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Performance evaluation of a spark ignition engine using gasoline and essential oil fuel blend

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ABSTRACT
Clove oil is an essential oil that has recently been used not only as a health or aromatherapy ingredient but is also widely used as an additive in fuel, especially for compression ignition engines. Essential oils are extracted through *distillation* from various parts of the clove tree, such as flowers, tree bark, leaves, and even fruit. This study aims to evaluate the combustion performance of a spark-ignition engine fueled by gasoline and essential oil at a concentration of 5-20 % as a blend. This type of research has not been conducted by many researchers, making it difficult to find scientific references related to this type of research. Experiments carried out on a research engine with engine speed variations of 1400–1800 rpm and a constant load of 3 kg. The results show that increasing the essential oil content increases the fuel energy and indicative power, thereby increasing the thermal efficiency. However, the brake power will decrease because most of it is lost owing to heat transfer and friction; therefore, the mechanical efficiency decreases if the percentage of essential oil in gasoline increases. Meanwhile, increased essential oils will reduce CO_2 emissions, but HC and CO emissions will increase, especially at high engine speeds.

Section: RESEARCH PAPER

Keywords: Essential oil; clove oil; evaluation; performance; spark ignition

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1. INTRODUCTION

The rate of environmental damage is increasing yearly because of an imbalance in the management, exploitation, and use of natural resources [1]. This damage largely contributes to the production of carbon dioxide emissions from fossil fuel combustion, especially in the transportation sector, to support the increasing and modern mobility of the population [2]. One of the policies and agreements of countries in the world to reduce CO_2 production is the 2015 Paris Agreement. The agreement regulates CO_2 production and consumption of CO_2-producing sources, as well as limits the use of fossil fuels [3]-[5]. CO_2 production is also limited through the recycling process and CO_2 capture using various media [6]. Accordingly, the use of alternative energy, especially for motorized vehicles and both gasoline and diesel engines, continues to increase. This is because using biofuel fuel in cars can reduce carbon emissions by up to 85 % [7]-[10].

In the last decade, an aromatic compound that has been continuously studied for use in internal combustion engines is the essential oil. Essential oils can be used as an additive fuel or fuel blend because they contain the eugenol compound $C_{10}H_{12}O_2$, which is a group of allylbenzene compounds [11]. The demand for essential oils in recent years has continued to increase, especially since the COVID-19 pandemic hit the world at the beginning of 2020. Essentials' oil market share reached 8.74 billion dollars, or an annual average growth of 14.08 %, in the period 2017-2020. It is predicted will increase from 9.62 to 18.24 billion dollars in the next 8 years [12]. The most significant

Table 1. Properties of several essential oils in the diesel fuel blend.

Fuel	Density @ 25 ºC kg/L	Viscosity @ 40 ºC mm²/s	HHV MJ/kg	LHV MJ/kg	Flash point ºC	Cetane number	Surface Tension @ 25 ºC mN/m
100D	0.853	2.75	45.585	43.95	60.7	43.2	26.09
100O	0.849	0.89	45.115	-	55	19.5	-
5O95D	0.852	2.545	45.679	43.87	58.5	42.1	26.15
10O90D	0.852	2.37	45.375	43.23	57.5	41	26.23
100E	0.914	1.66	40.648	-	55	10	-
5E95D	0.856	2.66	45.388	42.83	58	41.4	27.53
10E90D	0.859	2.60	45.144	42.35	57.5	41.1	27.30
100T	0.900	1.84	41.899	-	53.5	10.4	-
5T95D	0.855	2.63	45.454	42.72	57.5	40.0	27.36
10T90D	0.857	2.63	44.982	42.26	56.5	39.1	27.32

essential oil-exporting country in the world today is the Netherlands, with a volume of 25 % of the world's demand. Meanwhile, in terms of value, it is held by Francis with a value of 29 % of the total value of essential oil sales throughout the world. This is because essential oils have many benefits, especially in the health sector, including antiviral, antibacterial, antioxidant, antidiabetic, anticancer, and fuel additives [13].

Indonesia is an agricultural country with enormous potential to develop and produce essential oils. It recorded that in 2010 Indonesia exported essential oils worth 124 million dollars that were produced from all essential oil producers. The specificities of each region and plant in Indonesia produce essential oils that are unique and not the same as those in other countries [14]. Some of the main characteristics of essential oils include; being easily soluble in alcohol, ether, and carbon di-sulphide, insoluble in water, and oxigynate, and volatile at room temperature. Meanwhile, the physical characteristics of a mixture of 5 %, 10 %, and 100 % of several types of essential oils, namely orange (O), eucalyptus (E), and tea tree (T) oils with diesel fuel (D) are presented in Table 1 [15].The chemical composition of essential oils is very complex but generally divided into two main parts, namely Terpenes (related to hydrocarbon compounds) and High Oxygenate Compounds. Each type of essential oil consists of hundreds of single compounds, some of which are difficult to identify, with specific characteristics depending on the type of raw material. Terpenes are composed of tens or even hundreds of isoprene containing 5 carbon atoms and are the main constituent of terpenes. The composition and main compounds in essential oils are (a) hydrocarbons; consisting of the elements carbon and hydrogen which are exclusive building blocks and can form terpenes, monoterpenes, and sesquiterpenes; (b) oxygenate compounds; plants that produce oxygenate compounds from hydrocarbons are generally esters, aldehydes, ketones, alcohols, phenols, and oxides [16]. The structure of the carbon and hydrogen bonds of essential oils is shown in Figure 1.

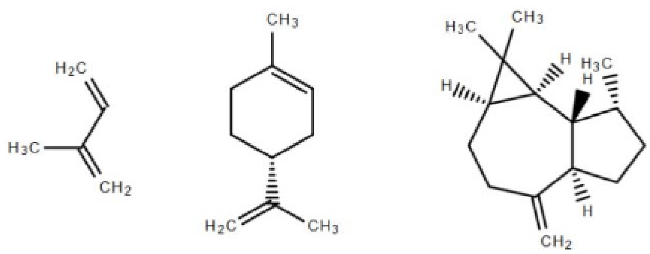

Figure 1. The structure of the carbon and hydrogen bonds of essential oils.

2. LITERATURE REVIEW

The use of essential oils in both gasoline and diesel engines is categorized in two forms, namely as a blend and as an additive fuel. The quantity of essential oil in the fuel used as a mixture is > 1 %, whereas < 1 % is an additive fuel [16]. Research conducted by Asep Kodarohman [17] compared the testing between diesel fuel and diesel-essential oil of 0.6 % fuel blend. Tests were carried out on diesel engines to determine the physical characteristics of the two fuel types. The results show that the specific gravity indicator of pure diesel fuel is lower than that of diesel and essential oil fuel blends. Other indicators such as fuel consumption, API gravity, aniline point, diesel index, viscosity, and flash point of diesel fuel are higher than a mixture of 0.6 % essential oil and diesel fuel.

Similar research was carried out by Jeyakumar et al. [18] by adding clove oil to diesel fuel and a mixture of diesel and biodiesel from cotton seeds (cottonseed). Each type of fuel is named based on the composition of essential oil (CL), diesel fuel (D), and biodiesel from cotton seed (B), namely B20 + CL1000 consisting of 20 % biodiesel + 80 % diesel + 1000 ppm essential oil, B20 + CL2000 (contain 2000 ppm essential oil, B100 is 100 % biodiesel, D100 is 100 % diesel). The tests were carried out on a 661-cc direct injection diesel engine at a constant speed of 1500 RPM. The results showed that the addition of essential oils to B20 will decrease the kinematic viscosity, flash point, calorific value, and density of the mixture, while the addition of essential oils will increase the oxidation stability of the mixture of B20 and diesel fuel (D100).

Similar tests were also carried out by Makame Mbarawa [19] using a 4-cylinder, 4-stroke diesel engine with a capacity of 2499 cc. The experiment intended to measure the performance of mixed diesel and clove stem oil (CSO) at a composition of 25 % and 50 % at 1500 and 2000 RPM engines. The results show that fuel consumption increases if the load, engine speed, and the percentage of CSO in the mixture also increase. BSFC decreases when the engine load increases, but BSFC and specific energy consumption (SEC) will increase if the RPM and CSO percentage in the fuel mixture also increase. Meanwhile, CO, HC, and NO emissions will increase if the load and engine speed increase. It also found that the three emissions will decrease with increasing the composition of CSO in the mixture if the engine is loaded at 25 % but will increase if the load is more than 25 %.

Meanwhile, research by Asep Kadarohman et al. [20] tested the performance of diesel engines by adding clove oil, eugenol, and eugenol acetate by 0.2 % to diesel fuel. The experiments were carried out at speeds of 1500–3500 RPM (increment of

500 RPM) with variations in fuel injection time. Fuel injection timing varies at 12 bTDC for 1500 RPM, 15 bTDC at 2000 RPM, 18 bTDC at 2500 RPM, 21 bTDC at 3000 RPM, and 24 bTDC at 3500 RPM. The results show that the terpene compounds in clove oil increase the combustion speed and shorten the ignition delay when the addition of clove oil in D100 fuel. It also found that the addition of eugenol would produce the highest heat release compared to other additives at 2500 RPM. The oxygen content in the mixture causes an increase in NOx emissions in the exhaust gas, so it is necessary to reformulate terpenes to produce maximum performance.

Studies on the performance of clove oil (CSO) and diesel (D100) fuel blends have also been carried out by M. Mbarawa and A. I. Haji [21]. The experiments were conducted by comparing the performance of diesel fuel (D100), a mixture of 50 % CSO and D50, and a mixture of 25 % CSO + D75. The tests were carried out on a direct injection diesel engine operated at a speed of 1000 – 2600 RPM (in 200 RPM increments). The results show that the addition of CSO to diesel fuel will reduce the cetane number of the fuel mixture. Therefore, CSO cannot possibly be used as an alternative and mixed fuel in a large composition for diesel fuel. A number of performance indicators for CSO and diesel mixed fuel engines are not too different from those of pure diesel fuel (D100). However, there was a slight reduction in energy loss and an increase in fuel consumption. This is because the calorific value of the fuel blend will decrease with increasing CSO concentration in diesel fuel.

The use of essential oils from different types of raw materials from the studies mentioned above has been carried out by S. A. Rahman et al. [22]. The types of essential oils used are tea tree oil which contains 5.4 % oxygen (w/w), and eucalyptus oil which contains 8.4 % oxygen (w/w). Then, both of them mixed with pure diesel oil which does not contain oxygen to get a mixed fuel with 2.2 % (w/w) oxygen content in each type of essential oil. Tests were carried out on a turbocharged 6-cylinder diesel engine, with a cylinder capacity of 5.9 liters, at a constant engine speed of 1500 RPM and varying loads of 25 %, 50 %, and 75 %. The test results show that the consumption of essential oil fuel is greater than diesel fuel and will continue to increase. However, the production of CO emissions and particulate (PM) emissions of essential oil fuels are lower than pure diesel fuel, where eucalyptus oil produces the lowest CO and tea tree oil produces the lowest PM emissions. Brake power, peak pressure, and average indicative effective pressure for all types of fuel tend to show similar trends.

This research aims to determine the combustion characteristics of gasoline and essential oils in spark ignition engines. Similar research is still very rarely carried out by researchers, so literature in this field is difficult to find.

3. MATERIALS AND METHODOLOGY

This study will examine and evaluate the performance of a single-cylinder 661 cc spark ignition engine fueled by a mixture of gasoline (G) and essential oil from clove oil (EO) in various compositions. The composition of clove oil in gasoline fuel is formulated in 4 types of mixtures namely, 5 % EO + 95 % G is represented by the names EO5, EO10 (10 % EO), EO15 (15 % EO), and EO20 (20 % EO). The engine operated at a speed of 1200–1800 RPM (100 RPM increments) and a constant load of 3 kg. The load of the engine could be varied in the range of 1 - 12 kg (increment of 1 kg), and it was arranged on the panel

Figure 2. Testing engine of research.

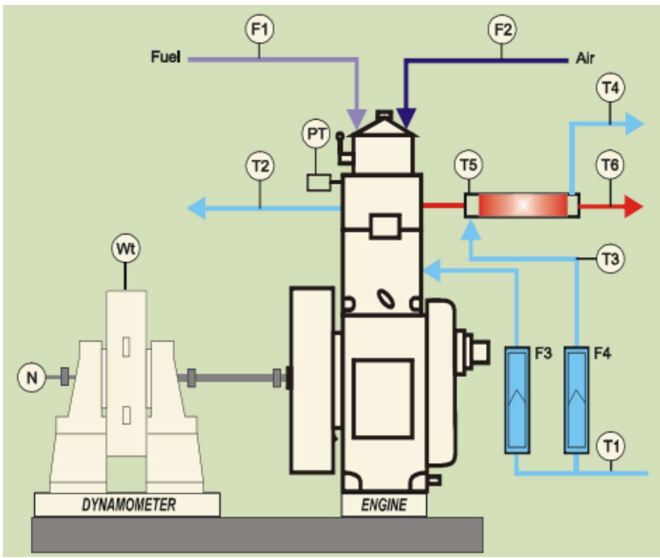

Figure 3. Schematic diagram of test engine.

T1 = Jacket water inlet temperature transmitter
T2 = Jacket water outlet temperature transmitter
T3 = Calorimeter water inlet temperature
T4 = Calorimeter water outlet temperature
T5 = Exh gas temp (engine)
T6 = Exhaust gas temperature (Calorimeter)
F1 = Flow of fuel
F2 = Flow of air
F3 = Air flow transmitter
F4 = Fuel flow transmitter
PT = Piezzo transducer
N = Engine load
WT = Water brake dynamometer

Table 2. The specification of the test engine.

Name of part	specification
Engine type	Four-stroke, SOHC
Number of cylinders	1
Stroke length	110 mm
Diameter	87.5 mm
Cylinder volume	661 cc
Length of connecting rod	234 mm
Max. Power	3.5 kW @1500 RPM
Range of speed	1200 – 1800 RPM
Range of compression ratio	6:1 – 10:1
Variation of injection timing	0 – 25° bTDC

engine's control monitor. The experiment was conducted in the combustion engine laboratory, mechanical engineering department, Faculty of Engineering Hasanuddin University Makassar using a research engine or engine-test rig, as shown in Figure 2 and Figure 3, and the specifications written in Table 2.

The engine combustion parameters are set to standard parameters, namely ignition timing on 12°bTDC and compression ratio of 10:1. The testing engine measurement uses an integrated computer system to obtain all experiment results through computer print-out. However, manual calculations have been carried out to validate the computer measurements using the fundamental formulas from many works of literature on thermodynamics and internal combustion engines.

4. RESULTS AND DISCUSSION

4.1 Fuel Energy Analysis

The energy potential of fuel can be known from the heating value of the fuel, which in this study found that the calorific value of gasoline is 44 MJ/kg with a density of 740 kg/m³. Meanwhile, the calorific value of essential oil is 126.95 MJ/kg with a specific gravity of 1066.3 kg/m³. Thus, the heating value and density of the fuel blend will increase as increase essential oil in the mixture. Figure 4 shows the energy produced from the combustion of gasoline and essential oil fuel blends under varying percentages of essential oil.

Based on Figure 4 it is known that the fuel energy of EO20 is higher than other types of fuel, and the smallest is pure gasoline fuel. The figure also indicates that the fuel energy increases when the percentage of essential oil in the blend increases. It is due to the caloric value will increase as an increase of essential oil in the blend. Meanwhile, fuel energy increases if the engine speed increases because the vaporization pressure and homogeneity of the fuel blend are better for the atomization process. The average fuel energy of gasoline and its blend is 9.41 kW for G100, 9.18 kW for EO5 kW, 10.87 kW for EO10, 11.50 kW for EO15, and 11.83 kW for EO20.

4.2 Indicative Power Analysis

Indicative power is power produced from the chemical reaction between air and fuel in the combustion chamber. Thus, the indicative power will increase with the increase in the calorific value of the fuel. This is shown in Figure 5 where the higher the calorific value of the fuel will produce a higher indicative power. However, the figure shows that the indicative power of EO15 is higher than EO20 on average. It is indicated that the homogeneity and atomization process of EO15 is better than EO20, so the combustion process is better and produces a higher indicative power.

The indicative power value of fuel combustion is also affected by the engine speed, so the indicative power increases when the engine speed increases. This is because an increase in engine speed will increase the cylinder temperature so that the heat of fuel vaporization will also increase. Figure 5 shows that the indicative power of EO15 is higher than EO20 because the density of EO15 is lower than that of EO20, making it easier to evaporate and produce well combustion.

In theory, the calorific value of the fuel will increase with an increase in the essential oil content up to 20 % in gasoline, which will have an impact on increasing the indicative power. However, the trend in Figure 5 indicates that the increase in indicative power is not dominated by the heating value of the fuel but is also influenced by the fuel density, cylinder temperature, and engine speed. The indicative power of E15 % is higher than that of E20 % at low engine speeds because the cylinder temperature is still low and cannot reduce the density of E20; thus, the atomization process becomes lower.

The average indicative power of G100 to EO20 fuel is 4.21 kW, 3.98 kW, 4.18 kW, 4.83 kW, and 4.57 kW, respectively. These results inform that the difference between fuel energy and indicative power is the loss of power through the exhaust gas, cooling system, and heat transfer. The power losses of G100 to EO20 fuel are 5.20 kW, 5.20 kW, 6.69 kW, 6.67 kW, and 7.26 kW, respectively. It shows the addition of essential oil concentration in gasoline will produce higher heat. This is the impact of the increase in calorific value so that heat losses become high.

4.3. Brake Power Analysis

Brake power is mechanical power by the crankshaft through the transfer of chemical energy in the combustion process in the

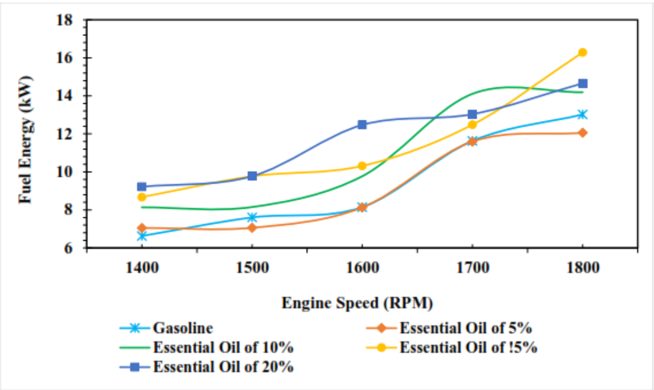

Figure 4. Fuel energy of gasoline and its blend.

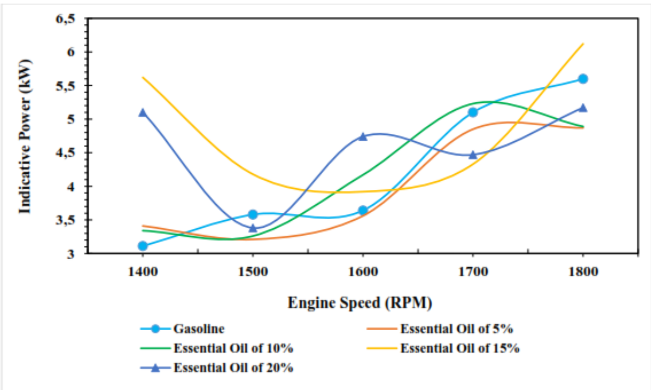

Figure 5. Indicative power of gasoline and its blend.

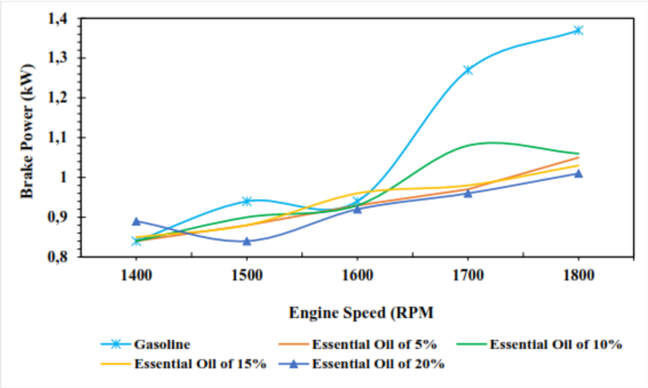

Figure 6. Brake power of gasoline and its blend.

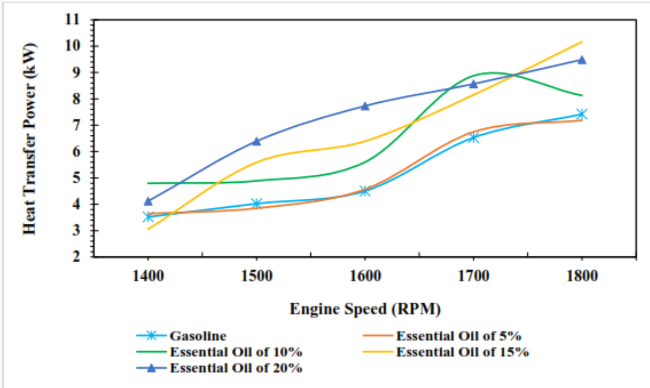

Figure 8. Heat transfer power of gasoline and its blend.

cylinder without losses in the clutch and transmission system. Brake power is the indicative power minus power loss due to friction or pumping. Figure 6 shows the highest brake power on average obtained on gasoline fuel. The figure also shows that the higher the essential oil composition in gasoline, the lower the brake power tends to be. It is due to the higher the essential oil content, the heating value of the fuel blend increases so that the heat generated also increases [23]. The high-temperature difference between the cylinder and the environment will increase heat loss due to heat transfer and friction [24].

4.4 Friction Power Analysis

In a mechanical system, energy loss due to friction is difficult to avoid but can minimized through the lubricating and cooling process for the moving engine components. In the previous analysis, the decrease in brake power was caused by increased power loss due to friction. Figure 7 shows that friction power increases when the concentration of essential oil in gasoline increases. It is because the high temperatures will cause an expansion in the material, so the potential for friction between moving engine components increases. Moreover, friction increases when the engine speed increases as shown in Figure 7. It is due to the faster repetition at high speeds which allows the moving engine components to rub together easily. In succession, the average power loss due to friction for fuel G100 to EO20 is 3.13 kW, 3.044 kW, 3.216 kW, 3.892 kW, and 3.646 kW, respectively.

4.5 Heat Transfer Analysis

Heat transfer occurs due to differences in temperature from one place to another. Therefore, the higher temperature difference between the system and its environment will increase the heat loss rate in the environment. Figure 8 shows the power loss due to the heat transfer process in the combustion of gasoline and essential oil in various blends. The figure shows that the loss of power due to the heat transfer will increase if the percentage of clove oil increases. It is because the calorific value of the fuel increases as the percentage of essential oil increases, so the system temperature increases. Figure 8 also shows that the power loss due to heat transfer between the system and the environment increases with increasing engine speed. This is because the high engine speed will have an effect on the atomization and the combustion process well done. High engine speed will cause the flow rate of the fuel into the cylinder to increase so that the heat energy generated becomes higher. Successively, the average power loss due to heat transfer from G100 to EO20 fuel is 5.20 kW, 5.20 kW, 6.46 kW, 6.67 kW, and 7.26 kW, respectively.

4.6 Brake Mean Effective Pressure Analysis

The brake mean effective pressure (BMEP) is the brake power divided by engine constants that consist of the number of cylinders, number of cycles, and dimensions of the cylinder, so that the trend of the BMEP value is similar to the brake power, as shown in Figures 6 and 9, and the analysis approach is also similar.

4.7 Specific Fuel Consumption Analysis

Specific fuel consumption indicates the quantity of fuel flow rate (in kilograms per second) required to generate 1 kilowatt of brake power. Figure 10 shows that specific fuel consumption increases as an increase the concentration of essential oil in gasoline. It means that high specific fuel consumption is produced when the fuel flow rate increases while the brake

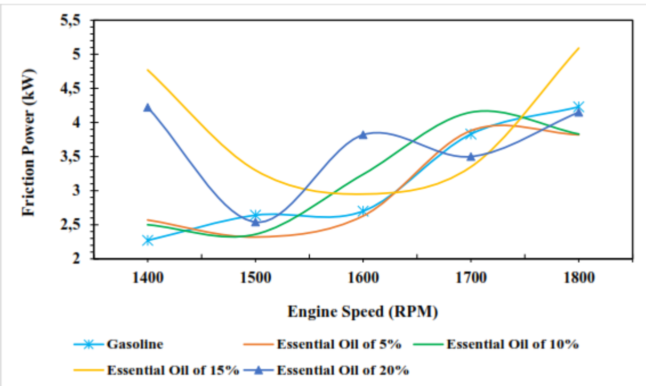

Figure 7. Friction power of gasoline and its blend.

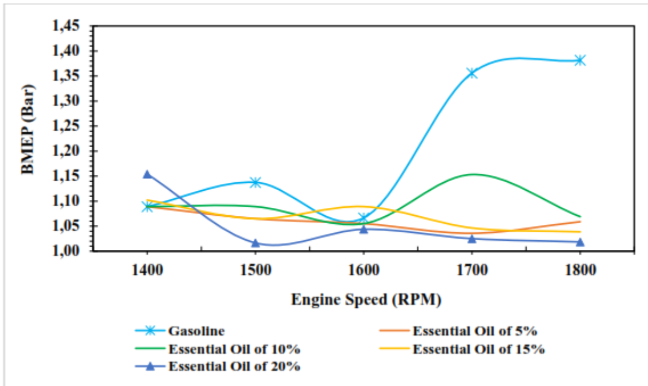

Figure 9. Brake mean effective pressure of gasoline and its blend.

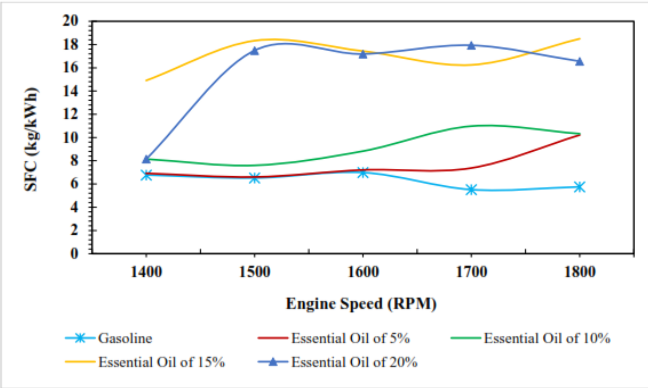

Figure 10. Specific fuel consumption of gasoline and its blend.

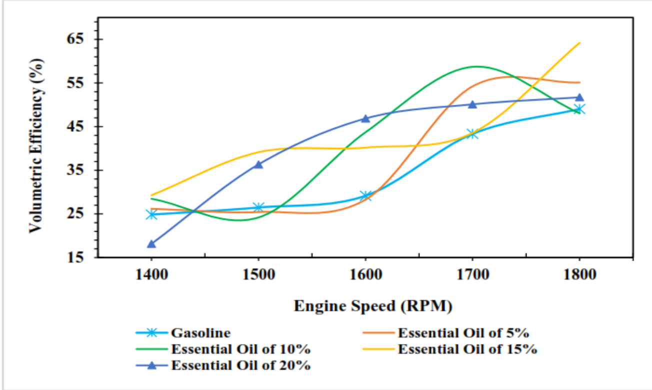

Figure 12. Volumetric efficiency of gasoline and its blend.

power decreases, and vice versa. Figure 10 shows that the changes in engine speed do not have a significant impact on the specific fuel consumption rate. This indicates that the ratio of fuel consumption and brake power generated at all engine speed variations tends to be steady. In this study, the average specific fuel consumption values for engines fueled by G100 to EO20 were $6.31\ \mathrm{kg/(kW \cdot h)}$, $7.66\ \mathrm{kg/(kW \cdot h)}$, $9.18\ \mathrm{kg/(kW \cdot h)}$, $17.08\ \mathrm{kg/(kW \cdot h)}$, $15.46\ \mathrm{kg/(kW \cdot h)}$, respectively.

4.8 Thermal Efficiency Analysis

Thermal efficiency is an engine performance indicator that shows the quantity of fuel energy converted into combustion heat which is measured in the form of indicative power. Therefore, the high indicative power produced will increase the thermal efficiency of combustion, and vice versa. Figure 11 shows the trend of decreasing thermal efficiency with increasing engine speed. Thermal efficiency decreases if the conversion of fuel energy into indicative power decreases. It is due to increased friction and heat transfer, as previously described and shown in Figure 7 and Figure 8. The average thermal efficiency values for fuel of G100 to EO20 are 45.11 %, 43.96 %, 39.11 %, 43.57 %, and 39.50 %, respectively.

4.9 Volumetric Efficiency Analysis

Volumetric efficiency shows the comparison between the actual air flow rate and the theoretical combustion air requirement. Thus, the volumetric efficiency increases when the factual air flow rate is equal to or close to the theoretical air requirement value. Volumetric efficiency indicates the engine's ability to induce air into the combustion chamber following theoretical air requirements. It aims to obtain stoichiometric combustion so that engine performance increases and combustion emissions decrease. Figure 12 shows that volumetric efficiency increases as the percentage of essential oil in gasoline increases. It is caused by the latent heat of vaporization of essential oil, so it will have a cooling effect on the combustion chamber so that airflow to the cylinder increases. Similarly, increasing speed will have an impact on increasing airflow into the combustion chamber so that volumetric efficiency increases. The average volumetric efficiency of G100 to EO20 fuel in this work is 34.57 %, 37.85 %, 40.62 %, 43.27 %, and 40.63 %, respectively.

4.10 Carbon Monoxide Emissions Analysis

The increase in carbon monoxide emissions is triggered by the inability of carbon elements to bind oxygen elements which is caused by several things, including insufficient air into the combustion chamber, low combustion temperatures, and inhomogeneous air-fuel blend conditions, causing incomplete combustion [25]. Figure 13 shows CO emissions resulting from burning gasoline and essential oil blends. The figure shows that CO emissions increase with the concentration of essential oil in gasoline increase, except at high speeds it tends to decrease. Based on previous analysis, the increase in CO emissions in this study was caused by the homogeneity of the fuel blend and the combustion temperature was not under the requirements for complete combustion. Low combustion temperatures are also triggered by the increasing number of essential oils in the mixed fuel due to the cooling effect of essential oils. The CO emissions of fuel G100 to EO20 are 0.072 %, 0.08 %, 0.073 %, 0.113 % and 0.13 %, respectively.

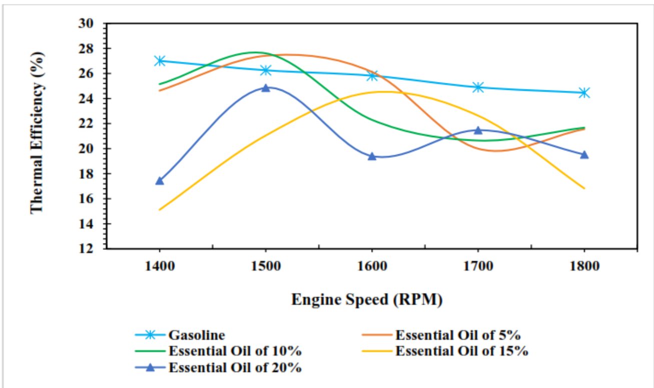

Figure 11. Thermal efficiency of gasoline and its blend.

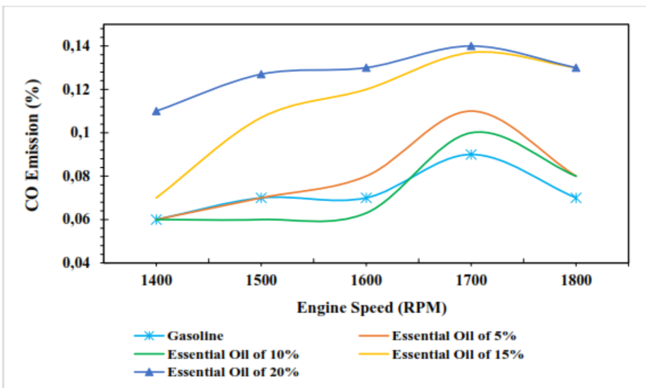

Figure 13. CO emissions of gasoline and its blend.

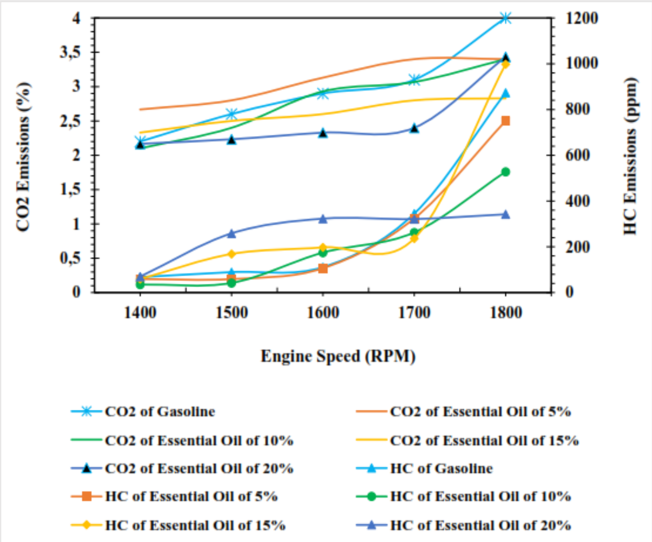

Figure 14. HC and CO_2 emissions of gasoline and its blend.

4.11 Carbon Dioxide and Hydrocarbon Emissions Analysis

Carbon dioxide is the main particulate in the combustion of fossil fuels, in addition to water vapor and nitrogen compounds. Stoichiometric combustion is obtained if the emissions that come out through the exhaust gas are carbon dioxide and water vapor if the oxidation process uses oxygen compounds. This is one indicator of engine performance where the need for combustion air is proportional to the mass of fuel injected into the combustion chamber to achieve complete combustion. Figure 14 shows CO_2 emissions that tend to decrease with increasing the percentage of essential oil in gasoline fuel. It can be because biofuels (bio-fossils) are hydroxyl compounds (OH) that contain oxygen compounds. Therefore, the mixture conditions become more stoichiometric as the percentage of essential oil in gasoline increases.

Meanwhile, CO_2 emissions increase when the engine speed increases. This is caused by the increased fuel flow while the combustion air flow decreased resulting in a rich mixture. The average CO_2 emission of G100 to EO20 fuel is 2.96 %, 3.08 %, 2.78 %, 2.61 %, and 2.51 %, respectively. Figure 14 also shows the tendency for HC emissions to decrease with increasing the percentage of essential oil, except for 10 % essential oil. The trend of increasing HC emissions also occurs with increasing engine speed. It is because the stoichiometric conditions of the mixture are difficult to obtain in rich mixture conditions, so the HC emission increases. The average HC emission values of G100 to EO20 fuel are 297.27 ppm, 259.67 ppm, 208.53 ppm, 332.0 ppm, and 262.93 ppm, respectively.

5. CONCLUSION

After carrying out a series of experiments and data analysis, several important things were found that were novelty from this research, namely:

1. This research is the first study using clove essential oil as a blended fuel with gasoline for spark ignition engines. Essential oils, especially clove oil, have been widely used by previous researchers both as additives and mixtures in diesel fuel for ignition compression engines.
2. The low solubility of essential oils, especially clove oil in gasoline, causes partial combustion of each fuel, and the results describe a fluctuating line graph.
3. Adding essential oil to gasoline fuel will increase the calorific value of the fuel and the engine's indicative power. However, almost all engine performance indicators decrease because most of it is wasted on the environment. Loss of heat through the walls in the form of radiation energy, heat in exhaust gases and cooling systems as well as friction.
4. Adding essential oil to gasoline will reduce CO_2 emissions, but at the same time, CO and HC emissions increase at an engine speed of more than 1600 RPM. It is indicated that stoichiometric conditions are obtained at engine speeds of 1400–1600 RPM. Meanwhile, HC and CO emissions increase sharply at engine speeds of more than 1600 RPM. It is because on an engine speed of 1600 RPM, the fuel is rich, and the ignition process does not work properly, resulting in incomplete combustion.

References in this article cited that as an additive, essential oil could improve engine performance if the concentration is less than or equal to 1 % in diesel fuel. These results provide a new challenge for further research using 0.5 to 3.5 % of essential oils in gasoline.

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