Implementation of an Electric Turbocharger on A Single-Cylinder Spark Ignition Engine in an Effort to Use Ethanol Gasoline E40

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Abstract **– This study delves into the impact of electric turbochargers on fuel efficiency and emissions in ethanol-gasoline blends. Informed by relevant literature, the research zeroes in on the positive influence of electric turbochargers, emphasizing their role in reducing fuel consumption and emissions while also addressing the trade-off between flame characteristics and NOx emissions. The experimental focus is on the injection modification of a single cylinder, with samples including engines equipped with and without an electric turbocharger. Statistical analysis utilizing percentage-based methods reveals that this technology leads to a substantial 94% reduction in CO emissions at idle speed, a 49% decrease in HC emissions at idle speed, and a 10% increase in CO2 at idle speed. Additionally, it also results in a notable 16.04% reduction in fuel consumption at 40 km/h. These outcomes underscore the potential of electric turbochargers to enhance automotive efficiency and sustainability while acknowledging the trade-off that necessitates further exploration for optimal emission control. The research provides concrete insights for refining electric turbocharger technology and optimizing its practical application.**

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1. Introduction

The annual increase in the number of motorized vehicles in Indonesia is directly proportional to the use of fossil fuels [1], [2]. This has a negative effect that contributes to the reduction of fuel resources as a result of the extensive use of fossil fuels. On the other hand, it contributes to air pollution through exhaust emissions, thereby threatening the health of living creatures. Air pollution from motor vehicle exhaust emissions is detrimental to human health and the environment, but it can be eliminated by reducing pollutant levels to a safe level [17]. Ethanol is a source of energy that is capable of being used as an alternative to gasoline [3]. Ethanol is a renewable fuel since it can be derived from plant matter. Using ethanol as a vehicle fuel has several advantages over using fuel oil. The high-octane number of ethanol makes it more resistant to knocking, allowing ethanol motors to operate at higher compression ratios with improved thermal efficiency [4]. In addition, ethanol as a vehicle fuel is more environmentally favorable than fossil fuels because it emits significantly fewer pollutants [2], [3], [4], [5].

Using a mixture of 65% gasoline (RON 90) and 35% ethanol it was discovered that reprogramming the ECU of a 4-stroke engine modified the injection and exhaust emissions when using a mixture of 65% gasoline (RON 90) and 35% ethanol [16]. The finest exhaust emission results for carbon monoxide are 1.21 percent, for carbon dioxide content they are 3.26 percent, and for hydrocarbon content they are 75 parts per million. Nevertheless, under these circumstances, the engine idles, and the acceleration is abrupt. The issue that arises is that effective power tends to decrease as the volumetric concentration of ethanol in the fuel mixture increases at all engine speeds [6].

Because the heating value of ethanol is approximately 35% lower than that of gasoline, increasing the percentage of ethanol in the fuel reduces the energy content of the gasoline-ethanol blend. As a result, increasing the ethanol content of the fuel mixture automatically reduces the engine's effective power.

The increased engine speed causes the volumetric efficiency to peak and then decline [6]. This condition is induced by the phenomenon of inlet airflow. The situation occurs when increasing the pressure but at the inlet cannot increase the fuel flow rate. Consequently, the phenomenon of air flow merging with fuel is not stoichiometric. Consequently, volumetric efficiency and engine power decrease significantly [5]. This study's findings regarding optimal rotation are consistent with [6] research. In contrast to the previous study [7], the relationship between power and the percentage of ethanol in the fuel exhibits a different trend. This difference may be due to the disparity in compression ratio between this study and the previous one.

In order to reduce exhaust emission levels from motorized vehicles, particularly motorcycles, it is necessary to create and develop technologies that minimize the occurrence of unbalanced air and fuel mixtures [8]. This research utilizes electric turbocharger technology as a result. This electric turbocharger's working system is to increase the air mass's density so that the combustion chamber will absorb a greater quantity of air. It is hoped that this electric turbocharger can reduce fuel consumption and the levels of pollutants generated by the motorcycle combustion process, as well as reduce the symptoms of a stuttering engine caused by a mixture of 40% ethanol and 60% gasoline with RON 90 fuel when accelerated.

Electric turbocharger is a centrifugal compressor that rotates a turbine with electrical energy to increase the vacuum into the combustion chamber thereby increasing the air density into the cylinder to increase energy output or engine performance. A high-pressure internal combustion engine's efficacy can be enhanced by installing an electric turbocharger. The increase in power at the same engine capacity indicates that engines with electric turbochargers perform better. However, the use of an electric turbocharger on the engine increases the temperature and pressure of the intake air. In comparison to normal conditions, an increase in intake temperature and pressure can lengthen the ignition (combustion) time, which may lead to ringing.

2. Material and Method

This research was conducted on a single-cylinder, 4-stroke, SOHC, air-cooled, spark-ignition engine with a stroke volume of 113.7 cc. 50 mm diameter x 57.9 mm step, 9.3:1 compression ratio. Testing fuel consumption and exhaust emissions with an electric turbocharger and testing fuel consumption and exhaust emissions without a turbocharger resulted in the collection of data. In the fuel consumption and exhaust emission tests, three speeds (1500, 5500, and 7500 rpm) were used to determine how the vehicle consumes fuel in different situations. Since the fuel consumption and exhaust emissions of a vehicle are not fixed at all speeds, testing at different speeds identifies the highest and lowest efficiency in the speed range.

This device is installed in the intake manifold channel after the air filter (Fig 1.a), before the throttle body (Fig 1.c), and then the intake manifold (Fig 1.d), while the electric turbocharger is positioned as depicted in Fig 1.b. This device's function is to modify the gas handle (Fig 2.d); when the handle is turned, the servo variable resistor (Fig 2.c) and the electronic speed controller (Fig 1.d) are moved. While the vehicle's circuit is depicted in Fig 2. This device adjusts to the gas handle (Fig 2.d), and when the handle is rotated, it drives the servo variable resistor (Fig 2.c) and electronic speed controller (Fig 2.b) to drive the electric turbocharger (Fig 2.a), after receiving a voltage supply from the battery (Fig 2.e). The electric turbocharger in this study has a variable maximum speed of 35,000 rpm and a DC voltage range of 7.4 to 16.8 V. In this study, testing was conducted statically and dynamically. However, the mileage testing procedure was not conducted dynamically on a straight track, and the vehicle was allowed to maintain a constant speed. While static testing is performed when measuring exhaust emissions, dynamic testing is also performed. This emission test adheres to the Indonesian regulation SNI 09-7118.3-2005.

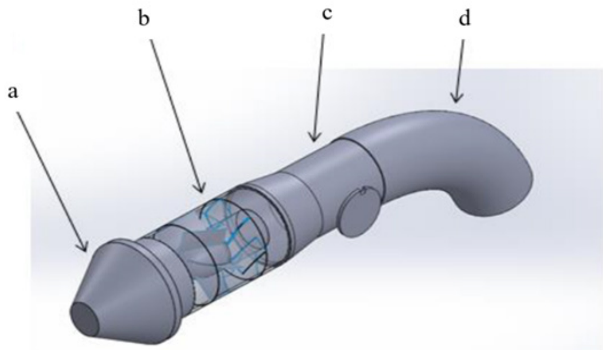


Figure 1. Design of electric turbocharger, a) air cleaner, b) electric turbocharger, d) throttle body, e) intake manifold

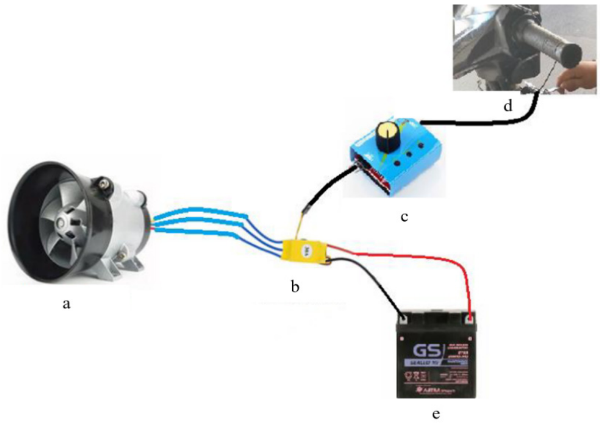


Figure 2. Electric turbocharger wiring, a) electric turbocharger, b) electronic speed controller, c) servo variable resistor, d) handle gas, e) battery

3. Experimental Results and Discussion

In comparison to the findings reported by [9] on the impact of GDI turbochargers on engine performance, which demonstrated fuel efficiency, and in contrast to the research conducted by [10] on the utilization of electronic turbochargers in reducing exhaust emissions from motorcycles, this study affirms a notable reduction in fuel consumption. The results align with previous research, indicating that the incorporation of turbocharger technologies can contribute to both improved engine performance and environmental sustainability, showcasing the potential for multifaceted benefits in the realm of automotive engineering. Every time an electric turbocharger is tested, the average petroleum consumption is reduced, as shown in Figure 3. In addition, Figure 3 also demonstrates that the fuel consumption of the test engine without an electric turbocharger can reach 38.40 km/L at an average speed of 40 km/h, 36.98 km/L at an average speed of 50 km/h, and 34.45 km/L at an average speed of 60 km/h.

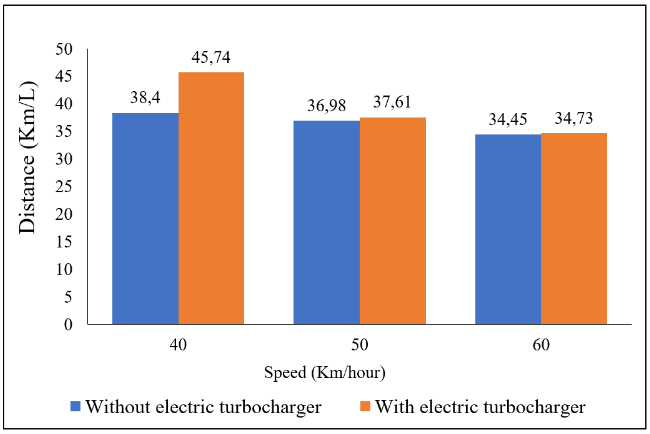


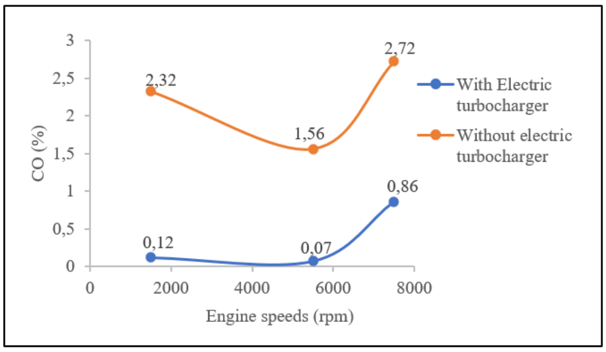
Figure 3. Fuel assessment comparison

In consumption examination using an electric turbocharger, the E40 ethanol gasoline fuel consumption was saved by 16.04% at an average speed of 40 km/h by spending E40 as much as 45.74 km/liter, by 1.70% at an average speed of 50 km/h by spending 37.61 km/liter of fuel oil, and by 0.80% at an average speed of 60 km/h by spending 34.73 km/liter of fuel oil. At low speeds, the larger airflow from the electric turbocharger can produce more power with less fuel, resulting in an increase in fuel efficiency [14], [15]. However, at high speeds, the engine requires more energy to increase power, overcome wind resistance, increase combustion, and maintain speed, so the impact of reducing fuel consumption at high speeds is not as significant as it is at low speeds.

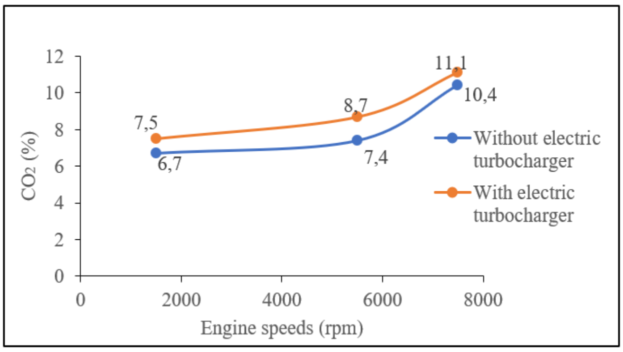
According to research [5] on the combustion that takes place in a gasoline engine with an injector system, the fuel is sprayed directly into the combustion chamber to combine with air, which is then compressed and burned. The sprayed fuel takes the form of a spray, which is a collection of particles. The value of the ignition delay time increases as the ratio of ethanol to gasoline increases [10]. This is because the latent heat of vaporization of ethanol is three times greater than that of gasoline, which is 307.3 kJ/kg. At the same temperature, this result indicates that the phase transition from liquid to gas requires more energy [11]. In addition, ethanol has a higher flash point than gasoline, which is -40°C, at 13°C. The flash point is the lowest temperature at which a fuel will emit vapor and produce a flammable mixture with air. Because of its sluggish vaporization speed (volatility), the higher the flash point value of a fuel, the greater its ignition time [12]. In contrast, the autoignition temperature of ethanol is approximately 423°C, while that of gasoline is approximately 257°C. The lower a fuel's autoignition temperature, the simpler it is to spontaneously ignite.

The influence of the gasoline-ethanol mixture percentage on flame length has been a subject of investigation. The length of the flame decreased until a concentration of 20% ethanol (E20) in gasoline and then increased at a concentration of 40% ethanol (E40). This occurs because at ethanol concentrations up to 20% (E20) in gasoline, micro explosions are prevalent, and the intensity of micro explosions decreases until ethanol concentrations reach E40 [13]. Micro explosions cause fuel droplets to fragment into small grains, which speeds up the vaporization and mingling of fuel with air, thereby accelerating the combustion reaction. Obviously, this occurrence will have an effect on the combustion outcomes in the combustion chamber.

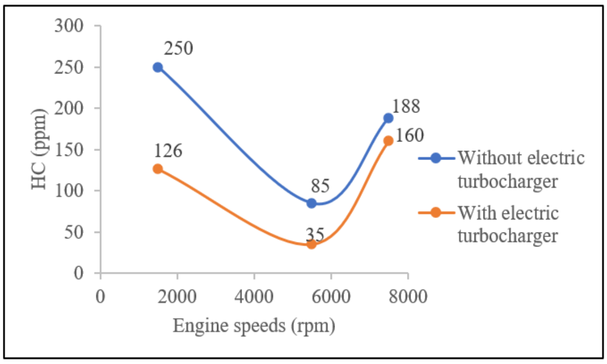
In this study, it was determined that the use of electric turbochargers on E40 had an effect on both diminishing and increasing the amount of exhaust emissions. Figure 4 demonstrates that, on average, the use of an electric turbocharger reduced the carbon monoxide and hydrocarbon content of exhaust emissions while increasing the carbon dioxide content of exhaust emissions from the test motorcycle.



(a) Engine speeds vs CO emission



(b) Engine speeds vs CO_2 emission



(c) Engine speeds vs HC emission

Figure 4. Engine emission characteristics

Figure 4.a depicts exhaust emissions testing without an electric turbocharger, which produces a carbon monoxide content of 2.32 percent at 1500 rpm, 1.56 percent at 5500 rpm, and 2.72 percent at 7500 rpm. Second, the engine produces carbon dioxide with a concentration of 6.7% at 1500 rpm, 7.4% at 5500 rpm, and 10.4% at 7500 rpm. The third produces a hydrocarbon content of 250 ppm at a speed of 1500 rpm, 85 ppm at a speed of 5500 rpm, and 188 ppm at a speed of 7500 rpm. Figure 4.b shows that the exhaust gas emission test with the first electric turbocharger reduces the carbon monoxide content by 94.82% at 1500 RPM engine speed by 0.012% carbon monoxide, of 95.51% at 5500 RPM engine speed by 0.07% carbon monoxide, and 68.38% at 7500 RPM engine speed by 0.86% carbon monoxide.

In Figure 4.b, this condition demonstrates that the electric turbocharger can increase the carbon dioxide content by 10.66% at 1500 RPM engine speed by 7.5% carbon dioxide, 14.94% at 5500 RPM engine speed by 8.7% carbon dioxide, and 6.3% at 7500 RPM engine speed by 11.1% carbon dioxide.

While in Figure 4.c the application of this component is able to reduce the hydrocarbon content by 49.6% at 1500 Rpm engine speed by producing a hydrocarbon content of 126 ppm, 58.8% at 5500 Rpm engine speed by producing a hydrocarbon content of 35 ppm, and 14.89% at 7500 Rpm engine speed by producing a hydrocarbon content of 160 ppm.

The highest combustion rate constant value was found in E40, with a value of 0.984 mm2/s, while the lowest value was found in E100, with a value of 0.658 mm2/s. The constant combustion rate of E30 and E40 has increased because ethanol contains 34% by weight of oxygen [13]. When the fuel is heated, the oxygen atoms in ethanol react first with the C (carbon) and H (hydrogen) atoms in ethanol, causing the combustion reaction to accelerate and the burning rate constant value to be greater [11]. However, E30 and E100 experienced a decrease in the value of the constant burning rate as a result of an increase in the latent heat of vaporization, which causes the rate of vaporization and diffusion of fuel to be sluggish, resulting in a low combustion speed.

Blends of 40% (E40) ethanol with gasoline decrease the calorific value and increase the latent heat of vaporization, resulting in low combustion temperatures and combustion velocities [16]. The high value of the burning rate constant in E40 fuel will produce more complete combustion at the same combustion time in a gasoline engine, resulting in reduced CO and HC emissions. In addition, it permits more fuel droplets to combust, resulting in an increase in combustion efficiency, which has an impact on increasing torque and power in petroleum engines.

In contrast, research from [11] indicates that an increase in the percentage of ethanol in gasoline decreases the maximal flame temperature. This is due to the lower heat release rate of the fuel mixture, which is a result of the lower calorific value of ethanol and the similar combustion rate constants of the fuels. Ethanol has a calorific value of 26,900 kJ/kg compared to 44,000 kJ/kg for petroleum. Therefore, when ethanol is combined with gasoline, the calorific value of the mixture will be between that of gasoline and that of ethanol. The calorific value of a fuel indicates, in units of volume or mass, the quantity of heat/calories released during combustion. The lower the maximum value of flame temperature generated in conjunction with an increase in the ethanol content of gasoline has an effect on the reduction of NOx emissions from engine combustion. Because NOx emissions will be produced if the combustion temperature is high enough.

At 1500 RPM, lambda engine speed produced up to 1.01 without electric turbocharger and 1.23 with electric turbocharger. At 5500 RPM, lambda engine speed produced up to 1.045 without electric turbocharger and 1.393 with electric turbocharger. In order to improve combustion efficiency, an electric turbocharger can increase airflow into the engine. If combustion is more effective, CO emissions from incomplete combustion will decrease and vice versa, it occurs in CO2 because combustion is more efficient than ideal combustion causes CO2 to increase. With an electric turbocharger, fuel delivery to the combustion chamber is optimized to prevent fuel consumption waste and reduce the occurrence of incomplete combustion, which can produce hydrocarbons (HC).

The air flow velocity at the electric turbocharger influences the lambda number's quantity or volume. Lambda measurements are used to measure combustion efficiency and control the fuel injection system in the engine.

If too much air enters (lambda > 1), the fuel does not burn completely and might produce cleaner exhaust emissions, but engine performance and efficiency could be affected.

If too little air enters (lambda 1), combustion becomes incomplete, and the engine can produce dirtier exhaust emissions. The ideal lambda value is dependent on the type of engine and other factors; for gasoline engines, the ideal lambda ranges from 0.95 to 1.05 for optimal efficiency and exhaust emissions.

4. Conclusion

The research demonstrates that electric turbochargers significantly optimize air supply in proportion to engine speed. This technology leads to a substantial 94% reduction in CO emissions at idle speed, a 49% decrease in hydrocarbon emissions at idle speed, but a 10% increase in CO2 at idle speed. Additionally, it results in a notable 16.04% reduction in fuel consumption at 40 km/h. The electric turbocharger consistently lowers exhaust emissions (HC and CO), increases CO2 levels, and reduces fuel consumption, extending the driving range. In summary, the study affirms the positive impact of electric turbochargers on fuel efficiency and emissions in ethanol-gasoline blends. The technology not only significantly reduces fuel consumption, especially at lower speeds but also optimizes combustion dynamics and minimizes emissions, contributing to environmental sustainability in automotive engineering.

Despite the positive impact of electric turbochargers on fuel efficiency and emissions in ethanol-gasoline blends, challenges exist. The trade-off between flame length and maximal flame temperature needs further exploration to optimize NOx emissions. Suggestions for future studies include a more in-depth exploration of fuel composition's influence, particularly varying ethanol percentages, on combustion efficiency and emissions. Advancing electric turbocharger technology and investigating external factors like road conditions could provide insights into real-world applicability. In summary, further research aims to refine our understanding of electric turbochargers, addressing challenges and optimizing their potential for automotive efficiency and sustainability.

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