Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 8, Issue 1, 2023, Page 42-55
ISSN: 2616-1192

(www.ujesr.org)

Design and Fabrication of an Automated Locally Made Soap Extruder

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Abstract
This study focused on the design and fabrication of an automated locally made soap extruder. The goal of the study is to develop a cost-effective bar soap manufacturing machine, create a computer simulation model of the planned bar soap making machine, and assess the equipment's technical and economic feasibility. A study of existing bar soap manufacturing machines in use in the local business was conducted to determine how much they cost and where they came from. This study provided an outline of the need for a less expensive, simple, and cost-effective design. It was observed that there were relatively few soap-producing machines in use in the nation (Nigeria), and those that are in use cost ₦5,000,000 to ₦8,000,000 and were imported mostly from the United States, China, and India. The AutoCAD design and SOLIDWORKS program was used to create the soap extrusion machine design. Performance, environmental issues, maintenance, aesthetics and ergonomics, size and weight, safety, and cost were all considered throughout the technical and economic examination of the design. The fabricated bar soap equipment costs around ₦800,000 in total. This research showed that the locally designed and fabricated bar soap machine is cost-effective since the cost of ₦800,000 is significantly less than the cost of imported machines, which cost ₦5,000,000 to ₦8,000,000. It was also observed that this new-fangled design of soap extruder had a high efficiency of 95.86%. This developed machine will assist researchers and industrialists in the massive production of locally produced soap extruders in Nigeria.

Keywords: *AutoCAD design, Cost-effective, Design and fabrication, Soap extruder*

Received: 5th October, 2023 *Accepted: 19th November, 2023*

1. Introduction

The machinery used to make soap has continually changed to allow the use of filling agents, soaps with a high liquid content, and particle material in accordance with the needs of the formulas in the manufacturing equipment (Ajao et al., 2010). The goal of this project is to produce the soap in the shortest amount of time possible. In daily life, we use soap to clean our clothes, wash our dishes, and maintain an aesthetically pleasing body (Ajao et al., 2022). Soap can be used in a wide variety of ways in our daily lives. Keeping our household in a much better environment to live and work is one of its significant values. Despite the fact that soap is the most often used product in Nigeria, many soap companies have struggled to provide high-quality soap at lower costs. This has resulted in the creation of low-quality, expensive liquid soaps (Bashir, 2014). The production of the soap extruding machine was made in order to produce a neat and accurate end product since it was very difficult to mold and cut the bar soap into the desired shape after production (Kingsley and Olodu, 2022). The cost of imported soap extruding equipment in Nigeria is likewise costly, ranging from ₦5,000,000 to ₦8,000,000. Providing that man is aware of the importance of maintaining a clean environment, the requirement for soap as a cleaning agent is of the utmost importance. In addition, apart from the fact that soap is being used for personal hygiene, soap also had other purposes (Warra, 2013). It has several uses in daily life, one of which is to maintain a better living and working environment in the home and at the office (Kililiku et al., 2006). As a result, it is a necessary product in today's developed society. When different animal and vegetable fats and oils are combined with caustic soda or potash, they produce soap, which is made up of fatty acids and alkalis. It is made when fat or oil is saponified or undergoes basic hydrolysis. Currently, the fatty acid is neutralized and turned into salt using sodium carbonate or sodium hydroxide (Charles, 2016). In order to meet and satisfy the expectations of the manufacturer and/or end customers, the final product is produced through a series of procedures, with value addition at each stage (Bashir, 2014). There are three different types of soap: liquid, bar, and powder.

Among the most prevalent sectors that have endured or continued to operate over time are the soap industries. According to Dickey and Fasano (2004), the marketability of a particular soap mostly hinges on how appealing the finished product is. This is determined by the technique used in soap-making. The majority of the modern processing techniques used today in the soap-making industry entail employing an extruder or press of different types, most of which can be either manually or electrically driven (Ogedengbe and Aderoba, 2005). The consideration of the above and numerous factors led to the development of this soap plodder which is based on the principles of conservation of mass, transmission of forces and motions. Formally, soap making has been done traditionally by mixture of the necessary soap ingredients and boiling it on fire after which it is being poured into various molding containers and allowed to solidify (Jirout and Rieger, 2021). After solidifying, the soaps are then removed from the moulds manually. This is labor-intensive and causes some of the soaps to crack before they are sold on the market. The purpose of this study is to increase the product's market value and aesthetic appeal, which is of ultimate economic relevance. As a result, the manufacturing of soaps with rough, unsightly surfaces and very low market quality and value will be substantially reduced, if not entirely eliminated (Khurmi and Gupta, 2010). As a result, human labour is eliminated from the final soap-making process, improving market value. This study therefore focused on the design and fabrication of an automated locally made soap extruder.

2. Materials and methods

2.1 Materials

In this study, pre-mixing operations were required during soap production; hence, the reservoir's cover was designed to be bolted to allow for simple disassembly for maintenance needs. The design features were then translated and applied to creating the conceptual design using AutoCAD and SolidWorks software. The design elements of the concept chosen are based on the following criteria: high functionality; high quality; cost-effectiveness; ease of maintenance; operator safety; and use of locally accessible materials. In order to solve the major issue of material compaction, the temperature around the barrel was controlled, and soap paste was utilized for the performance evaluation of the machine. The design took cognizance of the availability of the raw materials. The stresses that the system was subjected to were obtained through analytical approach and mathematical analysis using networks of formulae. The materials utilized for the construction of the machines are mild steel, stainless steel, and chemical paint (Parvizi et al., 2016). The stainless steel is an excellent choice for the primary material used in the manufacture of soap extruders because of its resistance to corrosion.

2.2 Design and construction

A 2-hp, three-phase electric motor was built to power a soap-plodding machine. A barrel that houses the screw shaft is part of the machine. The screw shaft is housed in the barrel, with space between them to prevent direct contact. The allowance is just big enough to prevent contact and just little enough to prevent leaks brought on by back pressure (Ogedengbe and Aderoba, 2002). Due to their qualities, such as excellent corrosion resistance, the screw shaft and barrel are composed of stainless steel (Khurmi and Gupta, 2010). The screw shaft conveys the soap paste from the hopper to the extreme end of the barrel. Attached to the extreme end of the barrel is a noodler. The noodler is responsible for the conversion of the transported paste into soap noodles; the essence of which is to ensure homogeneity and proper mixing. The noodler can then be replaced with a 25mm by 55mm profile which determines the shape of the soap. As the soap is extruded through the profile, the heater band attached to the end of the barrel regulates the temperature of the barrel and this gives the bar soap a fine surface finish.

2.3 Design criteria

1. The machine is designed for both small and medium scale soap production.
2. The machine is designed for an area with availability of electricity.
3. Soap Size as determined from the experiment of two soap specimens as shown below;
   = 25mm x 55mm x 95mm
4. The machine is designed to plod 250kg of soaps per hour using Equation (1)

$$volume = \frac{mass}{density} \qquad (1)$$

$$Volume\ produced\ per\ hour = \frac{250}{1150} = 0.217m^3$$

$$Number\ of\ soap\ tablets\ produced\ per\ hour = \frac{0.217}{25 \times 55 \times 95 \times 10^{-9}} = 1664$$

$$i.e. \frac{1664}{60} = 27.7 \approx 28\ tablets\ per\ minute$$

2.4 Design analysis

The design of soap plodder involves primarily sizing and selection of proper material for adequate strength, durability, suitability for the job which the machine is meant and the economy of manufacture (Patil et al., 2022).

2.4.1 Screw conveyor

Details of screw conveyor design such as helix angle, channel, depth profile and number of parallel flights contribute to the quantity of soap being plodded (Khurmi & Gupta). The screw shafts is designed with the pitch equal to the diameter (referred to as square pitched screw) which results in a helix angle of 17.6º (Khurmi and Gupta, 2005). They have a deep feed section to accommodate and convey the soap paste and a finer shallow channel for achieving thorough mixing. The design of conveyor greatly depends on the flow rate needed at the profile exit. Screw conveyor of 92mm nominal diameter was adopted (standard) (Euger et al., 1997). The power of the screw conveyor required for conveying material at a rate of 250 kg/h for the capacity of a continuous screw conveyors were calculated from the expression given by Eqn. 2 (Spivakovsky and Dyachkov, 1967).

$$Q = 60 \times \lambda \times \frac{\pi}{4} \times D^2 \times L \times N\rho\Psi C \quad (2)$$

$$250 = 60 \times 0.25 \times \frac{\pi}{4} \times 0.092^2 \times 0.092 \times N \times 1150 \times 0.3 \times 1$$

$$N = 78.99rpm$$

where Q is capacity of a screw conveyor, ρ is Bulk density of the material, $kg/m^3 = 1150kg/m^3$,
D is Nominal diameter of Screw in m = 0.092m, S is Screw pitch in m, N is RPM of screw Ψ is Loading efficiency of the screw (0.3), C is Factor to take into account the inclination of the conveyor = 1, λ is Fill coefficient of the section

2.4.2 Gear box

The gear box consists of various gears covered with casing made of cast iron. The gears are cut with teeth meshed together to transmit either a fraction of or more than the speed of the gear system. This is done to compensate for the torque needed to convey the material at high pressure. In this study, the speed of the shaft is calculated to be 79 rpm for the conveyor screw to discharge the desired mass flow rate (250kg/hr) as shown in previous calculations. Also, in this project, the machine was designed such that the velocity ratio of the electric motor pulley to that of the gear box pulley was 2:1. To calculate for the speed of the gearbox input shaft,

Let N_s = speed of the screw shaft = 79 rpm
N_g= speed of the input shaft (Gear box)
N_m= speed of the motor = 1400 rpm
The gear ratio of the shaft to Gear box adopted was 10:1

$$= \frac{N_s}{N_g} = \frac{1}{10}$$

$$N_g = 10 \times 79 = 790rpm$$

2.4.3 Velocity ratio

Fig. 1 show a gear box which was used in combination with a V-belt. V-belt has the ability to transmit velocity ratio as high as 10:1 (Joseph and Charles, 2001; Khurmi and Gupta, 2010) but velocity ratio of 2:1 was adopted.

$$\therefore \text{V.R} = \frac{Diameter\ of\ the\ driven}{Diameter\ of\ the\ driver} = \frac{D}{d} = \frac{N_m}{N_g} = \frac{1400}{790} = 1.77:1 \approx 2:1$$

D =2d= $2 \times 75 = 150mm$

Fig. 1: Gear box

2.5 Design concept of soap extruder

The design of the soap manufactured by the soap extruder is determined by the shape of the die used during production. In most cases the die is rectangular resulting in a bar shaped soap.

2.5.1 Design calculation

2.5.1.1 Design for the pulley system

Cast iron is the material used for pulleys. This was chosen because of the high Tensile strength which is about 483 MPa and high deformation resistance The number of teeth on each pulley is given by Equation (3).

$$\text{Diameter of pulley} = \frac{P}{Sin\ {}^{180}/_{n}} \quad (3)$$

where n is number of teeth, and P is the pitch
P = 0.03m

Diameter of pulley = 0.2m

$n = \frac{180}{Sin^{-1}\frac{0.03}{0.2}}$

n = 21 teeth.

2.5.1.2 Design of timing belt

The timing belt is made up of the following components: Steel wire or tension, Base material (neoprene) and Nylon. The calculations on the timing belt are shown below, Equation (4). Total length of timing belt.

$$\text{Length} = \frac{\pi}{2} + (D1 + D2) + 2C + \frac{1}{4C}(D1 - D2)^2 \quad (4)$$

$(D1 - D2)^2 = 0$

where D_1 is diameter of the driver pulley, D_2 is diameter of the driven pulley, and C is distance between the center pulley 1 and 2. D_1= 20cm; D_2= 20cm; C = 35cm.

$$\text{Length} = \frac{\pi}{2} + (20 + 20) + 2 \text{ x } 35 + \frac{1}{4X35}(0)^2$$

Length = 132.83cm

The thickness of the belt is 30mm as seen in the drawing of the pulley. The number of teeth as from the technical manual rubber timing drive table is 96 (Kingsley and Olodu, 2022).

2.5.1.3 Design of extrusion shaft

Carbon steel in grades 40C 8 (selected), 45C 8, and 50C 4 is used for ordinary shafts. As the soap noodles move through the extrusion shaft, a torque is generated due to the forces incurred. The torque was calculated using Equation (5).

$$T = \frac{Power}{Angular\ Speed} \quad (5)$$

where T is torque (Nm), and ω is the angular speed (rad/s)

Power =1492watts (1 horse power=746 watts)

$= \frac{1492\ X\ 60}{60\ X\ 2\pi}$

= 237.4 Nm

2.5.1.4 Design of hopper, stand, mixing tank and extrusion shaft housing

Fig. 2 shows the Hopper of a soap extruder. In this design, the hopper was made from a stainless steel.

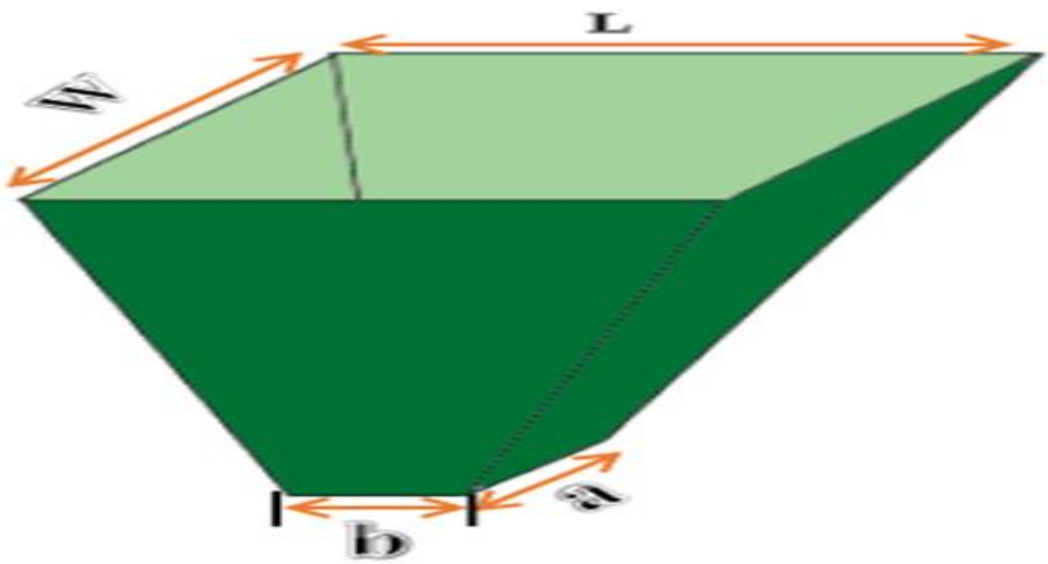


Fig. 2: The hopper of a soap extruder

Design calculations for hopper: The volume of the hopper was obtained using Equation (6).

H = 20cm L = 36cm w = 30cm

$Tan\ \theta = \frac{H}{X}$; $X = \frac{H}{Tan\ \theta}$

$X = \frac{20}{\text{Tan } 57°}$

= 12.988cm

b = 36 – (12.988 x 2)

b = 10.024cm

a = 30 – (12.988 x 2)

a = 4.024cm

$$\text{Volume of the hopper, } V = \frac{H}{3}\left(A_1 + A_2 + \sqrt{A_2\ X\ A_1}\right) \quad (6)$$

A_1 = L x W

A_2 = a x b

= 4.024cm²

Thus,

$$v = \frac{20}{3}\left[1080 + 40.33366 + \sqrt{1080\ X\ 40.33366}\right]$$
$$= 8860.3692 cm^3$$

2.6 Selection of dies

The die material was made of stainless steel. The die has the following specifications; breath (B) and height (H). The die dimension determines the dimensions of the bar soap. The standard size of most bar soaps is B=6cm and H=3cm. They have similar dimensions but with smaller tolerance (allowance). It has a tolerance of +0.05cm, B=6.05cm and H=3.05cm. The tolerance allows the soap to have exact dimensions as per the given standards. The length of the bar depends on the wish of the customer. Most of the bar soaps in the market are approximately 0.5m and weigh between 800-1000g.

3. Results

3.1 Measurements of the screw thread

Table 1 show the design specification of the screw thread while Figure 3 shows the screw thread.

Table 1: Measurement of screw thread

Parameter	Values
Barrel diameter D_b	14cm
Core diameter, D_c	8cm
Lead length, L	16cm
Meter channel depth, H	3cm
Flight width, e	0.9397cm
Flight start, n	2
Helix angle at the barrel, θ_b	20°
Helix angle at the screw core, θ_c	32.5°
Channel width at the barrel, W_b	6.5778cm
Channel width at the core, W_c	5.8088cm
Average channel width, W	6.1933cm
Channel aspect ratio, H/W	0.4844

The capacity of a screw conveyor depends on the screw diameter, screw pitch, speed of the screw and the loading efficiency of the cross-sectional area of the screw. The capacity of a screw conveyor with a continuous screw, it was obtained from Equation (7).

$$Q = V \times \rho \quad (7)$$
$$Q = 60 \times (\pi/4) \times D^2 \times S \times N \times \psi \times \rho \times C$$

where, Q is capacity of a screw conveyor, V is volumetric capacity in m^3 /hr, ρ is bulk density of the material, kg/m^3, D is nominal diameter of Screw in m, S is screw pitch in m, N is rpm of screw, Ψ is loading efficiency of the screw, and C is factor to take into account the inclination of the conveyor.

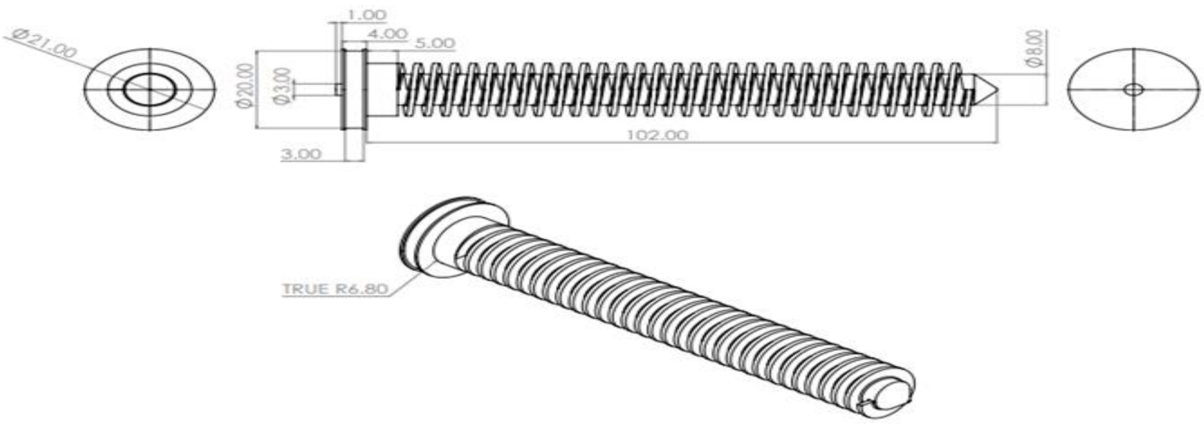


Fig. 3: The screw thread

3.2 Technical viability of bar soap making machine

3.2.1 Performance evaluation

For the performance evaluation, soap pastes were collected from local manufacturer. In the testing of the soap plodding machine, the following are the step-by-step procedures followed:

i. The soap plodding machine was connected to the 3-phase power source.
ii. The machine's electric switch was then turned ON and the machine was allowed to run for 5 minutes.
iii. The noodler was then coupled to the outlet of the barrel using the coupler.
iv. At this point, the already prepared soap paste of about 8kg was then poured into the hopper.
v. The soap paste was then pressed down with the aid of a wooden pestle to force

the paste into the running screw conveyor.

vi. The soap paste which is being conveyed by the screw was then extruded through the holes in the noodler in the form of noodles into a container.

vii. The noodled paste in the container was then sprinkled with fragrance to give the soap sweeter fragrance.

viii. The noodler was then removed and the profile was then coupled to the barrel outlet using the same coupler.

ix. The noodled paste was then poured back into the barrel and the heater band; W_s turned ON and increased gradually until a fine soap surface was obtained at 70^0C.

x. The plodding process was then timed using a stop watch for two minute and the plodded soap was collected on a flat horizontal sheet metal plate with the cutting done manually.

xi. Finally, the plodded soap total length was then measured for the duration of the test operation.

xii. The heater band was then turned OFF and the machine switched OFF.

3.2.2 Test result

Table 2 show the performance evaluation of the developed soap extruder. The following are the test specifications. Test specifications:

Soap tablet size =25mm x 55mm x 95mm

Mass of soap paste used = 8kg

Table 2: Performance evaluation

Input (soap paste)(kg)	Output (soap bar length) (mm)	Density of Soap (kg/m³)	Duration (minute)
8.0	5056	1150	2.0

2528mm of soaps were plodded in one minute. This implies that the length of soap plodded per hour = $60 \times 2528 = 151680mm = 151.68m$

$$volume\ plodded\ per\ hour = cross\ sectional\ area \times length\ produced\ per\ hour$$

$$= 25 \times 55 \times 151.68 \times 10^{-6}$$

$$= 0.208560\, {m^3}/{hr}$$

Moreover, the machine is designed to plod 250kg of soaps per hour

Since $mass = density \times volume$

Therefore, $mass = 1150 \times 0.208560 = 239.844\, {kg}/{hr}$

$$Performance\ efficiency\ (\eta_{pf}) = \frac{239.844}{250} \times 100\%$$

$$Performance\ efficiency = 95.94\%$$

Similarly, $Total\ length\ produced = 5056mm$

$$mass\ of\ the\ soap\ plodded = 1150 \times 25 \times 55 \times 5056 \times 10^{-9}$$

$$= 7.994kg$$

$$Plodding\ Efficiency(\eta_{pl}) = \frac{7.994}{8} \times 100\%$$

$$= 99.92\%$$

$$Overall\ Efficiency\ (\eta_o) = \eta_{pf} \times \eta_{pl} = 0.9594 \times 0.9992 = 0.9601$$

$$\eta_o = 95.86\%$$

3.3 Solidworks design of the developed soap extruder

Fig. 4 to 12 show the solidworks design of the component part and full drawing of soap extruder using solidworks design software programme.

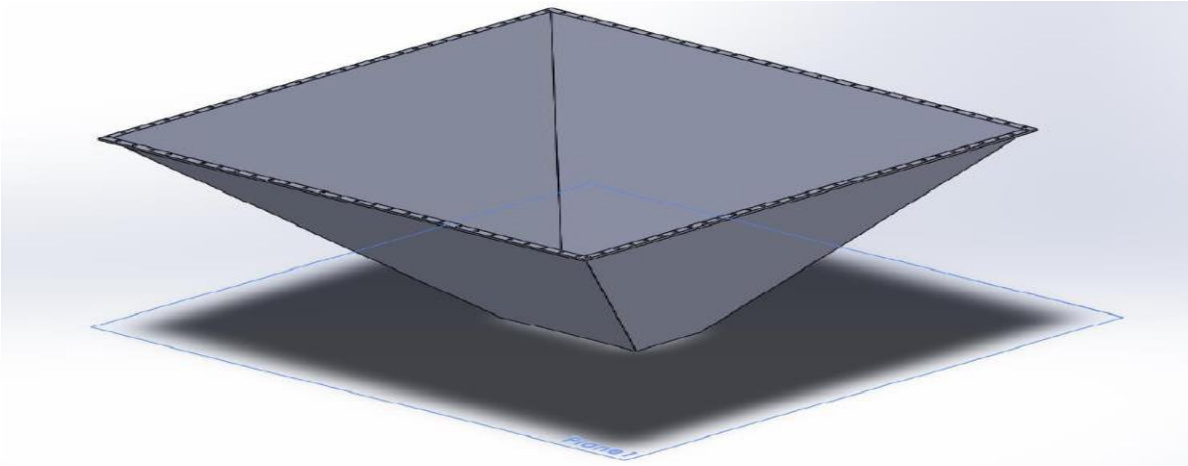


Fig. 4: The hopper

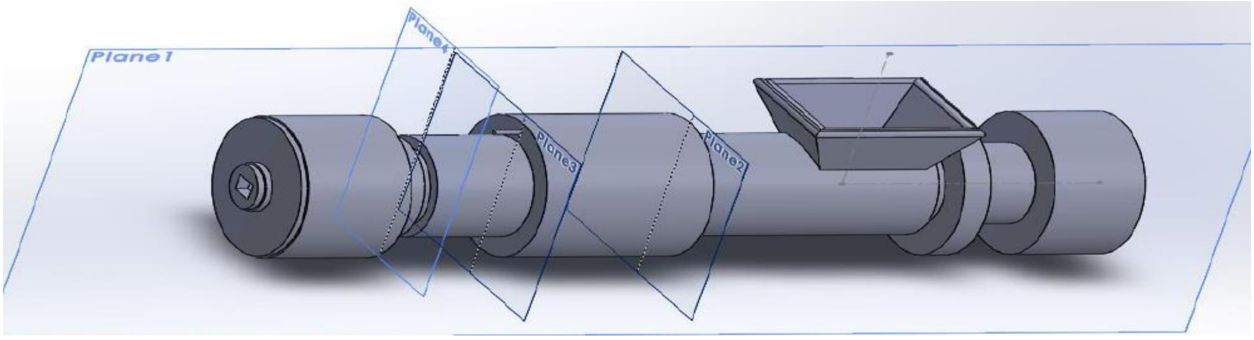


Fig. 5: Block diagram of bar soap making machine

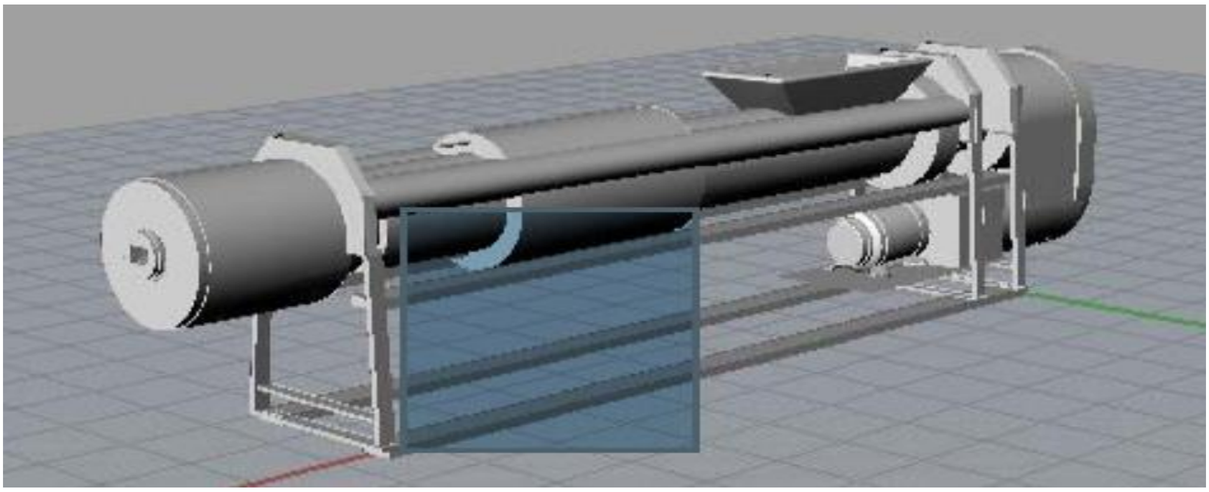


Fig. 6: Block diagram of bar soap making machine (side view)

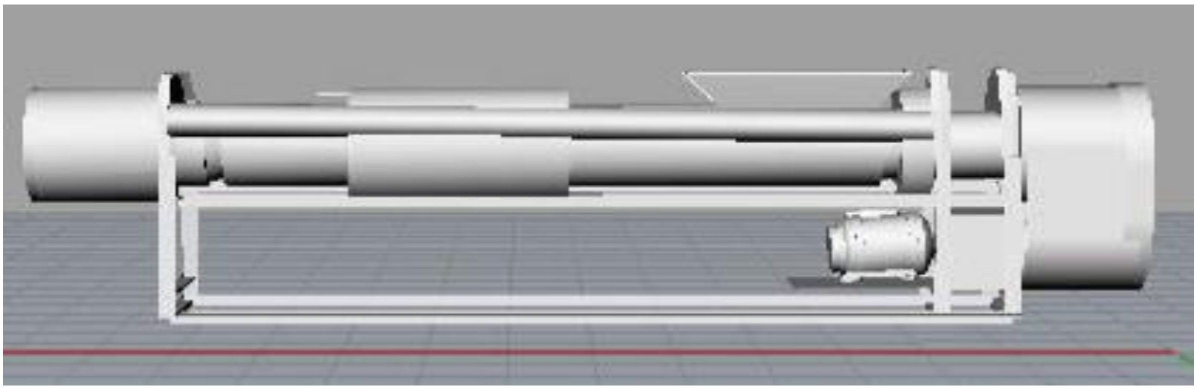


Fig. 7: Block diagram of bar soap making machine (front view)

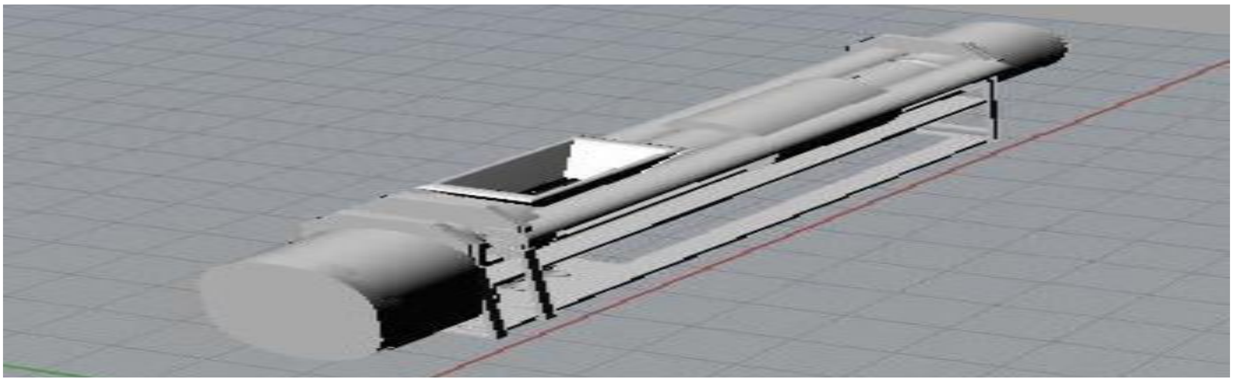


Fig. 8: Block diagram of bar soap making machine (top view)

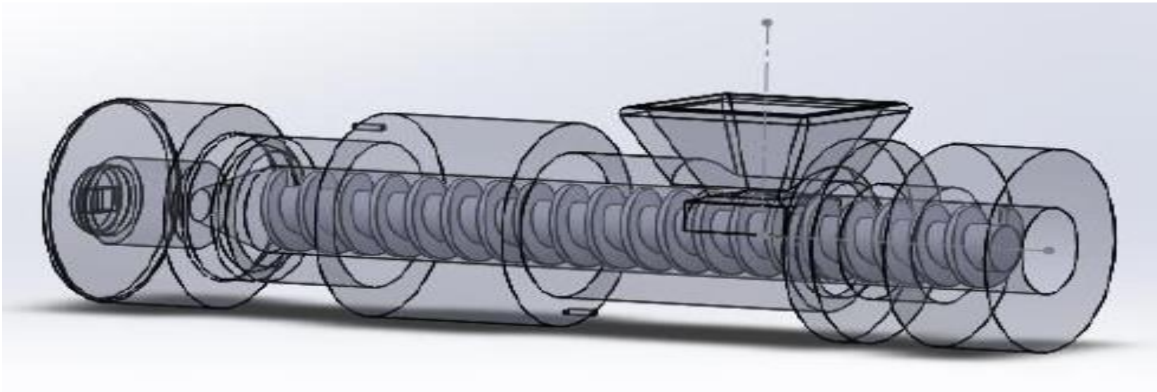


Fig. 9: Different views of the housing and hopper

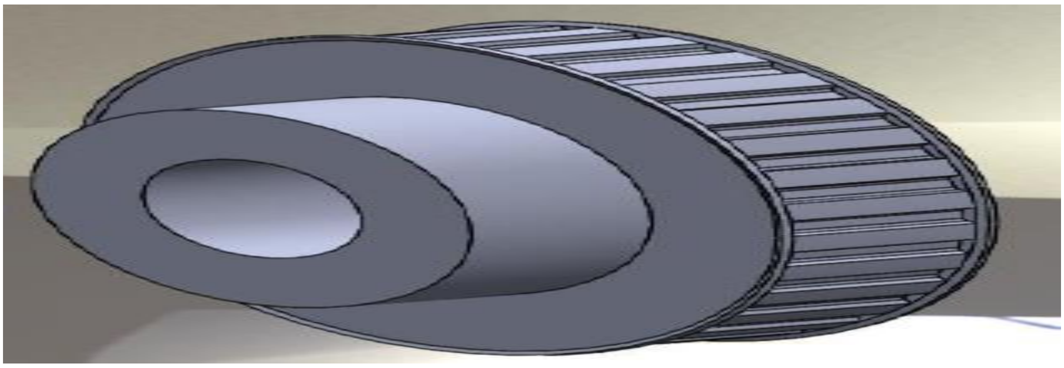


Fig. 10: Timing pulley block diagram

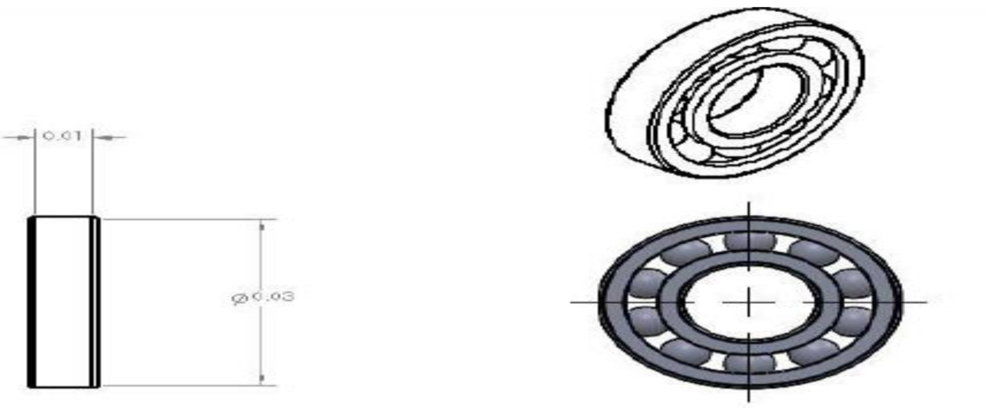


Fig. 11: The bearing

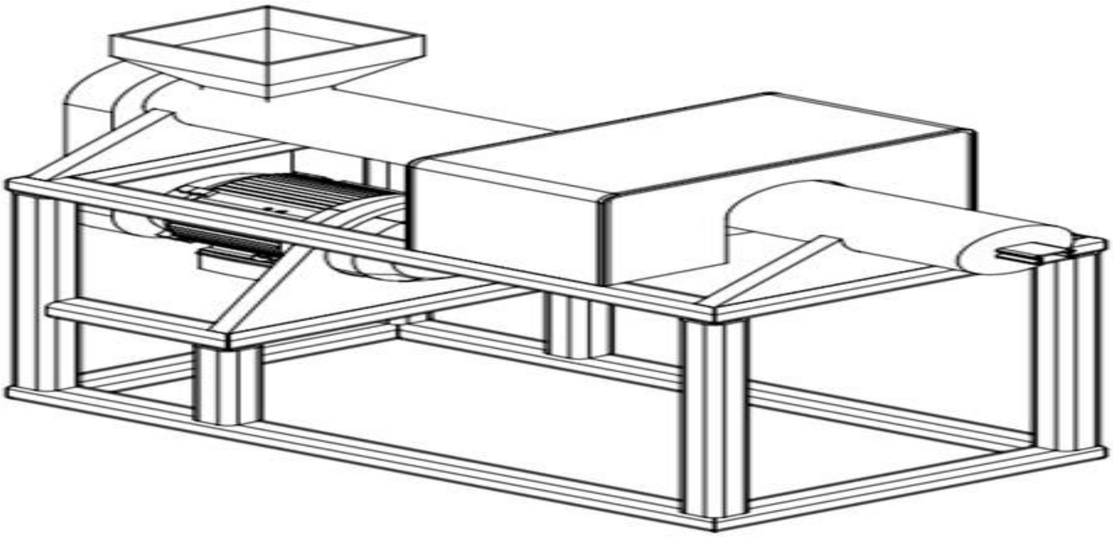


Fig. 12: The soap extruder

3.4 AutoCAD designs of the developed soap extruder

Fig. 13 to 20 show the AutoCAD design of the component part and full drawing of soap extruder using AutoCAD design software programme. Fig. 21 shows the actual fabricated model of the Soap extruding machine.

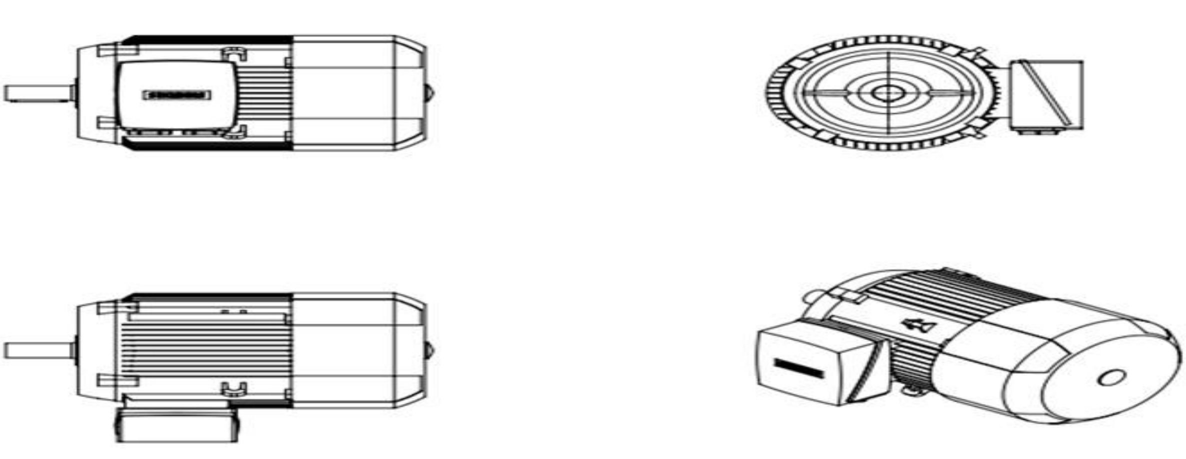


Fig. 13: First angle orthographic projection of the electric motor in the soap extruder

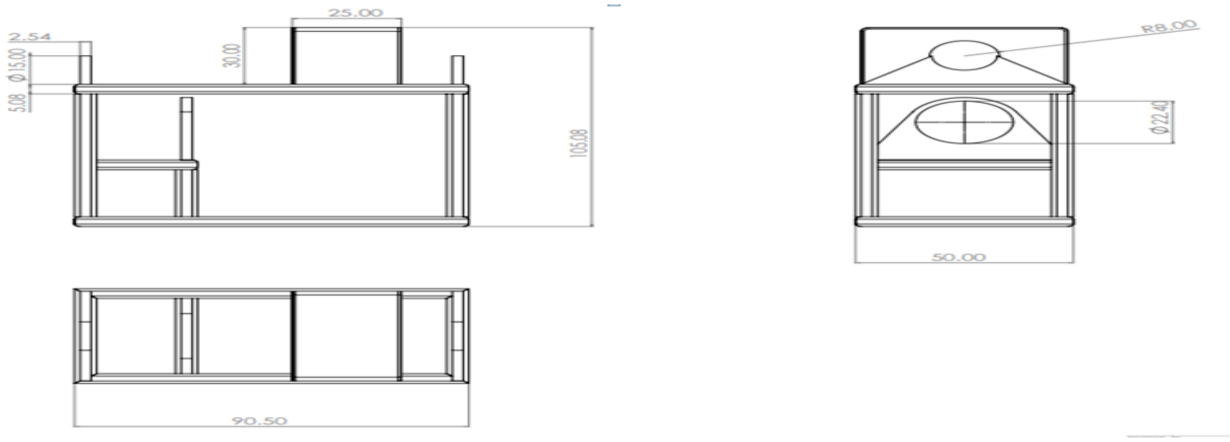


Fig. 14: First angle orthographic projection of the soap extruder stand and the heater case with dimensions

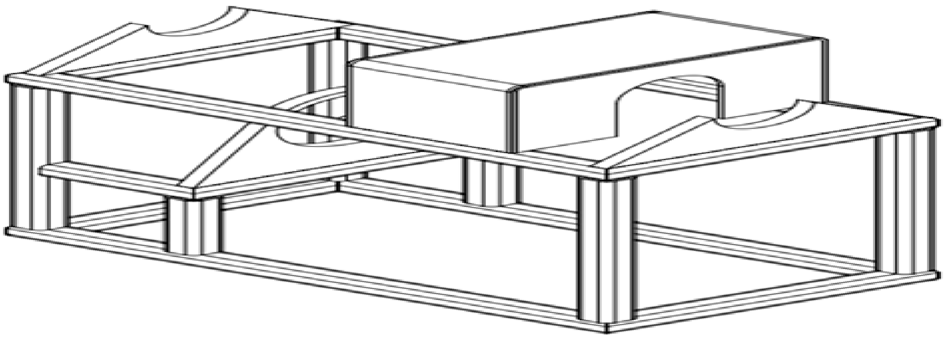


Fig. 15: The soap extruder stand and heater case

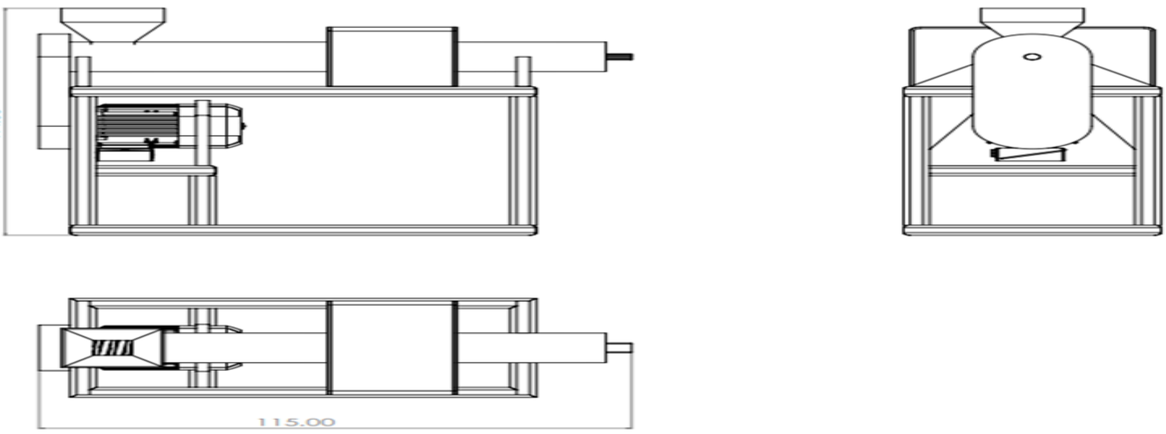


Fig. 16: First angle orthographic projection of the soap extruder

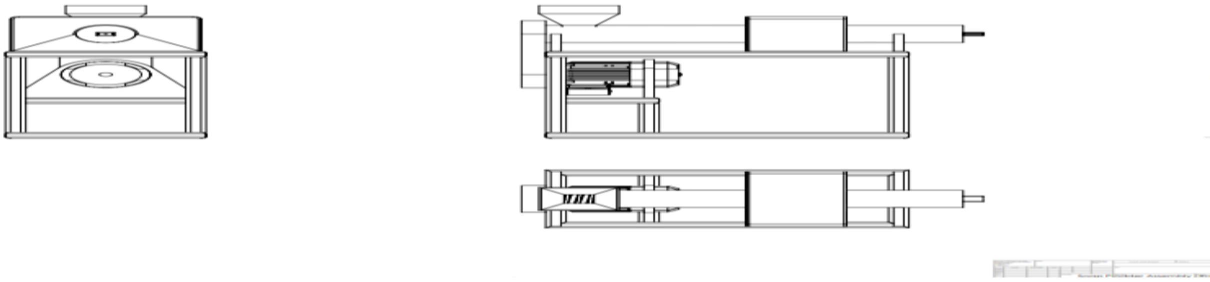


Fig. 17: Third angle orthographic projection of the soap extruder

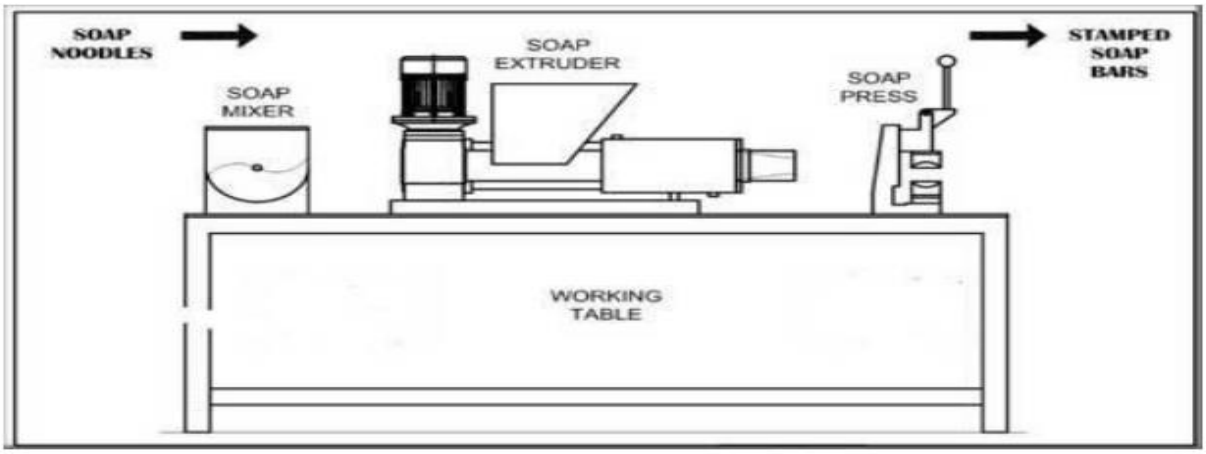


Fig. 18: Schematic representation of soap extrusion processes

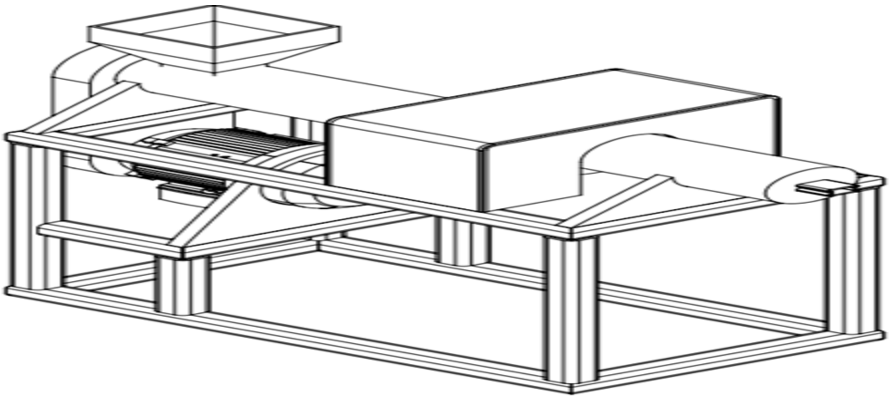
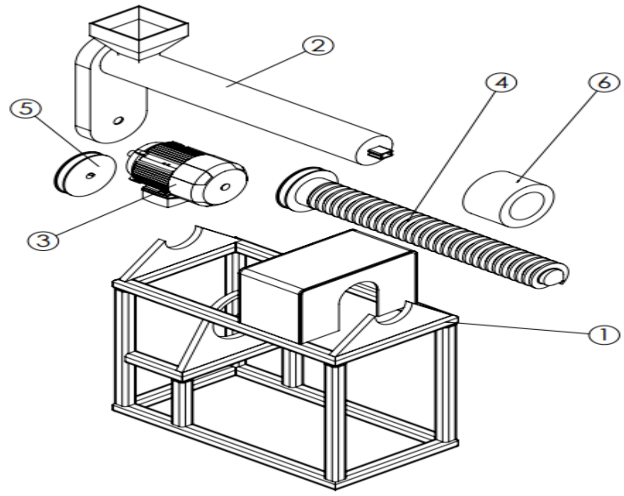


Fig. 19: The soap extruder



ITEM NO.	PART NUMBER	QTY.
1	Soap Plodder Stand	1
2	Hopper	1
3	35629 (4Kw)	1
4	Lead Screw	1
5	Motor Pulley	1
6	Heater	1
7	Belt1-3	1

Fig. 20: Exploded schematic diagram of all the components of the soap extruder

Fig. 21: Actual fabricated model of the soap extruding machine

3.5 Cost estimation

The estimated cost of the soap extruding machine is as summarized in Table 1.

Table 3: Engineering measurement and evaluation (BEME)

No	Item	Material	Quantity	Cost per unit (₦)	Total cost (₦)
1	Motor	Cast Iron	1	120,000	120,000
2	Pulley	Mild Steel	2	3,000	6,000
3	Pulley Guard		1	1,000	1,000
4	Variable Speed Drive		1	10,500	10,500
5	Mixer		1	12,000	12,000
6	Bearing	Aluminum	1	1,000	1,000
7	Hopper	Stainless Steel	1	150,000	150,000
8	Extrusion Shaft	Stainless Steel	1	100,000	100,000
9	Extrusion Shaft Housing	Mild Steel	1	8,000	8,000
10	Design Cost			80,000	80,000
11	Frame Mounting	Mild Steel	20	1,000	20,000
12	Mixing Tank	Mild Steel	1	30,000	30,000
13	Die Block	Stainless Steel	1	20,500	20,500
14	Bolts and Nuts	Alloy Steel	15	4,500	4,500
15	Timing Belt	Rubber	1	10,000	10,000
16	Immersion Heater		1	7,500	7,500
17	Labor			200,000	200,000
18	Miscellaneous			20,000	20,000
	Total				800,000

4. Discussion

The bar soap making machine uses a motor which when started rotates the extrusion shaft connected to it through a toothed timing belt and a pulley drive. This motor is connected electrically to a variable speed drive which steps down its speed from 1400 rpm to the required speed of 60 rpm. The extrusion shaft has bearing at its rear end to ensure that it is always in line and minimize friction. The extrusion shaft has spiral screws with lead length of 16cm. The soap noodles are made in a separate tank by mixing the various ingredients and chemicals using a mixer. The noodles at a high temperature were allowed to cool and dry. After the noodles were cooled and dried, it was then poured into the hopper directly above the extrusion shaft at the rear end (near the pulley system). As the extrusion shaft rotates, it pushes the soap noodles towards the die block. The soap noodles get into the space between the spiral screws where they are compressed as they rotate to make them compact before reaching the exit system. Apart from the opening for the hopper, the rest of the extrusion shaft is enclosed in a mild steel housing. This housing has a heater that has a thermostat placed just before the die block to heat the water jacket. After being compressed up to the right compactness, the soap exits the bar soap making machine through the die block. The bock has width of 6.05cm and height of 3.05cm in order to produce a bar soap of the standard measurement of 6cm by 3cm. A table is placed in line below the die block. The bar soap slides on this table where it is cut into the required length. The standard length is usually 50cm. The size of the bar soap produced can be altered by changing the dimensions of the die block.

5. Conclusion

The current design of the bar soap making machine had overall dimensions of 1350mm length, 500mm width and the total height 920mm. Focus which was laid on the reduction of the bulk and overall price of the machine without compromising on the quality of the bar soap produced was achieved. . Careful selection of materials was observed while considering their availability without compromising on the durability of the bar soap making machine which was fabricated. The working mechanism of the bar soap making machine was designed so that the total number of moving parts is reduced to a necessary few. This modification aided by sufficient lubrication of the machine has also made the machine to be adequately water cooled which resulted to high overall efficiency of the soap making machine. The cost analysis of the bar soap making machine also showed that it was much cheaper than the existing bar soap making machines and can be manufactured locally from the available materials.

Acknowledgments

The authors acknowledged the Department of Mechanical Engineering, Faculty of Engineering, Benson Idahosa University for the using some of their facilities during the fabrication process.

Conflict of interest

There is no conflict of interest among the authors.

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