IJMSHE
ISSN: 3082-3021

International Journal of Multidisciplinary Studies in Higher Education

Volume 1, Issue 1 | 2024

Davao City, Philippines, 8000

ISSN: 3082-3021 (Online)

IJMSHE
International Journal of Multidisciplinary Studies in Higher Education

Biodiesel Production Using Waste Cooking Oil: An Instrumentation and Control Technology Lab Apparatus

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Article Information

Received:
October 24, 2024
Accepted:
November 20, 2024
Published:
December 1, 2024

Abstract

The study titled "Biodiesel Production Using Waste Cooking Oil: An Instrumentation and Control Technology Lab Apparatus" aimed to design and develop a moveable device for the transesterification process to produce biodiesel from waste cooking oil. The primary goal was to create a device that is efficient, reliable, and suitable for laboratory use, particularly for academic purposes of Instrumentation and Control Engineering Technology program. Initial pre-laboratory experiments were conducted to determine optimal conditions, and three trials were performed with varying parameters, including temperature, stirring speed, and alcohol type, to refine the apparatus and enhance biodiesel quality. Methanol was chosen as the alcohol, resulting in a clear and clean biodiesel product. Testing confirmed that the apparatus was functional, reliable, safe, and effective. Experimental results showed that with constant parameters (1 liter of waste cooking oil, 5 grams of sodium hydroxide, 250 ml of methanol, 55–65°C temperature, 300 RPM stirring speed, and a 30-minute duration), biodiesel yields were 991 ml in Trial 1 and 992 ml in Trial 2, with glycerol yields of 248 grams and 249 grams, respectively. This consistency indicates the apparatus's effectiveness. Key findings from RTF Scientific Instrument Trading validated the biodiesel's quality, noting properties like density (886.1 kg/m^3), flash point (104°C), and viscosity (4.94 cSt), along with successful distillation results. Environmental impact analysis showed a significant reduction in carbon dioxide emissions compared to conventional fuels, with biodiesel emitting only 5.87 pounds of CO_2 per gallon. The study also produced a laboratory manual for ease of use in educational settings, demonstrating the feasibility of using locally sourced materials to create a portable, eco-friendly biodiesel production apparatus. Overall, the apparatus is user-friendly and contributes to cleaner, renewable energy solutions.

Keywords

apparatus; biodiesel; cooking oil

Introduction

As the global demand for sustainable and renewable energy sources continues to grow, biodiesel has emerged as an attractive alternative to conventional fossil fuels due to its biodegradable nature and reduced emissions. One of the most promising feedstocks for biodiesel production is waste cooking oil (WCO), which not only addresses environmental concerns related to waste disposal but also provides a low-cost raw material for biodiesel production (McKendry, 2022). The integration of biodiesel production into educational programs, especially within the field of Instrumentation and Control Engineering Technology, provides students with a unique opportunity to apply theoretical knowledge to real-world energy solutions. This study focuses on the development of a laboratory-scale biodiesel production apparatus using WCO, designed specifically to enhance learning in flow, level, temperature, and control systems—key areas in industrial automation and process control (Matinez et al., 2004).

The importance of this laboratory experiment lies in its ability to simulate an actual biodiesel production environment, allowing students to interact with and understand the intricacies of process control systems. In the context of Instrumentation and Control Engineering Technology, flow rate, temperature regulation, and level management are critical parameters that must be precisely monitored and controlled for optimal biodiesel production. Through the lab apparatus, students can gain hands-on experience in controlling these variables using sensors, actuators, and programmable logic controllers (PLCs), thus reinforcing their understanding of how control loops operate in industrial processes (Demirbas, 2009). This is especially vital as it prepares students for careers in industries that rely heavily on automation, such as energy production, manufacturing, and chemical processing. Furthermore, the use of waste cooking oil as the primary feedstock for biodiesel production aligns with the principles of sustainability and environmental responsibility. This not only adds relevance to the laboratory experiment but also fosters a deeper understanding of renewable energy technologies among students. As they learn about the transesterification process—the chemical reaction that converts WCO into biodiesel—they are simultaneously introduced to the role of instrumentation in maintaining the proper conditions (such as temperature and flow rate) for efficient and high-quality biodiesel production (Leung et al., 2010). The integration of such a laboratory experiment into the curriculum offers a multidisciplinary learning experience, blending chemical engineering concepts with the practical application of control systems technology.

This study is therefore highly relevant to both the academic and industrial fields, as it addresses the growing need for engineers who are not only skilled in automation and control systems but also knowledgeable about renewable energy production. By providing students with a controlled environment to experiment with biodiesel production, this laboratory apparatus enables them to develop critical problem-solving skills and gain practical insights into process dynamics. Ultimately, this prepares students for the technical challenges they will face in future careers, particularly in the fields of energy, automation, and environmental engineering (Goud et al., 2019).

Alcohol is one of the most important raw materials for the production of biodiesel. Primary and secondary monohydric aliphatic alcohols containing 1–8 carbon atoms are typically used in biodiesel production. Among these, methanol and ethanol are the most commonly utilized alcohols, with methanol being preferred due to its lower cost and renewability compared to ethanol. Methanol's renewability also offers environmental advantages, as it is considered carbon dioxide neutral and less toxic, making it an ideal substitute for ethanol in biodiesel production (Musa, 2016).

Biodiesel is produced by using an alcohol and a caustic catalyst such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). Both catalysts are highly hygroscopic, meaning they quickly absorb moisture from the air, which can interfere with the biodiesel production process by producing soap if excess moisture is present. NaOH is typically more cost-effective and purer, requiring a lower quantity during the reaction (Duda, n.d). The process involves dissolving the catalyst (NaOH) in methanol, with the generally accepted amount being 5 grams of NaOH per liter of vegetable oil for optimal conversion (Duda, n.d).

Common feedstocks for biodiesel production include vegetable oils, used cooking oils, and animal fats. The production process involves transesterification, which converts fats and oils into biodiesel and glycerin, the latter being a valuable coproduct (Energy.gov, 2022). Waste cooking oil (WCO) has gained attention as a more sustainable and cost-effective feedstock, contributing to the environmental benefits of recycling waste oil while producing renewable energy with lower pollution (Brahma et al., 2022). Biodiesel made from WCO is especially attractive because it reduces the cost of raw materials, making biodiesel production economically feasible (Gnanaprakasam et al., 2013). The transesterification process, where triglycerides react with alcohol in the presence of a base catalyst, converts fats and oils into biodiesel and glycerol. Methanol is often the alcohol of choice in this reaction, as it can be sourced from renewable origins Gnanaprakasam et al., 2013). According to Le Chatelier's principle, increasing the concentration of alcohol accelerates product formation, although excessive alcohol leads to challenges in glycerol and methanol recovery, which can increase production costs (Marchetti et al., 2007).

Studies have shown that the optimal molar ratio of alcohol to oil in the transesterification process plays a critical role in biodiesel yield. For example, a 6:1 molar ratio of alcohol to oil has been found to yield a 99.5% methyl ester when using waste sunflower oil and NaOH as a catalyst, whereas lower molar ratios result in significantly reduced yields (Hossain et al., 2010). Various catalysts, such as NaOH, KOH, and sodium methoxide, have been tested for biodiesel production, with NaOH emerging as the fastest and most efficient catalyst (Vicente et al., 2004).

In the absence of a catalyst, the conversion of waste cooking oil into biofuel requires high-temperature conditions (Tan et al., 2011). When catalyst concentration is increased, the yield of the product also increases due to an enhancement in the rate of reaction. However, conversion decreases with excess catalyst concentration, which may be attributed to the increased viscosity of the reaction mixture (Kiakalaie et al., 2013).

The mixing of reactants is crucial for achieving the completion of the transesterification reaction and enhancing product yield. Agitation increases collisions between particles and the diffusion of one reactant into another, through the mixing of the catalyst with the reactants, and enhances the rate of reaction. An increase in stirrer speed shortens reaction time and increases conversion (Canakci et al., 2003). Beyond a certain stirrer speed, there is no significant increase in yield, so optimization is necessary for different raw materials, which have varying physical properties. Increasing stirrer speed from 100 to 200 rpm leads to a higher conversion rate, but at 250 rpm, the rate stabilizes due to enzyme shearing, making 200 rpm the optimal speed for biodiesel production (Adeyemi et. al., 2011).

Temperature significantly influences the transesterification reaction. Higher reaction temperatures typically increase the rate of reaction and product yield (Darnoko et al., 2000). However, the temperature should not exceed the boiling point of the alcohol used to avoid vaporization (Highina et al., 2011). Maintaining temperatures below 50°C increases the viscosity of biodiesel, but preheating waste cooking oil to 120°C to remove water particles, then cooling it to 60°C, has been shown to reduce reaction time for maximum biodiesel yield (Chen et al., 2012). Additionally, maintaining mixing temperatures at 60°C ensures proper transesterification, especially when using acid catalysts (Canakci et al., 2003).

Studies show that transesterification can occur at varying temperatures (25°C to 60°C), with higher temperatures generally increasing ester yields. However, excessively high temperatures can promote enzyme denaturation and reduce catalytic activity (Freedman et al., 1984). Research has optimized the transesterification of waste cooking oil using a methanol/oil molar ratio of 6:1, potassium hydroxide as a catalyst, and a temperature of 65°C for an hour, yielding 96.15% biodiesel (Felizardo et al., 2006).

Different alcohol-to-oil molar ratios, alcohol types, and shaking times result in varied biodiesel yields, with methanol providing the highest yield compared to ethanol and 1-butanol (Refaat et al., 2008). Achieving high-quality biodiesel that meets ASTM D 6751 and EN 14214 standards requires optimizing the reaction conditions, including the volumetric ratio and stirring speed (Hossain et al, 2010). Biodiesel can also be distilled to improve its low-temperature properties and color (Sulzer n.a.).

Materials and Methods

2.1 Conceptual Framework

The study aimed to develop a portable apparatus for the transesterification process using waste cooking oil to produce biodiesel. The foundation of the study is based on the ideas, information, and insights gathered from related literature. The researchers followed the methodology, and input, process, and output (IPO) served as the basis of the conceptual paradigm of the study.

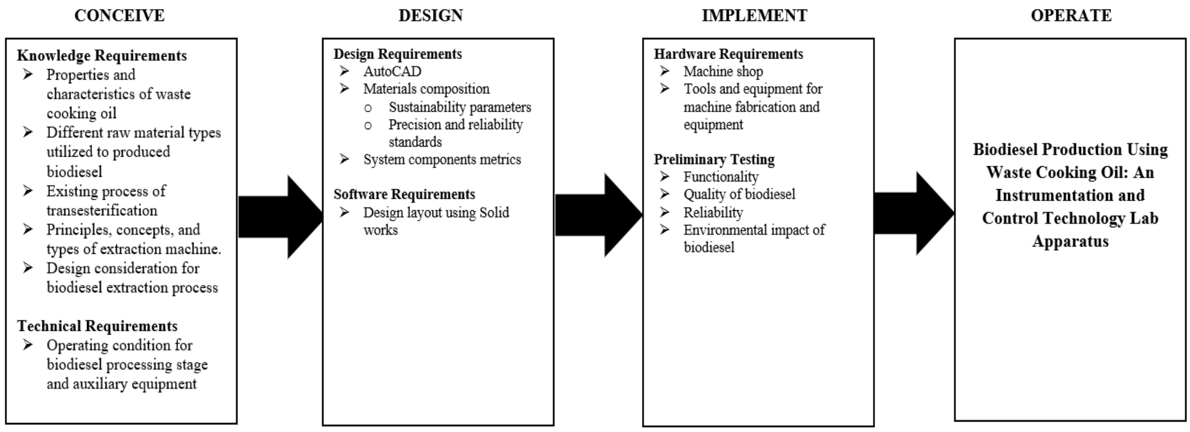

Figure 1. Conceptual Framework

The project titled "Biodiesel Production Using Waste Cooking Oil: An Instrumentation and Control Technology Lab Apparatus" follows a structured development process divided into four phases: Conceive, Design, Implement, and Operate.

In the conceive phase, the focus is on gathering knowledge about the properties and characteristics of waste cooking oil, exploring different raw materials used for biodiesel production, and understanding the transesterification process, which is key to converting oils into biodiesel. This phase also includes researching the principles and concepts of extraction machines and considering design elements for efficient biodiesel extraction. Additionally, the technical requirements, such as operating conditions for the biodiesel process and necessary auxiliary equipment, are outlined.

In design phase, the project requires the use of AutoCAD for technical designs and SolidWorks for 3D modeling. Key design considerations include material composition, ensuring sustainability, precision, and meeting reliability standards. System components are measured and evaluated based on their performance metrics. This phase is crucial for translating the conceptual design into a workable plan for constructing the apparatus.

In the implement phase, the focus shifts to the actual fabrication of the biodiesel apparatus in a machine shop, utilizing tools and equipment for construction. Preliminary testing is carried out to ensure the functionality, quality, and reliability of the biodiesel produced. Moreover, this phase includes assessing the environmental impact of biodiesel production to ensure the process aligns with sustainability goals.

And in operate phase represents the culmination of the project, where the biodiesel production apparatus is fully functional and can be used as a learning tool in an Instrumentation and Control Technology Lab. This apparatus will provide hands-on experience with biodiesel production using waste cooking oil, offering valuable educational and research opportunities.

2.2 Technical design and procedure

In addition, the researchers gathered information from the internet and books, which was the basis of the research design. The type of research is developmental research, wherein it focuses on the structure of "Biodiesel Production Using Waste Cooking Oil: An Instrumentation and Control Technology Lab Apparatus". The researchers gather information in order to come up with the results of the study. Equipment and other related objects in the project were examined properly to their technical specifications, ensuring that the effectiveness of the project was not compromised. All different sources and information were gathered by the researchers, reviewed thoroughly, and applied in the process of developing the project.

2.2.1 Pre-Design Stage

During the Pre-Design Stage, the researchers collected relevant data and conceptualized the project framework. They consulted with chemical experts to validate the principles, design considerations, and production methodologies required for the project. This collaborative effort also involved estimating the total material costs, ensuring all components needed for successful project completion were accounted for.

2.2.2 Planning

The Planning Stage is the cornerstone of the project, where the system design becomes actionable. Here, the researcher solidified the project title and its individual components based on extensive research from scholarly sources, books, and credible online platforms. The data collected was meticulously analyzed and synthesized to establish a structured procedure for the project's development, ensuring that each phase of the process was both feasible and efficient.

2.2.3 Designing

The Designing Stage incorporated various opinions, references, and expert consultations, all of which guided the creation of a suitable and optimized apparatus. The design process was informed by a combination of theoretical knowledge, technical skills, and procedural techniques, which were reviewed by advisers and subject-matter experts. This interdisciplinary approach ensured that the design aligned with the project's objectives and produced the desired outcomes.

2.2.4 Canvassing

In the Canvassing Stage, the focus was placed on the financial and material requirements of the project. The researchers assessed the cost implications by identifying and evaluating the prices of materials and supplies. A detailed budget estimation was prepared to ensure that the project was financially feasible and that sufficient funds were allocated for the procurement of all necessary components.

2.2.5 Purchasing

The Purchasing Stage involved the acquisition of all materials and components required for the fabrication of the apparatus. The researchers carefully sourced and procured each item, ensuring that they met the technical specifications and quality standards necessary for the project.

2.2.6 Fabrication

The Fabrication Stage is the core phase of the project, where the apparatus for the transesterification process using waste cooking oil to produce biodiesel was assembled. This stage required the application of advanced knowledge, technical skills, and precision in the construction and integration of components. The successful assembly of the prototype was critical, as it laid the foundation for subsequent testing and optimization.

2.2.7 Preliminary Testing

In the Preliminary Testing Stage, key parameters such as functionality, reliability, and safety were evaluated. The Biodiesel Production Using Waste Cooking Oil: An Instrumentation and Control Technology Lab Apparatus underwent rigorous testing to ensure that it met the design specifications and performance standards set by the researchers. The initial satisfaction rating was determined based on these evaluations, providing insights into the prototype's effectiveness and areas for improvement.

2.2.8 Modification

The Modification Stage was based on the results from preliminary testing. Any identified issues or areas for enhancement were addressed through design modifications, improving the apparatus to better meet the needs of the end users. These adjustments benefited both the beneficiaries and the researchers by refining the system for optimal performance and user satisfaction.

2.2.9 Final Testing

In the Final Testing Stage, the apparatus was subjected to a comprehensive evaluation to determine its peak performance. This stage confirmed whether the portable transesterification apparatus met all functional requirements and satisfied the project's objectives. The outcome of this testing dictated whether the system was ready for practical implementation and if it fulfilled the needs of the intended beneficiaries.

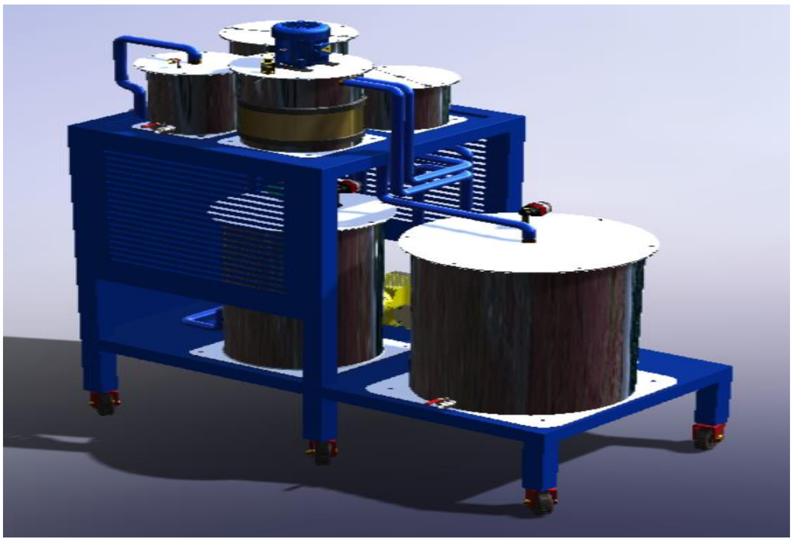

Figure 2. 3d Design of the Apparatus

The image depicts the 3D design of the apparatus for the project titled Biodiesel Production Using Waste Cooking Oil: An Instrumentation and Control Technology Lab Apparatus. The apparatus shown is designed for the transesterification process, which converts waste cooking oil into biodiesel. This equipment is likely intended for use in a laboratory or educational setting, allowing students and researchers to conduct experiments and control the biodiesel production process.
Key Components:

1. Framework:
   The apparatus is mounted on a sturdy, blue metal frame with wheels, which allows for mobility within the lab. This structure holds the various tanks and components necessary for the biodiesel production process.
2. Reactors (Processing Tanks):
   The apparatus includes several cylindrical tanks, each representing different stages of the biodiesel production process. These tanks are likely used for:
   - Pretreatment of the waste cooking oil.
   - Transesterification (the main chemical reaction converting oil to biodiesel).
   - Washing or purification of the biodiesel product.
3. Piping and Valves:
   There are piping systems connecting the different tanks, allowing the transfer of liquids between stages in a controlled manner. Valves are placed at various points, enabling users to manage the flow of liquids through the apparatus during the production process.
4. Agitator/Motor:
   A motor is visible at the top of the apparatus, which likely powers an agitator or stirring mechanism inside one of the tanks. Agitation is important during transesterification to ensure proper mixing of reactants (oil, alcohol, and catalyst) and to optimize the chemical reaction.
5. Instrumentation:
   The system would be fitted with flow, temperature, and level sensors and control systems to monitor various parameters (such as temperature, pressure, and flow rate) during the biodiesel production process. This is a critical aspect of the design, especially for lab use, as students can observe how these variables affect the output.
6. Mounted Equipment:
   Some auxiliary equipment is housed within the frame, which could include pumps for circulating fluids or heating elements to maintain optimal reaction temperatures.

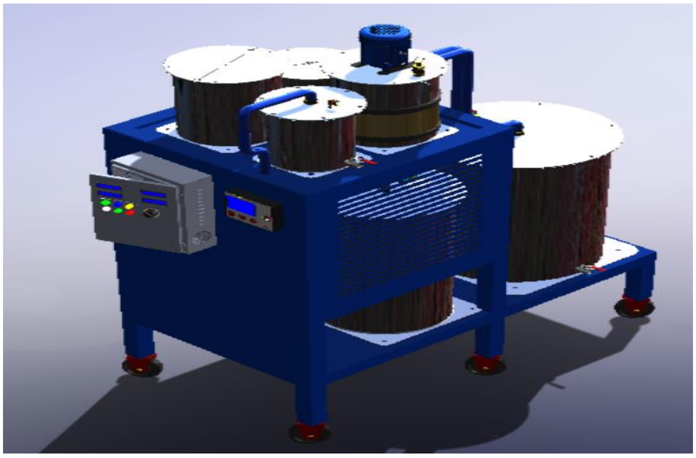

Figure 3. Control Panel and Monitoring Display Location

In figure 4, the biodiesel production apparatus has a control panel located on the left side of the main structure. The control panel features a set of buttons and indicators, likely used to start, stop, and manage the system's functions. Below the control panel, there is an LCD display, which is essential for showing real-time data such as temperature, flow rates, or operational status. The design suggests the control panel and LCD display are easily accessible for users, allowing them to monitor and adjust the system parameters. The setup is suitable for students to engage in hands-on learning activities, such as rewiring or configuring the instrumentation connected to the control system. The presence of terminal blocks inside the panel or nearby allows students to safely connect and reconnect push buttons, sensors, actuators, and other instruments as part of their learning process. Rewiring tasks may involve connecting sensors that monitor flow rates, temperature, and other relevant variables for biodiesel production, thus giving students practical experience in instrumentation and control technology.

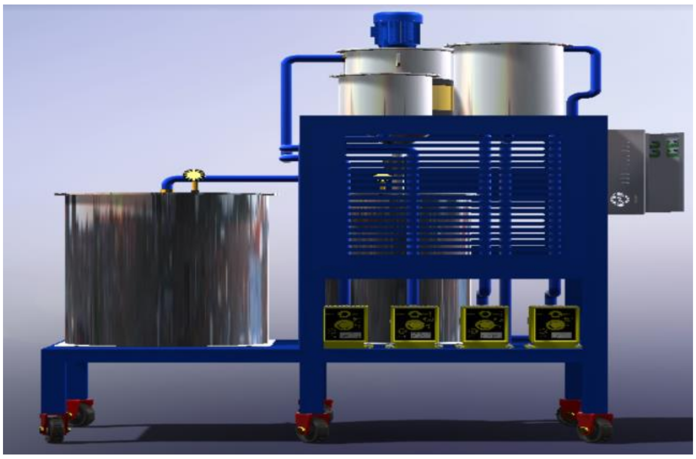

Figure 4. Rear View Set Up

From the rear view of the apparatus, the stainless-steel tanks, which are likely used for holding raw materials like waste cooking oil and catalysts during biodiesel production. These tanks are cylindrical and mounted securely on the structure, ensuring stability during operation. Stainless steel is commonly used for such tanks because of its durability and resistance to corrosion, particularly when dealing with chemical processes like biodiesel production. Additionally, the apparatus is equipped with wheels, visible at the base of the structure. These wheels make it easy to transport the equipment within the classroom or laboratory environment, facilitating its use in different setups or by different student groups. The mobility feature is especially helpful for educational purposes, allowing flexibility in classroom activities or demonstrations. The design, including the tanks and the wheels, highlights its purpose for hands-on learning, where students can engage with the equipment closely, whether they are testing biodiesel production processes or learning to control and monitor various system parameters.

2.3 Methods of Testing and Evaluation

2.3.1 Functionality Testing
To evaluate the functionality of the project, the apparatus was subjected to multiple operational tests prior to its deployment. Each component was systematically monitored over time to ensure it operated according to its design specifications and contributed to the overall performance of the system.

2.3.2 Biodiesel Quality Testing
To assess the quality of biodiesel produced by the apparatus, samples were analyzed by RTF Scientific Instrument Trading to determine the physicochemical properties of the biodiesel. These properties include parameters such as viscosity, density, and acid value, ensuring that the biodiesel meets the required standards for fuel use.

2.3.3 Reliability Testing
The reliability of the apparatus was determined by operating it continuously over a predetermined period. The researchers monitored the system to ensure it functioned as intended, without failure or significant performance degradation, and provided consistent results during the biodiesel production process.

2.3.4 Safety Testing
Safety testing involved a thorough inspection of all electrical wiring and connections to verify proper installation and secure connections. To minimize the risk of accidents, all wiring was organized at the back of the apparatus, out of the operator's direct work area. Additionally, labels were affixed to all tanks, and clear operational procedures were provided to ensure safe handling and operation of the apparatus.

Results

Preliminary testing stage aimed to consider and conduct tests to gauge if every component of the apparatus runs smoothly and free from any problem. Moreover, it was also conducted to know if the objectives of the project were met. Should there be any problem encountered during the preliminary testing, the researcher has enough time to resolve such problems before the final performance testing stage.

Table 1. Determining the Functionality of the Apparatus

Trial	Heating Device	Stirring Device	Temperature Monitoring	Transferring of Chemical Solutions
1	59 °C	150rpm	59 °C	100 l/hr
2	62 °C	200rpm	62 °C	100 l/hr
3	63 °C	300rpm	63 °C	100 l/hr

Table 1 shows the devices used in the portable apparatus. The researchers conducted up to three trials to test if the devices used in the apparatus were all functional. The heating device, stirring device, temperature monitoring, and transferring the chemical solutions into another tank using the pump were tested to make sure that everything that would be put in the machine was constantly giving accurate results and functions. In a heating device, the first trial gives 59 oC, the second trial is 62 oC, and the third is 63 oC. The stirring device is said to be functional as it continuously stirs up to 30–40 minutes that are needed in the apparatus; the first trial has 150 rpm, the second is 200 rpm, and the last is 300 rpm. In temperature monitoring, it gives accurate temperature in the mixing tank indicated in the control panel, as the results give 59 oC, the second trial is 62 oC, and the third is 63 oC. Lastly, in transferring the solutions from the other tank, the pump used is also functional because it transfers the solutions at the right time that is needed in the operation at 100 liters per hour.

Graph for temperature result

The researcher found out that Figure 5 does not give a consistent temperature for what is needed in the apparatus. The apparatus set temperature is 55–65 degrees Celsius while mixing the tank for up to 30 minutes. The researchers maximum set point for temperature is 65- degrees Celsius. When the target temperature is reached, the heating device will automatically turn off. However, the problem encountered is that when the temperature reaches 65- degrees Celsius, even when the heating device is turned off, the temperature in the mixing tank is still rising.

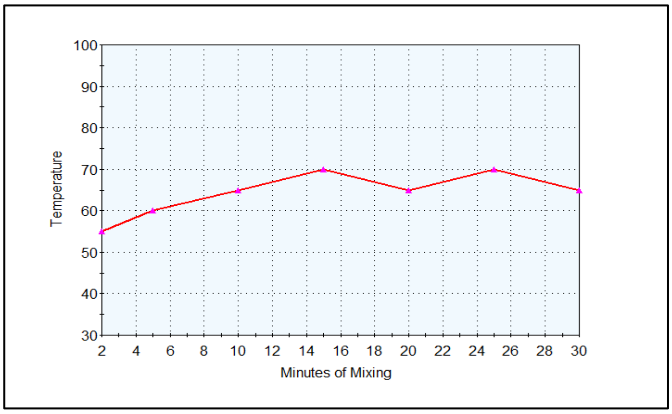

Figure 5: Graph for temperature result

In Figure 6, the researcher measured the stirring speed using a tachometer. The needed speed in the apparatus is about 250–300 RPM for 30 minutes while mixing the solutions in the heat tank. The 250–300 RPM is based on the results of the pre-laboratory. They wanted to get the same result from the machine. The stirring speed conducted in the machine gives a constant speed of 300 RPM, which is the same as what is needed in the apparatus.

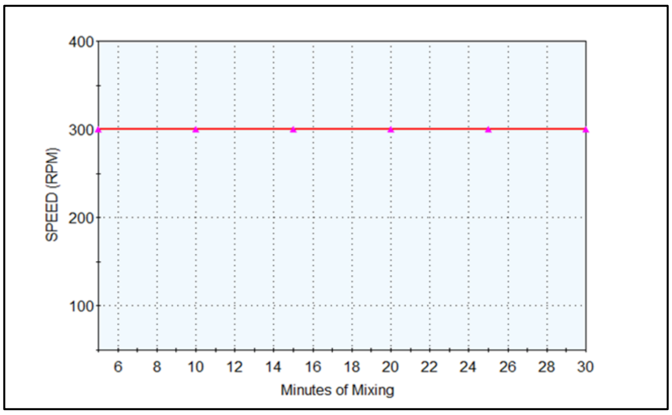

Figure 6: Calibrating the speed of Stirring Device

3.1 Modification Stage

After the preliminary testing stage, modifications were immediately conducted. The researchers modified the system in such a way that the flaws seen in the preliminary testing stage were resolved and corrected with the result of the pre-laboratory. During the preliminary stage, the problem encountered by the researchers is maintaining a temperature of 55–65 degrees Celsius. The researcher's set point is 55–65- degrees Celsius, but when the heating device was turned off at 65 degrees Celsius, the temperature was still rising up to 5 degrees Celsius. Therefore, the researchers decided to change the maximum set point of temperature to 55–60 degrees Celsius; even though the heating device was turned off at 60 degrees Celsius, it will rise up to 65 degrees Celsius. In short, even though the researchers set the maximum temperature at 60- degrees Celsius, they can still achieve 65 degrees Celsius because of the automatic rise of 5 degrees Celsius.

3.2 Final Testing

After the modifications and retesting process, the researchers of the study proceeded with the final performance testing stage. In this stage, the system was evaluated, and the components were assessed based on the final test conducted.

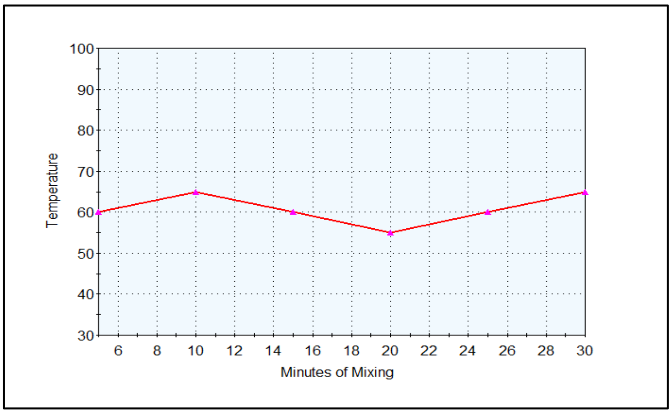

Figure 7: Final Testing of Temperature

The researcher conducted the final stage of testing and resolving the temperature needed in the apparatus. Researchers set the point at 55–60 degrees Celsius, and already got the same results in the pre-laboratory. Even though the temperature rises after turning off the heating device, it doesn't affect the result of the biodiesel. The problem was solved, and researchers decided to go with a temperature of 55–60 degrees Celsius to successfully complete the operation.

3.3 Quality of the Biodiesel

The researcher tested the biodiesel produced in the portable apparatus. The four physical characteristics of biodiesel were tested at RTF Scientific Instrument Trading, L7, B8, Don F. Caedo Vill., K. Ibaba Batangas City, namely: viscosity, density, flash point, and distillation. These characteristics are crucial for assessing the quality of biodiesel produced in the apparatus. Higher viscosity leads to poorer fuel atomization, which can negatively affect engine performance. The viscosity of biodiesel is a critical factor in determining the quality of the product, as it impacts its pour and flow properties (Unlu et al., 2018).

Regarding the specific density (ρ) of biodiesel, it is defined as the ratio of fuel mass to fuel volume at the same temperature and pressure. The density and viscosity of biodiesel are two essential physical properties widely used in combustion models, as they influence combustion efficiency and emissions (Knothe, 2009). The flash point of biodiesel is significant as it helps limit the amount of residual alcohol present in the biofuel, ensuring safety during storage and handling (Dias et al., 2008). However, distillation is noted for significantly lowering the cold filterability of most feedstocks while yielding the purest form of biodiesel, thus enhancing its performance in various applications (Haas et al., 2006).

Discussion

DOE - Physicochemical Properties of biodiesel			**Result of the study**	
Property	Limit	Method	Outcome	Method Used
Density @ 15 ^{0}C, Kg/L	0.86- 0.90	PNS ASTM D1290	886.1 or 0.88	ASTM D1298
Distillation Temperature 90% recovered ^{0}C, max	360	PNS ASTM D1160	360	ASTM D96
Flash Point ^{0}C Min	100	PNS ASTM D93	104	ASTM D3828
Viscosity @ 40^{0}C, mm^2/s	1.9 - 6.0	PNS ASTM D445	4.94	ASTM D445

Table 2. Comparison of the Standard Properties of Biodiesel from Department of Energy and the result of Physicochemical Properties of the Portable Apparatus

In Table 2, it shows the comparison of the physicochemical properties from the Department of Energy, Philippines, and the result of the Portable Apparatus. The properties used are density, distillation, flash point, and viscosity. In order to know if the produced biodiesel from the portable apparatus meets the standard set of physicochemical properties of biodiesel, the researchers analyzed and compared the results of the portable apparatus with the data gathered from the Department of Energy (DOE). The researchers tested the produced biodiesel in the portable apparatus at RTF Scientific Instrument Trading in order to know if the result passed the standard set of properties of biodiesel in the Department of Energy (DOE). The quality of biodiesel produced by portable apparatus was seen to be passed on to the standard set of physicochemical properties of biodiesel from the Department of Energy (DOE), as the outcome falls into the average range of each category.

Table 3. Determining the Reliability of the Apparatus

Trial	Volume of WCO	Volume of Sodium Hydroxide	Volume of Methanol	Temp	Stirring RPM	Time Mins	Set Period	Biodiesel Result	Glycerol Result
1	1 Liter	5 grams	250 ml	55-65 °C	300	30	24 hours	991 ml	248 grams
2	1 Liter	5 grams	250 ml	55-65 °C	300	30	24 hours	992 ml	249 grams

Table 3 shows the reliability of the portable apparatus in terms of measurements and operating parameters. The researchers made a trial up to twice in the portable apparatus to test if the machine gave a consistent result. Based on the observation and analysis of the researchers, there's a minimal difference in the results. In trial 1, the biodiesel produced is 991 ml, or 99.1%, while in trial 2, there is 992 ml, or 99.2%. The researchers made the process with the same unit of all raw materials, the same stirring speed, the same temperature, duration, and set period. There is a "residual" in the tube when it comes to transferring the biodiesel into another tank, and it results in 1 mL differences. Although it doesn't affect the physical appearance, texture, or quality of the biodiesel produced. The researchers observed that when the machine operates, it gives accuracy, consistent results, and a smooth flow of operations. There's no unforeseen failure in the result or malfunction in the machine.

Table 4. Comparison of Fuels

Types of Fuel	**Carbon Dioxide Emission (Pounds)**
1 Gallon Biodiesel	5.87
1 Gallon Diesel	22.44
1 Gallon Gasoline	19

Table 4 shows the comparison of fuels in terms of carbon dioxide per gallon. Annually, the transportation sector releases a substantial quantity of carbon dioxide (CO2) into the atmosphere. While gasoline and diesel fuel remain the most popular fuel sources, biodiesel has become a popular substitute that offers reduced pollution levels and mitigates climate effects. According to Smoot (2023), biodiesel has a low carbon footprint. One gallon of biodiesel emits 5.87 pounds (2,661 grams) of CO2 when combusted, and driving one mile on average emits 404 grams of CO2. Depending on the source, biodiesel can combat climate change and provide various environmental benefits. She also stated that diesel fuel has a very high carbon footprint; one gallon of diesel fuel emits 22.44 pounds (10,180 grams) of CO2 when combusted, while driving one mile on average emits 404 grams of CO2. Diesel fuel is considered a dirty fuel source that directly contributes to climate change.

Additionally, based on a study by the US Department of Energy, gasoline is a highly flammable and toxic liquid. Air pollution is caused by the vapors released when gasoline evaporates and the materials burned when gasoline is combusted, such as carbon monoxide, nitrogen oxides, particulate matter, and unburned hydrocarbons. About 19 pounds of carbon dioxide (CO2) are produced when a gallon of gasoline is burned. To conclude, biodiesel is a domestically produced, clean-burning, renewable substitute for petroleum diesel. Using biodiesel as a vehicle fuel increases energy security, improves air quality, and enhances environmental quality while providing safety benefits. Burning biofuels results in substantially lower carbon emissions and fewer pollutants. Biodiesel emits less sulfur dioxide, carbon monoxide, carbon dioxide, and unburned hydrocarbons than petroleum diesel. Overall, the use of biodiesel significantly improves air quality.

The researchers conducted three trials with different parameters and operating conditions to determine what needed to be designed and adjusted to the apparatus. In sample 1, researchers used a 55–60-degree Celsius temperature with 200 RPM for 30 minutes. The raw materials used were waste cooking (200 ml), ethanol (50 ml), and NaOH (1 gram). The result was a plain white solid glycerol. In sample 2, the researchers used the same number of raw materials but changed the percentage of alcohol to 70%. The results showed that the glycerol is still liquid and not easy to separate in biodiesel. In sample 3, the researchers still used the same number of raw materials but changed the type of alcohol to methanol. The results were clearer and cleaner biodiesel than the two samples.

The project was fully constructed and made with 100% locally sourced materials. The portable apparatus was tested and evaluated after multiple tests and was found to be reliable, functional, safe, and of good quality for the biodiesel produced. In the final stage, the apparatus gives consistent results, resolving the temperature and stirring speed needed

The quality of biodiesel was tested at RTF Scientific Instrument Trading using the four physiochemical characteristics, namely: viscosity, density, flash point, and distillation. The portable apparatus functions precisely and accurately.

The apparatus was safe and recommendable for the user since the test was run on it, resulting in highly acceptable conditions for operation. The researcher conducted research about the impact of biodiesel on the environment. To come up with the conclusions, the researchers compared other fuels in terms of carbon dioxide emissions produced. In 1 gallon of diesel, it produced 22.44 pounds of carbon dioxide emissions. In 1 gallon of gasoline, it produced 19 pounds of carbon dioxide emissions, while in 1 gallon of biodiesel, it only produced 5.87 pounds of carbon dioxide emissions in the environment.

The activities and worksheets for the portable apparatus coincide with its utilization and use. The manual for operating the machine was also included.

Conclusions

1. The Portable Apparatus was designed to use exact measurements of chemical solutions such as methanol, sodium hydroxide, and vegetable waste cooking oil. Additionally, operating parameters are also considered in this study as the basis for producing biodiesel using a portable apparatus, as it gives a more realistic result. The material selection was considered in the design of the apparatus.
2. The portable apparatus was tested and observed to be functional, safe, reliable, and pass some of the properties used in the Standard Physiochemical Characteristics of Biodiesel.
3. The biodiesel only produced fewer pounds of carbon emissions, resulting in the least impact on the environment. It is also found to be a cleaner-burning renewable alternative.
4. It was deemed important to provide activities that are to be performed using the apparatus.

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