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Development of a Cocoa Bean Roaster for Small-Scale Cocoa Processing

[1]Moses Ifraimu, [2]Chijioke Okechukwu

[1]Department of Electrical and Electronics Engineering, Taraba State Polytechnic, Suntai, Taraba State, Nigeria
[2]Advanced Manufacturing Technology Development Institute, Jalingo, Taraba State, Nigeria

***Abstract* - Cocoa is an important cash crop globally. It is a popular raw material in the pharmaceutical, cosmetics, and food industries. Despite many products and applications of cocoa, it is largely exported without any form of value addition. This is because the local producers lack machinery to add value to the produce. Imported roasters are very expensive and unaffordable by local cocoa farmers. Recently, Federal Government of Nigeria banned the importation of twenty-five products, including cocoa products. Consequently, there is urgent need to develop cocoa processing machines to leverage the government policy to enrich local farmers and investors in the beverage industry. This research is aimed at developing a cocoa roaster and evaluating same. Geometric modeling of a cocoa roaster was done with Pro/Engineer® Software. Theoretical design calculations resulted in the selection of 0.5 kW three phase gear motor and heating element of 1000 W forturning the roasting drum and heating same, respectively. Food grade stainless steel sheet and perforated sheet were used in developing the critical parts of the machine due to its high resistance to corrosion. Fabrication methods such as cutting, welding, drilling and grinding were used in developing the machine. Cocoa beans were sourced from Kurmi local government area, Taraba State, Nigeria, and used in evaluating the machine. 100 g of cocoa beans samples were roasted at 140, 145, 150, 155, 160 and 165 ^{0}C and corresponding roasting times of 45, 40, 35, 32, 32 and 28 minutes, respectively. Input current to the temperature control panel and output current from the panel to the gear motor and heating element were measured with a clamp meter at different roasting temperatures. Specific energy consumption chart showed that energy consumption decreases at higher roasting temperatures and lower roasting times. As long as the aroma and flavour of the cocoa are preserved, it is more economical to roast at higher temperatures and shorter times. The developed 7 kg capacity cocoa bean roaster is suitable for small-scale cocoa processing.**

Keywords: Cocoa, Roaster, Cocoa Processing, Beverages, Chocolate.

I. INTRODUCTION

Cocoa (*Theobroma Cocao*) is a very critical commodity whose impact on the economies of developing countries has been significant. Cocoa trees are typically grown in limited areas in Africa, Asia, and Central and South America. These areas offer conducive climate conditions for cocoa cultivation. Over 70% of cocoa beans worldwide come from West African countries: Ivory Coast, Ghana, Nigeria, and Cameroon. With Côte D'Ivoire and Ghana exporting over 50–60% of it. Most cocoa farms are owned in small portions by individual families. There is a gap in cocoa bean tonnage production and bean processing in these West African regions. Europe has the largest cocoa processing economy. Cocoa beans are processed into semi-finished products (cocoa liquor, butter, and powder) and further processed into confectionery products around the globe. Cocoa products are enjoyed by many individuals aside from its sensory qualities [1,2].

Cocoa products have characteristic flavor which is related to bean genotype, grouping, environments and processing features. Fermentation is one of the main primary processing steps that enable removal of pulp and later drying. The flavor precursors development, colour formation and reduction in bitterness occur during this step. Important changes that occur during roasting include maillard reactions with reducing sugars and amino acids and characteristic flavor. After roasting, the manufacturing routes that follow are winnowing, crushing, pressing and conching [3].

It has been reported that there are fourteen of Nigerian States that grow cocoa, of which more than 80% are from Southwest geopolitical zone; Taraba State is among the cocoa producing States in Nigeria. Nigeria ranks among top cocoa producing countries in the world, occupying the fourth position after Côte d'Ivoire, Ghana and Indonesia. The crop processing industry of Nigeria like other African countries is dominated by the informal sector comprising mainly of small- and medium-scale rural enterprises owned and operated by men and women who depend solely on indigenous technology. Human utilization of cocoa beans in different forms is increasing from time to time [4].

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At least fourteen States in Nigeria produce cocoa, Taraba State inclusive. Local farmers rely on labour-intensive methods to roast cocoa beans. This method yields low throughput that cannot be commercialized and contributes to emission of greenhouse gases, which damage the ecosystem. The local producers of cocoa lack roasting machines to convert the cocoa bean to more profitable beverages. Imported electric cocoa roasting machines are costly; hence, such machines are unaffordable to the local farmers. The use of non-electrical roasters is being challenged by the difficulty in controlling the roasting temperature. Electric roasters with temperature control system remains the best method of achieving uniformity in the characteristics of the roasted product.The specific objectives of this research are to;design an electric cocoa bean roasting machine; fabricate the cocoa bean roasting machine; and evaluate the performance of the cocoa bean roasting machine.

Recently, the Federal Government of Nigeria twenty-five (25) items from being imported into Nigeria, these include cocoa butter, powder and cakes, medicaments, fruit juice retail packs, etc. [5]; this implies that there is an urgent need to produce quality cocoa beverages, locally. Therefore, a cost efficient, affordable and easy to operate cocoa roasting machine need to be developed, to ease drudgery and produce quality cocoa products after roasting.

Development of cocoa roasters for small and medium scale enterprises in the cocoa value chain will shore-up their income and generate more revenue to the government. It will reduce capital flight through importation and create jobs along the cocoa value chain. Post-harvest losses will be reduced through proliferation of the roaster to the nooks and crannies of cocoa producing communities in Nigeria.

1.1 Global Outlook of Cocoa Production

Over the years more attention has been paid to the cultivation of cocoa. Cocoa does not grow throughout the African continent. The top five cocoa producers including 3 West African countries: Cote d'Ivoire, Ghana and Nigeria, where conditions for growing cocoa trees are most suitable [6].

In cocoa production, the weakness is in the poor producing countries whose communities do not receive the fair benefit. At the same time, the most promising strength for the future is the production of high-value fine cocoa and derived products [7].

1.2 Technologies of the Roasting Process

Since the heating profile during cocoa roasting strongly influences the product quality, specific roaster technologies have been developed with high energy efficiency. The most common equipment is heat conduction, hot air, rotary drum roasters, or continuous roasters. The roaster technology looks to achieve uniform heating of the beans, obtain more homogeneous results, and avoid parts that are over-roasted or burnt. Types of roasters for cocoa beans: (a) sirocco roaster designed and patented by G.W. Barth, Ludwisburg (1900), (b) industrial drum roaster up to 616 lb/h by Diedrich (USA), (c) infrared roaster by Die- drich (USA), (d) typical horizontal continuous bean roaster, and (e) continuous vertical roaster by Royal Duyvis Wiener (USA) [8].

In the cocoa industry, roasting is a key process for releasing the aroma and flavor precursors that will influence consumer acceptability. Roasting can be achieved via heat transfer through convection and/or conduction. Cocoa (*Theobroma cacao L.*) comprises a total of 24 botanical species. It is cultivated solely to produce chocolate [9].

1.3 Cocoa Roasting Techniques and Parameters

In the roasting process, dried cocoa beans are heated from room temperature up to the roasting temperature which is commonly from 110 to 160 °C. From 34 °C, the fat reaches its melting point and goes into a liquid state within the beans' structure. When the beans are further heated to temperatures above 100 °C, moisture is removed and low molecular weight compounds such as alcohols and acetic acid (formed in the fermentation process) are volatilized. Due to decreased humidity and water activity (< 0.6), heating induces non-enzymatic browning reactions [8].

It has been revealed that cocoa is a popular raw material in the pharmaceutical, cosmetics, and the food industries. The beans are roasted (at within a temperature range of 90-140°C for 90-95 minutes) to sterilize them, eliminate the acids formed during fermentation, make the beans amenable to fracture during decortication and enhance the development of the sensory attributes typical of chocolate. Cocoa roasting are mainly in two patterns, light roasts and dark roasts, depending on the choice of the individual taste. The dark roasts produce more fluidity during grinding, this is done at a temperature above 130^{o}C. Some roast until they hear the first beans pop; sounds like a popcorn, which can be above 140^{o}C [4].

Before cocoa nibs are roasted, cocoa beans are cleaned, pre-dried through a roasting process, and subjected to winnowing to separate cocoa nibs from the shells. Before grinding, the nibs are roasted – a critical step in flavour development. Roasting reduces the microbial load of cocoa, acidity and astringency, and lowers moisture content [10]. Cocoa nibs are subsequently ground to generate cocoa liquor before being used in chocolate manufacturing. For cocoa

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butter and powder, cocoa liquor is pressed using a hydraulic system.

In chocolate production, the conching process has been described as an integral and final part of the chocolate production process that enhances the final taste, aroma, texture, and consistency associated with high-quality chocolates. In this process, the chocolate is mixed thoroughly for several hours and at high temperatures, to smoothen all sugar and cocoa solids while allowing the evaporation of excess moisture and acid off the chocolate. The high temperatures help in the development of flavour [11].

1.4 Economic Importance and Uses of Cocoa

Cocoa is the commodity that is made of cocoa beans, which is widely used in various fields of human activity due to a variety of beneficial properties. Apart from being a source of income to farmers, it is enriched with so many benefits and serve many purposes in the health and consumer goods industries. The areas of application of cocoa and its derivatives are outlined as follow:

i. Confectionery industries: Cocoa is used in making cocoa drink, slab chocolate, sweets, toffee, caramel, lollipops, brittle and meringues, etc.
ii. Dairy industries: It is used in making yoghurts, ice cream, chocolate milk, chocolate butter and other dairy products.
iii. Bakery industries: It is used as a flavouring and colouring agent for baking.
iv. Distillery and wine industries: Cocoa is used as additives for the production of brandy, gin, wine and vinegar.
v. Pharmaceutical industries: Cocoa butter is used for suppositories, medicinal creams and ointments.
vi. Perfumery and cosmetic industries: It is used in making toilet soap, liquid soap, essential oils, synthetic, aromatic substances, masks and creams [4,6].

II. MATERIALS AND METHODS

Towards achieving the objectives of this research, the following procedures were used; material selection, geometric modeling, theoretical design, fabrication of parts, assembling and evaluation of roaster performance.

2.1 Materials

Materials selected for the development of the cocoa roaster were locally sourced. Machine base frame was made of low carbon steel because of its high strength; heating chamber, roasting chamber drum, baffles, hopper and discharge tray were made of stainless steel because its high resistance to corrosion; while the driven pipe carrying the roasting drum was made of medium carbon steel due to its good rigidity and moderate resistance to high temperature corrosion.

2.2 Methods

2.2.1 Geometric Modeling of the Cocoa Roaster

Drawing of the parts of the cocoa roaster and assembling of same were achieved with Pro-Engineer® software. Geometric model of the roaster with hidden details is shown in Figure 1, while its parts are listed in Table 1.

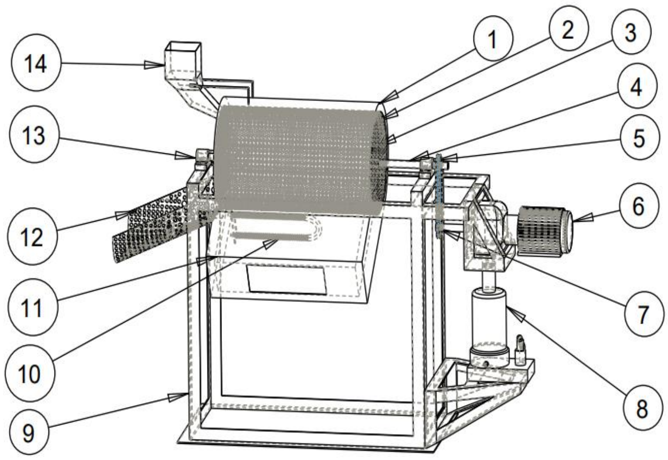

Figure 1: Geometric model of the cocoa roaster

Table 1: List of parts of the cocoa roaster

S/N	Component Name	Qty
1	Fiberglass lagging	1
2	Baffle	6
3	Roasting chamber	1
4	Pipe	1
5	Chain	1
6	Gear motor	1
7	Sprocket (14T)	2
8	Hydraulic jack	1
9	Machine base frame	1
10	Heating element	1
11	Heating chamber	1
12	Perforated discharge tray	1
13	Bearing	2
14	Hopper	1

2.2.2 Theoretical Design of the Cocoa Roaster

(a) Design of the Cocoa Roasting Drum-Pipe-Sprocket Sub-assembly

The driven parts of the cocoa roaster consist of a steel pipe, roasting drum and small sprocket weighing 6.35 kg. Assuming a cocoa seeds of mass 2 kg are to be roasted per

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batch, the total mass of the driven parts and cocoa seeds becomes 8.35 kg.

Let,

Mass of driven parts and cocoa seeds being roasted per time $M_1 = 8.35$ kg
Density of steel (ρ) = 7850 kg/m³

Assume diameter of an equivalent steel shaft that will represent M_1, $D_1 = 40$ mm = 0.04 m

Volume of the equivalent shaft can be calculated from equation (1) as follows:

$$\rho = \frac{M_1}{V_1} \text{ [12]} \qquad (1)$$

$$V_1 = \frac{8.35}{7850} = 0.0011 \text{ m}^3$$

Length of the equivalent shaft is calculated from equation (2):

$$V_1 = \pi \times D_1^2 \times L_1/4 \qquad (2)$$

By substitution, L_1 becomes,

$$L_1 = \frac{4 \times 0.0011}{3.142 \times 0.04^2} = 0.875 \text{ m}$$

Torque transmitted by the equivalent shaft of the roaster is calculated from equation (3),

$$T_1 = G \times \theta_1 \times J_1/L_1 \qquad (3)$$

where.

J_1 is the polar moment of inertia of the equivalent shaft of the roaster driven parts and load,

Given that: Speed of the driver sprocket, N_1= ?

Take angle of twist of the equivalent shaft of the roaster to be θ_1, G is the modulus of rigidity of the equivalent steel shaft.

$$\Theta_1 = 0.5° = 0.5 * \pi/180 = 0.0087 \text{ rad.}$$

$$J_1 = \pi \times D_1^4/32 \qquad (4)$$

By substitution, J_c becomes

$$J_c = 3.142 \times 0.04^4/32 = 2.51 \times 10^{-7} \text{m}^4$$

$$G = 8.0 \times 10^{10} \text{ N/m}^2 \text{[13]}$$

By substitution in equation (3), T_1 becomes

$$T_1 = \frac{8.0 \times 10^{10} \times 0.0087 \times 2.51 \times 10^{-7}}{0.875} = 199.65 \text{ Nm}$$

Roasters usually operate at low speed; assuming the speed of the equivalent shaft of the driven parts of the roaster is $N_1 = 15$ r.p.m.

Power transmitted by the equivalent shaft of the roaster driven parts, P_1 is given by equation (5)

$$P_1 = 2 \times \pi \times N_1 \times T_1/60 \quad \text{[14]} \qquad (5)$$

By substitution, P_1 becomes

$$P_1 = \frac{2 \times 3.142 \times 199.65 \times 15}{60} = 313.65 \text{ W}$$

(b) Sprocket-Chain Drive System

To achieve a low speed of 15 r.p.m., there is need to use a gear motor.

Speed of the driven sprocket, $N_2 = 15$ r.p.m.
Number of teeth on the driver sprocket, $T_1 = 14$
Number of teeth on the driven sprocket, $T_2 = 14$

Velocity ratio of a chain drive is given by equation (6) as follows:

$$\text{V.R.} = \frac{N_1}{N_2} = \frac{T_2}{T_1} \qquad \text{[13]} \qquad (6)$$

By substitution,

$$N_1 = \frac{14 \times 15}{14} = 15 \text{ r.p.m.}$$

(c) Selection of prime mover for the roaster

Efficiency of the roaster chain-sprocket drive system is given by equation (7):

$$E_1 = \frac{\text{Output power}}{\text{Input power}} \qquad (7)$$

Assuming efficiency of 90 %, input power, P_i, which is the power of the electric motor that will drive the roaster driven parts and cocoa seeds is given by:

$$P_i = \frac{313.65}{0.9} = 348.5 \text{ W} \approx 0.35 \text{ kW}$$

Consequently, a 0.5 kW, 260 Nm torque, 13 r.p.m three phase electric motor was selected as the prime mover.

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(d) Heating System and Temperature Control

Given that: mass of cocoa beans to be roasted is 2 kg, specific heat capacity of cocoa, c is 3746.3 $Jkg^{-1}K^{-1}$, temperature of the environment of the roaster is 32 ^oC and maximum roasting temperature is 170 ^oC. Heat required to roast cocoa beans is calculated with equation (8) as follows:

$$Q = M_1 \text{ x c x } \Delta T \quad [15] \qquad (8)$$

where,

$$\Delta T = (170 + 273) - (32 + 273) = 138 \text{ K}$$

By substitution, Q becomes

$$Q = 2 \text{ x } 3746.3 \text{ x } 138 = 1{,}033{,}978.8 \text{ J}$$

Let power of the heating element that will supply the heat be P_e; assuming a heating period, t, of 20 mins, P_e is calculated from equation (9) as follows:

$$P_e = \frac{Q}{t} \qquad (9)$$

By substitution, P_e becomes

$$P_e = \frac{1{,}033978.8}{20 \text{ x } 60} = 861.65 \text{ W}$$

Based on the calculated power, P_e, a heating element of 1000 W was selected.

A temperature control panel was used to achieve variation and steadying of roasting temperatures. Key components include: K-type thermocouple, Rex-C100 PID temperature controller digit display, contactors, breakers and power switches (on/off).

2.2.3 Fabrication Processes of Cocoa Roaster

The fabrication processes used in developing the parts of the cocoa roaster are summarized as follow:

Machine base frame: Angle bar was cut to sizes according the base frame drawing; the cut parts were welded and ground to the required finishing. The top frame was hinged at one end, to enable tilting of the roasting chamber after roasting.

Heating chamber: This component was made of stainless steel sheet; angle grinder was used to cut the shape before rolling and welding to form the shape. Welded joints were ground to obtain neater surface finishing. Provisions were made in the heating chamber for the attachment of heating element and positioning of the thermocouple. The heating chamber has double wall and was lagged with fiberglass.

Roasting chamber: Perforated stainless sheet was marked, cut and rolled into a cylinder. Circular cross-sectional ends of the chamber were also marked and cut to size. The centre of the end covers were cut with circular cutters to make provision for the driven pipe. Baffles were cut and welded to the internal parts of the roaster to enhance turning of the cocoa beans. Perforated end covers of the roasting chamber were welded to the cylindrical part and medium carbon steel pipe.

Pipe: Medium carbon steel pipe was measured and cut to size. The ends of the pipe were ground to fit into the bearing bore. The pipe was welded to the end covers of the roasting chamber and reinforced in the inner part of the roasting chamber.

Hopper: The parts of the hopper were developed on the perforated stainless sheet. The shapes were be cut out and joined with stainless steel electrode. The welded joints were ground to smooth surface finish. The perforated sheet helps in removing unwanted particles the cocoa beans before entering the roasting chamber.

Discharge tray: Dimension of the tray was marked on a perforated stainless sheet; thereafter, cutting of the sheet with angle grinder, bending in a bending machine and welding of the bent part to one end of the heating chamber with stainless steel electrode were done. The welded and cut parts were ground to a smooth surface finish.

Discharge door: A segment of the discharge end of the roasting chamber was cut and welded to a hinge on the curved part of the segment. Two metal clips were welded to the flat side of the segment for opening and closing of the discharge door. Welding was done with stainless electrode.

Control panel stand: Dimensions of the parts of the control panel stand were marked on the length of angle bar and cut accordingly. The cut parts were joined with E6013 electrode. Positions for fastening the panel were marked, drilled with hand drill and filed to smooth surface finish.

Painting: Parts of the roaster that are made of mild steel were filed to smooth surface finish with angle grinder, welded joints were covered with body filler and sanded with abrasive paper. Auto-refinish silver paint was missed with hardener, clear and thinner in proper proportion before spraying of the mild steel parts with a spraying gun.

2.2.4 Validation of the Roasting Drum Capacity

Diameter of the roasting drum, D_r = 300 mm = 0.3 m
Length of the roasting drum, L_r = 600 mm = 0.6 m

Volume of the roasting drum, V_r is given by equation (10):

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$$V_r = \frac{\pi \times D_r^2 \times L_r}{4} \quad (10)$$

By substitution,

$$V_r = \frac{3.142 \times 0.3^2 \times 0.6}{4} = 0.0424\ m^3$$

Bulk density of varieties of cocoa been varies from 505.05 kg/m^3 to 699.9 kg/m^3 as moisture content varies from 5.67 to 25.05 kg/m^3 [16].

Let, density of the cocoa ban be 600 kg/m^3; then, 2 kg mass of cocoa bean will occur a volume of 0.0033 m^3; this amounts to 7.78 percent of the roasting drum volume. Usually, thirty percent of the drum volume is allowed to be occupied by the cocoa beans; hence, the roasting drum can take more than 7 kg mass of the cocoa beans. Hence, the roasting drum carrying capacity is 7 kg.

2.2.5 Performance Evaluation of the Cocoa Roaster

The cocoa roaster was evaluated with dried fermented cocoa beans sourced from Kurmi local government area of Taraba State, Nigeria. Towards determining the temperature variations with varying roasting temperatures and recommending suitable roasting temperatures and time, a uniform mass of 100 g of cocoa beans was used for roasting temperatures of 140 ^oC, 145 ^oC,150 ^oC, 155 ^oC, 160 ^oC and 165 ^oC.

Clamp meter was used to measure the current in the three phase input cables before the control panel, three phase cables of the gear motor and two phase cables of the heating element, after the control panel; these measurements were done at the beginning and ending of the roasting process. Measurement of the current was done on each of the three phase input single cable before and after the control representing I1, I2 and I3, while I represents current measurement across combined cables.

Roasting time was measured with a stop watch, while the specific energy consumption (kWh/kg) was calculated using equation (11).

$$SEC = \frac{E_c \times t}{W} [15] \quad (11)$$

where,

SEC is the specific energy consumption (kWh/kg),
E_c is the electric power consumed (kW),
T is the total roasting time (h)
W is the initial weight of the dry cocoa (kg).

E_c was calculated with equation (12):

$$E_c = IV \quad (12)$$

where,

I is current (A) and V is voltage (volts).

III. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Summary of Design Calculations and Presentation of the Developed Cocoa Roaster

Summary of the theoretical design calculations for the cocoa roaster is presented as follows:

Calculated torque of the equivalent shaft = 199.65 Nm
Torque of the selected gear motor = 260 Nm
Calculated power of prime mover = 0.35 kW
Power of the selected gear motor = 0.5 kW
Calculated speed of prime mover = 15 r.p.m.
Speed of selected gear motor = 13 r.p.m.
Calculated power of heating element = 861.65 W
Power rating of selected heating element = 1000 W
Roasting drum carrying capacity = 7 kg

Pictorial view of the developed cocoa roaster is presented in Figure 2, while peeled samples of roasted cocoa is shown in Figure 3.

Figure 2: Side view of the cocoa roaster

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Figure 3: Peeled samples of roasted cocoa

3.1.2 Presentation of Results of Fluctuation of Current with Varying Roasting Temperatures

Fluctuation of input current to the control with roasting temperatures at the start and stop periods of roasting are presented in Figures 4 and 5 respectively. Similarly, the fluctuation of motor current with roasting temperatures at the start and stop periods of roasting are presented in Figures 6 and 7. More so, the fluctuation of heating element current with roasting temperatures at the start and stop periods of roasting are presented in Figure 8 and 9.

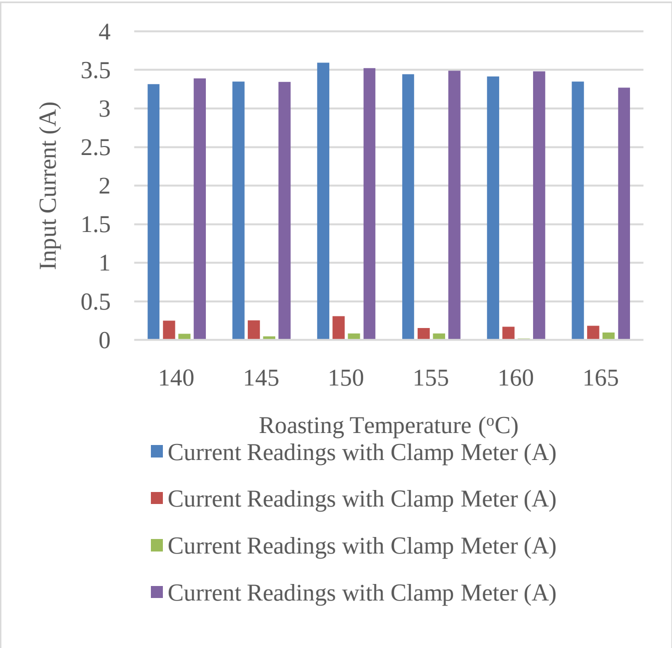

Figure 4: Fluctuation of input current with roasting temperature (start)

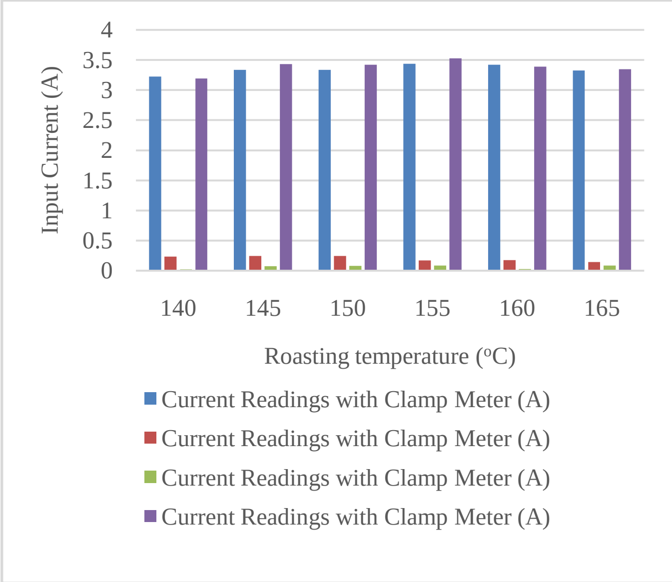

Figure 5: Fluctuation of input current with roasting temperature (stop)

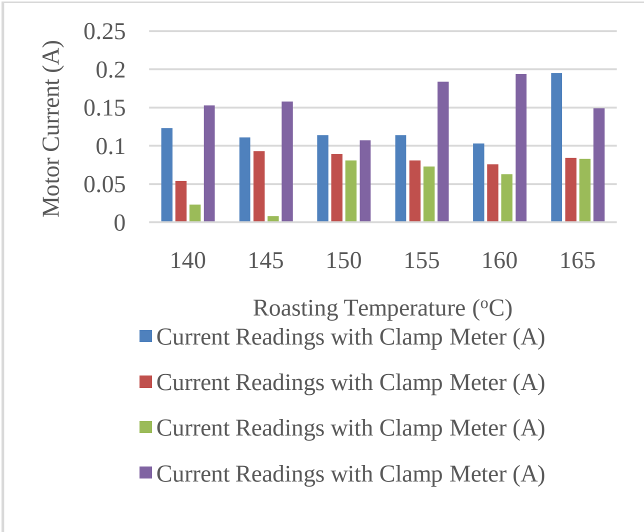

Figure 6: Fluctuation of motor current with roasting temperature (start)

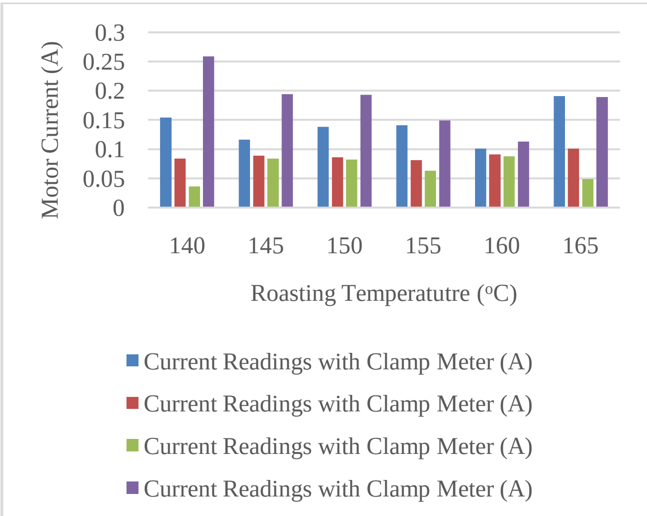

Figure 7: Fluctuation of motor current with roasting temperature (stop)

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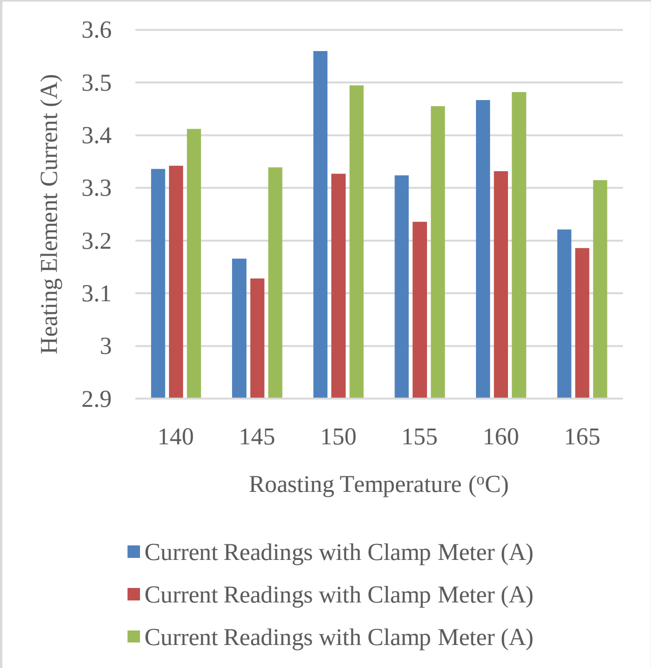

Figure 8: Fluctuation of heating element current with roasting temperature (start)

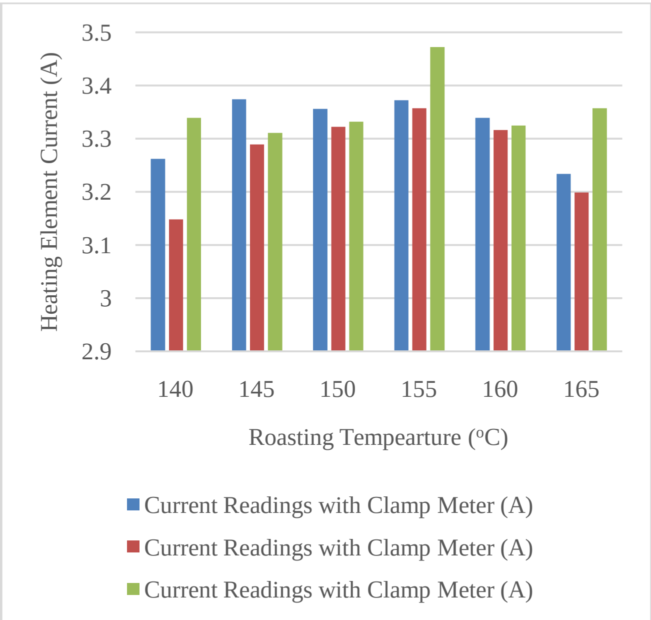

Figure 9: Fluctuation of heating element current with roasting temperature (stop)

Using equations (11) and (12), sum of the input current (I1 + I2 + I3) at stop periods of roasting, spanning 45, 40, 35, 32, 30 and 28 mins at corresponding roasting temperatures of 140, 145, 150, 155, 160, 165 ^{o}C, voltage of 240 V and 0.1 kg initial weight of cocoa beans, specific energy consumption was calculated and presented graphically as shown in Figure 10.

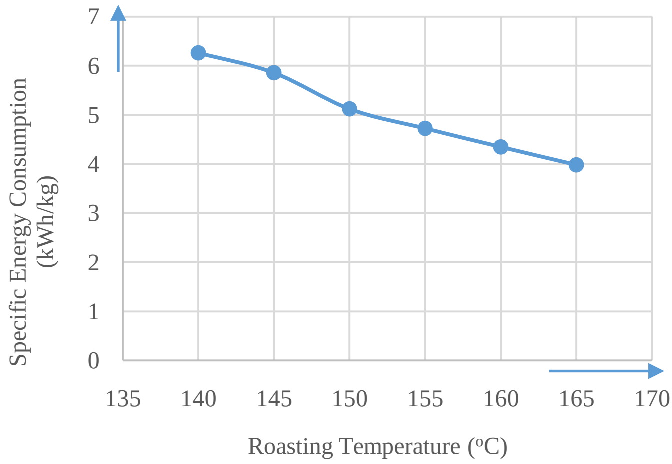

Figure 10: Effect of roasting temperature on specific energy consumption

3.2 Discussions

The torque and power of the selected gear motor were higher than the calculated values for the prime mover. Also, the output speed of the gear motor was a little lower than the calculated speed of the prime mover. Power rating of the selected heating element was above the calculated power requirement; these fall within acceptable ranges. The roasting drum carrying capacity of 7 kg of cocoa beans was recommended because it is less thirty percent of the drum volume.

Current flow through the three phase input cables and gear motor was summative as shown in Figures 4 to 7, while current flow through the two phase cables of the heating element showed approximately equal values when measured singly or across the both cables as shown in Figures 9 and 10. Neutral cable of the three phase lines of the input and gear motor did not show any reading on the clamp meter.

Specific energy consumption decreased with increasing temperature due to its direct proportion relationship with roasting time. Roasting of cocoa beans is usually achieved within a shorter period of time at higher temperatures [15]. Though it seems economical to roast at higher temperatures and shorter times; however, these may affect the taste and aroma or flavour of the roasted cocoa. Regarding the developed cocoa roaster, a temperature of 165 ^{o}C within a time range of 28 to 45 mins is recommended, depending on the quantity of cocoa to be roasted.

Note: Cost of Band A electricity tariff from Yola Electricity Distribution Company YEDC is ₦209/kWh [17]. Using YEDC's Band A charge, ₦1,308.97 was consumed while roasting 0.1 kg of cocoa beans at 140 ^{o}C for 45 minutes, while ₦831.61 was consumed while roasting 0.1 kg of cocoa beans at 165 ^{o}C for 28 minutes.

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IV. CONCLUSION

A cocoa bean roaster has been successfully designed with Pro-Engineer® software and developed with locally available materials and components. With a drum capacity of 7 kg, the roaster economically roasted cocoa beans within a temperature range of 140 to 165 ^{o}C for decreasing roasting times of 45 to 28 minutes. Current flow through the three phase input lines before the temperature and motor control panel was summative while the current flow through the heating element cables was approximately close for each cable and when measured across both cables with a clamp meter. Specific energy consumption decreased with increasing temperature due to reduction in the roasting time. Power consumption of the roaster was minimal, even with Band A electricity charge. The developed cocoa bean roaster is suitable for small-scale cocoa processing. Effective deployment and proliferation of this cocoa roaster will create jobs, reduce capital flight due to importation of cocoa beverages and increase the revenue of cocoa farmers and investors in Nigeria.

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AUTHORS' BIOGRAPHIES

Moses Ifraimu is a Lecturer in the Department of Electrical and Electronics Engineering, Taraba Sate Polytechnic, Suntai, Taraba State, Nigeria.

Chijioke Okechukwu is a Chief Engineer in the Manufacturing Services Department of Advanced Manufacturing Technology Development Institute, Jalingo, Taraba State, Nigeria.

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