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Design, Fabrication and Performance Evaluation of a Shea Butter (*Vitellaria Paradoxa)* Clarifying System

Gbabo Agidi[1], J.T Liberty[2], T.O Fakayode[1] and G.Y Olanrele[1]
Department of Agricultural and Bioresources Engineering, Federal University of Technology, Minna, Niger State[1]
Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria[2]

ABSTRACTS
This work was aimed at the design, fabrication and performance evaluation of a Shea butter clarifying machine. It consists of two units and each unit of the system was made up of three tanks. The inner tank houses the oil to be clarified; second tank holds the water meant for generating steam to melt the oil in the inner tank while the external (third) tank provides insulation needed to minimize heat loss. The first unit of the system was designed to clarify the Shea butter even as the second unit concentrates the oil. A pump was located between the two units to help force the clarified oil from the first unit into the second unit. The designed system had capacity to clarify 170litres of oil in an hour in a single batch operation. When the oil was gently stirred by the stirrer welded to a shaft, impurities in the oil settles down at the conical section of the inner tank due to difference in densities and the action of reagents added. The impurities can easily be separated out while the cleaned oil floats at the top and pumped into the second tank. Power was generated from a 0.5hp (373W) electric motor for shaft rotation through gear motors which also assisted to reduced the motor speed from 1450rpm to the selected speed of 45rpm. The test result indicated that the clarifying system functioned properly. About 80litres of Shea butter was used to test-run the machine. Sodium hydroxide (NaOH) and activated carbon were used as reagent to assist in the oil clarification. After the test, approximately 70litres of clarified Shea butter was recovered.
Keywords: Clarified, design, fabricate, performance evaluation, Shea butter

I. INTRODUCTION

Nigeria and many other Africa countries is making great effort to boost her economy by limiting imports and promote exports which has resulted to intense research into possibility of obtaining a wide range of products from locally available agricultural products. Food and agricultural processing, extraction of liquids from solid raw materials has been an area of interest to many researchers.

Recently, research and development in Shea butter extraction enterprise has become an essential task in vegetable oil extraction industry in Nigeria as it’s being used as raw material for food, soap, cosmetics, pharmaceutical, medical, cooking oil, and metal cutting fluids and as a substitute for cocoa butter in chocolate and confectionary industries. These products have high potential for export (Olaoye, 1994).

The traditional method of Shea butter clarification and purification involves stirring the butter extracted vigorously in a heating chamber, while the oil which floats up is then ladled off the top of the pot with the slurry settling down at the bottom of the pot. This however, despite the human effort exerted does not give a clear and pure Shear butter. Also, Shea butter produced by traditional method of or by the use of oil expeller contains physical impurities, high free fatty acid and other natural triglycerides. It is therefore imperative to have an efficient and effective clarifier that will produce a pure Shea butter, reduce human drudgery and requires less skills and strength to operate.

Therefore, this work is aimed at the:

i. Design of Shea butter clarifying system
ii. Fabricate a Shea butter clarifier
iii. Performance evaluation of the Shea butter clarifying system
iv. Produce a Shea butter void of any physical impurity and reduced free fatty acid (FFA) content

II. MATERIALS AND METHODS

Design Parameters

The design parameters considered for design of the clarification system include availability of material, thermal conductivity of material, versatility, durability strength, efficiency, ease of maintenance, ease of operation, cost of materials, ergonomics and the technological status of the intended users.

Materials Selection

Some of the factors considered in choosing materials for this fabrication work include; thermal conductivity of the materials, fabrication cost, operation and maintenance cost, availability of material, strength and rigidity.

Physical Properties Determination of Shea Butter

Melting point: This is the point at which Shea butter exist as oil. According to Alander (2002), Shea butter melts at approximately 30°C – 35°C depending on the variety and quality of the nut from which the oil was extracted.

Viscosity: The more viscous a vegetable is, the better it is as lubricant. According to Olaniyan and Oje (2007), Shea butter has an optimum viscosity of about 100cp when the heating temperature is 70^0-90^0C.

Moisture Content: Moisture content of oil must be made minimal as possible. This is because oils with high moisture content are susceptible to recontamination or rancidity. According to Olaniyan and Oje (2007), moisture content reduces as the temperature increases.

Colour Intensity: Yellow is the dominant colour of Shea butter at all heating temperature. Heating above 90^0C will results in darkening of the oil.

Rancidity Index: As the heating temperature increases, there is an increase in the rancidity index as indicated by the darkening of the oil. Rancidity index indicates the degree of deterioration of fats and oil. Rancidity index sets in at 90°C (Olaniyan and Oje (2007).

Components of the Machine

Tank: is the main component of the clarification system. They contain the oil to be clarified, water to generate steam and the insulating material.

Shaft: is the rotating component used to transmit power from electric motor to the stirrer/agitator. Power was delivered to the shaft by some tangential force and the resultant torque set up within the shaft permits power to be transferred to various parts linked to it. Members such as gears were mounted on the shaft in order for it to transfer power.

Stirrer/Agitator: this is the component used for gentle stirring of the oil. It was made up of stainless steel sheet attached welded to the shaft.

Worm Gear: transmits power at high velocity ratios between non-intersecting shafts that are generally but necessarily at right angle. The worm gear is widely used as speed reducer, which consist of worm and a worm wheel or gear.

Electric Motor: Converts electric energy into mechanical energy. It provides the rotational motion and power needed to rotate the shaft through the gear system.

Hollow Pipe: Helps convert the refined oil into the second unit (tank) for concentration of the oil and it was connected through an electric pump.

Electric Pump: Assists to force the oil under pressure through pipes into the second tank for concentration of the oil.

Description of the Machine

The Shea butter clarification system designed was made of two main units. The two units (tanks) were made of same material and volume. Both units consist of three compartments (tanks). The first (inner) tank houses the stirrer and the oil to be clarified. A hollow pipe extends from one edge of the tank (at different levels of oil) to the other, without passing through the centre of the tank so as not to impede the rotation of the stirrer. The hollow pipes serve to increase the rate of heat transfer into the oil by conveying the steam generated from the second tank into and through the first tank. The major task of the first tank was to clarify the oil. The second tank was meant to boil water so as to generate steam to melt oil in the inner tank (first tank). It had a boiler/heating element attached to it for boiling water while the third tank (external) provides insulation for the entire system hereby minimizes heat loss to the environment.

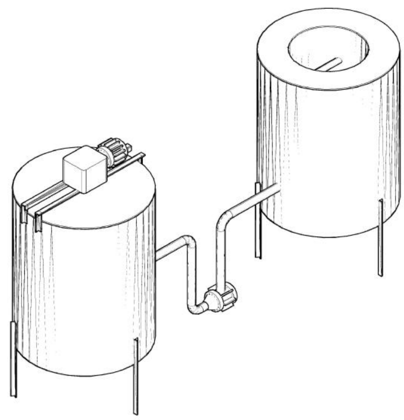

Fig.1: the two units of the Shea butter Clarifier

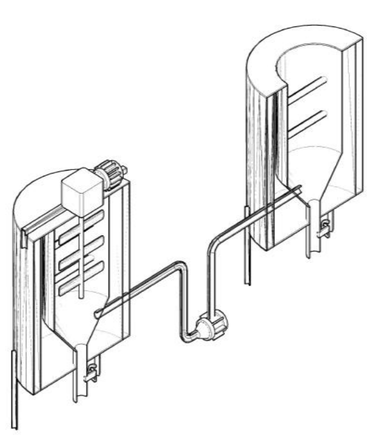

Fig.2: *A cross section through the Shea butter Clarifying System*

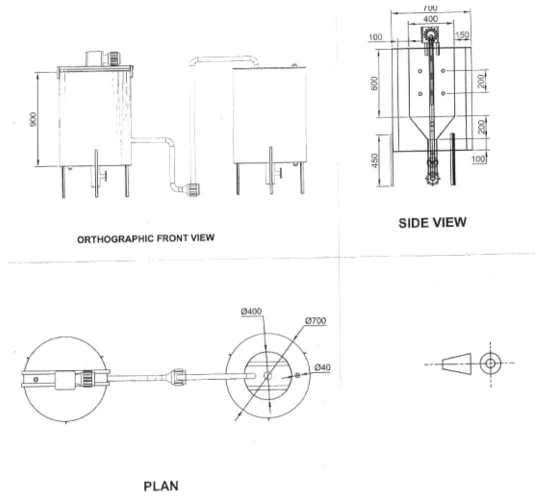

Fig3: Orthographic View of the Clarifier

Design Calculations of Major Components

1. Design of the Tank

(a) Inner tank

Capacity = 85litres = 0.085m^3

The capacity was divided between the three sections of the tank;

i. Upper cylinder

Capacity = 75litres = 0.075m^3

$$V = \pi r^2 h$$

A diameter of 0.4m was assumed for the inner tank to allow for easy rotation of the shaft

D = 0.4m, r = 0.2m

$$0.075 = \pi x 0.2^2 xh, \therefore h = \frac{0.075}{\pi x 0.2^2} = 0.59 \approx 0.6m$$

ii. Frustum of cone

Capacity = 9.8litres =0.0098m^3

$$V = \frac{1}{3}\pi h\left[R^2 + R(r) + r^2\right]$$

The same diameter of the upper tank was transferred as the top diameter of the frustum of the cone.

A diameter of 4cm (0.04m) was selected for the bottom diameter of the cone.

Therefore, if D = 0.4m; d = 0.04m; r = 0.02m; R = 0.2m

$$0.0098 = \frac{1}{3}\pi h\left[0.2^2 + (0.2x0.2) + 0.02^2\right]$$

Hence, $h = \frac{3x0.0098}{0.0444x\pi} = 0.21m \approx 0.2m$

iii. Lower cylinder for discharge of slurry

Capacity = 0.002m^3 (0.2litres)

The bottom diameter of the frustum of the cone was the same diameter of hollow pipe for discharge of slurry

d = 0.04m; r = 0.02m; $V = 2\pi r^2 h$

$$0.0002 = \pi x 0.02^2 xh; \therefore h = \frac{0.0002}{\pi x 0.02}$$

$$= 0.1521m \approx 0.15m$$

(b) Second tank

Capacity of the second tank = 250litres = 0.25m^3

A capacity of 250litres was designed so as to have enough space for the water needed to generate steam An allowance of 0.1m was allowed between inner tank and second tank. Therefore, the diameter of the second tank is;

$$D = 0.4 + (0.1 + 0.1) = 0.6m$$

$$d = 0.6m; r = 0.3m; V = \pi r^2 h$$

$$0.25m^3 = \pi x 0.3^2 xh; \therefore h = \frac{0.25}{\pi x 0.3^2}$$

$$= 0.884m \approx 0.9m$$

(c) Third tank (external)

Capacity of tank = 350litres = 0.35m^3

An allowance of 0.05m (5cm) was also given between the second and the external tank. Therefore,

$$d = 0.6 + (0.05 + 0.05) = 0.6 + 0.1 = 0.7m; r = 0.35m$$

$$V = \pi r^2 h; 0.35 = \pi x 0.35^2 xh$$

$$h = \frac{0.35}{\pi x 0.35^2} = 0.909m \approx 0.9m$$

(d) Volume of the space to be filled with water

Volume of space to be filled with water = volume of second tank-volume of inner tank

Let volume of the second tank be = V_2

Volume of second tank = V_1

Volume of space between the two tanks be = V_3

$V_3 = V_2 - V_1$

$V_2 = 0.2m^3$; $V_1 = 0.085m^3$

$V_3 = 0.2 - 0.085 = 0.115m^3$ = 115litres

Hence, the volume of the space to be filled with water was 115litres. Now assuming this space was 1/3 filled with water, then;

$$V = \frac{1}{3}x0.115 = 0.038m^3 = 38.33litres$$

Therefore, volume of water required to fill the space when it is 1/3 filled with water was 38.33litres

Since volume of water is known, the mass of the water was calculated thus;

$$Density = \frac{mass}{volume}$$

$$\therefore Mass = Density x Volume$$

Density of water at 4^{0}C is 1000kg/m^3 (Douglas, 2005)

Volume = 0.038m^3

$$\therefore Mass = 1000x0.038 = 38.33kg$$

2. Design of the Shaft

For a shaft with little or no axial load, the diameter may be obtained using the American Society of Mechanical Engineers (ASME) code equation given as;

$$d = \left(\frac{16}{\pi S_a} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \right)^{\frac{1}{3}}$$

Where,
d = diameter of the shaft
M_b = bending moment
M_t = torsional moment
K_b= combined shock and fatigue applied to bending moment
K_t = combined shock and fatigue factor applied to torsional moment
S_a = allowable stress
For rotating shaft when load is suddenly applied (minor shock) (Khurmi and Gupta, 20050;
K_b = 1.5 to 2.0; K_t = 1.0 to 1.5
For shaft without keyway, allowable stress S_a = 55MN/m^2
For shaft with keyway allowable stress S_a = 40MN/m^2

Determination of Maximum Torsional Moment

$$M_t = \frac{kWx1000x60}{2\pi rev/\min} = \frac{9550xkW}{rev/\min}$$ (Hall et al. 1981)

$$Power = 3hp; \ Speed N = 1450rpm$$

$$1hp = 746W; \ 3hp = 2238W = 2.238kW$$

$$M_t = \frac{9550x2.238}{1450} = 14.74Nm$$

Determination of the Bending Moment

Load distributed on shaft;

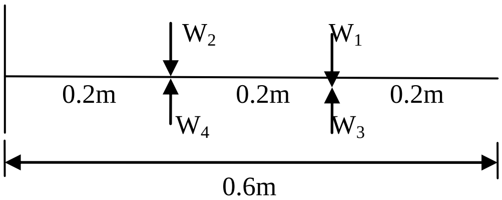

Fig. 3: Free body diagram of Shaft

$$W_1 = W_2 = W_3 = W_4$$

W_1 = weight of blade on shaft
To calculate the weight of the blade;

$$Density = \frac{mass}{volume}; \ mass = densityxvolume$$

$$Volume = Areaxthickness; Thickness = 2mm = 0.002\,m$$

$$Length = 10cm = 0.1m; \ Breadth = 5cm = 0.05m$$

$$Area = 0.1x0.05 = 5x10^{-3}m^2$$

$$Volume = 5x10^{-3}x0.002 = 1x10^{-5}m^3$$

$$Density \ of \ steel \ material = 7850kg/m^3$$

$$Mass = 7850x1x10^{-5} = 0.0785kg$$

$$Weigth = massxacceleration \ due \ to \ gravity$$

$$W = 0.0785x9.81 = 0.77N$$

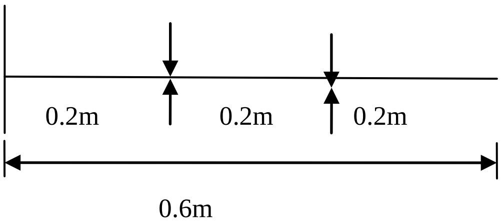

Fig. 4: Free body diagram of Shaft

$$W_1 = W_2 = W_3 = W_4$$

Taking moment at A

$$\sum M^+ = W_2x0.2 - W_4x0.2$$

$$= 0.77x0.2 - 0.77x0.2 = 0.154 - 0.154 = 0$$

Taking moment at B

$$\sum M^+ = W_3x0.2 - W_1x0.2$$

$$= 0.77x0.2 - 0.77x0.2 = 0.154 - 0.154 = 0$$

Taking moment about C

$$\sum M^+ = (W_1x0.4) + (W_2x0.2) - (W_3x0.4) - (W_4x0.2)$$

$$= (0.77x0.4) + (0.77x0.2) - (0.7x0.4) - (0.77x0.4)$$

$$= 0.308 + 0.154 - 0.308 - 0.154 = 0$$

Therefore bending moment = 0

$$d = \left(\frac{16}{\pi S_a} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \right)^{1/3}$$

$$K_b = 2.0; \ K_t = 1.5; \ M_b = 0; \ M_t = 14.74Nm; S_a = 40MN/m^2$$

$$d_3 = \left(\frac{16}{\pi x40x10^6} \sqrt{(2.0x0)^2 + (14.74x1.5)^2} \right)^{1/3}$$

$$= \left(\frac{16}{\pi x40x10^6} \sqrt{0^2 + (22.11)^2} \right)^{1/3}$$

$$= \left(\frac{16}{\pi x40x10^6} \sqrt{(22.11)^2} \right)^{1/3} = \left(\frac{16353.76}{\pi x40x10^6} \right)^{1/3}$$

$$= \left(\frac{16353.76}{125663706.1} \right)^{1/3} = (2.815x10^{-6})^{1/3} = 0.014m = 14.18mm = 15mm$$

3. Design of the Stirrer

The stirrer consists of three pairs of blade with equal dimensions, spaced equally on the three shaft rod. Each pair was made of two blades and each blade was welded on opposite side of the shaft.

Length of stirrer = 10cm = 0.1m
Breadth of stirrer = 5cm = 0.05m
Thickness = 2mm = 0.002m

$$Density = \frac{mass}{volume} \ Volume = areaxthickness;$$

Area = L x B

$$Volume = LxBxthickness = 0.1x0.05x0.002$$

$$= 1.0x10^{-5}m^3$$

Density of steel material = 7850kg/m^3

$$Mass = 7850\,x1.0x10^{-5} = 0.0785\,kg$$

Therefore the mass of each stirrer was 0.0785kg
Since there were six blades of the stirrer,

$$Total\ mass = 0.0785x6 = 0.471kg$$

$$Weight = massxacceleration\ due\ to\ gravity$$

$$= 0.471x9.81 = 4.62N$$

Fabrication and Evaluation of the Machine

Fabrication: All parts of the Shea butter clarifying system were fabricated from metals except the insulator made of a good insulting material, Rockwool. The inner and second tanks were fabricated from stainless steel while the external tank was fabricated from mild steel. The choice of stainless steel for the inner and second tank was because of the food material involved (Shea butter) and water which could cause corrosion of the metals and subsequent contamination of the food material.

The shaft was made of steel rod while the stirrers-stainless steel sheet. Also, the pipes in the inner tank designed for better heat circulation in the oil, were made of stainless steel material and the pipes for conveying the clarified oil into the second tank was made of galvanize steel because of the high temperature of the flowing fluid.

For this design, the shaft obtained power from the motor for rotation through the gear motor which eliminates completely attachments such as pulleys and the belt system thereby eliminating the problem of belt slipping off the pulley during rotation. The tanks were fabricated using 2mm thick metal material. The support for the motor was fabricated using 4mm thick angle iron while the tank-stand was also fabricated with 4mm thick angle iron. The pipe in the inner tank was made of $1\frac{1}{2}$ inch diameter pipe while the pipe for oil transfer into the second tank was made of $\frac{3}{4}$ inch. The gate valve was a brass material while the pressure relief valve was also $1\frac{1}{2}$ inch in diameter.

Testing: An evaluation was done to ascertain whether the constructed clarifying system functions properly. 80litres of Shea butter was used to test-run the machine alongside some reagents. The stirrer gently rotates as designed while the water in the second tank also boiled at the designed time, 30minutes.

Reagent Used;

a. **Caustic soda (NaOH)**

0.1M of NaOH solution was prepared in 250cm^3 of distilled water.
Preparation: 4g of NaOH dissolved in 1000cm^3 of distilled water to give 0.1M of NaOH solution. Therefore, 1g of NaOH dissolved in 250cm^3 of distilled water to give 0.1M of NaOH solution. The caustic soda reacts with Free Fatty Acids present in the oil and neutralized it to form soap which can be separating out at the conical section of the tank after agitation of the oil.

b. **Bleaching agent**

Activated carbon was used as the bleaching agent. 1kg of activated carbon was added to the 80litres of Shea butter to be clarified. The quantity of bleaching agent added depended on the end colour desired. The more the amount added toa certain level, the brighter the colour of the oil produced, because there will be more of the agent to absorb all the colouring pigment. The activated carbon reacted with the colur pigment present in the oil it thus, discolouring the oil.

Plate1: Sample of the Crude Shea Butter

Plate2: Sample of the Clarified Shea Butter

III. RESULTS OBTAINED

Volume of Crude Shea butter = 80litres
Colour of crude Shea butter = Dark Yellow
Volume of Caustic Soda (NaOH) = 250cm^3
Mass of Activated Carbon = 1kg
Time = 60minutes

The water in the tank was allowed to boil to generate the required heat to melt the oil completely before adding the reagents. Caustic soda was added first and the soap stock formed as result of the reaction between the NAOH and the free fatty acid was separated out first before adding the bleaching agent to remove the colouring pigment. The soap stock formed had to be removed first before adding

the bleaching agent so as not to impede the action of the bleaching agent.
Volume of Clarified Shea Butter = 70litres
Colour of Clarified Shea Butter =Yellow
Volume of Slurry Obtained $\approx$ 10litres.

IV. CONCLUSION AND RECOMMENDATION

The clarifying system developed will help improve the quality of Shea butter hence, make it more attractive and appealing to buyers.The results obtained from the performance evaluation showed that the clarifying system functioned properly as expected. Using 80litres of oil to test the machine while adding 0.1M of 500ml of sodium hydroxide (caustic soda) and 1kg of activated carbon as a bleaching agent, a golden yellow coloured Shea butter was obtained and approximately 10litres of slurry was also separated out. Visual inspection of the clarified Shea butter indicated that there was no visible evidence of any physical impurity present.

However, a filter bed should be introduced at the point of oil flow from the first unit into the second unit to further help trap finer particles and some other colouring pigment present in the oil. Also, a temperature sensor should be introduced into the oil to determine at any instant the temperature of the oil in order to avoid over heating of the oil.

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