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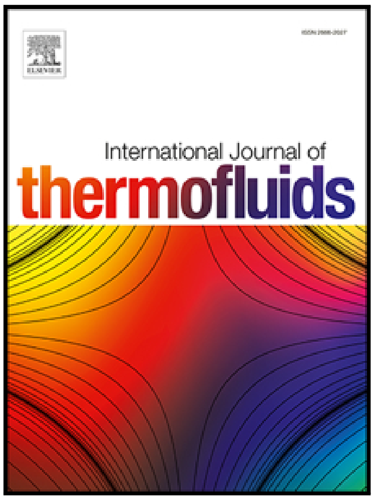

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Design of shea nut rotary roasting machine used for shea butter production in Ghana

Samuel Kofi Tulashie [1*], *Godfred Appiah* [1,2], *Ephraim Edem Amoah Akpari* [1] *and Samuel Muobom Saabome* [3,4]

[1] University of Cape Coast, College of Agriculture and Natural Sciences, School of Physical Sciences, Department of Chemistry, Industrial Chemistry Section, Cape Coast, Ghana.
[2]University of Chemistry and Technology,Faculty of Environmental Technology, Department of Water Technology and Environmental Engineering, Prague, Czech Republic.
[3]Kwame Nkrumah University of Science and Technology, Department of Chemical Engineering, Kumasi, Ghana.
[4]Sangmyung University, College of Engineering, Department of Chemical and Materials Engineering, Seoul, South Korea.

Email: stulashie@ucc.edu.gh

ABSTRACT

Shea nuts are dominantly grown in the Northern region of Ghana. Studies have shown that shea nuts undergo hydrolytic destruction during traditional post- harvest processing and storage. Due to poor infrastructure, local women in the area go through extreme measures of stress to process shea nuts into shea butter coupled with their inability to control moisture, a factor for the high yield of shea butter. The sole aim of this paper is to propose the design of a rotary roaster for shea butter production in references to the oil quality and yield. A preliminary study was conducted on the shea nuts in relation to their thermal pre-treatment in terms of oil quality and yield in which certain physicochemical properties like free fatty acid values, acid values, and peroxide values were examined. This aided the design of the rotary roaster, which uses pellets of firewood as its fuel source. The machine is designed for a capacity of 60 kg/batch to reduce fresh shea nuts moisture content from 40% to an appreciable amount so as to increase the oil yield. The proposed materials for the

construction of the machine are local materials that are affordable and will make the manufacture of the rotary roaster affordable for the local women in the Northern region of Ghana.

Keywords: Hydrolytic destruction, Rotary roaster, Pre-treatment, Physicochemical properties, Pellets.

Nomenclature

Variable	Meaning
FFA	Free Fatty Acid
AV	Acid Value
PV	Peroxide value
Q	Quantity of heat
Ms	Mass of fresh shea nut
Cp_s	specific heat capacity of fresh shea nut
T1	Temperature of feed
T2	Temperature of surrounding
M_r	Mass of roasted shea nut
Cp_r	Specific heat capacity of roasted shea nut
M_w	Mass of water
C_v	latent heat of vaporization
V_{TR}	volume of the roasting chamber
ρb	bulk density of the shea nuts
M_b	mass of material to be processed

q	heat loss per unit length
K	thermal conductivity of the insulating material

1. Introduction

There is a growing need for the production and processing of shea nuts, *Butyrospernum paradoxum,* globally as a substitute for cocoa due to their relatively low cost and high nutritive and cosmetic value and this information has guided the food sector to concentrate their study in products of this nature. Shea nut from shea trees is one of the major substantial crops in Africa, especially in West Africa where it acts as a great source of cooking oil to millions of persons. The shea fruit is made up of a pulp surrounding a nut which has a shell that houses the kernel that is dried and stored for processing into shea butter. The main shea nut producing countries include Ghana, Mali, Burkina Faso, Nigeria, Côte d'Ivoire, Benin, Togo and Guinea. The total production capacity of these countries was estimated at 600,000 tons with an average of 350,000 tons exported in 2008 (Lana, 2017). Accordingly, Ghana is one of the chief producers of this crop worldwide. It is identified as a cheap calorie and a staple oil source for most citizens in Ghana due to its health benefits. In Ghana, the consumption of shea butter helped lower the blood pressure as established by Amegah et al., 2019. Ghana is primarily split into four main territories: the north, the east, the west and the south. Statistically, the populace from the northern part of Ghana are the poorest as compared to the other territories, therefore, most of them resort to shea nuts cultivation (Moore, 1993). Shea butter is an oil extract from the shea nut crop (Abdul-mumeen et al., 2019). It is a triglyceride and is innately full of tocopherol, linoleic acid, linolenic acid, and retinol. In Ghana, shea butter is processed conventionally by womenfolk in the northern villages and traded in the local markets.

Throughout the years, the extraction of the butter from the nuts had to be performed by the traditional method. Traditional extraction is normally done by firstly procuring the aged nuts from the field, followed by cleaning, ousting the shells, grinding, boiling water and skimming off the discharged oil. These activities result in low yield, reduced and varying quality of the shea butter manufacturing and consequently affect the export capacities of the oil extract from Africa and Ghana particularly (Lovett, 2004). The post-harvest thermal treatment of vegetable oil seeds impacts on their physicochemical quality (Jibreel et al., 2013). Shea butter experiences hydrolytic and oxidative degradations throughout the post-harvest processing and storage, which brings about shea butter with high free fatty acid (FFA) and peroxide values (PV) (Kar and Mital, 1981). All these aforementioned reasons could result in inconsistencies in quality and limited shelf life of shea butter. Shea butter extraction is mainly branded by the oil yield and oil quality. The quality of the butter is a function of its FFA, acid value (AV), and PVs. To verify this theory and claims, a preliminary research work was conducted.

The preliminary research conducted showed the impacts of post-harvest thermal-treatment (roasting and boiling) on oil yield and oil quality of shea nuts by Soxhlet method of extraction using n-hexane as the solvent and it was evident that the oil yield and oil quality obtained from the roasting thermally-treated nuts were high as compared to both the boiling thermally-treated nuts and the raw untreated nuts. The roasting technique did not only increase oil yield but also reduced the PVs and the subsequent FFAs and AVs considerably. Roasting (heating) deactivates the enzyme that is accountable for the accumulation of free fatty acids of the nuts (Tame et al., 2015). It also stops the development of aspergillus species and thus expands the butter's shelf life (American shea butter institute, 2004).

A substantial quantity of moisture leaves the nuts with roasting Moisture induces hydrolytic and oxidative degradations of the butter and is also plagued by aflatoxin and other harmful micro-organisms during storage thus reducing its durability (Honfo et al., 2011). Optimum roasting time and temperature are very necessary factors considered during roasting.

In the processing of the shea nuts, rural women from the north of Ghana, roast their shea nuts using open fire sources (i.e., unenclosed boundary). This practice comes with critical safety issues such as burns on the skin and uncontrolled heating rate which can bring about charring of the nuts prior to oil extraction. The few existing roasting machines are only available on a large scale which is costly, requires extensive skills to operate and be maintained by small scale operators (Olaoye and State, 2012). Most locals in the West African sub-region use sun drying and oven drying which principally lacks control, automation and is inefficient (Saba et al., 2018). Furthermore, the application of steam roasters industrially for thermal treatment is on the rise. The rotary dryer is an equipment employed to minimize the moisture content of a feed material by bringing it in direct contact with a heated gas. It consists of an inclined long drum or cylindrical shell often fitted with internal flights or lifters; rotated slowly upon bearings through which the material to be dried flow with a tumbling/cascading action in concurrent (for heat sensitive materials) or counter-current flow with the heating air or gases (Saba et al., 2018).

The indigenous womenfolk do not consider it an alternative, because of their complexity, expensiveness, and the steam pertaining issues. The women who are into shea butter production require better product quality, improved safety practices, and most importantly, to obtain higher yield. According to the data outcomes acquired from the extensive research conducted, it was necessary for a simple, less costly, easy to fabricate but improved roasting system be made to curb these challenges.

Firstly, this paper presents the results of the preliminary studies conducted on the shea nuts in relation to their efficient thermal treatment in terms of oil yield and oil quality in which certain physicochemical properties like FFAs, AVs, and PVs were examined and also highlights the design of a shea nut rotary roasting machine using firewood as a fuel. The rotary roaster equipment is designed for a capacity of 60 kg/batch to reduce fresh shea nut moisture content from 40% to an appreciable amount thereby increasing oil yield. Energy and material balances were carried out on the roasting machine and the design considerations and calculations were also highlighted.

2. Material and methods

2.1. Chemicals and reagents

0.1N solution of Sodium hydroxide, Phenolphthalein indicator solution, Acetic acid-isooctane mixture (3:2v/v%), freshly prepared Potassium iodide solution, starch solution, 0.01 N sodium thiosulfate, neutralized ethanol and n-hexane were obtained from International Oils and Fats Limited (IOFL) laboratory. All glassware was properly cleaned with liquid soap and water, rinsed and dehydrated before usage.

2.2. Method

2.2.1. Collection of shea nut samples

Composite sampling was employed in the collection of the nuts from the IOFL, Techiman warehouse and properly cleaned. The cleaned samples were split into three fractions, two of which were imperilled for further post-harvest heat-treatment processing by boiling and roasting at different time intervals and the residual untreated raw nuts served as a control experiment. Fig. 1 below Fig. *1***.** sample of shea nuts**,** Butyrospernum paradoxumrepresents a composite sampled shea nut.

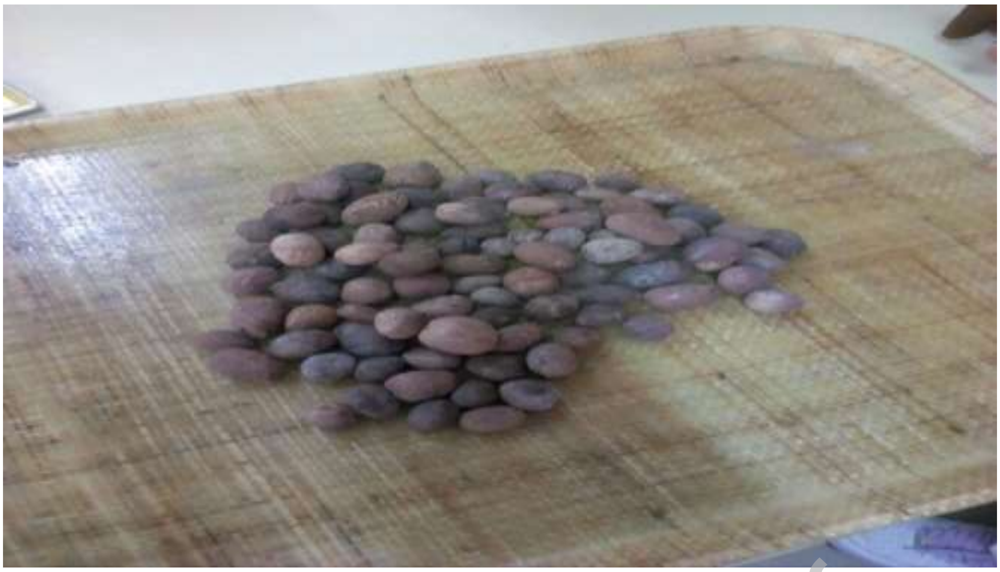

Fig. 1**.** sample of shea nuts**,** *Butyrospernum paradoxum*

The raw untreated sample was crushed into smaller samples using a knife mill and a portion of the crushed shea nuts was taken for the moisture determination and the remaining were taken through the process of extraction.

2.2.2. Treatment of shea nut samples

Initially, the shea nut samples were treated by first effectively cleaning off all the dirt and undesired solid particles such as stones, sand, and metal particles. The sun drying process was employed to get rid of all insects, and this was achieved for 3 days after which they were sorted and apportioned into two equal portions for the thermal treatment process (boiling and roasting). The two divisions were further split into two parts. The first portions were used for the boiling thermal process at different time intervals of 20 and 40 minutes both in a stainless-steel container placed on a hot plate at 100°C. The temperature was examined with the help of a temperature gun. Carefully, the other the portions were also used for the roasting thermal process at different time intervals of 20 and 40 minutes using an enclosed fire. The samples were cooled and dried for three days and crushed into a smaller size using a knife mill and kept in clean containers.

2.2.3. Determination of moisture content

The amount of moisture of the various thermally treated and untreated nut samples was investigated using (AOAC, 2000) . Initially, the weight of a dried unfilled dish was taken and recorded as M_1. 10g of the raw untreated sample was procured and recorded as M_2. The moisture was removed in a preheated air oven gauged at 105 ± 1 ˚C for 3 hours. It was then removed after the set time and cooled for about 30 minutes in a desiccator. Its weight was taken and recorded as M_3. The method was replicated for all the samples treated by heating. The weights of the samples were measured using Sartorius CP124S. The moisture content was calculated by the Equation 1:

Equation 1

$$\%\ Moisture\ content = \frac{M_2 - M_3}{M_2 - M_1} \times 100\% \tag{1}$$

where: M_1 denotes the weight of unfilled dish (g), M_2 represents the weight of dish + sample (g) and M_3 is the sample's weight (g).

2.2.4. Oil extraction

Oil extraction (oil yield) was achieved by the Soxhlet method using n-hexane as the solvent. In this method, an empty round bottom flask's weight was taken and recorded as W_1. 10g of the pulverized sample was weighed using a balance and recorded as W_t. It was later transferred into a thimble, stuffed with cotton wool and sited in the holder of the thimble. The sample's holder was sited in the extraction chamber and the round bottom flask was sited underneath the Soxhlet set up to collect the extract. N-hexane was added and permitted to boil for 3 hours. The oil extracted was assigned to an oven for about 30 minutes and the weight was taken as W_2. Using the Equation 2, the percentage of oil yield was calculated:

Equation 2

$$\% \text{ Oil yield} = \frac{W_2 - W_1}{W_t} \times 100\% \quad (2)$$

where: W_1 represents the weight of the empty flask (g), W_2 is the weight of extracted oil + flask (g), and W_t denotes the weight of shea nut sample (g)

2.2.5. Determination of free fatty acid (FFA)

Free fatty acids (FFA) are the oil -based fatty acids that have not been neutralized (Guy, 2009) or just not attached fatty acids confined in a fat (Sapna and Nirmali, 2009). To analyse FFA, about 5g of the extracted oil was weighed into a 250 ml flask and 50ml of warm neutralized ethanol was added. The mixture was heated on a hot plate while stirring for about 45sec to ensure the dissolution of the sample and nearly 2 to 3 dips of a phenolphthalein indicator were added. The solution in the beaker was stirred and titrated against standard 0.1N potassium hydroxide until there appeared a first permanent colour that persisted for over twenty (20) seconds. Using Equation 3 below, the FFA value present was calculated:

Equation 3

$$\text{FFA} = \frac{V \times 28.2 \times 0.1N}{w} \quad (3)$$

where: V is the titrant's volume (ml), and w represents the used oil's weight (g)

2.2.6. Determination of acid values (AV)

The acid value characterizes the destruction of the quality of the oil stemming from the hydrolysis of triacylglycerol along with the additional break down of hydroperoxides

(Ngassapa et al., 2012). The acid value was examined using the method described by Tame et al., 2015 and Gregory, 2005. This was done by mixing 25 ml diethyl ether with 25 ml alcohol (isopropanol) and 1ml phenolphthalein solution (1%) and carefully neutralized with 0.1 N NaOH. Shea nut oil sample (2g) was dissolved in the blended neutral solution and titrated against aqueous 0.1 N NaOH till a pink tint which stayed for 15 sec was obtained. Using Equation 4 below, the AV was calculated:

Equation 4

$$AV = \frac{A \times B \times 56.1}{w} \quad (4)$$

where: A denotes the sodium, hydroxide used (ml), B represents the normality of the sodium hydroxide solution and w is the weight of oil used (g).

2.2.7. Peroxide value (PV)

Peroxide value (PV) is a quantity of the peroxides confined in a sample of oil, stated as mill-equivalent of peroxide per 1000 g of the material (Ngassapa et al., 2012). Peroxide value is the most prevalent lipid oxidation determinant (Shahidi, 2005). To analyse the PV value, about 5g of the sample was weighed into a 250 ml Erlenmeyer flask and covered with a stopper. 30ml Acetic Acid-Isooctane (3:2v/v%) mixture was added to the measured sample and swirled for 1 minute for uniform dissolution of the mixture. A newly made saturated potassium Iodide (KI) solution was added. It was then shaken thoroughly for 60 seconds shunning direct sunlight by incubating at 45 ˚C. About 30 ml of water was added immediately after the set time and starch solution (0.5 ml) was also added. A colour change of yellowish to blue-black was observed for few seconds, and a magnetic stirrer was placed into the 250 ml Erlenmeyer flask and titrated against 0.1N Sodium thiosulfate solution ($Na_2S_2O_3$). The yellow colour disappeared, and a blue-black colour was observed shortly. A blank determination of the agents was conducted. Using the Equation 5 below, the PV was calculated as:

Equation 5

$$PV = \frac{(A-B)\ N \times 1000}{w} \qquad (5)$$

where: A is the volume of $Na_2S_2O_3$ solution titrated (ml), B represents the volume of $Na_2S_2O_3$ solution used in the blank test (ml), N denotes the normality of $Na_2S_2O_3$ solution and w is the weight of test sample (g)

3. Results and discussion

3.1. Percentage of moisture content

Results obtained from the analysis conducted on the shea nuts' moisture content were showed in Table 1 below.

Table 1 **:** Percentage moisture content of the raw untreated roasted and boiled shea nuts

Samples	Moisture content (%)
Raw untreated shea nuts	4.08 ± 0.02
Roasted nuts/20mins	2.35 ± 0.02
Roasted nuts/40mins	0.96 ± 0.04
Boiled nuts/20mins	5.03 ± 0.08
Boiled nuts/40mins	6.12 ± 0.02

Each value is a mean and standard deviation (±SD) of the percentage moisture content

From Table 1 , it was noted that the moisture content increased with boiling time and decreased with roasting time. The Shea nuts boiled for a time of 40 minutes showed the highest moisture content of 6.12 ± 0.02%, followed by the Shea nuts boiled for a time of 20 minutes with a moisture content of 5.03 ± 0.08%. In contrast, the moisture content of the control experiment prior to the heat treatment was 4.08 ± 0.02% decreased slightly after 20 minutes of roasting to 2.35 ± 0.02%. The lowest moisture content observed was for the roasting for a time of 40 minutes which is 0.96 ± 0.04%.

3.2. Effects of roasting and boiling on oil yield and oil quality of the shea nut oils

The stability of shea nut oils could be determined by using several physicochemical parameters. Some of which include: colour, FFA, PV, AV, saponification value, insoluble impurities, moisture, refractive index, volatile matters, soap content, and unsaponifiable matters. However, in this analysis, the oil yield and oxidative stability were determined by examining the results of roasting and boiling as pre-heat treatments on the FFA, PV, and AV as these parameters are strong indicators of the oil's stability**.** Effects of heating treatments (roasting and boiling) on oil yield and chemical properties of the shea oils are shown below in Table 2.

Table 2 **:** Effects of heating treatments (roasting and boiling) on oil yield and chemical properties of the shea nut oils

Treatment	Time(mins)	Fat (%)	FFA(mgKOH/g)	PV(meq O_2/kg)	AV(mgKOH/g)
Raw untreated	0	45.88±0.55	8.36 ± 0.24	2.17 ± 0.17	16.65 ± 0.15
Roasting	20	47.34±0.06	7.88 ± 0.10	2.55 ± 0.14	15.67 ± 0.32

	40	48.80±0.26	4.69 ± 0.08	3.40 ± 0.16	9.32 ± 0.25
Boiling	20	46.53±0.02	5.44 ± 0.19	2.33 ± 0.06	10.84 ± 0.14
	40	44.85±0.55	6.90 ± 0.24	2.93 ± 0.02	13.74 ± 0.24

Each value is a mean and standard deviation (±SD) of the four tests measurements.

Table 2 showed a considerable increment in the oil yield for the shea nuts with the corresponding roasting time but a significant decline in oil yield when boiled for 40 minutes. The oil yield of 45.88 ± 0.55% was observed for the control experiment at time zero, which increased to 47.34 ± 0.06% after 20 minutes of roasting and then further increased to 48.80 ± 0.26% after 40 minutes of roasting. In contrast, the value decreased considerably to 46.53 ± 0.02% at a boiling time of 20 minutes and continued to decrease further to 44.85 ± 0.55% after 40 minutes of boiling, therefore, it was evident that the longer the roasting time, the greater the oil recovery. The results depicted that long roasting time improved the property of shea oils better than short heating (both roasting and boiling) times when compared to the control treatment at time zero. Concerning the free fatty acid, the FFA values depicted a decrease from 8.36 ± 0.24 mgKOH/g at time zero to 7.88 ± 0.10 mgKOH/g and 5.44 ± 0.19 mgKOH/g at time 20 and finally to 4.69 ± 0.08 mgKOH/g and 6.90 ± 0.24 mgKOH/g after 40 minutes of roasting and boiling respectively, therefore, the lower the FFA value, the higher the oil quality. Peroxide values (PVs) however showed an opposite trend rising with increasing roasting time and boiling time. An increase in PVs from 2.17 ± 0.17 meqO_2/kg at time zero to 2.55 ± 0.14 meq O_2/kg at 20 minutes and finally to 3.40 ± 0.16 meq O_2/kg was observed for roasting. The PV at 20 minutes of boiling was obtained as 2.33 ± 0.06 meq O_2/kg increasing against the control experiment value of 2.17 ± 0.17 meq O_2/kg. It, however, rose significantly to 2.93 ± 0.02 meq O_2/kg when the boiling time was 40 minutes. On the acid values (AVs), they also showed consistent decrement from 16.65 ± 0.15 mgKOH/g at time zero for the control experiment to 15.67 ± 0.32 mgKOH/g and 10.84 ± 0.14 mgKOH/g for roasting and boiling process respectively at time 20 minutes and finally to 9.32 ± 0.25 mgKOH/g and 13.74 ± 0.24 mgKOH/g after 40 minutes of roasting and boiling processes respectively. The data obtained from Table 1 and Table 2 were graphically represented in Fig. 2 below.

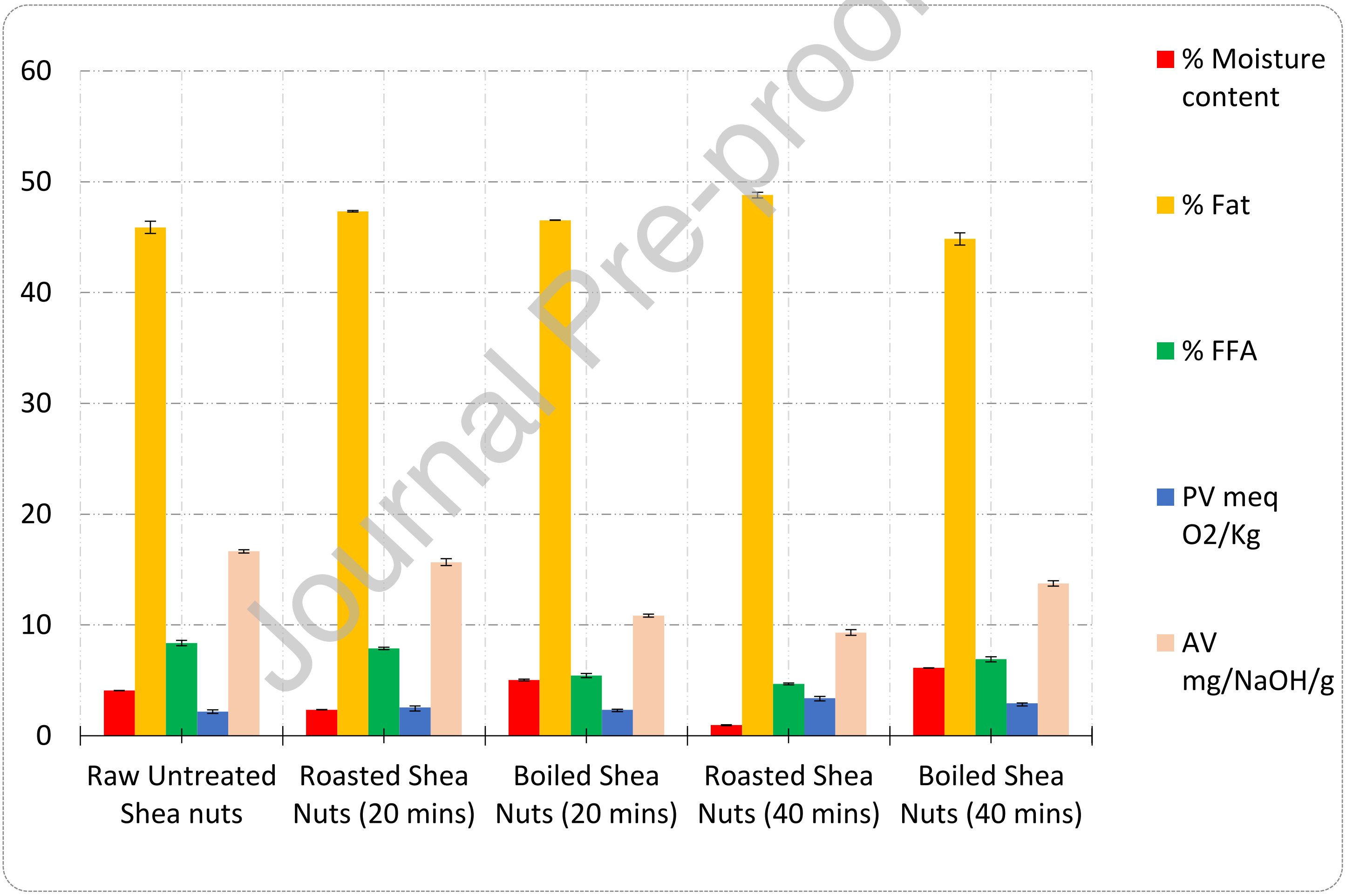

Fig. 2. graph showing the effects of the various pre-heat treatments on the moisture content, oil yield, FFA, PV and an AV of the shea nuts with respect to time

Based on the aforementioned preliminary work, which indicated higher yield and quality of the shea nut butter oil extracted by roasting method, there is a need to design an appropriate rotary roaster machine.

4. Designing of the rotary roaster machine

The design of the roaster was done by considering its material balances, energy balances, and the machine specifications. Fig. 3 below shows the designing of a shea nut rotary roaster machine and its basic parts. NB: All dimensions are measured in meters (m).

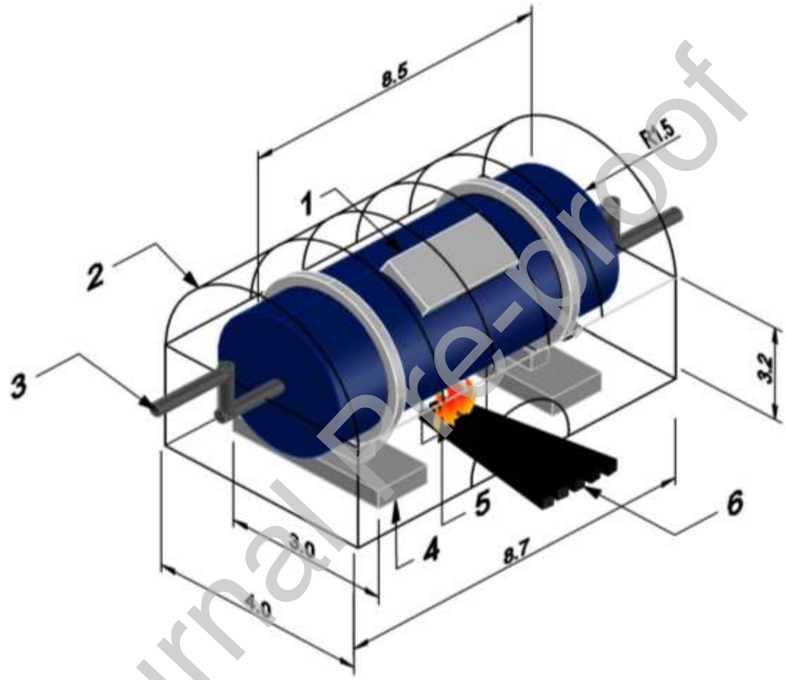

Fig. 3. design of a shea nut rotary roaster machine

Table 3 **:** Main parts of the shea rotary equipment and their material used for their construction

Part	Name	Material of Construction	Quantity
1	Seed Inlet	Carbon Steel	1
2	Insulator	Carbon Steel	1
3	Rotary Handle	Wood	2
4	Support	Carbon Steel	1
5	Drum	Carbon Steel	1
6	Pile of Wood Pellets	Wood	5

Fig. 4, Fig. 5, and Fig. 6 below show the disassembled major parts of the rotary roaster machine.

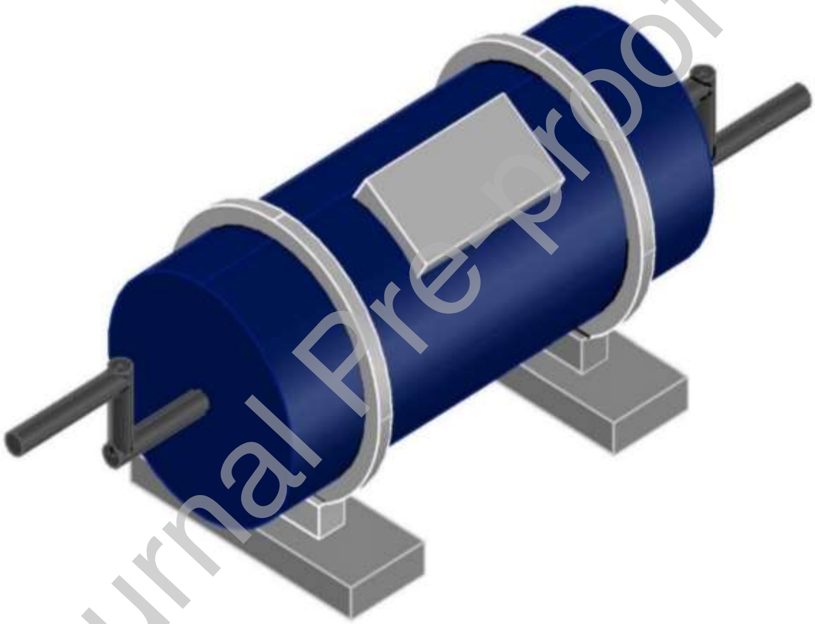

Fig. 4. rotary roasting chamber

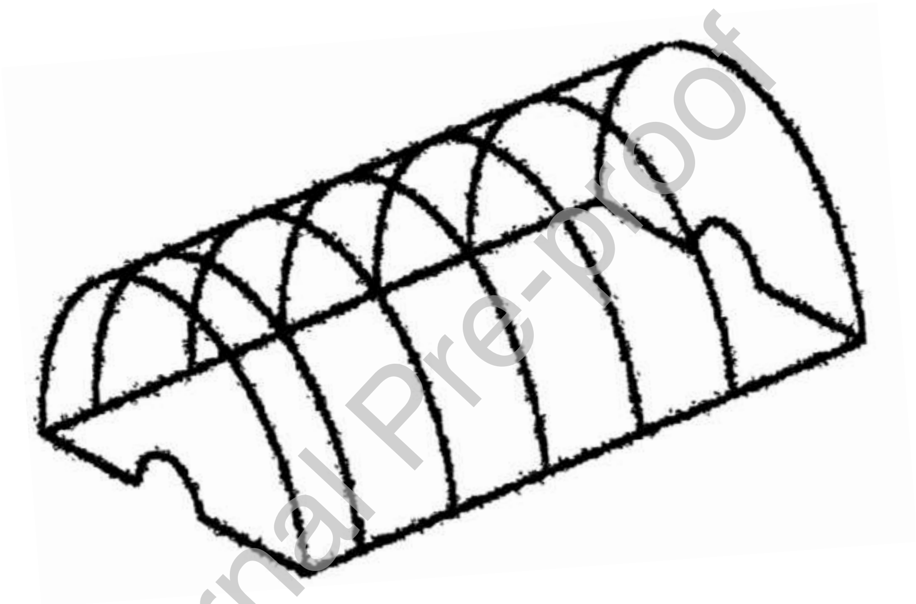

Fig. 5. insulating chamber

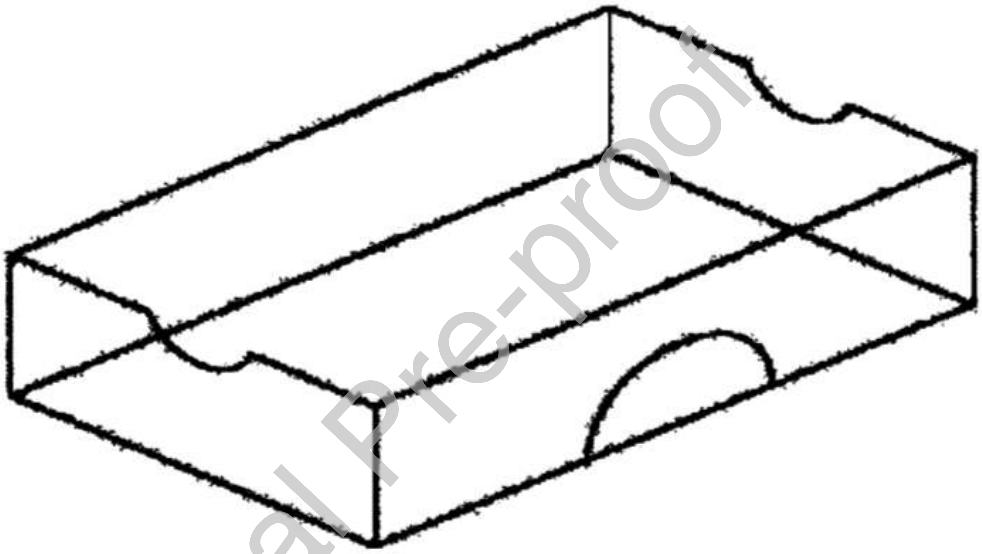

Fig. 6. Basement

4.1. Description of the rotary roaster machine

The rotary roaster machine is a cylindrical shaped vessel with three compartments: roasting chamber, basement and insulating chamber.

4.1.1. Roasting chamber

The roasting chamber houses the fresh shea nuts and has baffles attached to it which help in the turning (stirring) of the nuts as heat energy is directed to the edgings of the roasting chamber. As such, with incessant agitating and application of heat, even roasting of the seeds is attained through conduction, convection and even radiation via the walls of the roaster.

4.1.2. Basement

The basement chamber is the heat energy source chamber situated beneath the cylindrical roaster. This chamber accommodates the firewood, and when burnt, the heat is been transferred via convection and heats up the outer wall surface of the roasting chamber thereby enabling roasting to take place.

4.1.3. Insulating chamber

The insulating chamber is the third compartment of the rotary roaster equipment. It is made of strong insulating material. This insulator helps in reducing heat loss by conduction through the face of the walls of the roaster, as such conserving the heat energy in the system.

4.2. Material and energy balances for the rotary roaster machine

This shows material input and output and the energy balance across the roaster machine.

Basis**:** 60 kg of fresh shea nut per batch was chosen with the aim of obtaining at least 50 kg of shea kernel Fresh shea nut contains 40% moisture with approximately 40% of that moisture content removed by the rotary roaster. Shea nut is composed of 4% shell.

4.2.1. Material balance across the rotary roaster machine

This is the machine where the fresh shea nut is roasted (Fig. 3) using the heat generated from the firewood. It consists of three chambers: the rotary roaster containing the fresh fruits, the basement housing the heating medium i.e., heat from firewood and the insulator to prevents/controls heat loss.

The summary of material balance around the roaster is as shown in Table 4 below.

From the fundamental laws: Input = Output

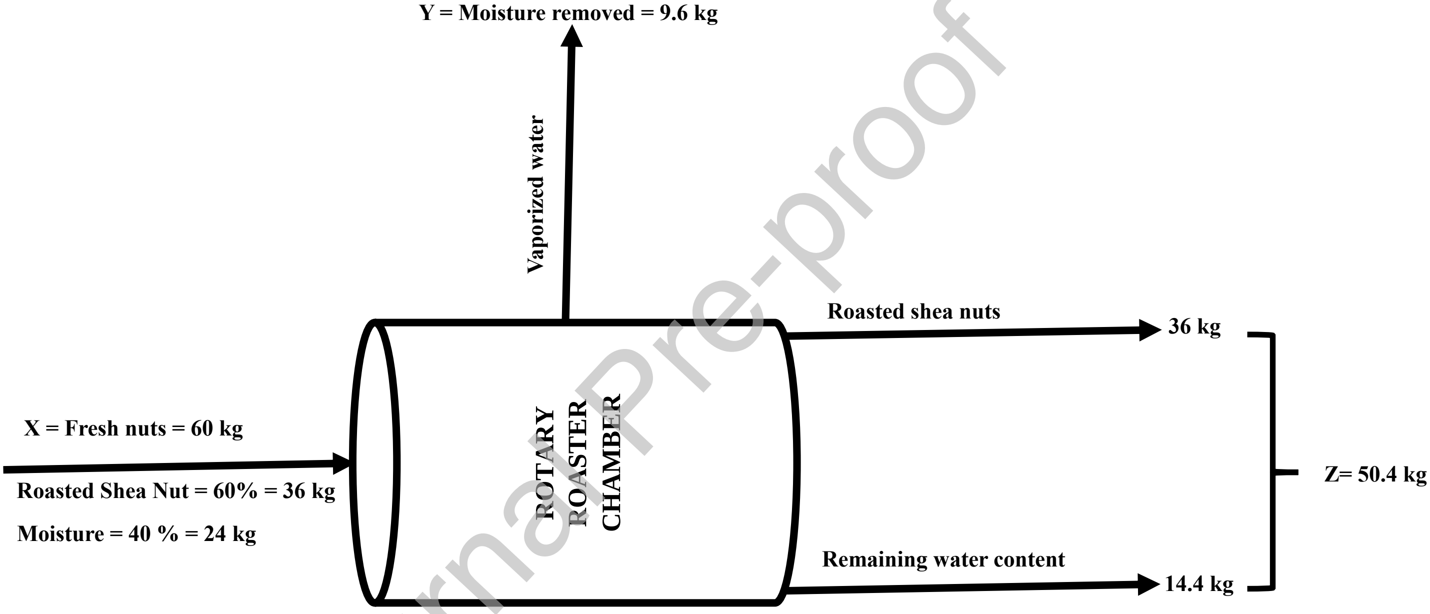

Fig. 7. diagram depicting the material balance across the rotary roaster machine

Table 4 **:** Summary of material balance around the rotary roaster machine.

Feed Streams (kg)	Roasted Shea nut (kg)	Water Content (kg)	Total (kg)
X	36	24	60
Y	-	9.6	9.6
Z	36	14.4	50.4

4.2.2. Energy balance across the rotary roaster

Basis: 60 kg/batch.

Assumptions**:** Specific heat of fresh shea nut was presumed to be stable throughout the temperature range used (Saba et al., 2018). Ambient temperature was chosen as 30°C and the datum temperature is 0°C. Time taken to roast a batch was taken to be 3 hours. Specific heat of fresh shea nut = 3.4 kJ/kg°C, the mass of fresh nut entering the dryer = 60 kg, the mass of water evaporated = 9.6 kg, and the mass of roasted shea nut = 50.4 kg.

The heat content of feed entering the roaster is estimated using Equation 6:

Equation 6

$$Q = M_s \times Cp_s \times (T_1 - T_2) \quad (6)$$

where: M_s denotes the mass of fresh shea nut (kg), Cp_s denotes the specific heat capacity of fresh shea nut (kJ/kg°C), T_1 is the temperature of the feed (°C) and T_2 is the temperature of surrounding (°C), and Q signifies the fresh shea nut's heat content (kJ).

Also, the heat content of roasted shea nut exiting the rotary roaster is estimated using Equation 7:

Equation 7

$$Q = M_r \times Cp_r \times (T_1 - T_2) \quad (7)$$

where: M_r designates the mass of roasted shea nut (kg), Cp_r represents the specific heat capacity of roasted shea nut (kJ/kg°C), T_1 is the temperature of the inner roasting chamber (°C) and T_2 is the temperature of the feed entering the roasting chamber (°C), and Q signifies the heat content of the roasted shea nut (kJ).

If the average heat applied to the shea nut is measured at 150°C, then Equation 8 becomes:

Equation 8

$$Q = M_W \times C_V \quad (8)$$

where: M_w represents the mass of water (kg), C_v is the latent heat of vaporization (kJ/kg), and Q signifies the heat content of vaporized water

Taking heat balance across the rotary roaster machine.

Heat In = Heat out (Assuming losses of heat due to convection, radiation, and conduction are negligible).

Heat In = Heat content of fresh shea nut + heat supplied by the firewood.

Heat out = Heat content of roasted shea nut + heat content of vaporized water.

Heat supplied by firewood = Heat content of roasted shea nut + Heat content of vaporized water- Heat of the fresh shea nut.

Table 5 **:** Summary of energy balance across the roaster

Heat energies (kJ)	Energy In (kJ)	Energy Out (kJ)
The heat content of the fresh nuts	6.120	-

Heat supplied by firewood	63.384	-
The heat content of the roasted nut	-	12.8112
The heat content of vaporized water	-	56.6928
Total	69.504	69.504

Source: Saba et al., J Chem Engineering Process Technology 2018, 9:3

4.2.3. Mean rate of heat transfer

Using Equation 9 below, the mean rate of heat transfer could easily be deduced when the time used for the roasting process is known.

Equation 9

$$Q = \frac{M_r \times Cp_r \times (T_1 - T_2)}{t} \quad (9)$$

where: M_r is the mass of the roasted shea nuts (kg), Cp_r represents the specific heat capacity of roasted shea nuts (kJ/kg°C), T_1 is the temperature of the inner roasting chamber (°C) and T_2 is the temperature of the feed entering the roasting chamber (°C), t is the time (min) and Q denotes the mean rate of heat transfer (kJ/min).

4.3. Design consideration and calculations

The design consideration and calculations are estimated in view of evaluating the necessary design factors such as strength and size of materials of the several machine compartments so as to avoid failure by excessive yielding and fatigue during the required working life of the machine.

4.3.1. Height of roasting chamber

The shape of the rotary roaster is made cylindrical, and for cylindrical roasters, the most economical height to diameter ratio is 2:1. Because the radius is half the diameter, then the height becomes four times the radius.

4.3.2. Design of the baffles

The baffles comprise two pairs of vanes (blades) with various measurements (breadth), regularly separated on the rotary roaster chamber. Each set of vanes is fused on the other side of the chamber. The weight of each baffle vane was estimated as product of the mass of the vane and the acceleration due to gravity.

4.3.3. Volume of the roasting chamber

The roasting chamber is cylindrical, as such; the formula for estimating the volume of a cylinder is applied. This is done with reverence to the number of seeds it can roast per time. Considering safety and volume in line with the ratio of 2 to 3, 33 % of the calculated volume is added to the volume Therefore, Equation 10 becomes:

Equation 10

$$V_{TR} = V + V\,(0.33) \tag{10}$$

where: V_{TR} is the total volume of the roasting chamber (m^3), and V represents the volume of the roasting chamber (m^3).

4.3.4. The capacity of the roasting chamber

The bulk density and mass of fresh shea nuts to be roasted has a great relationship with the capacity of the roasting chamber. Since the roasting capacity is cylindrical, the capacity was presumed to be in the ratio of two to three times of the calculated capacity (Shehu et al., 2017)

Using Equation 11 below, the bulk density could be estimated:

Equation 11

$$\rho_b = \frac{M_b}{V} \quad (11)$$

where: M_b is the mass of material to be processed (kg), ρ_b represents the bulk density of the shea nuts (kg/m^3) and V is the volume of material to be processed (m^3).

4.3.5. Loss of heat through the walls of the roasting chamber

Losing heat through the outer and inner walls of the roasting chamber was anticipated therefore, it is considered during the designing. Every cylindrical surface concentric to the axis of the tube is an isothermal surface and the heat flow route is normal to the surface owing to symmetry (Rayner, 1989). Considering that the rotary roaster is in the form of cylinder, Fourier's law of heat conduction was employed. The heat loss formula, q, (Equation 12) is:

Equation 12

$$q = \frac{2\pi kl(T_1 - T_2)}{\text{In}(\frac{r_2}{r_1})} \quad (12)$$

Where: q expresses the heat loss per unit length (KJ/m), l is the length (heated) of the roaster (m), K denotes the thermal conductivity of the insulating material (W/m˚C), T_1 is the inside temperature of the insulator (˚C), T_2 is the outside temperature of the insulator (˚C), r_1 is the internal radius of the insulating material (m), and r_2 is the external radius of the insulating material (m).

4.3.6. Thickness of insulating material of the insulator

Familiarity and awareness of the quantity of heat loss via the roasting chamber walls show the thickness of the insulating material of the insulator. In ascertaining the thickness of insulating material to be used in the roasting unit, Ali and Shitu, 2013 gave the formula as indicated in Equation 13:

Equation 13

$$\frac{q}{l} = \frac{2\pi k(T_2 - T_1)}{In(\frac{r_2}{r_1})} \tag{13}$$

where: q is the heat loss per unit length (KJ/m), l is the length (heated) of the roaster (m), K denotes the thermal conductivity of the insulating material (W/m˚C), T_1 is the inside temperature of the insulator (˚C), T_2 is the outside temperature of the insulator (˚C), r_1 is the internal radius of the insulating material (m), and r_2 is the external radius of the insulating material (m).

4.3.7. Volume of the basement

The basement of the machine is cuboidal, as such; the formula for estimating the volume of a cuboid is employed. The product of length, breadth and height of the machine helps calculate the volume of the basement.

4.3.8. Volume of the insulating chamber

The insulator of the equipment is shaped half cylindrical, as such; the equation for calculating the volume of a cylinder is applied but modified. Equation 14 indicates the volume of the insulating chamber and it is given as:

Equation 14

$$V = \frac{(\pi r^2 h)}{2} \tag{14}$$

where: V represents the volume of the insulating chamber (m^3), r denotes the internal radius of the insulating chamber (m), h is the height of the insulating chamber (m).

4.3.9. Materials selection of equipment components

Fig. 3 illustrates a detailed isometric drawing view and Fig. 4, Fig. 5, and Fig. 6 shows the exploded view of the rotary roaster. The seed inlet was designed to be made with a standard length of 1.5 mm carbon steel sheet. The insulator chamber was designed to be made of carbon steel with a radius of 2.5 m. Also, the rotary handle was designed to be made of wood due to its relatively high specific heat capacity, thus, its insulative properties. The heat generating compartment (basement) was designed to be made with the carbon steel plate and using wood pellets as its heat source. The rotary drum was also made of carbon steel.

5. Conclusion

Shea nut Rotary Roaster machine has been designed for roasting. Based on the assumption considered for the design, the rotary roaster machine gives efficient yield. The Shea nut Rotary Roaster machine is energy efficient based on the energy balance. The technology transfer aspect of the Shea nut Rotary Roaster machine would be easily achievable as it is easy to operate. The Shea nut Rotary Roaster machine is more convenient to the local community since it is user friendly. Consequently, the machine will offer as a right-hand partner and appropriate device to oil extractors. It can thus be utilized as a part of the manufacturing process for the extraction of oil.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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