BREE495
Engineering Design 3
Bioresource Engineering
McGill University

‘Micro’ Peanut Butter Production Plant

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Our Vision: Provide rural Nigerians with a reliable stream of income and healthy supplement through the affordable processing of groundnut.

Abstract

This paper presents a compact peanut butter production plant, which is designed for Ejigbo, a rural community in Osun State, Southern Nigeria, mentored by Dr. Michael Ngadi. Unit operations considered in this project include shelling, roasting, cooling, grinding and mixing. Each unit operation follows engineering standards. Life cycle assessment was carried out for each unit operation, along with economic and social analysis for the whole project. Alternative energy sources for grinder and mixer are also discussed. This project is a paper design but a model or a real prototype can be built according to the technical drawings, installation instructions, and dimensions.

zKeywords: Nigeria, Peanut Butter, Unit operations

1. Introduction

Nigeria produces the 3rd most groundnuts in the world, a significant portion of which is carried out by its rural subsistence farmers. Job opportunities created by the labor-intensive groundnut makes it an important sector in rural poverty-stricken areas. Peanut butter is a product of greater economic value than nuts. Additionally, it can provide a more accessible and protein-rich supplement, balancing the low-nutrient carbohydrate diet of Africans. Through implementing a mechanized, higher capacity peanut butter production system to rural communities, a step towards improving habitant livelihoods can be made.

2. Design Criteria and Considerations

2.1. Client Information

The 'Micro' Peanut Butter Production Plant is designed to satisfy conditions that would typically characterize a small-to-medium sized rural community in Southern Nigeria. For time and economic constraints, an understanding of what would prove satisfactory for the client was gathered from the literature review. The quantitative data that would dictate the capacity of the system was developed through the cross-referencing of several publications. Based on information gathered on population and peanut production in Ejigbo Local Government Area of Osun State (Ogburur and Ayeni, 2016), Lafi Local Government Area of Nasarawa State (Audu et al., 2017), and Nigeria averages the capacity of the system was created. The key factors were population, groundnut cultivation area, groundnut harvest yield, kernel and shell properties, the percentage of harvested groundnut allotted to groundnut butter production, and shelf life.

2.1.1. Population: 750 people (150 families/households)

Ejigbo LGA of Osun State served as the basis for population assumptions. The total population of Ejigbo LGA is 132,641 persons, from whom 88,457 dwells in the town of Ejigbo, headquarters of the greater Local Government Area. Aside from Ejigbo, there are 34 listed villages elsewhere within the jurisdiction. It is surmised that there is an average of 1,250 people in a village, with general variance throughout. This design will be fitted for a small-to-medium village, which is then taken as having a population of 750 people.

Additionally, the average rural family consists of approximately 5 people per household. Thus, a small-to-medium sized village is composed of around 150 individual families. This information is important as it dictates the levels of crop production.

2.1.2. Groundnut cultivated area: 190 acres (77 hectares)

The rural population in Nigeria largely relies on subsistence farming where the average farm size ranges from 0.7 - 2.2 hectares. 70% of the rural population in Nigeria participate in subsistence farming. From this, it can be estimated that there are at least 105 households in the village that cultivate personal crops. Based on the groundnut cultivation area averages in the Ejigbo LGA (estimating less than one acre as 0.7 acres, and 1-5 acres as 2.2 acres) the total land area is cultivated by habitants amounts to around 190 acres (31.85+123.19+34.965) or about 77 hectares.

2.1.3. Groundnut harvest yield: 107.87 metric tons (107,800 kg)

The average yield for groundnuts is 1.4 metric tons per hectare (1,400 kg/ha). In turn, the total groundnut yield in the village would amount to approximately 107.8 metric tons (107,800 kg).

2.1.4. Groundnuts for PB processing: 53.9 metric tons (53,900 kg)

Groundnuts are put to use in a variety of ways and are consumed in both roasted and boiled forms. Derived oils and popular dishes such as gbegiri, kuli-kuli, and maafe all make use of harvested peanuts. Due to numerous consumption possibilities, the percentage of cultivated groundnuts that are to be turned into peanut butter is reduced. For the village in which the 'Micro' Peanut Butter Production Facility is designed, the goal is to provide a means of groundnut butter processing for half of the harvested nuts. That is, 53.9 metric tons (53,900 kg). On average, the peanut shell accounts for 20% of the total weight. Thus, there will be (1-0.2) x 53,900 kg = 43,120 kg of peanut kernels available for processing. 10,780 kg of peanut shells for biofuel contribution.

2.1.5. Rate of peanut butter production: 359.33 kg/day

Groundnuts have a growing season of 90 to 100 days, allowing for three planting cycles every year. The first planting occurs in May or June and the harvest takes place in September/October. For every harvest, there are 43,120 kg of peanuts that require processing. Raw, dried groundnuts can be stored for 4 to 10 months in good conditions but as little as 2 months if adverse factors such as high moisture levels or contaminations exist. For this design, the capacity of each unit operation is modeled on the mass and volume of peanuts available for processing in a four-month storage period (120 days). Furthermore, the calculations are made under the scenario that the plant is operated daily for a duration of six hours. The mass of peanut kernels and shells processed per day is: 43,120kg/120 days = 359.33 kg kernels/day, and 10,780 kg/120 days = 89.93 kg shells/day.

2.2 Design Criteria

As stated before, this design is meant to satisfy the needs and circumstances that are generally seen in a Southern Nigeria rural community small to medium. As there is variability between each village, the conditions listed below may require supplementation or alteration accordingly. Pulling from a collection of information regarding Ejigbo Local Government Area, Southern Nigeria, and similar situations across West Africa; the following criteria were derived:

2.2.1 Manufacturing and Installation Cost Under $1,000 USD (₦364,000 NGN)

Price must be minimized due to lack of available funds. In Nigeria, 67% of those employed in rural agriculture live in poverty, thus there is little ability to invest enough capital for a project of this scale communally. (Banful, Nkonya, & Oboh V, 2011) However, if the cost is low enough, the client may deem such an investment more attainable. It is more likely that the purchaser of this processing plant will be a non-government organization (NGO) involved in rural development programs. Regardless, minimizing cost makes such a prospect more realistic.

2.2.2 Maximum 30 kg Lifted at a Time

It will be the responsibility of the client community to operate, manage, and maintain the peanut butter plant. The groundnut agricultural sector in rural areas employs women as the principal groundnut cultivators and processors. The weight of products must be manageably lifted and carried between the different components of the system. Out of convenience and from reason, 30 kg was set as the weight ceiling. This load represents half of the 60 kg handled per hour from any unit operation.

2.2.3 Repairable by Community Members with Local Materials

Components and mechanisms along the process should work for an indefinite period of time. However, in the case of failure the community should be capable of carrying out repairs with materials easily accessible, i.e. within or close to the village.

2.2.4 Meet EHEDG Hygienic Equipment Design Criteria

Equipment used for the processing of foods must adhere to hygienic design criteria in order to prevent microbial contamination. The European Hygienic Engineering Design Group (EHEDC) publishes criteria that dictate whether a mechanism is safe to be used hygienically. It is these conditions that this design must adhere to.

2.2.5 Physical Safety

In addition to hygienic standards, the design must limit are risk of direct physical injury. There are numerous possible safety risks that must be addressed such as those involved with biomass burning, milling blades, mixer entanglement, electric circuits, and the lifting of weights.

2.3 Design Considerations

Each unit operation that comprises the overall food processing system requires individual design, however, the steps to determine the optimal option was followed a similar methodology universally. A decision-making flowchart, **figure 1**, below exhibits the analysis methodology.

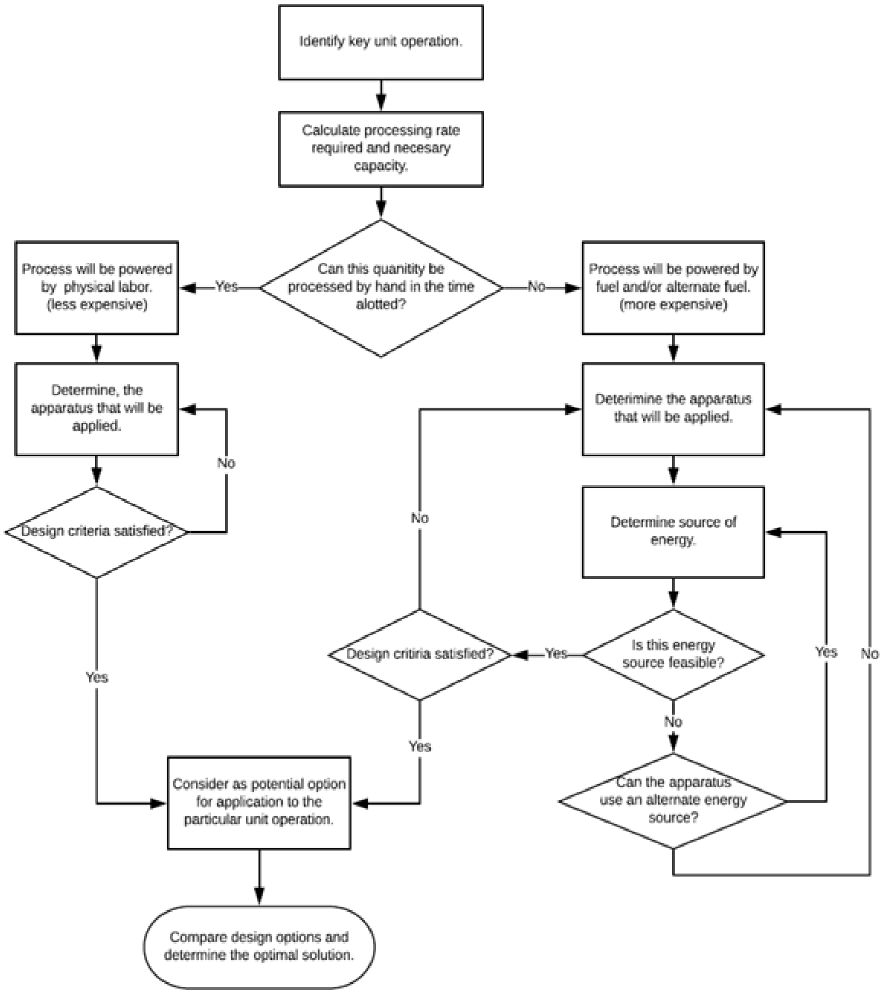


Figure 1: Unit operation systematic design decisions

3. Final Design

The 'Micro' Peanut Butter Production Plant encompasses five of the chief unit operations required in traditional peanut butter production systems: shelling, roasting, cooling, grinding, and mixing. The process flow diagram of the plant, figure 2**,** portrays the encompassing system.

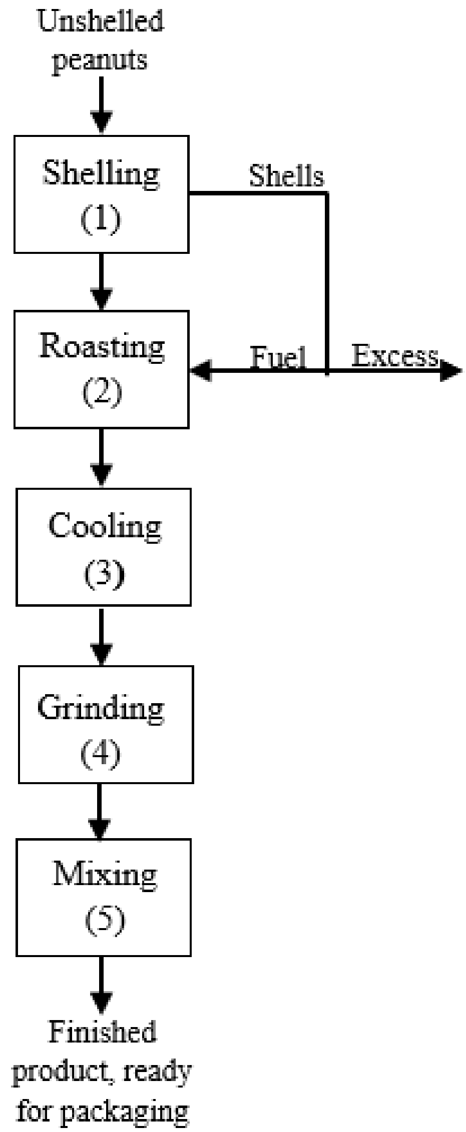


Figure 2: Process flow diagram of the plant.

1. Shelling	75 kg of unshelled peanuts are shelled each hour. From this, 60 kg of kernels and 15 kg of shells are made available. The kernels are further processed in the roaster, while the shells act as a fuel source for the heat generation.
2. Roasting	The peanut kernels are roasted at 160 °C to 180 °C for 30 minutes. The incoming 60 kg of kernels are split into two 30 kg batches and roasted. The shells leftover from the shelling process are burned in the oven roaster, providing heat to cook. Excessive shells may be discarded. Reduction in mass due to moisture loss is neglected, thus 60 kg of roasted kernels exit the unit operation per hour.

3. Cooling	A total 360 kg of kernels are roasted each day. After the completion of each 30 kg batch, the roasted nuts are poured into one of two storage hoppers, undergoing overnight storage. The following day, the kernels are removed and ground.
4. Grinding	The kernels are removed from the hopper silo at roughly 10 kg loads. 10 kg of peanuts results in 10 kg of peanut butter under theoretical conditions.
5. Mixing	Additional ingredients such as salt, sweeteners, and emulsifying agents may be added to the peanut butter and uniformly distributed. Exiting this operation is the finished peanut butter product.

In the following overview, each unit operation and the functional designs applied will be explained sequentially. The order of analysis follows the path a peanut batch undergoes through this system, beginning with the introduction of shelled nuts and concluding with the final peanut butter product:

a. Shelling

b. Roasting

c. Cooling

d. Milling

e. Mixing

A well-rounded analysis of each unit operation design will be carried out using a base organization methodology, while variant features unique to a particular design will be noted when necessary. The fundamental factors are as follows:

a. Overview

b. Operation

c. Fabrication Details

i. Materials, Construction, and Manufacturing

ii. Cost Analysis

d. Technical Details

i. Design Drawings

ii. Used Principals and Equations

e. Design Validation

3.1 Unit Operation: Shelling

3.1.1 Overview

Shelling must handle an hourly peanut inflow greater than that of any of the subsequent processes. 75 kg of unshelled peanuts per hour must undergo a separation process, splitting the initial bulk mass into 60 kg of kernels and 15 kg of shells. Women shelling by hand can generally process 1 kg of unshelled nuts per hour. In addition, the act of doing so puts them at risk of aflatoxins being transmitted from the shell and absorbed through their skin. The mechanism applied to shell the groundnuts is a pre-existing design called the universal nut sheller (UNS). Developed by Jock Brandis, the universal nut sheller has been hailed for its functionality and low cost. He later founded the Full Belly Project, an NGO that has further developed the UNS and made possible greater stability.

3.1.2 Operation

The operator loads the groundnut into the opening at the top of the UNS. The user then turns the handle, subsequently rotating the rotor continuously. This motion facilitates the descent of nuts down the gradually narrowing gap. The groundnut shell is broken at the point in which the gap becomes sufficiently narrow and the rotor motion generates sufficient friction to crack open the hull. Afterwards, the kernel and shell fragments fall into a container below the UNS and are later separated by winnowing.

3.1.3 Fabrication Details

<u>Materials, Construction, and Manufacturing</u>

Material	**Cost**
One time	
Design plans	$28.00
Fiberglass molds	$200.00
Subsequent	

Cement	$10.00
Metal components	$10.00
Total:	$248.00 (initial) $20 (subsequent)

Component	**Dimensions**	**Material**
1	L = 2 in Thread pitch = 32 Size = #6	Fastener/Connector:steel Finish: yellow zinc
2	l = 300mm w = 50mm t = 2mm	Carbon Steel
3	l = 200mm w = 30mm t = 2mm	Carbon Steel
4	D = 50mm l = 120mm	Carbon Steel
5	L = 1 in Thread pitch = 32 Size = #6	Carbon Steel
6	l = 200mm w = 50mm t = 2mm	Carbon Steel
7	D = 30mm l = 500mm	Carbon Steel
8	**Top** Di = 160mm Do = 200mm **Bottom** Di = 400mm Do = 440mm	Concrete
9	**Top:** D = 130mm	Concrete

	Bottom: Di = 240mm Do = 320mm Hi = 120mm Ho = 240mm	
10	l = 440mm w = 50mm t = 2mm	Carbon Steel

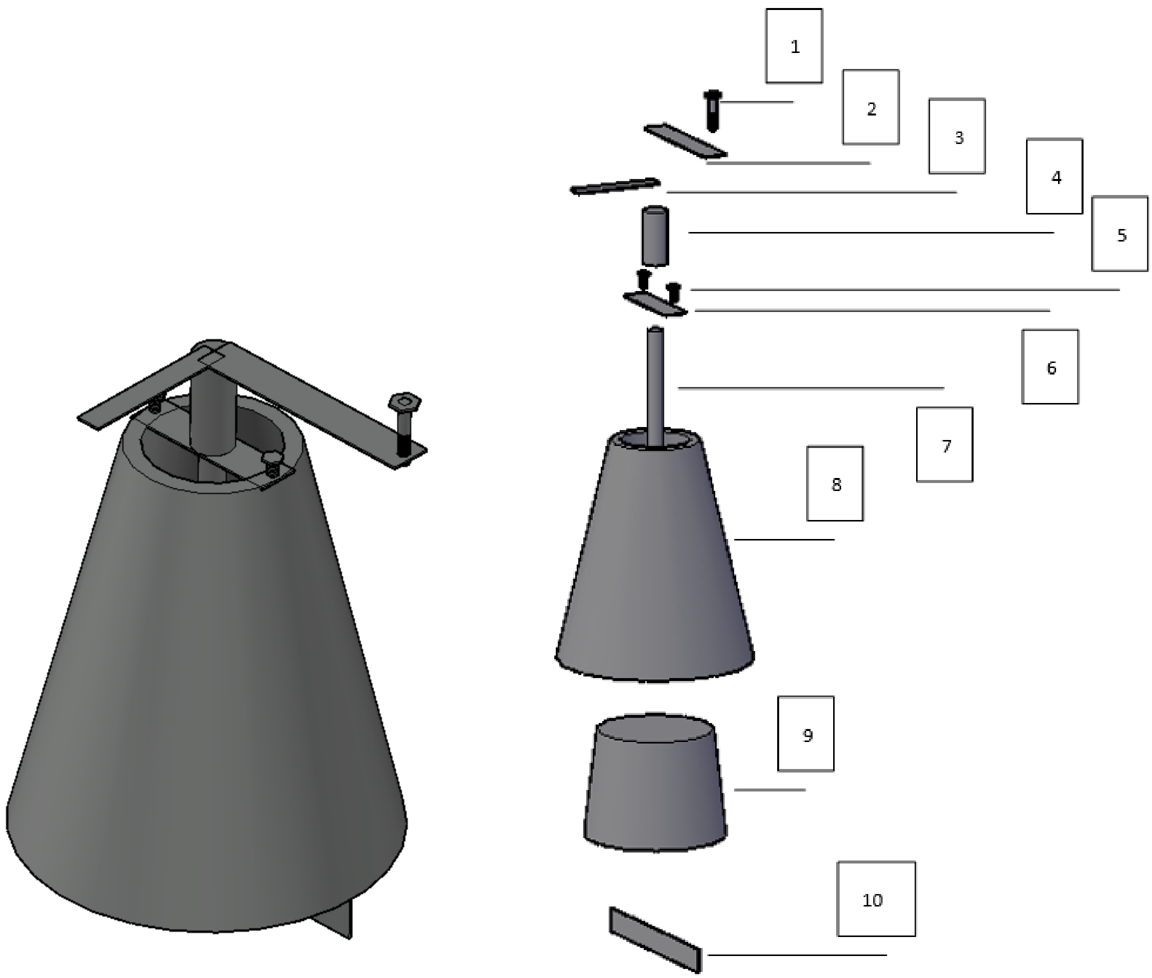
The universal nut sheller design allows for simple manufacturing that can be carried out on a local level in the community of its use. In this circumstance the life expectancy of the sheller is 25 years. By manufacturing the sheller in advance with more control, the life span becomes 50 years. A metal shaft, bracket, screws, nuts, and washers encompass the metal components of the sheller.

3.1.4 Cost Analysis

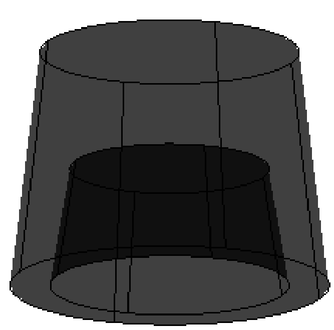
Both the metal components and the molds can be procured from Full Belly Project. The design plans and fiberglass molds account for an initial, one-time cost of $228.00. Materials comprising the physical unit can otherwise be purchased at a hardware store, amounting to $20.00.

3.1.5 Technical Details

<u>Design Drawings</u>



Component 9



Utilized Principals and Equations

Mathematical breakdown of the physical forces involved in the UNS process was deemed unnecessary due to its track record of proven performance.

3.2 Unit Operation: Roasting

3.2.1 Overview

The roasting process is carried out in a batch oven roaster, adhering to a design released by Practical Action. Practical Action undertakes projects in developing countries, applying innovative technology to improve access to a variety of utilities. The apparatus consists of a manually operated drum subject to heat from an external fire. Operating at temperature of 160 °C -180 °C, it takes 30 minutes to roast 30 kg of peanuts; thus, there is a capability to roast 60 kg/hr. The heat required to reach these temperatures is generated from burning the peanuts shells that were obtained through the earlier shelling operation. There are 15 kg of shells available to combust for every hour of operation.

3.2.2 Operation

Within the brick housing, the roaster is partitioned into two major components: the lower hearth and the duel drum roaster above. In this case, the hearth is filled with leftover peanut shells, however the literature suggests various biomass alternatives such as paddy husks or sawdust are viable. The added shell load is well compacted leaving a cylindrical opening at the center (vertical) extending it horizontally at the bottom. This is done by inserting two cylindrical poles before packing with fuel source. Once the packing is complete the two poles are pulled out carefully creating two tunnel shaped openings. The hearth is lit by inserting some firewood into the base of the "airways". The hearth is placed at the inlet of the stove which is constructed around the peanut drum roaster. The drum roaster is loaded with the peanuts or other food commodities (using the drawer that is detachable). Once the hearth is lit, operators continue rotating the inner drum while checking the peanuts occasionally. Allow 20 minutes of roasting before checking it and then check every 3 minutes. When peanuts have been suitably roasted, unload the peanuts onto a wire mesh to avoid over burning.

3.2.3 Fabrication Details

Materials, Construction, and Manufacturing

The drum is housed in a brick and clay construction. Biomass is burned upon the base of the clay oven heating the drum that is suspended above. The roasting drum can be fabricated at any welding workshop and an ordinary mason can carry out the installation and construction of the oven.

The roaster is comprised of two drums. The outer drum, a simple tar barrel, is positioned flush to the surrounding brickwork. The drum is positioned as to allow for a detachable bottom plate to be removed and inevitably replaced when damage due to heat exposure becomes too high. The inner drum, made from 22 gauge galvanized steel, contains the peanuts for the duration of the roasting process. A small portion of this drum is made similar to a drawer which can detach for loading and unloading peanuts. To alleviate any potential food safety issues, the tar barrel must be cleansed by used a metal brush and sanitizing materials. Such is a traditional practice carried out to convert old petroleum barrels into high-heat roasting, smoking, or grilling vessels.

A housing structure, made of brick and clay, provides encasement to a manually operated rotating drum. The heat required to roast the groundnuts will be provided by the burning of a biomass mixture (firewood and groundnut shells). Firewood and groundnut shells will continuously burn on the internal floor of the brick encasement, heating the groundnut drum above.

Roaster

Component	**Dimensions**	**Material**
1	**Overall:** h = 1250mm w = 1000mm l = 825mm **Upper proportion:** D = 750mm Brick wall thickness = 125mm **Lower proportion:** H = 440mm	Brick (Clay & Sand)

	W = 450mm Brick wall thickness = 275mm **Opening:** Arc: r = 75mm Square: w = 150mm	
2	300mm x 300mm x 300mm	Marga tin
3	**Half-circle:** R = 290mm Thickness = 10mm	Marga tin
4	1200mm x 1025mm x 100mm	Brick (Clay & Sand)

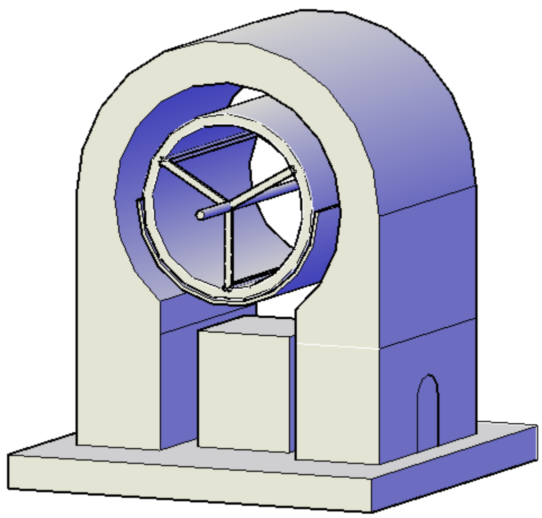
Drum

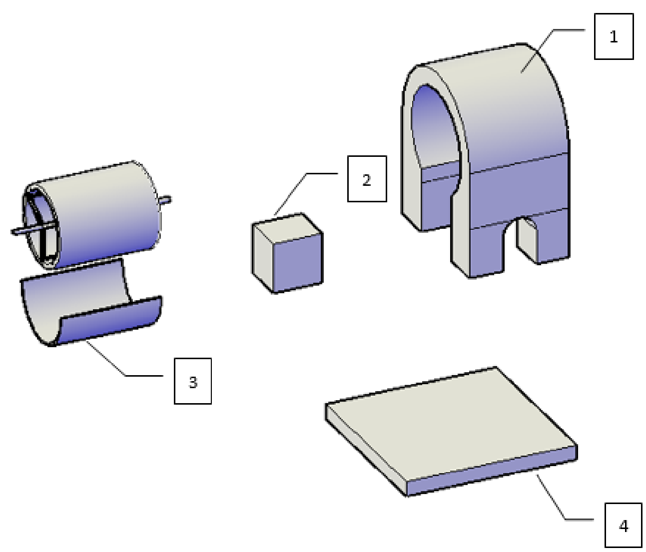
Component	**Dimensions**	**Material**
1	D = 25mm L = 200mm	Mild Steel Rod
2	D = 500mm l = 700mm	Wood/Stainless Steel
3	**6x:** l = 700mm t = 25mm w = 25mm	Angle Iron
4	**3x:** l = 250mm t = 10mm w = 20mm	Flat Iron
5	D = 25mm l = 700mm	Mild Steel Rod
6	**3x:** l = 250mm t = 10mm w = 20mm	Flat Iron
7	D = 25mm L = 200mm	Mild Steel Rod

3.2.4 Technical Details

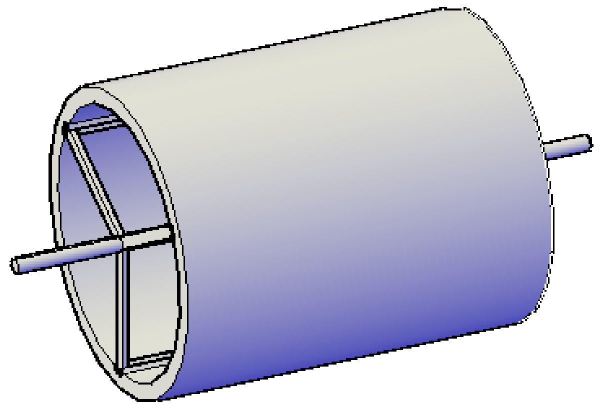
<u>Design Drawings</u>

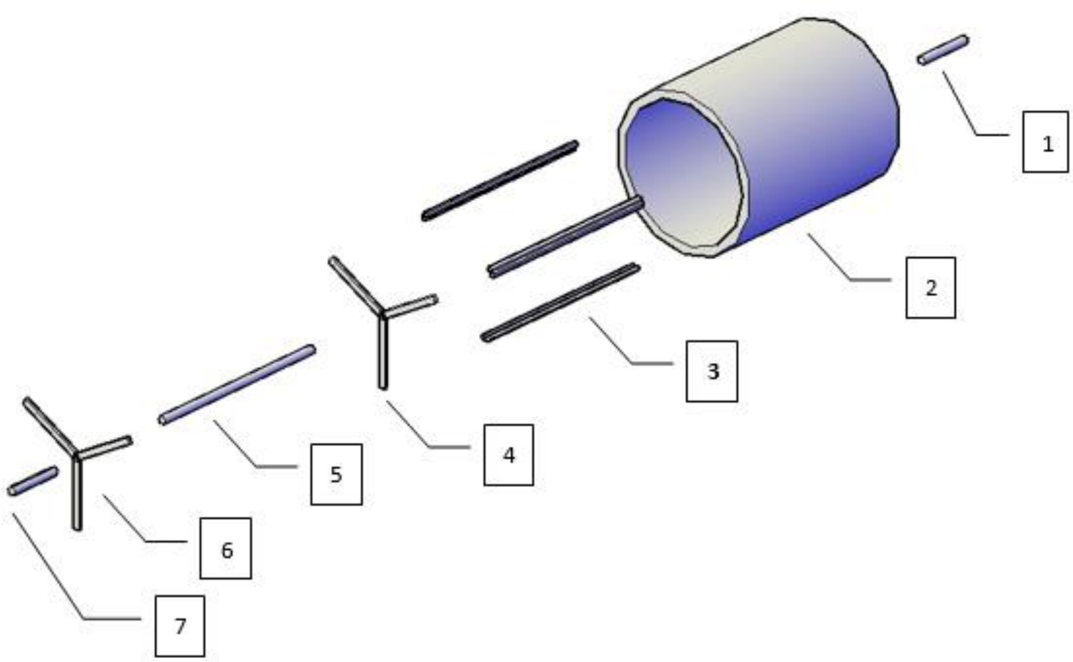
Roaster





Drum





Utilized Principals and Equations

To determine the amount of biomass that needed to be burned for heat production, heat transfer equation was applied. The peanuts need to be heated from 20 ℃ to 180 ℃ to reduce the moisture content from 18~22% to 0.2%~0.6%. The heat required to satisfy these conditions is 11,232 kJ. As this is carried out over a span of 30 minutes, 22.464 MJ of heat are required an hour. The required heat, Q_{req}, is calculated as the product of peanut kernel mass, m_{kernel} , specific heat capacity of peanut kernels, c_{kernel},and the kernels change in temperature, ΔT.

$$Q_{req} = m_{kernel} c_{kernel} \Delta T$$

To assess the amount of heat produced by burning the peanut shells, the mass of the shells,m_{shell} , available every hour was multiplied by the average heat value.

$$Q_{hulls} = HV \times m_{shell}$$

This equated to an available 266 MJ/hr, far exceeding the roasting requirements of the peanut kernels.

3.3 Unit Operation: Cooling

3.3.1 Overview

Roasted peanut kernels will be cooled overnight, housed in a pair of hopper-bottom silos designed for their storage. Hoppers are commonly used for the storage of granular material. A major aspect of its usefulness in this operation comes the ease in which the peanuts are removed. Gravitational forces drive the contained granular mass downward, exiting the bottom outlet at a mass flow rate of 2 kg/s. The volume within each hopper is 0.22 m^3, holding 180 kg of roasted groundnuts each when fully loaded.

3.3.2 Operation

After the completion of the roasting process it is recommended that the peanuts be placed out in the open for a short to subject the batch to natural convection forces. To load the hopper, the peanuts are simply poured into the inlet valve located at the top of the vessel. For extraction, a controlled output valve is opened with a lever and the descending kernel are retrieved in a smaller bin and transported.

3.3.3 Fabrication Details

<u>Materials, Construction, and Manufacturing</u>

316 stainless steel (26 gauge) form the hopper-bottom silo walls. The total surface area for both vessels is 4.44 m^2.

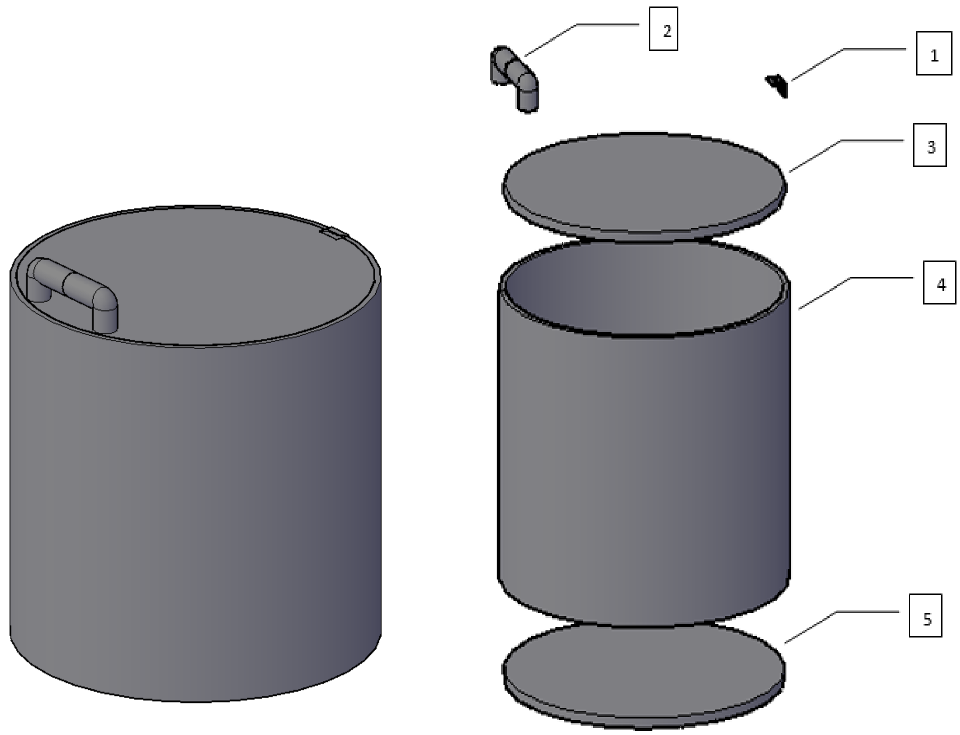
Component	**Dimensions**	**Material**
1	h = 115mm w = 102mm ***Hole sizes adjustable depending on screw sizes.**	Copper Brass-plating

2	**Uniform Diameter:** D = 40mm **Joints:** 2x R = 35mm **Vertical:** 2x l = 40mm **Horizontal:** l = 160mm	Brushed nickel
3	D = 600mm Thickness = 20mm	316 stainless Steel
4	H = 610mm D = 600mm Wall thickness = 20mm	316 stainless Steel
5	D = 600mm Thickness = 20mm	316 stainless Steel
Hopper	H = 215mm D(top) = 600mm D(bottom) = 170mm Wall thickness = 20mm	316 stainless Steel

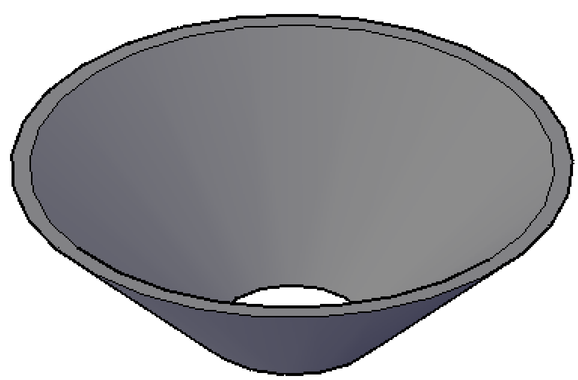
3.3.4 Technical Details

Design Drawings

Silo(s)



Hopper



Utilized Principals and Equations

Preliminary calculations made it clear that a single storage container would not be realistically viable for use primarily due to the height. By partitioning the mass of nuts between two vessels the height requirement is decreased and operators can load it with relative ease. Hopper design is largely dictated by the flow properties and characteristics of the material it intends to house. Common issues arise involving the flow of bulk material through a hopper such as arching, a total blockage to exit, and plug flow in which the food material may collect and stagnate in regions near the outlet. The hopper-bottom solo is designed for mass flow. The desired flow pattern follows hopper mass flow characteristics, considering the physical properties of peanut kernels and the storage requirements. Each vessel can handle 200 kg of peanut kernels to account for the 180 kg input. The vessel volume, V_{vessel}, necessary was calculated as the product of the mass capacity, m_{vessel}, and the average bulk density of peanut kernels, $\rho_{b,kernels}$:

$$V_{vessel} = m_{vessel} \times \rho_{b,kernels}$$

For the cylindrical portion of the vessel, the cross-sectional area, $A_{cylinder}$, was found by applying a cylinder height of 0.6 m, $H_{cylinder}$, using the following equation:

$$H_{cylinder} = m_{vessel}/(\rho_{b,kernels} \times A_{cylinder})$$

From this, the radius of the cylindrical portion, $r_{cylinder}$, was found to be 0.3 m. To ensure for the safety of the outlet retriever, a manageable mass discharge rate was chosen to be 2 kg/s. Finally, the hopper angle from the vertical, θ, was calculated using the mass flow rate equation, where M_f is mass flow rate, A_{outlet} is the area of the outlet, $B_{outlet}$is the size of the outlet, and g is the acceleration.

$$M_f = \rho_{b,kernels} \times A_{outlet} \times \sqrt{(B_{outlet} \times g)/[2 \times 1 + m) \times tan\theta]}$$

3.4. Unit Operation: Grinding

3.4.1 Overview

The grinder enlisted for use in the facility is the Compatible Technology International made Ewing IV Grinder. After the roasted peanuts are cooled down to room temperature (preferably 25°C), they are transferred from the cooling silos to the grinder. Being loaded from the top, the peanuts are to be grounded into powder-like granules with the shaft being operated by hands or by pedaling. The helix on the shaft, along with two turning burrs installed at both ends of the shaft are alternating with the rotation of the shaft and hence the nuts are grinded into smaller pieces.

3.4.2 Operation

The grinder chassis has an open face in which the operating party will feed peanuts into. By rotating the lever, the internal helix mechanism will guide descending peanut kernels into the burr grinder which will crush the peanuts into peanut butter as they are forced in. A container placed below will capture the freshly ground peanut butter.

3.4.3 Fabrication Details

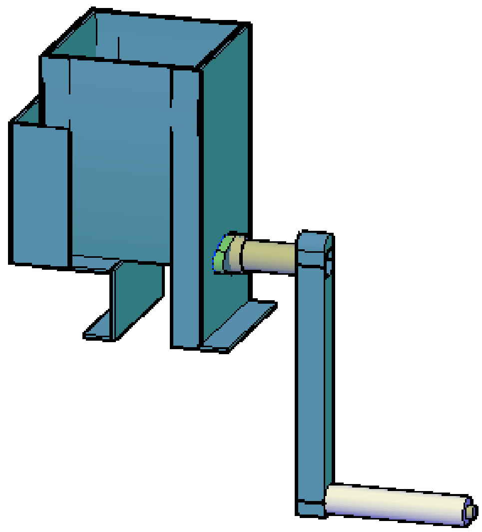
Materials, Construction, and Manufacturing

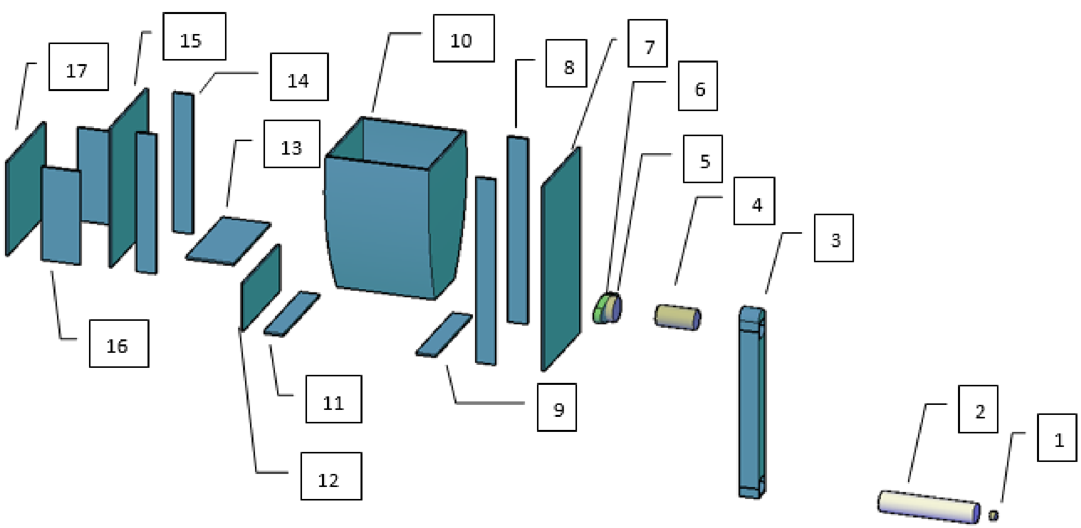
Component	**Dimensions**	**Material**
1	D = 8mm l = 110mm	Hardened steel
2	D = 20mm l = 100mm	304 stainless steel **[Coated with rubber]**
3	l = 200mm w = 20mm Thickness = 20 mm **Cylinder cut:** Distance from the top = 20mm D = 20mm **Rounded arc:** R = 10mm	430 stainless steel sheet metal
4	L = 40mm D = 20mm	Hardened steel
5	D = 25mm Thickness = 34mm	Hardened steel
6	L = 55mm H = 30mm **2 x merged circles:** D = 15mm	Hardened steel **[Coated with C3 coating]**
7	110mm x 210mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
8	**2x:** 20mm x 200mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**

9	110mm x 20mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
10	Wall thickness = 2mm H = 150mm **Top:** 110mm x 110mm **Bottom:** 60mm x 105mm	430 stainless steel sheet metal **[Coated with C3 coating]**
11	110mm x 20mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
12	110mm x 50mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
13	110mm x 50mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
14	**2x:** 20mm x 150mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
15	100mm x 20mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
16	**2x:** 100mm x 40mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**
17	112mm x 100mm x 2mm	430 stainless steel sheet metal **[Coated with C3 coating]**

3.4.4 Technical Details

<u>Design Drawings</u>





<u>Utilized Principals and Equations</u>

Mathematical analysis of the grinding mechanisms was deemed necessary due to its proven past record.

3.5 Unit Operation: Mixing

3.5.1 Overview

This agitation vessel applied in the mixing process allows for increased product variation and quality. Ingredients often added to peanut butter ranges from salt and sweeteners to emulsifying agents. Due to the highly viscous nature of peanut butter, a low-rpm, high power mixer was necessary. The mixing speed is about 60 rpm, which can be supplied with a 3hp motor. The motor is to be run by diesel or biodiesel. Alternative energy sources such as solar energy can be used according to the location of operation and the funding available for this project.

3.5.2 Operation

Peanut butter and additives are combined in the open tank. Once the power source is active, the mixing process is activated by through a starter. The final peanut butter peanut butter product is adequately mixed within 5 minutes of operation.

3.5.3 Fabrication Details

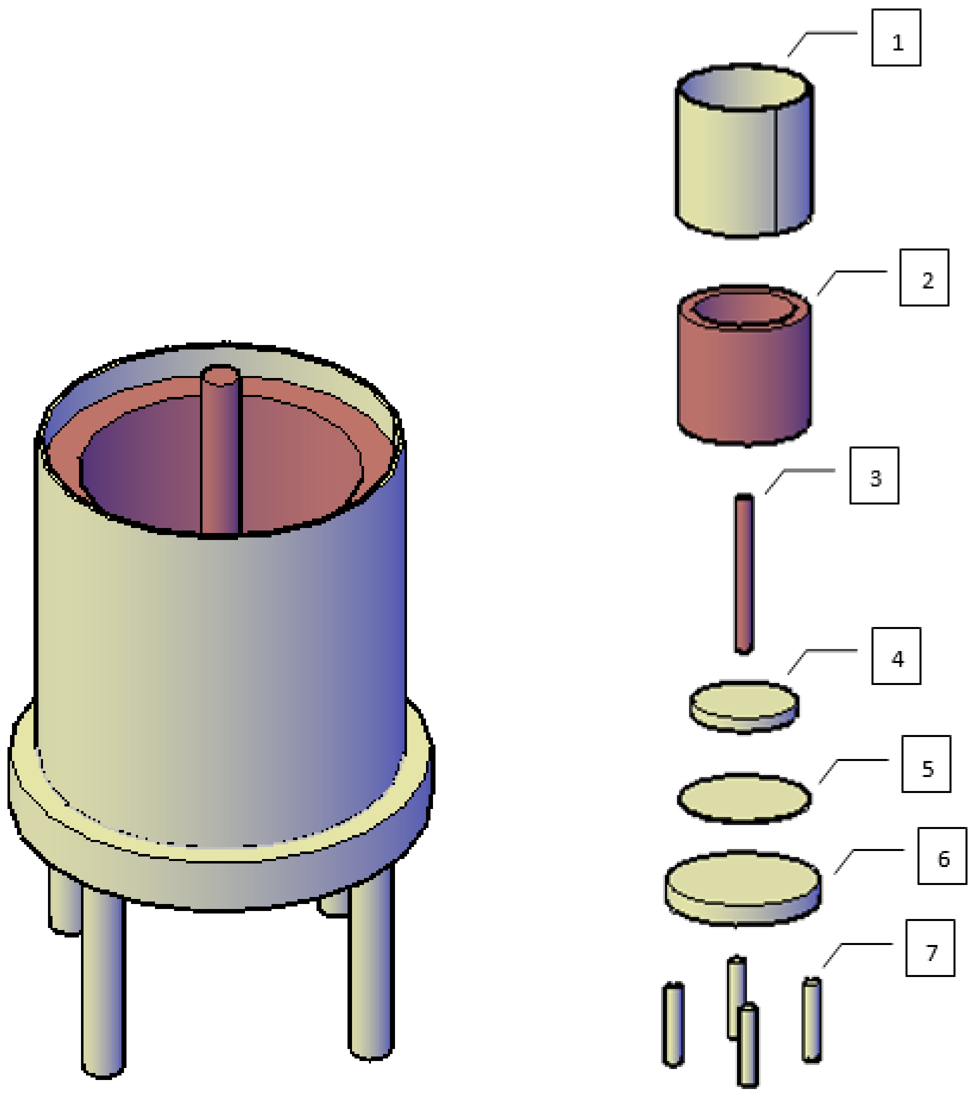
Materials, Construction, and Manufacturing

Component	**Dimensions**	**Material**
1	H = 330mm Di = 323.5mm Thickness = 3.235mm	304 Stainless Steel Sheet Metal
2	H = 300mm Di = 260mm Thickness = 32.35mm	316 Stainless Steel **[Resistive to NaCl]**
3	D = 32.35mm H = 400mm	316 Stainless Steel
4	D = 260mm Thickness = 32.35mm	304 Stainless Steel Sheet Metal
5	D = 323.53mm Thickness = 3.235mm	304 Stainless Steel Sheet Metal
6	D = 380mm Thickness = 50mm	304 Stainless Steel Sheet Metal

7	4x D = 35mm l = 200mm	304 Stainless Steel

3.5.4 Technical Details

<u>Design Drawings</u>



Used Principals and Equations

Anchor impellers are typically applied to mixing processes subject to high viscosity fluids and low rpm operation. At 250,000 cP, Peanut Butter is very viscous. Geometric ratios exist for commonly used impeller, that of an anchor impeller in a high viscosity fluid was referred to when determining functional dimensions. The diameter and height of anchor impeller mixers is 1.02:1 and selected chosen to be .323 m and .33 m, respectively. To determine the required power, *P,* Reynolds number,N_{Re}, must be calculated:

$$N_{Re} = \rho_{pb} N D_i^2 / \mu$$

Where$\rho_{pb}$is the density of peanut butter, *N* is the rotation rate, μ is the peanut butter viscosity, and D_i is the internal diameter of the mixer walls. Based on anchor impeller relationships, the power number, N_p, correlating with the reynolds number was found. From this, the power required for mixer operation, *P*, was determined using the formula:

$$P = N_p \, \rho_{pb} N_{\blacksquare}^3 / D_i^5$$

The resultant total power requirement of the mixer was 3, 850 J/s, or 3.84 kW.

4. Life cycle assessment

Life cycle assessment of this project has been carried out analyzing the potential environmental impacts from “cradle to grave”. Figure 3 below shows the life cycle assessment of this ‘micro’ peanut butter production plant. Raw materials such as metals and sand are to be mined from earth which pollutes the soil to some extent and potentially contaminate water bodies on the planet. With the input of raw materials, this plant is manufactured and assembled. To reduce the energy input and environmental impacts, this plant is to be manufactured on site i.e. where the plant is to be operated. During the installation and manufacture of this plant, noise and dust production are two severe impacts, along with solid wastes production. Operating this plant exerts bad influences on environment through noise pollution, gas emissions, waste water and ashes generation. The disposal of debris and waste materials at the end of the lifespan of this plant may reduce the soil quality and biodiversity. Slight radiation could be emitted by the disposed metals additionally. Besides, solid wastes including metals generated by this project will be tough to degraded.

To alleviate these impacts, this project is designed to be sustainable and to recycle energy and resources throughout the whole process from manufacturing to waste management. For example, peanut shells are to be used as an energy source; hence, the solid wastes generated during operation will be reduced. In addition, burning biomass decreases the amount of gas emitted, compared to diesel or petroleum burning. Alternative energy resources such as sunlight could be a possible solution to reduce the environmental impacts brought by this project as well. "Green operation methods" are encouraged in this project. Unit operations such as shelling and grinding, for instance, can be powered manually or with pedals.

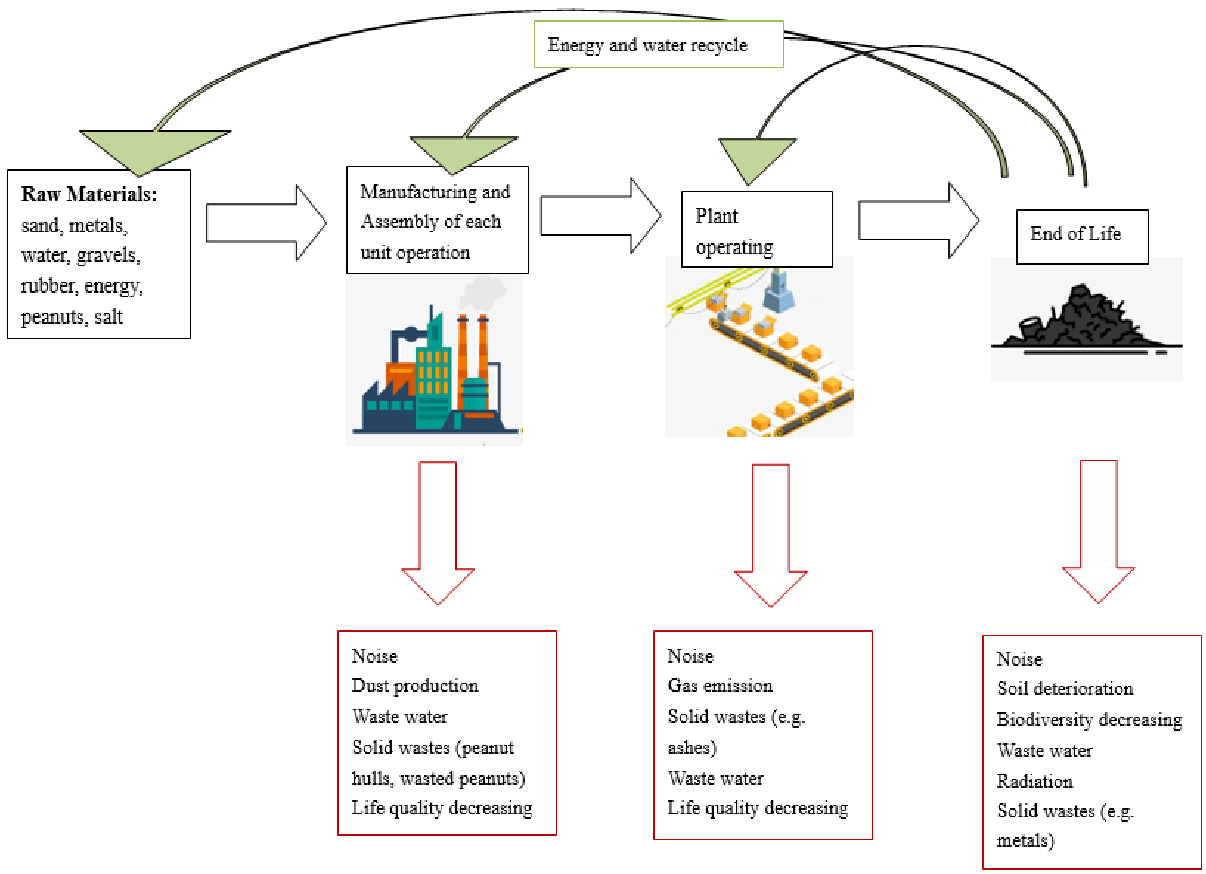


Figure 3: Life Cycle Assessment of this project.

5. Social considerations

Social considerations are not included in the life cycle assessment above but discussed separately. This project is proposed to create job opportunities for women in rural areas since the plant is compact, light and easy to operate, which can be operated by six women alone. Besides, with the peanuts being processed into peanut butter, there is a potential to boost the production and consumption of peanuts in Nigeria and other developing countries. Peanut butter, in addition, is an excellent source of nutrients including proteins and heart-healthy dietary fiber. With more peanut butter intake, therefore, the carbohydrate-concentrated diet in Africa could potentially be more balanced.

However, this project may bring some social impacts. First, air, noise and water pollution may worsen the life quality of the community or influence the public health. Moreover, it may provoke competitions between the local peanut butter suppliers and the owner of this plant. With money invested into this project, additionally, less funding may be available for other usages in that community. To prevent this situation, sponsors or funding should be sought so that less investment will be required from the rural communities.

6. Economic analysis

This project promotes the cycle of producing and consuming peanuts. Peanut butter, as an additional option to intake peanuts, may attract more consumers to this industry and hence promote the production of peanuts.

Considering the material selection, dimensions of machines, and energy input, the total manufacturing and operating cost is estimated to be \$1318.87 (Table 1). Two options are to be discussed in this paper, including personal use and commercial use. For personal use, clients can operate the plant and consume peanut butter on their own. Meanwhile, clients can purchase this plant for career development. Around 250 kg of peanut butter can be produced per day. Including the labor cost (for hiring 6 women), the payback period is estimated to be about 5 years, with the price of peanut butter set as \$5/kg.

Table 1: The cost breakdown of each unit operation and the total cost.

Major Apparatuses	Material Costs	Manufacturing Costs	Installation Costs	Operation costs/year	Total Cost per Unit Operation

Sheller*2	$240.00	$ 0.00	$10	$ 0.00	$250
Roaster	$ 150.00	$0.00	$ 78.87	$10.00	$228.87
Cooling Silo*2	$ 200.00	$ 0.00	$ 0.00	$ 0.00	$200.00
Grinder	$ 200.00	$ 20.00	$ 20.00	$ 20.00	$ 240.00
Mixer	$150.00	$ 20.00	$20.00	$ 180.00	$190.00
Totals	**$940.00**	**$40.00**	**$ 128.87**	**$ 210.00**	**$1318.87**

7. Future developments

Shortage of time and funding leads to a failure of building this project. However, further developments can be done to build a model or real prototype based on this paper design. More detailed AutoCAD drawings can be developed and hence models can be built through 3D-printing. Adjusting according to the models are to be followed by scaling up to a real size.

Seeking for funding, NGOs such as Full Belly Project could be reached out in hope to collaborate and to expand upon pre-existing groundnut-related projects in rural communities.

References

Ajeigbe HA, Waliyar F, Echekwu CA, Ayuba K, Motagi BN, Eniayeju D and Inuwa A. 2014. A Farmer's Guide to Groundnut Production in Nigeria. Patancheru 502 324, Telangana, India: International Crops Research Institute for the Semi-Arid Tropics. 36 pp.

Akcali, I., Ince, A., & Guzel, E. (2006). Selected physical properties of peanuts: *International Journal of Food Properties, 9*(1), 25-37.American Society for Testing and Materials. (2017). *Standard Specification for Mixing Machines, Food, Electric.* (ASTM F952 – 12: 2017). Danvers, MA.

American Society for Testing and Materials. (2017). *Standard Specification for Food Cutters (Electric).* (F1126 – 12: 2017). Danvers, MA.

American Society of Agricultural and Biological Engineers. (2018). *Safety for Farmstead Equipment*. (ANSI/ASAE S354.7 SEP2018). St. Joseph, MO.

Audu S. I., Girei A. A., Onuk E. G., & Onyenye P. O. 2017. Productivity and Profitability of Groundnut Production (Arachis hypogea L.) in Lafia Local Government Area, Nasarawa State, Nigeria. Asian Research Journal of Agriculture. 4(3), 1-11. doi: 10.9734/ARJA/2017/30705

Banful A. B., Nkonya E., Oboh V. (2011). Constraints to Fertilizer Use in Nigeria: Perspectives and Insights from the Agricultural Extension Service. International Food Policy Research Institute.

Maynard, E. (2013). Ten Steps to an Effective Bin Design. AICHE.

Maduako, J. N. & Hamman, M. (2004). Determination of Some Physical Properties of Three Groundnut Varieties. Nigerian Journal of Technology. 24(2), 12-18.

Ogburo J. O. & Ayeni L. S. 2016. Groundnut Production and Consumption Rate in Ejibo Local Government Area of Osun State, Nigeria. Greener Journal od Agricultural Sciences. 6(4), 145-150. doi: 10.15580/GJAS.2016.4.031816066

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Appendix

Appendix A: Physical Properties of Materials

Physical properties of groundnut kernels RMP-9 variety (Maduako and Hamman, 2016), relatively similar to variants observed in (Akcall, Ince, and Guzel, 2007).

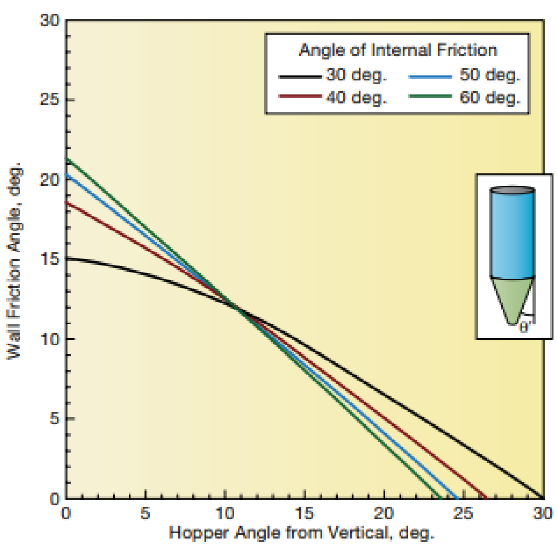
Length: 14.2 mm
Diameter: 8.9 mm
Angle of repose: 20.5 degrees
Coefficient of friction (galvanized steel surface) = 0.29
Bulk density: 611 kg/m^3
Kernel density: 0.88-0.93 g/cm3
Weight: 0.547 g
Roundness: 49.1%   Sphericity: 67.7%
Internal friction angle: 29.7 degrees (Akcall, Ince, and Guzal, 2007).
Specific heat capacity of peanuts: 1.17 kJ/kg·°C

Physical Properties of Groundnut shells.

Shell density: 0.27-0.30 g/cm3
HHV of hulls: 18.547 MJ/kg
LHV of hulls: 17.111 MJ/kg
Average HV: 17.829 M
Burning efficiency = 60%

Appendix B: Design Correlations

Relationship between wall friction angle and hoppe angle (AICHE.



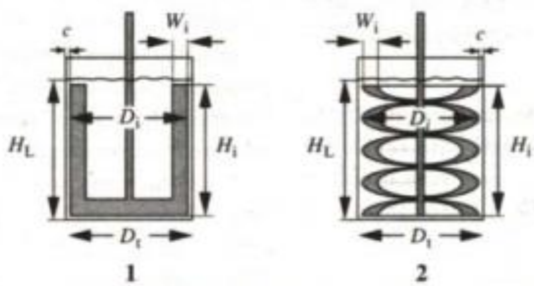
▲ **Figure 7.** This chart for conical hopper design determines wall slope based on the wall friction angle. Mass flow results from a combination of sufficiently low wall friction and steep enough hopper angle.

Anchor Impeller Constants

Table 6.1 Constants in Eq.(6.7) and (6.8)

Impeller type	k_1 , $(Re)_i = 1$	N_p', $(Re)_i = 10^5$
Rushton turbine	70	5~6
Paddle	35	2
Marine propeller	40	0.35
Anchor	420	0.35
Helical ribbon	1000	0.35

Anchor Impeller Dimensions



Impeller	D_t/D_i	c/D_i	H_i/D_i	W_i/D_i
1. Anchor	1.02	0.01	1	0.1
2. Helical ribbon	1.02	0.01	1	0.1