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Design Consideration and Performance Evaluation of a Coconut Oil Extracting Machine

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Abstract: Extraction of virgin coconut oil from coconut kernel is a major influential step for their commercialization. There are many extraction processes among which cold and hot extraction are conventional extraction processes. This paper focused on the design, construction and testing of a coconut extractor using fresh-dry process based on the low pressure oil extraction method production of virgin coconut oil to reduce the settling time of oil. Additionally, tests carried out on the machine were the oil quality test, yield comparison with conventional oil extractors and user experience. The drying motor of 1500hp was used for grinding and a 12V Dc motor converted to an AC drive was used for conveying to the extraction chamber. A heating element of 3KW was incorporated in the extraction chamber which was properly lagged to avoid heat losses. Results obtained showed that it takes 800 seconds of heating time at 70°C to actually extract oil from dried coconut under different parameter such as drying temperature, extraction time and moisture content. The production efficiency of machine was calculated to 69.5% and the machine performance was certified good. Oil quality was recorded at 0.46% free fatty acid. The designed extractor yielded approximately 20.7% of oil against 14.1% as recorded from traditional methods. User experience was rated an average of 8.47 on a maximum scale of 10 with ratings obtained from experts (7.5) experienced users (8.7) and non- experienced users (9.2). The production machine is novel for easier, safer and more economical extraction of virgin coconut oil over the traditional and conventional methods.

Keywords: Coconut Oil, Extraction Machine, Small-Scale Extraction, Cost-effective Extractor, User-Friendly Extractor, Performance Evaluation.

I. INTRODUCTION

Extraction of virgin coconut oil from coconut kernel is a major influential step for their commercialization. There are many extraction processes among which cold and hot extraction are conventional extraction processes. The hot extraction process carried out by pressing the clean, ground and fresh coconut to yield coconut milk followed by heating at the high temperature that could remove the useful micronutrient. Cold process extraction of coconut oil takes place through destabilization of the coconut milk emulsion without heating such a fermentation, chilling and thawing, or centrifugation. The oil extraction technology has been in use for a very long time in the developed countries and the techniques that are followed for expelling oil are very laborious and relatively inefficient. There has not been any significant improvement in the oil extraction processes and even today a century old technology such as single screw press, hydraulic presses are being used in various part of the country. The oil extractor is a screw type machine, which presses nuts through a caged barrel-like cavity. coconut enter from the hopper, grinded, pressed and oil exit the other side. The machine uses friction and continuous pressure from the screw as it drives in and compresses the seed material. The oil seeps through small openings that do not allow solid seed fibre to pass through.

Afterward, the pressed nut is formed into a hardened cake, which is removed from the machine. Extractor pressing (also called oil pressing) is a mechanical method for extracting oil from raw materials. The raw materials are squeezed under high pressure in a single step. When used for the extraction of food oils, typical raw materials are nuts, seeds, and algae, which are supplied to the press in a continuous feed. If we scale down the industrial oil extractor, we can see that the main workings of the extractor are the helical thread in the barrel that creates a large amount of force pressing the coconut in the process extracting the oil. The best scale down version of the helical thread is to use a screw press in a cage barrel or press chamber. It will act as a miniature extractor and it will be cost-effective for a setting up a small business. In other words, the oil extractor in this report is a miniature or a scale down version of its industrial cousins. The design of the oil extractor needs to be suitable for small-medium businesses where the total cost of setting up and running the machine is low

Virgin coconut oil (VCO) is a growing in popularity as functional food and the public awareness of it is increasing .it is expected that VCO will experience a dramatic growth in the market. It has a mild to intense fresh coconut scent depending on the type of process used for production. VCO can be consumed in its natural state without the need for further processing.

A. Problem Statement

Production process of the coconut oil in Nigeria is by the fermentation method. In this process, the coconut is fermented for 24 to 36 hours. During this period, the lighter oil is separated from the water and the resulting wet oil is slightly heated for a short time to remove the moisture and it is then finally filtered. Industrial facilities utilizing this procedure often require advanced refining techniques to expunge the fermented odour. Furthermore, this method of producing oil from coconuts has been seen to be tedious, inefficient and generally yields little oil.

These problems therefore make production hard and unprofitable. A high yield equipment, based on high quality process for both high and medium scale production is needed.

B. Objectives Of Study

The main objective of this study is to design and evaluate the performance of a coconut oil extracting machine. The specific objectives include:

1) To design a mechanical extractor for coconut oil
2) To construct using the design parameters a mechanical extractor for coconut oil
3) To determine the mechanical efficiency of the designed and constructed extractor for coconut oil

II. LITERATURE REVIEW

A. Economic Importance Of Coconut Oil

1) Characteristics of Coconut Oil

In its purest form, coconut oil is clear (like clean water), with a distinct coconut flavour and aroma and no rancid smell, even without undergoing chemical refining and deodorisation processes. It was only in the late 1990s that the clear version of coconut oil (otherwise known as virgin coconut oil) became known in the market. The coconut oil which has been traditionally produced and traded since the later part of the 19th century is yellow in colour. The most significant physical property of coconut oil is that, unlike most fats, it does not exhibit gradual softening with increasing temperature but passes rather abruptly from a brittle solid to a liquid within a narrow temperature range. Coconut oil is liquid at temperatures of 27°C or higher and is solid at 22°C or lower, when it is similar to the consistency of cocoa butter. Coconut oil that does not rapidly solidify when placed in the refrigerator is not pure, and presumably has been mixed with other oil or other substances. Copra-derived coconut oil has been produced and used commercially for almost a century as such, its use for edible and inedible applications have already been well established (Banzon, 1990). For edible purposes, coconut oil is generally used as:

a) As a frying and cooking oil because of its excellent resistance to rancidity development.
b) It is also used as a substitute for expensive butter fat in filled milk, filled cheese and ice cream making these products cheaper without changing their palatability.
c) When hydrogenated, coconut oil is used as margarine, shortening and baking fat. Other edible applications of coconut oil are (Banzon,1990):
d) As a source of fat in infant formulas and baby foods because of its easy digestibility and absorbability;
e) As a spray oil for crackers, cookies and cereals to enhance flavour, increase shelf-life and impart a glossy appearance;
f) As an ingredient in confectionaries such as candy bars, toffee, caramels, etc

And as an oil obtained from the fresh, mature kernel of the coconut by mechanical or natural means, with or without the use of heat, without undergoing chemical refining, bleaching or deodorizing, and which does not lead to the alteration of the nature of the oil. The intensity of the scent depends on the process used in its production, coconut oil has the same physical and chemical characteristics but have different sensory attributes and prices.

2) Uses and Applications

As an edible oil, coconut oil is used for frying and cooking because of its good resistance to rancidity development Bawalan *et al*. (2006). It is also used as a substitute for expensive butterfat in filled milk, filled cheese (reconstituted milk/cheese) and ice cream to make these products more affordable without altering their palatability.

When hydrogenated, coconut oil is used as margarine, shortening and baking fat. Other edible applications are as follows:

a) a source of fat in infant formulas and baby foods because it can be easily absorbed and digested;
b) a spray oil for crackers, cookies and cereals to enhance flavour, increase shelf-life and impart a glossy appearance;
c) an ingredient in confectionary. The Spectrum of Coconut Products (PCA undated) states that in food preparations and in diet, coconut oil performs the following functions:
d) It serves as an important source of energy in the diet.
e) It supplies specific nutritional requirements.
f) It provides the lubricating action in dressings and the leavening effect in baked items.
g) It acts as a carrier and protective agent for fat-soluble vitamins.
h) It contributes to palatability and enhances the flavour of food.

The major inedible use of coconut oil is as a raw material for (Bawalan *et al*., 2006):

- The manufacture of laundry and bath soaps,
- Coconut chemicals for the production of biodegradable detergents, shampoos, shower gels and other cleaning agents,
- Cosmetics and toiletries,
- Foam boosting of non-coconut oil-based soaps, and
- The production of synthetic resins and plasticisers for plastic.

3) Traditional and Mechanized Methods of Coconut Oil Extraction

It is important to note the following comparison between the mechanized extraction and the traditional method. Or the advantage of mechanized extraction has over the local method.

a) The mechanized extraction saves time unlike the traditional method which is time consuming.
b) In mechanized extraction, a greater percentage of oil is obtained unlike the traditional method where much oil been loss.
c) The stress undergone in the traditional method is highly reduced when it is done mechanically. However, in traditional method, the mechanized extraction has disadvantage, if not properly checked the fluid will contaminate the oil.

B. Design Principles

Sangameshwara (2015) highlights that the machine has a simple construction and is light in weight which makes it portable and can be used for domestic and commercial purposes. His study, however was limited in its applications as he chose to focus only on the size of the machine. It may have been more illustrative to broaden the scope of the study. Aremu *et al*. (2013) presented the design of an oil extractor machine for kenaf. The designed machine having the capacity of 36.5 kg/hr and capable to extracted oil efficiency up to 62.2%. The designed machine is provided with the best lubrication and easily maintained. Shankar Haldar *et al*. (2012) presented the research study on the information about the oil extractors including the availability of raw materials. This study mainly emphasis on the different issues related with used oil; extractor its design features and process and developing the site for extractor industries. Zamandeh *et al*. (2004) presented the different failures analysis methods and the materials selection for oil extractors. In this report paper, various subsets of the design materials are taken in to consideration applicable to the study. This study includes mainly on the failures in the, paints and coatings, plastics and electronics, as well as failure caused by corrosion and principles of root cause determination within that particular field. Deli *et al*. (2011) carried out the research study effects of physical parameters in screw press machine. In this study, sativa seeds were studied using a screw type oil extractor. The study is carried out with different sizes of nozzle and at different speed of the shaft, also the different diameter of the shaft is taken into the consideration for the study. It is found that the shaft diameter with 8mm shows low yields output but the diameter of the shaft 11mm with speed of 65 RPM shows the good performance. The nozzle size of 12mm recorded the same percentages of yields. The most of results obtained are varying with changes in the physical parameters, the optimum conditions of parameters recorded 22.27% oil yields with 8mm diameter and 19.05% with 11mm diameter of extractor shaft.

Ebuka *et al*. (2015) did precisely that in their pivotal longitudinal, multi-facility, broad-scope of study which a machine is incorporated with both heating element and a plunger to get at least 80 percent of virgin oil in a single operation. What this reveals to us is that coconut oil extractions from coconut gratings using the ram press, the sundried coconut gratings containing approximately 3% moisture can be processed in a ram press. Sreenatha Reddy *et al*. (2010) developed the mini model of the oil extractor screw shaft and finding out the effect with variation of compression ratio of oil chamber along with speed of screw shaft.

The experimentation is carried out with Pongamia and Jatropha seeds and the compression ratio are maintained at 14:1 to 21.5:1 with alternating speed of shaft between 35 to 654 RPM. The results of the study concluded that the compression ratios have significant impact on the performances of the oil extractor screw. Ibrahim *et al.* (2005) carried out the review on the different technologies for oil extraction from agricultural product. The presented study included the use of different techniques for pre-processing conditions including the removal of hulls and shells, pre-processing conditioning such as size reduction, moisture content adjustment, heat treatment and pressure application, as well as the method employed in the extraction namely; traditional and modern(improved) methods discussed in this paper.

Adesoji *et al*. (2012) designed, an oil extractor screw press and tested with extraction of oil in palm kernel and soya bean. The extractor is powered with 15 HP three phase motor. The average extraction efficiency of 13.48 and 22.79% obtained with designed extractor screw. The results concluded that the mini extractor can be useful in the production of oil for soybean and palm extraction for community. This is equivalent to an extraction efficiency of 85% which is comparable to that achieved by a small-scale extractor. This process shows considerable promise, but has yet to be widely adopted. A weakness with this argument, however is that the efficiently of the virgin coconut oil fully depends on the accurate management of the moisture content of the raw coconut before the extraction of the oil.

This is very important because the fresh dry low pressure oil extraction method is also called intermediate moisture content method by the researchers from the Natural Resources Institute (NRI) of the United Kingdom which developed and introduced the technology to the Philippines and several countries in Africa. It works on the principle that oil from seeds or nuts can be extracted using low pressure (About 31.7bar) provided that the moisture content of the raw material is within the range of 10-13%. The traditional process of extracting plant-based oil is through the use of high-pressure extractors (above 110.3bar) generally at a feed moisture content of 3-4%.

C. Moisture Content And Temperature

Arunkumar *et al.* (2014) found that the extraction of oil from coconut either by dry process or wet process could be more difficult during rainy seasons and for those who are not comfortable with the conventional method of oil extraction process, they have developed a new machine without making use of solar heat for 10-15 days for drying coconut. Hence this compact model has been developed to eliminate the disadvantage for drying mature coconut in the sun for more than a week.

Ewuzie (2018) made a very valid point that instead of drying mature coconut for dehumidification, he made use of heater and blowers to dehumidify the coconut moisture. He countered the numerous village-scale industries that use wet processing and said that most of them are in effect, scaled-up versions of domestic method, he further added that such operations usually incorporate a powered grater and some form of manual press to extract the coconut milk.

Over the years, researchers found that moisture content is one of the principal factors, which govern the overall quality of desiccated coconut. Generally, rancidity and microbial contaminations may proportionately Increase with the Increase of moisture content of the sample. Choe *et al.* (2006) study made a strong point that, moisture and volatile matter are important determination of oil quality. He further suggested that it actually desirable to keep the moisture content low as it will increase the shelf life by preventing oxidation and rancidity process. Raghavendra *et al.* (2001) study suggested that moisture content promotes hydrolytic rancidity of fats and oil. Refined Coconut Oil (RCO) had significantly lower moisture content that all Virgin Coconut Oil samples (Asian and Pacific Coconut Community, APCC, 2009). Enzymatic and centrifugation techniques had moisture content of 0.39 and 0.34%, respectively which were both above APCC set standard of < 0.2% as separation of water and oil phase is based on the centrifugal force used.

D. Extraction Processes

Virgin coconut oil, coconut oil that has been expressed from copra obtained from the fresh kernel of coconut by mechanical or natural means with or without the application of heat and which does not lead to alteration of oil in any way. The extraction of oil from oilseeds is a major influential step for the commercialization.

Ravindra (2017) study found that the extraction process has a direct effect on the quality and quantity of oil obtained. Virgin coconut oil is extracted from fresh and mature kernel of the coconut by natural mechanical means with or without the use of heat and without undertaking chemical treatment and refining procedure therefore, retaining the sensory and functional characteristics of fresh coconut various methods like solvent extraction method, dry method and wet methods are available for extraction of coconut oil from coconut kernel. Marina (2009) made a strong suggestion that the use of solvents for oil recovery has several drawbacks such as high safety hazard, high-energy input, low quality oil, environmental risk and low-quality meal.

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Bhosle *et al*. (2005) did that precisely in wet method, oil is extracted through coconut milk by heating and non-heating processes. In heating process, oil is extracted by direct heating of coconut milk whereas in non-heating process the oil is extracted through aqueous extraction process and enzymatic extraction process. In non-heating for the extraction of VCO therefore found to be advantageous over heating process in retaining the functional characteristics of fresh coconut.
A more common procedure, carried out in Tanzania, is to allow the milk to stand overnight. The oily upper layer (cream) which separates is then pre-heated to obtain oil. Using this method oil extraction rates vary from about 12 to 23litres of oil/100 kg fresh coconut kernel. Modh *et al*. (2011) presented the thrust ball bearing analysis in the oil extractor. The thrust bearing is designed with analytical treatment and the analysis results the Principal stress, Principal strain and axial deformation found to be reduced. Khanagar *et al*. (2012) addressed the different techniques in failures analysis of shaft used in oil extractor. Roll shaft failure can be prevented primarily by introduction of better material design optimization and by using correct manufacturing processes. In conclusion, the type of expeller depends largely on the following investigated parameter; power applied per mass (in kg) of the material being processed, the types of barrel, the form of expeller's feed end, the form of the choke section and the worm configuration.

E. Dearth In Literature

Cold weather condition: the cold weather has been a cog in the wheel in production of coconut in traditional method. Heating tray: using heating tray to reduce the moisture content has limitations and it exposes the coconut to contaminant.
Therefore, this project will bridge those gaps in previous works by designing coconut extractor that works in diverse weather conditions with improved heating efficiency.

III. MATERIALS AND METHODS

A. Material Selection

Certain considerations were made in the selection of different materials for the extractor. These include cost and availability, strength, thermal and chemical properties, and machinability of the material for the required optimal design.

Table 3.1: Parts and materials of coconut oil extracting machine

S/N	Parts	Materials used
1	Hopper	Stainless Steal
2	Worm shaft	Stainless Steal
3	Oil barrel	Stainless Steal
4	Oil outlet	Stainless Steal
5	Grater shaft	Stainless Steal
6	Industrial bearings	Mild Steal
7	Pulley	Mild Steal
8	Belt	Rubber
9	Machine Frame	Mild Steal
10	Bolt and Nut	Mild Steal
11	Electric Motor (2 hp)	Cast Iron with Winding
12	Electric heater	Stainless Steal

1) Design Consideration

In the design of coconut oil extracting machine many things were considered when analysing the system. Manufacturing processes includes the processes involved in using various construction methods in producing the extracting machine. In manufacturing, the principal common characteristic is that something physical is being produced or created i.e., output consists of goods or machine, which differs physically. Manufacturing therefore requires some physical transformation or a change in utility of resources. The parts are different components that when assembled make up the unit in such processes care precision should be the top most priority when carrying out the construction. As far as the selection of material for the construction of machine component and parts is a vital aspect of design.
Other important considerations included:

a) Ease of use, availability and cost of construction materials.

b) Desire to design the press barrel to accommodate the required quantity of coconut
c) Desire to design the screw press to ensure maximum pressing and conveyance of the coconut.
d) Consideration of incorporating a heating element to pre-heat coconut by conduction before extraction.
e) Consideration was given for a strong machine frame to ensure stability and firm support for machine parts.

2) Description of the Coconut Oil Extractor

The coconut oil extractor is shown in plate 1(c). It consists of an electric motor, feed hopper, expressing chamber, heater, worm shaft, oil barrel, oil outlet, belt, pulley and machine frame.

a) The Machine Frame

This forms the housing of the whole machine components, including the motor. It has to be rigid to withstand all the forces generated in the component parts during operation and ensure continuous service with less vibration.

b) The Hopper

The hopper is a stationary part and mounted onto the machine. It forms the receptacle through which coconut meat is admitted into the machine for extraction. Feeding does not need any energy; gravity is sufficient for feeding. The passage hole of hopper has a moving grater to drag in the meat to the extracting chamber for pressing after crushing.

c) Extracting Chamber

The extracting unit consists of a cylindrical barrel that housed a screw shaft to crush and transport the coconut meat, slots are provided on the bottom part of the barrel so that the expressed oil can drain through them.

d) Oil and Cake Outlet

The oil outlet is located below the press barrel, while the cake outlet was located at the end of the press barrel. They are made of mild steal.

e) The Power Unit

This consists of a 2 hp, 1800 rpm, and single-phase AC electric motor. Speed of the motor is a high and low torque guided by the power requirements for driving the machine, transporting the coconut in the pressing barrel, crushing and exerting sufficient pressure for oil extraction.

f) The Worm Shaft

The shaft speed is low and there is an accurate rigid axial alignment, the shaft assembly consists of a shaft fitted with worms of different pitches. The configuration of the worm section is such that the volume displacement at the feed section of the press is equal to the discharge end. The worm shaft is enclosed inside the cylindrical barrel. The worm conveys the nuts through the barrel land at the same time exert pressure on the material.

3) Machining and Fabrication Process

EQUIPMENT	MACHINING/FABRICATION USE
Hacksaw	Used for cutting straight edges on work piece manually
Files (square, round)	Used to tarnish sharp edges to ensure smoothness and prevent injuries.
Spanners (flat, ring, adjustable), ratchet and socket	Used for tightening and losing bolts or nuts.
Scriber and marking chalk	Used for making the markings on metal visible.
Vernier caliper, steel rule and tape	Used for measuring dimensions for marking out on the work piece. Tape were employed for longer dimensions.
Dividers	Used for marking out circles or circular distances to be cut using hand cutting disc.
Hammer	Used for beating metals into the desired shape.
Welding machine	Used in conjunction with electrode and tong for joining two or more

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	metals together. It was used with mild steel electrode when welding the mild steel. Welding can either be tacking (which can be easily dismantled) during setting, stitching (which can be used to hold thin metals; 1mm metal sheets together) or running (used for thick metal plates; 3mm).
Shear cutter	Used for cutting plate less than 3mm and 4mm, and it was used to shear off the uneven side of metal sheet giving a straight cut edge unlike the hand cutting disc.
Hand grinding/cutting machine	This is hand held and it is powered electrically. The grinding/cutting disc comes in various sizes. The 7" disc was used for cutting and grinding.
Drilling machine	There are two types of drilling machine; the hand drilling and pillar drilling machine. It was mostly to create holes in the work piece.
Pedestal grinding machine	It was used for sharpening the tools, work piece and drill bits.
Center-punch	Used for marking the point to be drilled. It is a hand tool primarily used to prepare a work piece prior to drilling a hole.

B. Methods

1) Description of The Coconut Extractor

The coconut oil extractor is shown in figures 1 and 2. Key components of the extractor include a rigid frame that forms a firm housing for other machine components, a feed hopper that forms a receptacle for the admission of coconut milk, a cylindrical extraction chamber, oil and cake outlets, a power unit, and a shaft assembly. Feeding in the hopper is by gravity. A passage hole in the hopper has a moving grater that crushes the coconut meat and drags it into the extraction chamber. The extraction chamber consists of a cylindrical press barrel that houses a heating element and a screw shaft for further crushing, pressing, and transportation of the meat. Slots are provided at the bottom and ends of the barrel for the exit of extracted oil and waste cake. The moving components of the extractor are primarily driven by a high speed (1800 rpm), low torque, 2 hp, single-phase AC electric motor. The power transmission assembly includes a shaft fitted with worms of different pitches. The configuration of the worm section is such that the volume displacement at the feed section of the press is equal to the discharge end. The worm conveys the nuts through the barrel and, at the same time, exerts pressure on the material.

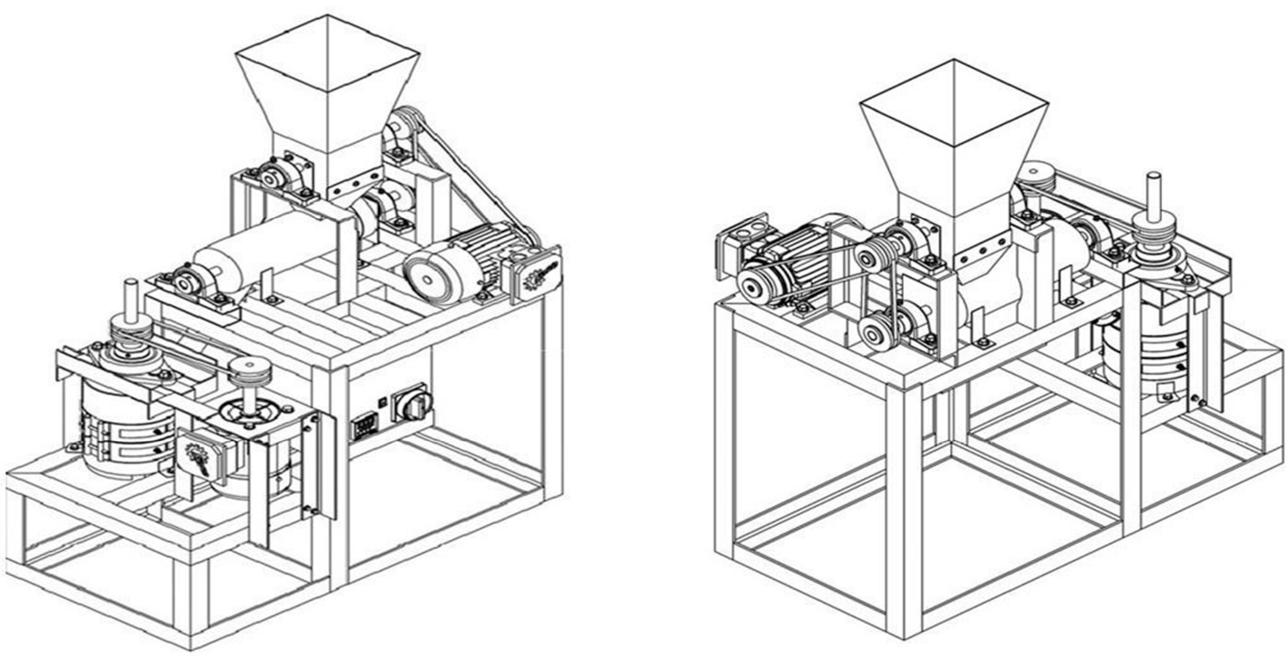

Figure1: Isometric views of the coconut oil extractor.

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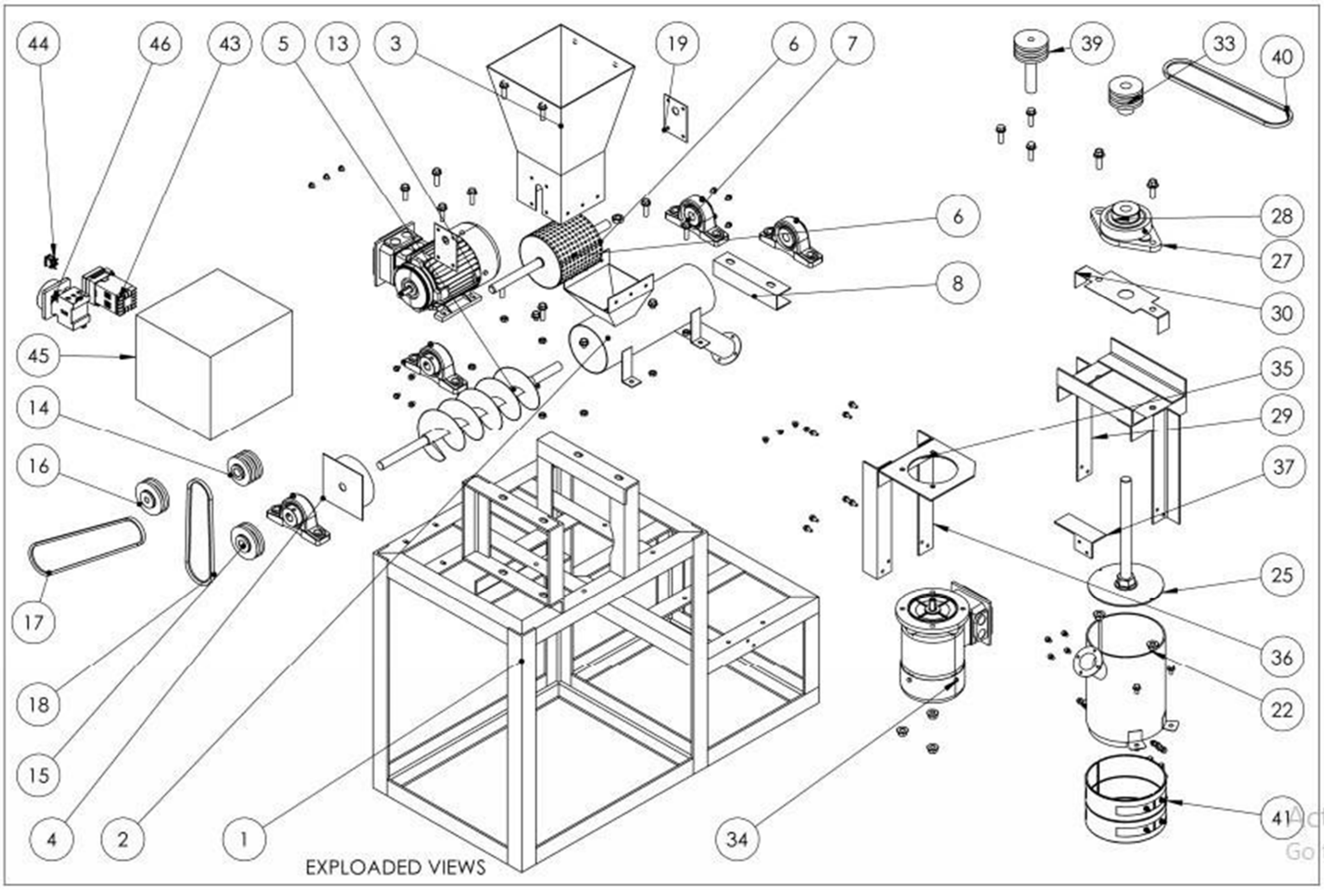

Figure 2: Expanded views of the coconut oil extractor.

2) Theoretical Considerations for The Coconut Oil Extractor.

This design is based on the following assumptions (Olayanju *et al*., 2002):

a) No pressure development in the feed section. The pressure development and the expression of oil start at the beginning of the press section.

b) The temperature of the oil seed mass remained constant in the ram section. In reality, temperature would increase in the ram section due to the shearing action of the shaft.

c) As the oil solid mixture passes through the section, it is subjected to radial pressure exerted by the worm shaft. The pressure causes flow of oil in the radial direction. This oil flow in turn changes the flow rate of mixture in the axial direction.

Based on these assumptions and on careful analysis of existing oil expellers (Olayanju *et al*., 2002), the following specifications were chosen:

- length of chamber, L = 290 mm;
- number of worms, n = 5;
- worm pitches, P = 33.00 mm, 33.30mm, 33.40mm;
- depth of worm, H = 12mm;
- thickness of worm, e = 9 mm;
- Helix angle, = 15 degrees;
- screw diameter at the feed section, D_f = 50mm;
- screw diameter at the discharge section, D_d = 50.9 mm;
- mean diameter of screw, D_m = 50.45mm;
- speed of rotation, N = 200 rpm.

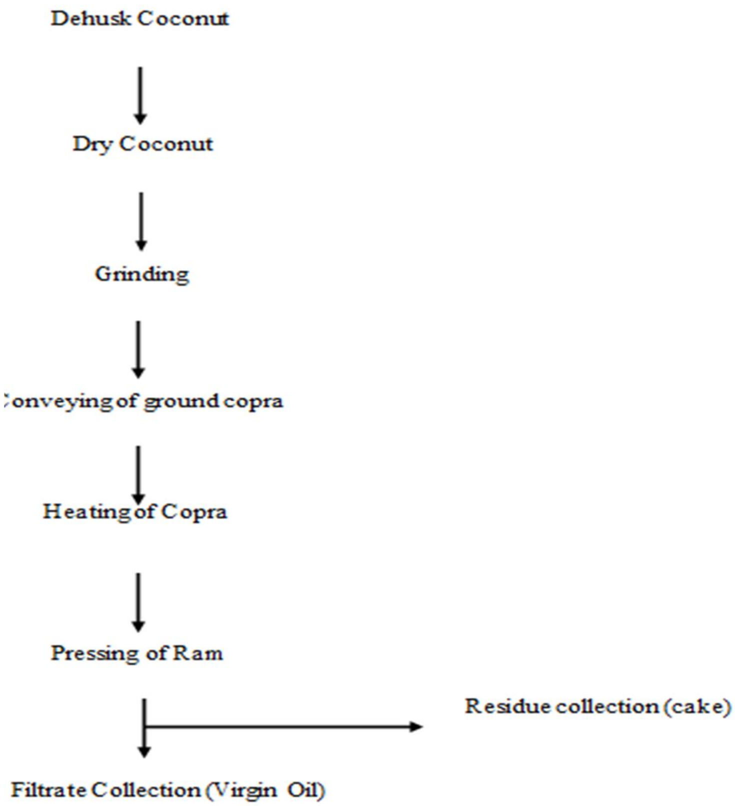

Figure 3: Flowchart of Sequence of Operation/Design System

3) *Machining Operations*

a) Marking and Cutting: Both operations include the use of scriber to mark out the needed work material and hand cutting machine to cut out the marked work piece.

b) Joining: Full welding was used to join the machine frame and some other parts while bolts and nuts was used for others.

c) Grinding: The welding is smoothened (dressed), and then excess work pieces are trimmed off.

d) Drilling: The hand drilling machine was used to make bolt holes and holes on some other component parts.

e) Welding: This is the method by which the sheet metals were joined together. The welding method employed were stitching and running depending on the thickness of the metal plates to be welded.

4) *Design Capacity of the Extracting Machine*

The capacity of an expeller is controlled by drag flow, pressure flow and leak flow in the barrel assembly. The theoretical capacity of an expeller with single flight in feed section was given by Varma (1998).

$$Q = \pi DN \cos\alpha \, (P\cos\alpha - e) \, H \qquad (1)$$

Where:

Q is the volumetric flowrate,

D is the mean diameter of the screw,

N is the rotational speed of the worm shaft,

P is the pitch of the screw,

H is the depth of screw, e is the flight width, and α is the helix angle.

Oil expeller works on the principle of a pressure differential between the pressure applied to the incoming oil seed against that applied to the discharge material. This can be referred to as compression ratio. According to Shukla *et al*. (1992), compression ratio, C.R. is defined as the ratio of the volume displaced per revolution of the shaft at the feed section to the volume displaced per revolution of the shaft at the discharge section.

$$C.R. = \frac{Db^2 - Df^2}{Db^2 - Dd^2} \quad (2)$$

Where:
Db is the diameter of the expression chamber = 88 mm,
Df is the Diameter of the worm shaft at Feed section = 43 mm, and
Dd is the diameter of the worm shaft at Discharge section = 85 mm.

a) Barrel Volume

The barrel volume can be derived using equation 3.

$$\text{Volume of cylindrical barrel (Vb)} = \pi r^2 L \quad (3)$$

Where r and L are the radius and length of cylinder respectively.

b) Hopper Volume

The hopper is in the form of a truncated rectangular pyramid. Its volume can be calculated using the relation:

$$V = 1/3 \times h \times (a^2 + b^2 + ab) \quad (4)$$

Where "V", "h", "a" and "b" are volume of the truncated pyramid, height of the truncated pyramid, the side length of the base of the whole pyramid, and the side length of the base of the smaller pyramid.

c) Mass of Oil Extracted Per Batch

The oil content of coconut falls within the (18-25) % range (Ibrahim *Et al*, 2016); assuming an oil content of 21.5%, the mass of oil extracted is determined using equation 5.

$$\frac{M_o}{M_c} = 21.5\% \quad (5)$$

Where M_O and M_c are the mass of oil and mass of coconut respectively.

d) Heater Capacity

The Quantity if heat required, Q can be determined using equation 6

$$Q = \frac{M_w \times C}{\acute{\eta}_h} \quad (6)$$

Where:
M_w is the desired amount of water to be removed,
C is the specific heat capacity of coconut kernel, and
η_h is the heater efficiency.

e) Performance Evaluation of the Heating Element

Assuming that the extraction chamber is adiabatic, for adiabatic system,

$$Q = \frac{-dT}{\Sigma R}, \quad (7)$$

$$dT = Ts - T\alpha; \quad (8)$$

$$\Sigma R = Ra + Rb + Rc = \frac{1}{h_{inside} \times (2\pi r_{inside} L)} + \ln \frac{V_{inside}/V_{outside}}{2\pi KL} + \frac{1}{h_{outside} \times (2\pi r_{outside} L)} \quad (9)$$

$$h_{inside=}\frac{NuK}{L}; Nu = Gr \times Pr; Gr = \frac{L^3 g\beta\Delta T}{V^2}; Pr = \rho\frac{\sqrt{Cp}}{K} \quad (10)$$

$$h_{outside} = 1.42 \times \left(\frac{\Delta t}{L}\right)^{\frac{1}{4}} \text{(for laminar flow)} \quad (11)$$

Where:
β= 1/*T*;
Ts is the surface temperature taken to be 37℃;
Tα is the temperature of the surrounding fluid assumed taken to be 80℃;
L is the characteristics length,

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g is the acceleration due to gravity, 9.81;
V is the kinematic viscosity of coconut oil, 37.3X 10-6 m/s;
ρ is the density of coconut oil, 910kg/ms3;
√ is the kinematic viscosity of coconut oil, 37.3 × 10-6 m/s;
Cp is the thermal conductivity of coconut oil, 2100 j$kg^{-1}K^{7}$;
K is the material constant for Stainless steel (type 347) = 14.3w/mk.

f) Torque On Screw Thread

Torque and axial load are related to each other through the following equation:

$T = Wr_m \tan(\alpha + \phi)$; $T = F \times r_m$; $F = W \tan(\alpha + \phi)$ (12)

F is the axial load required to expel a great deal of oil at the rupture point and has been determined to be 1.4KN (Ibrahim *et al.*, 2016)

g) Power Requirements

Power input to the expeller is used to transport and heat the material for oil expression. The power drive mechanism incorporates the use of reduction gear coupled to the expeller shaft directly. The chosen speed for the expeller, N_e is 200rpm.

The angular speed, $\omega_e = 2\pi \frac{N_e}{60}$ (13)

Power input to the expeller, P_e, and power of the electric motor required to drive the expeller, P_m, can be computed using equations 13 below.

$P_e = T$, $P_m = \frac{P_e}{\acute{\eta}}$ (14)

To give allowance for power used in the driving shaft, crushing, pressing, and squeezing of coconut, an electric reduction gear motor with power greater than P_m was chosen.

h) Determination of Specifications for Transmission Shaft

To ensure satisfactory strength and rigidity during power transmission, the shafts specification was calculated using equation 14 (Shigley & Mischke, 2001; Khurmi & Gupta, 2005).

$ds = \frac{16T}{.27\pi\delta o}$; $T = \frac{60p}{2\pi N}$ (15)

Where:
ds is the shaft diameter,
T is the torque transmitted by the shaft, and
δo is the yield stress for mild steel, 318 MPa.

i) Belt and Pulley Design

Based on power calculated from equations 13 and according to Indian standards (IS: 2494- 1974), belt type B was selected (Khurmi & Gupta, 2005). The following relations were used in the design of the belt and pulley (Khurmi & Gupta, 2005).

$T = (T_1 - T_2) R$; (16)

$P = (T_1 - T_2) V$ (17)

$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu.\theta$; $\theta = 180 + 2\alpha$; $\alpha = \frac{r_1 + r_2}{y}$ (18)

$T_c = mV^2$; $m = \rho A$, $V = \omega r$, $\omega_e = 2\pi \frac{N}{60}$; (19)

$L = \pi(r_1 + r_2) + 2y + \frac{(r_1 + r_2)^2}{y}$ (20)

Where:
T is the torque supplied by the belt drive to the shaft;
T_1 and T_2 are the tensions on the belt;
Tc is the centrifugal tension; m is the mass per unit length of the belt;
ρ is the density of the belt material (Rubber), 1140kg/m^3;
A is the cross-sectional area of the V – belt;

L is the length of the belt,
r_1 and r_2 are the radius of the small and big pulleys respectively;
α is the angle of wrap;
θ is the angle of wrap; μ is the coefficient of friction between belt and pulley, 0.3; and
P is the power transmitted.

j) Shear Force, Bending and Twisting of the Shaft

The shearing force, twisting moment and point of maximum bending was derived thus:

$$\text{force on shaft} = \frac{\text{torque}}{\text{radius of pulley}};\ Fy = f\sin\theta;\ fx = f\cos\theta; \qquad (21)$$

The maximum twisting moment is given by;

$$M_t = (T_i - T_j)\frac{D_2}{2} \qquad (22)$$

Where Ti and Tj are the tensions in the tight and slack sides of the pulley respectively. Also,

$$Ti = Tmax - Tc;\quad Tc = mV_2^2;\quad 2.3\log\frac{T_i}{T_j} = \mu\theta cosec\beta;\ \theta = 1800 - 2\alpha;\ \ Tmax = \sigma.t.b \qquad (23)$$

Where:
Ti and Tj are the tensions in the tight and slack sides of the pulley respectively;
Tc is the centrifugal tension;
σ is the maximum allowable shear stress, 56N/mm^2 for a steel shaft without keyway (Khurmi & Gupta, 2005);
T_{max} is the maximum tension,
t and b are the thickness and breadth of the belt respectively;
m is the mass per unit length of the belt;
V is the velocity of the belt;
β is the groove angle, 19 degrees for V-belt (Khurmi & Gupta, 2005),
θ is the angle of lap,
α = is the angle of wrap; and
μ is the coefficient of friction between the belt and the pulley.

The belt specifications were selected with adherence to Indian Standards (IS: 2494 – 1974). According to Indian Standards, V-belts are made in five types i.e. A, B, C, D and E. The pulleys for V-belts may be made of cast iron or pressed steel in order to reduce weight. The dimensions for the standard V-grooved pulley according to IS: 2494 – 1974, with power rating between 0.7-3.7kw are t=8mm, b=13mm and shear stress 2.1N/mm2. Also weight per unit length is 1.06N. These specifications were used in solving equations 22 and in deriving the bending moment and shearing force diagrams.

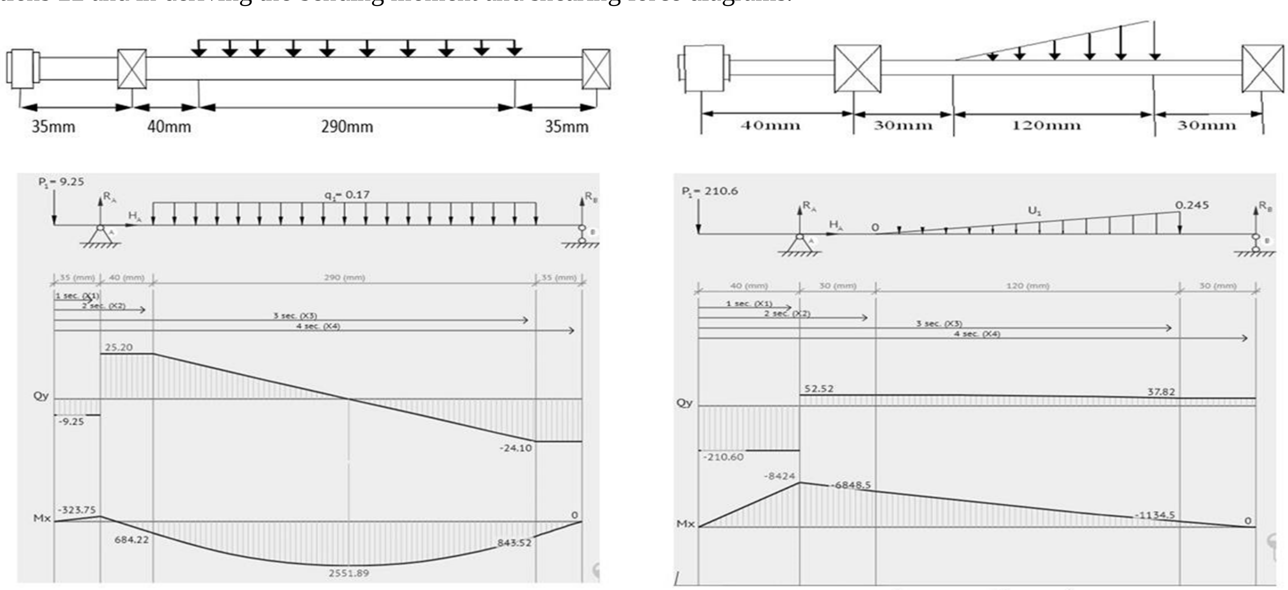

Figure 5: Design and Bending Moment Diagrams of Extractor Shafts.

5) Oil Quality Analysis

Free Fatty Acid (FFA) percentage was used as a yardstick to measure the quality of the extracted oil. FFA analysis were carried out on the samples of extracted oil following AOCS Official Method Ca 5a-40. The oil samples were mixed with a 0.1 N potassium hydroxide (KOH) alkaline solution and titrated using a 0.1 N hydrochloric acid (HCl) solution. The FFA content was calculated as a percentage of oleic acid equivalent.

6) Yield Comparison

The quantity of oil extracted using the designed extractor was compared to that extracted using traditional methods. An equal weight of 22.7 N of coconut flesh was subjected to both our extractor and traditional methods of extraction, and the oil yields were measured.

7) User Experience

A survey was conducted to determine the user-friendliness of the designed extractor. Thirty (30) participants were randomly sampled from Imo State, Nigeria. The participants come from diverse backgrounds. 10 were professionals in industrial oil extraction, 10 were skilled in traditional oil extraction, and 10 had no prior oil extraction experience. Participants were given the guides on how to set up and use the extractor and to rate their user experience on a scale of 1–10, with 10 being the best experience after operating the extractor for 20 minutes.

IV. RESULTS AND DISCUSSION

A. Effect Of Moisture Content On Extraction Time

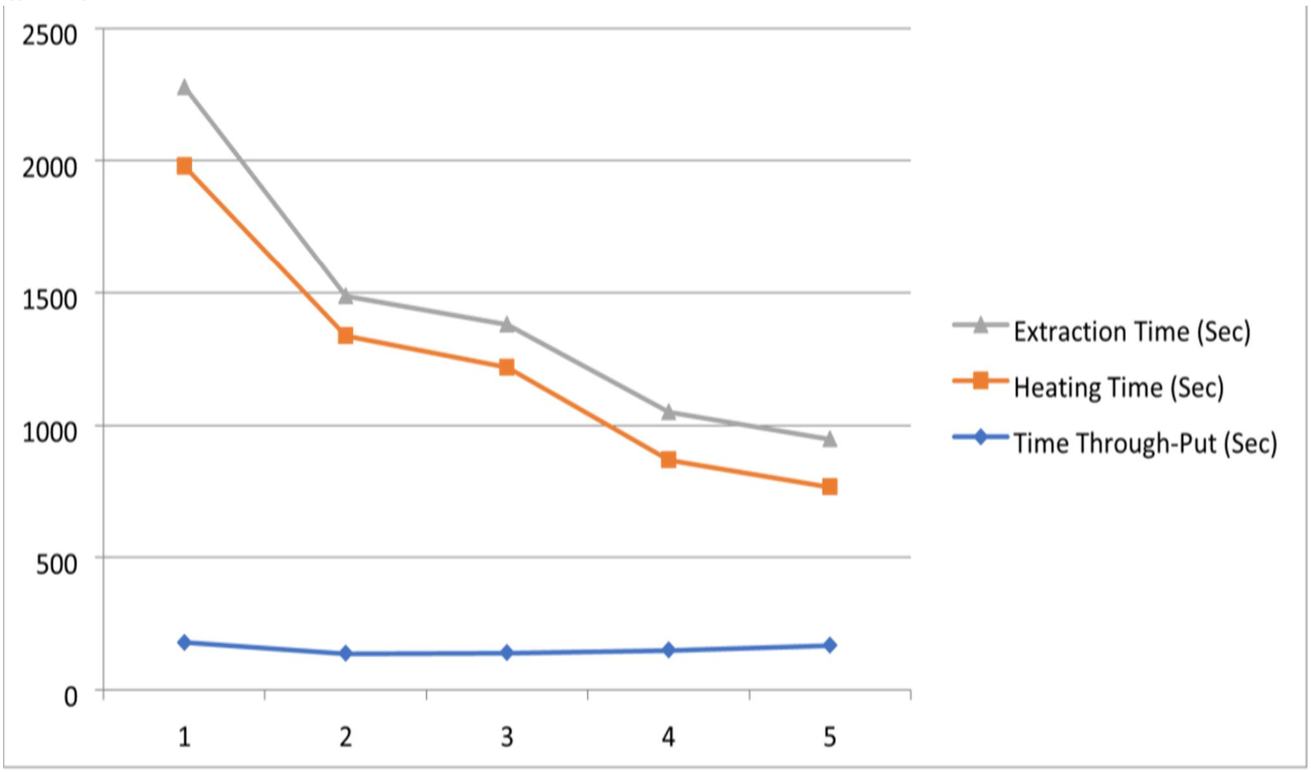

Figure 6: Graph of weight of dry copra against Extraction time, heating time and time throughput

The effect of moisture content on the overall extraction time was investigated. It was observed how extraction time, and heating time increases with decrease in weight of dry copra in the sample. Figure 5 shows a graphical representation of the effect of extraction time with variations in quantity of dry copra in the whole sample. This time-weight inverse relationship is the direct effect of pre-processing drying operation. Drying leads to the production of more oil which in turn reduces friction and adhesive forces. The drying curve from our extractor is shown in figure 6. It is a downward curve from left to right, indicating the decrease in moisture content with respect to time.

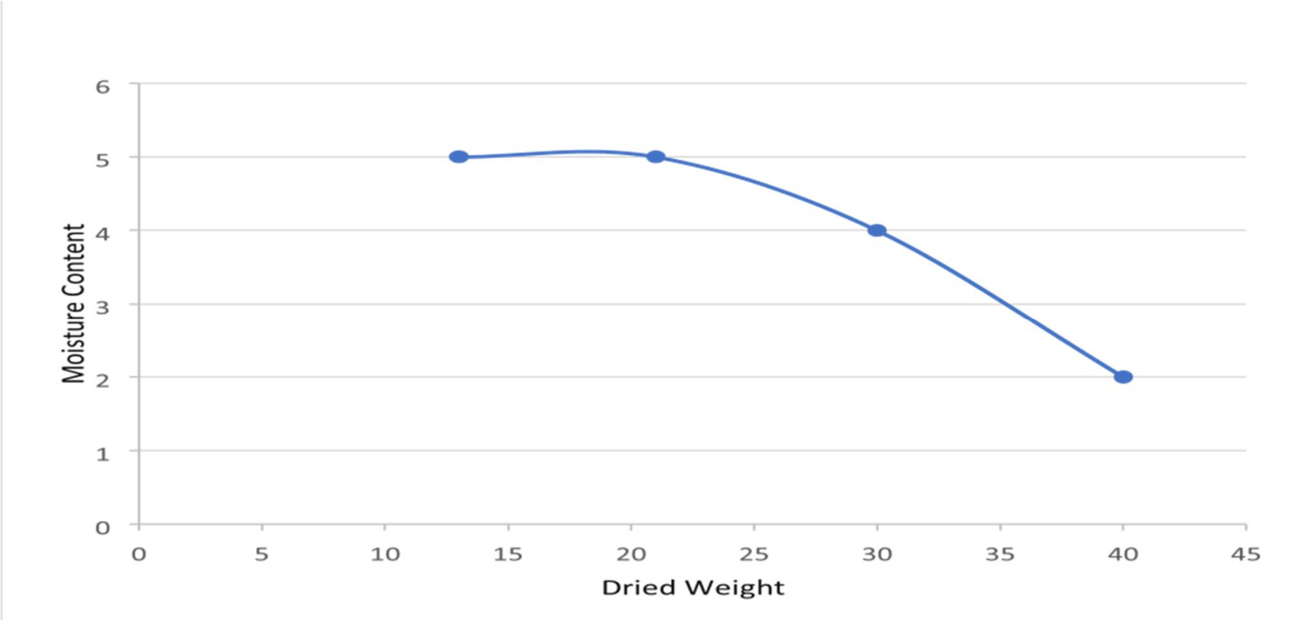

Figure 6: Drying Curve

B. *Oil Production Efficiency*

The production efficiency of our extractor was calculated using the following procedure

Average production Efficiency: $\frac{actual\ output}{theoretical\ production\ output} \times 100$

Average Weight of coconut used for Extraction $= \frac{10+13+12+30+40}{5}$ = 22.8N

Average Weight of oil collected during extraction $= \frac{9+2+4+7+9.9}{5}$ = 4.7N

In research from Radhakrishnan (2019), 25N of dried coconut gave 7.5N of coconut oil

From calculations

Theoretical Output = 6.84

Actual Output = 4.76

Production Efficiency $= \frac{4.76}{6.84} \times 100$ = 69.59%

From the results gotten, it indicates the machine can be used for commercial purposes and reliable.

C. *Oil Quality Analysis*

The result revealed that the coconut oil extracted using our extractor has an average FFA content of 0.46%. This indicates that our extractor is efficient in preserving oil quality.

D. *Yield Comparison*

The designed extractor yielded approximately 20.7% of oil (4.7 N), while the traditional methods yielded an average of 14.1% (3.2 N). This highlights the efficiency of our extractor for maximizing yield in small scale oil production.

E. *User Experience*

Following the user experience survey carried out on the extractor, the professionals gave an average rating of 7.5. The experts in traditional extraction gave an average rating of 8.7, while participants with no prior extraction experience gave an average rating of 9.2. This feedback from our participants demonstrates a high level of satisfaction with our extractor design.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This project work has successfully presented an efficient low cost coconut oil extraction process by minimizing the traditional technique of extracting and improving health condition of individuals by use of proper material (stainless steel). It is expected that in average home or industry in Nigeria can afford the machine. It is a design for both home and industry usage. Also it can be seen from the graphs and bar chart that for better extraction process, coconut should be dried before being fed into the machine. This lowers the moisture content and brings about an increase in oil production due to a reduction in the cohesive and adhesive forces between the coconut particles and the machine part respectively.

B. Recommendation

In future work, we hope to explore the fatigue stress and durability of our design, further explore techniques that can be applied to reduce work input and increase output while scaling down on the overall size of the machine. We equally hope to incorporate smart systems that will help automate the extraction process. For the current designed machine, the following are recommended.

a) There should be a convergent collector below the extracting chamber to assist in oil
b) the extraction chamber should have a stirrer to prevent the copra from roasting
c) There should be heating element under the extraction chamber to ensure even distribution.

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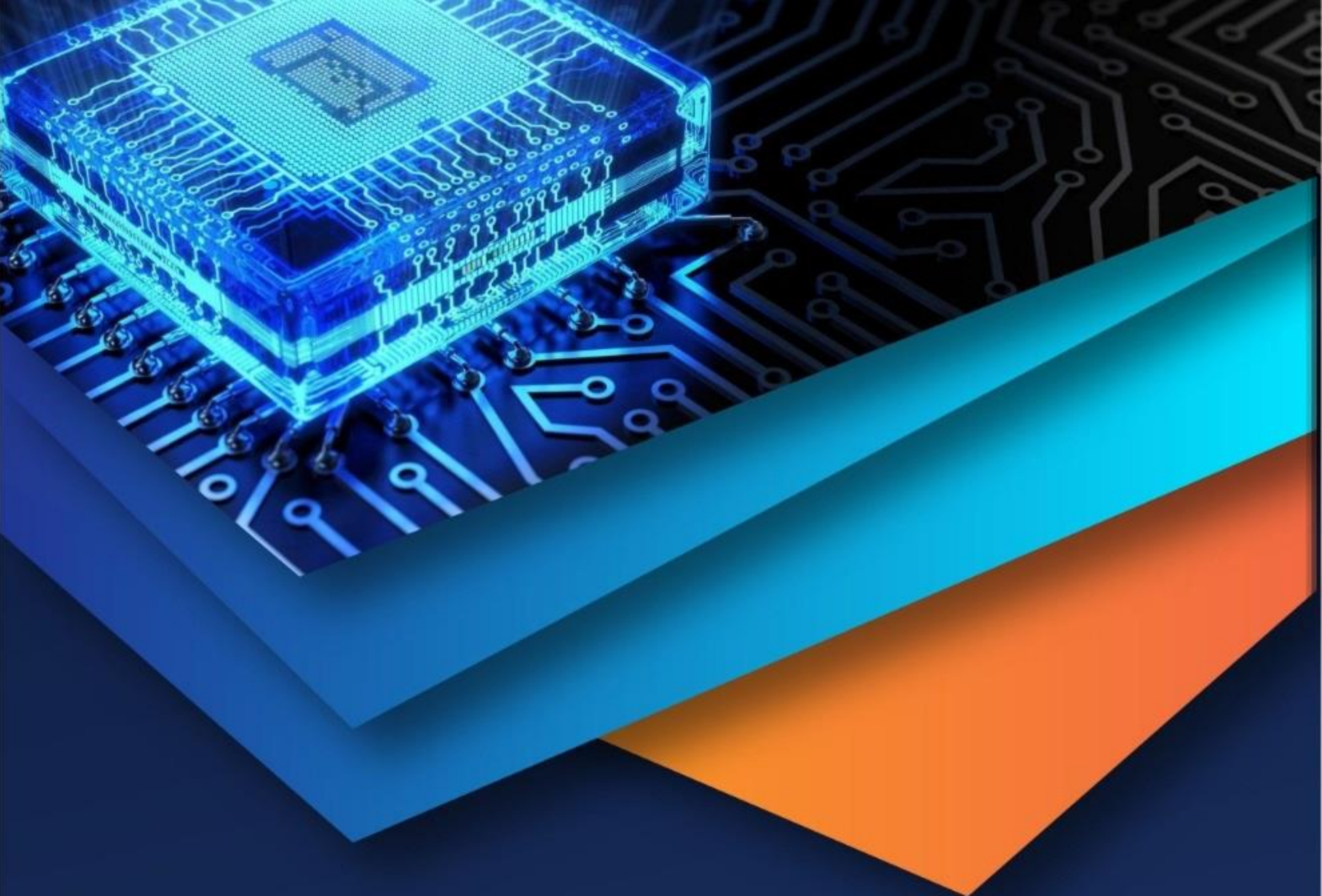

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