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# Design analysis and construction of a biodiesel processing plant

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## Abstract

This research focuses on the design, analysis, and construction of a biodiesel processing plant with the aim of improving global processes, control, and overall design efficiency. Biodiesel, a renewable energy source, offers environmental benefits and extends engine life. The study addresses the challenges associated with biodiesel usage, such as higher initial costs and potential engine issues, and proposes the use of waste vegetable oil to reduce processing costs. Various reactor designs from past studies are analyzed, emphasizing the need for effective mixing techniques. The research presents a novel prototype reactor and considers the selection of materials, stresses, strains, and insulation for each tank. Additionally, the study explores the use of different heating elements, including mica band heaters and immersion heaters, to achieve the required temperatures for transesterification. The findings also discuss the selection of gear motors and pumps for effective mixing and fluid transfer. The results of the construction and assembly of the biodiesel plant are presented, highlighting the inclusion of various accessories to enhance functionality. Finally, the research emphasizes the economic and environmental advantages of biodiesel production, considering energy consumption and cost savings in the Nigerian context.

**Keywords:** Biodiesel; Renewable; Processes; Prototype; Transesterification; Techniques

## 1. Introduction

The focus of this research work is centered on the understanding of the production process for biodiesel, the biodiesel processor design, modeling, and simulation towards achieving a global improvement in the design of the processor, production process and control.

Biodiesel can generally work in an existing oil heating systems and diesel engines without many modifications to such engines, and it can be distributed through existing diesel fuel pumps. The initial cost of biodiesel over other types of alternative energy can be expensive but its cost effectiveness is worthwhile when considering its benefits on health and environment. The energy provided in a unit volume of Biodiesel is equivalent to an equal energy per unit volume of a fossil diesel. Life of engines are prolonged by the effects of lubricating properties of biodiesel [1].

The use of biodiesel however has its disadvantages. At present, the cost of biodiesel is higher than fossil diesel fuel [2]. However, to avoid the high costs implication as an obstacle, this work would be focusing on the use of waste vegetable oil for biodiesel production to influence a lower processing cost. It was observed that non-metallic pipes (hoses) in car engines could be destroyed in vehicles made before the 21$^{st}$ century [3]. Due to the cleaning effect properties of Biodiesel, engine dirt may gather to cause the clogging that sometimes occur in cars fuel filters especially when the cars just switched from fossil diesel to biodiesel. Therefore, the need for filter change is necessary in the first few days of converting to biodiesel to avoid clogging. Currently, the distribution of Biodiesel has not become as regular and

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conventional as fossil diesel, although there is awareness for improved infrastructure [4]. However, there are generations of biodiesel production that had evolved over the years.

Rahmat et. al, [5] discussed the design of the reactor used to study the effect of glycerol separation on transesterification reaction. The design enables the determination of biodiesel quality, and mass balance analysis. The reactor was designed by integrating circulated pump/stirrer, static mixer, and sprayer that intensify the reaction in the outer tank reactor. The objective was to reduce the use of methanol in excess and to shorten the processing time. The results suggested that the efficiency of biodiesel production could be increased with the glycerol separation technique.

A novel oscillatory flow reactor was design in [6]. The design focused on the development of acceleration reaction in the process of continuous biodiesel production system by optimizing the oscillatory flow reactor (OFR). The study developed an optimized model with short resident time of production. The process was accelerated twice as much as using a batch type reactor for biodiesel production. A turbulent reactant flow pattern was observed which ensured that continuous reaction process takes place in the reactor.

It has been observed that one of the major challenges of the reactor design for biodiesel production is the need for effective mixing of the alcohol and the feedstock. The need to develop an effective mixing technique can therefore not be overemphasized. Alamsyah, [7] did a comparison of static-mixer and blade agitator reactor in biodiesel production. In his study, an assessment of static-mixer utilization in a transesterification reactor for biodiesel production in terms of kinetics reaction was carried out. The experiments showed that static mixer has significant effect in reducing reaction time to reach required fatty acid methyl ester content. Transesterification reaction time with static mixer were shorter than with blade agitator for all temperature levels.

Nguyen, [8] attempted the design of a new generation biodiesel plant, direct carboxylation and glycerolises routes were developed to convert the biodiesel byproduct into a value-added product, production by direct carboxylation plant and biodiesel-glycerol carbonate production by glycerolises, to reduce the unit cost of the biodiesel production plant. A direct comparison of the economic analysis based on deterministic and stochastic models of the conventional biodiesel plant; biodiesel glycerol carbonate was presented. The author showed that such as stirring speed, concentration at a steady time interval was analyzed either route can be used to reduce the unit cost of the biodiesel production plant. Daniyan et. al, [9] examined the design of small-scale biodiesel processor capable of transesterifying 20 litres of biodiesel per batch from biodiesel feedstock at minimum cost and near perfect purity of biodiesel to reduce treatment after biodiesel production. Basic design requirements such as: stir speed, maximum reaction temperature, and mass and energy balance and heat requirements as well as drive and control system were fixed.

Malone et. al, [10] design and produce an automated biodiesel processor to minimize the processing time and increase the biodiesel yield. The aim of the study was to eliminate the time-consuming chemical titration required for each batch of biodiesel produced in converting a batch of WVO into usable biodiesel. In [11] some existing typical batch reactor was modified for increased biodiesel yield. Two different stirring arms stages with a horizontal baffle were used. These arms arrangement was meant to increase turbulence during the fluid mixing and create more liquid surface to surface interactions for greater molecular separation and interface reaction. The result of performance evaluation carried out on the modified reactor show that, multiple stages of agitators increased the interface mobility of the alkoxide solution, yielding 98% of biodiesel in a record time of 60minutes at a mixing speed of 300 rpm. The result of this research shows that, the conversion of alkoxide in the reactor was enhanced by the use of multiple levels of agitators, thus leading to increased biodiesel yield at a lower mixing speed and power requirement.

In Achara and Nyitamen [12] a scalable biodiesel reactor for the transesterification of vegetable oil was discussed. The study carefully selected a stainless-steel material for the design of the processor to cater for both base and acid catalyzed processes. Methods for determining the extra catalyst required to neutralize the free fatty acid in restaurant waste oil and testing for completion of reaction was adequately outlined. Shaaban, [13] analyzed the micro reactor with T-mixer to study the effect of the factor affecting biodiesel production with varying diameter of the mixer. The effect of some reaction factors (including molar ratios of methanol to oil, temperature, and the residence time) on Fatty Acid Methyl Ester (FAME) transesterification reaction were studied using deferent T-shaped mixers. It was shown that the yield of fatty acid ethyl esters depends strongly on mass transfer limitations. The mass transfer expanded with developing efficiency of micro-mixing. This was also conspicuously observed in the design presented in [14] which described the engineering design for the reactor vessel development beginning at the stoichiometric equations for the production process and the thermal energy balance to the detail engineering including the equipment selection and fabrication to meet the design and objective specifications. Biodiesel produced from cashew shell pyro oil, coconut shell pyro oil, Kikar seeds pyro oil and velikkathan seeds pyro oil are used in this setup to produce the Bio diesel. The bio diesel pyro oil properties are very near to diesel fuel and this design system showed close value to the requirements of diesel standard.

Igbokwe et. al, [15] discussed the characterization of a 5 Litres continuous stirred tank reactor. Tracer experimentation was carried out on the reactor and the effect of different parameters such as stirring speed, concentration at a steady time interval was analyzed. The effect of solute concentration (sodium chloride) on the stirrer speed in a CSTR was observed to be significant.

Improvement in the transesterification process of biodiesel production had been achieved to an extent through modeling, control and optimization of the production process and reactor design. The possibility to stabilize open-loop unstable processes using robust static output feedback controllers for chemical reactors was also studied in [16]. The non-iterative algorithm based on solving of linear matrix inequalities was used for design of a robust PID like controllers for the reactor. The design procedure was guaranteed with sufficient conditions the closed-loop robust quadratic stability and the guaranteed cost of control. An earlier study in [17] presented a process modelling step with linear identification followed by an optimum PID control design step based on engineering specification. The design methodology was applied to a continuously stirred chemical reactor for desired operation.

The designed of a Sono-Chemical reactor for biodiesel production via transesterification was carried out in [18]. Numerical modelling of the physical phenomena such as the wave propagation, attenuation, and reactive flow within the reactor was carried out. The equations governing the reactive flow circulation and simultaneous sonication in the cylindrical reactor were simulated and a 2D axi-symmetric model of the proposed reactor was developed. The study tends to underline the fundamental knowledge required for the design of sono-reactors.

Modern technique for biodiesel processing device had been studied [19]. This includes the development of cellular manufacturing process for fabrication and assembly of a full-scale biodiesel micro reactor capable of producing biodiesel fuel at the rate of 2.47 L/min and at a capacity of over 1.2million Litres of fuel per year. The scale-up of the micro reactor was done through fabrication of over 14,000 individual micro channel laminae, and assembly of these laminae into a hierarchical system of modules and manifolds, thus duplicating many times over the intensification of the reaction rate per reactor volume that occurs in a single micro channel lamina. The work describes the design of the micro reactor, the production process to fabricate and assemble the micro reactor, the design of the manufacturing cell and the testing of the micro reactor to verify its performance.

The development of the biodiesel production devices was also discussed in Yeh et. al [20]. The authors designed a milli-metrically scaled droplet-based co-axial fluidic system for biodiesel transesterification. The study demonstrated the high potential of droplet-based fluidic chips for energy production. The small energy consumption and low cost of the highly purified biodiesel transesterification system described conforms to the requirements of distributed energy such as the need for inexpensive production on a moderate scale. Chanpirak and Weerachaipichasgul [21] identified optimization and nonlinear model-based control as two concerned strategies for the improvement of biodiesel processing. These strategies were used to modify the optimal temperature set point. The optimization strategy was first performed with objective function to provide optimal reactor temperature and maximum product in minimum batch time. In the study the production of biodiesel in the batch transesterification improved by a generic model control.

## 2. Material and methods

The plant was built in sub-assemblies. These include the support structural frames, the vessel/tank networks, pipe network, and the energy systems.

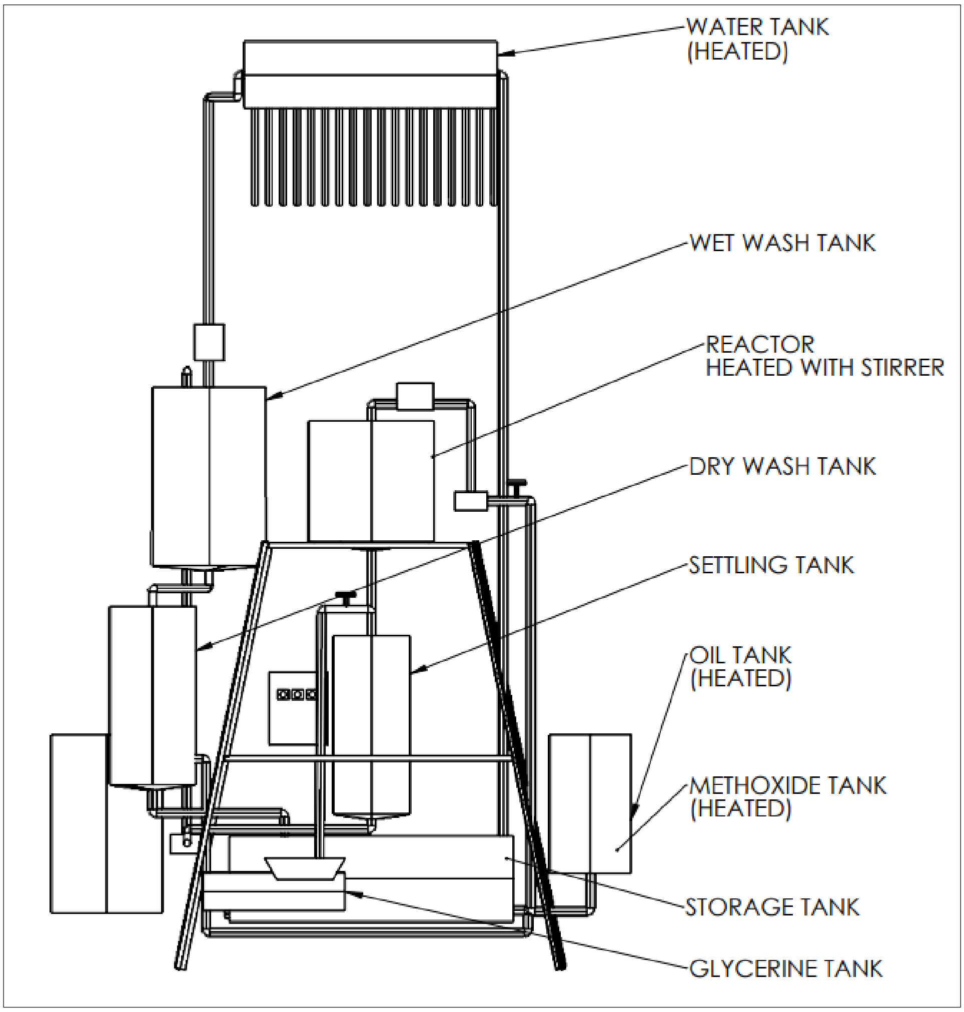


**Figure 1** Conceptualized Biodiesel prototype reactor

### 2.1. Design analysis of the cylindrical vessels

The design of the reactors is based on certain considerations which include consideration for mass transfer of the reactants and products, mixing activities, fluid viscosity, reliability, shear sensitivity of the vessels, cost of fabrication and operation of the plant.

The cylindrical vessels network comprised of ten thin-walled cylinders. The reactor (tank 1), waste vegetable oil (WVO) tank (tank 2), methoxide tank (tank 3), Settling tank (4), Glycerol tank (5), Wet-wash tank (6), Waste-water tank (7), Dry tank (8), Storage tank (9) and Solar water heater tank (tank 10). The prototypes plants is shown in Figure 1. The detailed analysis of the reactor design could be obtained in the part 2 of this article.

The transesterification of the mixture of waste vegetable oil, alcohol and catalyst occur in the reactor tank. The reactor, where the transesterification of the mixtures (vegetable oil, alcohol and catalyst) occurs. The methoxide tank contains the mixture of the methanol and lye before it is injected into the reactor. The freshly reacted batch of biodiesel is from the reactor is transferred into the settling tank to free the reactor and allow another batch. The glycerin from the reactor and settling tank is drained in the glycerin tank. The wet and dry wash tanks are used to wet wash the product from the settling tank using heated water from the solar water tank and then dried in the dry wash tank by passing the product through silica sandbag and heat provided by the heater in the dry wash tank. The wastewater from the washing process is received in the wastewater tank and the product flows into the storage tank. The tanks were designed as pressure vessels to retain the elasticity of the material when loaded. The design against failure of the vessels also determines the stresses and deformations in the cylindrical tanks. The parameters required for the design of the tank is as shown in the Figure 2.

The appropriate thicknesses for the tanks were determined from design expressions for thin wall cylinders.

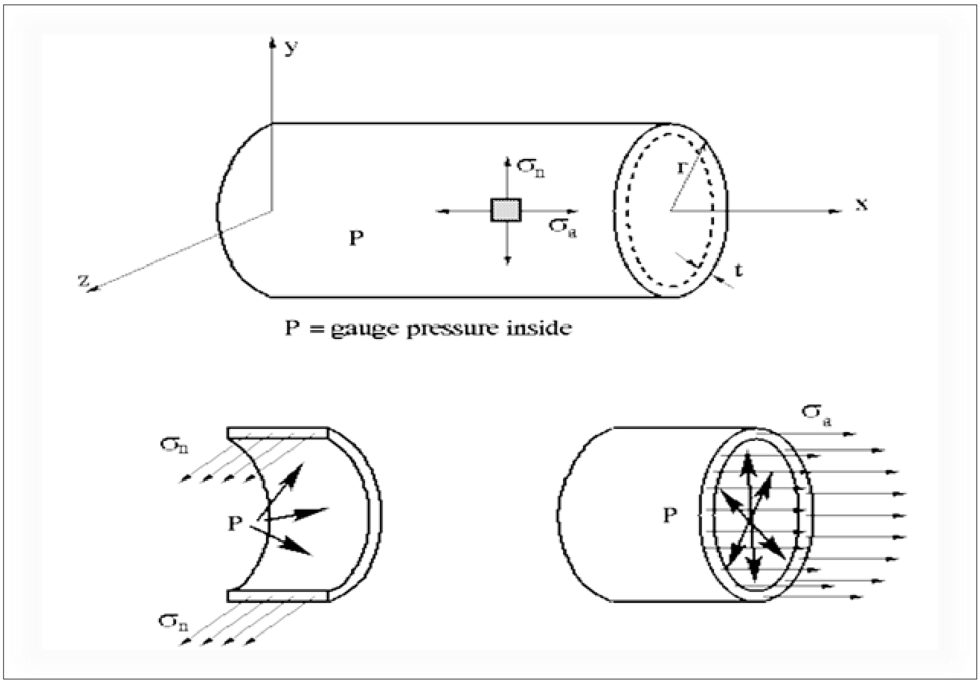


**Figure 2** Hoop and longitudinal stress expressions

The equations for stresses created by an internal pressure on a thin wall cylindrical pressure vessel are formulated using the terms σ n (Hoop stress), σ a (Longitudinal stress), L (Length of Cylinder), d (Diameter of Cylinder), t (Thickness of Cylinder wall), P (Internal pressure). Longitudinal stress of thin-walled pressure vessel occurs when the vessel has closed ends. The internal pressure acts on them to develop a force along the axis of the cylinder. This is known as the axial or longitudinal stress and is usually less than the hoop stress [22].

The use of stainless steel, mild steel and galvanized steels was based on the functionality of each of the tanks in the design. The stainless steel was specified for nine of the tanks which had contact with the biodiesel and glycerol to avoid any form of contamination. The mild steel was specified for the three insulated tanks (reactor, dry tank, and methoxide tank) and the galvanized steel was specified for the waste wash water.

**Cylinder sizing**: The current formulation for the cylinders prescribed ASTM section I (which ensures the rules for construction of parabolas) vessel code:

$$t=(PD/(2\sigma+2yP))+C \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where P = internal pressure, D = outer diameter, y = temperature dependence molecular property and C = 0.065"and D ≤ 3.5". The material characteristic usually varies between 0.4 and 0.7 [26], σ is the allowable stress value at the design temperature. The limiting cases applied in the design involves:

For OD (outer diameter) ≤ 3.5" at y = 0.4

$$t=(PD/(2\sigma+0.8P))+0.065 \text{ in} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

For OD ≤ 3.5"at y = 0.7

$$t=(PD/(2\sigma+1.4P))+0.065 \text{ in} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

For OD ≤ 3.5"at y = 0.4

$$t=(PD/(2\sigma+0.8P)) \quad \ldots\ldots\ldots\ldots\ldots (4)$$

For OD ≤ 3.5"at y = 0.7

$$t=(PD/(2\sigma+1.4P)) \ldots\ldots\ldots\ldots\ldots (5)$$

**Stress analysis**: The magnitude of the stresses developed in the cylinders is determined by a free body diagram of half the pressure vessel as shown in Figure 2.

The circumferential and longitudinal stress is obtained from equations (6a) and (6b).

$$\sigma_\theta=Pr/t \ldots\ldots\ldots\ldots\ldots (6a)$$

$$\sigma_l=Pr/2t \ldots\ldots\ldots\ldots\ldots (6b)$$

Usually, if equations (6) are of the assumption that r >> t for thin cylinders, the material is taken to be in a state of plane stress with the fact that the radial stress for thin cylinders is negligible. The cylindrical sheet will experience the longitudinal strain as expressed in equation (6a)

$$\in_L=-\mu/\varepsilon\ (\sigma_\theta+\sigma_L) \ldots\ldots\ldots\ldots\ldots (7a)$$

In this case, the hoop strain is obtained from equation (7b)

$$\in_\theta=Pr/Et\ (1-\mu/2) \ldots\ldots\ldots\ldots\ldots (7b)$$

Volume expansion: The volume of each cylinder during operation is obtained from equation (8)

$$Vn=Vo\ (1+\in_v) \quad \ldots\ldots\ldots\ldots\ldots (8)$$

The volumetric strain $\epsilon v$ is obtained as expressed in equation (9).

$$\in_v=2\in_\theta+\epsilon_L \ldots\ldots\ldots\ldots\ldots (9)$$

$\in_\theta$ is the hoop strain and$\in_L$ is the longitudinal strain.

The conical sections were developed with inner surface area obtained for development as expressed in equation (10). The area of the inner conical (frustum) section A;

$$A=(\pi h.(D+d))/2 \ \ldots\ldots\ldots\ldots\ldots (10)$$

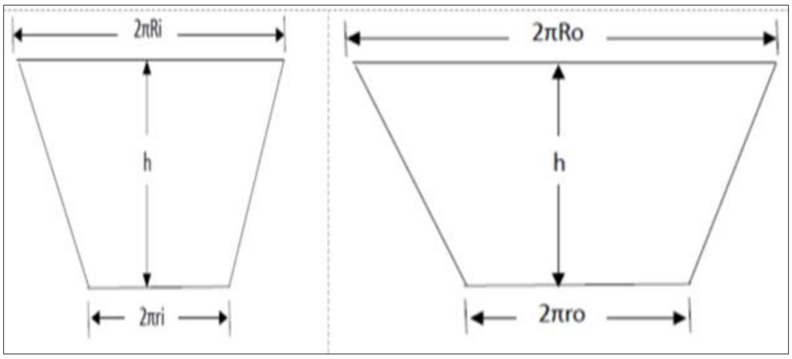


**Figure 3** Conical section design for tanks

## 2.2. Design for the heating element

Two types of heating elements were employed in this research work: Mica band heaters and immersion heaters. The type of heating element used is determined by the underlying mechanisms such as:

- The intended application of the thermal energy required at a specific geometry, such as with the band heater that was chosen for the reactor because the heat required in the reactor needed to be applied at the circumference of the reactor body.
- The type of heat transfers applicable through either: convection, conduction, or radiation is also important. Various types of heaters make use of these fundamental concepts of thermodynamics and apply those principles for generating and dispensing thermal energy to the desired materials or items.
- The power source: while some heaters are electrically powered, other types may transfer heat energy through the heating of a medium such as water or steam. The energy source, if not a direct generation of heat through the transformation of electrical power, may dictate that the heater itself be just one component of an overall heating system that may consist of other components such as boilers, pumps, piping, and valves. Yet, other heaters use combustion means, where the burning of fuel directly generates the heat that is passed through convection.
- Thermal control is a key factor for consideration too as this control, monitors, gives feedback and prevents damage of equipment using sensors and relays. It is useful in preventing heater failure.

**Mica Band Heaters**: Mica Band heaters are ring-shaped heating devices that are clamped around a cylindrical material for heating purposes. They were clamped around the outer surface of the reactor diameter before lagging and after which another layer of steel is wrapped around the reactor tank to reduce heat loss and protect the operator. These fast-heat band heaters electrically warm the external surface of the cylindrical part of the reactor through conductive heat transfer to provide direct heating of WVO and methoxide to be heated in the tank/reactor for transesterification reaction.

Biodiesel reaction requires the oil to be heated up to 600C and maintained for up to 60 minutes or more at a time. Most batches will require heating the processor up, run it for an hour or two and shut it down. The rate at which the reactor heats up can be an issue for several batches target a day.

The heat energy required to raise the temperature of the reactor to required level is obtained from equation (11).

$$Q=M.C_p.\Delta T \ldots\ldots\ldots\ldots\ldots (11)$$

Where Q is the magnitude of heat required, M is the mass of the mixture, Cpis the specific heat capacity and ΔT is the temperature difference. The physical properties of the input reactants are as obtained in [23, 24].

There are different types of mica bands heaters; imported and locally made but due to foreign exchange restrictions and logistics, locally made heaters were used. They come in standard size of 4000 watts.

**Immersion heater**: Two immersion heaters (single general purpose density type element heater of 10,000 watts) were also considered to provide heat for dry and storage tanks. These were installed by boring a hole on the side of the dry and storage tanks close to the bottom of the tanks and sealed.

### 2.3. Specification of insulation material

The reactor and dry tank were insulated to preserve heat and save energy. The insulation helps to minimize the heat loss due to temperature difference between tank and ambient air temperature. The fiberglass insulation material was selected for its lower installation cost equivalent thermal resistance (R-Value) performance.

The specification for the size of the insulation was obtained considering the likely heat loss value obtained from equation (12).

$$\dot{Q}=\alpha.A.dt \ldots\ldots\ldots\ldots\ldots (12)$$

$\dot{Q}$ is time rate of heat loss, α is the heat transfer rate (W/ ($m^2$ $^oC$), A is the area ($m^2$)- and dt is the temperature difference ($^oC$)

### 2.4. Gear motor selection

The assembly of reactor and the wet wash tank for this research both required the use of mechanical stirrer each at reduced speed (rpm) and increased torque to mix methoxide with waste vegetable oil while the wet wash tank uses it to stir biodiesel and warm water from the solar water heater to wash off soap, excess methanol and any other impurities at a controlled speed to obtain a uniform mixture in a confined space yet, avoiding splashing of the liquid. To achieve this, a BLDC gear motor was introduced to achieve continuous stirring at steady speed. The motor's shaft is fed into the gearbox to provide the torque and speed conversion.

The electric gear motor was coupled to the head/cover of the reactor (1hp) as well as the top of the wet wash tank (1hp) to obtain the stirring application. The purchase was made at the Spare Parts market Section, Alaba International market, Ojo, Lagos State. The gear motor selection is achieved as discussed in Raji et. al [25].

### 2.5. Pump selection

Pumps are normally used to transfer liquid substances from one point to another using pipes, hoses etc as medium of transportation while converting mechanical energy to kinetic energy. Two centrifugal pumps were installed for the transfer of WVO and Methoxide separately into the reactor. Another 1 hp pump was used to transfer biodiesel from the settling tank to the wash tank and a 0.75 hp (0.56 kW) surface pump was installed for the transfer of water from source to the solar water heater tank.

## 3. Results and discussion

The construction of the designed plant is as shown in Figures 5 and 6.

The shape of reactor and dry tank was obtained as in Figure 4. The tanks consist of the cylindrical and conical sections.

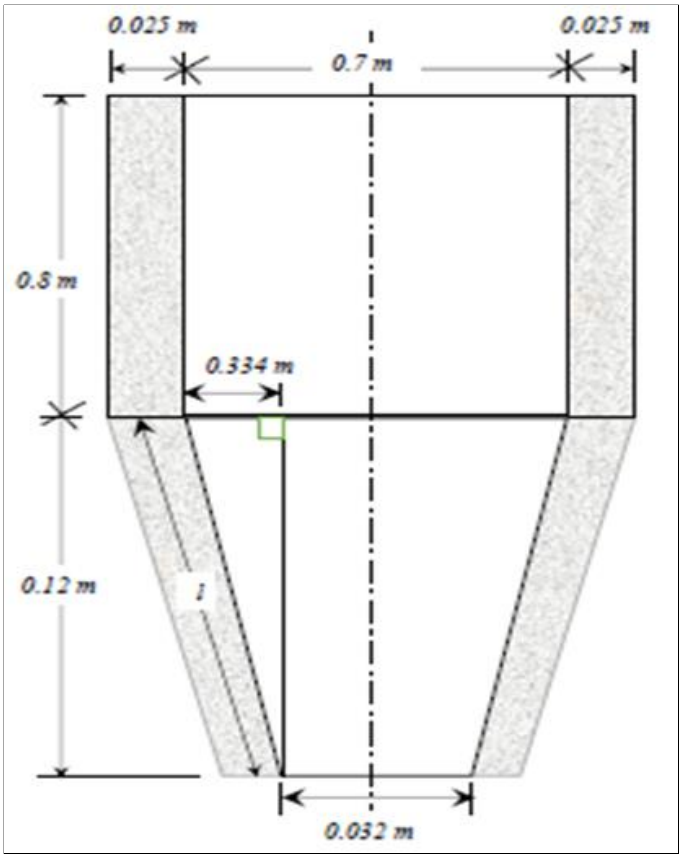


**Figure 4** Tanks sizing

The results of the sizing for each of the tank is as detailed in table 1 and stress analysis obtained for each of the tank is as expressed in table 2.

**Table 1** Table of calculated tank parameters

| S/N | Description of Tanks | Height of cylinder ($h_1$)/cm | Diameter (D)/cm | Thickness (t)/cm | Volume, Vc, of cylindrical part ($cm^3$) | height of Cone ($h_2$)/cm | Vol. of Conical part, ($cm^3$) | Total Vol, Vn/$cm^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | Waste Vegetable Oil | 71 | 56 | 0.3 | 174,896.29 | 10 | 8,211.09 | 183,107.38 |
| 2 | Methoxide | 48 | 34 | 0.4 | 43,585.82 | 8 | 2,421.43 | 46,007.26 |
| 3 | Reactor | 80 | 70 | 0.4 | 307,916.00 | 12 | 15,395.80 | 323,311.80 |
| 4 | Glycerol | 97 | 25 | 0.3 | 47,620.94 | 6 | 981.88 | 48,602.81 |
| 5 | Settling | 122 | 56 | 0.3 | 300,526.02 | 7 | 5,747.77 | 306,273.78 |
| 6 | Wet wash tank | 122 | 77 | 0.3 | 568,182.00 | 7 | 10,866.87 | 579,048.87 |
| 7 | Wastewater** | 88 | 57 | 0.3 | 224,583.88 | 0 | 0 | 224,583.88 |
| 8 | Dry wash tank | 122 | 56 | 0.4 | 300,526.02 | 7 | 5,747.77 | 306,273.78 |
| 9 | Storage* | 194 | 56 | 0.3 | 477,885.63 | 7 | 17,243.30 | 495,128.93 |
| 10 | Solar water heater** | 175 | 46 | 0.2 | 290,870.65 | 0 | 0 | 290,870.65 |

* Hemisphere at the two ends; ** Flat ends

**Table 2** Table of Stress and Strains of the Tanks

| S/N | Description of Tanks | Hoop Strain, Ɛ⍰ | Longitudinal Strain, $\varepsilon_L$ | Vol. Strain, Ɛv | New Vol, $V_n$ | Radial expansion, δr (in) | Transverse/ Hoop stress, σ⍰ (kPa) | Longitudinal stress, $\sigma_L$ (kPa) |
|---|---|---|---|---|---|---|---|---|
| | | | | | ($in^3$) | | | |
| 1 | Waste Vegetable Oil | 4.15E-08 | 9.56E-09 | 9.26E-08 | 183107.364 | 1.16E-06 | 9457 | 4728.5 |
| 2 | Methoxide | 1.89E-08 | 4.35E-09 | 4.22E-08 | 46007.257 | 3.21E-07 | 4306.313 | 2153.156 |
| 3 | Reactor | 3.89E-08 | 8.96E-09 | 8.68E-08 | 323311.772 | 1.36E-06 | 8865.938 | 4432.969 |
| 4 | Glycerol | 1.85E-08 | 4.27E-09 | 4.13E-08 | 48602.81 | 2.32E-07 | 4221.875 | 2110.938 |
| 5 | Settling | 4.15E-08 | 9.56E-09 | 9.26E-08 | 306273.753 | 1.16E-06 | 9457 | 4728.5 |
| 6 | Wet wash tank | 5.71E-08 | 1.31E-08 | 1.27E-07 | 579048.794 | 2.20E-06 | 13003.375 | 6501.688 |
| 7 | Wastewater** | 4.09E-08 | 9.63E-09 | 9.14E-08 | 224583.855 | 1.17E-06 | 9625.875 | 4812.938 |
| 8 | Dry wash tank | 3.11E-08 | 7.17E-09 | 6.95E-08 | 306273.76 | 8.72E-07 | 7092.75 | 3546.375 |
| 9 | Storage* | 4.15E-08 | 9.56E-09 | 9.26E-08 | 495128.882 | 1.16E-06 | 9457 | 4728.5 |
| 10 | Solar water heater** | 5.12E-08 | 1.18E-08 | 1.14E-07 | 290870.617 | 1.18E-06 | 11652.375 | 5826.188 |

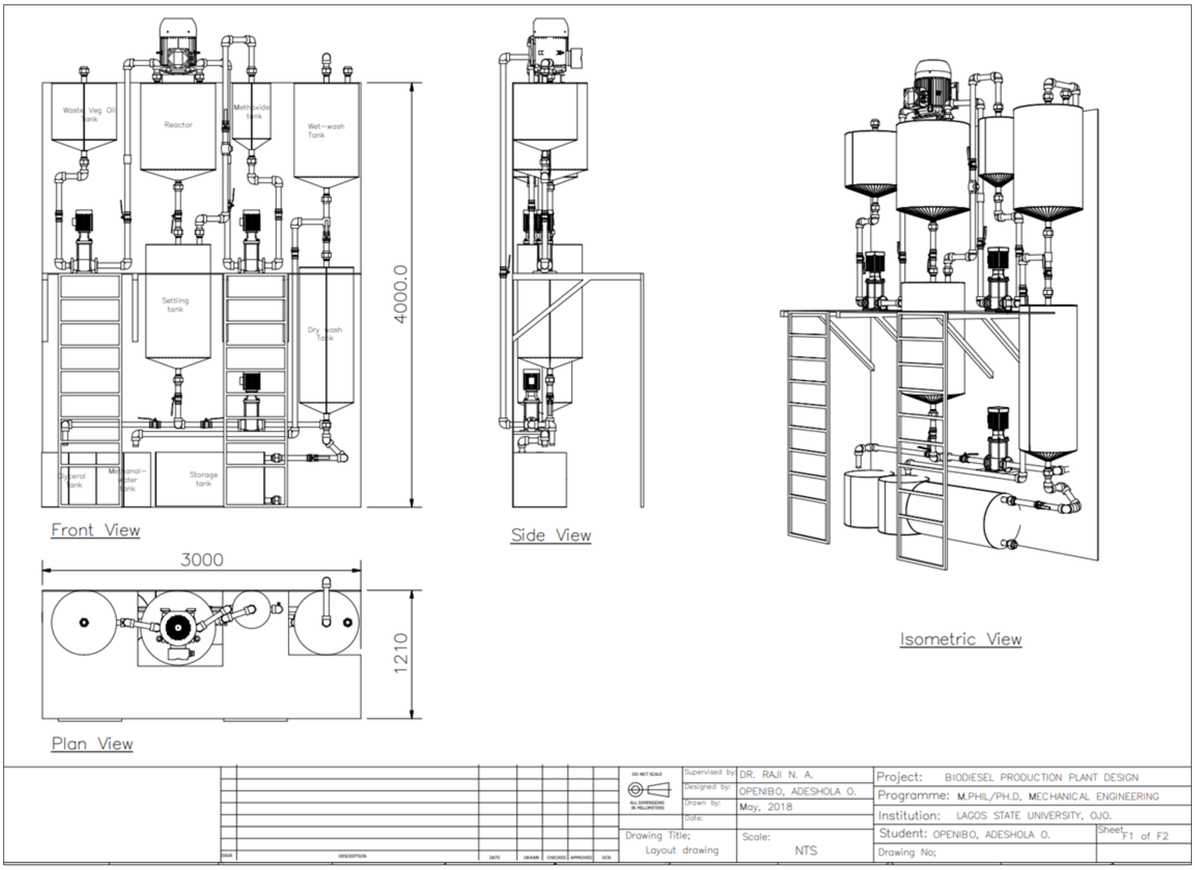


**Figure 5** Biodiesel production plant

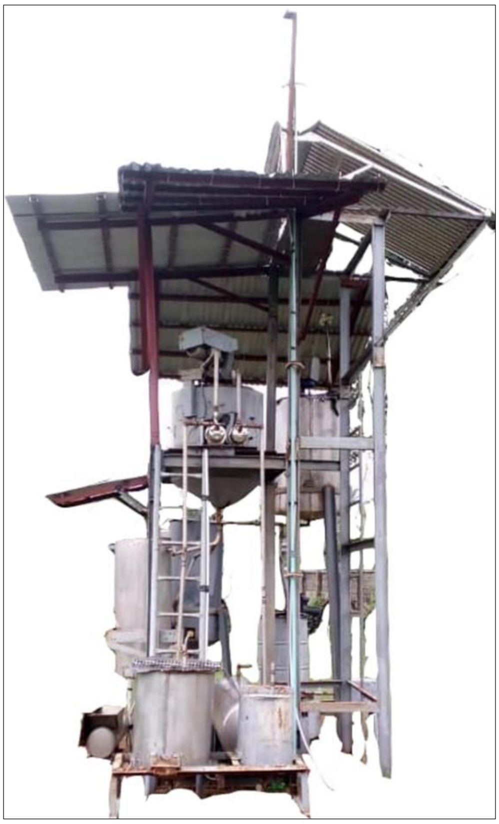

**Figure 6** Fabricated biodiesel processing plant at Lagos State University, Nigeria

### 3.1. Band heaters estimation

Figure 7 relates the time it will take the band heaters to raise the temperature of the mixture to from ambient temperature of 25 °C to 60oC. The graph shows that the time is inversely proportional to number of band heaters. It could be observed that more than two band heaters will be required. Three 4000 watts band heaters as the closest to the estimated fractional two were installed on the reactor.

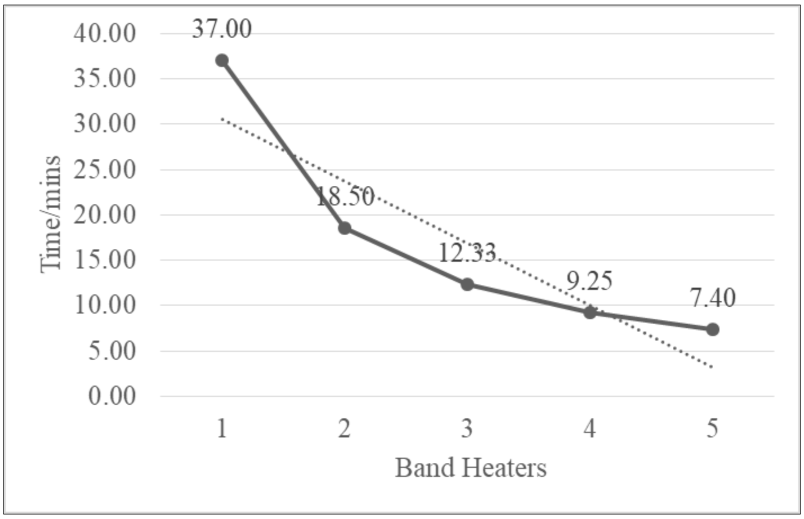


**Figure 7** Mica band selection curve

The height of the reactor is 0.80 m, and the mica band width is 0.15 m which is approximately 6". The height of the tank could accommodate five sets of mica bands which would have given a height of 0.75 m (0.15 m x 5). Since more than two band heaters were required, 3 mica bands spaced equally along the height of the reactor were used. More so, the regulated temperature of the reactor has been pegged at 60°C to avoid factory hazard since the boiling point of methanol is 64.7°C. The effective heating area is the surface area per linear meter of the heater multiplied by the heated length. Therefore, for an effective heating area of the reactor, the area of the cylindrical part of the reactor where the mica heater would be installed needed to be calculated taking into consideration the following cylindrical dimensions: Reactor cylindrical section diameter D = 0.70 m, height, H = 0.80 m, radius, R = 0.35 m. The diameter of the cylinder determined the diameter of the mica bands used. The mica bands came in 2-halves rings of 0.35 m each to cover the reactor diameter.

### 3.2. Immersion heater estimation

The dry tank capacity is 306 litres and the intended temperature rise is 85 °C (raising the biodiesel temperature from 25 °C to 110 °C – to vaporize the moisture in the biodiesel)

The heat requirement is 58148747.84 J and the time taken is 97 minutes for the effective functioning of the dry tank heater. The heat requirement for the immersion heater of the storage tank of 495 litres capacity was obtained as 15144024.96 J for 25.24 minutes. It will take about 25 minutes to raise the temperature of the biodiesel in the storage tank to 400C whenever it freezes/congeals during cold weather before dispensing to customers/final user.

The solar water heater is being powered by solar energy and this in a way will save cost of energy bills as well. It came with insulation. As for the storage tank, it would operate more on ambient temperature except for few times to heat it up during cold weathers. Hence the need to insulate it did not arise.

The standard SI unit for fiberglass is kilograms per cubic meter ($kg/m^3$) while its density is 20 $kg/m^3$, with an ultimate tensile strength of 0.02 MPa, melting Point of 1227°C, thermal conductivity of 0.03 W/mK and heat capacity840 J/g K.

## 4. Conclusion

In conclusion, this research work delves into the comprehensive exploration of biodiesel production processes, reactor design, modelling, and simulation, with the goal of global improvement in processor design, production efficiency, and control mechanisms. Biodiesel, derived from renewable sources such as waste vegetable oil, is recognized for its potential to mitigate environmental impacts and improve engine performance.

The construction of a biodiesel processing plant at Lagos State University further solidifies the practical implementation of the research. The plant's design, involving various tanks, heating elements, and pumps, reflects a systematic approach considering factors such as mass transfer, mixing, fluid viscosity, and cost-effectiveness. The use of band heaters and immersion heaters, supported by detailed estimations and calculations, exemplifies the emphasis on energy efficiency and controlled heating in the reactor and associated tanks. The inclusion of insulation materials further enhances energy conservation. In Nigeria, electricity tariff depends on the tariff classification/plan that one is placed/ categorized as stated by the Nigerian Electricity Regulatory Commission. The average cost of tariff for service Band B and C as categorized by NERC for industrial area isN53.33k per kWh. The tariff for Ibadan Disco was chosen because LASU, Epe campus where the Biodiesel Plant is located falls under Ibadan electricity distribution. Although tariff has increased by 40% recently, yet as at 2022 that this bill was estimated, it showed that the lagging done on the Reactor and Drying Tank saved over Two Hundred Thousand Naira PHCN bill through effective heating per annum and the use of solar water heater to heat the wash water also saved PHCN bills further.

The use of waste vegetable oil for biodiesel production aims to lower processing costs, contributing to economic feasibility. Finally, the research not only contributes to the theoretical understanding of biodiesel production but also translates this knowledge into a tangible and functional biodiesel processing plant.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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