Provisional chapter

Application of Design for Manufacturing and Assembly: Development of a Multifeedstock Biodiesel Processor

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Additional information is available at the end of the chapter

Abstract

Design for manufacturing and assembly (DFMA) is the method for process and cost optimization of subsystems, whole system as well as the entire manufacturing process. While minimizing assembly operations, it helps in eliminating component redundancy, facilitates assembly and manufacturing of products that are cost effective in terms of material requirements, parts production, labor and overhead. In this study, a multi feedstock biodiesel processor with intelligent systems for control and monitoring was developed using the principles of design for manufacturing and assembly. It consists of a 2 kW variable speed sparkless electric motor, reaction chamber, a thermostatically controlled 3 kW electric heater, saw dust insulation, ball valve, thermostat, funnel, a stirrer of diameter 20 mm with five blades that rotate in the reaction chamber and two baffles to control the splashing. The stirrer is driven by the electric motor. A 2 mm thick galvanized steel was used in the fabrication of the reaction chamber because of its high resistance to corrosion. This work provides a design framework for both small and large scale biodiesel plant for industrial, laboratory and experimental purposes. In addition, the assembly operations of the processor's components via the principles of DFMA were simplified to reduce ambiguity and redundancy. Hence, the overall processor is cost effective in terms of material requirements, parts production, labor and overhead.

Keywords: design, biodiesel, manufacturing and assembly, multi feedstock, cost optimization

1. Introduction

Design for manufacturing and assembly is a combined method developed to evaluate product assembly in order to enhance simplicity and cost effectiveness in manufacturing during the product development. It is a two part analysis of product development namely; design for assembly (DFA) and design for manufacturing (DFM), with the aim to increase flexibility and profitability [1, 2], reduce overall cost in terms of material, production, labor and overhead [3, 4], as well as to reduce the complexity of manufacturing process [5]. A complex process increases manufacturing time, cost and rigidity. Design for assembly (DFA) is the method of product design for ease of part assembly which involves optimization of part or subsystem. According to Strienstra [6], DFA is a tool used in the design of product parts or subsystems that will transit into production at an effective cost, focusing on the number of parts, handling and ease of assembly. The aim is to minimize part lists without sacrificing quality, reduce assembly cost and to select the optimum cost of material that will be employed in manufacturing. On the other hand, design for manufacturing (DFM) is a method of design for ease of manufacturing via optimization of the process of product integration into the final product [7]. The process of optimization presents several optimum solutions for the manufacturing process hence DFM select the best solution out of the possible solutions. This reduces overall production cost as well as the complexity of the process of product development without compromising the standard. The process of product development starts with the conceptual design stage to design for assembly from where it transits to design for manufacturing and detailed design of the product. Depending on the orientation and geometry of different component parts, manufacturing processes are utilized as a single approach or in combination. This may include forming or machining processes, etc. Besides designing a component to function and fit for the intended application, it is important to put manufacturing processes into consideration. This proactive step is known as Design for Manufacture and Assembly (DFMA). It reduces the product development cycle while helping in ensuring that rework and time wasting activities are eliminated as parts are produced in the most judicious and economic way. According to [2, 8] other advantages of DFMA includes; correct interpretation of design information, optimization of design and manufacturing methods into one single step, increase in productivity with attendant decrease in production cost as well as high degree of precision in design and manufacturing. The basic principle for DFA involves the minimization of part list via the design for parts with self-locating and fastening ability. This makes the design simple as the use of locators and fasteners are reduced. In addition, parts are designed for ease of handling, insertion and retrieval. This increases design flexibility and minimizes the re-orientation of parts during assembly. Modular design of parts and part assembly from top to bottom is an effective DFA concept that can be employed to optimize the design phase. According to Whitney [9], product assembly can be done via manual, fully automated or semi-automated means. While manual assembly relies on human effort for assembly operations, automatic assembly uses robotic technology and computer controlled systems [3]. Semi-automatic relies partly on both human effort and intelligent systems for assembly operations. The method of assembly however depends on the nature of product, product complexity, environment, manufacturing structure, the efficiency required amongst other factors. Manual method of assembly has the merit of flexibility, cost effectiveness and mostly suitable for simple products with short assembly cycle. The demerits however lies in the low speed of assembly which increases assembly time, poor handling, and lower efficiency due to stress and fatigue on the part of personnel when compared to automatic means and most times not suitable for assembly of complex geometry.

Robots are programmable machines which receives signals from the system and environment to carry out programmed activities autonomously or semi autonomously [10]. They take decisions and interact with other interface as well as the central control system via the sensors and actuators. Robots combine the techniques of numerical control and remote control to replace human personnel with numerically controlled mechanical actuators. Robots are classified into two categories; artificially intelligent robots and non-artificially intelligent robots. Artificially intelligent robots are robots which are controlled by artificial intelligent programs involving learning, perception, problem-solving, language-understanding and logical reasoning to perform complex tasks while non-artificially intelligent robots simply carry out a defined sequence of instructions without the use of artificial intelligent programs. Robots possesses good material handling ability and suitable for assembly of complex products at higher efficiency and reduced assembly time. The use of robots for assembly is costly and some robots are not flexible enough when compared to manual method.

The emerging technology in product assembly involves the use of machines operated and controlled by computer programs. There are limitations in the rate of production using manual or robotic means because time is wasted during assembly. The computer controlled system uses some codes of instruction consisting of numbers, letters of the alphabets and symbols. These instructions are converted into electrical pulses which the machine's controls follow to carry out the assembly operations and the process is automated with the help of micro-controllers. They are costly, but highly efficient and can carry out any type of assembly operation with high degree of precision and accuracy within a short time. The pace of assembly delivery with high precision will offset the high initial cost. This work applies the design principles for design for manufacturing and assembly in the development of a multi-feedstock biodiesel processor limited to the production of 50 L of biodiesel per day. Several researchers have worked on the development of a biodiesel processor. For instance, Leevijit et al. [11] developed a continuous stirred tank reactor for the transesterification of palm oil to biodiesel. Process simulation was performed to optimize the mixing performance of the continuous reactor and the required time for the transesterification of palm oil in the optimized reactor was predicted as 5 h. However, the analysis of plant design was not sufficiently highlighted. Marjanovic et al. [12] also developed a batch reactor for the production of biodiesel from divers' feedstock but the analysis of integration of plant components was a missing link. Bello et al. [13] developed a batch biodiesel processor that can transesterify used and unused oil to biodiesel but there are some redundant complex geometries which increases manufacturing time, cost and rigidity. Musa [14] designed and constructed a pilot plant for the production of biodiesel from cottonseed. The capacity of the plant is limited to 20 L of biodiesel per day. The biodiesel pilot plant consists of a transesterification reactor with heater, a stirrer, chemical mixing tank, three glycerol settling tanks, and washing tank. However, the analysis of control circuitry and effect of process parameters were not studied. Bhachu et al. [15] designed a mobile biodiesel production plant, which is capable of producing 3000 L of biodiesel per week. The limitation lies in the fact that there are many redundant parts that increased the overall cost of manufacturing. Also, Highina et al. [16] reported on biodiesel production using *Jatropha curcas* oil in a batch reactor in the presence of zinc oxide as catalyst. The reactor is limited to single feed and use of heterogeneous catalyst only. Although, heterogeneous catalysts boast of several advantages over homogeneous catalysts in the conversion of feedstock to biodiesel [17–20]. The analysis of material handling was however not sufficiently highlighted. Hashem et al. [21] developed a bench top automated system that simulates an existing processor design with modifications necessary to make it run by computer control. The processor is adaptable to test alternatives and novel processing techniques in the laboratory on the bench top scale. The automation was done using a program controller integrated data acquisition software and Labview software to monitor and control the operation. The prototype developed is useful in simulating full scale automated system and in testing new processing technologies. The specific goals of the design are to minimize manual labor and cost while ensuring plant flexibility in processing multi feedstock. The aim of the work is to develop a multi-feedstock biodiesel processor with a capacity of 50 L per day using the principles of design for manufacturing and assembly (DFMA).

The objectives of the work are to:

i. design a smart multi-feedstock biodiesel processor with a capacity of 50 L per day with reduction in the part list;

ii. consider existing processors and reduce the overall manufacturing cost via redesign and elimination of redundant parts;

iii. increase the versatility and flexibility of the processor.

2. Methodology

This work uses the principles of design for manufacturing and assembly for development of a smart biodiesel processor. The design considerations are as follow;

i. The number of parts and number of interfaces which determines the simplicity or complexity of the overall assembly. The parts are listed in order of assembly and are assigned numbers to identify the parts. The complexity factor is expressed as Eq. (1).

$$CF = \left(\sum N_p \times \sum N_i\right)^{0.5} \tag{1}$$

where $\sum N_p$ is the total number of part list and $\sum N_i$ is the total number of part-to-part interface.

ii. The practical and theoretical minimum parts as well standard parts with their cost. Parts of different materials are identified and functional analysis is carried out with respect to existing design and possibility of redesign. This is a crucial consideration because the aim of product development is for profitability and to come up with reliable products that will meet customers' requirement by performing satisfactorily in service. Hence, the right balance must be struck between cost and component parts without sacrificing quality.

The theoretical part list efficiency is expressed by Eq. (2).

$$\frac{T_m}{T_n} \times 100\% \tag{2}$$

where T_m is the theoretical minimum number of parts and T_n is the total number of parts.

iii. Nature of the parts to be assembled. This determines the method of handling, insertion an alignment.

iv. The method of joining the different parts together. This is followed by evaluation of the assembly and readjustment.

v. The determination of the right drafting and modeling tools in transforming conceptualized design into reality with parts specifications.

2.1. Design novelties

The design novelties of the developed processor are as follow:

a. Significant reduction in part list and short assembly cycle with parts designed for ease of handling, insertion and retrieval.

b. Provision of a smart processor that is flexible and versatile enough to process biodiesel from different feedstock via incorporation of all feedstock requirements for the production of biodiesel.

c. Provision of suitable template for scaling its development; and

d. Incorporation of intelligent systems for control and monitoring.

The intelligent systems for control and monitoring comprises of the following;

2.1.1. Arduino Uno microcontroller

The Arduino Uno is a microcontroller board that provides a simple and modular way of interfacing the real world with the computer to handle basic processing tasks on a chip while working with hardware sensors (**Figure 1**). The Arduino Uno uses the ATmega328 chip that supports 14 digital pins that can be configured as either input or output and 6 analog inputs [22].

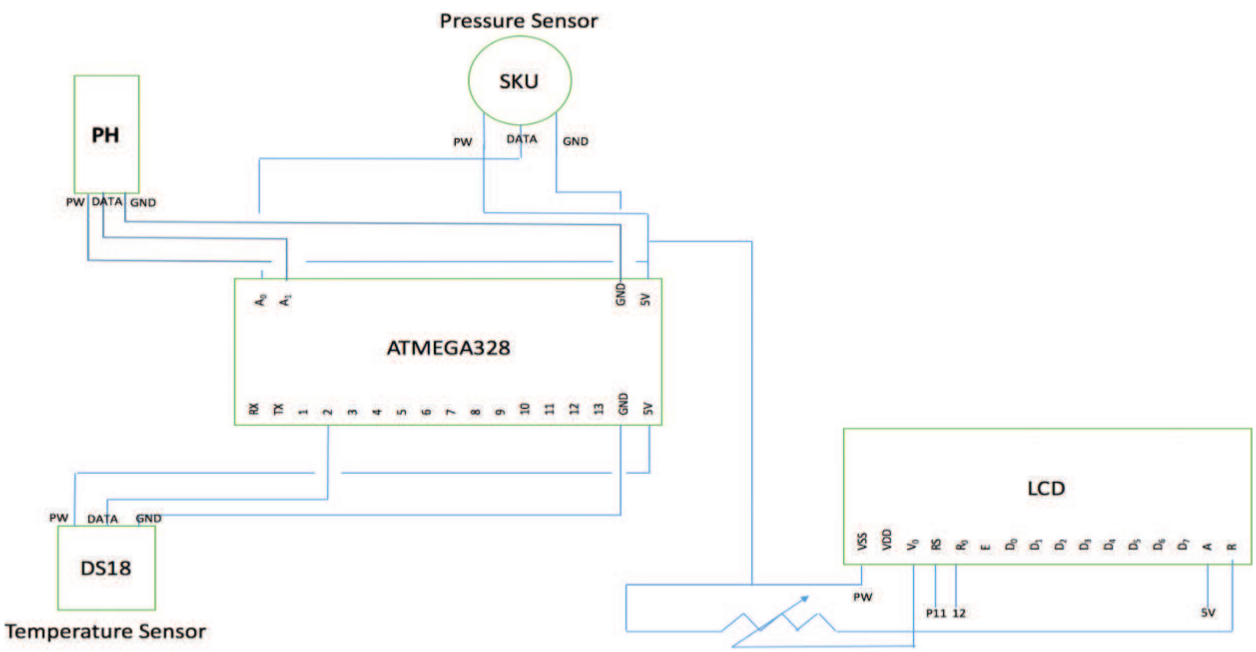


Figure 1. The monitoring system circuit with Arduino Uno microcontroller.

The technical specification of the Arduino Uno is presented in **Table 1**.

The Arduino is programmed using the Arduino IDE with source code will be written in C.

S/N	Item	Value	Remarks
1	Micro-controller	8-bit Atmel ATmega328p	1 mm sheet metal
2	Operational voltage	5 V	Input range: 7–12 V
3	Digital GPIO	14	6 capable of PWM
4	Analog IO	6	10-bit
5	Program memory	Flash 32 kb, EEPROM 1 kb	SRAM 2 kb
6	Clock speed	16 MHz	
7	USB	Type B socket	
8	Programmer	In-system firmware	USB-based
9	Serial communications	SPI, I2C	Software UART
10	Other	RTC, watchdog, interrupts	

Table 1. Technical specifications of the Arduino Uno.

2.1.2. Pressure transducer sensor

This measures the pressure of gas with a carbon steel alloy sensor material (**Figure 2**). It has a working pressure range of 0–1.2 MPa. The normal working temperature range is 0–85°C and the response time is approximately 2 ms.

Figure 2. Pressure transducer sensor.

It consists of an elastic material that deforms under the application of pressure and an electrical element which detects the deformation and transmits it as changes in voltage.

2.1.3. pH meter kit

This is a kit that measures pH of a substance. It is specially designed for the Arduino and has an accuracy of ±0.1 pH (at 25°C). The kit has a range of 0–14 pH. The kit consists of a pH sensor probe, a BNC connector and a pH 2.0 interface. The pH meter kit is shown in **Figure 3**.

Figure 3. pH meter kit.

2.1.4. Temperature sensor

This takes temperature readings for the plant to aid process insights. It has a temperature range of 0–400°C.

2.2. Processor design

The processor design involves the determination of a detailed, industrial-scale engineering model for a biodiesel processor and the associated parametric specification. The components parts are linked up with the aim of integrating and optimizing the entire process in the conversion of oil to biodiesel. The design involves the determination of the reactor geometry and capacity as well as the choice of construction material. The first design consideration is the reactor capacity which is determined by the mass balance of input and output streams. The sum of the volume of all streams entering the reactor gives the total liquid volume of the reactor for one batch. In order to meet an annual production of 18,000 L, daily production is calculated as 50 L per day.

2.3. Materials

The processor part list as well as the materials employed in the construction of a biodiesel processor is presented in **Table 2**.

S/N	Description	Quantity	Remarks
1	Sparkless electric motor (E2A), 3000 Hz, max 700 NCm	1	2 kW capacity
2	Reactor	1	2 mm thick galvanized sheet metal
3	Heater	1	3 kW of heat capacity of 0.44 kJ/kgK
4	Valve	1	regulatory valve
5	Insulator		Saw dust
6	Thermostat	1	TED-2001 (0–400°C)
7	Stirrer	1	Stainless steel
8	Funnel	1	Glass
9	Arduino Uno	1	Microcontroller
10	pH meter kit	1	43 × 32 mm
11	Pressure transducer sensor	1	¼″ 1.2 MPa
12	Temperature sensor	1	
13	Valves and fitting	2	½″ ball valve ½″ adapter ¾″ socket ¾″ × ½″ bushing ¼″ gas outlet valve ½″ T-fitting ½″ PVC pipe

Table 2. Processor parts list and materials employed.

2.3.1. Sparkless electric motor

This is a device powered by electric current to produce continuous motion. It rotates at a maximum speed of 300 rpm and attached to it, is the shaft. The power of the electric motor is rated as 2 kW and it is such that it is a variable speed electric motor from which different stir speed can be selected. It has a maximum frequency of 3000 Hz. The electric motor drives the stirrer which in turn stirred the raw materials inside the reaction chamber tank.

According to [23] a 2 kW electric motor is adequate to stir fluid of density 800–900 kg/m^3 at a speed of 300 rpm. This informs the choice of this type of electric motor.

2.3.2. Reactor

This is the main chamber where transesterification takes place. The reactor is pressurized and its chamber is constructed into cylindrical shape with galvanized steel. The reaction tank has a galvanized steel lid welded on. The lid for the tank is important in order to prevent escape of methoxide fumes during the process and also allows for distilling out the methanol after each batch. The lid also helps to prevent exposure to poisonous fumes, dangerous chemicals and fire. The capacity of the reaction tank is limited to 25 L per batch of vegetable oil.

2.3.3. Heater

The bottom of the cylindrical reaction chamber is fitted with an internal heating element. The heater is a 3 kW, 120 V a/c stainless steel heating element. It is used to raise the temperature of the reaction chamber and its content between 0 and 400°C. The processor chamber is heated by this thermostatically controlled electric heater and the temperature of the content is measured and regulated by means of a thermostat.

The fluid density is expressed as Eq. (3).

$$\rho = \frac{m}{v} \tag{3}$$

where v is the volume (0.027 m^3) and ρ is the fluid density (830 kg/m^3), then the mass m of the fluid is calculated 22.41 kg.

The weight of the fluid is expressed as Eq. (4).

$$w = mg \tag{4}$$

where m is the mass of the fluid (22.41 kg) and g is the acceleration due to gravity (9.81 m/s^2).

Therefore, the weight of the fluid is calculated as 219.84 N.

The specific heat capacity of vegetable oil is 2340 J/kg K, weight (W) of 25 L of vegetable oil is 219.84 N, the heater has a power rating of 3 kW, assuming the ambient temperature of 30°C, and the mixture is heated to a temperature of 60°C, therefore, the heat transferred to the fluid (workdone by the heater) is given as Eq. (5).

$$Q = mc\Delta T \tag{5}$$

where m is the fluid mass (kg); c is the specific heat capacity of the fluid (J/kg K); and ΔT is the temperature difference between the final T_2 and ambient temperature T_1.

Hence, 1573 kJ is the quantity of heat transferred to 25 L of vegetable oil per batch. The assumed electrical to heat conversion efficiency (η_e) is 80%. The heat loss coefficient for the reaction tank is 1.0 J/S-m^2-°C and the surface are of the reactor is 0.5430 m^3.

The power rating of the heater is expressed as Eq. (6).

$$P = \frac{W}{T} \tag{6}$$

where P is the power rating of the heater (3 kW); W is the workdone by the heater (1573 kJ).

Therefore, the estimated heating time for the used vegetable oil is 530 s.

The rate of heat loss is expressed as Eq. (7).

$$R_L = \alpha * SA * \Delta T \tag{7}$$

where α is heat loss coefficient for the reaction tank (1.0 J/S-m^2-°C); SA is the total surface area of the reactor (0.5430 m^3); ΔT is the temperature difference between the final T_2 and ambient temperature T_1 (30°C).

Therefore the rate of heat loss R_L is calculated as 16.29 J/s.

2.3.4. Valve

The ball valve is fitted to the bottom of reaction tank in order to control the rate of discharge of reaction products from the reaction chamber.

2.3.5. Insulator

The reaction tank is well lagged all through to keep the temperature of the reaction tank and its content constant by preventing heat loss. The insulating material employed is saw dust and has a thermal resistivity of 33.3 mK/W. Insulated tanks maintain heat better than un-insulated ones due to continuous escape of heat from the tank.

2.3.6. Thermostat

This is essential for temperature regulation or control. It is a safety device capable of gauging temperature and helps in accurate temperature control as well as prevention of pressure build up within the reaction tank. The temperature range of the temperature regulator is between 0 and 400°C. This allows transesterification reaction to take place at selected temperatures. A temperature probe was attached to sense the temperature inside the reaction tank for two reasons; to indicate that the oil has been pre-heated so that methanol/catalyst can be loaded into the reaction tank and to keep the temperature of the solution between a given temperature range during the reaction loop. The outside temperature probe is to indicate when the inline heater should be engaged or disengaged.

2.3.7. Shaft

A shaft of 20 mm diameter is used, which ensures satisfactory strength and rigidity when the shaft is transmitting power under different operating and loading conditions. It is fabricated from stainless steel because of its high resistance to corrosive effects of chemicals and catalysts, since the shaft often comes in contact with chemicals and catalyst during mixing process at high temperatures.

2.3.7.1. Design of shaft

Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions [24].

Using the relationship given in Eq. (8).

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l} \tag{8}$$

where G is the modulus of rigidity (N/m^2); L is the length of shaft (m); θ is the angle of twist (degree); T is the total resisting torque (N); τ is the maximum shearing stress (N/m^2); J is the polar moment of inertia (m/s^4); R is the radius of shaft in (m).

From the relation in Eq. (9),

$$\frac{T}{J} = \frac{\tau}{r} \tag{9}$$

The resisting torque is expressed as Eq. (10).

$$T = \frac{P}{2\pi N} \tag{10}$$

where P is the power rating of the electric motor (2 kW); N is the number of revolution per sec (400 rev/s).

Hence, the total resisting torque is calculated as 0.80 N.

Furthermore, the polar moment of inertia is expressed as Eq. (11).

$$J = \frac{\pi d4}{32} \tag{11}$$

where d is the diameter of the shaft (mm).

According to [25], using τ = 55 MN/m^2 (maximum shearing stress of steel from which the shaft is made) and substituting for T in Eq. (8), the shaft diameter is calculated as 17 mm and designed as 20 mm to a safety factor of 1.2. The weight of the shaft is negligible since the shaft is vertical in orientation for mixing, it is subjected majorly to twisting moment.

Stainless steel was employed for the fabrication of the shaft and galvanized steel for the reaction tank in order to overcome the problem of corrosion.

2.3.7.2. Design for shaft deflection

For a plate of length d (mm), shorter side b and thickness t (mm), the maximum deflection y_{max} (Eq. (12)) is found to occur at the centre of the plate.

$$y_{max} = \frac{\alpha q b^4}{E t^3} \tag{12}$$

where q is the fluid weight and the value of factor α depends on the ratio of d/b and E is the modulus of elasticity (N/m^2).

The maximum bending moment also occur at the centre of the plate and are given by the relationships expressed by Eqs. (13) and (14).

$$M_{XYmax} = \beta_1 q b^2 \tag{13}$$

$$M_{YXmax} = \beta_2 q b^2 \tag{14}$$

The factors β_1 and β_2 are given for an assumed value of Poisson's ratio v equal to 0.3.

Furthermore, recall the weight of the fluid given by Eq. (4).

Then the weight of the fluid is 219.84 N.

The maximum deflection given by Eq. (12) is calculated where q = 219.84 N; b = 0.6 m; $t = 2.0 \times 10^{-3}$ m; E = 200 GN/m^2; α = 0.0843.

Hence, maximum deflection $y_{max} = 1.5 \times 10^{-3}$ mm. This small value of the maximum deflection indicates that the processor has satisfactory strength to withstand the loading forces without significant distortion.

2.3.8. Funnel

After completion of the reaction, the product is transferred into a separating funnel for a certain time interval (approximately 24 h) for phase separation. Since the solubility of methyl ester is low, the glycerine tends to collect at the bottom. With excess alcohol, the unconverted triglycerides should essentially be zero. However, some monoglyceride and diglycerides must be present [26]. Due to their polarity, partially reacted glycerides should be preferentially attracted to the glycerine phase and then removed when the phase is separated. The funnel is employed during separation of biodiesel from the glycerine. It is also used for separating washed methyl esters from impurities such as water, sodium hydroxide and glycerine.

2.4. Construction of the biodiesel processor

A 2 mm thick galvanized steel was used in the fabrication of the reaction tank because of the following reasons:

i. It does not catalyze the oil unlike copper;

ii. Its high resistance to pressure and temperature;

iii. Its ability to withstand the actions of chemicals and catalyst without any sign of rust or corrosion.

2.5. Design for volume

The volume of the reaction tank (cylinder) is given by Eq. (15).

$$V = \pi r^2 h \tag{15}$$

where π = 22/7; r is the radius of the cylinder (0.12 m) and h is the height of cylinder (0.60 m).

The capacity of the processor is limited to 25 L of vegetable oil per batch.

2.6. Total surface area of the processor

The total surface area of the reactor is expressed by Eq. (16).

$$\text{T.S.A} = 2\pi r^2 + 2\pi rh \tag{16}$$

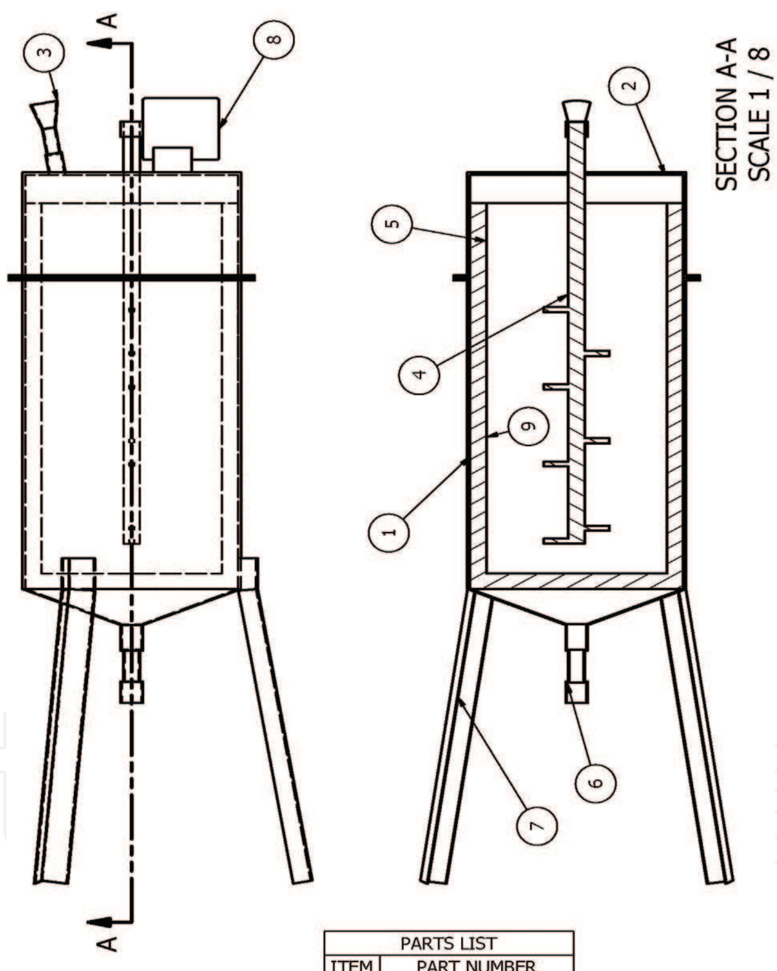
where π = 22/7 and R is the radius of the cylinder (0.12 m).

Then the total surface area of the tank is 0.5430 m^3.

2.7. Design for manufacturing and assembly

Existing biodiesel processor has a separate pre-treatment tank either as a stand-alone facility or in addition to the reactor which makes the overall assembly expensive and cumbersome. The application of the design for manufacturing and assembly (DFMA) in the development of the biodiesel processor eliminates the need of the pre-treatment tank while the reactor serves both functions. Depending on the nature of feedstock, the incorporation of intelligent systems for control and monitoring helps in determining the need for the pre-treatment process or otherwise. In addition existing biodiesel processor has a base which makes drainage of the product a challenge. The application of DFMA in the development of the biodiesel processor replaces the base with a conical base which makes drainage quite easy. Other significant improvements in the new design compared to the existing design via the application of the DFA are discussed in Section 2.9. Autodesk inventor was employed in the design and assembly drawing of the processor the developed processor.

Figures 4–**9** show the various views of the assembly diagram of the existing processor while **Figure 10** shows the new design for the biodiesel processor upon the application of design for manufacturing and assembly.



PARTS LIST	
ITEM	PART NUMBER
1	REACTION TANK
2	REACTION TANK TOP
3	INLET PIPE
4	STIRRER
5	LAGGING
6	RELEASE VALVE
7	STAND
8	ELECTRIC MOTOR
9	BAFFLE

Figure 4. Sectional view of the developed processor.

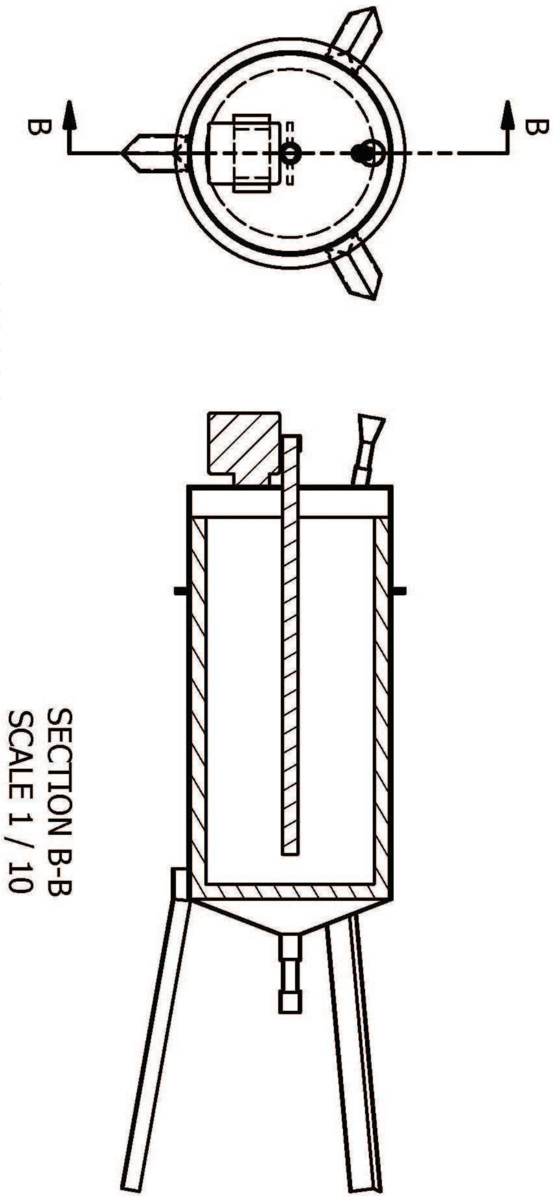


Figure 5. Sectional view (top) of the developed processor.

2.8. Method of assembly

The procedural steps for the assembly operation are as follow;

- **i.** Rolling of the inner cylinder of diameter 240 mm and height and height 350 mm.
- **ii.** Rolling of the outer cylinder of diameter 360 mm and height 500 mm.
- **iii.** Lagging of the space in between the inner and outer cylinder followed by welding of the inner and outer diameter to give a single cylinder of diameter 360 mm with an overall height of 600 mm.
- **iv.** Welding of the stand of height 180 mm to the cylinder.

v. Welding of five blades to the shaft of diameter 20 mm and length 400 mm to form the stirrer assembly.

vi. Welding of the flat cover to the tank and use of hinges to create a top opening for maintenance purposes.

vii. Attachment of the electric motor to the stirrer assembly using bolt and nuts.

viii. Finishing operations: deburring and painting.

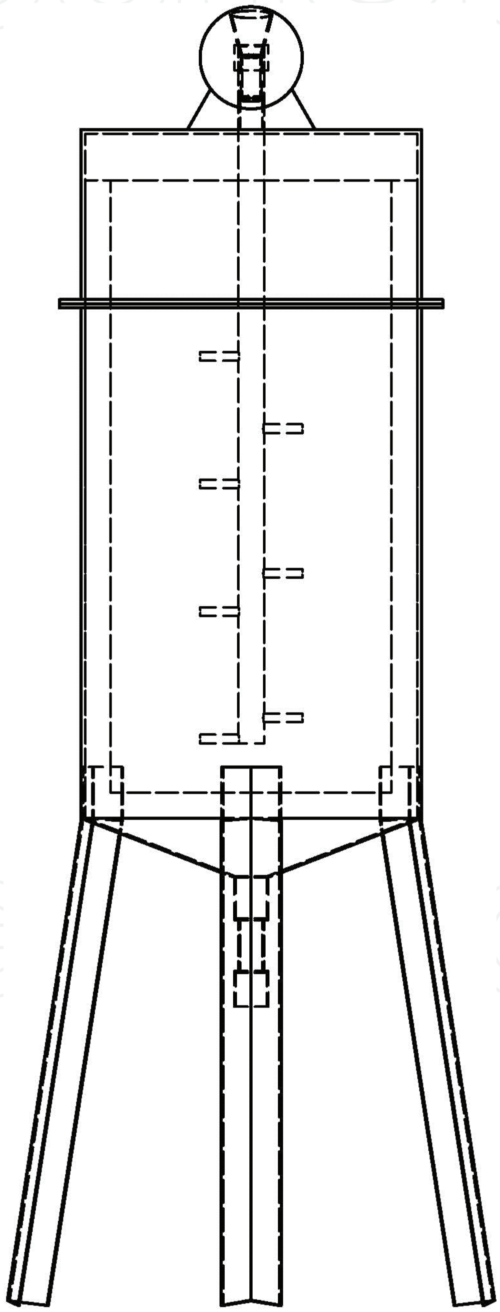
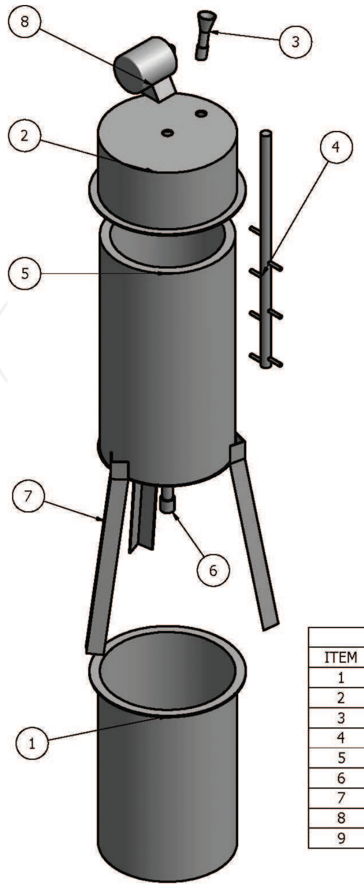


Figure 6. Right view of the developed processor.



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	REACTION TANK
2	1	REACTION TANK TOP
3	1	INLET PIPE
4	1	STIRRER
5	1	LAGGING
6	1	RELEASE VALVE
7	3	STAND
8	1	ELECTRIC MOTOR
9	1	BAFFLE

Figure 7. Exploded view of the developed processor.

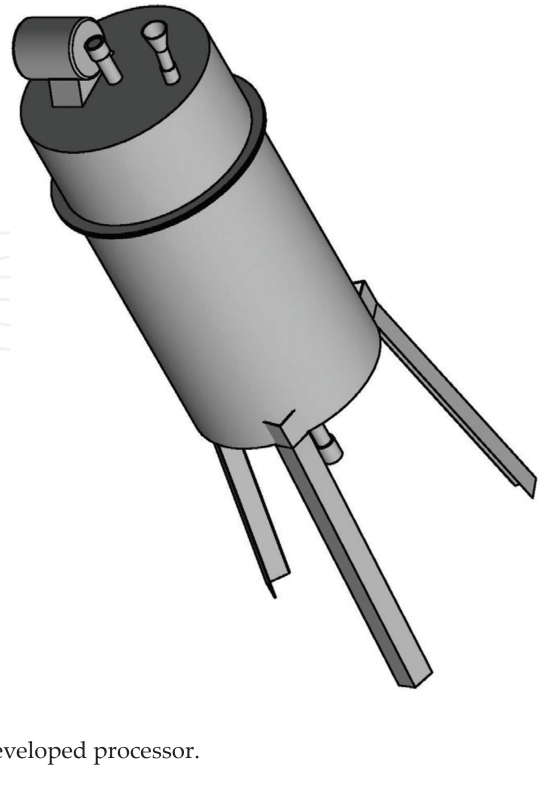


Figure 8. Isometric view of the developed processor.

Figure 9. The developed biodiesel processor.

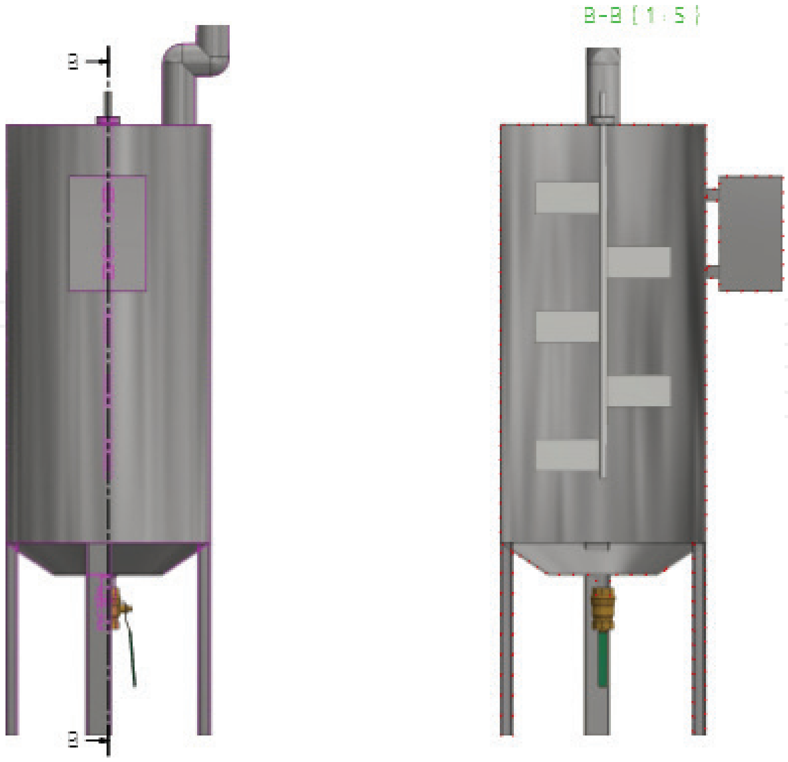


Figure 10. The new design for the biodiesel processor.

2.9. Differences between the existing and new design

Following the application of the design for manufacturing and assembly (DFA) in the development of the biodiesel processor, the following are the differences between the existing and new design;

i. Existing design involves rolling of the cylinder cover whose inner diameter is 240 mm and outer diameter 360 mm. The space in between the inner and outer cylindrical cover was also lagged after which the two are brought together by welding. In the new design, the cylindrical cover replaced with a flat cover welded to the tank with an opening at the top for maintenance purposes.

ii. Existing design has seven blades welded to the shaft to form the stirrer assembly with four baffles to prevent splashing. In the new design fives blades ensures homogeneity of the mixture with two baffles to prevent splashing of the mixture.

iii. In the existing design, the shaft was joined to the cylindrical cover using bearing, bolt and nuts while this was simplified in the new design with the replacement of the cylindrical cover with a flat cover. There was no joining of the shaft to the cover. This makes disassembly quite easy for maintenance purposes. The shaft was passed through the flat cover with the electric motor attached to the top of the shaft using bearing, bolts and nuts.

iv. Welding of the rectangular control panel whose length is 300 mm and breadth 200 mm, as well as welding of the stand of height 550 mm to the control panel was done in the existing design. In the new design, the fabrication of the control panel was replaced with a smart control panel bought out at price lesser than the cost of fabrication in the existing design.

v. Smart and intelligent systems were incorporated into the new design for process monitoring and control which was lacking in existing design.

vi. The application of the design for manufacturing and assembly (DFA) in the development of the biodiesel processor replaces the base with a conical base which makes drainage quite easy.

vii. The new design is smart, robust and more efficient than the existing design. The cost comparison of the new and existing design is shown in **Tables 3** and **4**, respectively

2.10. Summary of development analysis

The bill of engineering measurements (development and evaluation) is presented in **Table 5**.

S/N	Parts	Process	Materials	Cost (USD)
1.	7 support legs	Cutting/welding	Mild steel	77
2.	Cylindrical body	Cutting/rolling	Galvanized steel	30
3.	Cylindrical cover	Cutting/rolling	Galvanized steel	60
4.	Control panel	Cutting/welding	Galvanized steel	60
5.	Stirrer assembly	Cutting/ welding	Stainless steel	75
			Total	337

Table 3. Cost analysis of the existing design.

S/N	Parts	Process	Materials	Cost (USD)
1.	3 support legs	Cutting/welding	Mild steel	33
2.	Cylindrical body	Cutting/rolling	Galvanized steel	70
3.	Flat cover	Cutting/welding	Galvanized steel	12
4.	Control panel	Bought out	Galvanized steel	30
5.	Stirrer assembly	Cutting/welding	Stainless steel	65
			Total	210

Table 4. Cost analysis of the new design.

Item #	Name	Quantity	Description	Unit price (USD)	Total price (USD)
1	Stainless steel rod	1	0.60 m length	60	60
2	Mild steel	1	2 m length	45	45
3	2 kW electric motor	1	AC motor with speed control	70	70
4	Ball valve	3	Outlet and inlet valves	0.55	1.64
5	Galvanized sheet metal	3 rolls	Square cross section	41	123
6	Welding electrodes	1 packet	E020, E6023	2.73	2.73
7	Heater	1		8.22	8.22
8	Temperature probe	1		8.22	8.22
9	Contactor	1		10.95	10.95
10	Funnel	1		8.22	8.22
11	Neon and switch light	2		2.73	2.73
12	Arduino Uno	1	Microcontroller	17.8	17.8
13	Pressure transducer sensor	1	¼″ 1.2 MPa	14.79	14.79
14	Analog pH meter	1	43 × 32 mm	34.2	34.2
15	LCD	1		3.28	3.28
16	Electric cables	5 yards		1.40	6.84
17	Angle iron		1	20	20
	Control panel		1	30	30
18	Resistors and capacitors			2.75	2.75
19	Transport			40	40
20	Labor			12.3	12.3
21	Performance evaluation			275	275
				Subtotal	752.67
22	Miscellaneous		10% of total costs		75.267
	Total				**827.937**

Table 5. Bill of engineering measurement.

From **Tables 4** and **5**, the development of the biodiesel processor was cost effective with the elimination of pre-treatment and use of simple manufacturing processes.

2.11. Design specifications

The specifications in accordance with design is as follow:

i. Size	Fits in a 1.524 m × 0.609 m space
ii. Operating temperature	20–90°C
iii. Stir speed	50–600 rev/min
iv. Production amount	25 L per batch
v. Production time	3 h per batch
vi. Methanol consumption for unused oil	200 mL per 33 mL of oil olein vegetable oil
vii. Methanol consumption for used oil	200 mL per 25 mL of oil frying oil
viii. Catalyst consumption	4.5 g per 200 mL methanol

3. Contribution to knowledge

The work will contribute to knowledge as follows:

- **i.** Application of the principles of design for manufacture and assembly in the development of a smart biodiesel processor.
- **ii.** Improvement in process control and monitoring via the use of sensors and a micro-controller.
- **iii.** Incorporation of low-cost monitoring system in the biodiesel processor.
- **iv.** Provision of design framework for both small and large scale biodiesel processor for industrial, laboratory and experimental purposes.
- **v.** Development of a processor for processing biodiesel from different feedstock which could serve as a template for scaling its development.

4. Conclusions

This work brings about the development of a smart small scale biodiesel processor with a capacity of 50 L per day. The processor incorporate all feedstock requirements for the production of biodiesel hence, both alkali-catalyzed and acid-catalyzed transesterification can be undertaken with the processor. In addition, the assembly operations of the processor was simplified to reduce ambiguity and redundancy. This saves a total cost of 127 USD with increased efficiency and robustness. Hence, the overall processor is cost effective in terms of material requirements, parts production, labor and overhead. The principles of DFMA also minimizes part requirements without sacrificing quality. This reduces the overall assembly and manufacturing cost.

The development and performance evaluation of the processor cost a total sum of 827.937 USD. This is relatively cost effective considering the price of ready-made biodiesel processors in the market. Using the principles of DFMA, This work provides a design framework for both small and large scale biodiesel plant for industrial, laboratory and experimental purposes.

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