

Designing a Domestic Biodiesel Generation Machine for Rural Communities

O.G. Tiro

Department of Mechanical and Industrial Engineering Technology,
University of Johannesburg, South Africa.
bokangtiro093@gmail.com

A.T. Molale

Department of Mechanical and Industrial Engineering Technology,
University of Johannesburg, South Africa.
Tumelomolale451@gmail.com

M.M. Setwaba

Department of Mechanical and Industrial Engineering Technology,
University of Johannesburg, South Africa.
217026898@student.uj.ac.za

S. Khumalo

Department of Mechanical and Industrial Engineering Technology,
University of Johannesburg, South Africa.
217038503@student.uj.ac.za

D.V.V. Kallon

Department of Mechanical and Industrial Engineering Technology,
University of Johannesburg, South Africa.
dkallon@uj.ac.za

O. Awogbemi

Department of Mechanical and Industrial Engineering Technology,
University of Johannesburg, South Africa.
jolawogbemi2015@gmail.com

Abstract

This paper discusses the design of a Biodiesel pilot plant that uses waste cooking oil collected from fried food retailers to produce biodiesel. Greenhouse gas emissions, land pollution, a bad rural economy, a lack of foreign exchange, and unemployment are all issues that have a negative impact on the South African national economy, and the machine is designed to address these issues. User-friendly, raw material storage capacity, cost-effectiveness, and environmental friendliness were all requirements for the designed machine. Three designs of the biodiesel pilot plant were generated to reduce the problem by converting the waste cooking into biodiesel. The most convenient design was the pilot plant 'one reactor tank' since it is cost-efficient due to fewer components used when manufacturing. Safety considerations have been integrated with the design to minimise the possible risks that may be experienced while using the machine. In the second semester, the supervisor recommended that a group design a biodiesel pilot plant to improve on the ones done individually. In theory, the final design is more efficient, cost-effective, and simple to construct when compared to the others. The biodiesel pilot plant recycles used cooking oil to promote environmental social responsibility as a commodity while also informing the public about the importance of renewable energy sources. The model also encourages communities to get involved in the recycle economy concept. The machine will reduce the country's dependency on imported fossil fuels while also promoting long-term rural development.

Keywords

Biodiesel, Design, Machine, Plant, Oil, Domestic, Rural Communities.

1. Introduction

Biomass is organic, meaning it is made of material that comes from living organisms. The source of biofuels production is commonly known as biomass, this source can be 'converted to liquid or gaseous fuels such as ethanol, methanol, methane and hydrogen (Awogbemi et al, 2021a: Dahiya, 2015). Two biofuel products are mainly produced are known as ethanol and biodiesel (Awogbemi and Kallon, 2021). Biodiesel is a fuel that is produced from vegetable oils or animal fats, and it acts as an alternative for fuel for diesel engines (Awogbemi et al, 2021b: Zanzi, et al., 2006 : Leidel, 2014). Ethanol is produced from sugarcane, corn, and sugar; is used as an additive for automotive gasoline production (Awogbemi et al, 2021c: Manochio, et al., 2017). The focus of this papers is on the production of biodiesel since it uses used vegetable oils and animal fats as source.

A Biofuel Plant is a machine that is used to convert biomass into liquid fuel, known as "biofuels". Biodiesel is made under the process called transesterification, where oil goes through five chambers namely: reactor, separator, methanol removal, neutralisation and washing, and finally a dryer. The process allows the removal of the glycerine component of the oil, to allow thinner, less viscous solutions which remain liquid in lower temperatures (Awogbemi et al, 2021d: Balasubramanian, et al., 2016).

1.1. Research Aim

This project aims to design a domestic biofuel generation machine using waste cooking oil collected from restaurants fried food retailers to produce biodiesel. The machine should be mobile for relocation purposes and should work properly under harsh conditions.

2. Existing models

In the process of developing a new design concept for a Biodiesel Production Machine, several existing concepts were carefully studied, and certain ideas were offered and modified from the explored concepts, Figure 1.

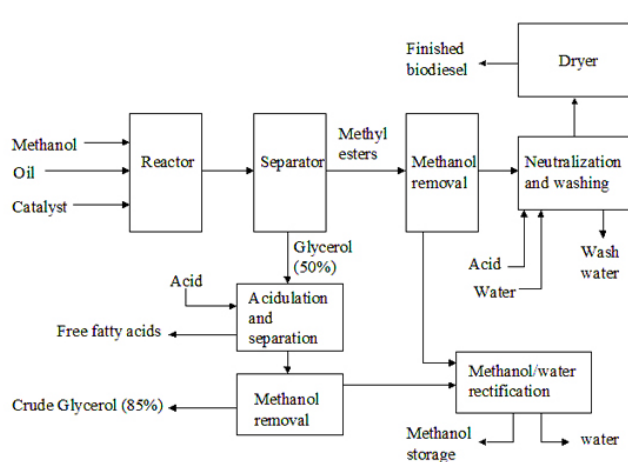


Figure 1. Processes and chambers used for Biodiesel production (Farm Energy, 2019).

2.1. Biodiesel Production Machine with one Reactor tank

The Biodiesel production machine shown in Figure 2 has one reactor tank, whereby it operates as a multifunctional reactor tank unit. There is one motor pump, that is used for transporting oil from the filtering tank to the processor tank and used for recirculation of the biodiesel for the purification process. The inline filter is connected to the recirculation pipe system to filter out the solid catalyst. The stirrer is used for mixing oil, methanol and catalyst and used again for the washing process.

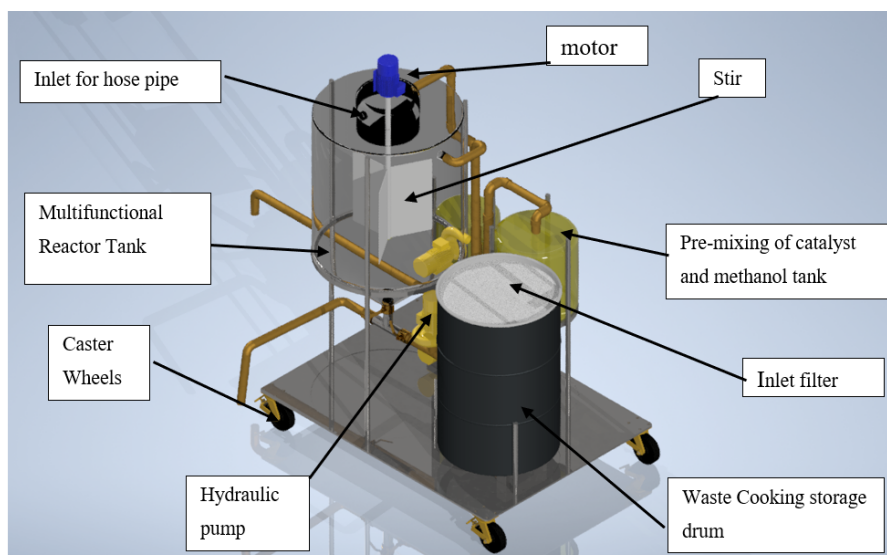


Figure 2. Biodiesel Production Machine with one Reactor tank.

2.2. Portable Biodiesel Machine

Figure 3 shows a portable biodiesel generating machine. It consists of two pulleys with one connected to the motor and the other one connected to the shaft that is responsible for mixing the inputs and ensuring that they react. It has a metal bench where the tank is mounted. Just like concept 1, the reactants are prepared outside the machine and passed to the machine. It can be easily dissembled which making it portable. There is a valve at the bottom of the bottom that controls the discharge of the products.

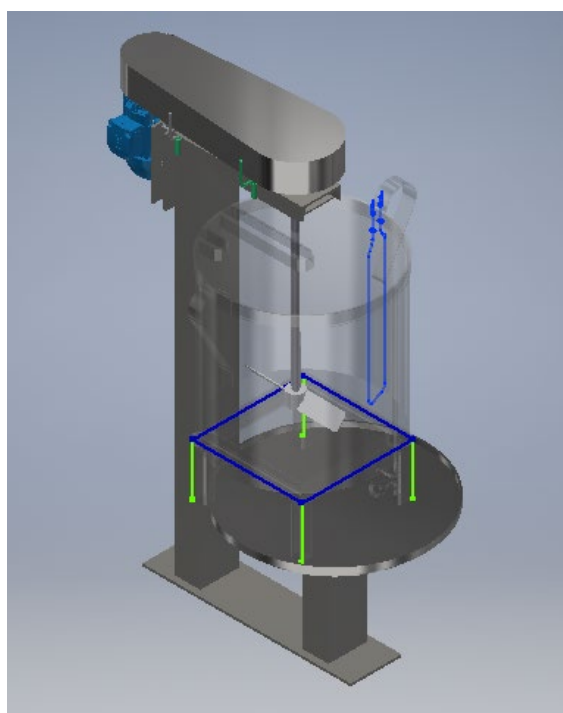


Figure 3. Portable Biodiesel Machine (outside view).

2.3. Biodiesel Production Machine with Three Reactor tanks

A biodiesel machine in Figure 4 can speed up the process of producing ethanol from used cooking oil. The feedstock brown cooking oil. The machine is made up of three buckets or containers, labelled A through C. The first container is mounted with bag filter inside to catch any biofuel fragments that get caught in the bag. Container

B has a motor mixer built into it to aid combine two chemicals, notably sodium hydroxide and methanol, before combining both cooking oils with sodium hydroxide and methanol to prevent stopping the flow of cooking oil to container B. After that, the mixture in container B is permitted to flow to container C. Container C also has a motor mixer and a water sprayer. The water sprayer sprays the liquid in the container so that no methanol-oxide components remain while the motor mixes. This is repeated 3 or 4 times until no cream remains. The mixture is then allowed to dry in container C. Biofuel is created by allowing water to evaporate until there is no more water.

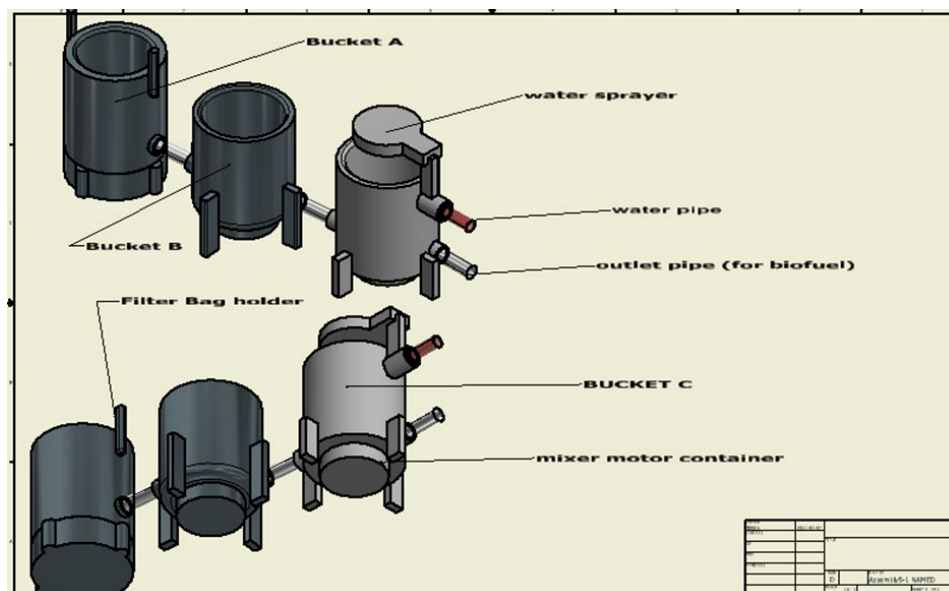


Figure 4. Biodiesel Production Machine with Three Reactor tank.

2.4. Biofuel reactor system

This biodiesel machine design in Figure 5 can handle intensively used cooking oil and a 2 kW oil heater. It has an electrically operated 230 V and 240 W immersion heater (uses low-density vegetable oils and biofuel). The steel frame of this machine processor is galvanized steel, and the tanks are cylindrical. This concept's design entails the modification of domestic biodiesel green solid catalyst producing biodiesel machines. In 8 hours, this machine processor can produce 150-600 liters of biodiesel.

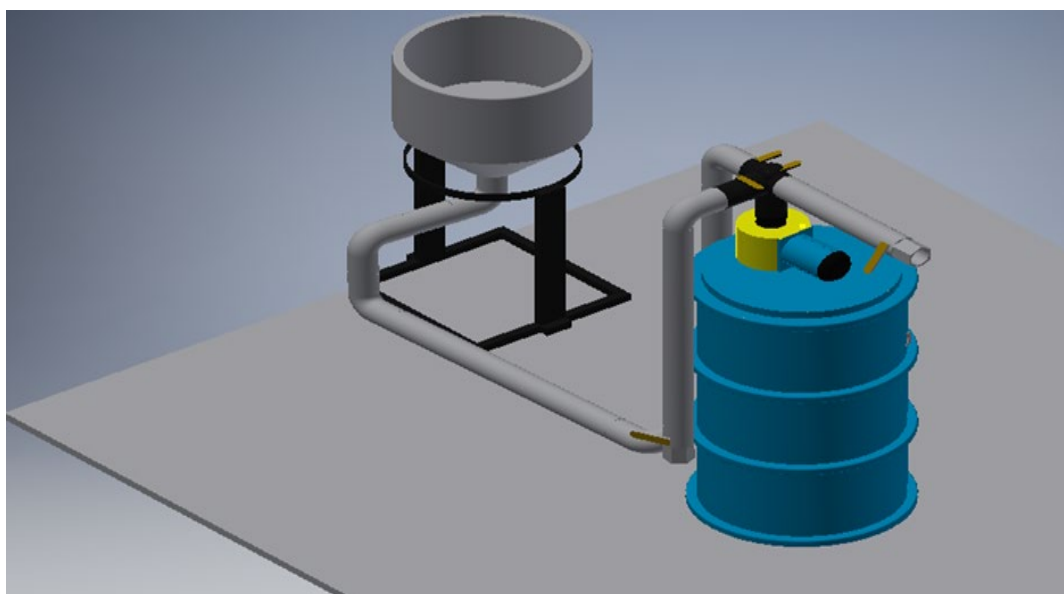


Figure 5. Biodiesel reactor system.

3. Biodiesel Pilot Plant Design

The design shown in Figure 6 consists of two tanks namely the filtering tank (black) and the processor tank. There are two motor pumps, with the first one transporting oil from the filtering tank to the processor tank, and the second one recirculating the biodiesel for the purification process.

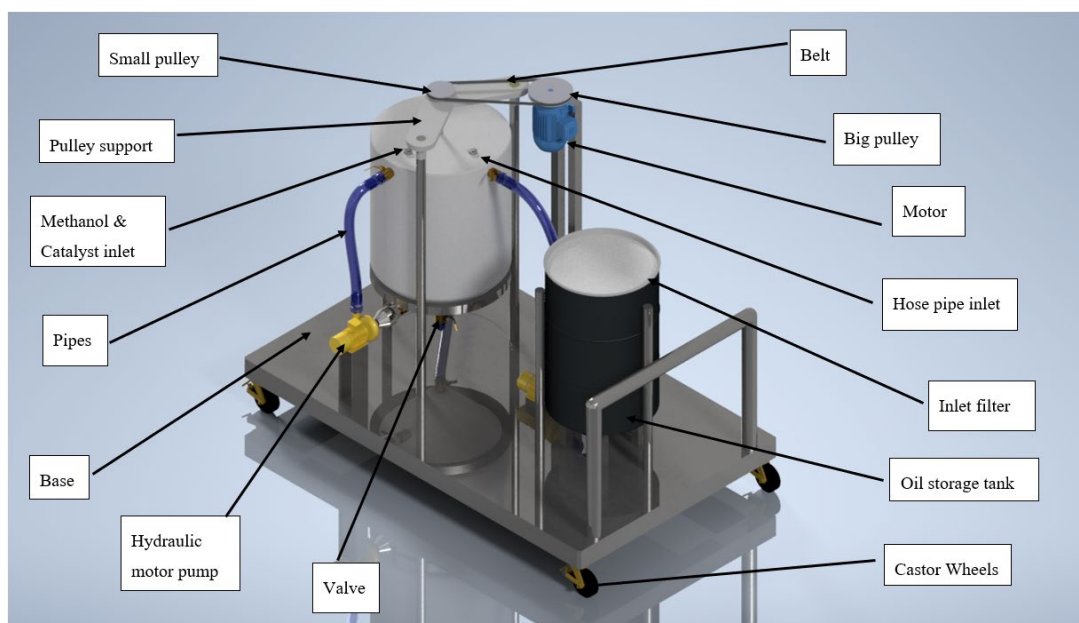


Figure 6. Final group design of biodiesel machine design

The catalyst soot filter is connected in line with the motor pump to the catalyst soot filter after the production of biodiesel. The motor is connected to the stirrer via a pulley system since it would not be safe to connect it directly to the stirrer on top of the processor tank. The stirrer helps with mixing the reactants to produce biodiesel. This machine is mobile, this makes it easy to be moved and placed at any location, the pipes are transparent, and this helps in discharging of glycerine to be able to separate glycerine from biodiesel. Some valves control the flow of the mixture.

In the first stage, the waste cooking oil is filtered to remove debris, this is achieved by using the carbon filter sheet placed at the inlet of the tank. The valve below the storage tank will be opened to allow the oil to be siphoned by the motor pump to the processor tank through a pipe. After the transportation of oil is complete, the oil inlet valve on the processor tank is closed. Due to the strict budget, the system used to mix catalyst and methanol will not be included in the project, therefore the catalyst and methanol will be prepared outside the current machine. The mixture is poured manually at the inlet located at the top of the processor tank. The motor is activated to allow the rotor to mix the reactants. The heater is used to increase the temperature of the reactants to meet the minimum temperature for activation of the transesterification process at 55 °C for at least 2 hours.

For the separation process, the stirring system and heater are turned off for the mixture to be allowed to settle down for 24 hours. Due to gravity and different densities, the product in the mixture will separate. The glycerine will situate itself at the bottom, while the biodiesel will be at the top. The discharge valve situated at bottom of the processor tank is opened to allow the glycerine to be removed, with the help of the transparent pipe it will be easy to notice the colour change during a discharge, to know that all the glycerine has been fully removed then the valve is closed.

For biodiesel purification, warm water is employed for the washing process to remove all the impurities, contaminants, and volatile substances to decrease the possibility of emulsification, the mixing take about 1 hour. The mixture is allowed to settle for 24 hours for the water by-products to be drawn to the bottom of the container by gravity. The discharge valve at bottom of the processor tank is opened again, but this time the water by-products to be removed and afterwards the valve is closed. The motor pump linked to the processing tank is turned on, and the valve in line with that motor is opened, allowing the biodiesel to recirculate for purification. This process can take some time, and the quality of the biodiesel can be seen via transparent pipes. The biodiesel is then ready for usage after it has been purified.

4. Model calculations and results

According to (Awogbemi et al, 2021b; Chuah et al, 2015) the properties of waste cooking oil are given in Table 1.

Table 1. Properties of waste cooking oil

| Properties | Temperature (°C) | mean \pm standard |
|---|------------------|---------------------|
| <i>Density (kg/m³)</i> | At 20 | 915.67 \pm 0.03 |
| | At 40 | 901.95 \pm 0.04 |
| | At 60 | 888.44 \pm 0.03 |
| <i>Kinematic viscosity</i> ($\times 10^{-6} \text{ m}^2/\text{s}$) | At 20 | 124.00 \pm 0.01 |
| | At 40 | 51.04 \pm 0.03 |
| | At 60 | 26.28 \pm 0.02 |
| Moisture content (wt%) | - | 0.12 \pm 0.00 |
| Heating Value (MJ/kg) | - | 39.96 \pm 0.04 |

Interpolation using the values in Table 1 the mean density of waste cooking oil at 25 °C (room temperature) and flow velocity are estimated in equations 1 and 2.

$$\rho_2 = \frac{(t_2 - t_1)(\rho_3 - \rho_1)}{(t_3 - t_1)} + \rho_1 \quad (1)$$

$$\rho_2 = \frac{(25 - 20)(901.95 - 915.67)}{(40 - 25)} + 915.67$$

$$\rho_2 = 911.1 \text{ kg/m}^3$$

$$V_{k2} = \frac{(t_2 - t_1)(V_{k3} - V_{k1})}{(t_3 - t_1)} + V_{k1} \quad (2)$$

$$V_{k2} = \frac{(55 - 40)(26.28 - 51.04)}{(60 - 40)} + 51.04$$

$$V_{k2} = 32.47 \text{ mm}^2/\text{s}$$

Calculations for mass of waste cooking oil occupying 88% capacity of 500 litres as shown in equation 3

$$\rho = \frac{m}{V} \quad (3)$$

$$m = \rho V$$

$$m = (911.1)(0.37)$$

$$m = 337.12 \text{ kg}$$

According to Engineering tool box, 2021, the densities of methanol are given as Table 2.

Table 2. Properties of methanol

| Properties | Temperature | mean |
|--|-------------|--------|
| <i>Kinematic viscosity</i> ($\times 10^{-6} \text{ m}^2/\text{s}$) | At 20°C | 0.7500 |
| | At 25°C | 0.9606 |
| <i>Density (kg/m³)</i> | At 20°C | 791.1 |
| | At 25°C | 786.3 |

Mass of methanol is calculated by equation 4

$$m = \rho V \quad (4)$$

$$m = (786.3)(0.074)$$

$$m = 58.19 \text{ kg}$$

Energy requirement is calculated in equation 5.

$$q = (mc_p \Delta T)_{oil} + (mc_p \Delta T)_{methanol} \quad (5)$$

$$q = (\Delta T) [(mc_p)_{oil} + (mc_p)_{methanol}]$$

$$q = (65 - 25)[(337.12)(1.67) + (58.19)(2.53)]$$

$$q = 28408.44 \text{ kJ}$$

4.1 Shaft Design

Stirring Speed of 350 rpm is suitable for this reaction as it induces high biodiesel yields for the first minutes of reaction and at the same time no foam is formed (Peiter, et al., 2020). For shaft connected to the motor, assuming that the power is 1.5 kW (Tables 3 and 4).

Table 3. Specifications of a shaft

| Shaft Parameter and properties | Specification |
|---------------------------------------|---------------|
| Height | 1078.46 mm |
| Diameter | 25 mm |
| Modulus of rigidity (stainless steel) | 77.2 GPa |

Table 4. Shaft Design calculations

| | |
|---|--|
| <p>Total resisting Torque</p> $T = \frac{P}{2\pi N}$ $T = \frac{1500}{2\pi(350)}$ $T = 0.68 \text{ N} \cdot \text{m}$ | <p>Polar moment of inertia</p> $J = \frac{\pi d^4}{32}$ $J = \frac{\pi(0.025)^4}{32}$ $J = 3.835 \times 10^{-8} \text{ m}^4$ |
| <p>Maximum shear stress</p> $\tau = \frac{Tr}{J}$ $\tau = \frac{(0.68)(0.0125)}{3.835 \times 10^{-8}}$ $\tau = 0.222 \times 10^6 \text{ N/m}^2$ $\tau = 0.222 \text{ MN/m}^2$ | <p>Angle of twist</p> $\theta = \frac{Tl}{GJ}$ $\theta = \frac{(0.68)(1.07846)}{(77.2 \times 10^9)(3.835 \times 10^{-8})}$ $\theta = 4^\circ \times 10^{-7}$ |

5. Cost Analysis

The cost analysis was used to give the estimated cost of components based on the raw materials, manufacturing processes, and distribution costs. The components of the lowest costs offered by various suppliers were chosen to construct the analysis based on the findings of product cost research. The price shown in Table 5 is for a single quantity of a component, whereas the total cost is for the entire number of quantities desired. The overall cost of the machine is the sum of the total costs of all desired component amounts.

Table 5. Cost analysis of the combined biodiesel machine

| Component | Quantity | Material | Price (R) | Total cost (R) |
|-----------------------|----------|-------------------|-----------|----------------|
| Caster wheel | 4 | Rubber | 1 226 | 4 904 |
| Motor | 1 | Various materials | 1 397 | 1 397 |
| Hydraulic motor pump | 2 | Various materials | 2 040 | 4 080 |
| Valve | 5 | Steel | 185 | 925 |
| catalyst soot filter | 1 | | 230 | 230 |
| Conical tank in frame | 1 | Polyethylene | 4843 | 4 843 |
| Inlet filter | 1 | Carbon | 30 | 30 |
| Oil drum | 1 | Steel | 1890 | 1 890 |

| | | | | |
|-----------------------------|----------|-----------------|-------|--------|
| Flexible Pipe | 4 meters | Nylon | 29 | 116 |
| Recirculation pipe | 1 | Stainless steel | 687 | 687 |
| Base | 1 | Stainless steel | 1 095 | 1 095 |
| Square Frames | 1 | Stainless steel | 846 | 846 |
| Circular Frames | 1 | Stainless steel | 900 | 900 |
| Overall cost of the machine | | | | 18 343 |

6. Other Design considerations

6.1. Safety considerations

The recommended safety precautions to be applied are as follows:

- The Personal Protective Equipment (PPE) should be utilised.
- The machine should be used in a ventilated area.
- The caster wheels should be locked, when doing the production of the biofuel.
- Avoid the use of devices that can generate sparks near an open container of methanol.
- When adding the catalyst, make sure the methanol is not exposed to air by closing the valve connecting the methanol tank and pre-mixing the methanol and catalyst tank.
- The operation and maintenance manual must be provided to the buyer.
- Before use, the machine should be calibrated.
- The wastewater used for washing, should not be used for other purposes.
- The motors should be operated at a suitable speed.
- The in-line filter should be cleaned after use.
- The valves should be handled with care.

6.2. Impact of design

6.2.1. Environment

Biodiesel is biodegradable, non-toxic, and renewable. The machine produces allowable noise to people. The gaseous chemical reactants produced, are minimal and contribute with the lowest amount to Green Houses gases emissions. The manufacturing of this machine might pollute the environment as cutting, welding of steel will take place where the tools used tend to produce noise pollution.

6.2.2. Health

When working with a machine there might be some gaseous chemical reactants during the esterification process that can be released outside the machine that can pose negative effects on end-users' health. The heating element used in the machine can produce heat radiation that may lead to illnesses like heat stroke when the end-user is in contact with it for a long period of time.

6.2.3. Safety

When the machine is in the production process there is a reduced chance of it being moved which may lead to an accident that may result in the machine dysfunctionality or physical harm to the end-user and all the inlets and outlets are closed to minimise factors that can contribute to fire ignition.

6.2.4. Social

The biodiesel pilot plant recycles the waste cooking oil to promote aspects of environmental social responsibility as a commodity and educate the public on the significance of renewable energy sources.

6.2.5. Ethical

The machine will obey the local government's standards as well as increase public understanding of sustainable development and the circular economy. Encouraging the region's consumers to recycle.

6.2.6. Economical

The machine will decrease the country's dependence on fossil fuel imports, supporting long-term rural development, minimizing the final customer's cost of fuel, preserving national consumers against unstable fossil fuel costs and energy insecurity, and encouraging national teaching and research organizations' research on biofuels manufacturing techniques, especially technology related to local communities.

6.2.7. Political

According to South African laws, a licensed petroleum manufacturer may not refuse to buy biodiesel unless it can prove that it does not have enough petroleum diesel to handle the level of biodiesel being supplied. All petroleum diesel generated by a licensed petroleum manufacturer is destined for a blending facility for this sub-regulation.

7. Conclusions and Future Research

The project aimed to develop a Biodiesel pilot plant that would generate biodiesel from waste cooking oil collected from restaurants and fried food sellers. The machine must be user-friendly, can store raw materials, be cost-effective, and be environmentally friendly. Three designs of the biodiesel pilot plant were generated to address the problem, the more convenient design was the one reactor tank since it is cost-efficient due to fewer components used. Safety considerations have been drafted to minimise the possible risks that may be experienced while using the machine. The design was based on the standards provided by the South African National Standard (SANS).

The machine's prototype can be constructed so that testing can be run to see if the machine satisfies the aim of this project. Methanol is a highly costly fuel, and its price is linked to the change in oil prices. The objective should be to create a long-lasting yet low-cost pilot unit by including a methanol recovery phase in a design. The recovery is ensured by heating the processor tank to 65°C to ensure that all methanol boils. The evaporated methanol is then passed through a condenser before being recovered and reused in the next biofuel production. For further optimisation, the simulation may be done with the aid of Autodesk Inventor and ANSYS to test if the machine will be able to resist the temperature, pressure, and forces being applied.

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Biographies

Mr. Oratile Godwill Tiro obtained BEng Tech degree in Mechanical Engineering from the University of Johannesburg, South Africa in 2021. He has done research on Biofuel generation machine under the supervision of Dr. Daramy Vandi Von Kallon and Dr. Omojola Awogbemi.

Mr. Aron Tumelo Molale obtained an undergraduate BEng Tech degree in Mechanical Engineering from the University of Johannesburg, South Africa in 2021. He has done research on Biofuel generation machine under the supervision of Dr. Daramy Vandi Von Kallon and Dr. Omojola Awogbemi.

Mr. Marion Setwaba obtained BEng Tech degree in Mechanical Engineering from the University of Johannesburg, South Africa in 2021.

Mr. Sandile Khumalo obtained BEng Tech degree in Mechanical Engineering from the University of Johannesburg, South Africa in 2021.

Dr. Daramy Vandi Von Kallon is a Sierra Leonean holder of a PhD degree obtained from the University of Cape Town (UCT) in 2013. He holds a year-long experience as a Postdoctoral researcher at UCT. At the start of 2014 Dr Kallon was formally employed by the Centre for Minerals Research (CMR) at UCT as a Scientific Officer. In May 2014 he transferred to the University of Johannesburg as a full-time Lecturer and later a Senior Lecturer in the Department of Mechanical and Industrial Engineering Technology (DMIET). Dr Kallon has more than twelve (12) years of experience in research and six (6) years of teaching at university level, with industry-based collaborations. He is widely published, has supervised students from Master to Postdoctoral levels and has graduated seven (7) Masters Candidates. His primary research areas are Acoustics Technologies, Mathematical Analysis and Optimization, Vibration Analysis, Water Research and Engineering Education.

Dr. Omojola Awogbemi obtained PhD in Mechanical Engineering from the University of KwaZulu-Natal, South Africa in 2020. He had earlier graduated with a Higher National Diploma in Mechanical Engineering from Yaba College of Technology, Lagos, Nigeria in 1998, Post Graduate Diploma in Mechanical Engineering from University of Ado Ekiti (now Ekiti State University), Nigeria in 2004, and Master of Engineering degree in Mechanical Engineering from Ekiti State University, Ado Ekiti, Nigeria in 2014. Dr. Awogbemi is a registered Engineer with the Council for the Regulation of Engineering in Nigeria and an active member of Nigerian Society of Engineers, South African Institution of Mechanical Engineering, among other professional bodies. He has published widely in peer reviewed journals and presented papers in local and international conferences. His research interest includes Renewable Energy, Bioenergy, Waste to Energy, Biomass Conversion, Biofuel generation and utilization, and Engineering Education.