Effectiveness of glass wool and stainless-steel-based diesel particulate filter technology to reduce smoke opacity from four-stroke diesel engine

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Abstract. Diesel engine exhaust emissions are one of the contributors to increased air pollution. One automotive technology that can reduce diesel engine exhaust opacity is the diesel particulate filter (DPF). The purpose of this research is to analyze the effectiveness of using glass wool and stainless-steel-based DPF technology to reduce the opacity of four-stroke diesel engine exhaust. The research method was carried out experimentally in an automotive laboratory. The diesel engine exhaust opacity testing standard uses SNI 19-17118.2-2005, which refers to SAE J1667. The research results show that glass wool and stainless-steel-based DPF technology is proven to be effective in significantly reducing diesel engine exhaust opacity by up to 90.85% compared to the use of a standard muffler.

1 Introduction

One of the global goals, Goal 13 of the 17 Sustainable Development Goals (SDGs) established by the United Nations, is to address climate change and its impacts. Motor vehicle exhaust emissions are known to be one of the contributing factors to the increase in air pollution worldwide [1]. As we know, the combustion of fossil fuels in motor vehicles results in the emission of carbon monoxide (CO), carbon dioxide (CO2), hydrocarbons (HC), and nitrogen oxides (NOx) [2]. Additionally, the combustion process in diesel engines produces particulate matter (PM) emissions, including both PM2.5 and PM10, which are released from the exhaust system. Therefore, strategic measures are required to control these exhaust emissions, which contribute to global warming, to ensure a sustainable and enduring environment.

At least five strategies can be implemented to control air pollution globally. First, regulation and policy [3]. Governments can enact laws and ministerial regulations to limit motor vehicle exhaust emissions to meet established thresholds. In Indonesia, Law No. 32 of 2009 on Environmental Protection and Management [4] and Minister of Environment and Forestry Regulation No. 8 of 2023 on the Application of Emission Standards for Motor Vehicles in Categories M, N, O, and L [5] are already in place.

Second, inspection and maintenance [6]. This involves conducting vehicle inspections (KIR test) for passenger cars and goods vehicles [7]. For private vehicles (cars and motorcycles), regular emissions testing is performed during routine maintenance at automotive workshops [8].

Third, automotive technology. The application of automotive technology to reduce exhaust emissions is continuously innovated by automotive manufacturers and academic institutions. Several automotive technologies that can be used to reduce exhaust emissions include diesel particulate filters (DPF) [9], catalytic converters [10], positive crankcase ventilation [11], exhaust gas recirculation [12], thermal reactors [13], air injection systems [14], electric vehicles [15], among others.

Fourth, is transportation management. This involves increasing the availability of public transport such as bus rapid transit, monorail, mass rapid transit (MRT), high-speed rail (HSR), and others. Fifth, land use [16]. This includes expanding urban green spaces such as city forests and parks, which serve as green open spaces to significantly reduce CO2 emissions as part of the efforts to address global warming [17].

The compression-ignition engine (CIE) using fossil fuels produces exhaust emissions in the form of smoke opacity during diesel engine operation. Therefore, the application of DPF technology is imperative for diesel engines to reduce exhaust smoke emissions generated by the vehicle exhaust system.

1.1 Diesel particulate filter

DPF is a technology used to filter particulate matter (PM2.5 and PM10) emitted from the exhaust gases of diesel engines [18]. DPF, also known as Diesel Particulate Trap (DPT), is commonly used to filter smoke emitted from the diesel engine's muffler. It is

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well known that conventional diesel engines, whether using inline pumps or rotary pumps, tend to produce higher opacity compared to diesel engines with common-rail systems. Therefore, the exhaust systems of diesel engines must be equipped with DPF technology to become more environmentally friendly [19].

1.2 Particulate matter emissions

Diesel engine exhaust emissions contain hazardous compounds, including PM, CO, HC, NOx, and SOx. The commonly known emission from diesel engines is PM, which ranges in size from 100 microns to less than 0.01 microns. PM is a dangerous compound for human health, consisting of a mixture of solid particles and liquid droplets found in the air [20]. PM is a complex mixture of organic and inorganic substances produced by diesel engine exhaust emissions [21]. PM is the pollutant that has the most negative impact on health compared to other pollutants. The size of PM that can enter the human respiratory system is less than 10 µm, with specific details as follows:

- Particles sized 5-10 µm are easily filtered physically by fine hairs in the nasal cavity [22].
- Particles sized 2-5 µm are deposited in the alveoli [23].
- Particles smaller than 2 µm can easily enter the respiratory tract and can be easily exhaled with expiratory air [24].

If inhaled into the body, PM can deposit in lung cells, potentially disrupting lung function and causing black spots on the human lungs [25].

2 Method

This research is experimental. The research aims to determine the effectiveness of glass wool and stainless-steel-based DPF technology in reducing the opacity of exhaust gases from four-stroke diesel engines compared to the use of standard exhaust systems [26].

1.3 Research variables

There are three types of research variables: independent variables, dependent variables, and control variables. The independent variable in this study is the standard muffler and modified muffler equipped with glass wool and stainless-steel-based DPF technology. The weight of the glass wool inserted into the DPF is 130 grams. The dependent variable is the smoke opacity resulting from the diesel engine combustion process. The control variables are engine RPM, fuel, and oil temperature.

1.4 Research instruments

The research instruments are the measuring tools used to obtain data for the study. The measuring tools used in this study are a smoke opacity meter, a 4-in-1 multi-function environment meter, and a blower. The research object is an Isuzu C190- type diesel engine.

1.5 Test procedure

The smoke opacity test on diesel engines follows the SNI 09-7118.2-2005 standard, which involves accelerating the engine without load [27] according to the SAE J1667 (snap acceleration test procedure) [28]. The measuring instrument used is the Technomotor OPA-820 smoke opacity meter.

1.6 Data analysis technique

The data analysis employs a descriptive quantitative method by systematically describing the facts according to the test results [29]. The test data is presented in a table and displayed as bar charts for smoke opacity. The research data is then described to facilitate understanding. This aims to provide a clear picture of the phenomena before and after using DPF technology on the Isuzu C190-type diesel engine

3 Result and discussion

Table 1 below presents the average test data on exhaust gas opacity, noise level, and fuel consumption for the Isuzu C190 engine using a modified muffler with glass wool and stainless-steel-based DPF technology at SMK Semen Gresik, East Java, Indonesia.

From Table 1 above, it can be seen that the use of glass wool and stainless-steel-based DPF technology significantly reduces exhaust gas opacity, vehicle noise, and fuel consumption at every engine speed compared to using a standard muffler.

Table 1. Average test result data.

Engine RPM	Smoke Opacity (%HSU)	Noise Level (dBA)	Fuel Consumption (liters/hour)	Back Pressure at DPF (kPa)	Exhaust Gas Temperature (°C)
750	8,70	75.83	17.18	2.39	174.80
1250		83.40	17.90	4.17	186.21
1750		85.70	19.87	7.47	186.60
2250		92.00	21.24	10.87	205.09
2750		92.60	24.15	11.92	240.00
3250		95.70	24.80	13.85	251.31
3750		96.50	26.24	17.02	274.60
4250		98.07	26.97	18.30	320.81
4750		99.43	29.02	18.88	404.20
5250		99.67	32.67	21.92	486.67

To understand the extent of the effect of using glass wool and stainless-steel-based DPF technology on the modified diesel engine muffler of the Isuzu C190 in reducing opacity, see Table 2 below.

Table 2. Reduction of smoke opacity from Isuzu C190 diesel engine by using glasswool and stainless-steel-based DPF technology.

Muffler Type	Average of Smoke Opacity (%HSU)	Reduction of Smoke Opacity (%)
Standard muffler	95.07	
Modified muffler with glass wool and stainless-steel-based DPF technology	8.70	90.85

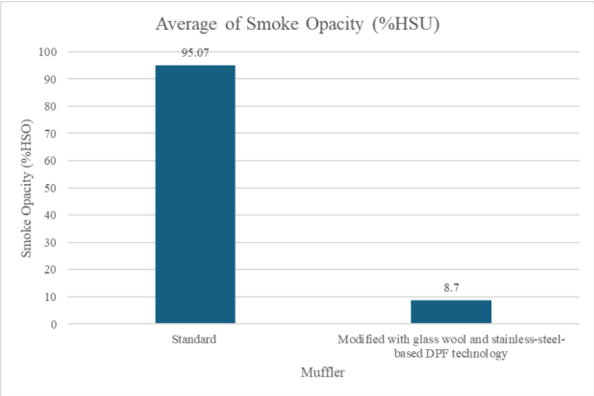

Fig. 1. Comparison of exhaust gas opacity test results using glass wool and stainless-steel-based DPF technology.

In general, it can be concluded that the use of glass wool and stainless-steel-based DPF technology significantly reduces the exhaust gas opacity of the Isuzu C190 engine. According to research conducted by Tsai et al. [30], using filter materials such as glass wool and stainless steel in DPFs is proven effective in capturing harmful small particles and reducing vehicle emissions.

Consistent with previous research findings, the test results show that the average exhaust gas opacity produced by the standard muffler of the Isuzu C190 diesel engine is 95.07 %HSU. In contrast, the average exhaust gas opacity produced by the modified muffler of the Isuzu C190 diesel engine with glass wool and stainless-steel-based DPF technology is 8.70 %HSU. This reduction demonstrates that DPF technology can reduce exhaust gas opacity by 90.85%. A previous study by Singh & Bharj [31] also supports these findings, indicating that using stainless steel DPF can improve particulate filtration efficiency and reduce overall exhaust emissions. Therefore, the application of glass wool and stainless-steel-based DPF technology not only positively impacts the environment by reducing air pollution but also supports efforts to improve air quality and public health.

In the standard muffler, exhaust gases from the combustion chamber to the atmosphere are not filtered or trapped by any material. Consequently, these exhaust gases are released without any filtration or trapping, resulting in higher exhaust gas opacity. A study by Wihersaari et al. [32] shows that exhaust gases from vehicles without a filtration system have higher and more hazardous emission levels compared to those with a filtration system.

Conversely, in the modified muffler, the reduction in exhaust gas opacity occurs because the particulate emissions from the combustion chamber must pass through the Diesel Particulate Filter (DPF) first. Within the DPF, these particulate emissions are filtered by the glass wool material installed at the DPF's intake end. This study by Bermúdez et al. [33] demonstrates that the distribution of particulate matter (PM) significantly impacts the pressure drop in wall-flow particulate filters. The porous filter substrate creates a flow restriction, which worsens as soot and ash accumulate. Research by Yang et al. [19] reveals that using DPF with filtering media such as glass wool can significantly reduce the number of harmful particles in exhaust gases, resulting in cleaner and more environmentally friendly emissions..

As evidence of the reduction in exhaust gas opacity (particulates) using glass wool and stainless steel-based DPF, refer to Figure 2 below.

Fig 2. Glass wool and stainless-steel-based DPF technology: (a) Before testing, (b) After testing.

How many grams of particulate emissions (PM) can be absorbed by this glass wool and stainless-steel-based DPF technology? To calculate this, before conducting the test, the glass wool and stainless-steel-based DPF were weighed using a digital scale to determine the DPF's weight. The weight of the glass wool and stainless steel-based DPF before testing was 4,620 grams. After testing, the DPF's weight increased to 4,710 grams (see Fig. 3). This indicates that 90 grams of particulate emissions (PM) were filtered by glass wool and stainless-steel-based DPF technology.

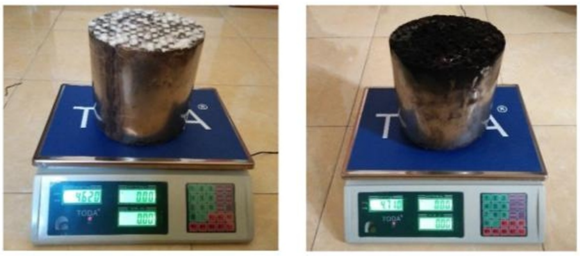

Fig. 3. weight of glass wool and stainless-steel-based DPF technology: (a) Before testing 4.620 gr, (b) After testing 4.710 gr.

To determine whether the use of glass wool and stainless-steel-based DPF technology on the Isuzu C190 diesel engine meets the exhaust gas opacity limits set by the Minister of Environment and Forestry Regulation No. 8 of 2023[5], a comparison between the standard muffler and the modified muffler with glass wool and stainless-steel-based DPF technology is necessary, as shown in Table 3 below.

From Table 3, it can be concluded that the use of glass wool and stainless-steel-based DPF technology in the modified muffler of the Isuzu C190 Diesel engine significantly reduces exhaust gas opacity compared to the standard muffler. The glass wool and stainless-steel-based DPF technology can reduce exhaust gas opacity well below the opacity limits established by the government. It can be said that the use of glass wool and stainless-steel-based DPF in the modified muffler of the Isuzu C190 Diesel engine supports the "blue sky and green school" program launched by the Indonesian government. Additionally, this PDF technology contributes to one of the seventeen Sustainable Development Goals, specifically Goal 13: "Take urgent action to combat climate change and its impacts," as it has been proven to significantly reduce exhaust gas opacity (PM emissions) in Diesel engines[34].

The test results indicate that the use of glass wool and stainless steel-based DPF technology can reduce average exhaust gas opacity by 90.85%. This result is superior to the study by Zhang et al. [9], which focused on advanced DPF regeneration technologies and additional emissions during regeneration, and the research by Quiles-Díaz et al. [35], which investigated the performance of a $CuO/Ce_{0.8}Zr_{0.2}O_2$ catalyst on a SiC-DPF for NO oxidation and soot combustion, where opacity reduction was not the primary focus.

Other studies, such as Vasanthan [36], achieved a reduction in exhaust gas opacity of 60-70% using a copper oxide-based DPF. Meanwhile, research by Akroot et al. [37], which examined the use of copper oxide nanoparticles in biodiesel blends, successfully reduced carbon monoxide and nitrogen oxide emissions, although it did not specifically measure opacity. Further research by Yamin et al. [38] on the effect of oxygenates on the opacity level of a DI diesel engine with and without a DPF showed an opacity reduction of up to 70% with the addition of 15% ethanol at 3000 RPM.

Table 3. Comparison of exhaust gas opacity test results of Isuzu C190 diesel engine with glass wool and stainless-steel-based DPF technology.

Category	Year of Production	Exhaust Opacity Threshold (% HSU)	Testing Method	Opacity of Standar Muffler (% HSU)	Result	Opacity of Modified Muffler with Glass wool and Stainless-steel-based DPF Technology (% HSU)	Result
Compression-Ignition Engine (Diesel Engine)	<2010	65	Free Acceleration	95.07	Not Passed Emission Test	8.70	Passed Emission Test

4 Conclusion

Based on the research results and discussion, it is concluded that glass wool and stainless-steel-based DPF technology is effective in significantly reducing diesel engine exhaust gas opacity by up to 90.85% compared to the standard muffler. The DPF technology has proven effective in addressing air pollution caused by diesel engines and helping mitigate global warming effects due to climate change.

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References

1. UN DESA, SDGs Report 2023. 2023. https://unstats.un.org/sdgs/report/2023/
2. M. Prabhahar et al., Copper Oxide Nanoparticles Incorporated in the Metal Mesh Used to Enhance the Heat Transfer Performance of the Catalytic Converter and to Reduce Emission. J. Nanomater. **2022**, 1–9 (2022). https://doi.org/10.1155/2022/9169713
3. Afifa, K. Arshad, N. Hussain, M. H. Ashraf, and M. Z. Saleem, Air pollution and climate change as grand challenges to sustainability. Sci. Total Environ. **928**, 172370 (2024). https://doi.org/10.1016/j.scitotenv.2024.172370
4. Republik Indonesia, Undang-undang No 32 Tahun 2009 tentang Perlindungan dan Pengelolaan Lingkungan Hidup. 19 (2009)
5. Men-LHK, Peraturan Menteri Lingkungan Hidup dan Kehutanan Nomor 8 Tahun 2023 tentang Penerapan Baku Mutu Emisi Kendaraan Bermotor Kategori M, Kategori N, Kategori O, dan Kategori L. 1–23 (2023)
6. L. M. Baptista Ventura, F. de Oliveira Pinto, A. Gioda, and M. de Almeida D'Agosto, Inspection and maintenance programs for in-service vehicles: An important air pollution control tool. Sustain. Cities Soc. **53**, 101956 (2020). https://doi.org/10.1016/j.scs.2019.101956
7. J. Hudec, B. Šarkan, and R. Cződörová, Examination of the results of the vehicles technical inspections in relation to the average age of vehicles in selected EU states. Transp. Res. Procedia. **55**, 2–9 (2021). https://doi.org/10.1016/j.trpro.2021.07.063
8. S. Dandapat, T. Ghosh, U. Shankar, S. Maitra, and B. Maitra, A relook at the pollution certification of in-use vehicles in India and a way forward. Asian Transp. Stud. **6**, 100020 (2020). https://doi.org/10.1016/j.eastsj.2020.100020
9. Z. Zhang, R. Dong, G. Lan, T. Yuan, and D. Tan, Diesel particulate filter regeneration mechanism of modern automobile engines and methods of reducing PM emissions: a review. Environ. Sci. Pollut. Res. **30**, 39338–39376 (2023). https://doi.org/10.1007/s11356-023-25579-4
10. J. Lucas, M. A. Houghton, and I. G. Masheter, Heat exchanger/catalytic system for reducing the exhaust emissions from diesel engines. Int. J. Automot.

Technol. **13**, 853–860 (2012). https://doi.org/10.1007/s12239-012-0086-4
11. G. Ding, Positive Crankcase Ventilation System. Int. J. Eng. Manuf. **1**, 13–19 (2011). https://doi.org/10.5815/ijem.2011.01.03
12. V. Dhana Raju and P. S. Kishore, Effect of exhaust gas recirculation on performance and emission characteristics of a diesel engine fuelled with tamarind biodiesel. Int. J. Ambient Energy. **40**, 624–633 (2019). https://doi.org/10.1080/01430750.2017.1421579
13. A. Shere and K. A. Subramanian, Emissions reduction in an automotive compression ignition engine using hydrogen and exhaust gas recirculation. Int. J. Ambient Energy. **43**, 8220–8238 (2022). https://doi.org/10.1080/01430750.2022.2091032
14. E. Fayyadh, N. Mahdi, and A. Mohammed, The effect of air injection system on airlift pump performance. FME Trans. **48**, 800–807 (2020). https://doi.org/10.5937/fme2004800F
15. F. Alanazi, Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation. Appl. Sci. **13**, 6016 (2023). https://doi.org/10.3390/app13106016
16. D. Sofia, F. Gioiella, N. Lotrecchiano, and A. Giuliano, Mitigation strategies for reducing air pollution. Environ. Sci. Pollut. Res. **27**, 19226–19235 (2020). https://doi.org/10.1007/s11356-020-08647-x
17. D. P. M. Junior, C. Bueno, and C. M. da Silva, The Effect of Urban Green Spaces on Reduction of Particulate Matter Concentration. Bull. Environ. Contam. Toxicol. **108**, 1104–1110 (2022). https://doi.org/10.1007/s00128-022-03460-3
18. K. Lee, S. Kim, and K. C. Oh, The Effect of Pore Structure on Thermal Characteristics of a Cordierite Diesel Particulate Filter for Heavy Duty Diesel Vehicle. Int. J. Automot. Technol. **22**, 243–251 (2021). https://doi.org/10.1007/s12239-021-0024-4
19. Z. Yang, H. Chen, C. Li, H. Guo, and Q. Tan, Performance Test and Structure Optimization of a Marine Diesel Particulate Filter. Energies. **16**, 4336 (2023). https://doi.org/10.3390/en16114336
20. I. Manisalidis, E. Stavropoulou, A. Stavropoulos, and E. Bezirtzoglou, Environmental and Health Impacts of Air Pollution: A Review. Front. Public Heal. **8**, 1–13 (2020). https://doi.org/10.3389/fpubh.2020.00014
21. Z. Stelmasiak, J. Larisch, J. Pielecha, and D. Pietras, Particulate Matter Emission from Dual Fuel Diesel Engine Fuelled with Natural Gas. Polish Marit. Res. **24**, 96–104 (2017). https://doi.org/10.1515/pomr-2017-0055
22. X. Zhou et al., Chemical nature and predominant sources of PM10 and PM2.5 from multiple sites on the Silk Road, Northwest China. Atmos. Pollut. Res. **12**, 425–436 (2021). https://doi.org/10.1016/j.apr.2020.10.001
23. S. L. Lewis, L. M. Russell, J. A. McKinsey, and W. J. Harris, Small contributions of dust to PM2.5 and PM10 concentrations measured downwind of Oceano Dunes. Atmos. Environ. **294**, 119515 (2023). https://doi.org/10.1016/j.atmosenv.2022.119515
24. E. L. Draper, J. D. Whyatt, R. S. Taylor, and S. E. Metcalfe, Estimating background concentrations of PM2.5 for urban air quality modelling in a data poor environment. Atmos. Environ. **314**, 120107 (2023). https://doi.org/10.1016/j.atmosenv.2023.120107
25. S.-Y. Jiang, A. Ma, and S. Ramachandran, Negative Air Ions and Their Effects on Human Health and Air Quality Improvement. Int. J. Mol. Sci. **19**, 2966 (2018). https://doi.org/10.3390/ijms19102966
26. J. Wang et al., Research on the Measurement of Particulate Matter Concentration in Diesel Vehicle Exhaust Using the Light Scattering Method. Sensors. **25**, 1898 (2025). https://doi.org/10.3390/s25061898
27. SNI 09-7118.2-2005, Exhaust gas emissions - Moving sources - Part 2: How to test motorized M, N, and O category vehicles with compression-ignition engine under free acceleration conditions. National Standardization Agency.
28. SAE J1667, Snap Acceleration Smoke Test Procedure for Heavy-Duty Powered Vehicles. 1996.
29. R. Aggarwal and P. Ranganathan, Study designs: Part 2 – Descriptive studies. Perspect. Clin. Res. **10**, 34 (2019). https://doi.org/10.4103/picr.PICR_154_18
30. Y. I. Tsai et al., The Influences of Diesel Particulate Filter Installation on Air Pollutant Emissions for Used Vehicles. Aerosol Air Qual. Res. **11**, 578–583 (2011). https://doi.org/10.4209/aaqr.2011.05.0066
31. G. N. Singh and R. S. Bharj, Experimental study of filtration behavior of diesel particulate filter in a diesel engine to meet BS-VI emission norms in INDIA. J. Phys. Conf. Ser. **1276**, 012078 (2019). https://doi.org/10.1088/1742-6596/1276/1/012078
32. H. Wihersaari et al., Particulate emissions of a modern diesel passenger car under laboratory and real-world transient driving conditions. Environ. Pollut. **265**, 114948 (2020). https://doi.org/10.1016/j.envpol.2020.114948
33. V. Bermúdez, J. Serrano, P. Piqueras, and E. Sanchis, On the Impact of Particulate Matter Distribution on Pressure Drop of Wall-Flow Particulate Filters. Appl. Sci. **7**, 234 (2017). https://doi.org/10.3390/app7030234
34. B. M. Campbell et al., Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems. Curr. Opin. Environ. Sustain. **34**, 13–20 (2018). https://doi.org/10.1016/j.cosust.2018.06.005
35. S. Quiles-Díaz, J. Giménez-Mañogil, and A. García-García, Catalytic performance of CuO/Ce0.8Zr0.2O2 loaded onto SiC-DPF in NOx-assisted combustion of diesel soot. RSC Adv. **5**, 17018–17029 (2015). https://doi.org/10.1039/C4RA15595E
36. B. Vasanthan, Copper Oxide Coated Diesel Particulate Filters. Int. J. Sci. Res. Dev. **1**, (2013).
37. A. Akroot, S. Kareem, A. Alfaris, and M. Bdaiwi, Enhancing Diesel Engine Performance with Different Concentrations of Copper Oxide

Nanoparticles in Biodiesel Blends. Int. J. Des. Nat. Ecodynamics. **19**, 907–916 (2024). https://doi.org/10.18280/ijdne.190320

38. J. A. A. Yamin, M. S. Hijazi, and M. A. Hamdan, Effect of Some Oxygenates on the Opacity Level of a DI Diesel Engine with and without DPF. Mod. Appl. Sci. **13**, 35 (2019). https://doi.org/10.5539/mas.v13n3p35
39. Setiawan and Warju, Rancang Bangun Diesel Particulate Trap Berbahan Dasar Kuningan Untuk Mereduksi Tingkat Kepekatan Asap (Opasitas) Gas Buang Mesin Diesel Stasioner. Universitas Negeri Surabaya. (2009).
40. T. A. Sulistyono and Warju, Rancang Bangun Diesel Particulate Trap Berbahan Dasar Tembaga Untuk Mereduksi Tingkat Kepekatan Asap Gas Buang Mesin Diesel Stasioner. Universitas Negeri Surabaya. (2009).
41. Warju and Marsudi, The effect of the use of diesel particulate trap (DPT) made from stainless steel and glasswool to reduce opacity, fuel consumption, and the noise level of the Isuzu Panther engine. Otopro J. **9**, 111–121 (2015).
42. S. R. Ariyanto and Warju, Unjuk Kemampuan Diesel Particulate Trap Berbahan Tembaga dan Glasswool Terhadap Reduksi Opasitas Gas Buang. J. Otopro. **11**, 187–195 (2016).