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by Thathit Suprayogi

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Performance of Diesel Particulate Filter (DPF) in reducing Exhaust Gas Opacity in Diesel Engines

Agung Samudra[1*], Muhammad Hudan Rahmat[1], Sri Murwantini[1], Thathit Suprayogi[2]
[1]Mechanical Engineering Education Study Program, Universitas Palangka Raya, Palangka Raya, Indonesia
[2]Physics Study Program, Universitas Palangka Raya, Palangka Raya, Indonesia

Abstract
This study investigates the performance of Diesel Particulate Filters (DPF) in reducing the opacity of diesel engine exhaust gases. The DPFs employed in this research are constructed from copper and stainless steel, designed with a metallic honeycomb structure. This experimental study involves installing DPFs on the standard exhaust systems of diesel engine vehicles and measuring the resulting exhaust emissions using an opacity meter. 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). The opacity measurements obtained were 90.2% HSU for Non-DPF, 20.73% HSU for DPF, 17.50% HSU for DPF+SS50, 15.40% HSU for DPF+SS100, and 11.63% HSU for DPF+SS150. The results demonstrate that the use of DPFs significantly reduces the opacity of diesel engine exhaust gases. Notably, the DPF with 150 grams of stainless steel achieved the highest reduction, decreasing exhaust gas opacity by 87%.

Keywords:
DPF; Diesel Engine; Opacity; Opacitymeter

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Corresponding Author:
Agung Samudra
Mechanical Engineering Education Study Program, Universitas Palangka Raya, Indonesia
Email:
agungsamudra@fkip.upr.ac.id

INTRODUCTION

The development of transportation in Indonesia is increasing every year. This can be seen by the increasing number of vehicles on the highway which of course also causes serious problems, especially the problem of air pollution. The latest data from the Indonesian Central Bureau of Statistics (BPS) states that the number of motorized vehicles in Indonesia in 2023 has increased [1]. Diesel cars are one type of vehicle that produces air pollution in the form of black smoke/soot [2], [3]. Soot is an air pollution particle formed from incomplete combustion in motor vehicles [4], [5], [6]. 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 [5], [7], [8]. The higher the PM 2.5 value, the worse the air quality [10]. With this problem, a technology is needed that can overcome the problem of vehicle exhaust emissions, especially diesel engines. The technology used to reduce exhaust emissions is the Diesel Perticulate 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 [9], [10], [11].

Muliatna, *et al.* in 2019 have conducted research on DPF. This research compares the test results of standard exhaust and experimental exhaust (DPF). DPF is made in 3 sizes namely; 20 mm, 15 mm, and 10 mm. The results of this study concluded that the largest opacity reduction occurred in the 10 mm size DPF by 82% [12].

Baidhowi, *et al.* in 2021 also conducted similar research. This study tests the effectiveness of exhaust emission filters using zeolite raw materials and conducts SEM (Scanning Electron Microscope) tests, using analysis on particulate matter PM 2.5 and PM 10. The materials used are 70 mesh and 80 mesh zeolites. The results of this study concluded that zeolite is very effective for filtering exhaust emissions [13]. Zhang, *et al.* in 2023 also conducted a similar study, which 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 [9].

In addition, Puyo, *et al.* in 2023 in 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 [14].

Based on the mentioned research, DPF can effectively reduce the opacity of diesel engine exhaust gas. The DPFs used in these studies have different sizes and materials. Therefore, this study aims to determine the performance of DPFs made from copper and stainless steel with a honeycomb model with a mesh size of 5 mm.

METHOD

This research is experimental research [15], [16]. This study will test the exhaust gas opacity of diesel engines using standard exhaust and experimental exhaust (DPF). The research procedures include design, manufacture, and testing. Copper and stainless steel (SS) are used in this study as materials for making DPFs. Copper is a metal that can be used as a DPF material [17] . In addition, stainless steel (SS) is also a metal that can be used as a DPF material [18].

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, 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, using a honeycomb DPF design 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 [19]. The DPF design is shown in Figure 1. The DPF will be installed on the exhaust of the 1997 Isuzu Panther (Figure 2).

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 iron plate with a thickness of 1 mm. The

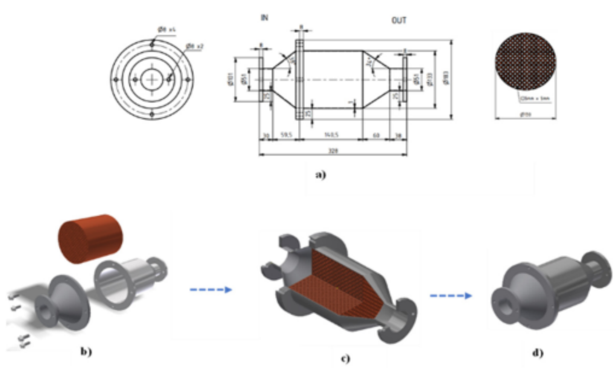

Figure 1. DPF design (a) DPF Casing Dimensians, (b) Casing and DPF, (c) DPF Inside the Case, (d) Complete DPF

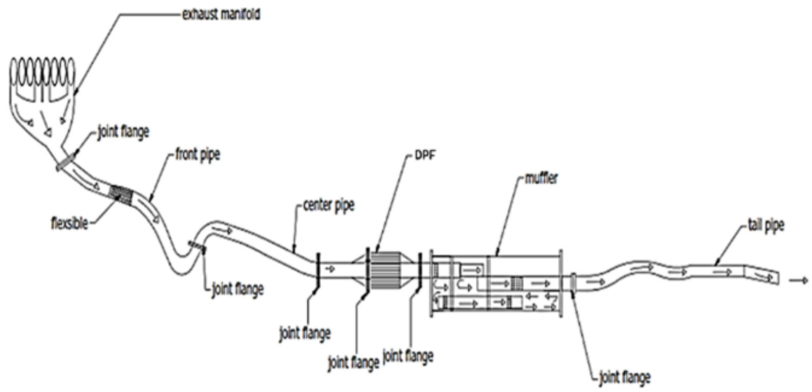

Figure 2. DPF position on the 1997 Isuzu Panther car exhaust

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, where this model is used by researchers who have done in previous studies. The results of making the casing and DPF can be seen in Figure 3 dan 4.

Figure 3. Casing

Figure 4. DPF

Testing

DPF testing was conducted to determine the ability of DPF in reducing the opacity of diesel engine exhaust gas (Isuzu Panther). Figure 5 is the flow of DPF testing carried out to determine the ability of DPF to reduce the opacity of Isuzu Panther engine exhaust gas in 1997.

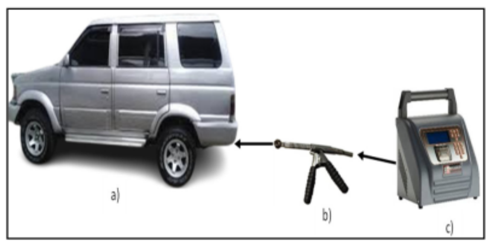

Figure 5. DPF Testing Flow (a) Isuzu Panther 1997, (b) Probe, and (c) Smoke Opacitymeter Brand Tecnomotor Type G-820

Based on figure 5, testing is done with the following procedure:

- Preparation for the 1997 Isuzu Panther Engine Exhaust Gas Opacity Test. Vehicle emission test measuring instrument that has met the requirements such as ISO/DIS-11614E Doc. 1999 article 9.4 by using a device called smoke opacitymeter. The test equipment must be able to measure the opacity concentration (smoke density) at free running acceleration [20]. Then, the emission test equipment must have a valid calibration certification [21].
- Exhaust Gas Opacity Testing of 1997 Isuzu Panther Engine. The most important thing is when accelerating (according to the "accelerate" command displayed on the opacitymeter monitor screen) quickly but

gently and maintain it for 4 seconds (until the opacitymeter displays the "release/decelerate" command), then release the gas pedal (deceleration) until the engine speed returns to idle in accordance with SAE-J1667 (snap acceleration test procedure) and do this step at least 3 times or according to the opacitymeter [22].

- In the final stage of the test, gradually lower the engine speed until the acceleration speed, then turn off the engine [22].

RESULTS

In this study, 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 exhaust gas opacity test of 1997 Isuzu Panther engine in the Tabel 1 and Figure 6.

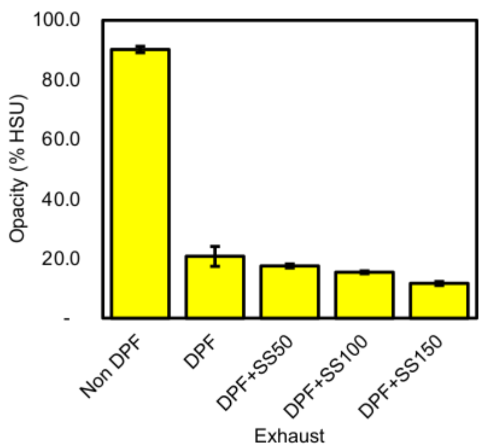

Figure 6. Exhaust Gas Opacity Test Results

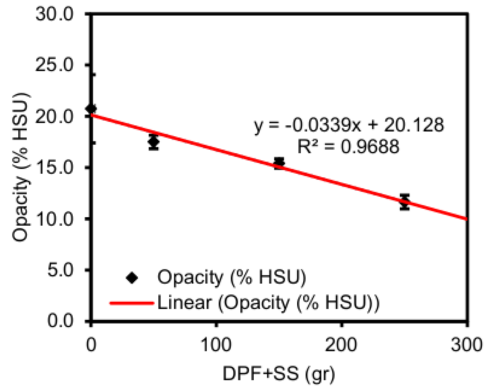

Figure 7. Opacity of the exhaust with DPF and various mass of stainless steel

DISCUSSION

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 DPF as a particulate trap, so the opacity is high [23], [24]. 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 DPF [25]. 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 [20].

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. These results show that the use of DPF is very influential on the reduction of diesel engine exhaust opacity [25] [26], [27], [28], [29]. 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 VI [30].

Table 1. Exhaust gas opacity test of 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

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 influence reducing the opacity of exhaust gas [31], [32]. 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 gr and it can be said that the opacity decreases. This shows that the addition of more filters can affect the amount of opacity reduced [12].

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 experiment 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 the number of 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. The regression equation obtained is:

$$y = -0.0339x + 20.128$$

where y represents exhaust opacity and x denote 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.

CONCLUSION

This research indicates that increasing the mass of stainless steel in the Diesel Particulate Filter (DPF) significantly enhances the reduction of exhaust opacity. Consequently, utilizing heavier materials in DPF design emerges as an effective approach to boost emission control in diesel engines. The largest opacity reduction was produced by DPF + 150 gr stainless steel which was able to reduce the opacity of exhaust gas by 87.1±1.1%.

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