated as:
Weight of Wet Sample, W_w = 95 kg
Weight of Dry Sample, W_d = 77 kg
Percentage of Moisture Content, %M.C. = $\frac{Ww - Wd}{Wd} \times 100$
%M.C. = $\frac{95-77}{77} \times 100 = 23.38\ \%$

2.5 Performance Evaluation of the Lyophilizer

Tests were carried out to ascertain the performance of the freeze dryer. The evaluation was based on the effects of properties such as dry bulb temperature, dew point temperature, and relative humidity of the environment within the chamber of the samples used for the experiment. This was determined by the use of a USB data recorder which was placed on one of the evaporator trays inside the chamber. The temperature measurement ranges between -35^{o}C to 80^{o}Cand relative humidity of 0 to 100% of ±0.5^{o}C and ±3.0% temperature and relative humidity accuracy respectively.

III. Results and Discussion

3.1 Behavioral Characteristics of the Sample Used

The conditions within the dryer for the variation of dry bulb temperature, dew point temperature, and relative humidity for the freeze-drying process are shown graphically in Figure 1. Temperature and dew point temperature are given in degrees centigrade (^{o}C), while the relative humidity is given in percentage (%).

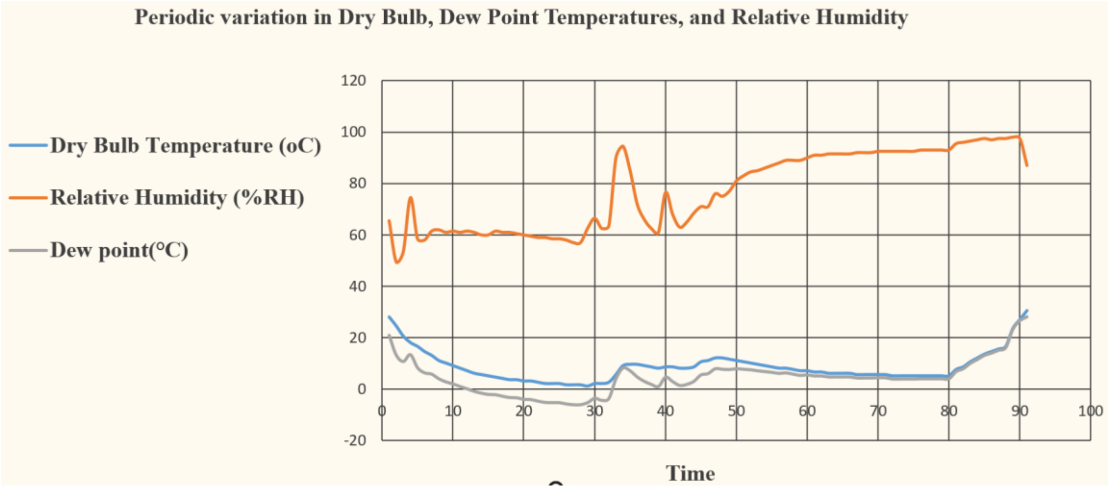

Figure 1: Periodic variation inDry Bulb, Dew Point Temperatures, and Relative Humidity

3.1.1 Dry Bulb Temperature

The result shown in Figure 2 is for the dry bulb temperature during freeze drying process. The temperature at the commencement of cooling was obtained to be 28^{o}C, gradually decreasing and tending towards zero as cooling progressed with the product physically observed to be frozen. This means the product attained a frozen state between 2^{o}C and 0^{o}C. However, this is different from what (Rao, *et al.*, 2005) stated, that the frozen state of a product other than water is below 0^{o}C since it contains percentages of other solid content while that of water is 0^{o}C since water is a pure substance. Therefore, the result shows that the freeze-dried sample attained a frozen state atbelow 0^{o}C.

The dehydrationprocess commenced immediately after the cooling stage of the product withthe use of a vacuum pump to reduce the air pressure and water vapor within the chamber environment for sublimation to take place. This act of pressure reduction makes the vapor pressure in the system below that of the product in the chamber, which makes drying take place since there is an exchange of heat between the system and the product. This shows from the result that, the temperature within the system increases from 0^{o}C to 9.5^{o}Cin the first 30 minutes of vacuuming. Thereafter, after about 30 minutes of the first vacuuming, the temperature dropped from 9.5^{o}Cto 8^{o}Cand later rose to 11.5^{o}C. This continued till the end of the freeze drying when a temperature of 30.5^{C}was finally recorded. This indicated that the sublimation process took place with a pressure of 100 mmHg recorded. This took a total of 4 hours before this temperature was attained.

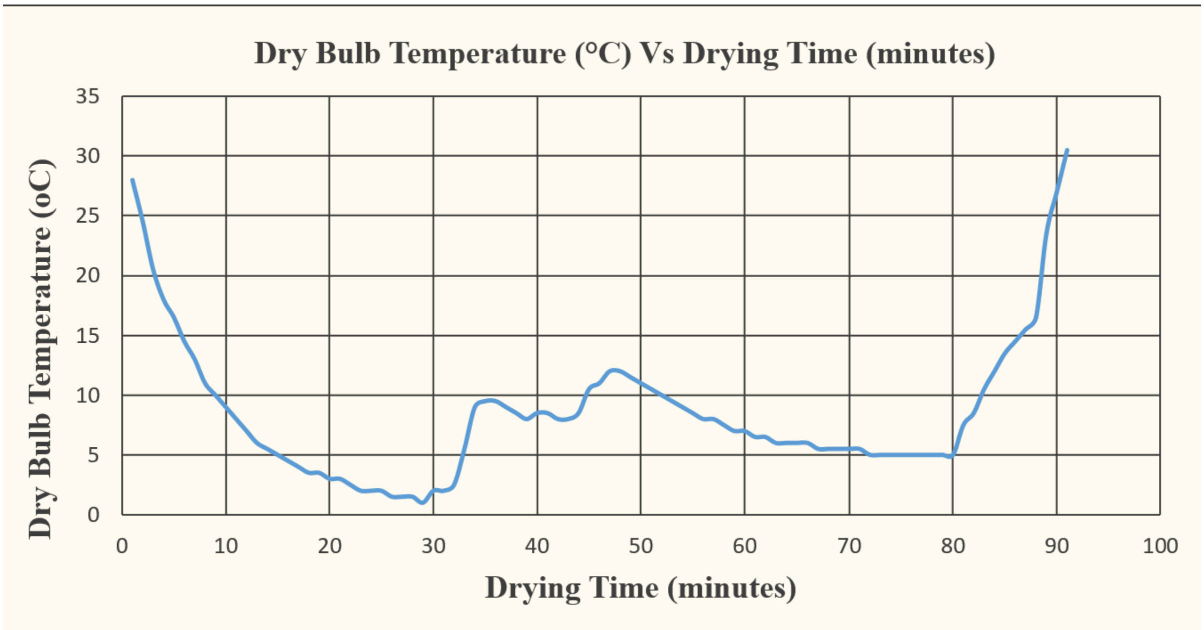

Fig 2: Periodic variation of Temperature (^{o}C) against Time (min) for tomato puree

3.1.2 Relative Humidity

It can be deduced from the result shown in Figure 3 that, the relative humidity within the system at the commencement of freeze drying was obtained as 79%, progressively increasing towards 100% and a final value of below 87% was recorded at the end of the process. The increment in value might be due to the cooling (frozen state) that the product had attained, while the fall in value was due tothe dehydration process. This indicates that the vapor pressure within the chamber tends to be below that of the product that is being dry. Meanwhile, this corresponds to the theory of Lide (1999), which states that the rate of drying is dependent on the extent to which the pressure in the chamber is below the vapor pressure of ice.

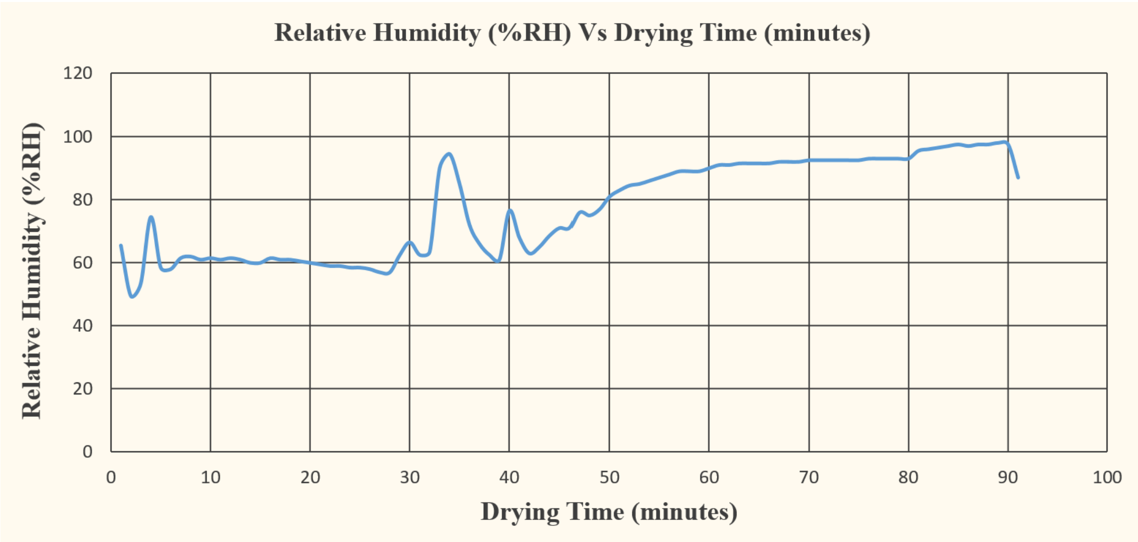

Fig 3: Periodic variation of Relative humidity (%RH) against Drying Time for tomato puree

3.1.3 Dew Point Temperature

The result for dew point temperature is presented in Figure 4. It can be inferred from the result that, 20.8^{o}C temperature was recorded at the commencement of cooling. This temperature gradually decreases as cooling progresses, when the product attainsa frozen state. A value of -6.5^{0}C was finally recorded at the end of the cooling stage (i.e. after about 2 hours). As the dehydration process progresses, it was observed that the dew point temperature gradually increases from -6.1 ^{o}C to 28.1 ^{o}C. This shows that there was condensation of the product during dehydration.

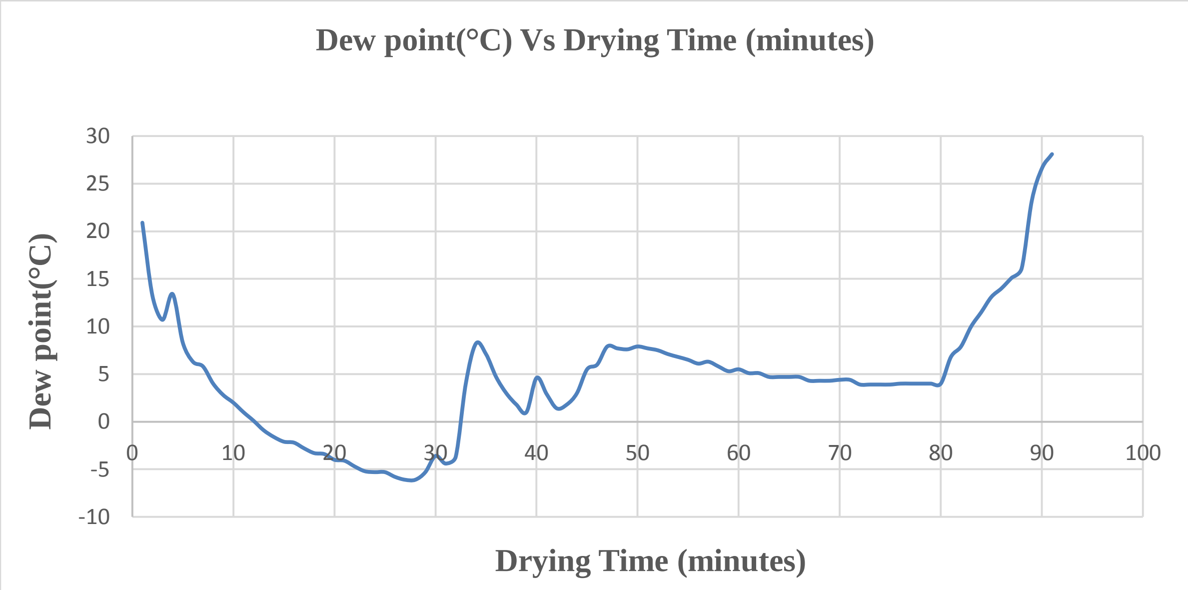

Fig 4: Periodic variation of Dew Point Temperature (°C) against Drying Time (min) for Tomato puree

IV. CONCLUSIONS

The results derived from this study on freeze drying offer significant insights. Notably, a direct correlation was observed between the cooling temperature and the dew point temperature. As the cooling temperature decreases, a corresponding decrease is observed in the dew point temperature. Furthermore, it was observed that an increase in the rate of cooling results in a decrease in the cooling temperature. This relationship suggests an inverse proportionality between the cooling temperature and the duration of cooling. Consequently, prolonged freezing times yield lower temperatures.

In the experimental phase, a total of 6 hours was used to dry the test sample utilized for the freeze-drying trial. The designed and fabricated freeze dryer demonstrated its user-friendly nature and ease of maintenance. Leveraging locally sourced materials for the construction of the freeze dryer proved cost-effective and accessible, underscoring the potential for affordability among small-scale food processors and household users.

In summary, freeze-drying not only facilitates the conversion of food into storable formats but also upholds the nutritional integrity of these products. This preservation method holds significant promise for curtailing post-harvest losses and bolstering food security. The research outlined in this study is centered on the development and creation of an adapted freeze-drying system, tailored to local contexts. This endeavor addresses pressing challenges within the agricultural sector and contributes to food security and safety.

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REFERENCES

[1]. Beals J. M., M. J. Edwards, M. J. Pikal, and J. V. Rinella, Jr.(1997). Formulations of obesity protein, Europian Pat. Appl. (Eli Lilly and Co., USA). EP, 1997, pp. 48

[2]. Bello, R.O., Raji A.O. and Oyefeso B.O.(2017). Design and construction of a lyophilizer system using locally available material. Proceedings of 18th Annual General Meeting of the Nigerian Institution of Agricultural Engineers (NIAE), Umudike, 2017.

[3]. FAO. 1995. Small-scale Post-harvest Handling Practices -A Manual for Horticulture Crops. 3rd edition. Series No. 8.

[4]. Franks F. Freeze drying: from empiricism to predictability (1990). CryoLetters 11:93–110.

[5]. International Trade Administration (ITA), 2022. https://www.trade.gov/country-commercial-guides/nigeria-market-overview. Assessed 8/7/2023

[6]. Ndukwu, Macmanus Chinenye (2011). Development of Clay Evaporative Cooler for Fruits and

[7]. Vegetable Preservation. Agricultural Engineering International: CIGR Journal. Manuscript No.1781. Vol. 13, No.1

[8]. NCHFP Resource (2017) National Center for Home Food Preservation. https://www.extension.usu.edu/foodpreservation/htm/vacuum
[9]. Olosunde William Adebisi ; J.C. Igbeka and Taiwo Olufemi Olurin (2009). Performance Evaluation of absorbent materials in an Evaporative Cooling System for the Storage of Fruits and Vegetables. International Journal of Food Engineering Volume 5, Issue 3
[10]. Pikal, M. J. (1990). Freeze-drying of proteins. Part I: Process design. BioPharm **3**:18–28 (1990).
[11]. Rao M.A., Syed S.H. and Rizvi Ashim K. Datta,2005. Engineering Properties of Foods. Third edition. Pg 149, 153-155.
[12]. Shewfelt, R. 1994. Quality characteristics of fruits and vegetables.
[13]. Soham S. (2011). Freeze Drying Process: A Review. International Journal of Pharmaceutical Sciences and Research Vol. 2(12):3061-3068.
[14]. Xiaolin Charlie Tang and Michael J. Pikal (2004). Design of Freeze-Drying Processes for Pharmaceuticals: Practical Advice. Pharmaceutical Research, Vol. 21, No. 2, February 2004.

Appendices

Appendix A1

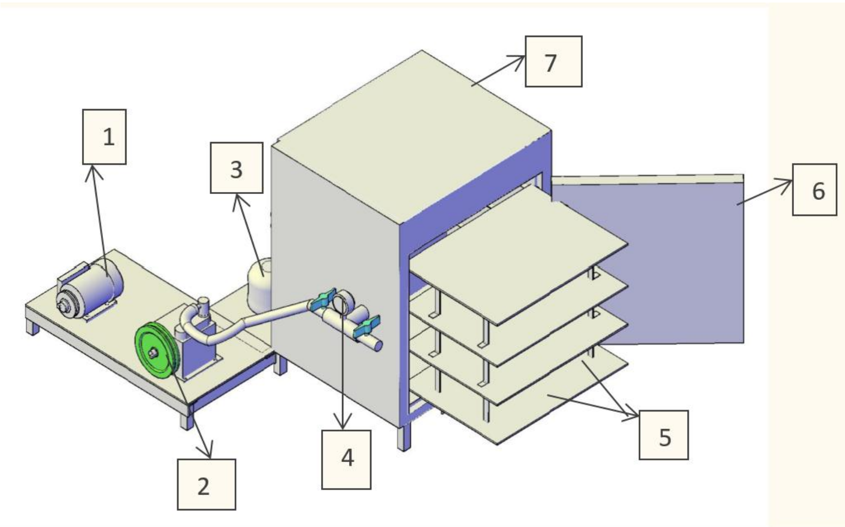
Table A1: Parameters for Testing in a Freeze Dryer

Time (minutes)	Dew Point Temperature (°C)	Relative Humidity (%RH)	Dry Bulb Temperature (^{o}C)
13/02/2014 08:10:00	20.9	65.5	28
13/02/2014 08:15:00	13.2	49.5	24.5
13/02/2014 08:20:00	10.7	53.5	20.5
13/02/2014 08:25:00	13.4	74.5	18
13/02/2014 08:30:00	8.3	58.5	16.5
13/02/2014 08:35:00	6.3	58	14.5
13/02/2014 08:40:00	5.8	61.5	13
13/02/2014 08:45:00	4	62	11
13/02/2014 08:50:00	2.8	61	10
13/02/2014 08:55:00	2	61.5	9
13/02/2014 09:00:00	1	61	8
13/02/2014 09:05:00	0.1	61.5	7
13/02/2014 09:10:00	-0.9	61	6
13/02/2014 09:15:00	-1.6	60	5.5
13/02/2014 09:20:00	-2.1	60	5
13/02/2014 09:25:00	-2.2	61.5	4.5
13/02/2014 09:30:00	-2.8	61	4
13/02/2014 09:35:00	-3.3	61	3.5
13/02/2014 09:40:00	-3.4	60.5	3.5
13/02/2014 09:45:00	-4	60	3
13/02/2014 09:50:00	-4.1	59.5	3
13/02/2014 09:55:00	-4.7	59	2.5
13/02/2014 10:00:00	-5.2	59	2
13/02/2014 10:05:00	-5.3	58.5	2
13/02/2014 10:10:00	-5.3	58.5	2
13/02/2014 10:15:00	-5.8	58	1.5
13/02/2014 10:20:00	-6.1	57	1.5
13/02/2014 10:25:00	-6.1	57	1.5
13/02/2014 10:30:00	-5.3	62.5	1

13/02/2014 10:35:00	-3.6	66.5	2
13/02/2014 10:40:00	-4.4	62.5	2
13/02/2014 10:45:00	-3.7	63.5	2.5
13/02/2014 10:50:00	4	90	5.5
13/02/2014 10:55:00	8.2	94.5	9
13/02/2014 11:00:00	7.1	85	9.5
13/02/2014 11:05:00	4.7	72	9.5
13/02/2014 11:10:00	3	66	9
13/02/2014 11:15:00	1.8	62.5	8.5
13/02/2014 11:20:00	1	61	8
13/02/2014 11:25:00	4.6	76.5	8.5
13/02/2014 11:30:00	2.9	68	8.5
13/02/2014 11:35:00	1.4	63	8
13/02/2014 11:40:00	1.8	65	8
13/02/2014 11:45:00	3	68.5	8.5
13/02/2014 11:50:00	5.5	71	10.5
13/02/2014 11:55:00	6	71	11
13/02/2014 12:00:00	7.9	76	12
13/02/2014 12:05:00	7.7	75	12
13/02/2014 12:10:00	7.6	77	11.5
13/02/2014 12:15:00	7.9	81	11
13/02/2014 12:20:00	7.7	83	10.5
13/02/2014 12:25:00	7.5	84.5	10
13/02/2014 12:30:00	7.1	85	9.5
13/02/2014 12:35:00	6.8	86	9
13/02/2014 12:40:00	6.5	87	8.5
13/02/2014 12:45:00	6.1	88	8
13/02/2014 12:50:00	6.3	89	8
13/02/2014 12:55:00	5.8	89	7.5
13/02/2014 13:00:00	5.3	89	7
13/02/2014 13:05:00	5.5	90	7
13/02/2014 13:10:00	5.1	91	6.5
13/02/2014 13:15:00	5.1	91	6.5
13/02/2014 13:20:00	4.7	91.5	6
13/02/2014 13:25:00	4.7	91.5	6
13/02/2014 13:30:00	4.7	91.5	6
13/02/2014 13:35:00	4.7	91.5	6
13/02/2014 13:40:00	4.3	92	5.5
13/02/2014 13:45:00	4.3	92	5.5
13/02/2014 13:50:00	4.3	92	5.5
13/02/2014 13:55:00	4.4	92.5	5.5
13/02/2014 14:00:00	4.4	92.5	5.5
13/02/2014 14:05:00	3.9	92.5	5
13/02/2014 14:10:00	3.9	92.5	5

13/02/2014 14:15:00	3.9	92.5	5
13/02/2014 14:20:00	3.9	92.5	5
13/02/2014 14:25:00	4	93	5
13/02/2014 14:30:00	4	93	5
13/02/2014 14:35:00	4	93	5
13/02/2014 14:40:00	4	93	5
13/02/2014 14:45:00	4	93	5
13/02/2014 14:50:00	6.8	95.5	7.5
13/02/2014 14:55:00	7.9	96	8.5
13/02/2014 15:00:00	10	96.5	10.5
13/02/2014 15:05:00	11.5	97	12
13/02/2014 15:10:00	13.1	97.5	13.5
13/02/2014 15:15:00	14	97	14.5
13/02/2014 15:20:00	15.1	97.5	15.5
13/02/2014 15:25:00	16.1	97.5	16.5
13/02/2014 15:30:00	23.2	98	23.5
13/02/2014 15:35:00	26.6	97.5	27
13/02/2014 15:40:00	28.1	87	30.5

Appendix A2



S/N	Component Part	Quantity	Type of material
7	Vacuum Chamber	1	Galvanized Plate
6	Chamber Door	1	Galvanized Plate
5	Evaporator Trays	4	Galvanized Plate
4	Pressure Gauge	1	
3	Compressor	1	Mild Steel
2	Vacuum Pump	1	
1	Electric Motor	1	
Figure	The Vacuum chamber showing the Component Parts of the Freeze Dryer		