Design and development of a low-cost reactor for biodiesel production from waste cooking oil (WCO)

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Abstract

Biodiesel stands out as a renewable, biodegradable, and non-toxic fuel when compared to fossil fuels, and has attracted significant attention from researchers and industries for environmental protection and sustainable development. However, around 95% of the world biodiesel production is derived from edible oils, which leads to a competition between oil production for food or for fuel and results in increased costs compared to diesel fuel. Biodiesel production from WCO offers a clean technological solution for both disposal of WCO and cost production problems. For these reasons, non-edible waste cooking oils are considered one of the most promising alternatives of raw material for biodiesel production. WCO can also promote social inclusion in urban areas by generating extra revenue by recycling. The aim of the present work was to develop a low-cost biodiesel reactor by Biosystems Engineering students and teachers from the School of Sciences and Engineering of São Paulo State University (UNESP). The primary goal was to include biofuels technology into the Biosystems Engineering undergraduate curriculum in order to integrate and transcend the contents contemplated in our course by helping the students to build a technological low-cost reactor with innovative research in the biofuels technology field.

Keywords: Technologies 4.0; sustainability; transdisciplinary; renewable energy

1. Introduction

Historically, our energy system is based on burning fossil fuels for power generation, leading to the emission of greenhouse gases, such as carbon dioxide-CO_2, which have a clear impact on global climate change. Also, over the past few years, the demand for energy supply has sharply increased due to an exponential population growth, which stresses the problems related to the use of fossil fuels. Besides, fossil fuels are a limited resource and their value depends on various geopolitical and economic issues. This scenario presents problems to the increasing world energy needs as well as risks of catastrophic and irreversible consequences to the environment, which have led scientists to propose intensive actions to prevent them [1-4]. A transition of energy sources beyond fossil fuels has become one of the greatest challenges of the twenty-first century and innovation in this sector depends on studies of alternative fuel sources for overcoming the economic and environmental impacts of fossil fuels consumption around the world.

Biofuels synthesized from biomass, especially biodiesel, offer a promising alternative substitute for petroleum-based fuels. Biodiesel has been considered as a potential fuel to reduce the green house effects, since it is environmentally friendly due to characteristic such as being biodegradable, non-toxic, renewable and for emitting less CO_2, CO and sulfur [1, 2, 5]. Despite all these advantages, biodiesel does not compete economically with diesel derived from fossil fuels due to its high production cost [4].

Normally, biodiesel is produced by a transesterification reaction of refined oil with short-chain alcohols (methanol or ethanol) in the presence of suitable catalysts (alkali or acid) with glycerol as a by-product. Biodiesel can be obtained from vegetable oil, animal fat and non-edible plant oil, however, vegetable oils are the most common source, leading to an intense debate between the use of such oils for food or for fuel, since vegetable oils are very important for animal and human food purposes, and their utilization for biodiesel synthesis is not yet viable due to its high production cost [4, 6]. Different technological solutions have been proposed to increase the use of other sources of oil, such as waste cooking oil, to reduce biodiesel production cost, since frying oil is much less expensive than pure vegetable oil [4, 5].

Waste cooking oils (WCO) are accumulated in very large amounts each year due to the tremendous growth in human population and can cause significant environmental impact. The release of WCO into the environment via drainage or a landfill could cause water and soil pollution and disturb the aquatic ecosystem. A single liter of WCO can pollute 20,000 L of water if discarded into sanitary sewage and rivers systems [7]. WCO can emulsify with organic matter clogging the inside of drainage pipes and can also impact aquatic ecosystems due to a tendency to form a thin film on the water surface, which depletes oxygen levels, resulting in the death of fish and other aerobic organisms. When exposed to the environment, decomposition by bacteria results in release of polluting gases [6, 8, 9].

Therefore, the use of WCO for biodiesel production is a clean technology solution to handle with environmental problems, produces economic, environmentally and social benefits by exploiting this oil as a raw material since its cheaper than virgin edible oils, avoids the cost of the current waste disposal, reduces the need to use land for biodiesel-producing crops and the quality of the biodiesel is the same as that produced from edible oils [4, 7]. In Brazil, according to the Brazilian Association of Vegetable Oil Industries (ABIOVE), an estimated 2.5% of waste frying oil (6.5 million L) is collected for recycling, meaning that 97.5% of this material is discarded irregularly [10]. The scarcity of collection points and the lack of public awareness campaigns about the importance of correct destination of frying oil may be the reasons to explain this low collection rate [7, 9]. Currently in Brazil only ~1% of WCO is recycled to make biodiesel and in 2015 this value was only 0.5% [2]. To increase this number is necessary developments in biodiesel technologies in many areas and government subsidies, so they can be profitable for the producers and to be affordable by the public.

As part of a range of measures to reduce greenhouse gas emissions, Brazil is encouraging the use of biofuels and presented itself as a pioneer country in this area. Biodiesel was introduced into Brazil in 2002 and since 2008, by Law No.11.097/2005, has become mandatory to add a proportion of the biofuel to all diesel fuels sold in the country. According to this Law, biodiesel is a *'biofuel derived from renewable biomass for use in internal combustion engines with compression ignition or, in accordance with regulations, for the generation of other kinds of energy, which may partially or wholly substitute fossil fuels'* [11]. Initially the voluntary addition of 2% biodiesel to diesel (B2) was allowed in 2005, and such practice became mandatory in 2008. The increase in additions has occurred gradually over the years by the National Petroleum Agency (ANP), which is responsible for regulating and complying with established rules for the commercialization of biofuels, accompanied the growth of the sector. With Resolution No.16/2018, since from September 2019, 11% of biodiesel in petroleum diesel (B11) was implemented in the national energy matrix. Subsequently, by March 2023, all diesel sold to the final consumer will contain 15% biodiesel [12].

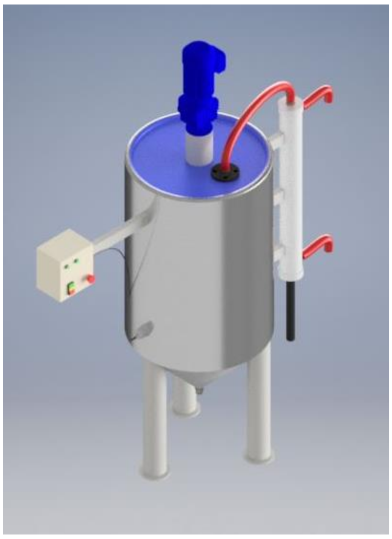
According Law No.11.097/2005, the goal of biodiesel introduction into Brazil's energy matrix is to increment the participation of biofuels in the national energy matrix, on economic, social and environmental bases. [11]. After this measure, Brazil already occupies the second place in the world ranking of biodiesel producers [13]. However, as mentioned earlier, the amount of WCO used for biodiesel production is still very low and, even if increased, it would not be viable to replace current conventional diesel use, due to quality and cost issues. In order to overcome these shortcomings, it is necessary to efficiently improve biodiesel fabrication process, which can be partially achieved by developing low-cost and efficient reactors.

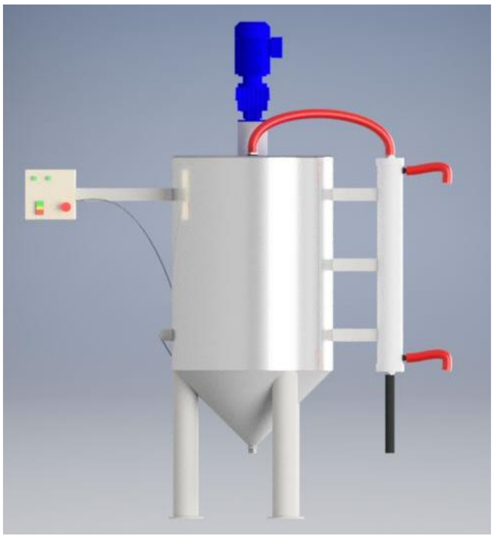
In the present work, one of the goals was to develop an ecological cost effective reactor consisting of low-cost materials, that can be easily found in any hardware and electrical stores and in junkyards, such as used steel drum, stainless steel bar, steel plates, electric engines, electrical resistances, thermal isolations, and others, as detailed throughout this work. Another goal was to address the education needs of undergraduate students concerning the emerging biofuel field before the international and national scenarios.

2. Material and Methods

Biosystem Engineering curriculum has primarily modules focused on an engineering formation, such as Physics I, II and III, Technical Design, Chemistry, Material Resistance, etc. followed by more specific formation like Mechanical Elements, Automation, Instrumentation and Renewable Energies. In order to integrate these disciplines in a inter and transdisciplinary way and to include fundamental principles and concepts involved in biofuel processes in the students learning, a low-cost reactor for biodiesel production was designed and built from scratch.

The concept requirements and specifications of an integrative educational machinery involves a series of steps. The project design started with research and planning to develop the definitions and approaches. Then it follows the conceptualizing, which is the construction drawing, where a technological alternative to a build a reactor system for biodiesel production is presented. For this part, a 3D project was developed in *Autodesk's Inventor Professional 2017 software*, *Build 142 version*, as shown in figures 1 (a) and 1 (b).





a) b)

Figure 1. a) Assembly of isolated reactor system - isometric view; b) Assembly of isolated reactor system - front view.

As the design project for the reactor concept was chosen, the next step of the process was to start building the reactor.

2.1 Reactor Mounting

Low-cost materials were used for the equipment construction that can be easily found in building supply stores, as follows:

1) 200L steel drum with removable lid, taken from junkyards (Figure 2).

Figure 2. Steel Drum with removable lid.

2) ½ CV motor, 220V voltage, 67% rated output, 60Hz frequency, 1680 rpm and 2.1 A current (Figure 3).

Figure 3. Electrical motor.

3) Gear reduction to decrease the speed of the rotary machine and increase torque, with maximum supported power output of 1 CV and 53.30 reduction factor (engine speed changes from 1680 rpm to 31.52 rpm) as illustrated in Figure 4.

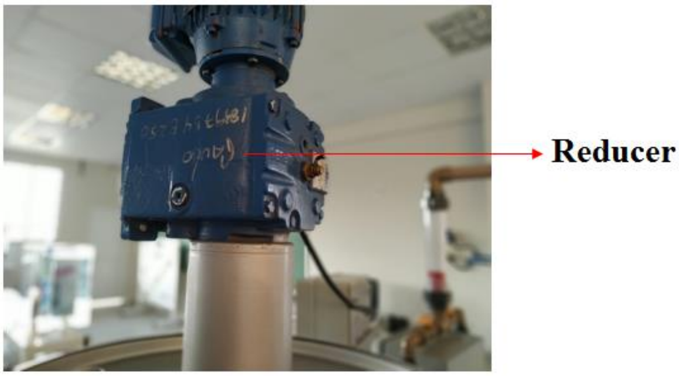


Figure 4. Gear Reduction.

4) The outer shell to protect the reactor agitator shaft coupling with gearmotor assembly, flanged to the reactor-lid drum (Figure 5).

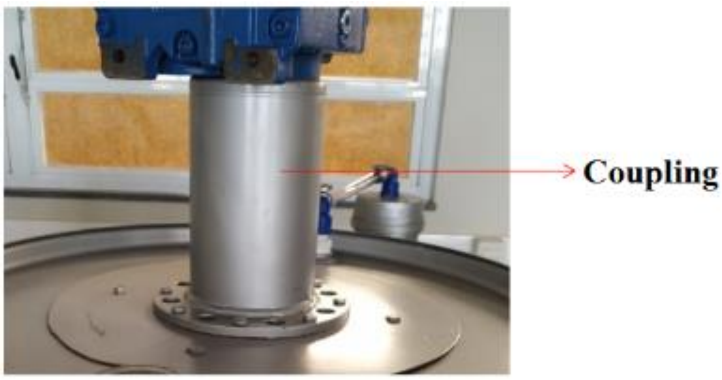


Figure 5. Coupling.

5) Brass condenser tubes, to condense the steam released during the transesterification reaction, to recover part of the unreacted alcohol in the reaction (Figure 6).

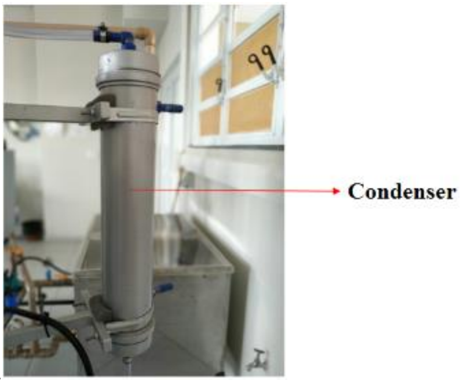


Figure 6. Brass condenser tubes.

6) A 30 kΩ electrical resistance for reactor heating for biodiesel production: from 60 ºC to 65 ºC during the transesterification reaction; from 100 °C to 105 ° C during biodiesel drying (Figure 7).

Figure 7. Electrical resistance.

7) Tripods and dampers to support the entire structure of the biodiesel reactor and reduce mechanical vibrations (Figure 8).

Figure 8. Tripods and dampers for controlling vibrations.

8) Stainless Steel Cone Bottom Tanks, to use the entire mixture throughout the process and it is connected to a manual flow-control valve (Figure 9).

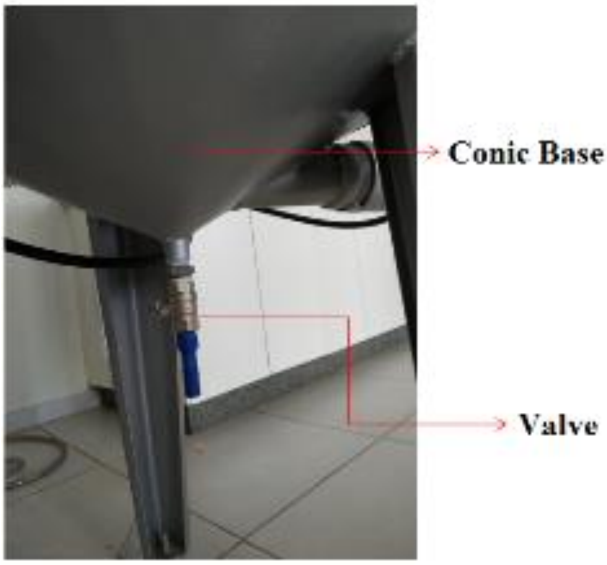


Figure 9. Cone Bottom Tanks and manual flow-control valve.

9) Level transparent hose for reactor volume control.

10) Fiberglass Thermal Insulation Blankets and zinc foil for insulation isothermal inside the reactor, thus preventing its dissipation in the environment.

11) PHENICON HS WHITE Anticorrosive Paint, composed of epoxy resin, additives, ketone, alcohol, aromatic solvent, mineral filler, pigment and titanium dioxide; PHENICON HS catalyst consisting of polyamide resin, additives, alcohol, ketone.

2.2 Electrical Panel

The reactor electrical panel (power distribution board), which is a component of an electricity supply system, was designed to receive electrical power from a 220 V power supply and divides an electrical power feed into subsidiary circuits.

The main components of the panel are:

(i) Thermostat for temperature control at each stage of the biodiesel production process;

ii) One push button On/Off controller to manages motor power, one emergency stop push button switch to be used as a safety measure to stop hazardous parts, in accordance with the requirements specified in the NR-12 Machine and Equipment Protection, one set of lights indicator as following:

a) Electrical resistance light for his activation;

b) Electric motor drive, for mixture stirring at the reactor;

c) Emergency stop pushes button switch.

The reactor electrical panel is shown in Figure 10.

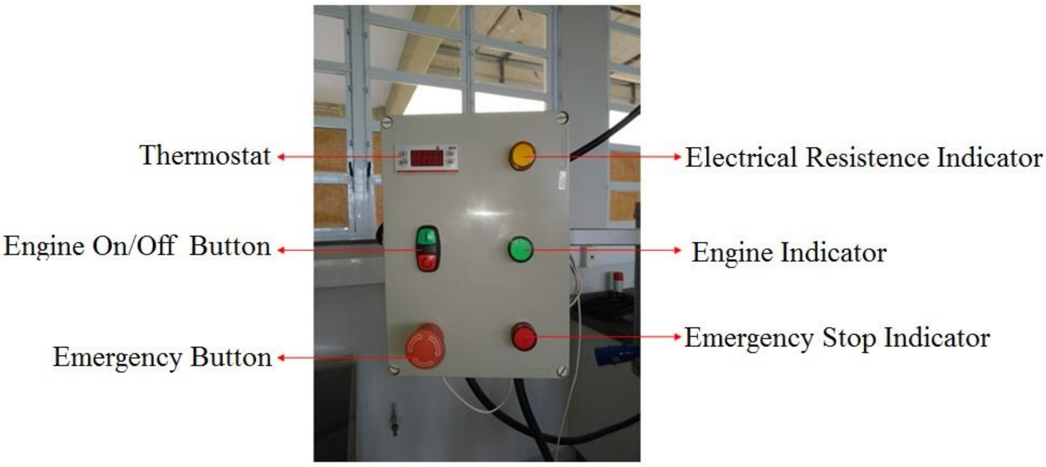


Figure 10. The reactor electrical panel.

2.1.1 Distribution Board Interior

Distribution Board Interior consists of: contactors, which is an electromagnetic device used as electrically-controlled switch to make or break of any electrical circuit; a three-pole circuit breaker to protect the reactor, which connects power across a collapsible breaker and is designed to protect an electrical circuit from damage caused by excess current that are unsafe for the entire circuit. Its basic function is to interrupt current flow after a fault is detected, and opening the circuit. The Distribution Board Interior of Reactor Design is shown in Figure 11.

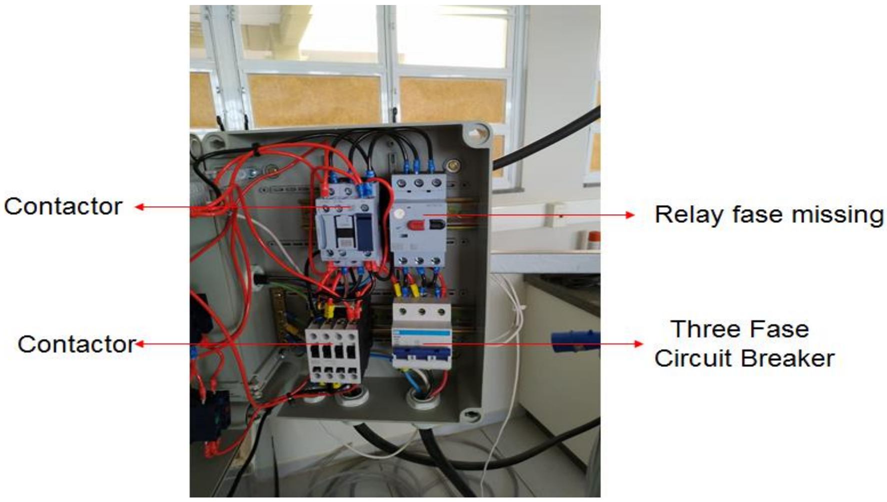


Figure 11. Distribution Board Interior

2.1.2 Electric diagram

The Reactor electrical diagram control circuit is shown in Figure 12.

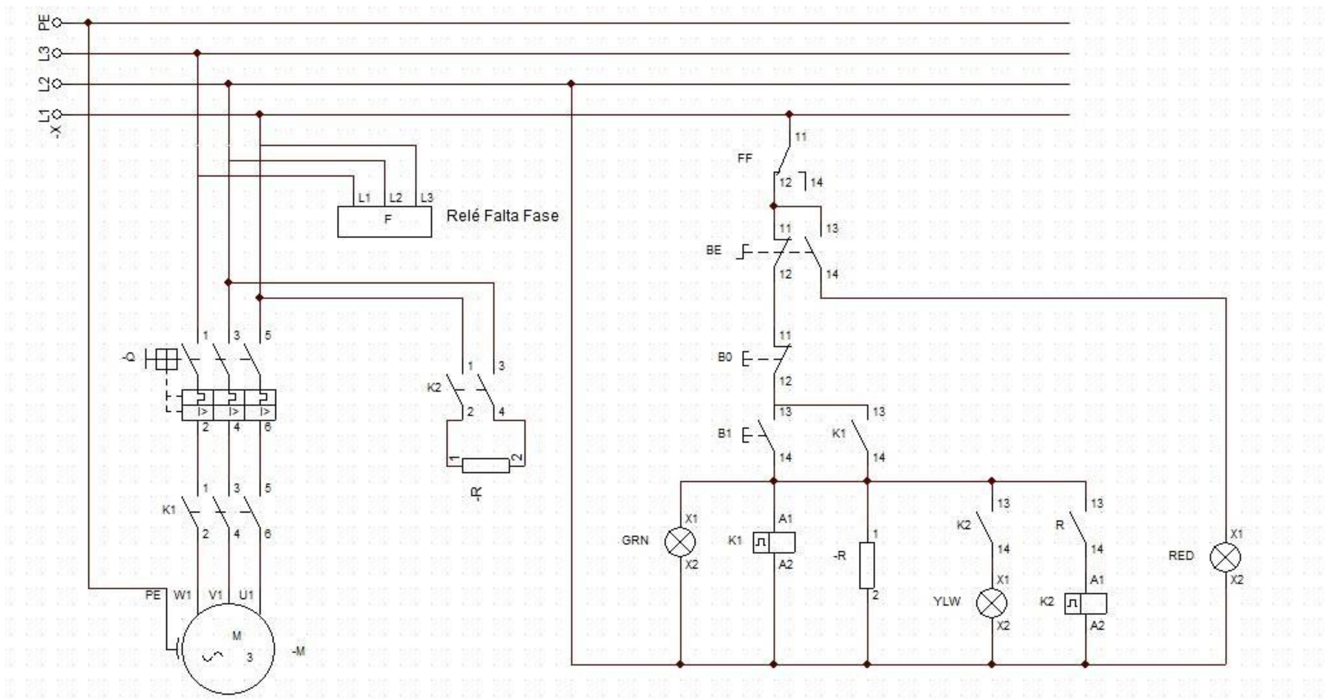


Figure 12. Electrical Diagram.

3. Results and Discussion

A set of tests were conducted before the reactor mounting, namely:

i) Paint Corrosion Test, which was conducting in a test body to confirm the efficiency of the paint used and the PHENICON HS catalyst.

ii) Condenser and Drum Leakage Tests, which shows leakage problems and demand repairs to seals it, for example, the drum leakage required repairs to the inner welds of the cone bottom tanks, as shown in Figure 13.

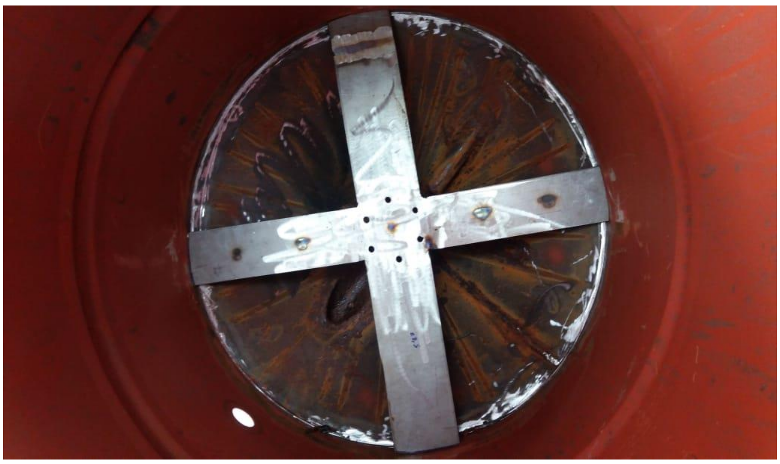


Figure 13. Cone Bottom Tanks Solder.

iii) Motor drive for fluid agitation;

iii) Thermostat programming for monitoring and temperature control, with activation of the electric resistance for heating when the value is below the set point and also its shutdown when the programmed is reached;

iv) Light Signal Indications Tests as shown in Figure 14.

Figure 14. Reactor Electrical Panel Test.

iv) Emergency stop push button test, to verified that when turned on does not allow the motor and the electrical resistance to be activated. By trigged the emergency stop when the motor is working, the reactor's agitation and heating must be stopped immediately, with the light indication on the panel.

v) Stirring and heating tests with 200 L of water, where it was possible to obtain agitation without excessive vibrations, due to the stirring blades balance on the reactor shaft and the damping performed at the base of the equipment. The heating tests was performed and the desired temperature values in the fluid can be obtained according to the thermostat programming.

After making the necessary corrections due all test done, the reactor was internally painted with PHENICON HS paint and catalyst. It was painted with three coats, with 18-hour intervals and it was possible to cover the entire reactor internal surface to avoid corrosive effects of the catalyst used in transesterification reaction. Figure 15 represents the internally painted reactor.

Figure 15. Internally painted reactor drum.

The Figure 16 illustrates the finished biodiesel reactor for use.

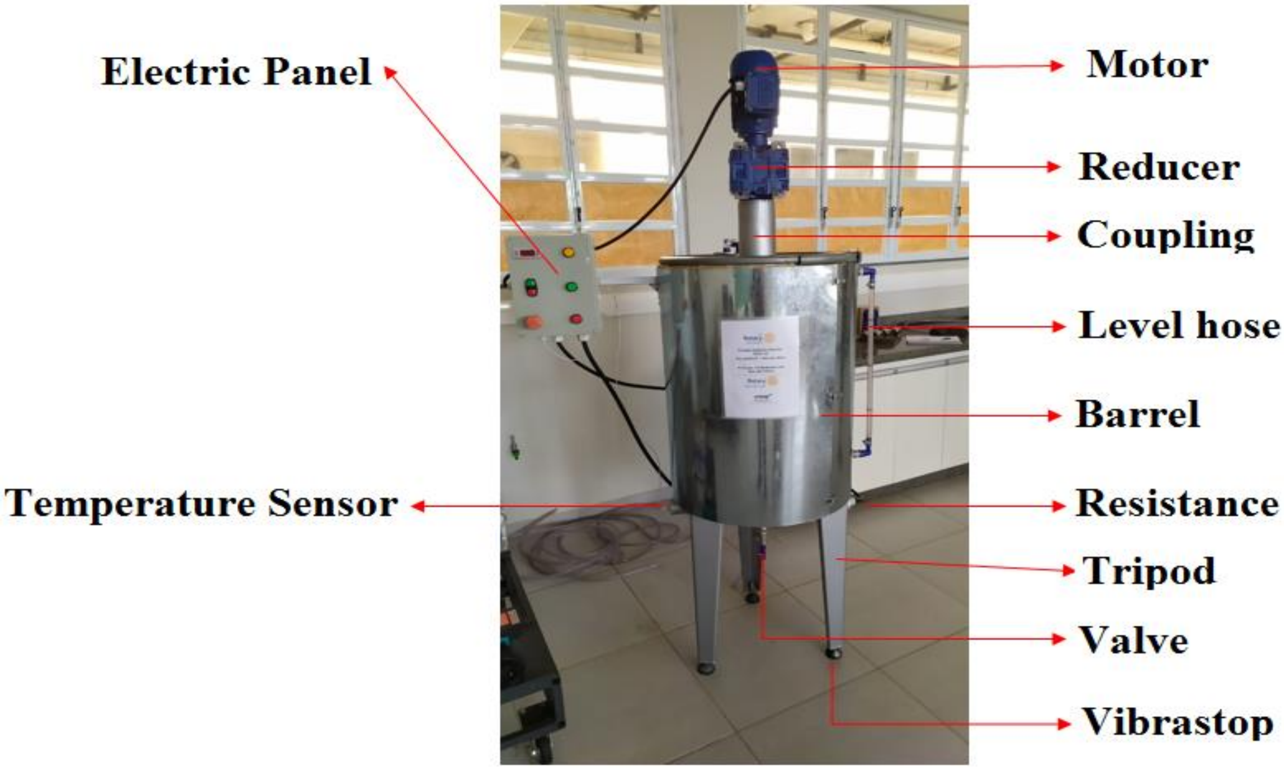


Figure 16. Final reactor system for biodiesel production.

4. Conclusion and Open Problems

The development of computer and information technology has reached a milestone with Internet of Things (IoT) leading to modern and future internet technology being essential approaches to enhance the performance of cyber-physical systems. Besides, with the increasing use of smart computing technologies, it becomes necessary - and really important - to stop being a mere bystander and consumer in the system to become the protagonist in the business itself in elaboration and construction of equipment that add technology and sustainability. This is the profile of Engineer 4.0.

The reactor construction carries the function of training engineers with the above profile and also shows the commitment and concern of an educational institution with an education based on several of the objectives inherent to the commitments made by Brazil with the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDG), specifically SDG 4, SDG 7 and SDG 9, namely [14]:

SDG 04: Quality Education

SDG 07: Affordable and Clean Energy;

SDG 09: Industry, Innovation and Infrastructure.

The construction of a low-cost reactor by undergraduate students and faculty members with the goal to generate fewer polluting emissions meets the SDGs above.

To complete the reactor system and finalize the analyses of the actual cost savings, future work must be conducted in terms of system automatization. An automatic phase separation system to will be made to separate the glycerin-biodiesel from biodiesel-water phase reactor wash and to develop a supervisory system suitable for use on mobile devices, as well as the possibility to perform the entire process without the presence of an operator in the equipment location system.

5. Acknowledgement

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