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Performance of Diesel Particulate Filter (DPF) in reducing exhaust gas opacity in diesel engines

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Abstract
This research aims to determine the performance of the Diesel Particulate Filter (DPF) in reducing exhaust gas opacity, smoke temperature, and noise levels on the 1997 Isuzu Panther. The DPF used in this research is composed of copper and stainless steel, featuring a metallic honeycomb design. This experimental study involved installing a DPF on a standard diesel vehicle exhaust system and measuring exhaust emissions, smoke temperature, and noise levels. The measuring instrument used to test the opacity and temperature of the exhaust gas is a smoke opacity meter based on the SAE-J1667 test procedure (snap acceleration test procedure). Meanwhile, to test the noise level, a sound level meter based on ISO/FDIS 5130:2006 (E) standard was used. Tests were carried out under various conditions, including standard exhaust testing (Non-DPF), standard exhaust with DPF (DPF), DPF with 50 gram stainless steel material (DPF + SS50), DPF with 100 gram stainless steel material (DPF + SS100), and DPF made of 150 gram stainless steel (DPF + SS150). The test results showed that DPF had a significant effect on reducing exhaust opacity, smoke temperature, and noise level of the 1997 Isuzu Panther. The greatest reduction in exhaust opacity, smoke temperature, and noise level was produced by DPF + 150 gram stainless steel, with exhaust opacity that could be reduced by 87 1 ± 1.1%, smoke temperature of 43.2 ± 1.7%, and noise level of 15.2 ± 1.3%. These findings open up opportunities for the development of DPF technology that is more efficient in reducing diesel vehicle emissions, contribute to stricter emissions regulations, and support filter design innovation to improve air quality and reduce the negative impact of vehicles on the environment. In addition, the results of this research show that the use of DPF is in accordance with the diesel vehicle emission threshold regulations set in Indonesia.

Keywords:
Copper;
DPF;
Exhaust emissions;
Metallic Honeycomb;
Stainless Steel;

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INTRODUCTION

The development of transportation in Indonesia is increasing every year. This can be seen from the latest data from the Indonesian statistics, which shows that the number of motorized vehicles in Indonesia in 2023 has increased [1]. The Indonesian Police Traffic Corps in 2024 also stated that the data on the number of vehicles had reached 164,136,793 units [2]. The increasing number of vehicles on the highway, of course, also causes quite serious problems, especially the problem of air pollution [3]. People who live near the highway are more at risk of diseases due to air pollution [4]. In addition, vehicular pollution also poses a risk to the health of students who attend schools near the highway [5]. Diesel cars are one type of vehicle that produces air pollution in the form of black smoke/soot [6, 7, 8, 9]. Soot is an air pollution particle formed from incomplete combustion in motor vehicles [10]. Soot (PM 2.5) is very harmful to human health because it can settle in the lungs and cause serious diseases such as lung cancer [11], and can even cause disability and death [12][13]. With this problem, a technology is needed that can overcome the problem of vehicle exhaust emissions, especially from diesel engines. The technology used to reduce exhaust emissions is the Diesel Particulate Filter (DPF), which functions as a filter or soot trap, so that the residual combustion gas coming out of the exhaust becomes clean and does not endanger health [11, 14, 15].

Zhang *et al.* conducted a study that examined the effectiveness of using DPF in reducing diesel engine exhaust emissions. The results of this study concluded that DPF is considered an effective method for controlling particulate matter (PM) emissions from diesel engines and complies with national/regional laws and regulations such as CHINA VI, Euro VI, and EPA Tier3 [14]. This shows that the DPF can effectively reduce PM emissions from diesel engines, thus complying with the emission standards adopted in China. Similar research was also conducted by Phyo et al. Their research examined the combustion and exhaust behavior of a 3 L four-cylinder common rail diesel engine with three different types of B7 conventional diesel fuel, with and without a platinum diesel oxidation catalyst (DOC) system and a non-catalytic partial flow diesel particulate filter (P-DPF). The results concluded that diesel engine particulate emissions could be reduced by about 50% by using the P-DPF system [16]. These results show that DPFs are effective in reducing particulate emissions. However, because the material used is platinum, it requires more cost because the price of platinum is relatively high.

Research conducted by Bakhchin *et al.* on PM control technology concluded that further investigation of PM control technology is needed. This study found that the material used for SCR is platinum. They also suggested developing the technology in order to reduce the level of diesel engine particulate emissions with other cheaper materials [17]. This research is the same as research by Phyo et. al, the material used for DPF is platinum, which is relatively expensive. Therefore, materials are needed that are cheaper but can be used effectively in reducing diesel engine exhaust emissions.

Based on the results of previous studies, further research is needed to optimize the design and material of the DPF to improve filtration efficiency and ensure compliance with applicable emission regulations. The DPF used in this study has different sizes and materials, namely copper and stainless steel honeycomb models with a mesh size of 5 mm, which aim to improve DPF performance in reducing exhaust opacity, smoke temperature, and diesel engine noise levels, so that the resulting exhaust emissions comply with the emission thresholds set by the Indonesian government. Therefore, the problem formulations in this study are 1) How effective are copper and stainless steel honeycomb models with a 5 mm mesh size in reducing exhaust opacity, smoke temperature, and diesel engine noise levels? 2) Do the DPF test results meet the emission standards set by the government?

METHOD

This research is experimental [18]. This research will test exhaust gas opacity, smoke temperature, and 1997 Isuzu Panther noise using standard exhaust and experimental exhaust (DPF). The measuring instrument used to test the opacity and temperature of exhaust gas is a smoke opacity meter. Meanwhile, to test the noise level, use a sound level meter. The research procedures include design, manufacture, and testing. Copper and stainless steel (SS) are used in this study as materials for making a DPF with a metallic honeycomb model. Copper is a metal that can be used as a DPF material because it has high conductivity and is harmless [19]. In addition, stainless steel (SS) is also a metal that can be used as a DPF material because it is resistant to corrosion and has high durability [20]. In this study, there are 3 variations of stainless steel used, namely 50 gr, 100 gr, and 150 gr. The stainless steel used is in the form of fiber. Stainless steel is placed in the crevices of the DPF as an additional filter to filter flue gas opacity, reduce smoke temperature, and reduce noise levels.

Designing

At the design stage, an important step that must be taken is to understand the needs and technical specifications of the DPF according to applicable emission regulations, such as Euro 5 or Euro 6. The DPF design can capture fine particles produced from diesel combustion without significantly reducing engine performance. This involves calculating the pore size, wall thickness, and geometric shape of the filter. In addition, it is necessary in the design of the DPF that the material used is also very important. This material must be able to withstand high temperatures and provide sufficient durability so that it does not need to be replaced frequently. In this study, a honeycomb DPF design was made from copper and stainless steel. The honeycomb model is a model commonly used in catalysts, so this model can also be used in DPFs [21]. The DPF design is shown in Figure 1. The DPF will be installed on the exhaust of the 1997 Isuzu Panther (Figure 2). Stainless steel fibers are inserted into the crevices of the DPF as a filter that functions to filter the opacity of diesel engine exhaust gas. The position of the stainless steel is shown in Figure 3.

Manufacturing

The DPF manufacturing process includes 2 stages, namely casing and DPF manufacturing. Making the casing is done according to the size of the DPF that will be inserted in it. The casing is made of an iron plate with a thickness of 1 mm.

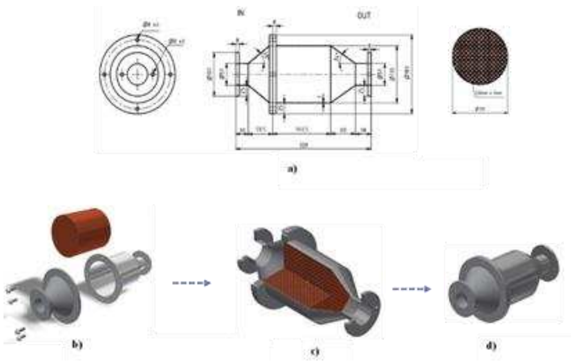

Figure 1. DPF design (a) DPF Casing Dimensions, (b) Casing and DPF, (c) DPF Inside the Case, (d) Complete DPF

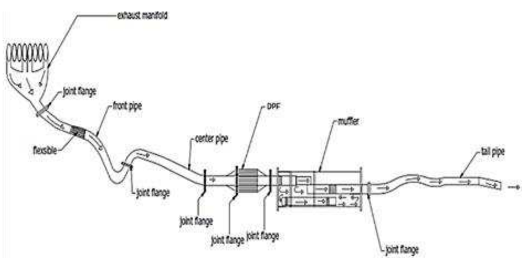

Figure 2. DPF position on the 1997 Isuzu Panther car exhaust

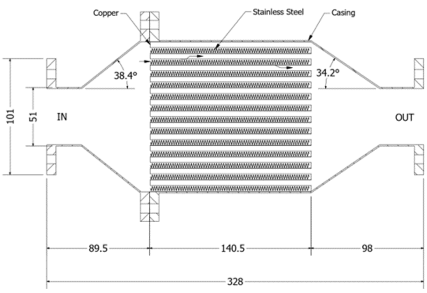

Figure 3. Stainless steel position on DPF

The size of the inner diameter of the casing must match the size of the outer diameter of the DPF, so that the DPF can be inserted into it with precision, and there should be no exhaust gas leakage when testing. Furthermore, the DPF manufacturing process uses copper material with a thickness of 1 mm and stainless steel in the form of fibers. The DPF is made according to the previously designed size. The DPF is made with a honeycomb model, which is used by researchers who have done so in previous studies. The results of making the casing and DPF can be seen in Figure 4.

Figure 5 shows the flow of testing/collecting data on the exhaust gas opacity and smoke temperature of a 1997 Isuzu Panther, which is carried out in several procedures. The first step was to prepare the Isuzu Panther car and smoke opacity meter, and ensure that the car and test equipment were functioning properly and that there were no leaks in the exhaust pipe.

In addition, the test device must be able to measure opacity concentration (smoke density) at free-running acceleration [22], and the test device must have a valid calibration certification [23].

Testing

The testing process was carried out to determine the results of the influence of the DPF on exhaust gas opacity, smoke temperature, and noise level of the 1997 Isuzu Panther. Figure 5 is the flow of DPF testing carried out in this research.

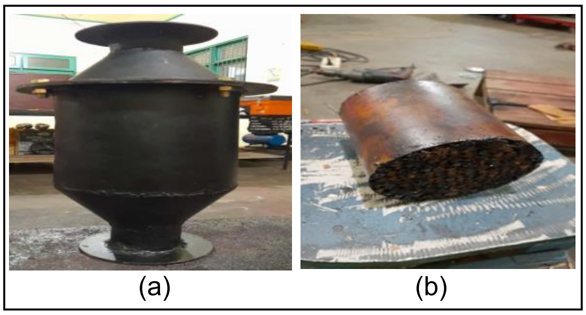

Figure 4. DPF Manufacturing (a) DPF, (b) Casing

Figure 5. DPF Testing Flow (a) Isuzu Panther 1997, (b) Probe, and (c) Smoke Opacitymeter (d) Sound Level Meter

Next, the engine was operated until it reached working temperature. The exhaust system is cleaned by stepping on the gas pedal or accelerating three times to the maximum engine speed. This step also serves to adjust the foot to the condition of the gas pedal. After that, the engine is left at idle for approximately five seconds. The gas sensor/probe was then inserted into the exhaust gas pipe to a depth of at least 30 cm to prevent data errors. Next, accelerate quickly but gently, according to the "accelerate" command on the smoke opacity meter monitor screen, and maintain it for 4 seconds until the "release/ decelerate" command appears. After that, the gas pedal is released until the engine speed returns to idle, according to the SAE-J1667 test procedure [24]. The test result data was then printed or recorded in the data recording form. This test was conducted three times to obtain average results.

Figure 5 also shows the noise level data collection process, which was conducted based on the ISO/FDIS 5130:2006 (E) [25] standard, with the following test procedure: The first step is to prepare a noise level meter. Then, install the device at 0.5 meters from the axis point of the exhaust pipe at an angle of 45 degrees, and make sure the height of the device is not less than 0.2 meters from the ground. Ensure that there are no other sounds that can interfere with the testing process. Next, press the gas pedal to maximum speed as quickly as possible until the engine reaches maximum speed, then hold it for 3 to 5 seconds. After that, record the test results. Perform the test three times and calculate the average of the results.

RESULTS

Smoke Opacity

In this research, the tests were conducted under various conditions: standard exhaust (Non-DPF), standard exhaust with DPF (DPF), DPF with 50 grams of stainless steel (DPF+SS50), DPF with 100 grams of stainless steel (DPF+SS100), and DPF with 150 grams of stainless steel (DPF+SS150). Based on the test results that have been done, the use of DPF can reduce the exhaust gas opacity of the 1997 Isuzu Panther engine. The 1997 Isuzu Panther engine exhaust gas opacity test results are presented in Table 1, Figure 6, and Figure 7.

Smoke Temperature

Based on the test results, the use of DPF can reduce the exhaust temperature of the 1997 Isuzu Panther engine. The test results of the smoke exhaust temperature of the 1997 Isuzu Panther are presented in Table 2, Figure 8, and Figure 9.

Table 1. Exhaust gas opacity test of the 1997 Isuzu Panther engine

Exhaust	Opacity (% HSU)	Opacity Difference (% HSU)	Opacity Reduction (%)
Non DPF	90.2 ± 1.1	-	-
DPF	20.7 ± 3.3	69.5 ± 2.6	77.0 ± 2.6
DPF+SS50	17.5 ± 0.7	72.7 ± 0.8	80.6 ± 0.8
DPF+SS100	15.4 ± 0.5	74.8 ± 0.8	82.9 ± 0.8
DPF+SS150	11.6 ± 0.7	78.6 ± 1.1	87.1 ± 1.1

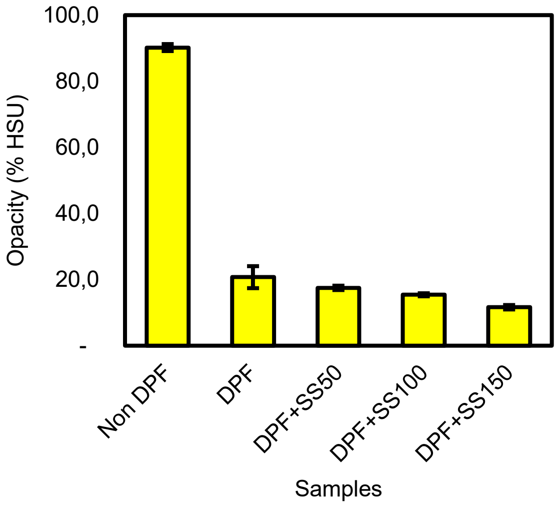

Figure 6. Exhaust Gas Opacity Test Results

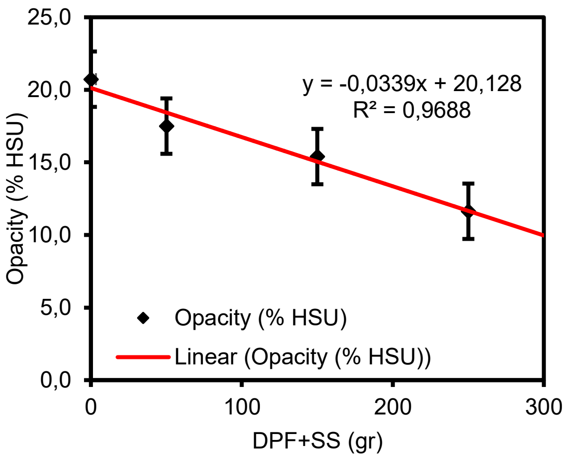

Figure 7. Opacity of the exhaust with DPF and various masses of stainless steel

Table 2. Smoke Temperature Test of 1997 Isuzu Panther Engine

Exhaust	Temperature (°C)	Temperature Difference (°C)	Temperature Reduction (%)
Non DPF	44 ± 2	-	-
DPF	37.3 ± 1.5	6.7 ± 2.9	15.2 ± 2.9
DPF+SS50	33.0 ± 1.0	11.0 ± 1.7	25.0 ± 1.7
DPF+SS100	29.0 ± 1.0	15.0 ± 1.7	34.1 ± 1.7
DPF+SS150	25.0 ± 1.0	19.0 ± 1.7	43.2 ± 1.7

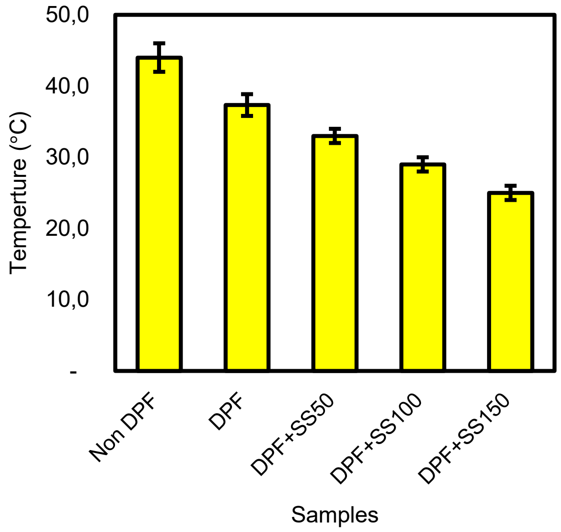

Figure 8. Smoke Temperature Test Results

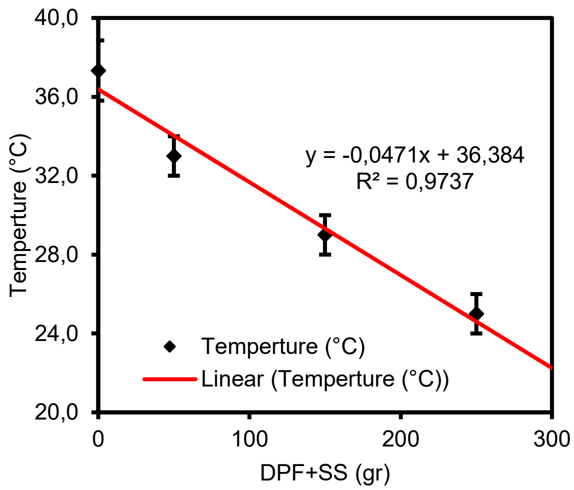

Figure 9. Exhaust smoke temperature with DPF and various masses of stainless steel

Noise Level

Based on the test results, the use of DPF can reduce the noise level of the 1997 Isuzu Panther exhaust. The test results of the 1997 Isuzu Panther noise level are presented in Table 3, Figure 10, and Figure 11.

Data Analysis

DPF test results were analyzed using the ANOVA statistical technique. The test criterion is that if the significance result is <0.05, then there is a significant difference in exhaust opacity, smoke temperature, and noise level between the five exhaust variations tested. The ANOVA test results using SPSS are presented in Table 4.

Based on Table 4, the opacity variable obtained an F value of 1244.860 with sig. <0.05, which is 0.00. This shows that there is a significant difference in exhaust opacity between Non DPF, DPF, DPF+SS50, DPF+SS100, and DPF+SS150 exhausts.

Table 3. Noise test of the 1997 Isuzu Panther engine

Exhaust	Noise (dB)	Noise Differences (dB)	Noise Reduction (%)
Non DPF	102.3 ± 0.9	-	-
DPF	94.1 ± 0.7	8.1 ± 0.7	8.0 ± 0.7
DPF+SS50	92.2 ± 0.6	10.1 ± 0.6	9.9 ± 0.6
DPF+SS100	89.1 ± 0.6	13.2 ± 0.4	12.9 ± 0.4
DPF+SS150	86.7 ± 0.5	15.5 ± 1.3	15.2 ± 1.3

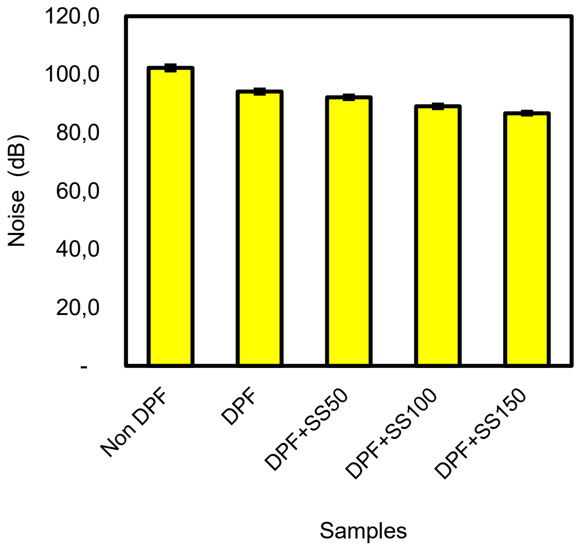

Figure 10. Noise Level Test Results

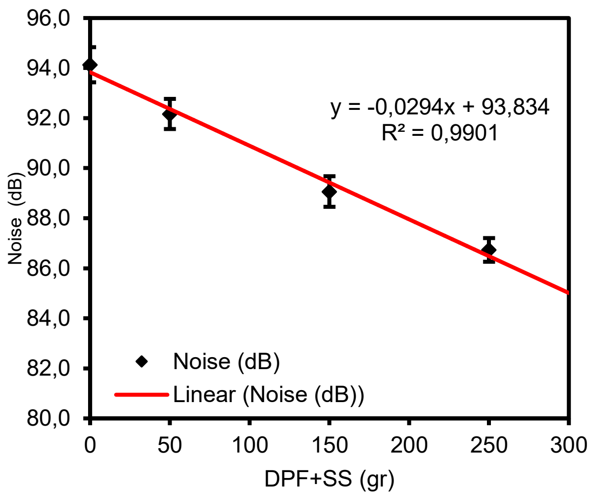

Figure 11. Exhaust Noise with DPF and Various Masses of Stainless Steel (SS)

For the smoke temperature variable, the F value is 87.411 with sig. <0.05, which is 0.00. This shows that there is a significant difference in smoke temperature between Non DPF, DPF, DPF+SS50, DPF+SS100, and DPF+SS150 exhausts.

For the noise level variable, the F value is 243.287 with sig. <0.05, which is 0.00. This shows that there is a significant difference in the noise level between Non DPF, DPF, DPF+SS50, DPF+SS100, and DPF+SS150 exhausts.

DISCUSSION

Smoke Opacity

Figure 6 shows that the standard exhaust produces an exhaust gas opacity level of 90.20% HSU. This result is very large because the standard exhaust does not use a DPF as a particulate trap, so the opacity is high [26][27]. In the standard exhaust, the flow of exhaust gases coming out of the combustion chamber into the free air is not blocked by anything, so that the exhaust gas just comes out without any barriers/traps, such as a DPF [28]. Referring to the emission quality standards in Indonesia, the exhaust gas opacity of 90.2±1.1%HSU does not meet the emission standard threshold, which, in this rule, states that the emission quality threshold for diesel vehicles under 2010 is 65% HSU [22].

On experimental exhaust, I (DPF) produced an exhaust gas opacity level of 20.7±3.3%HSU. The percentage reduction in exhaust gas opacity was 77.0±2.6%. This result is smaller than the reduction result of the standard exhaust, and it can be said that the opacity decreases.

Table 4. Anova Test Results

ANOVA						
		Sum of Squares	df	Mean Square	*F*	Sig.
Smoke Opacity	Between Groups	13232.036	4	3308.009	1244.860	.000
	Within Groups	26.573	10	2.657		
	Total	13258.609	14			
Smoke Temperature	Between Groups	652.667	4	163.167	87.411	.000
	Within Groups	18.667	10	1.867		
	Total	671.333	14			
Noise Level	Between Groups	427.536	4	106.884	243.287	.000
	Within Groups	4.393	10	.439		
	Total	431.929	14			

These results show that the use of DPF is very influential in the reduction of diesel engine exhaust opacity [28, 29, 30]. Thus, DPF is very effectively used to reduce exhaust emissions in diesel engine vehicles. Thus, the use of DPF is in accordance with the rules set by EURO VII [31].

Experimental exhaust II (DPF+SS50) produces an exhaust gas opacity level of 17.5±0.7HSU% with a percentage reduction in exhaust gas opacity of 80.6±0.8%. This reduction result is greater than the reduction result of the experimental exhaust I without Stainless steel. Where the opacity of the resulting exhaust gas has decreased. The amount of Stainless steel added to the DPF is 50 g. This shows that the use of Stainless steel as an additional filter influences the reduction of the opacity of exhaust gas. The addition of filters proved effective in reducing the opacity of diesel engine exhaust gas.

The exhaust of experiment III (DPF+SS100) produced an exhaust gas opacity level of 15.4±0.5%HSU. The percentage reduction in exhaust gas opacity is 82.9±0.8%. This reduction result is greater than the reduction result of the experimental exhaust II with the addition of Stainless steel 100 g, and it can be said that the opacity decreases. This shows that the addition of more filters can affect the amount of opacity reduced [32].

The experimental exhaust IV (DPF+SS150) produced an exhaust gas opacity level of 11.6±0.7%HSU. The percentage reduction in exhaust gas opacity is 87.1±1.1%. The reduction results are greater than the reduction results of the exhaust experiments I, II, and III. It can be said that the reduction results in the exhaust of experiment IV are the greatest among the four exhaust experiments. The amount of stainless steel added to the DPF is 150 g. These results show that the more filters added in the DPF, the greater the opacity reduction. This indicates that the variation in the amount of stainless steel as a filter added to the DPF is very influential in reducing opacity [33]. The more filters added, the greater the opacity that can be reduced.

The measurement results indicate that the addition of stainless steel mass in the DPF significantly affects exhaust opacity. As shown in Figure 7, there is a linear relationship between the added stainless steel mass and exhaust opacity. Regression equation obtained in (1).

$$y = -0.0339x + 20.128 \quad (1)$$

where y represents exhaust opacity and x denotes the added stainless steel mass. The coefficient of determination (R^2) value of 0.9688 indicates that 96.88% of the variation in exhaust opacity can be explained by the variation in stainless steel mass. From these results, it can be concluded that increasing the mass of stainless steel added to the DPF leads to a decrease in exhaust opacity. This suggests that using heavier stainless steel in the DPF can enhance the filter's efficiency in reducing particulate emissions, thereby contributing to lower air pollution levels.

Smoke Temperature

Based on the research data in Table 2 and Figure 8, it is known that the average value of smoke temperature in the standard exhaust is 44°C, while the experimental exhaust I (DPF) obtained an average temperature of 37.33°C. The addition of stainless steel fiber in DPF shows a lower exhaust gas temperature, namely in the experimental exhaust II (DPF + SS50), the temperature is 33°C, in the experimental exhaust III (DPF + SS100), the temperature is 29°C, and in the experimental exhaust IV (DPF + SS150), the temperature is 25°C.

Experimental exhaust I (DPF) produced a smoke temperature of 37.3±1.5°C. The percentage reduction in exhaust gas opacity was 15.2±2.9%. This result is smaller than the reduction result of the standard exhaust, and it can be said that the temperature decreases. These results show that the use of DPF is very influential in reducing the smoke temperature of diesel engines. Thus, DPF is very effectively used to reduce smoke temperature in diesel engine vehicles.

The experimental exhaust II (DPF+SS50) produced a smoke temperature of 33.0±1.0°C with a percentage reduction in exhaust gas opacity of 25±1.7%. These reduction results are greater than the reduction results of the experimental exhaust I without Stainless steel. Where the smoke temperature produced has decreased. The amount of stainless steel added to the DPF is 50

g. This shows that the use of stainless steel as an additional filter has an effect in reducing the smoke temperature. The addition of filters has proven effective in reducing the smoke temperature of diesel engines.

The experimental exhaust III (DPF+SS100) produced a smoke temperature level of 29.0±1.0°C. The percentage reduction in exhaust gas opacity was 34.1±1.7%. These reduction results are greater than the reduction results of the experimental exhaust II with the addition of Stainless steel 100 g, and can be said to have decreased temperature. This shows that the addition of filters proved effective in reducing the smoke temperature of diesel engines.

Exhaust experiment IV (DPF+SS150) produced a smoke temperature level of 25.0±1.0°C. The percentage of smoke temperature reduction was 43.2±1.7%. The reduction results are greater than the reduction results in the exhaust experiments I, II, and III. It can be said that the reduction results in the exhaust experiment IV are the greatest among the four exhaust experiments. The amount of stainless steel added to the DPF is 150 g. This result shows that the more filters added to the DPF, the greater the temperature reduction. This indicates that the variation in the amount of stainless steel as a filter added to the DPF is very influential in reducing temperature. The more filters added, the greater the temperature that can be reduced. The measurement results show that the addition of stainless steel fiber to the DPF significantly affects the smoke temperature. As shown in Figure 9, there is a linear relationship between the added stainless steel fiber and the smoke temperature. Regression equation obtained in (2).

$$y = -0.0471x + 36.384 \quad (2)$$

where y indicates the smoke temperature and x indicates the added stainless steel fiber. The coefficient of determination (R^2) value of 0.9737 indicates that 97.37% of the variation in smoke temperature can be explained by the variation in stainless steel fiber. This study does not specifically measure the temperature during the regeneration process, but discusses the difference in smoke temperature in the exhaust of diesel vehicles installed with DPF and standard exhaust. The results showed that the addition of stainless steel (SS) fibers to the DPF can significantly reduce the smoke temperature. The exhaust gas flow in the DPF is blocked by trapped particles, so this can cause a decrease in smoke temperature. The decrease in temperature in some DPF configurations with SS fibers indicates a more efficient heat transfer mechanism.

The decrease in average temperature from 44°C (standard exhaust) to 37.33°C (experimental exhaust I) demonstrates the ability of copper to absorb and distribute heat more effectively. The high thermal conductivity of copper (387 W m^{-1} K^{-1}) enables rapid heat transfer from the exhaust gas to the DPF substrate, thereby reducing the temperature of the exiting smoke [34]. The addition of SS fibers showed a more significant reduction in smoke temperature, reaching 43.2% in the DPF+SS150 configuration (average temperature 25°C). Despite having a lower thermal conductivity than copper, the presence of stainless steel serves as an additional heat spreading material. These fibers increase the surface area for convective heat transfer, accelerating heat release from the flue gas to the filter substrate. This theory is in line with research on porous materials for heat transfer applications, where a larger surface area increases heat transfer efficiency [35].

The greater temperature reduction with increased stainless steel fiber density (DPF+SS50, DPF+SS150, DPF+SS150) can be explained by conduction and convection heat transfer theories. Conduction theory suggests that the addition of stainless steel fibers increases the heat transfer path in the substrate, which accelerates the release of thermal energy from the flue gas, and Convection theory suggests that the flue gas comes into contact with more surfaces of the heat-absorbing material, increasing the heat transfer from the gas to the substrate [36]. The temperature reduction achieved shows great potential in reducing heat emissions to the environment and improving thermal efficiency. This result is consistent with previous findings showing that the integration of heat-absorbing materials into the DPF substrate can improve thermal efficiency and significantly reduce smoke temperature [37]. Thus, the addition of stainless steel fibers in the copper-based DPF significantly improved the ability of the DPF to absorb and disperse heat, and reduced the smoke temperature by 43.2%.

Noise Level

Figure 10 shows that the standard exhaust produces a noise level of 102.3±0.9 dB. This result is very large because the standard exhaust does not use a DPF as a silencer, so the noise is high. There are no additional components in the standard exhaust that filter solid particles from the exhaust gas before it is released into the atmosphere. Referring to the vehicle noise quality standards in Indonesia, the noise of 102.3 ± 0.9 dB has not met the established threshold [38].

Experimental exhaust I (DPF) produced a noise level of 94.1 ± 0.7 dB. The percentage of noise reduction was 8±0.7%. This result is smaller than the result of the standard exhaust noise, and it can be said that the noise decreases. These results show that the use of DPF is very influential in reducing diesel engine noise [39].

The use of a copper-based DPF in a diesel exhaust system can reduce noise because the DPF can work to filter out fine particles from the exhaust gas, which not only reduces particle emissions but also contributes to noise reduction. This filtering process changes the flow characteristics of the exhaust gas, which can reduce the sound produced by the diesel engine [39]. In the filtration process, the honeycomb structure of the DPF in this study causes turbulence and a decrease in sound wave energy, which helps to reduce exhaust noise. In addition, the copper material can serve as a catalyst in the oxidation process, which helps reduce harmful gas emissions and improve combustion efficiency, thereby contributing to noise reduction [40].

Exhaust experiment II (DPF+SS50) produced a noise level of 92.2 ± 0.6 dB with a noise reduction percentage of 9.9 ± 0.6%. The results of this decrease are greater than the results of the decrease in noise from Exhaust I without Stainless steel. Where the noise produced has decreased. The amount of stainless steel added to the DPF is 50 g. This shows that the use of stainless steel as an additional filter influences noise reduction [41]. The addition of filters is proven to be effective in reducing diesel engine noise.

The third experimental exhaust (DPF+SS100) produced a noise level of 89.1±0.6 dB. The percentage of noise reduction is 12.9 ± 0.4%. This reduction result is greater than the reduction result of the experimental exhaust II, with the addition of 100 g of stainless steel, and it can be said that the noise has decreased. This shows that the addition of more filters can affect the amount of noise reduced [41].

Exhaust experiment IV (DPF+SS150) produced a noise level of 86.7 ± 0.5 dB. The percentage of noise reduction was 15.2±1.3%. The reduction results are greater than the reduction results of the exhaust experiments I, II, and III. It can be said that the exhaust gas reduction results of experiment IV are the greatest among the four exhaust experiments. The amount of stainless steel added to the DPF is 150 g. This result shows that the more filters added to the DPF, the greater the noise reduction. This shows that the variation in the amount of stainless steel as a filter added to the DPF is very influential in reducing noise [39][41]. The more filters added, the greater the noise that can be reduced.

The measurement results show that the addition of stainless steel fiber to the DPF significantly affects the exhaust noise. As shown in Figure 11, there is a linear relationship between the added stainless steel fiber and the noise. Regression equation obtained in (3).

$$y = -0.0471x + 36.384 \quad (3)$$

where y indicates the noise and x indicates the added stainless steel fiber. The coefficient of determination (R^2) value of 0.9901 indicates that 99.01% of the noise variation can be explained by the variation of stainless steel fiber.

From these results, it can be concluded that increasing the stainless steel fiber added to the DPF leads to a decrease in noise. This shows that the use of heavier stainless steel in the DPF can increase the efficiency of the filter in reducing noise. When stainless fibers are added, the filter structure becomes more efficient in capturing particles, which not only increases the filtration efficiency but also reduces the noise generated by the exhaust gas flow [42]. The use of copper-based DPFs and the addition of stainless fibers in DPFs make a significant contribution to noise reduction in diesel exhaust systems, although in this study, only Experiment IV exhaust (DPF+SS150) has met the noise standards of diesel car vehicles in Indonesia, which is below 87 dB [38].

Based on the results of DPF testing that has been carried out on exhaust gas opacity, smoke temperature, and noise level, it shows that these results have met the emission standard threshold set by the government. So, this DPF can be applied to diesel engine vehicles that have not used a DPF in the exhaust system. Of course, with the application of DPF, it will have an impact on reducing exhaust emissions produced by diesel engine vehicles. Thus, this will have an impact on reducing air pollution and making a clean and healthy environment. Clean air from vehicle emissions will have an impact on public health. Improved air quality can increase labor productivity by reducing working days lost due to air pollution-related illnesses.

In addition, the automotive sector can experience increased demand for DPF technology and create new jobs in DPF manufacturing and maintenance. This study certainly has limitations, and further research is needed to improve it. These limitations include: the vehicle used in the study is only one type of diesel engine vehicle, namely the 1997 Isuzu Panther. Therefore, further research is needed and applied to other types of diesel engine vehicles. In addition, this study only tested copper and stainless steel as DPF materials. Thus, investigation of other alternative materials is needed that are expected to improve the performance and durability of the DPF. In this study, no DPF durability test was conducted, so further research is expected to test the durability of DPFs used in diesel engine vehicles within a certain period of time.

CONCLUSION

This research shows that DPF significantly affects the reduction of exhaust opacity, smoke temperature, and noise level of the 1997 Isuzu Panther. The largest reduction in exhaust opacity, smoke temperature, and noise level is produced by DPF + 150 g stainless steel with a reducible exhaust opacity of 87.1 ± 1.1%, smoke temperature of 43.2 ± 1.7%, and noise level of 15.2 ± 1.3%. This result is in accordance with the emission standard threshold set by the government.

These findings open up opportunities for the development of DPF technology that is more efficient in reducing diesel vehicle emissions, contribute to stricter emissions regulations, and support filter design innovation to improve air quality and reduce the negative impact of vehicles on the environment. Future research is expected to examine the optimization of DPF materials and design, regeneration efficiency, and DPF service life, the impact of DPF implementation on vehicles, and integration with other environmentally friendly technologies.

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