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Development of a Hybrid Thermal Processing Unit for *Nono* (Local Raw Cow Milk) and Thermal Resistance Analysis of Aerobic Plate Count

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Abstract

Despite the health benefits of *nono* (Hausa) (row cow milk) for healthy living, its consumption poses a great health concern to its consumers. This could be due to its widespread exposure to microbial contamination through its processing and handling operations. A hybrid food thermal processing unit was developed to thermally process this product. The equipment is made up of the following components: a boiler, furnace, heaters, water reservoir, and sterilization chamber. The equipment used to thermally process nono processed locally was thermally processed for 0, 15, 30, 45, and 60 minutes at a heating temperature of 100, 105, 110, 115, and 120 ºC, respectively, to find the values of D and Z. The results revealed that the highest value of total aerobic plate count of 5.0 log10 cfu/ml obtained from the sample was greater than the maximum recommended allowed value of 4.6 log10 cfu/ml by SON. Generally, the rate of microbial survival decreases as there is a rise in temperature and heating. The D values of 25 minutes, 23.8 minutes, 21.5 minutes, 20.28 minutes, and 19.53 minutes were obtained at sterilization temperatures of 100, 102, 104, 106, and 108°C, respectively. The estimated D values were used to get the equivalent Z value, which was 70.4 °C. The development of this equipment will increase food safety by removing, killing, and eliminating microorganisms from the products. Because it can be used for both liquid and solid food products, it will increase utilization.

Keywords

Bacteria; Contamination; Hybrid; *Nono*; Thermal Processing

1. Introduction

A *Nono* (Hausa), or raw cow milk, is a milk product. It is made locally and consumed in Nigeria and other African nations. It results from the spontaneous fermentation of fresh, raw, unskimmed milk after starter culture is added. The milk extraction procedure, nono production, and marketing are done under unhygienic conditions using inappropriate equipment [1]. It has been reported to be extensively contaminated with microorganisms due to the egregiously filthy techniques of its processing and handling. Microbial contamination during milk production often comes from three main places: the surface of the equipment used to handle and store milk, as well as the inner and outer surfaces of the udder. The amount of time and temperature spent in storage are equally crucial because they promote microbial contamination growth. The microorganisms contain in raw milk will both be influenced by all of these variables. According to [2], microbial contamination lowers the quality of cow's milk, endangering human

health. Moreover, *nono* doesn't really undergo any further processing to protect against pathogenic organisms, so customers run the risk of contracting milk-borne pathogens [3, 4]. In *nono* products, [5] found that the minimum values of coliform and TAPC were above the acceptable requirement, indicating a significant level of contamination with coliforms and other bacteria. Therefore, drinking raw milk should be avoided. The milk must be heated to 72°C (162°F) for a minimum of 15 seconds or 63°C (150°F) for at least 30 minutes [6]. According to [7], the psychrotrophic bacteria are usually linked to modifications in milk. The majority of them are destroyed during pasteurization, but others, such as Pseudomonas fragi and florescens, survive. There is a need to subject the *nono* to heat treatment, such as sterilization. Hence, designing a system that will thermally process by penetrating the product with heat and a system that is simple to install, has reasonable operating costs, is nontoxic, and is safe for the environment is essential. More significantly, however, is a system that will kill more bacteria than pasteurization alone. This presentation's goal is the development of a *nono* (raw cow milk) hybrid thermally processing unit and the determination of d and z values of a locally thermally processed cow's milk total aerobic plate count.

2. Methods

2.1 Machine Description

The following parts were included in the equipment:

i. Water Reservoir: Sheets of stainless steel were used to make this. Its diameter was 390 mm while the height was 260 mm. To enable water discharge into either the boiler or the copper tube for cooling of the product, a valve was installed on the reservoir's bottom side. It is shown in Figures 1 and 2.

ii. Sterilization Chamber: This was made up of stainless sheet, with the outer and inner walls being 0.460 m and 0.450 m in diameter, and each being 0.300 m high. From the bottom of the drums, a 20-mm-diameter hole was made, and a host pipe was fixed. This serves as an outlet for the outflow of liquid, including water, during the cleaning operation of the equipment. It is shown in Figures 1 and 2.

iii. Boiler: Sheets of stainless steel were used to make it. Its dimensions for the inner drum of the boiler were 0.2 m in diameter, 0.56 m in height, and 0.002 m in thickness. The boiler's outer drum has the following dimensions: 0.250 and 0.456 m for diameter and height, respectively, and a thickness of 0.002 m. It has a hole of 20 mm in diameter on its base where a host pipe is fixed. This serves as an outlet for the outflow of liquid and also water during the cleaning operation of the equipment. It is shown in Figures 1 and 2.

iv. Heaters: This is a 2 kw heater; it was installed on the water boiler.

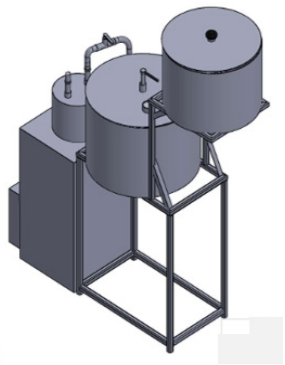

Figure 1. AutoCAD Drawing of the Hybrid Thermally Processing Unit.

Figure 2. The Developed Hybrid Thermal Processing Unit.

2.2 Design Analysis of Equipment Components

2.2.1 Design of the Thermal Processing Unit Chamber

Twenty litres of raw *nono* milk were to be processed per batch, and the dimension of the chamber was determined as reported by [8, 9] and are given as

$$M_s = \rho_n \times V_n \tag{1}$$

$$V_n = \frac{M_n}{\rho_n} \tag{2}$$

Where M_s is the mass of the *nono* (kg), V_n is the quantity of the *nono* to be treated in each batch (m^3), ρ_n is the density of raw *nono* (kg/m^3),

The dimension of the sterilization chamber was obtained by considering the diameter of the chamber as 0.35m; the density of raw *nono* is 960kg (m^3) as reported by [1], [10].

$$h_s = \frac{M_n}{\rho_n \times \pi r_s^2} \tag{3}$$

Where h_s and r_s are the height and radius of the drum, respectively.

2.2.2 Determination of Wall Thickness

As reported by [9, 10], the highest stress that can be created in the shell for a given pressure shouldn't be more than the material's maximum allowable tensile stress.

But

$$\delta_c = 2\delta L \tag{4}$$

δ_c is not to exceed δ_t. therefore, $\delta_c \leq \delta_t$

Working stresses for thin cylinders range from 5 MN/m^2 to 30MN/m^2.

$$\delta_c = \frac{Pr}{t} \tag{5}$$

$$t = \frac{Pr}{\delta_c} \tag{6}$$

Where, δ_c is the stress on the working cylinder, P is the pressure, r and t are the radius and thickness of the cylinder, respectively (m).

2.2.3 Determination of the Boiler Dimension

If the volume of water in the boiler is 2L, then the total value of the boiler should be 3L in order to allow for steam expansion. That is

Volume of water = 2L

Then L should be added for expansion of system.

$$V_{Tb} = V_w + V_c \tag{7}$$

$$V_{Tb} = 2L + L \tag{8}$$

Where V_{Tb} is from total volume of the boiler (m^3), V_w is the volume of water (m^3), V_c is the clearer for expansion, L is the litre of water by substring the volume

2.2.4 Heat Transfer

The heat transfer by conduction was determined as reported by [11], [12] and is given as

$$Q = -k\left(\frac{T_2 - T_1}{d_x}\right) \tag{9}$$

Where Q is the heat transfer, k is the thermal conductivity of stainless steel (w/m.k), T_1 is the initial temperature (°C), T_2 is the final temperature (0C), d_x is the change in thickness of material (m).

2.2.5 Heat Required to Increase the Water's Temperature

According to [11], the findings, the heat required to increase the water's temperature was calculated as

$$Q_1 = MC\Delta T \tag{10}$$

Where Q_1 is the heat required to increase the water's temperature to 100℃ (kj/kg/0c), M is the mass of water (kg), C is the specific heat capacity of water (kT/kg), ΔT is the temperature difference.

2.2.6 Determination of Latent Heat of Vaporization

The latent heat of evaporation of water was calculated as follows:

$$Q_2 = ML_h \tag{11}$$

Where Q_2 is the heat needed for vaporization of water (kj/kg), L_h is latent heat of vaporization of water (kj/kg), and M is mass of water kg.

$$Q_T = Q_1 + Q_2 \tag{12}$$

Where Q_T is the total heat needed by the system (kj/kg), Q_1 is the amount of heat needed to raise the water to 1000c (kj/kg/0c), Q_2 is the heat required to vaporize water (ky/g)

2.2.7 Thermal Resistance

Thermal resistance Rwall of the wall agent heat conduction was calculated as reported by [11], as

$$Rwall = \frac{L}{KA} \tag{13}$$

$$Rwall = \frac{\pi D^2}{4} \tag{14}$$

Where L is the height of the chamber (m), A is the cross-sectional area of the chamber (m²), k is the thermal conductivity of stainless Steel (w/m.°c)

2.2.8 Heat Loss

The heat loss through the surface of the cylinder was determined as reported by [11] and is given as

$$Q_c = \left(\frac{T_2 - T_1}{R_T}\right) \tag{15}$$

Where Q_c is the heat loss (ky/kg), T_1 and $T_2$are the internal and external temperatures (°C) respectvely, R_T is total heat resistance.

2.2.9 Determination of The Thickness of the Insulating Material

The thickness of the insulating materials was established according to what [12] reported

$$\frac{q}{l} = \frac{2\pi k(T_3 - T_2)}{Ln\left(\frac{r_3}{r_2}\right)} \tag{16}$$

$$Ln\left(\frac{r_3}{r_2}\right) = \frac{2\pi k(T_3 - T_2)}{\frac{q}{l}} \tag{17}$$

$$\Delta r = r_2 \times \left[e^{\frac{2\pi k(T_3 - T_2)}{\frac{q}{l}}}\right] - r^2 \tag{18}$$

But $\Delta r = r_3 - r_2$

Where the internal and external radii of the layer are r_2 and r_3 (mm) respectively, T_2 is the inner unit temperature (℃), T_3 is the outer unit temperature (℃), Δr is the diameter of radius, k is the thermal conductivity of stainless steel (w/m℃), q is the heat loss (kj/kg), L is the length of water chamber (m),

2.2.10 Design of The Furnace

The volume of the furnace was calculated using the relationship reported by [13]

$$V_F = \frac{Q_T}{R_L} \tag{19}$$

Where V_F is the volume of the furnace (m3), $Q_T$is the total heat required, $R_L$is the visible volumetric heat loading in the furnace (kg m^3/h)

2.3 Working Procedure of the Equipment

The water valve is open to allow the inflow of water into the boiler. The boiler was filled up to 2/3 of its volume in order to allow steam expansion. Depending on the type of source heat to be used, either an electric heater or biomass. If it is a heater, the desired temperature is set, and then the system power is switched on. Food products are then introduced into the sterilization chamber. The moment the water starts boiling, steam is generated, expanded, and then passed through the steam host into the copper tube inside the sterilization chamber. As the temperature

reaches the desired temperature, the temperature is held for a particular duration. After that, the steam valve is closed to cut off the steam supply into the chamber, and then the water valve is opened, and water flows into the sterilization chamber through the copper tube to cool the product. After that, the products are discharged.

2.4 Design of Experiments

Two sets of trials were carried out. In the first trial, the performance of the equipment was tested by varying the heating duration, temperature, and the equipment stirrer's speed. For the second trial, the samples of the *nono* were thermally processed for 0, 15, 30, 45, and 60 minutes at a heating temperature of 100, 102, 104, 106, and 108°C, respectively, to calculate the D and Z values as shown in Table 1.

2.5 Experiments Set Up

Considering the experiment's layout, sixty litres of locally processed *nono* were divided into 60 samples of 1 litre each and then thermally processed using the design of the experiment in Table 1. The experiments were each repeated three times. The samples were then taken to the lab for calculating TAPC. The log10 of the microbial count at each temperature was obtained, and the D values were calculated. The log10 of the D values was then used to determine the Z value

Table 1. Experimental Set Up

S/N	Temperature (^{O}C)	Heating Time (min)			
		15	30	45	60
1	100				
2	105				
3	110				
4	115				
5	120				

2.6 Sample Preparation

Sixty litres of *nono* samples were purchased from Bida town in Niger State, Nigeria, then put into sterile containers sealed right away. Samples were transported in an ice-filled cooler to the laboratory for sterilization. After which the samples were collected in another sealed container, sealed, and then taken to the Microbiology Laboratory of Federal Polytechnic Bida, Niger State, Nigeria, for analysis [2].

2.7 Performance Evaluation

2.7.1 Total Aerobic Plate Count

The Total Aerobic Plate Count (APC) was employed to quantify the viable, mesophilic aerobic bacteria present in the raw cow milk samples. A serial dilution technique was carried out on the raw cow milk using sterile 0.1% peptone water. Specifically, 1.0 mL of the raw milk sample was subjected to tenfold serial dilutions up to 10^{6}. Subsequently, 0.1 mL aliquots of the selected dilutions (10^{-6}) were surface-inoculated onto sterile Nutrient Agar (NA) plates and spread uniformly using a sterile glass spreader. The inoculated plates were then incubated in an inverted position at 37 °C for 24 hours. Following incubation, colony counting was restricted to plates yielding between 30 and 300 Colony Forming Units (CFU). The final microbial load was calculated as the number of CFU per millilitre (CFU/mL) of the original sample using the following formula, as described by [2]:

$$N_b = \frac{N_{OC}}{V_P \times D} \tag{20}$$

Where, N_b is the number of organisms of colony-forming units per mL (CFU/ml) of samples, V_P is the volume of the plate (0.1 mL), D is the dilution factor.

2.7.2 Determination of D and Z Values

The bacteria's log10 survival rate was plotted against the corresponding heating durations to produce a regression line (y = mx + b), which was then used to calculate the D values as stated by [15]. Using the formula D = -1/m, the

slope was utilized to calculate the D value. The expression Z = -1/m was employed to determine the z values, and it was generated from the regression line's negative slope over the log10 of D values.

3. Results and Discussion

3.1 Testing the Performance of the Equipment

The hybrid thermally processing unit was fabricated and tested. At a constant temperature of 104 °C and a stirrer's speed of 15 rpm. The TAPC decreases from 4.38 to 3.45 as the time increases from 15 minutes to 45 minutes, as shown in Figure 3. This indicated that more microbial inactivation occurs when the heating period is prolonged. This is in line with [14] findings, which revealed that higher OH temperatures and longer heating times result in increased inactivation of microorganisms.

At a constant heating time of 104 °C and a stirrer speed of 15 rpm. The TAPC decreases from 3.78 to 3.1 as the temperature increases from 102 °C to 106 °C, as shown in Figure 4. This could be because, as the temperature level increases, more spores and vegetative cells are destroyed, and food enzymes are denatured. In addition, the process also eliminates poisons created by specific microbes. This is consistent with [15] findings, which showed that subjecting food material to a high temperature eliminated more vegetative cells, poisons, enzymes, and spores of microbes that could either be harmful to people or lead to food spoiling.

At constant heating time of 104ºC and heating duration of 30 minutes, the TAPC decreases from 3.76 to 3.51 as the stirring speed increases from 10 to 20 rpm (Figure 5). This might happen as a result of enhanced mild agitation and more even heating of the product. This agrees with the results of [16], who demonstrated that greater mixing speeds resulted in more equal product mixing.

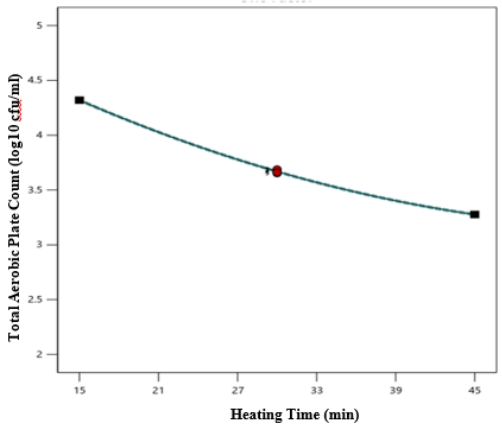

Figure 3. Relationship between Total Aerobic Plate Count and Heating Time.

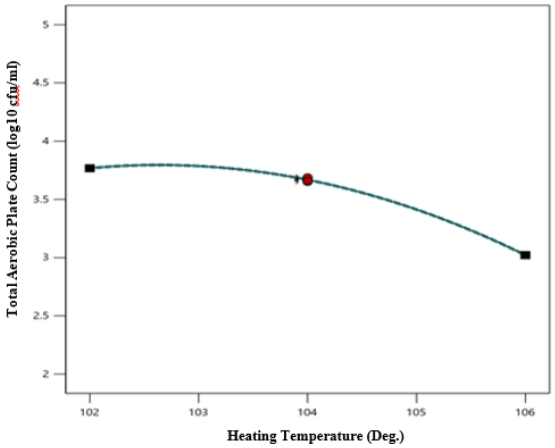

Figure 4. Relationship between Total Aerobic Plate Count and Heating Time.

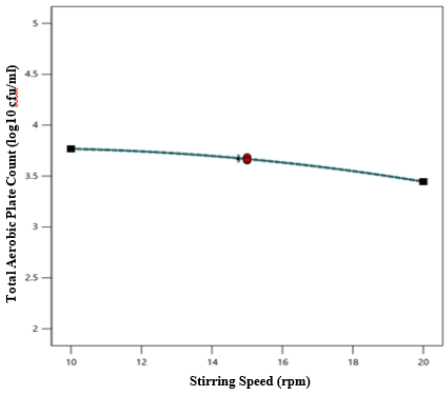

Figure 5. Relationship between Total Aerobic Plate Count and Heating Time.

3.2 Determination of D and Z Values of the Sterilization Product

The results of testing of the equipment using *nono* to determine the decimal reduction time (D value) of the microorganism at sterilization temperatures of 100, 102, 104, 106, and 108 °C, each with heating times of 0, 15, 30, 45, and 60 minutes, are presented in Table 2. The result of temperature changes necessary to change the Z-Value is presented in Table 3. The mean log TAPC of the *nono* samples ranged from 1.69 to 5.0 log10 cfu/ml. The highest value was obtained from the sample without sterilization, as reported by [15].

Table 2. Result of the mean D value of Sterilization of *Nono* at various temperatures

Heating Temp (Deg)	Heating Time (min)					R-squared	D- values (min)
	0	15	30	45	60		
100	5± 0.11	4.2± 0.21	3.7±0.29	3± 0.58	2.6± 0.14	0.9804	25
102	5± 0.11	4.15± 0.31	3.62± 0.08	2.9± 0.3	2.47± 0.38	0.989	23.8
104	5± 0.11	4.07± 0.36	3.58± 0.12	2.8± 0.99	2.15± 0.32	0.9931	21.5
106	5± 0.11	3.9± 0.09	3.5± 0.076	2.7± 0.22	1.9± 0.21	0.9849	20.28
108	5± 0.11	3.54± 0.49	3.15± 0.24	2.48± 0.16	1.69± 0.18	0.9586	19.53

The value of Total Aerobic Plate Count of 104,000/ml (5± 0.11 log10 cfu/ml) obtained from the sample without sterilization indicated that the bacterial content of *nono* that had been prepared locally hawked around Federal Polytechnic Bida and its environs is above the standards set by the Standards Organization of Nigeria (SON), which states that milk intended for human consumption cannot have a Total Aerobic Plate Count greater than 50,000/ml (4.6 log10cfu/ml). (SON 1996). According to [17], aerobic count is a useful indicator of food quality and shelf life because it indicates the microbial quality of food products. The overall total aerobic count (TAC) obtained after thermal processing in this study ranged from 1.69 to 4.20 log CFU/mL, which was markedly lower than values reported in previous Nigerian studies. For instance, [18] observed higher microbial loads in locally processed cow milk products sold in Keffi metropolis, Nasarawa State. Similarly, [19] reported a TAC value of 5.34 log CFU/mL in *nono*, a traditional fermented milk product widely consumed in Northern Nigeria. In addition, [20] documented even higher counts, ranging from 6.04 to 6.41 log CFU/mL, in raw cow milk samples collected in Ilorin, North Central Nigeria. These comparisons highlight that the sterilization process applied in the present study was effective in reducing microbial loads to levels substantially below those previously reported in related studies.

3.3 Relationship between Log10 of the Bacterial Count and the Heating Time

The D values indicate the amount of time or dose needed to thermally process a material to achieve a 90% reduction in the number of microbes present. Figures 6 to 10 depict the thermal inactivation of total aerobic plate count utilizing the developed thermally processing unit at 100 °C, 102 °C, 104 °C, 106 °C, and 108 °C, whilst Z values (Figure 11) measure the resistance of the microorganism to death by the sterilizing source. The number of bacterial survivors decreases with an increase in heating temperature. It decreases from 104,000 to 400 when the sample is thermally processed from 0 min to 60 min at 100ºC. It decreases from 104,000 to 300 when the sample is thermally

processed from 0 min to 60 min at 102 ºC. Also, it decreases from 104,000 to 140 when the sample is thermally processed from 0 min to 60 min at 104 ºC. In addition, the number significantly decreased from the initial population of 104,000 to 80 when the sample was thermally processed from 0 min to 60 min at 106 °C. The highest decrease in the TAC population was observed when the sample was thermally processed at a temperature of 108 °C for the various sterilization times. From Figure 7, the D-values decreased from 25 min to 19.53 min with an increase in heating temperature from 100 ºC to 108 ºC. The D-values obtained are D100 = 25 min, D102 = 23.8 min, D104 = 21.5 min, D106 = 20.28 min, and D108 = 19.53 min. The trend is similar to the D values of D52 of 53.19 ± 0.16 min, D55 of 20.45 ± 0.96 min, D58 of 6.95 ± 0.67 min, and D61 of 1.60 ± 0.04 min obtained by [16] for S. Typhimurium ATCC 14028's thermal inactivation in the "Cavacas de Resende" batter at 52, 55, 58C, and 61 °C. Similar investigations by [16] found that S. Senftenberg 775W inoculated in custard had a D value of 11.32 min at 60 °C. Additionally, [21] infected flour with a mixture of S. Newport, S. Typhimurium, and S. Senftenberg 775W and got D values of 62.16 ± 2.99 min, 40.09 ± 0.88 min, and 16.46 ±1.71 min at 55, 58, and 61 °C, respectively, with a z value of 10.40± 0.63 °C. The values obtained by these authors differ from the values found in this study. This might be caused by variations in the food's composition and microbial temperature resistances.

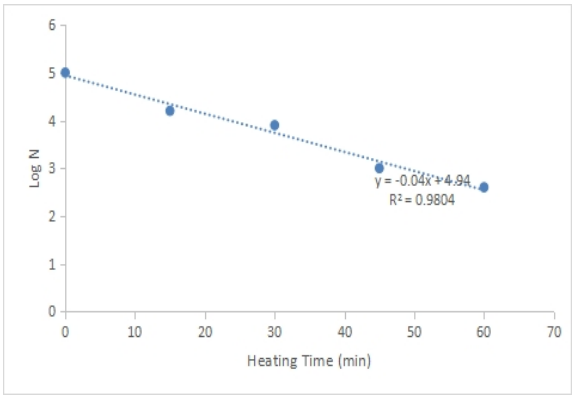

Figure 6. Interaction between Log10 of the bacterial count and the Time at 100 °C.

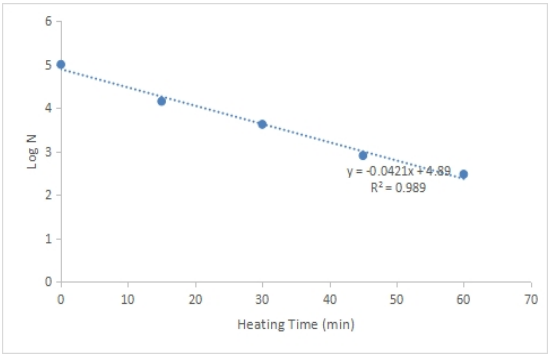

Figure 7. Interaction between Log10 of the bacterial count and the Time at 102 °C.

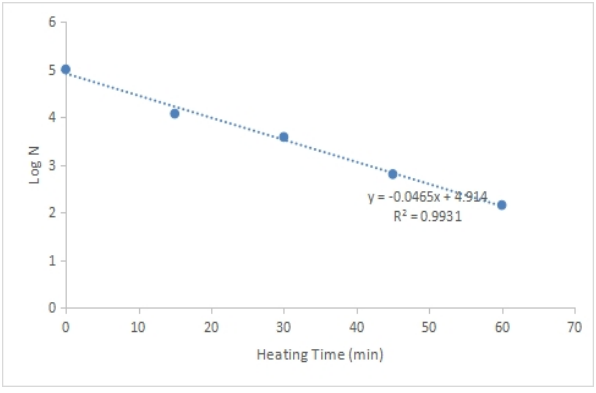

Figure 8. Interaction between Log10 of the bacterial count and the Time at 104 °C.

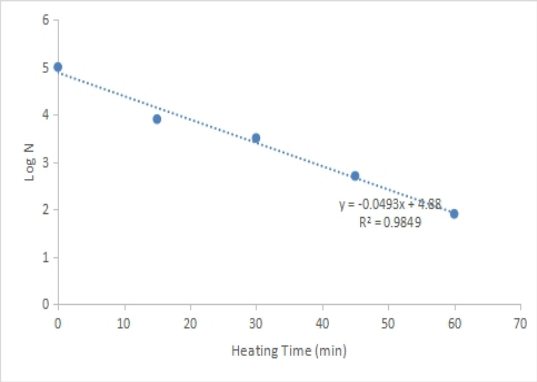

Figure 9. Interaction between Log10 of the bacterial count and the Time at 106 °C.

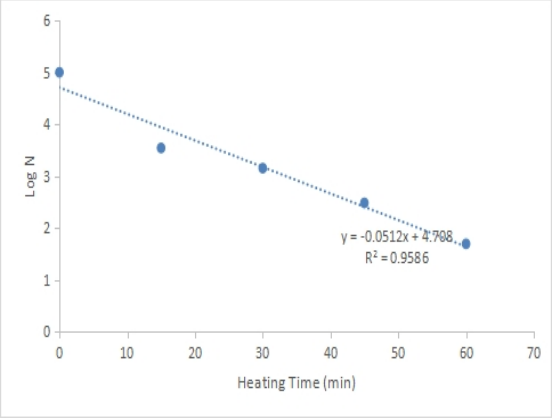

Figure 10. Interaction between Log10 of the bacterial count and the Time at 108 °C.

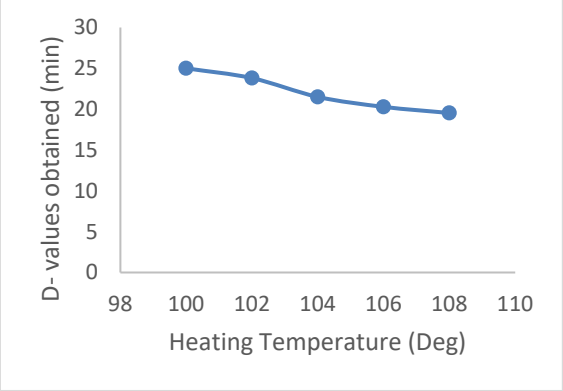

Figure 11. Interaction between D-values and Heating Temperatures.

3.4 The Regression Equation for the Sterilization Process

The linear regression for calculating the D values was illustrated in Figures 2 to 6. The regression equations were obtained using the recommended minimum of 5-point heating times needed to obtain a linear relationship. The obtained correlation coefficients and r-squared values are greater than the recommended minimum of 0.90 [22]. The following are the equations that were derived.

i. Temperature of 100 °C

$$y = 0.04x + 4.94 \quad (21)$$

$$R^2 = 0.9804 \quad (22)$$

Where, y is the total log10 of the bacterial survival, x is the sterilization time (min), and R is the correlation coefficient.

ii. Temperature of 102 °C

$$y = 0.0421x + 4.89 \quad (23)$$

$$R^2 = 0.989 \quad (24)$$

iii. Temperature of 104 °C

$$y = 0.0465x + 4.914 \quad (25)$$

$$R^2 = 0.9931 \quad (26)$$

iv. Temperature of 106 °C

$$y = 0.0512x + 4.708 \quad (27)$$

$$R^2 = 0.9586 \quad (28)$$

v. Temperature of 108 °C

$$y = -0.0512x + 4.708 \quad (29)$$

$$R^2 = 0.9586 \quad (30)$$

Z- values

Z values were calculated using the formula z = -1/m, which was derived from the regression line's negative slope over the log10 of D values at the appropriate temperatures. The z value, which was determined from Table 3 and Figure 6, was 70.4 minutes.

4. Conclusion

The hybrid thermally processing unit was designed, fabricated, and tested. The traditionally produced and hawked *nono* around the institution contains a high value of total aerobic plate count of 5.0 log10 cfu/ml, which is greater than the suggested upper limit of allowable value of 4.6 log10 cfu/ml by SON. The equipment was able to reduce this total aerobic plate count to 1.69 log10 cfu/ml. Generally, the rate of bacterial survival decreases with an increase in heating temperature and heating time. At sterilization temperatures of 100, 102, 104, 106, and 108 °C, the D values of 25 minutes, 23.8 minutes, 21.5 minutes, 20.28 minutes, and 19.53 minutes were obtained from the calculated D values; the corresponding Z value was obtained as 70.4 °C. The development of this equipment will increase food safety by removing, killing, and significantly reducing the microbial load, including vegetative pathogens and spoilage organisms, present in the food products. It will also increase utilization because it can be used for both liquid and solid food products.

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