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Analysis of diesel engine vehicle emissions using egr with temperature variations

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Abstract

This study aims to analyze the exhaust emissions of diesel engine vehicles with and without the use of the Exhaust Gas Recirculation (EGR) system at engine temperature variations of 60°C, 70°C, and 80°C. The study was conducted on a 2008 Mitsubishi L300 Diesel vehicle to measure the effect of EGR on NOx emissions and soot emissions (smoke opacity). The research method used was an experiment with a quantitative approach. Data were obtained by measuring exhaust gas temperature as an indication of NOx emissions and using a smoke opacity meter to measure the level of vehicle smoke concentration. The results showed that the use of EGR was able to reduce NOx emissions, but increased soot emissions. The higher the engine temperature, the NOx emissions tended to increase both in vehicles with and without EGR. Conversely, soot emissions decreased along with increasing engine temperature. The conclusion of this study is that the EGR system is effective in reducing NOx emissions but has side effects in the form of increased soot emissions. Therefore, optimization of EGR technology needs to be combined with other strategies to reduce the negative impact on air quality.

1. INTRODUCTION

Diesel-powered vehicles, plays an important role in human life, but is also a major contributor to air pollution (Iskandar et al., 2024; Suhadi & Febrina, 2013). Harmful emissions produced by diesel vehicles include carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and soot emissions (smoke opacity) (Iskandar et al., 2020; Purnomoasri & Handayani, 2022). These pollutants contribute to air pollution and have negative impacts on human health and the environment (Dhahad et al., 2021).

One of the technologies used to reduce diesel vehicle emissions is Exhaust Gas Recirculation (EGR) (Fayad, 2019). This technology works by recirculating some of the exhaust gas into the combustion chamber, which can lower the combustion temperature and inhibit the formation of NOx (Siregar et al., 2024). Several studies have shown that increasing the EGR rate can significantly reduce

NOx emissions, but its impact on soot emissions is still debated (Huang et al., 2022).

This study aims to analyze the effect of EGR on diesel vehicle emissions with temperature variations of 60°C, 70°C, and 80°C. Testing was carried out by comparing NOx and soot emissions when the vehicle uses EGR and without EGR. The results of this study are expected to provide further insight into the effectiveness of EGR in reducing air pollution and support the implementation of more environmentally friendly technologies in the transportation sector.

2. RESEARCH METHODS

This study uses a quantitative approach with an experimental method to test diesel vehicle emissions using Exhaust Gas Recirculation (EGR) and without EGR at engine temperature variations of 60°C, 70°C, and 80°C. The research procedure begins with a literature study, preparation of tools and materials, and calibration of tools before testing. The test was conducted in front of the Electrical Engineering Lab, Faculty of Engineering, Semarang State University on February 25, 2025. Data was taken under two conditions, namely when the vehicle used EGR and without EGR, with exhaust gas emission measurements including NOx based on exhaust gas temperature (exhaust gas temperature measurements were carried out as an indication of the NOx value produced by the vehicle) and soot emissions (smoke opacity).

The vehicle used in the study was the 2008 L300 Diesel, exhaust gas temperature measurements using a temperature detector, soot emission testing using a smoke meter, engine speed measurements using a timing light, and engine temperature measurements using a thermogun.

The independent variables in this study are the use of EGR and engine temperature variations, while the dependent variable is the exhaust gas emissions produced. Control variables such as vehicle type, measuring instruments, and environmental conditions remain controlled to maintain the validity of the research results. Data were collected from direct test results using measuring instruments, and supported by secondary sources such as journals and previous research.

Data analysis was conducted descriptively and using statistical tests to compare vehicle emissions under various test conditions. The results of the study are presented in the form of tables and graphs to facilitate interpretation of the differences in emissions between the use of EGR and without EGR, and also to see the effect of engine temperature on the emissions produced. This study aims to determine the impact of EGR use on diesel vehicle emissions at various operating temperatures and to provide insight into the effectiveness of EGR technology in reducing air pollution.

3. RESULTS AND DISCUSSION

The results of motor vehicle emission tests in the Electrical Engineering Laboratory, Faculty of Engineering, Semarang State University, using a thermocouple to measure the exhaust gas temperature as an indication of the formation of NOx emissions produced and a Smoke meter to measure soot emissions (Smoke Opacity) produced by vehicles. The test was carried out three times each variation test. In this test, it was carried out when the test vehicle was in neutral with the engine speed at 2000 rpm. After testing, the data is presented in the form of tables and diagrams, to make it easier to analyze the test results. Testing was carried out at three variations of engine temperature, namely at temperatures of 60, 70, and 80°C, engine temperature measurements were carried out using a thermogun. The vehicle used for testing in this study was the 2008 L300 Diesel.

Table 1. Exhaust gas temperature testing when using EGR

Temperature	Testing			Average
	T1	T2	T3	
60°C	82.8 °C	79.7 °C	75.7 °C	79.4 °C
70°C	95.4 °C	92.7 °C	90.3 °C	92.8 °C
80°C	95.4 °C	94.2 °C	95.1 °C	94.9 °C

Table 1. shows the results of exhaust gas temperature testing (as an indication of the formation of NOx emission values) when the vehicle uses EGR.

Table 2. Exhaust gas temperature testing when not using EGR

Temperature	Testing			Average
	T1	T2	T3	
60°C	83.8°C	85.6°C	90.3°C	86.6°C
70°C	100.3°C	100°C	99.8°C	100.0°C
80°C	100.2°C	100.1°C	99.9°C	100.1°C

Table 2. shows the results of exhaust gas temperature testing (as an indication of NOx emissions) when the vehicle does not use EGR.

Table 3. Average results of exhaust gas temperature testing using EGR and without using EGR

	Average exhaust gas temperature value (NOx emission indication value) generated with engine temperature variation		
	60°C	70°C	80°C
EGR	79.4 °C	92.8°C	94.9°C
Non EGR	86.6°C	100°C	100.1°C

Table 3. shows the average results of exhaust gas emission temperature testing which will later be used as an indication of NOx emission values. The average results are the test results when the vehicle uses EGR and when the vehicle does not use EGR at engine temperature variations of 60, 70, and 80°C.

Table 4. Soot emission testing when using EGR

Temperature	Testing			Average
	T1	T2	T3	
60°C	54,3%	52.9%	54.4%	53.9%
70°C	46%	49.3%	50.3%	48.5%
80°C	45.8%	45.9%	42.7%	44.8%

Table 4. shows the results of soot emission testing (smoke opacity) when the vehicle uses EGR.

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Table 5. Soot emission testing without using EGR

Temperature	Testing			Average
	T1	T2	T3	
60°C	42.9%	43.7%	44.4%	43.7%
70°C	37.9%	39.1%	37.7%	38.2%
80°C	33.1%	34.4%	34.1%	33.9%

Table 5. shows the results of soot emission testing (smoke opacity) when the vehicle does not use EGR

Table 6. Average results of soot emission testing (smoke opacity)

	Average soot emission value (smoke opacity) produced by vehicles at various engine temperatures		
	60°C	70°C	80°C
EGR	53.9%	48.5%	44.8%
Non EGR	43.7%	38.2%	33.9%

Table 6. shows the average results of soot emission testing (smoke opacity) when the vehicle uses EGR and when it does not use EGR at engine temperature variations of 60, 70, and 8 °C.

After the emission testing process and data recapitulation and input into a table, the data is then presented in graphic form.

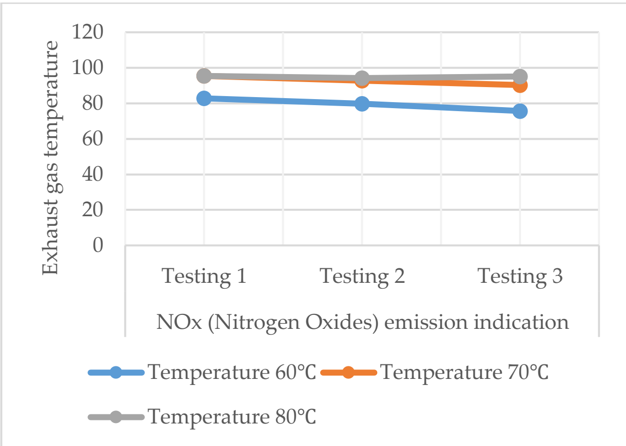

Figure 1. Comparison of exhaust gas temperature values as an indication of the formation of NOx emissions at engine temperature variations of 60, 70, and 80°C (with EGR)

Figure 1. shows that when the vehicle uses EGR (Exhaust Gas Recirculation) at engine temperatures of 60, 70, and 80°C, there is an increase in the exhaust gas temperature value. This increase in exhaust gas temperature occurs consistently in all tests, namely the first test, the second test, and the third test. This increase in exhaust gas temperature shows a relationship between engine temperature and the exhaust gas temperature produced. The higher the

engine temperature, the greater the temperature produced in the combustion process, which ultimately causes the exhaust gas temperature to increase.

In addition, with increasing exhaust gas temperature, it can be indicated that the NOx emissions produced also increase. This indication method is also carried out in research (Syarifudin & Syaiful, 2018) which explains that exhaust gas temperature measurements are carried out to see indications of increasing NOx emissions produced by diesel engines. This is due to the characteristics of NOx formation which tends to increase at higher temperatures. At higher combustion temperatures, nitrogen oxidation in the combustion chamber becomes more intensive, resulting in greater NOx emissions. Therefore, the graph in Figure 1 clearly shows that the increase in exhaust gas temperature is in line with the increase in engine temperature. This confirms that higher engine temperatures have a direct impact on increasing exhaust gas temperatures and NOx emissions produced.

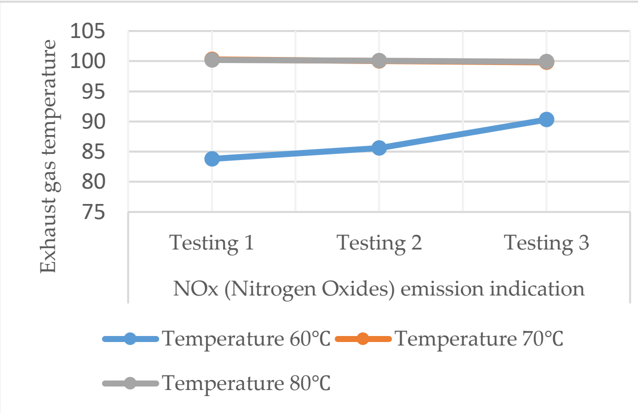

Figure 2. Comparison of exhaust gas temperature values as an indication of the formation of NOx emissions at engine temperature variations of 60, 70, and 80°C (without EGR)

Figure 2. shows the effect of engine temperature on the exhaust gas temperature value of the vehicle (as an indication of NOx emissions) produced by a diesel engine at engine temperature variations of 60, 70, and 80°C when without using EGR (Exhaust Gas Recirculation). It can be seen that engine temperature affects the exhaust gas temperature value produced. The increase in the exhaust gas temperature value occurred in all tests, namely the first, second, and third tests. It can be seen in Figure 1 that the higher the engine temperature value, the higher the exhaust gas temperature value produced. With the increase in the exhaust gas temperature value, it can be indicated that the NOx emission value produced also increases. At engine temperatures of 60°C and 70°C, the difference in exhaust gas temperature values in Figure 1 is clearly visible. However, at temperatures of 70°C and 80°C, the exhaust gas temperature value produced only has a small difference in the first test, the second test, and the third test. If averaged, the difference in the difference is only 0.1. This occurs when the vehicle is released with EGR (Exhaust Gas Recirculation).

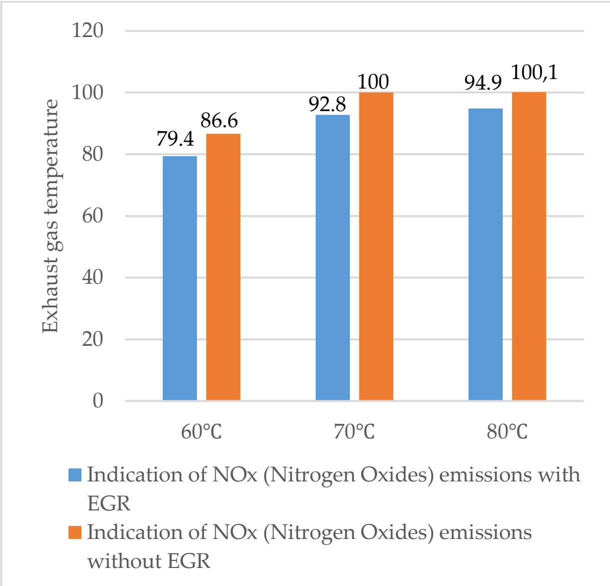

Figure 3. Average exhaust gas temperature value as an indication of NOx emission value with EGR and Non EGR at engine temperature variations of 60, 70, and 80°C

In Figure 3., we can see the trendline graph comparing the average exhaust gas temperature value as an indication of NOx emissions produced by diesel engine vehicles, at temperature variations of 60, 70, and 80°C when the vehicle uses EGR (Exhaust Gas Recirculation) and does not use EGR (Exhaust Gas Recirculation). At an engine temperature of 60°C when the vehicle does not use EGR (Exhaust Gas Recirculation) it produces an average NOx emission indication value (exhaust gas temperature value) of 86.6°C, while when the vehicle uses EGR (Exhaust Gas Recirculation) with the same engine temperature it produces an exhaust gas temperature value of 79.4°C. This difference shows that the exhaust gas temperature value (NOx emission indication) when the vehicle uses EGR (Exhaust Gas Recirculation) with an engine temperature of 60°C decreases by 8.3% compared to when the vehicle does not use EGR (Exhaust Gas Recirculation) with an engine temperature of 60°C.

At an engine temperature of 70°C when the vehicle does not use EGR (Exhaust Gas Recirculation) it produces an average NOx emission indication value (exhaust gas temperature value) of 100°C, while when the vehicle uses EGR (Exhaust Gas Recirculation) with the same engine temperature it produces an exhaust gas temperature value of 92.8°C. This difference shows that the exhaust gas temperature value (NOx emission indication) when the vehicle uses EGR (Exhaust Gas Recirculation) with an engine temperature of 70°C decreases by 7.2% compared to when the vehicle does not use EGR (Exhaust Gas Recirculation) with an engine temperature of 70°C.

At an engine temperature of 80°C when the vehicle does not use EGR (Exhaust Gas Recirculation) it produces an average NOx emission indication value (exhaust gas temperature value) of 100.1°C, while when the vehicle uses EGR (Exhaust Gas Recirculation) with the same engine temperature it produces an exhaust gas temperature value of 94.9°C. This difference shows that the exhaust gas temperature value (NOx emission indication) when the vehicle uses EGR (Exhaust Gas Recirculation) with an engine temperature of 80°C decreases by 5.2% compared to when the vehicle does not use EGR (Exhaust Gas Recirculation) with an engine temperature of 80°C. Of the six average test results, the largest NOx emission indication value (exhaust gas temperature value) occurs in the 80°C engine temperature test when the vehicle does not use EGR (Exhaust Gas Recirculation) where the average NOx emission indication value (exhaust gas temperature value) produced is 100.1°C. Meanwhile, the smallest average NOx emission indication value (exhaust gas temperature value) occurs in the 60°C engine temperature test when the vehicle uses EGR, which is 79.4°C.

The difference occurs because EGR (Exhaust Gas Recirculation) works by recirculating exhaust gas into the intake manifold, so that less oxygen enters the combustion chamber because some parts have been replaced by exhaust gas, because of this the temperature in the combustion chamber decreases and also reduces the concentration with oxygen which can reduce NOx emissions. Unlike vehicles that do not use EGR (Exhaust Gas Recirculation) all mixtures come from new air, which means that the oxygen content in the combustion chamber is higher and the concentration with oxygen is also higher compared to vehicles when using EGR (Exhaust Gas Recirculation), this makes that the combustion temperature in the combustion chamber is higher and the concentration with oxygen is higher, so that when vehicles do not use EGR (Exhaust Gas Recirculation) it produces higher NOx emissions. Overall NOx emissions at engine temperatures of 60, 70, and 80 °C are produced less when vehicles use EGR (Exhaust Gas Recirculation).

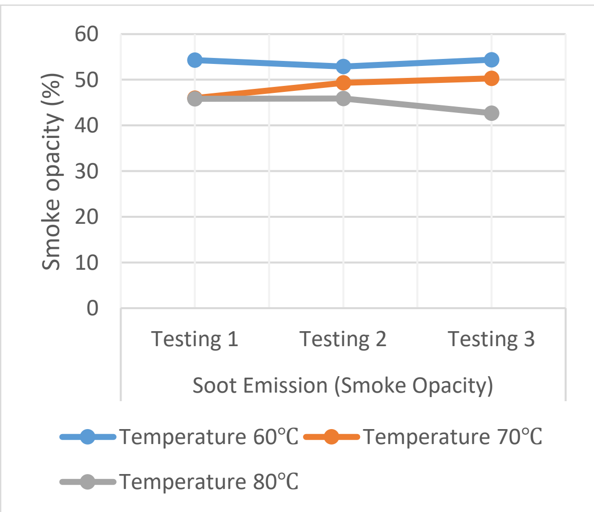

Figure 4. Comparison of soot emission values (smoke opacity) at engine temperature variations of 60, 70, and 80°C when the vehicle uses EGR

Figure 4. shows that when the vehicle uses EGR (Exhaust Gas Recirculation) at temperature variations of 60, 70, and 80°C, there is a decrease in the soot emission value (smoke opacity) produced by the vehicle. This decrease occurs consistently in all tests, namely the first test, the second test, and the third test. It can be seen in Figure 4. that the soot emission value (smoke opacity) produced at the three temperature variations has a difference. Figure 4 shows that the decrease in soot emission (smoke opacity) occurs along with the increase in engine temperature, the higher the engine temperature, the less the soot emission value (smoke opacity) produced. This confirms that engine temperature affects the soot emission value (smoke opacity) produced by the vehicle. The increase in engine temperature that occurs during vehicle operation contributes to more perfect combustion, thereby reducing the production of unburned carbon particles and reducing the levels of black smoke produced by the engine.

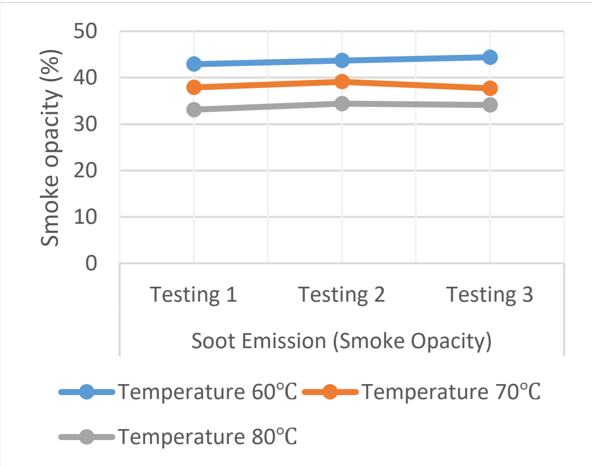

Figure 5. Comparison of soot emission values (smoke opacity) at engine temperature variations of 60, 70, and 80°C when the vehicle does not use EGR

Figure 5. shows that when the vehicle operates without the use of an Exhaust Gas Recirculation (EGR) system at engine temperatures of 60°C, 70°C, and 80°C, there is a consistent decrease in soot emissions (smoke opacity). This trend is observed across all three test iterations. The soot emission values vary at each temperature level, but overall, the data indicate that higher engine temperatures are associated with lower smoke opacity levels. This suggests that increasing engine temperature improves combustion efficiency, thereby reducing the formation of unburned carbon particles, which are the primary cause of black smoke emissions. These findings are in line with previous studies which state that higher combustion temperatures enhance fuel atomization and oxidation, ultimately leading to cleaner exhaust gases (Rahman et al., 2021; Sharma et al., 2019). Additionally, it has been observed that soot particles tend to form more rapidly at lower combustion temperatures due to incomplete combustion (Heywood, 1988).

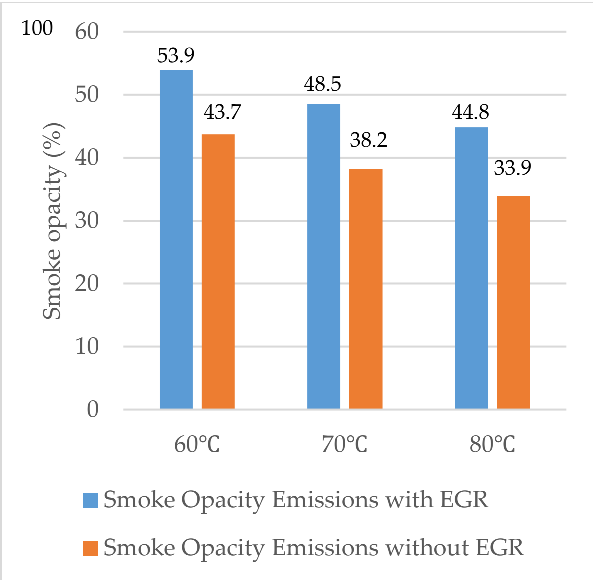

Figure 6. Average soot emission values (smoke opacity) with EGR and without EGR at engine temperature variations of 60, 70, and 80°C

In Figure 6, you can see the trendline graph comparing the average soot emission value (smoke opacity) formed at temperature variations of 60, 70, and 80°C when the vehicle uses EGR (Exhaust Gas Recirculation) and does not use EGR. At an engine temperature of 60°C, when the vehicle does not use EGR, the average soot emission value is 43.7%, while with EGR at the same temperature, it increases to 53.9%. This indicates a 23.3% rise in soot emissions due to the EGR application at 60°C. At an engine temperature of 70°C, the average soot emission without EGR is 38.2%, while with EGR, it is

48.5%, showing a 27% increase. At 80℃, soot emissions rise from 33.9% (without EGR) to 44.8% (with EGR), marking a 32.2% increase. This pattern confirms that the use of EGR consistently leads to higher soot emissions across the observed temperature range, which aligns with previous studies indicating that EGR tends to reduce oxygen availability and combustion temperature, thereby increasing soot formation (Rakopoulos et al., 2018; Shen et al., 2015).

Among the six average test results, the highest soot emission was recorded at an engine temperature of 60℃ when the vehicle used EGR (Exhaust Gas Recirculation), with a smoke opacity value of 53.9%. In contrast, the lowest soot emission was observed at 80℃ when the vehicle operated without EGR, showing a smoke opacity of just 33.9%. This variation can be explained by the difference in the combustion air composition. When EGR is not used, the engine receives only fresh air, resulting in a higher oxygen concentration that supports more complete combustion. On the other hand, using EGR introduces a portion of exhaust gases back into the combustion chamber, which reduces the oxygen content and lowers the combustion temperature. These conditions promote incomplete combustion and the formation of soot due to unburned carbon (Song & Lee, 2016; Yoon et al., 2014). Additionally, the presence of EGR enriches the air-fuel mixture, increasing the likelihood of carbon residue formation. This unburned carbon exits as visible black soot in the exhaust. Overall, soot emissions (smoke opacity) are consistently lower at all tested engine temperatures—60, 70, and 80℃—when EGR is not used. This supports previous research showing that while EGR effectively reduces nitrogen oxide (NO_x) emissions, it often leads to higher particulate matter (PM) emissions due to changes in combustion behavior (Kook et al., 2006).

4. CONCLUSION

Based on the analysis of a 2008 Mitsubishi L300 diesel vehicle, the use of Exhaust Gas Recirculation (EGR) effectively reduces nitrogen oxide (NO_x) emissions, particularly as engine temperatures rise from 60°C to 80°C. However, this benefit comes with a trade-off: an increase in soot emissions, although higher engine temperatures tend to mitigate this effect. To address the elevated soot levels associated with EGR, integrating a Diesel Particulate Filter (DPF) is recommended, especially for vehicles adhering to Euro 4 standards or lower, as commonly found in Indonesia. This combination of EGR and DPF technologies offers a balanced approach to minimizing both NO_x and particulate emissions, aligning with global efforts to enhance air quality. For future research, exploring the synergistic effects of combining EGR with Selective Catalytic Reduction (SCR) systems could provide deeper insights into optimizing NO_x reduction while managing fuel efficiency. Additionally, investigating the impact of alternative fuels, such as biodiesel blends, and the incorporation of nano-additives like titanium dioxide (TiO_2), may reveal further strategies to reduce both NO_x and soot emissions. Such studies would contribute to the development of more sustainable and cleaner diesel engine technologies.

5. DECLARATION/STATEMENT

5.1. Acknowledgment

We would like to thanks to all parties who helped this research.

5.2. Author Contribution

Fa’iq Taufiqul Hakim contributed to do the research. M. Burhan Rubai Wijaya, Abdurrahman, and Ahmad Roziqin contributed as supervisors.

5.3. Conflict of Interest

Authors declare no conflict of interest.

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