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CITRONELLA OIL AS BIOADDITIVES ON SI ENGINE PERFORMANCE CHARACTERISTICS

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Abstract

Current dynamics of world energy supply have driven various innovations by the industry as well as research communities. Fossil fuels, although experiencing a declining interest due to sustainability issues, remain undeniably crucial since they are nearly irreplaceable in some sectors including electricity generation, it is necessary to continuously establish efforts to improve efficiency of those kinds of fuel. In this work, the authors evaluate the potential of locally sourced essential oils, namely citronella, as a fuel additive in a vision of raising the fuel economy of gasoline RON 90. Citronella oil was selected based on a positive hypothesis deduced from its chemical properties, as mentioned in multiple published works. Tests were made on a generator-set powered by gasoline engine using the mixture of RON 90 and citronella oil of various concentrations as the fuels. In addition, a commercial synthetic additive was also tested alongside the essential oil to provide a comparative figure. Meanwhile other investigators suggest a favorable effect of essential oils, our results show that citronella oil additions lead to higher fuel consumption at the same power level. A similar negative effect was also demonstrated by the synthetic additive. The only sector showing positive results is in terms of exhaust temperature where experiments with citronella additives create lower exhaust temperature as compared to pure gasoline and synthetic additives. However, rooms for innovation remain open by exploring other variables such as higher additive concentrations or combining different kinds of essential oils.

Keywords: *Bio Additives, Citronella Oil, Gasoline, Engine Performance, SI Engine.*

1. INTRODUCTION

Global energy demand is increasing almost every day in line with technological developments and increasing human needs. In the future decades, demand will be driven because of an increasing human population desiring affordable energy. Currently, energy from fossil fuels cannot be sustainable because of their limited supply on earth. This will result in an energy crisis if it occurs in the long term. Therefore, the need for alternative energy sources that are environmentally friendly and sustainable is needed to support energy needs in the future.

The growth in world population and industrialization has resulted in a huge increase in fossil fuel use. Petroleum-based fuels as commonly used in today's machineries and vehicles are unsustainable by nature. Resources are estimated to be limited. The endeavor to diminish the superiority of fossil fuel as the energy source of internal combustion engines has become

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essential in terms of reducing dependence on oil and avoiding an oil crisis with minimal losses in the future. As a consequence, numerous studies have been conducted in order to get efficient fuel oil in the internal combustion engine, which has been accelerated in order to reach the expected target.

Engine fuel has an important role in vehicles. Without a good fuel composition, the vehicle will not be able to work with good performance. Therefore, the composition of the fuel that will enter the engine combustion chamber will affect the combustion reaction that occurs at the onset of the power stroke. Higher octane rating fuels have been one of the solutions to solve the problem of fuel wasting caused by the fuel combustion process in gasoline engines [1]. This ensures that the combustion process is completed entirely. When the fuel has a high octane number, the combustion process in gasoline-powered vehicles is more efficient. Good fuel characteristics and sufficient oxygen availability are two factors that determine the quality of gasoline fuel. The density, viscosity, aniline point, and diesel index of gasoline fuel are all factors that influence its performance [2].

Reformulating the fuel with additives that enrich the oxygen content in the fuel is an alternative for improving fuel combustion efficiency and reducing pollution [3]. The additive is intended to upgrade the characteristics of the base fuel so as to improve the overall combustion performance and suppress the emission of unfavorable gases [4]. Natural additives (bioadditives) obtained from plants and chemical additives (synthesis) obtained through chemical processes are currently the two types of additives commonly used in fuel mixtures. With the current global geopolitical circumstances that spreads into multidimensional crises including energy, it becomes a matter of national interest to strengthen energy sovereignty by reducing dependencies to foreign resources. As a net importer of oil [5], Indonesia is susceptible to oil supply volatility governed by other major producers, hence any disruption in the outside world will adversely impact national energy stability that in turn converts into a multitude of problems. Renewable energy, despite being massively endorsed by the government, is still in its infant stage in terms of contribution to the Indonesian energy mix scenario. Eventually, fossil fuels still see a long way ahead as the country's primary energy sources. Since national oil lift and refinery capacity cannot cope with the domestic demand, reducing fossil fuels consumption becomes a common-sense solution. All those things considered, the authors believe that it is important to find a way to increase fuel efficiency and the solution must come from local resources. Therefore, exploring essential oils as fuel bioadditives to improve fuel economy is in line with the issue outlined above: revealing the potential of these homegrown commodities to reduce fuel consumption.

Indonesia has abundant natural resources and a high potential for assisting in fuel conservation and preservation. So that the selection of bioadditives as an alternative fuel mixture can be a breakthrough to carry out this fuel reformulation process. The use of bioadditives as a fuel mixture is encouraged because the oxygen content can optimize the combustion process in the combustion chamber, reducing fuel consumption [6]. Essential oils are oxygenated hydrocarbon compounds that are rich in oxygen [7]. Some of the most commonly used as essential oils are extracted from clove [8], patchouli [9], mandarin [10], eucalyptus [11], sweet orange peel [12], and lemongrass [13]. Essential oil distillation from citronella has characteristics that are similar to or close to the characteristics of fuel oil, such as specific gravity, boiling point, and volatile properties. Citronella oil is composed of specific hydrocarbon organic compounds and oxygenated hydrocarbons. That hydrocarbons content becomes the underlying reason of citronella's potential as a bioadditive [14].

Several investigators have elaborated and studied the potential of citronella oil as bioadditives, however the authors found out that those works were experimented on diesel (CI) engines [15, 16]. Meanwhile, the characteristics of citronella on which the other investigators describe as favorable for a CI engine are also beneficial for SI engine, mainly pertaining to the oxygen content [17]. Thus, in this work, the authors introduce citronella oil as bioadditive for gasoline that power a SI engine. The major purpose of this study is, therefore, to observe and analyze the effect of citronella bioadditive on the fuel economy of a SI engine and compare the results with those observed in CI engine.

2. METHOD AND MATERIAL

This study aims to produce a fuel mixture that is intended to improve fuel economy of spark-ignited internal combustion engines. To prepare the fuel blends, citronella oils of certain concentrations are mixed with comercial RON 90, as illustrated in Figure 1. In line with this goal, the fuel mix is made using four percentage compositions of ingredients consisting of citronella oil as a bioadditive with various percentages of 0% (pure gasoline), 0.3%, 0.6%, and 1% mixed with gasoline with pertalite type to test in a gasoline engine. In addition, it also mixes synthetic additives obtained in the market with gasoline to compare with other mixtures. Table 1 lists all the fuel samples used in our experiments.

Citronella oil contains citronellal, citronellol and geraniol [18]. These compounds have bonds, interactions, and properties that resemble essential oils, which have been used in bioadditive applications. The composition of citronellol, citronellol, and geraniol reflects the oxygen content that affects the combustion process in engines. Oxygenates are the key to a higher octane rating and can improve or minimize knock tendency in a gasoline engine [19]. It also helps boost fuel economy by reducing the need for regular and premium-grade fuels. Citronella oil is an excellent choice for use as a hydrocarbon oxygenate additive because it burns with a clean, smokeless flame, which improves engine efficiency and increases horsepower. Increased engine efficiency indirectly indicates optimal combustion in the combustion chamber to reduce fuel consumption. Therefore, many studies have been carried out on essential oils from citronella to formulate them into additives to improve the performance of fuel oils [17]. Some physical and thermal characteristics of citronella oil are tabulated in Table 2.

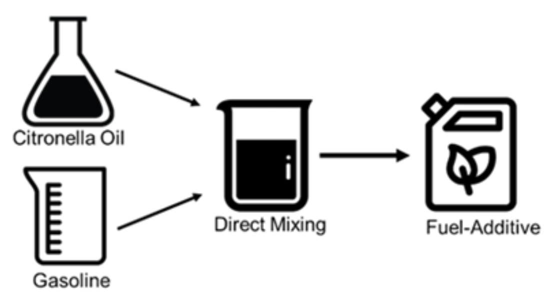

Figure 1. Blending of citronella oil-gasoline fuel.

Table 1. Different fuel-additive blends used in experiments.

No.	Formulation
1	RON 90
2	RON 90+0.3% Citronella Oil
3	RON 90 +0.6% Citronella Oil
4	RON 90 +1% Citronella Oil
5	RON 90 +Synthetic Additive

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Table 2. The characteristics of citronella oil [16]

No.	Properties	Value
1	Kinematic viscosity, cSt at 40ºC	52.4
2	Specific gravity at 15ºC	0.94
3	Flash point, ºC	94
4	Fire point, ºC	100
5	Calorific value kJ/kg	41400
6	Density, kg/m³	0.89

Engine performance testing is carried out at constant engine speed with different electrical load variations with parameters including: torque, brake thermal efficiency (BTE), brake mean effective pressure (BMEP), specific fuel consumption (SFC), and exhaust temperature [20, 21]. Experiments were conducted by varying the output load of the generator set from 200 W to 2000 W at the increment of 200 W. In all cases, the engine speed was kept constant at 2500 rpm. During the experiments, we measured the output power, fuel consumption, and exhaust temperature. Those measurement results were in turn being used to calculate the parameters of interest (BTE, BMEP, and SFC). The equipment involved in our experiment was comprised of a four-stroke engine, single cylinder 0.196 liter which is mainly used in household electrical generators. Acting as the electrical load, an array of independently switched filament bulbs were connected to the output line of the generator. The specifications of the test engine using an electrical generator were comprehensively tabulated in Table 3.

Table 3. Test Engine Specifications.

No.	Specification	Description
1	Power Input (Maks)	2.2 KVA (at 50 Hz)
2	Power Output (Average)	2.2 KVA (at 50 Hz)
3	Frequency	50 Hz
4	Voltage	220 V/ Single Phase
5	Type	Single cylinder, 4-stroke, air cooled
6	Starter System	Recoil Starter
7	Ignition System	Transistorized Magneto
8	Fuel Capacity	14.5 L
9	Lubricating Oil Capacity	0.6 L
10	Noisy Level	95 dB
11	Dimension	591 mm x 432 mm x 462 mm
12	Cylinder Volume	196 cc

Figure 2 demonstrates the configuration of the experiment and equipment settings. The engine settings have been modified in a number of ways to simplify the process for authors to keep track of all measurement-related activities, such as electrical load, engine speed, and fuel mass flow rate. The data were collected three times for data sampling to determine the average fuel consumption for various variations in electrical load. The fuel consumption data was collected using measuring cylinders at intervals of every 5 ml of fuel consumed. Measurement of engine speed is controlled using a tachometer with a constant speed of 2500 rpm. A clamp meter was used to measure the electrical load, which varied from 200 to 2000 W depending on the number of parallel-connected light bulbs being used. A flow chart can be used during the experiment to confirm that the experimental design has been implemented properly. Figure 3 illustrates the experiment's flow chart. After the experiment was completed successfully, the outcomes were examined and discussed.

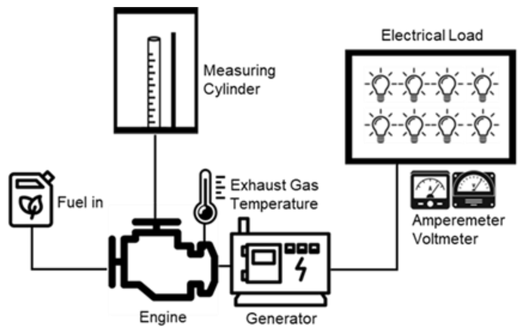

Figure 2. Test Engine.

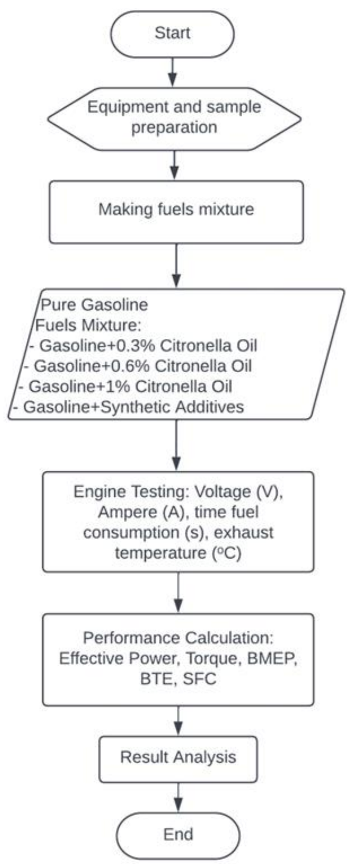

Figure 3. Schematic flowchart for experimental methodology.

3. RESULT AND DISCUSSION

The ability of the engine to do work can be seen from the performance of the internal combustion engine when converting the chemical energy of the fuel into useful mechanical work. Several engine performance parameters will be calculated in this section, including effective power parameters, torque values, BMEP, BTE, SFC, and exhaust gas temperature. Those values are to be obtained for all of the fuel blends samples in Table 1 and then the results will be compared to each other. The following outcomes were obtained based on the calculation data.

3.1. Engine Characteristics.

This experiment result will display the characteristics of different variations of fuel mixtures. There are five types of fuel mixtures that were used for this particular experiment i.e. pure gasoline, 0.3% citronella oil, 0.6% citronella oil, 1% citronella oil and synthetic additive with various electrical loads at constant engine speed 2500 rpm. Based on the results of experiments that have been carried out, several graphs of engine characteristics are obtained which consist of effective power, torque, BMEP, and BTE. After analyzing each graph as shown in Figure 4, it shows the same trend for the effective power, torque, BMEP, and BTE at different variations of fuel mixtures.

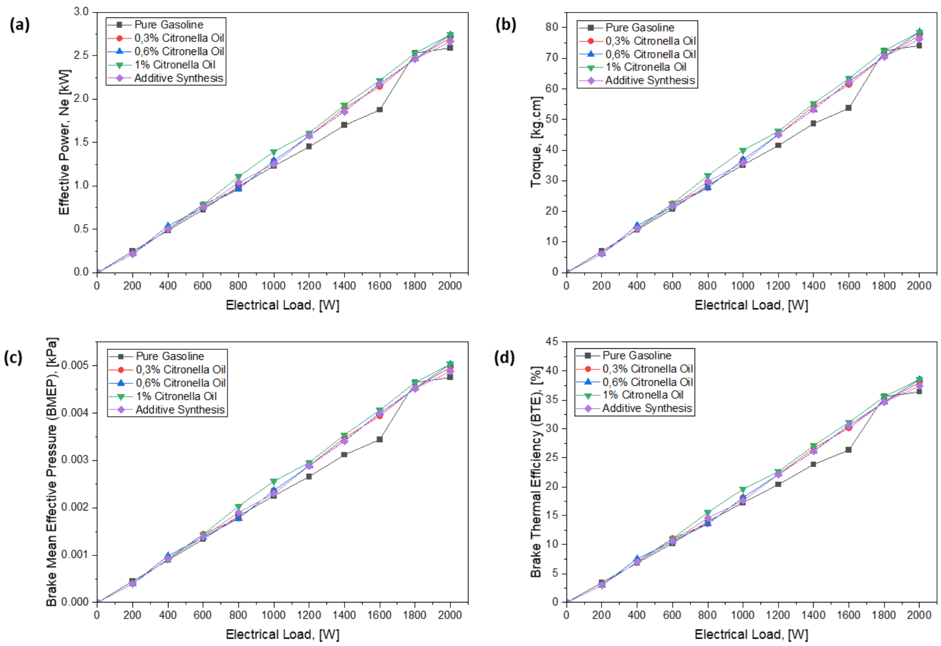

Figure 4. Engine characteristics at different electrical loads and fuel samples: (a) effective power, (b) torque, (c) BMEP, and (d) BTE.

In this study, mechanical power is obtained by operating an engine to control an electrical load as specified. Figure 4 (a) shows the values of effective engine power based on electrical load variation for different fuel mixtures at a constant engine speed of 2500 rpm. For electrical loads between 200 and 1000 W, the effective power trend of pure gasoline is very close to that of the other fuel variations. The effective power trend for pure gasoline shows a sharp decrease for a load of 1000–1800 W. However, on average, the effective power rises as the electrical load rises for use with all variations of the fuel mixture. The coupling of the engine to an electric generator, where the voltage, current, and efficiency of the generator affect the amount of electrical load, is responsible for this rise in effective power.

As a result, the higher the electrical load, the higher the effective power for all variations of the fuel mixture [22].

Figure 4 (b) illustrates the variation in torque induced by the fuel mixture as a result of the electrical load on an engine running at a constant speed. On all variations of the fuel mixture, as depicted in the figure, the torque will rise as the electrical load rises up to 2000 W. The increase in torque that results from an increase in electrical load correlates with an increase in effective power and the effect of mechanical losses. The same findings for the increase in torque to electrical loads were also found in another study [23, 24]. In terms of torque, the 1% citronella additive yields the highest value among other samples, while the plain gasoline is in the bottom rank. One possibility behind this phenomena is because of the higher latent evaporation temperature of citronella compared to pure gasoline [25], hence higher concentration of the additive will pronounce the effect.

Brake Mean Effective Pressure (BMEP) is the average pressure that causes the piston to move with the intention of generating a measurably torque on the crankshaft. The BMEP for each fuel mixture is shown in Figure 4 (c) along with variations in electrical load. BMEP will increase with increasing electrical load [26]. For all fuel mixtures, the highest BMEP value was attained at a maximum load of 2000 W. As can be seen, at all loads, the fuel mixture containing 1% citronella oil has the highest BMEP value. The number of engine cylinders, the cross-sectional area of the piston, and the length of the piston stroke all have a significant impact on the BMEP value. The characteristics of the fuel and the engine design parameters also have an impact on the amount of BMEP. For the various fuel mixtures used, Nwufo et al. [27] reported the correlation of BMEP with engine torque based on engine speed.

Brake Thermal Efficiency (BTE) can be defined as the ratio between the actual output power to the heat energy used in the combustion chamber for the combustion process. Generally speaking, the combustion process attempts to convert the heat energy existence in the fuel into mechanical energy for the purpose of generating work. Figure 4 (d) displays the BTE value for each fuel mixture with varying electrical load while maintaining a constant engine speed. Pure gasoline fuel, fuel mixtures with citronella oil ratios of 0.3%, 0.6%, and 1%, and additive synthesis all demonstrated an increase in BTE along with an increase in electrical load. For all variations of the present fuel mixture, the BTE value range from the smallest of 3% and the highest of 39%. When compared to other fuel mixture variations in electric load variations, the highest BTE was obtained at 1% citronella oil fuel mixture variation, and the lowest value was for pure gasoline. The amount of effective power and specific fuel consumption (SFC) have a significant impact on BTE, which explains that an increase in BTE corresponds to an increase in electrical load [28].

3.2. Fuel Consumption.

The graphs in figure 5 describe the specific fuel consumption for various fuel mixtures at different electrical loads. As common sense may lead, a lower SFC reflects a higher efficiency engine [29]. This observation confirms that the value of specific fuel consumption will be lower when the electrical load increases for all variations of the fuel mixture [30]. Trends for each fuel mixture show results close to each other. The results did not show a significant difference, in pure gasoline or a mixture of bioadditives and synthetic additive fuels blends. According to test results for an electrical load of 1200–1600 W, a mixture of citronella oil fuel with a variation of 0.6% shows the best specific fuel consumption when compared to all other fuel mixtures, but on a different electrical load it reveals that the specific fuel consumption of pure gasoline is lower than various other existing fuel mixtures. Additionally, at low electrical loads, between 400 and 600 W, synthetic additive mixtures show relatively low specific fuel consumption. SFC values are influenced by fuel properties and engine operating conditions. The properties in question are, as reported by investigators, the calorific value and density [31].

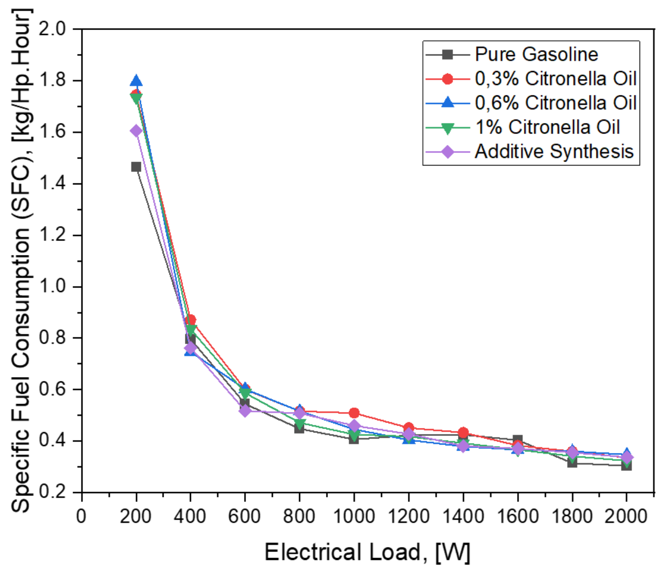

Figure 5. Specific Fuel Consumption at different electrical loads and fuel samples.

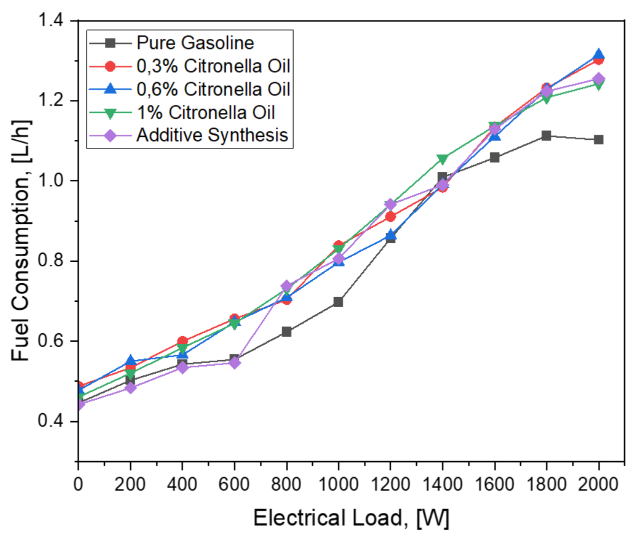

Figure 6. Fuel Consumption at different electrical loads and fuel samples

Figure 6 shows the effect of the additives on fuel economy. It can be seen that gasoline with citronella oil of 0.6% has a lower value of consumption per unit time at an electrical load of 800-1600 W than other ratio citronella oil added to gasoline, but for other electrical loads pure gasoline does have the best savings value compared to other fuel blended. Although the intention of additives is to reduce fuel consumption, it turned out that both bioadditives and synthetic additives were not making significantly positive influence. Other investigators have experimented with citronella additives in diesel fuels and obtained diverse and even contradictory results in terms of fuel economy, either positive [16, 32] or neutral to negative [15]. Our study indicates that for gasoline, citronella additives do not provide any favorable result in fuel saving, which is similar to the latter reference. The possible cause of this negligible effect is that the engine combustion has taken place at the stoichiometric mixture, hence all fuel has been burned. Thus, the additional oxygen content from citronella oil will serve nothing and simply be released during the exhaust stroke.

3.3. Exhaust Gas Temperature.

The temperature of the exhaust gas is another test method to evaluate the performance of an engine. The temperature of the gas leaving the engine exhaust manifold is evaluated during the measurement process. Engine failure can occur when the temperature of the exhaust gas in the engine is too high. The possibility remains that high exhaust gas temperatures will melt metal components, joint areas, and even cause catastrophic failure [33, 34]. For this reason, measuring the exhaust gas temperature is crucial in order to determine the performance of the engine according to the type of fuel mixtures used in the combustion chamber.

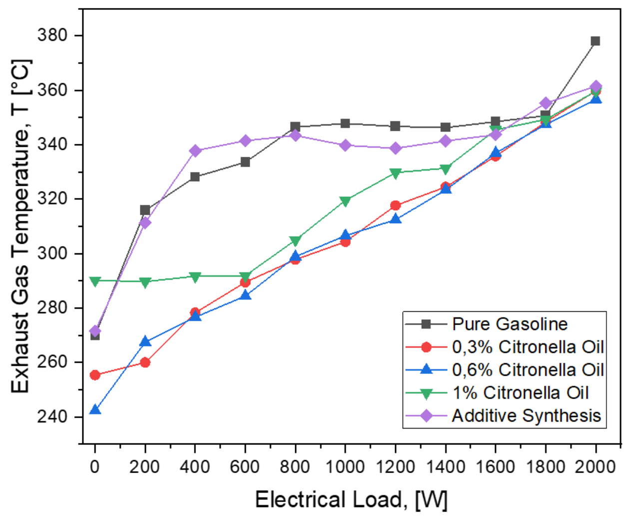

Figure 7. Exhaust gas temperature at different electrical loads and fuel samples.

The trend of exhaust gas temperature as a function of electrical load is depicted in Figure 7. As can be seen, when the electrical load is low, around 0 and 1600 W, the exhaust gas temperature for pure gasoline, citronella oil and synthetic additives mixture tends to rise. This reaches its maximum value at an electrical load of 800 W, or about 343 to 347°C. However, at electrical loads higher than 1600 W, all variations of the fuel mixture have exhaust gas temperatures that are reasonably close to the result. Overall, in all variations of electrical load ranging from 0-2000 W, the use of citronella oil as an additive demonstrates that the exhaust gas temperature results are quite low in comparison to pure gasoline mixtures or synthetic additives. Based on the results, it can be concluded that adding citronella oil to pure gasoline can lower the temperature of the exhaust gas. This occurs as a result of an increase in the combustion reaction and an increase in the relatively high oxygen concentration in the fuel mixture. These findings indicate that adding citronella oil additives has positive benefits for reducing exhaust gas temperature [15].

4. CONCLUSION

Citronella oil with various concentrations had been experimented as bioadditive for a RON 90 (Pertamina Pertalite) gasoline. This work was motivated by the previous works published by other investigators that hypothesized positive effects of essential oils, including citronella. However, analysis on our experimental results show negligible change in engine power characteristics, after the addition of citronella oil into the base gasoline fuel. Moreover, fuels with citronella additive at any tested concentration show higher fuel consumption compared to the pure RON 90 gasoline. These results therefore contradict with the hypothesis and conclusions drawn by other investigators. Keep in mind that the other investigations we referred to are based on diesel fuels, and in fact they are also contradicting with each other. In our case where we apply the bioadditive to gasoline, we attribute this negligible to negative effect to the already stoichiometric mixture of fuel and oxygen in the combustion chamber, hence additional oxygen expectedly supplied by citronella will not create any effect. Another observation that is worthy of remark in this experiment emerges from the results of experiments with synthetic additives, where it also yields negative results. All in all, the author concludes that the citronella oil and synthetic additive do not render any encouraging effect in the case of generator set operations as in the experiments conducted in this work. The only sector where observation shows positive results is in terms of exhaust temperature where experiment with citronella additives create lower exhaust temperature as compared to pure gasoline and synthetic additives. Nevertheless, this work evaluated a limited range of additive concentration, thus the possibility for further investigations to acquire positive results at higher concentration levels remain open.

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