THE EFFECT OF ADDING CLOVE OIL BIOADDITIVE TO PERTAMAX RON 92 AND BIOETHANOL MIXTURE ON EXHAUST GAS EMISSIONS AND FUEL CONSUMPTION OF 1000 W GASOLINE GENERATOR

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ABSTRAK

Ketergantungan pada bahan bakar fosil mendorong pemanfaatan bioetanol sebagai komponen pencampur bensin, tetapi formulasi campuran masih perlu dioptimalkan agar emisi menurun tanpa memperburuk konsumsi bahan bakar. Penelitian ini bertujuan menganalisis pengaruh penambahan bioaditif minyak cengkeh pada campuran Pertamax RON 92 dan bioetanol terhadap emisi gas buang serta konsumsi bahan bakar genset bensin 1000 W. Penelitian dilakukan secara eksperimental menggunakan variasi bioetanol E2,5; E5; E7,5; dan E10 serta minyak cengkeh 1-5 ml per liter bahan bakar. Parameter yang diukur meliputi konsumsi bahan bakar, HC, CO, dan CO2 pada beban 500, 750, dan 1000 W. Data dianalisis menggunakan MANOVA dan indeks efektivitas De Garmo. Hasil menunjukkan bahwa konsentrasi bioetanol berpengaruh signifikan terhadap konsumsi bahan bakar dan emisi gas buang (MANOVA, $p < 0,05$), sedangkan konsentrasi minyak cengkeh tidak berpengaruh signifikan pada sebagian besar kondisi operasi. Campuran Pertamax RON 92 E10 MC4 merupakan formulasi terbaik berdasarkan indeks efektivitas De Garmo dengan NH sebesar 0,827. Dibandingkan Pertamax Green 95, campuran E10 MC4 menurunkan HC hingga 69,2%, CO hingga 62,9%, dan CO2 hingga 53,9%, tetapi meningkatkan konsumsi bahan bakar pada beban rendah. Penurunan CO2 yang diamati merupakan konsentrasi volumetrik gas buang yang terukur oleh gas analyzer, bukan emisi massa karbon total. Temuan ini menunjukkan bahwa optimasi kadar bioetanol lebih menentukan peningkatan kinerja lingkungan dibandingkan variasi dosis minyak cengkeh.

Kata kunci: bioetanol; emisi gas buang; konsumsi bahan bakar; minyak cengkeh; Pertamax RON 92

ABSTRACT

Dependence on fossil fuels encourages the use of bioethanol as a gasoline blending component; however, the blend formulation must be optimized to reduce emissions without worsening fuel consumption. This study aimed to analyze the effect of clove oil bioadditive in Pertamax RON 92-bioethanol blends on exhaust emissions and fuel consumption of a 1000 W gasoline generator set. An experimental method was applied using bioethanol variations of E2.5, E5, E7.5, and E10, combined with 1-5 ml of clove oil per liter of fuel. The measured parameters were fuel consumption, HC, CO, and CO2 at 500, 750, and 1000 W loads. The data were analyzed using MANOVA and the De Garmo effectiveness index. The results show that bioethanol concentration significantly affected fuel consumption and exhaust emissions (MANOVA, $p < 0.05$), whereas clove oil concentration was not significant under most operating conditions. The Pertamax RON 92 E10 MC4 blend was the optimum formulation, with an effectiveness score (NH) of 0.827. Compared with Pertamax Green 95, E10 MC4 reduced HC by up to 69.2%, CO by up to 62.9%, and CO2 by up to 53.9%, but increased fuel consumption at low load. The observed decrease in CO2 represents the volumetric concentration measured by the gas analyzer, not total carbon mass emissions. These findings indicate that optimizing bioethanol concentration is more decisive for environmental performance than varying the clove oil dosage.

Keywords: *bioethanol; exhaust emissions; fuel consumption; clove oil; Pertamax RON 92*

INTRODUCTION

Energy needs for productive activities still rely on fossil fuels, including small-scale portable power generation engines. Gasoline generators are widely used because they are easy to operate and widely available, but their exhaust emissions contribute to air pollution. The parameters of HC, CO, and CO2 are important indicators because they describe non-combustible fuels, incomplete combustion, and carbon oxidation products in exhaust gases.

In gasoline engines, fuel quality and the air-fuel mixture ratio affect emission formation. Gasoline with a higher octane rating can increase resistance to *knocking*, while the oxygen component can assist the oxidation process during combustion. Bioethanol is one of the most studied oxygenates because it has a high octane number, contains

oxygen, and is derived from renewable materials [1]-[6].

State-of-the-art research shows three groups of approaches. The first group tested octane differences and gasoline-bioethanol blends to reduce emissions and improve engine performance [1]-[6]. The second group used essential oil bioadditives, such as eucalyptus oil, citronella oil, and clove oil, as additives in gasoline [7]-[10]. The third group began to assess the selection of the best treatment using a *multi-parameter* approach because one mixture may be good in one parameter but weak in another.

Bioethanol can currently be considered the most mature method for gasoline blends because it is already available in low-grade formulations such as E5 and E10. Bioethanol increases the oxygen content of the fuel, resulting in more complete combustion and reduced HC and CO emissions. However, bioethanol also has a lower calorific value compared to gasoline, so fuel consumption has the potential to increase if formulation and operating conditions are not correct.

Clove oil contains eugenol, which theoretically can increase oxygen contribution in the fuel mixture. The addition of this additive is expected to help oxidize soot and CO in the combustion chamber. However, quantitative evidence regarding the effectiveness of clove oil in the Pertamax-bioethanol mixture is still limited, especially for small generator engines operating at several load levels.

The research gap in this study is the lack of studies testing three components simultaneously, namely Pertamax RON 92, bioethanol, and clove oil, in a 1000 W gasoline generator. Some previous studies have only compared gasoline-bioethanol or gasoline-bioadditives. Another gap is the absence of a ranking of the best blends based on fuel consumption, HC, CO, and CO2 simultaneously.

This study aims to analyze the effect of variations in bioethanol E2.5, E5, E7.5, and E10 as well as clove oil in 1-5 ml on fuel consumption and exhaust gas emissions of a 1000 W generator. The novelty of this research lies in the integration of the Pertamax RON 92-bioethanol-clove oil mixture, evaluated using a multivariate statistical approach (MANOVA) and the De Garmo decision-making method to determine the optimum formulation based on several emission and fuel consumption indicators simultaneously.

The hypotheses of this study are: (1) increasing bioethanol content significantly reduces HC and CO; (2) adding clove oil affects emissions and fuel consumption; and (3) there is an optimal combination that produces the best compromise between fuel consumption and emissions. These hypotheses are then compared with the results of MANOVA and De Garmo rankings.

RESEARCH METHOD

The type of research is a quantitative experiment. The independent variables consist of bioethanol content and clove oil volume, while the dependent variables are fuel consumption, HC, CO, and CO2. Electric loads of 500, 750, and 1000 W were treated as operating conditions to observe the mixture's sensitivity to load changes.

The test object was a Fujigen 1500 PS four-stroke gasoline generator with a maximum output power of 1000 W, voltage of 220 V, frequency of 50 Hz, and nominal speed of 3000 rpm. The generator was operated without mechanical modifications so that the results reflected the possibility of mixing applications in commercial engines.

The research materials included Pertamax RON 92 as the base fuel, Pertamax Green 95 as a reference for comparison, commercial bioethanol, and clove oil as bioadditives. Bioethanol was mixed at 2.5%, 5%, 7.5%, and 10% by volume. Clove oil was added to each mixture at doses of 1, 2, 3, 4, and 5 ml per liter.

The research equipment consists of *a Koeng KG-500 four gas analyzer* to measure HC, CO, and CO2, a burette and measuring cup to measure fuel and bioadditives, *a stopwatch* to calculate consumption time, and an electrical load circuit to maintain the test load. *The gas analyzer* is used after the heating and stabilization process of the engine.

Material preparation was carried out by measuring Pertamax RON 92, bioethanol, and clove oil according to the composition. The mixture was homogenized before being fed into the fuel system. Each test began with checking for leaks, rotation stability, load conditions, and readiness of measuring instruments.

The data collection procedure was carried out by operating the generator at a certain load, waiting for stable conditions, recording the depletion time of a certain fuel volume, then reading the HC, CO, and CO2 values from the *gas analyzer*. The unstable data were repeated until a similar reading pattern was obtained.

Fuel consumption rate is expressed in ml/s. Emission data are expressed as HC in ppm, CO in volume percentage, and CO2 in volume percentage. To determine the significance of the treatment factors, MANOVA was used with a significance level of 0.05. The best mixture was selected using the De Garmo effectiveness index method based on the optimization direction, the

lower the optimization direction, the better the consumption and emissions.

The success criteria for the study are obtaining a mixture with the highest total NH, lower emissions than the reference fuel, and consumption that does not increase extremely. With this criterion, the best blend does not have to be the lowest in all parameters, but provides the best compromise overall.

Table 1. Fuel treatment design

Components	Variations	Description
Base fuel	Pertamax RON 92	Mix main controls
Comparison	Pertamax Green 95	Emission and consumption references
Bioetanol	2,5%; 5%; 7,5%; 10%	Mixed volume fraction
Clove oil	1-5 ml/L	Bioaditif MC1-MC5
Generator load	500; 750; 1000 W	Test operating conditions

The research methodology flowchart in this study :

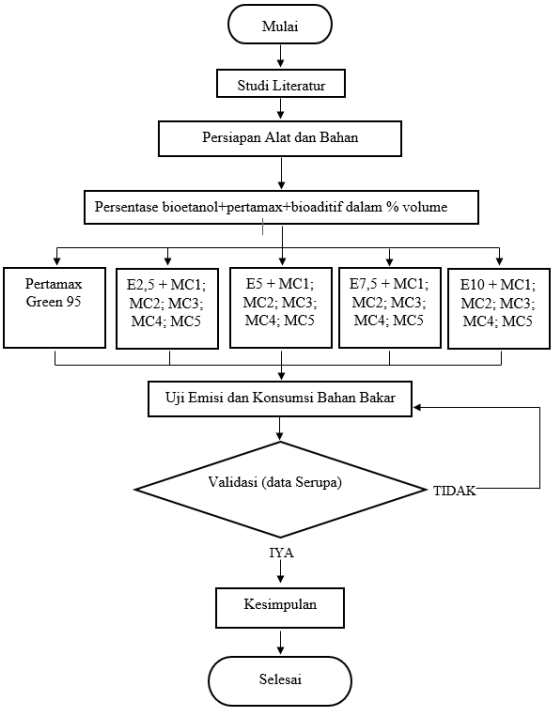


Figure 1. Research Flowchart

RESULTS AND DISCUSSION

In terms of fuel consumption, Pertamax Green 95 has reference values of 0.070 ml/s at 500 W, 0.060 ml/s at 750 W, and 0.060 ml/s at 1000 W. The minimum test mixture values are 0.063 ml/s, 0.053 ml/s, and 0.060 ml/s, respectively. Thus, the clearest improvement occurs at a load of 750 W, while at a load of 1000 W, the best mixture produces values equivalent to the reference values.

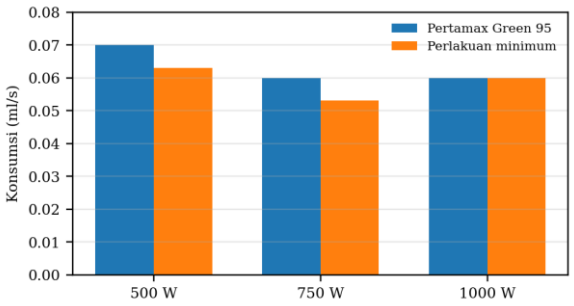


Figure 2. Reference fuel consumption and minimum treatment.

For the HC parameter, the mixture of E10 with 5 ml clove oil showed the most consistent results. The HC value dropped from the reference of 189 ppm to 77 ppm at 500 W, from 224 ppm to 101 ppm at 750 W, and from 189 ppm to 75 ppm at 1000 W. This decrease indicates that adding bioethanol at higher concentrations can help reduce unburned hydrocarbons.

CO values showed a significant decrease especially at a load of 750 W, from 5.4% to 0.3% by volume. At 500 W, the minimum CO value obtained was E10+MC4 at 2.7% volume, while at 1000 W the minimum value was E7.5+MC4 at 1.7% volume. Lower CO indicates a tendency for more complete combustion, although the mixture response is still influenced by load and additive composition.

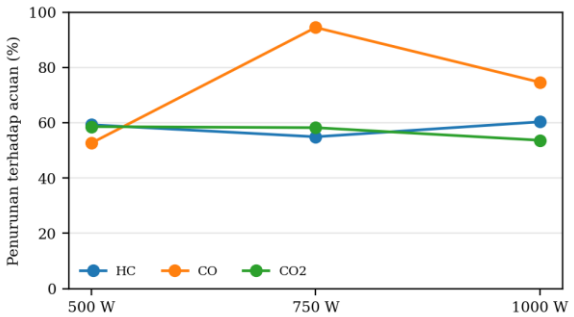


Figure 3. Percentage reduction of HC, CO, and CO_2 relative to the reference.

The CO_2 pattern shows that the minimum value is in the range of 5.3-5.7% volume for loads of 500-1000 W. Although CO_2 is often associated with more complete combustion, the CO_2 reduction in this study cannot be directly interpreted as a decrease in total carbon emitted. The reported values represent volumetric concentrations from gas analyzer readings and are not mass-based emission factors. Therefore, the final assessment needs to consider fuel consumption, HC, CO, CO_2, and effectiveness values simultaneously.

The De Garmo method synthesized all parameters. Based on the total results, the mixture of Pertamax RON 92 E10 with 4 ml clove oil was the best treatment, while E2.5 with 2 ml clove oil was the lowest treatment. These results show that 10% bioethanol content with 4-5 ml clove oil is the most promising composition range for balanced consumption and emissions.

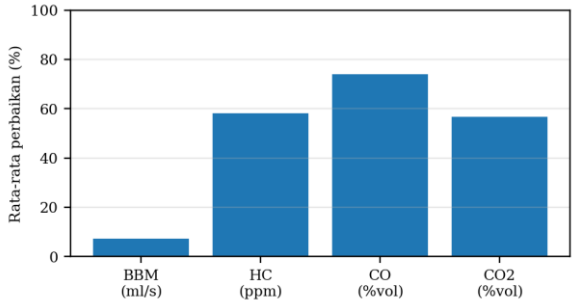


Figure 4. The best average parameter improvement against the reference.

Data at a 500 W load show that fuel consumption does not follow a linear pattern with bioethanol increase. The lowest consumption was found in E5 MC2 at 0.063 ml/s, while E10 MC4, as the best De Garmo blend, had a consumption of 0.088 ml/s. This means that a low-emission blend is not necessarily the most economical mixture at low load.

At a load of 500 W, the HC value sharply decreased in group E10. The HC value of Pertamax Green 95 was 189 ppm, while E10 MC5 reached 77 ppm and E10 MC4 reached 88 ppm. This decrease is consistent with the role of bioethanol as oxygenate, which reduces non-flammable fuel. The CO value in E10 MC4 also dropped to 2.7%, lower than the reference of 5.70%.

Table 2. Average test data at 500 W load

Mix	Kons.	HC	CO	CO_2
PG95	0,070	189	5,70	12,80
E2,5 MC1	0,083	278	6,5	12,0
E2,5 MC2	0,075	314	5,9	14,3
E2,5 MC3	0,072	209	4,1	14,1
E2,5 MC4	0,076	206	4,9	13,7
E2,5 MC5	0,076	253	6,3	13,2
E5 MC1	0,072	222	3,5	14,2
E5 MC2	0,063	147	8,5	13,5
E5 MC3	0,069	234	10,0	14,0
E5 MC4	0,069	252	9,7	12,9
E5 MC5	0,077	220	8,1	14,97
E7,5 MC1	0,083	214	6,7	11,3
E7,5 MC2	0,082	214	6,3	11,6
E7,5 MC3	0,084	192	7,3	11,1
E7,5 MC4	0,087	191	6,1	11,1
E7,5 MC5	0,085	158	3,4	5,3
E10 MC1	0,086	152	4,6	6,2
E10 MC2	0,085	103	3,3	5,1
E10 MC3	0,085	90	3,3	6,0
E10 MC4	0,088	88	2,7	5,9
E10 MC5	0,087	77	3,2	6,3

At a load of 750 W, the E10 MC5 mixture produced the lowest consumption of 0.053 ml/s. Group E10 also dominated the reduction of HC and CO. E10 MC3 produced the lowest CO at 0.3%, while E10 MC4 produced the lowest CO_2 at 5.6%. The differences between MC3, MC4, and MC5 indicate that clove oil doses do not produce monotonous trends.

At a load of 1000 W, the lowest consumption was not in group E10, but rather in E2.5 MC4 at 0.060 ml/s. However, the emission indicator remained better in the high bioethanol blend. E10 MC4 produced HC 77.7 ppm, CO 2.5%, and CO_2 6.5%, far below some E2.5 and E5 mixtures. This indicates that increasing bioethanol is more dominant in controlling emissions compared to consumption savings.

Table 3. Average test data at 750 W load

Mix	Kons.	HC	CO	CO_2
PG95	0,060	224	5,4	13,4
E2,5 MC1	0,070	297	8,8	7,0
E2,5 MC2	0,095	343,3	9,8	8,9
E2,5 MC3	0,093	240	10,0	8,3
E2,5 MC4	0,095	221	9,7	7,2
E2,5 MC5	0,088	255	10,0	9,5
E5 MC1	0,062	221	10,0	8,6
E5 MC2	0,066	147	8,0	10,5
E5 MC3	0,060	234	9,7	8,9
E5 MC4	0,074	251	10,0	6,8
E5 MC5	0,064	239	8,5	11,7
E7,5 MC1	0,073	185	6,3	12,6
E7,5 MC2	0,070	210	4,7	13,0
E7,5 MC3	0,071	182	0,9	14,9
E7,5 MC4	0,070	178	7,7	11,7
E7,5 MC5	0,058	154	4,7	11,6
E10 MC1	0,057	148,3	4,0	9,6
E10 MC2	0,055	131	3,1	11,7
E10 MC3	0,058	113,7	0,3	13,4
E10 MC4	0,056	111	1,8	5,6
E10 MC5	0,053	101	0,7	7,3

Table 4. Average test data at 1000 W load

Campuran	Kons.	HC	CO	CO_2
PG95	0,070	252	6,73	12,27
E2,5 MC1	0,069	328,3	6,8	11,7
E2,5 MC2	0,070	370,7	6,8	13,7
E2,5 MC3	0,067	270	4,2	14,5
E2,5 MC4	0,070	231	3,983	14,3
E2,5 MC5	0,075	269	5,893	13,3
E5 MC1	0,069	220	4,987	14,0
E5 MC2	0,072	158	5,773	16,0
E5 MC3	0,068	236	3,9	14,7
E5 MC4	0,066	251	3,230	14,6
E5 MC5	0,065	257	3,887	15,7
E7,5 MC1	0,065	164,7	1,9	13,3
E7,5 MC2	0,077	193	3,9	12,8
E7,5 MC3	0,064	171,7	2,107	12,7
E7,5 MC4	0,071	176	1,650	7,5
E7,5 MC5	0,070	148	1,913	7,9
E10 MC1	0,067	140,7	4,245	5,8
E10 MC2	0,067	151	3,380	6,5
E10 MC3	0,070	118,7	2,6	5,7
E10 MC4	0,069	77,7	2,5	6,5
E10 MC5	0,074	75	2,5	6,9

Comparison between loads shows that engine load affects the effectiveness of the mixture. At medium to full loads, the air-fuel mixture flow tends to be more turbulent, allowing combustion to proceed better. This explains why some mixtures have lower consumption at 750 W compared to 500 W.

MANOVA results confirmed that the bioethanol factor was significant at all loads with *a P-value* of 0.000. Conversely, the addition of clove oil was not significant at 500 W and 750 W loads because *the P-value* was above 0.05. At 1000 W, *the Lawley-Hotelling* indicator showed *a P-value* of 0.035, but *Wilks* and *Pillai* were not significant; therefore, the effect of clove oil at full load cannot yet be declared strong without further testing.

The De Garmo method provides *a multi-parameter* synthesis. E10 MC4 obtained a total NH of 0.827, followed by E10 MC5 at 0.798 and E10 MC3 at 0.756. The top three positions, all from the E10 group, show that the 10% bioethanol content is the main factor in improving overall results.

Table 5. Total De Garmo yield value (NH)

Mix	NH
PG95	0,420
E2,5 MC1	0,337
E2,5 MC2	0,215
E2,5 MC3	0,407
E2,5 MC4	0,398
E2,5 MC5	0,289
E5 MC1	0,466
E5 MC2	0,461
E5 MC3	0,415
E5 MC4	0,422
E5 MC5	0,387
E7,5 MC1	0,504
E7,5 MC2	0,408
E7,5 MC3	0,543
E7,5 MC4	0,520
E7,5 MC5	0,686
E10 MC1	0,690
E10 MC2	0,742
E10 MC3	0,756
E10 MC4	0,827
E10 MC5	0,798

Table 6. Summary of MANOVA Significance

factor	500 W	750 W	1000 W	Interpretation
Bioethanol	0,000	0,000	0,000	Signifikan
Clove oil	>0,05	>0,05	product mix	Inconsistent

Compared to Pertamax Green 95, the E10 MC4 blend reduces HC by 69.2%, CO by 62.9%, and CO_2 by 53.9%. However, this CO_2 reduction should be read as a decrease in volumetric exhaust gas concentration, not a decrease in total carbon mass emissions. At the same time, consumption at low loads increases, so the recommendation for E10 MC4 is stronger as a low-emission formulation than as a minimum-consumption formulation.

Compared to the literature, these results reinforce the finding that bioethanol can reduce gasoline engine emissions [1]-[6]. However, the results also clarify the limitations of clove oil bioadditives because their statistical effects are inconsistent. Thus, the novelty of this research lies in the integration of the Pertamax RON 92-bioethanol-clove oil mixture, which was evaluated using a multivariate statistical approach (MANOVA) and the De Garmo decision-making method to determine the optimum formulation based on several emission and fuel consumption indicators simultaneously. This article also shows that the bioadditive effectiveness claims need to be tested statistically because numerical reductions in the graph are not necessarily significant when data variation and load interactions are taken into account.

Fuel consumption characteristics indicate a *trade-off* between emissions and fuel volume requirements. Bioethanol carries oxygen that aids combustion, but its calorific value per unit volume is lower than gasoline. Therefore, in some blends, especially at low loads, engines require a larger fuel volume to maintain output power. This condition explains why E10 MC4 excels in emissions and total index, but not the treatment with the lowest consumption at 500 W.

In group E2.5, the addition of clove oil did not produce stable improvement. HC and CO values at some doses were still higher than in comparisons, especially at loads of 750 and 1000 W. This indicates that the 2.5% bioethanol content is not sufficient to provide strong oxygenate. At low oxygen levels, the clove oil bioadditive is unable to be a dominant factor in improving combustion.

Group E5 is interesting because commercially it approaches the fuel characteristics of Pertamax Green 95. Some E5 blends produce low consumption, for example, E5 MC2 at 500 W. However, emission indicators do not always improve consistently. This condition supports the conclusion that adding clove oil to an E5-equivalent composition has not had a significant effect, so its practical benefits still need to be reviewed from the side of cost and mixture stability.

Group E7.5 falls between E5 and E10. The results show emission improvements compared to some mixtures of E2.5 and E5, but still lag behind E10 on the HC indicator. E7.5 MC5 has an NH of 0.686, quite high, mainly because CO2 at 500 W and CO at 1000 W decrease. However, this performance has not surpassed group E10, which is generally better in combined parameters.

Group E10 was the most dominant group in the De Garmo ranking. All variations from E10 MC1 to E10 MC5 had NH above 0.690, while most groups E2.5 and E5 were below 0.500. These data strongly indicate that 10% bioethanol content is the more effective formulation point for this experiment. Clove oil dosage then acts as a setting factor, not the main factor.

Choosing E10 MC4 as the best treatment does not mean MC4 is always the minimum value for every parameter. E10 MC5 is lower for HC at some loads, and E10 MC3 is lower for CO at 750 W. However, De Garmo considers all indicators simultaneously, making E10 MC4 the most balanced compromise. This approach is important in fuel research because optimizing one emission can sacrifice another.

The decrease in HC in E10 indicates that the unburned fuel fraction is reduced. Mechanistically, the oxygen in bioethanol helps form a more even reaction zone. In gensets with carburization or simple mixing systems, the addition of oxygen can reduce the rich mixing area that is usually the source of HC and CO. However, without *lambda* or *AFR* measurements, this interpretation should be considered as an emission data-based indication.

Low CO indicates that carbon oxidation to CO_2 occurs further. However, the simultaneous decrease in CO_2 with the decrease in CO and HC needs to be interpreted carefully. In this test, CO_2 is used as the volumetric concentration from the *gas analyzer reading*, not as the calculation of total carbon mass emissions. Changes in CO_2 can be influenced by fuel composition, exhaust gas flow rate, load, and combustion conditions. Therefore, further research needs to add the exhaust gas flow rate and carbon balance calculations to calculate mass emissions.

Statistically, MANOVA is appropriate because the response variables are interrelated. Fuel consumption and emissions do not stand alone; mixing changes can reduce HC but increase consumption. With MANOVA, the effect of treatments was assessed on the response combination. Consistent bioethanol *P-values* below 0.05 reinforce that ethanol variation causes systemic changes in combustion performance.

The main limitation of the study is the absence of measurements of NOx, exhaust gas temperature, *AFR*, and net effective power. NOx is important because increasing combustion temperature can raise NOx even if HC and CO decrease. Furthermore, economic analysis can only be concluded as limited because the prices of bioethanol and clove oil can change. Therefore, technical recommendations need to be complemented by cost per kWh analysis in subsequent studies.

The practical implication of the study is that the E10 formulation could be a starting point for developing low-emission fuel for small generators. However, the use of clove oil as a bioadditive must be considered proportionally. If the main goal is emission reduction, MC4 in E10 provides the best combined performance. If the main goal is consumption efficiency, other mixtures may be more suitable depending on the operating load.

From an energy policy perspective, these results align with the biofuel diversification agenda. Gasoline-bioethanol blends are relatively easier to implement compared to engine replacements, but raw material quality, storage stability, material compatibility, and supply consistency must still be guaranteed. Laboratory-scale research like this needs to be continued into field testing so that blend recommendations are more *robust*.

Based on all the data, the E10 MC4 formulation can be positioned as the optimal mix candidate for further testing. Subsequent testing should narrow the variation around E10, for example E8, E10, and E12 with MC3-MC5, then add more repeatability. This design will help determine whether the optimal point is indeed at E10 MC4 or shifts to broader operating conditions.

CONCLUSION

This study shows that bioethanol content has a significant effect on fuel consumption and exhaust emissions in a 1000 W generator with a significance $p<$ value of 0.05, whereas the addition of clove oil does not have a significant effect on most operating conditions. Based on the De Garmo effectiveness index, the E10 MC4 mixture is the best formulation with a yield value of 0.827. Compared to Pertamax Green 95, the E10 MC4 mixture can reduce HC emissions by up to 69.2%, CO by 62.9%, and CO_2 by 53.9%, although fuel consumption increases at low loads. Thus, bioethanol content optimization becomes a more decisive factor in improving environmental performance compared to variations in clove oil dosages.

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