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Impact of Excess Air on the Performance and Emissions of an ethanol-fueled spark ignition (SI) Engine

Toni Haikal Saputra, Nasrul Iminnafik*, M. Fahrur Rozy Hentihu

Department of Mechanical Engineering, University of Jember, Jember 68121, Indonesia

*Corresponding author: nasrul.teknik@unej.ac.id

Abstract

Ethanol-blended fuels, such as E60 (60% ethanol and 40% gasoline), have gained interest as an alternative to conventional fuels due to their potential to improve engine performance and reduce emissions. However, the effect of excess air on combustion characteristics remains a key factor in optimizing efficiency. This study investigates the impact of varying excess air levels on the performance and emissions of a 100 cc four-stroke Spark Ignition (SI) engine fueled with E60. The engine was connected to a Prony brake for performance testing, while exhaust emissions were analyzed using a gas analyzer. Results indicate that an excess air level of 22 L/m produced the highest power output (2.48 kW at 1600 rpm) and maximum torque (15.38 Nm at 1200 rpm). Additionally, at 22 L/m, the lowest fuel consumption of 0.110 kg/kWh and the lowest CO emissions were observed. However, at 23 L/m, a decline in performance was noted, likely due to incomplete combustion. The findings suggest that optimizing excess air in ethanol-fueled SI engines enhances performance and minimizes emissions. These insights contribute to the development of efficient combustion strategies for ethanol-based alternative fuels in small-scale transportation applications.

Keywords:

Excess air, ethanol, engine performance, emissions

1 Introduction

In the modern industrial world, transportation is essential. Many developed countries rely heavily on transportation for economic and social activities. [1]. The major issue in Indonesia is the dwindling reserves of fossil fuels. so, before fossil fuels are exhausted, alternative energy sources such as biofuel must be explored. Biofuel has a relatively high energy density as a promising substitute for fossil fuels while also reducing exhaust emissions [2]. Ethanol is one of the viable alternative fuels in Indonesia which has great potential in using spark ignition engines (SI) as it can effectively reduce exhaust emissions [3]. Ethanol fuel is derived from plant-based materials through glucose fermentation which can be produced continuously and has an unlimited supply [4].

Engine performance is critical in the combustion process related to its efficiency, where ethanol has the molecular formula C_2H_5OH [5]. Ethanol has promising advantages in terms of combustion, including the high octane value of 111 [6]. The use of ethanol is acceptable throughout the industrial world as a safe fuel because it has a good flash point in combustion [7]. The choice of fuel is very influential on engine performance. The selection of ethanol as an alternative fuel or as a mixed fuel is a strategic decision [8]. Ethanol can reduce Carbon Oxide (CO) and hydrocarbon (HC) emission levels significantly, ethanol can

reduce CO levels by 37.48% compared to pure fossil fuels. [9]. Additionally, Ethanol has a fairly high oxygen content when compared to fossil fuels and ethanol also has a small lower heat, which can significantly increase fuel consumption [10]

Several experimental studies have investigated Spark Ignition (SI) engines using ethanol-mixed fuel. Because ethanol has high latent heat properties, it can produce high volumetric efficiency, which will have an impact on increasing the power produced [11]. As the demand for higher combustion, innovations in air intake systems are necessary because they will produce efficient fuel mixing and air ratio [12]. The excess air system is one method that plays a role in the intake of excess air to approach more perfect combustion. In this case, it is important because it ensures clean combustion results to reduce exhaust emissions [13].

Proper regulation of excess air is essential because if the incoming air is less, oxygen starvation will occur, while if the excess air that enters is too excessive, it will also affect the combustion results [14]. To improve engine performance and reduce efficient exhaust emissions, the right fuel mixture and air ratio are needed in the combustion process in the engine cylinder. Proper combustion can affect the results of torque, power, and fuel consumption used [15]. Perfect combustion will be able to reduce the occurrence of knocking or detonation during the combustion process [16]. In spark ignition engines are also analyzed, the use of pure H_2 for the use of air and air ratio is quite high. If the fuel-air ratio is higher, the lower the temperature in the cylinder during the combustion process [17].

Excess air can increase power efficiency which also affects torque, but the more excess air that enters the combustion process reduces engine performance and increases fuel consumption, so it is less efficient in its use [18]. Providing innovation in the supply of incoming air input to increase the amount of oxygen in the combustion process is the way to achieve increased performance in spark ignition engines. This method to achieve a high air ratio without sacrificing the flow coefficient significantly includes modifying the intake port features [19]. Meanwhile, utilizing the right hydrogen-air mixing to improve engine performance and combustion stability, however, are still obstacles including reduced volumetric efficiency at the bottom dead center and increased susceptibility to detonation[20].

Technological innovation in developing the combustion process is needed. This research uses fossil fuels such as Pertamina and alternative fuels such as ethanol, the composition used in this fuel (Pertamax 40% + Ethanol 60%). The purpose of this study is to determine the effect of the addition of excess air on engine performance and exhaust emissions in a 4-stroke engine with E60 fuel. By utilizing local fuel-based ethanol blends and excess air systems. The originality of this research lies in the concentration of E60 and excess air systems in spark ignition engines.

This research involves modifying the air intake system on the motorcycle to allow the addition of excess air in a controlled manner. The evaluation results of the E60 fuel mixture used in the experimental test engine and the excess air system that will be the air supply into the combustion so that this research gets the results of engine performance and exhaust emissions to be tested. The findings are expected to provide valuable insights for the automotive industry and the energy sector in Indonesia, contributing to advancements in sustainable transportation technologies.

2 Research Methods

The method used in this study is an experiment, to determine its performance and emissions, namely the SI engine is connected to the prony brake and the exhaust is connected to the gas analyzer to determine the emissions of each level. To determine the available engine speed, this study uses a tachometer and to regulate the speed, a throttle control cable can be used. The test tool scheme can be seen in Fig. 1.

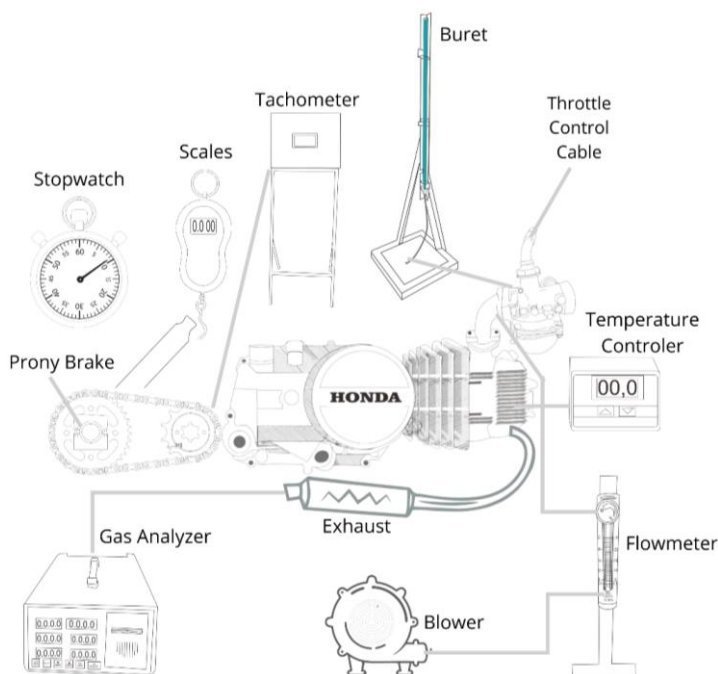


Fig. 1. Engine test scheme

In research, it is necessary to determine the specifications of the engine being tested, because the condition of the engine affects the results of the data obtained. The following test machine specifications are shown in Table 1 [21].

Table 1. Test machine specifications

Item	Specification
Length x width x height	1,907 x 702 x 1,069 mm
Wheelbase	1,234 mm
Diameter x Stroke	50 x 49.5 mm
Stroke Volume	97.1 cc
Compression Ratio	90.0 : 1
Maximum Power	7.3 PS/8,000 rpm
Maximum Torque	0.74 kgf.m/6,000 rpm
Transmission Gear	4 Speed, Fixed Linkage
Spark Plug	ND U20FS-U;NGKC6HSA, C7HSA
Ignition System	AC-CDI, Magneto

The fuel used in this study is a mixture of the first 40% and ethanol 60% (E60), the composition of the fuel is: E60P40, and the 60% Ethanol + 40% Gasoline. The variables used in this study are independent variables and dependent variables (Table 2).

Table 2. Variable

Free Variable	Bound Variable
Excess Air (L/m): 10, 15, 20, 22, 23, 24	Power, Torque, Fuel Consumption, Volumetric Efficiency, Exhaust Emissions
Engine Speed (rpm): 1200, 1400, 1600	

2.1 Torque

The brake applied to the frame is calculated by the arm connected to the balance load pony brake (Eq. 1).

$$T = F \times t \quad (1)$$

T is the brake torque in Nm, F is the load applied in N and t is the distance from the center of the rotor in m. The engine torque measurement is done using a load measuring instrument which is mounted on the rotor arm and will give the load value. In recent studies, these parameters are compared with typical engine data for SI engines. Torque is a measure of the engine's ability to perform work. Torque is a good parameter in determining the performance of the engine, torque is defined as the force acting on a momentary distance with units of (Nm) [22].

2.2 Power

The brake power value is calculated based on the engine torque value. The brake power P given by the engine and absorbed by the rotor is the product of torque and engine speed (rpm) (Eq. 2).

$$P = \frac{2\pi \times N \times T}{60000} \quad (2)$$

Where P value is the brake power in kW and N is the engine speed (rpm). The engine output torque at the crankshaft, when associated with engine displacement, results in other performance parameters. In this power performance, looking at the value (F) generated between the pony brake and the connected SI engine, the power value will be greater as the engine speed increases. Power is an effort that produces energy at a certain time [23].

2.3 Fuel Consumption

The engine in operation produces mechanical power, to produce mechanical power requires fuel that can provide power to the engine. Fuel consumption is the need for fuel used by the engine during the combustion process. To determine fuel consumption (Eqs 3-4).

$$P = \frac{2\pi \times N \times T}{60000} \quad (3)$$

$$mf = \frac{v \times p \text{ bahan bakar}}{t} \quad (4)$$

Fuel consumption is crucial in the economy, in an engine combustion process fuel efficiency has an important role. How efficient fuel is depends on engine performance, where fuel consumption has a relationship with engine speed. The higher the engine speed, the harder the performance performed in the cylinder, and with that, the required consumption will increase. Conversely, if the engine speed is low, the required fuel consumption will also decrease, because the engine performance is not too hard in the cylinder [24].

2.4 Exhaust Gas Emissions

Exhaust emissions are harmful compounds produced when gasoline does not burn completely, so it can be said that exhaust emissions are exhaust gases from incomplete combustion in motor vehicles. Emission testing aims to determine the levels produced by the E60 fuel mixture. The combustion process requires 3 basic components, namely oxygen (O₂), fuel, and heat. The combustion process cannot occur if just one of the above components is missing. Because the combustion process must occur perfectly so that the exhaust gas produced is perfect in the form of carbon dioxide (CO₂) and water vapor (H₂O) [25].

3 Results and Discussion

Based on the research parameters, several graphs of engine test results are shown, one of which is a graph of the effect of excess air on power with E60 fuel (Fig. 2). An important parameter to determine the performance of an engine is usually called power. In this study, power is obtained directly from the crankshaft relationship measured from a direct sensor so that it can measure changes in resistance values. The relationship between engine speed is related to the torque produced in the SI engine. Fig. 2 shows the effect of excess air on power with E60 fuel shows the maximum power results generated from this test of 2.48 kW at excess air of 22 L/m engine speed 1600 rpm and the lowest power of 1.277 kW at excess air of 24 L/m engine speed 1200 rpm. This condition can occur because the higher the engine speed, the greater the power produced, while the lower the speed, the lower the power produced. In this study the excess air system affects

power, the higher the excess air value, the greater the power produced, but when the excess air is too excessive it will decrease the power value, as seen in the graph at 23 L/m power variation begins to decrease this occurs with the same trend at each rpm variation. In the variation of 23 L/m engine speed 1600, the power decreased by 1.88 kW, and in the variation of 24 L/m engine speed 1600, the power value decreased further by 1.79 kW. This states an optimal point in the system setting of excess air entering the combustion chamber and the right engine speed setting. The maximum power value reaches 2.48 kW because there is an excess air supply so that the combustion process is more complete and the addition of ethanol with high octane can improve the performance of the power produced, but the right settings on excess air and engine speed are needed to get maximum results. In this study, the 22 L/m excess air system gets optimal results at each variation of its engine speed. The results of the power test in this study state that higher engine speeds can increase power due to faster, and more efficient combustion processes and higher gasoline calorific value [1].

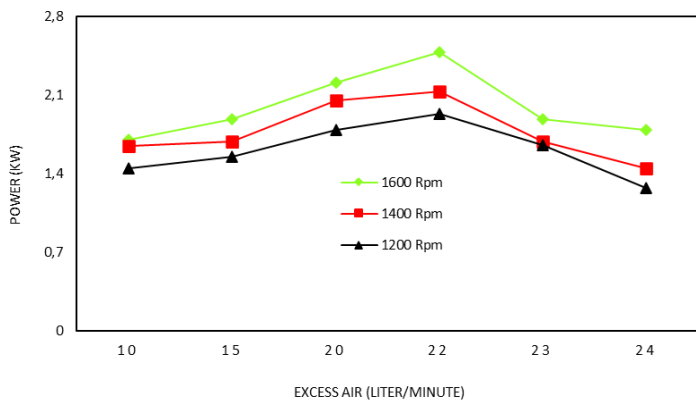


Fig. 2. Effect of excess air on power with E60 fuel

The torque results can be seen in Fig. 3 the effect of excess air on torque with E60 fuel. The octane value contained in the fuel affects the torque test results, the higher the octane value, the greater the torque produced. Using E60 fuel in this study affects the torque results tested. The Torque graph can be seen in Fig. 3, the effect of excess air on torque with E60 fuel which states that there is an optimal point or the highest value at excess air of 22 L/m with an engine speed of 1200 valued at 15.382 Nm, but at excess air of 23 L/m with 1200 rpm the torque value decreased by 13.184 Nm.

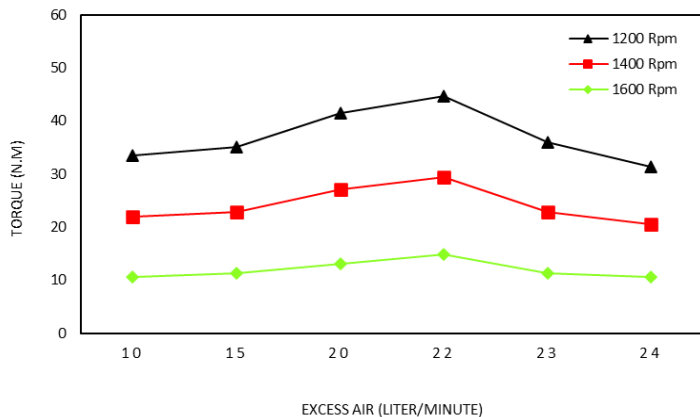


Fig. 3. Effect of excess air on torque with E60 fuel

This happens because too much air enters the combustion, resulting in less-than-optimal torque. The lowest value is at excess air of 24 L/m with an engine speed of 1400 amounting to 9.888 Nm. This study shows that engine speed affects torque, the higher the engine speed, the torque value decreases, and all experience the same trend along with the increasing excess air value. The results of this test provide a broad innovation that the

collaboration of adding excess air and mixing fuel affects the relationship between engine speed. The results of the torque test in this study state that the addition of ethanol increases torque but there is an optimal point at each rpm and torque increases with the addition of excess air [25].

Meanwhile, the results of fuel consumption can be seen in Fig. 4 the effect of excess air on fuel consumption with E60 fuel.

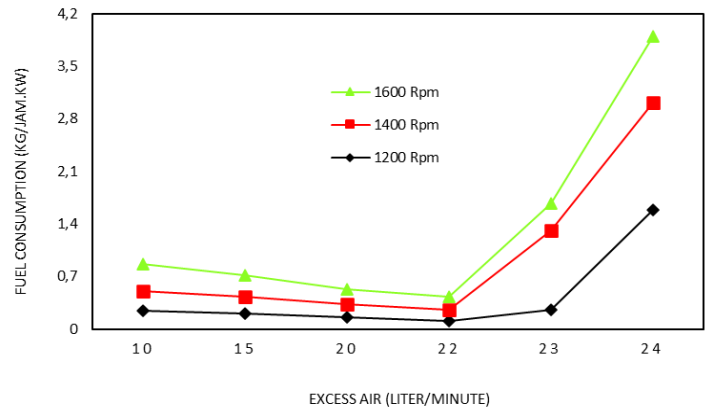


Fig. 4. Effect of excess air on E60 fuel consumption

Fig. 5 shows the relationship between the excess air system and varying engine speeds. Engine speed affects fuel consumption, because the higher the engine speed, the greater the power output produced, based on this statement, with the large and high engine speed, the power requirement will increase.

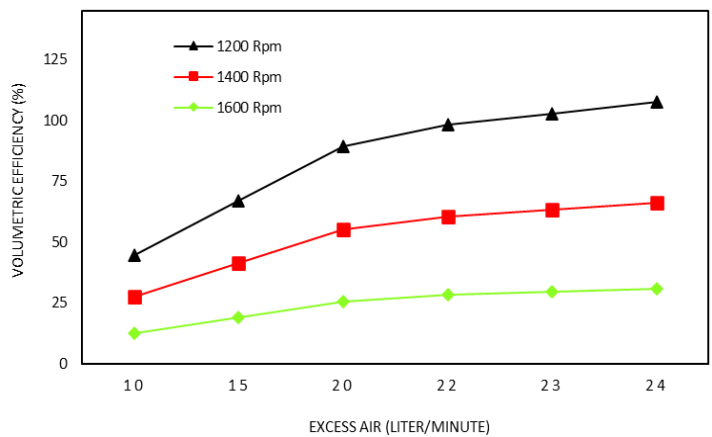


Fig. 5. Effect of excess air on volumetric efficiency with E60 fuel

The effect of excess air on fuel consumption with E60 fuel which shows the highest fuel consumption value is in excess air 24 L/m with engine speed 1600 of 1.590 kg/hour.kW and the lowest value is in the excess air variation 22 L/m with engine speed 1200 of 0.110 kg/hour.kW (Fig. 4). Testing on each excess air variation with different engine speeds each experienced the same trend, such as in excess air 23 L/m engine speed 1400 experienced an increase in fuel consumption of 1.062 kg/hour.kW. This condition is because if there is too much excess air, it will increase fuel consumption. Meanwhile, the addition of ethanol can affect engine performance in terms of fuel consumption because it has a higher flash point than pure fossil fuels. The results of the fuel consumption test in this study are by research (W. Rauf, 2023) which states that the higher the ethanol mixture, the lower the fuel consumption value, this is in line with the decrease in engine speed (rpm). The increasing excess air affects the decrease in fuel consumption [26].

Power, torque, and fuel consumption parameters are interrelated with the resulting volumetric efficiency, the graph can be seen in Fig. 5 the effect of excess air on volumetric efficiency with E60 fuel.

The study of Sidabutar, et.al [27] showed the results that rpm affects the results of volumetric efficiency, the higher the rpm used, the lower the volumetric efficiency value because there are factors that shorten the filling of air and fuel in the cylinder [27]. The volumetric efficiency graph can be seen in Fig. 5. The effect of excess air on volumetric efficiency with E60 fuel shows varying results in the relationship between engine speed and the excess air system. In the combustion process, the air-fuel ratio mixture has an important role, the volumetric efficiency value at high speeds decreases, especially at excess air of 10 L/m at 1600 engine speed has a value of 12.8%. This is influenced by high engine speeds so that the time available for the air and fuel filling process is shorter, another factor is the intake channel which has a high airspeed. Another factor in this case is the amount of air mass will decrease due to the heating of the air that occurs in the cylinder. In Fig. 9. Volumetric efficiency increases with the increase in the excess air system, in this study there is the highest volumetric efficiency value at 1200 rpm excess air 24 L/m of 41.2%. Overall volumetric efficiency increases based on the addition of excess air and engine speed in this study also affect the percentage results. The role of ethanol in volumetric efficiency can increase efficiency because it has a low carbon content that can increase oxygen, so combustion will be more perfect compared to pure fossil fuels.

Prasetyo, et.al [28], shows that the lower the rpm the CO will increase, if the rpm is higher the CO will decrease. Discussion of HC levels at high rpm the HC level will decrease, on the other hand, the RON number also affects HC. Engine speed affects CO₂ and O₂ levels, these two levels have an inverse trend, if the engine speed is high the CO₂ level will increase, while at low speed the O₂ value will increase, on the other hand, the addition of ethanol also affects the effect on exhaust emissions. Based on this statement, it is necessary to develop innovations to reduce exhaust emissions. One of them is a mixture of fossil fuels with alternative ethanol fuels, each of which has an important role in the combustion process. With additional methods such as excess air, it is hoped that it can produce more efficient exhaust emissions because it is used to increase the role of industry in the automotive world and renewable energy. The results of the CO emission graph can be seen in Fig. 6 the effect of excess air on CO emissions with E60 fuel.

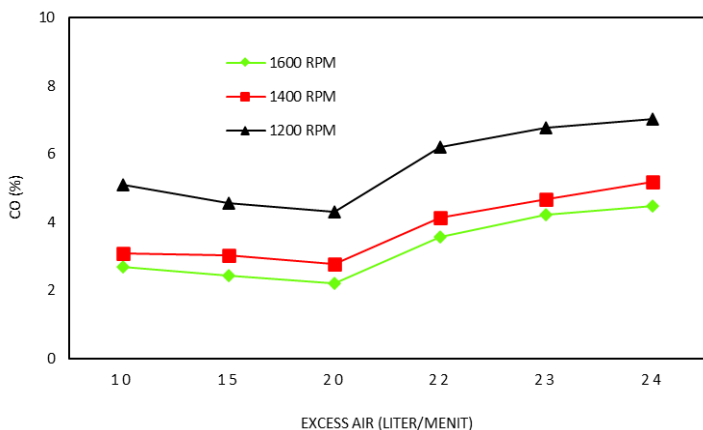


Fig. 6. Effect of excess air on CO emissions with E60 fuel

Susanto, et.al [6], which states that the addition of ethanol affects reducing CO emissions, all rpm have the same trend, and at certain excess air emissions increase. The CO result graph can be seen in Fig. 6 the effect of excess air on CO emissions with E60 fuel shows the best CO obtained at 1600 rpm engine speed, with excess air variation of 20 L/m of 2.21%, while the highest CO was obtained at 1200 rpm engine speed excess air of 24 L/m of 7.02%. Apart from the engine speed in this study, the excess air system has an effect. The variation of excess air of 10 L/m - 20 L/m tends

to consistently decrease. After 20 L/m excess air from each engine speed, the CO level increases, this indicates that there is an optimal point that occurs in the combustion process. In addition to engine speed and rpm, the workload contained in combustion affects the results of the levels because the workload interacts directly with the components in the cylinder. On the other hand, ethanol has a low carbon atom which can reduce CO levels compared to pure fossil fuels. There is an optimal point that occurs in excess air and the addition of ethanol can reduce the HC value, thereby increasing combustion efficiency. Ethanol has extra oxygen for complete combustion, so it can reduce the HC value in this study [11]. The results of the HC emission graph can be seen in Fig. 7, the effect of excess air on HC emissions with E60 fuel shows the results of the excess air variation of 24 L/m with an engine speed of 1200, the HC content has a high value of 232 ppm, this is due to improper combustion. With high rpm and low excess air, the combustion process will experience a lack of air-fuel ratio. The lowest HC value is found in the excess air variation of 10 L/m engine speed of 1600 with a value of 50 ppm, this occurs because the rotation and air-fuel ratio are properly adjusted, thus reducing the HC value. This study shows that the higher the excess air value, the higher the HC value, as happened in excess air of 15 L/m with an engine speed of 1400 experiencing an increase of 138 ppm, this is the same trend in every variation of engine test. Excess air and engine speed have a significant effect on the level of HC produced, therefore it is necessary to have proper regulation in the application of the excess air system and engine speed to the E60 fuel mixture.

Meanwhile, the results of the HC emission is shown in Fig. 7, the effect of excess air on HC emissions with E60 fuel.

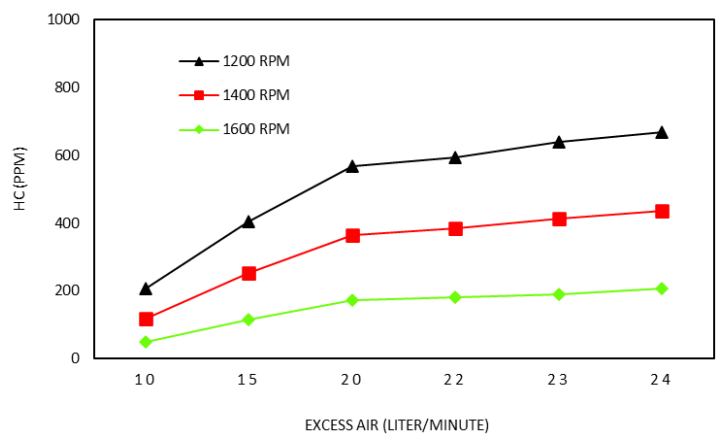


Fig. 7. Effect of excess air on HC emissions with E60 fuel

The results of the O₂ test in this study are by research Ismatullah and Muhaji [5] which states that the addition of ethanol can increase the O₂ content value, and the excess air system affects the O₂ results in internal combustion. Excess air can increase O₂ levels, this indicates that the combustion process is more complete. The results of the O₂ test in this study state that the addition of ethanol can increase the O₂ content value, and the excess air system affects the O₂ results in internal combustion [5]. Excess air can increase O₂ levels, this indicates that the combustion process is more complete. The graph of O₂ emission results can be seen in Fig. 9, the effect of excess air on O₂ emissions with E60 fuel shows that the excess air system plays a high role in the O₂ content results, at excess air 22 L/m in all engine speed variations experiencing the same trend where at excess air 22 L/m there is a decrease in the O₂ value. The highest O₂ value is found in the excess air variation of 24 L/m with an engine speed of 1200 by 23.4% and the lowest O₂ value is found in excess air with a 22 L/m engine speed of 1600 by 15.5%. In this study, engine speeds of 1200 and 1400 rpm at excess air 10 L/m experienced the same trend where the resulting values were not

much different. At excess air of 23 L/m at 1200 rpm, the O₂ content increased again by 21.17%. Combustion can be said to be perfect if oxygen can burn during the combustion process so that it will produce efficient emissions.

For the results of the CO₂ emission graph, it can be seen in Fig. 8 the effect of excess air on CO₂ emissions with E60 fuel. For the O₂ emission results graph, it can be seen in Fig. 9 the effect of excess air on O₂ emissions with E60 fuel. The lambda results can be seen in Fig. 10 the effect of excess air on lambda emissions with E60 fuel.

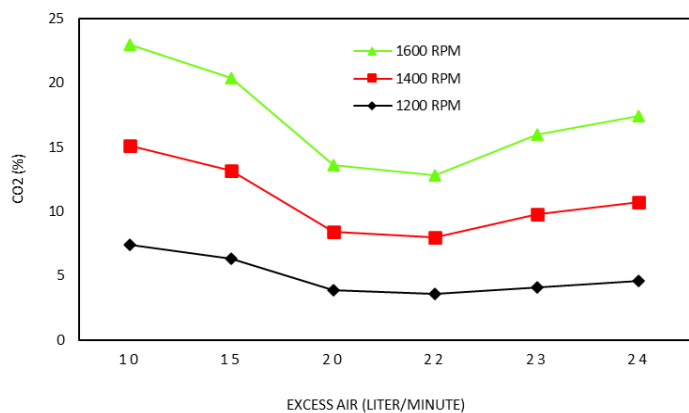


Fig. 8. Effect of excess air on CO₂ emissions with E60 Fuel

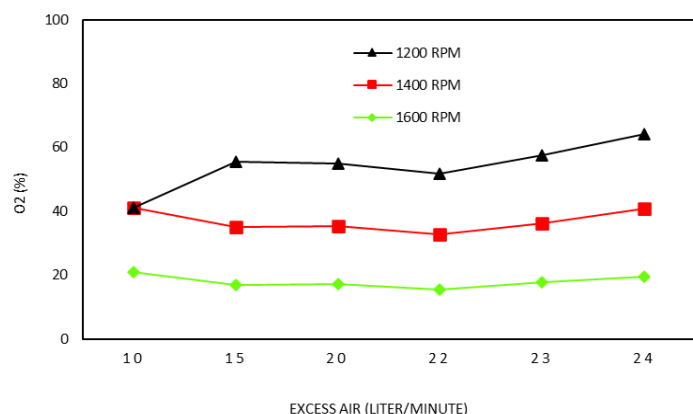


Fig. 9. Effect of excess air on O₂ emissions with E60 Fuel

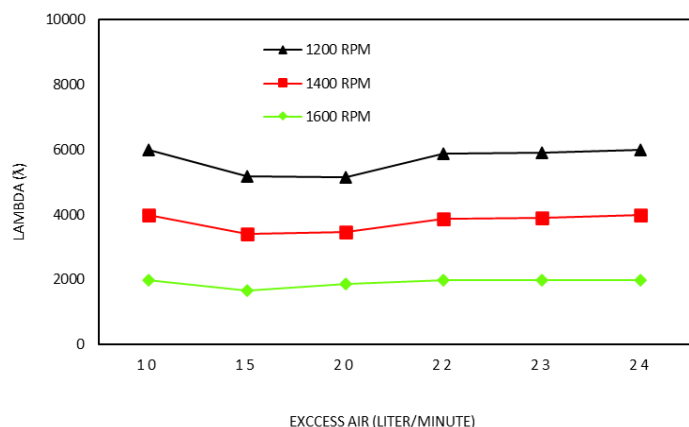


Fig. 10. Effect of excess air on Lambda (λ) emissions with E60 Fuel

The effect of lambda on the test engine providing a relationship between engine speed and excess air system, ideally at stationary rotation lambda has increased so that combustion becomes inefficient [5]. the effect of excess air on lambda emissions (λ) with E60 fuel shows relatively stable results that are not much different and close to stoichiometric combustion (Lambda 1), based on this it is necessary to have the right settings to get stoichiometric lambda. At excess water 15 L/m 1600 rpm lambda decreased it occurs at other engine speeds such as 1400 rpm and 1200 rpm. The lowest lambda value occurs at 1600 rpm

engine speed excess water 15 L/m of 1661 λ. To achieve efficient combustion and low emissions, the right settings are needed (Fig. 10).

4 Conclusion

This research demonstrates that ethanol-blended fuel (E60) combined with optimized excess air regulation can enhance engine performance while reducing emissions in small SI engines. The highest power output (2.48 kW) and torque (15.38 Nm) were achieved at an excess air level of 22 L/m, which also resulted in the lowest fuel consumption and CO emissions. However, further increases in excess air beyond this level led to performance degradation due to incomplete combustion. These findings highlight the importance of precise air-fuel ratio control in ethanol-fueled engines to achieve optimal efficiency. Future research should explore the impact of different ethanol blends and engine configurations to refine combustion strategies for alternative fuel applications in the automotive industry and small-scale transportation.

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