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Conversion of Waste Cooking Oil Combined with Corn Oil into Biodiesel Using the Trans-esterification Method

Suardi[1], Faisal Mahmuddin[2], Syerly Klara[3], Wira Setiawan[4], Muhammad Uswah Pawara[5], Jumardi[6]

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Abstract- **This research endeavors to explore a novel alternative fuel source by combining waste used cooking oil and corn oil to create a biodiesel blend. The study addresses two main objectives: first, to investigate the properties of used cooking oil biodiesel with the addition of methanol and NaOH catalysts, and second, to assess engine performance using the biodiesel blend. The experimental approach employs transesterification, varying the catalyst quantity during biodiesel production. Preceding diesel engine testing, properties such as viscosity are assessed, revealing improved values meeting Indonesian National Standards post-catalyst addition, albeit with a decrease in calorific value. Engine performance is then evaluated, demonstrating that as the catalyst content increases, torque and thermal efficiency decrease, while specific fuel consumption (SFC) rises. Notably, the study concludes that a higher catalyst ratio aligns fuel properties closer to government-set standards. The most favorable engine performance is observed in the B50 sample with a catalyst variation of 1000 ml of methanol and 25 g of NaOH, showcasing superior torque, thermal efficiency, and opacity values compared to higher catalyst variations. This research underscores the importance of catalyst optimization in achieving an environmentally friendly biodiesel blend with enhanced engine performance.**

Keywords- Biodiesel, Waste Cooking Oil, Corn Oil, Engine Performance, Catalyst Optimization

I. INTRODUCTION

Biodiesel, renowned for its renewable characteristics and lower emissions compared to diesel oil, emerges as a sustainable solution that contributes to environmental preservation and initiates a harmonious natural cycle. Its eco-friendly attributes are further underscored by the fact that the combustion emissions, when released into the atmosphere, undergo reabsorption by plants during the photosynthesis process, enhancing its environmental credentials [1], [2]. The fuel used must also refer to government regulations in accordance with the Decree of the Director General of EBTKE No. 189K/10/DJE/2019 dated November 5, 2019 concerning Standards and Quality (Specifications) of Biofuel Types of Biodiesel as Material Other Fuels Marketed Domestically [3]. Despite its environmental benefits, biodiesel is not devoid of challenges. Issues surrounding variations in viscosity pose a notable challenge, particularly in engines operating at low rpm. The inherent higher viscosity of vegetable oil characterizes this concern, resulting in an elevation of fuel injection pressure. This issue warrants careful consideration and mitigation strategies to ensure the optimal performance of engines utilizing biodiesel [4].

A distinguishing feature of diesel engines, setting them apart from other combustion engines, lies in their fuel ignition method. In diesel engines, fuel injection occurs into a cylinder with high-pressure air [5]–[7]. The power generated by these engines is directly linked to the quantity of consumed fuel, particularly diesel, emphasizing the significance of optimizing the combustion process [8], [9]. Enhanced combustion efficiency can contribute to decreased fuel consumption. The incomplete combustion process is often attributed to the mixture of fuel and air in the combustion chamber. In cases where not all fuel evaporates during the air mixing process, an uneven distribution of the mixture occurs, leading to a higher air-to-fuel ratio. This imbalance hinders effective combustion in the chamber, resulting in inefficient fuel utilization and reduced engine performance [10].

The biodiesel production process, also known as the free fatty acid esterification or transesterification reaction, involves reacting triglycerides with alcohol and a catalyst. This reaction, akin to alcoholysis, enhances biodiesel quality through the exchange of fatty acids and the formation of new esters [11], [12]. In this study, biodiesel is synthesized from cooking oil (palm oil) through the transesterification process, employing methanol and NaOH as catalysts. Sodium hydroxide (NaOH) is chosen due to its higher reactivity compared to potassium (K) [13]. Methanol is a preferred catalyst in transesterification processes due to its high-quality attributes, providing a deterrent effect on the resulting fuel [14], [15]. Subsequent to biodiesel production, essential properties such as viscosity,

Suardi, Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail :suardi@lecturer.itk.ac.id
Faisal Mahmuddin, Department of Marine Engineering, Engineering Faculty, Hasanuddin University, Gowa 92171, Indonesia. e-mail : f.mahmuddin@gmail.com
Syerly Klara, Department of Marine Engineering, Engineering Faculty, Hasanuddin University, Gowa 92171, Indonesia. E-mail: elikapal83@gmail.com
Wira Setiawan, Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail : wira@lecturer.itk.ac.id
Muhammad Uswah Pawara, Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail : uswah.pawara@lecturer.itk.ac.id
Jumardi, Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail : 09191036@student.itk.ac.id

density, and heating value are meticulously tested. The evaluation extends to direct engine testing, aiming to ascertain crucial engine performance metrics. Contrary to some findings suggesting suboptimal values in power, thermal efficiency, and fuel consumption with biodiesel usage, multiple studies indicate its pronounced positive impact on reducing fuel emissions [16], [17].

II. Method

Aligned with the overarching theme of exploring innovative alternative fuels, this research focuses on combining used cooking oil and corn oil to produce biodiesel. Two distinct methodologies are employed in this study. The primary approach involves the production of biodiesel, commonly referred to as transesterification [18]. This experimental method serves to assess the viability of the fuel for diesel engines and discern the resultant engine performance outcomes [19], [20].

Subsequent to assessing the fuel properties, the investigation progresses to direct testing on a diesel engine, aiming to scrutinize the fuel's performance. Refer to Table 1 for the specifications of the utilized engine in this study.

TABLE 1.
THE SPECIFICATIONS OF ENGINE.

Brand/Model	Yanmar TF 85 Series
Type	TF 85MH
Number of Cylinders	1 Cylinder 4 Stroke
Displacement	493 cc
Continuous Power	7.5 Kw/2200 rpm
Compression Ratio	1:18
Specific Fuel Consumption	171 gr/HP h

Source: Yanmar 2022 [21]

The test flow can be seen in Figure 1 below:

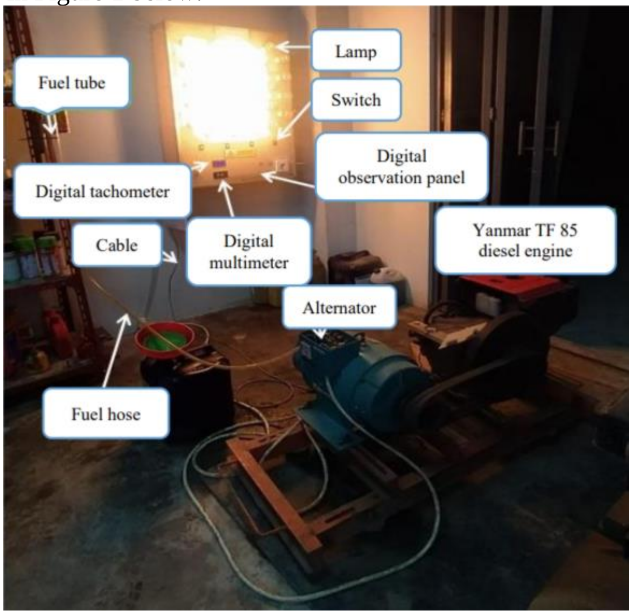


***Figure 1**. Experimental System* [22]

III. Results and Discussion

As outlined earlier, the research comprises two main phases: the production of biodiesel from used cooking oil (palm oil) and the subsequent testing of biodiesel in diesel engines. Additionally, comprehensive tests were conducted to assess the properties of biodiesel fuel, encompassing measurements of viscosity, density, and heating value.

A. Biodiesel Production Process

The biodiesel production process involves the transesterification method. Following the preparation of tools and materials, specific stages must be meticulously followed. The catalyst preparation stage combines methanol and NaOH, with two variations in catalyst amounts. The first variant comprises 1000 ml of methanol and 25 grams of NaOH per 5 liters, while the second variant involves 1200 ml of methanol and 30 grams of NaOH.

a)

b)

Figure 2. a) The summation of the quantities of NaOH employed. b. The combination of methanol quantity utilized and the methanol-NaOH mixture

The transesterification method is employed in producing biodiesel from used cooking oil, where a catalyst is used to reduce high acid levels, facilitating the separation of glycerol from biodiesel and enhancing biodiesel yield. The process involves heating the used cooking oil to 75 oC using a hot pot equipped with a stirring machine. The catalyst liquid is added after lowering the temperature to prevent strong odors. The mixture is stirred for 30 minutes to ensure thorough blending. The oil-catalyst mixture is then transferred to a pre-prepared container for the washing stage, aiming to separate oil, glycerol, and water. This washing process utilizes water at temperatures of 80–100 oC with a 1:1 biodiesel ratio for efficient washing, where an increased water quantity results in a cleaner and faster washing process.

Figure 3. Biodiesel manufacturing process

A. Viscosity, Density and calorific value Testing

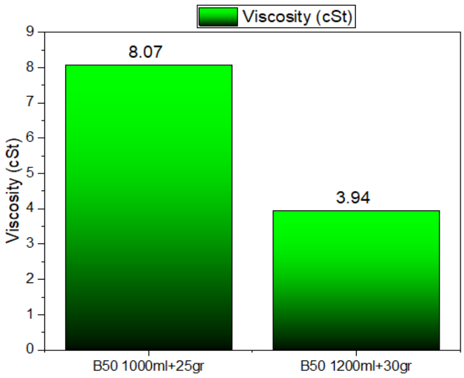
Testing biodiesel characteristics serves the purpose of adherence to government standards regarding fuel quality and compare the results of biodiesel production and facilitates a comparative analysis of biodiesel production outcomes. Key parameters in characteristic testing include viscosity, density, and heating value. These values play a crucial role in determining the lower heating value (LHV) of biodiesel, impacting fuel consumption per unit of time. Adhering to these standards ensures the quality and efficiency of biodiesel as a viable fuel alternative.

TABLE 1.
BIODIESEL SPECIFICATION IN INDONESIA

Parameter Test	Unit	Limit
Kinematic Viscosity at 40^0C	cSt	2.3 - 6.0
Density at 40^0C	Kg/m^3	850 - 890

Source: Biodiesel Specificatin Director General of EBTKE [3]

Viscosity testing in this study employs a viscometer, while density testing adheres to ASTM D 1298 standards using a 10 ml pycnometer and an analytical balance. Additionally, the heating value of biodiesel is determined through testing following the ASTM D 5865 method. These standardized testing procedures contribute to the comprehensive evaluation of biodiesel characteristics, ensuring accurate and comparable results in line with established protocols.



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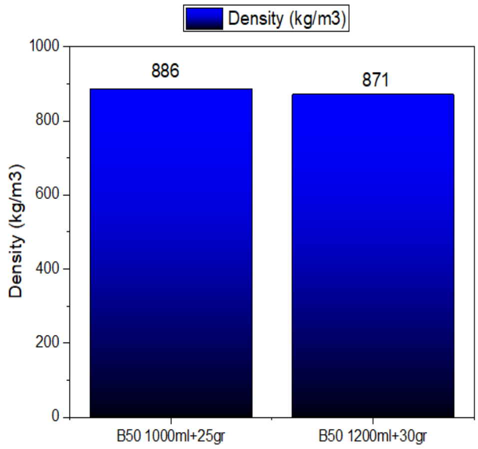

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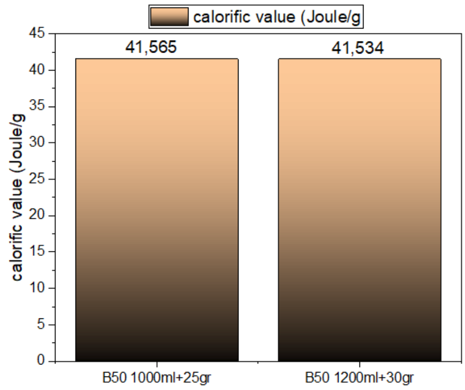

c).

Figure 4. Comparison graph of fuel properties based on catalyst variations. a) Viscosity Value, b) Density Value, c) Calorific Value

The outcomes of the aforementioned test are directly affected by the preceding biodiesel production conducted through the transesterification process. This method involves the separation of glycerol and the formation of new esters, with the quantity of separated glycerol increasing proportionally to the number of catalysts employed during biodiesel production. The test results thus reflect the influence of catalyst quantity on the separation efficiency of glycerol, shedding light on the correlation between catalyst usage and the biodiesel production process.

B. Diesel engine performance testing process

After evaluating density, viscosity, and heating value, the subsequent step involves engine testing. The assessment was conducted on a diesel engine operating on a 4-step working system model TF 85MLYS with an observation table equipped with 40 lamps, each carrying a load of 100 watts. A meticulous examination of the fuel tank ensures the absence of any fuel mixture, guaranteeing a clean engine devoid of previous fuel. Subsequently, the diesel engine crank is turned clockwise with the clutch off, and then started simultaneously with the clutch engaged. After initiating the engine, a brief pause is observed until the load, represented by lights, illuminates. Subsequent tasks involve recording the current generated at each step and calculating the corresponding time. The engine operates at speeds of 1000 RPM, 1200 RPM, and 1400 RPM, with loads of 1000 watts, 2000 watts, 3000 watts, and 4000 watts. This comprehensive test serves to gauge the engine's performance using the previously produced fuel. The analytical facets encompass torque under load, SFC with load, and thermal efficiency under varying loads.

TABLE 3.
MACHINE TEST RESULTS DATA IN FOUR LOAD CONDITIONS

B50 catalyst methanol 1000ml + 25 gram

Engine rotation RPM	Load	Voltage (volt)	Current (Ampere)	Time (minute)	Time (s)	Amount of fuel (ml)	Power (watt)	Power (kw)
1000	1000	112	2.91	2.07	127	10	325.92	0.33
	2000	107	5.69	1.47	107	10	608.83	0.61
	3000	99.2	8.17	1.32	92	10	810.46	0.81
	4000	90.6	10.3	1.24	84	10	933.18	0.93
1200	1000	143	3.33	1.4	100	10	476.19	0.48
	2000	133	6.4	1.21	81	10	851.20	0.85
	3000	118	8.96	1.13	73	10	1057.28	1.06
	4000	98.9	10.8	1.08	68	10	1068.12	1.07
1400	1000	170	3.65	1.14	74	10	620.50	0.62
	2000	157	7	1.06	66	10	1099.00	1.10
	3000	130	9.47	1.02	62	10	1231.10	1.23
	4000	100	10.9	0.59	59	10	1090.00	1.09

B50 catalyst methanol 1200ml + NaOH 30 gram

Engine rotation RPM	load	Voltage (volt)	Current (Ampere)	Time (minute)	Time (s)	Amount of fuel (ml)	Power (watt)	Power (kw)
1000	1000	109	2.87	2	120	10	312.83	0.31
	2000	107	5.69	1.42	102	10	608.83	0.61
	3000	97.4	8.07	1.27	87	10	786.02	0.79
	4000	90.3	10.02	1.2	62	10	904.81	0.90
1200	1000	146	3.37	1.36	96	10	492.02	0.49
	2000	135	6.45	1.17	77	10	870.75	0.87
	3000	117	8.96	1.13	73	10	1048.32	1.05
	4000	98.4	10.7	1.11	71	10	1052.88	1.05
1400	1000	165	3.6	1.23	83	10	594.00	0.59
	2000	153	6.91	1.07	67	10	1057.23	1.06
	3000	126	9.32	1.04	64	10	1174.32	1.17
	4000	98.9	10.8	0.57	57	10	1068.12	1.07

1. Torque vs load

The torque-load relationship was scrutinized to comprehend the engine's behavior under diverse loads. This analysis was conducted by varying loads (1000 watts, 2000 watts, 3000 watts, and 4000 watts) at engine speeds of 1000 RPM, 1200 RPM, and 1400 RPM. The findings indicated noteworthy trends in torque values concerning load variations.

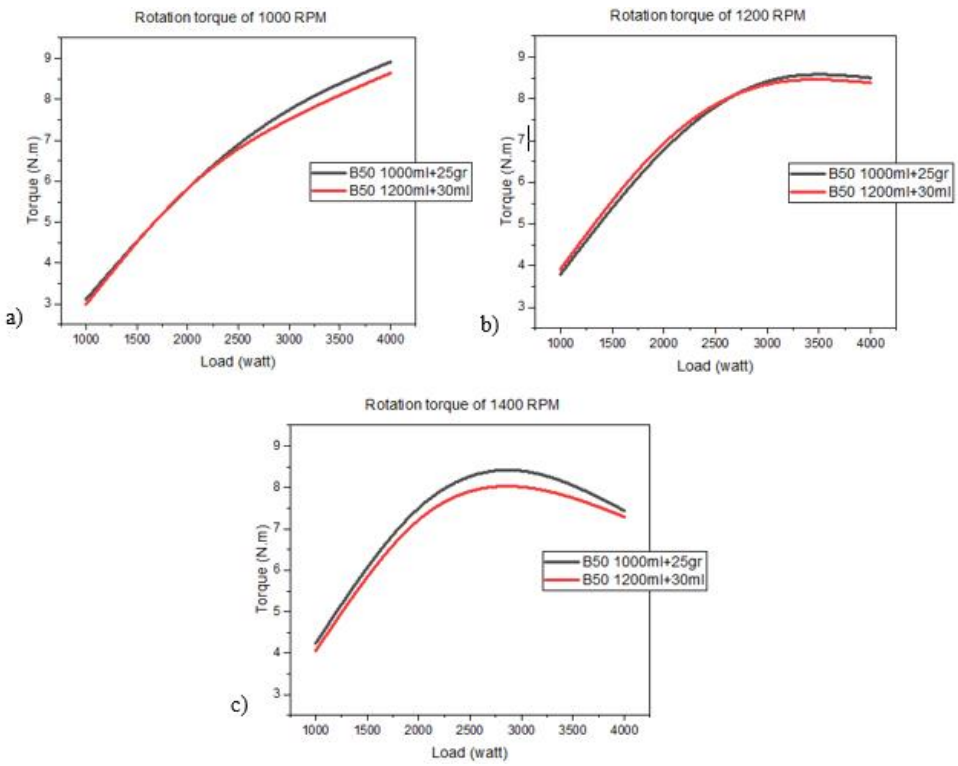

Figure 5. Comparison Graph Between Torque and Load. a) 1000 RPM, b) 1200 RPM, c) 1400 RPM

The torque values derived from the graph, particularly at the engine speed of 1000 RPM with various B50 fuel compositions (1000 ml + 25 grams), unveil insightful information about the performance characteristics. At a load of 4000, the torque peaks at 8.92 N.m., representing the highest recorded value in the test. This substantial torque output at a relatively high load indicates the capacity of B50 fuel, with the specified catalyst amount, to deliver robust performance in terms of rotational force.
Conversely, when examining B50 fuel with a composition of 1200 ml + 30 grams at the same engine speed of 1000 RPM, a distinct pattern emerges. The torque registers at 2.99 N.m., marking the lowest recorded value, and this occurs at a load of 1000. The lower torque at this specific load implies that the engine's rotational force is comparatively reduced when subjected to this particular composition of B50 fuel. This variation in torque values under different load conditions provides valuable insights into the fuel's behavior and performance across different operational demands.

It is crucial to emphasize that these torque outcomes are not isolated measurements but are intricately linked to the voltage and current generated by the engine when utilizing the B50 fuel variations. The torque values serve as indicators of the engine's ability to produce rotational force under varying conditions, shedding light on the dynamic relationship between the fuel composition, engine speed, and applied load. This nuanced exploration of torque values at different loads and fuel compositions contributes to a comprehensive understanding of how B50 fuel, with distinct catalyst proportions, influences the performance of the diesel engine. This information is pivotal for optimizing engine efficiency, enhancing fuel utilization, and furthering the development of biodiesel blends for sustainable and efficient combustion in diesel engines.

2. SFC vs load

The specific fuel consumption (SFC) in relation to load was investigated to assess the fuel efficiency under varying engine loads. The study encompassed load variations at engine speeds of 1000 RPM, 1200 RPM, and 1400 RPM, exploring the SFC trends. Notably, the SFC values demonstrated a nuanced pattern, with B50 fuel consistently exhibiting lower SFC compared to B0 fuel across different loads. For instance, at 1000 RPM, B50 fuel showcased superior fuel efficiency, emphasizing its potential in optimizing energy utilization. This scrutiny of SFC against load contributes valuable insights into the fuel consumption dynamics, offering a basis for enhancing overall engine efficiency.

The comprehensive analysis of the three graphs above reveals a notable trend: the increased use of catalyst variations corresponds to a less favorable impact on the fuel consumption rate in the engine. This observation is crucial for understanding how varying catalyst amounts influence specific fuel consumption (SFC) across different engine speeds. When examining the SFC values, a clear pattern emerges. The lowest SFC is attained at RPM 1000, precisely at 406.9 g/kWh, as depicted in the black graph. In contrast, the highest SFC is recorded at RPM 1000, reaching a value of 835.3 g/kWh. This contrast in SFC

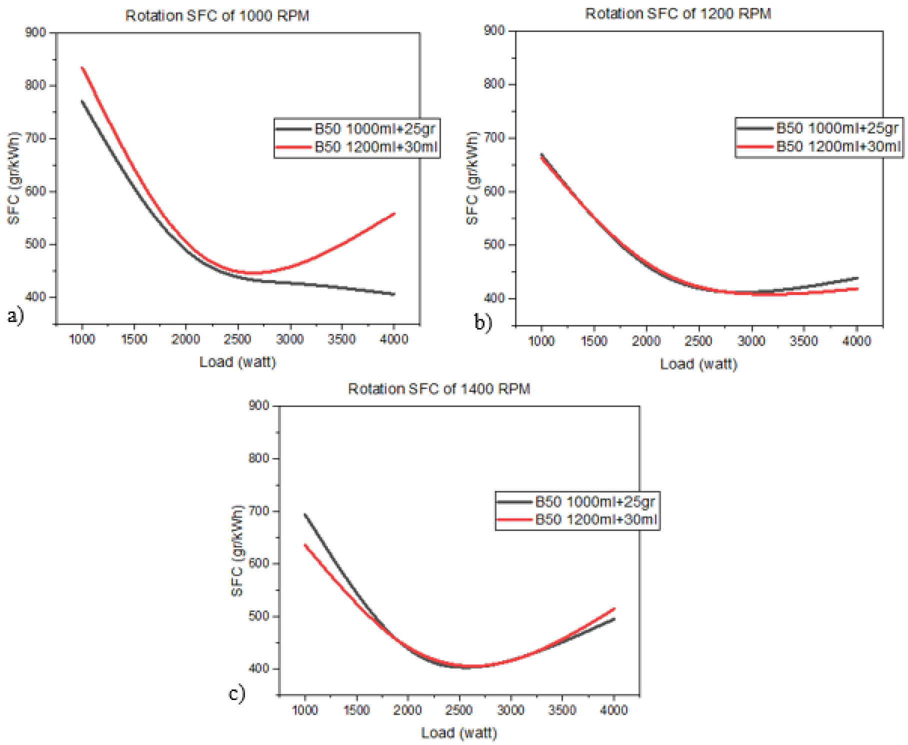

Figure 6 Comparison Graph Between SFC and Load. a) 1000 RPM, b) 1200 RPM, c) 1400 RPM

values indicates that the addition of catalysts is associated with an increase in fuel consumption, particularly evident at this specific engine speed.

The findings underscore the intricate relationship between catalyst variations and fuel consumption rates. The observed increase in SFC values with higher catalyst amounts suggests that the combustion efficiency or fuel utilization may be compromised under these conditions. This insight is crucial for optimizing biodiesel production processes, emphasizing the need to strike a balance between catalyst utilization and fuel consumption to enhance overall engine efficiency. In conclusion, the correlation between catalyst variations and SFC values, as illustrated in the graphs, provides valuable information for researchers and practitioners in the field. This understanding contributes to the ongoing efforts to refine biodiesel production methods, ensuring a more sustainable and efficient utilization of alternative fuels in diesel engines.

3. Thermal efficiency vs load

The investigation into thermal efficiency concerning load provides crucial insights into the engine's overall performance and energy utilization. The thermal efficiency values were scrutinized across various loads at engine speeds of 1000 RPM, 1200 RPM, and 1400 RPM. The data depicted a distinctive trend, with thermal efficiency varying with load. Notably, B50 fuel consistently exhibited higher thermal efficiency compared to B0 fuel, emphasizing its positive impact on the engine's ability to convert fuel into useful work. This analysis of thermal efficiency against load offers valuable information for optimizing engine performance and enhancing energy efficiency, aligning with the research's objective of evaluating the efficacy of B50 fuel in diesel engines under diverse operating conditions.

The analysis of the three thermal efficiency graphs, particularly in relation to load variations, mirrors the trends observed in fuel consumption values. The introduction of additional catalyst, specifically up to 1200 ml of methanol and 30 g of NaOH, manifests a discernible impact on diminishing the thermal efficiency of the engine. This highlights a noteworthy trade-off associated with catalyst quantities and their influence on engine performance. For instance, when examining the efficiency values at 1000 RPM with a standard catalyst, the engine yields an impressive efficiency of up to 21.9%. However, when the same RPM is considered for B50 fuel with an augmented catalyst, the efficiency value notably declines to 15.9%. This observation provides conclusive evidence that an excess of catalyst can have a detrimental effect on the engine's thermal efficiency, contrary to the anticipated improvements associated with catalyst utilization.

These findings underscore the delicate balance required in determining the optimal catalyst amounts to achieve enhanced engine performance. The inverse correlation between increased catalyst volumes and reduced thermal efficiency emphasizes the need for precision in catalyst application to strike an equilibrium between biodiesel production efficiency and engine performance.

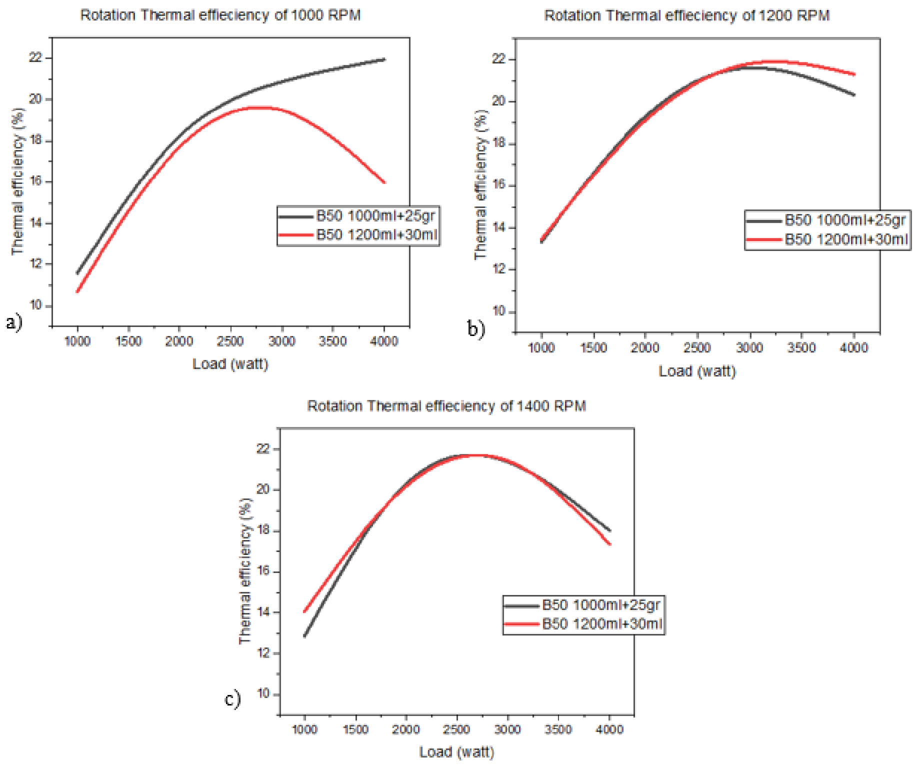

Figure 7. Comparison Graph Between Thermal Eff and Load. a) 1000 RPM, b) 1200 RPM, c) 1400 RPM

In summary, the comprehensive comparison of thermal efficiency and load across the three graphs sheds light on the nuanced relationship between catalyst variations and engine efficiency. This understanding is pivotal for refining biodiesel production processes, ensuring that catalyst quantities are optimized to maximize both fuel efficiency and thermal performance in diesel engines.

4. Emission (Opacity)

The assessment of opacity resulting from the combustion of the produced biodiesel fuel was a crucial aspect of this test. Conducted with an NHT6 opacimeter, this test specifically targets the visibility of contaminants in emissions emitted by diesel engines. The obtained results have been graphically represented to provide a comprehensive depiction of the opacity levels observed. Opacity, in this context, serves as a key indicator of the presence of visible pollutants in the exhaust gases produced during combustion. By utilizing an opacimeter, which measures the degree to which light is obstructed by particulate matter in the emissions, a quantitative assessment of the emissions' visibility is achieved.

The graphical representation of the test results offers a visual insight into the opacity levels associated with the combustion of biodiesel fuel. This information is invaluable in understanding the environmental impact of the fuel and its combustion byproducts. The opacity graph serves as a tangible metric for assessing the cleanliness of emissions, contributing to a holistic evaluation of the environmental performance of biodiesel in comparison to conventional diesel. In conclusion, the opacimeter test provides a quantitative and visual analysis of emissions visibility, elucidating the environmental implications of biodiesel combustion. This information aids in comprehensively evaluating the environmental sustainability of biodiesel as an alternative fuel source for diesel engines.

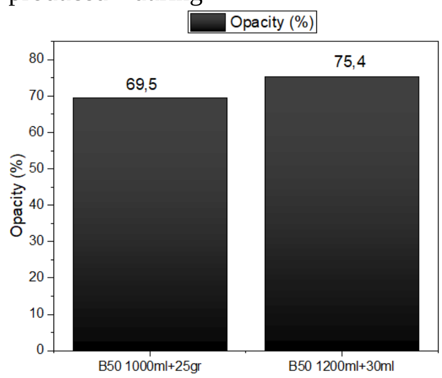

Figure 8. Comparison Graph of Opacity Values Between Various Fuel Samples

The observed low opacity in the emissions from biodiesel combustion can be attributed to the characteristics of biodiesel, particularly its composition of fatty acids. In theory, these fatty acids present in biodiesel are known to be more prone to oxidation or complete combustion. This inherent property of biodiesel contributes to a more efficient and cleaner burning process, resulting in reduced opacity in emissions.

The correlation between opacity and the catalyst used in the biodiesel production process is noteworthy. As the catalyst quantity increases, there is a corresponding decrease in the fatty acid content of the biodiesel. This phenomenon occurs because an elevated catalyst concentration facilitates a more effective separation of glycerol during the transesterification process. Glycerol removal, in turn, reduces the presence of fatty acids in the biodiesel, enhancing its combustion efficiency.

This observation aligns with the principle that biodiesel, when produced under specific conditions, can yield a fuel with lower emissions and improved combustion characteristics. The graphically presented opacity test results provide empirical evidence of the environmental benefits associated with biodiesel combustion. In summary, the combustion efficiency and reduced opacity in biodiesel emissions are outcomes of its unique composition and the influence of catalyst quantity during production.

IV. Conclusion

In this research, the characteristics of biodiesel from used cooking oil are influenced by variations in the catalyst in the transesterification process. The density and viscosity values of biodiesel increase with increasing catalyst concentrations to meet fuel quality standards, but the calorific value of biodiesel decreases. The performance of diesel engines using biodiesel shows a decreasing trend in torque and thermal efficiency as the catalyst improves. The lowest results in thermal efficiency were recorded in B50 with 1200 ml and 30 gram catalyst at 1000 RPM with a load of 1000 watts (10.377%), while the highest performance was found in B50 with 1000 ml catalyst at 1000 RPM with a load of 4000 watts (21.285%). Meanwhile, the highest specific fuel consumption (SFC) was seen in the B50 with a catalyst of 1200 ml and 30 grams (835.278 gr/kWh) at 1000 RPM with a load of 1000 watts. In conclusion, the influence of catalyst variations on biodiesel properties and engine performance requires a careful balance to meet standards and maintain engine efficiency.

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