The influence of centrifugal particulate matter reducer on gas opacity and fuel consumption of inspection train

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Abstract. This study aims at determining the level of exhaust gas opacity and fuel consumption using a centrifugal particulate matter reducer in a diesel-engine inspection train. The opacity level was tested using a smoke tester and fuel consumption measurement per 30 seconds. The test was carried out by varying the types of diesel fuel including Bio-solar, Dexlite, and Pertamina Dex. Based on the test results, there is a decrease in exhaust gas opacity for the use of Bio-solar and Dexlite fuels by 5.75% and 6.3%, while the type of Pertamina Dex gained an increase of opacity by 0.6%, respectively. Besides, it was an escalation of fuel consumption in Bio-solar and Pertamina Dex by 7.7% and 2.7%, respectively, while Dexlite did not change the amount of fuel consumption.

1. Introduction

The train is a land transportation means as one of the solutions to reduce road traffic congestion [1]. Currently, the use of diesel-engine rail trains in Indonesia is quite numerous, such as Prameks, Kertosono, and Bojonegoro trains. The increase in rail transportation with diesel engines causes more air pollution from the exhaust gases produced by diesel engines [2]. Diesel engines can produce pollutants that are harmful to humans. The inspection train is one type of railroad facility that can be categorized as special equipment. This kind of train is used for special purposes only, for example checking or measuring railway crossings. This train is a railroad vehicle driven by diesel electricity in which the propulsion system uses electricity and the diesel engine is to turn the generator. The electricity generated by the generator is supplied to the traction motor which is then channeled to the wheels [3].

One of the harmful exhaust emissions produced by diesel engines is a particulate matter [4]. The particulate diesel matter is so dangerous that it can be inhaled and remaining in the alveolar region of the lungs and may cause carcinogenic effects. Other consequences are like pneumonia, bronchitis, and lung disorders [5] due to polycyclic aromatic hydrocarbons and nitro compounds that are adsorbed on the surface [6]. The impact of air pollution by particulates is not only dangerous for humans but also for the environment like the occurrence of acid rain which may disrupt the ecosystem and affects the next chain, i.e. flora and fauna [7].

The factor that affects the high particulate level from a diesel engine is influenced by the use of fuel. Audri in his research explained that the quality of the fuel will also affect the exhaust emissions for
humans and the surrounding environment [8]. There are three types of diesel fuel currently available in Indonesia, Bio-solar, Dexlite, and Pertamina Dex. Each of them has a cetane value. Bio-solar has cetane number 48, Dexlite cetane contains number 51, and Pertamina Dex gets 53 [9] [10]. Each type of diesel fuel produces different levels of exhaust emissions. Wardan Suyanto in his research found that the exhaust gas opacity of a diesel engine that uses a higher cetane value results in a lower exhaust gas opacity [11]. Similarly, Hari Boedi said that the opacity value of exhaust gas from the diesel engine with a higher cetane value results in a lower exhaust gas opacity level [12].

It means that the use of diesel fuel which has a larger cetane number can reduce the level of exhaust gas opacity. Moreover, there are several technologies and innovations to reduce exhaust gas opacity, such as DPT (Diesel Particulate Trap). This technology is considered as one of the best alternatives due to its simplicity and its easy handling [6]. A research conducted by Made Muliatna showed opacity decrease in all variants of DPT, i.e. 77% for DPT Cu + Zn 20 mm, 80% for DPT Cu + Zn 15 mm, and 82% for DPT Zn_Cu 10 mm [13]. It is supported by Andika in his research that the installation of DPT can decline significantly the opacity level of exhaust emissions by 46% [14]. A study from Jefri also highlighted the use of particulate traps to reduce the opacity of diesel exhaust gas [15].

In addition to reducing opacity, diesel particulate traps also influence fuel consumption. Ariyanto in his study mentioned that the use of DPT makes fuel consumption more economical [16]. The measurement of fuel consumption level is based on the Indonesian National Standard (abbreviated SNI) SNI 7554: 2010 [16]. Ihda’s research on DPT from brass material stated that the percentage reduction in fuel consumption was in the average of 13.09% for the exhaust manifold variation 1 and 18.14% for the exhaust manifold variation 4, respectively [17]. The measurement of fuel consumption referred to SNI 7554: 2010. A Research from Buchari regarding the use of High-Speed Diesel and Bio-solar (B30) on fuel consumption concluded that there was an increase in the SFC (Specific Fuel Consumption) value of 3.11% at 50% loading, 3.12% at 75 loadings, and 2.74% at 100% loading when using Bio-solar (B30) comparing to the use of High-Speed Diesel fuel [18].

Based on the above discussion, this study aimed at revealing the influence of centrifugal particulate matter reducer on exhaust gas opacity and fuel consumption in the diesel-engine inspection train of the Indonesian Railroad Polytechnic. The types of fuel used for the experiment were Bio-solar (B20), Dexlite, and Pertamina Dex.

2. Method
This research was conducted using an experimental approach to determine the impact of exhaust gas opacity by using a centrifugal particulate matter reducer and fuel consumption with various types of diesel fuel. The first research stage was testing the exhaust gas opacity of diesel engines for each type of diesel fuel with and without the centrifugal particulate matter reducer. The opacity measurement was using a smoke tester which was carried out at the engine speed of 1500 rpm because the inspection train engine speed had been set at that rotation speed.

Figure 1: Design of centrifugal particulate matter reducer
The next stage was testing fuel consumption with and without a centrifugal particulate matter reducer. The test was done by measuring the fuel consumption every 30 seconds at the engine speed of 1500 rpm without any load. Each fuel was taken 10 samples. The equipment used a measuring cup and a stopwatch. The fuel volume in the measuring cup was set at 1000 ml.

![Figure 2: Testing opacity and fuel consumption](image)

The data obtained were then analyzed with descriptive methods, i.e. systematic description of the obtained test results. The data were tabulated in a table and then presented in diagrammatic form. It was followed by the data display in the form of sentences to describe the phenomena that occurred before and after the experiment.

3. Result and discussion

The results of the exhaust gas opacity test and fuel consumption of the diesel engine using centrifugal particulate matter reducers for the Inspection Train of the Indonesian Railroad Polytechnic are as follows:

3.1. Result of exhaust gas opacity test

The exhaust gas opacity test on the inspection train was done to reveal the gap of production when using a centrifugal particulate matter reducer.

| No | Type of Fuel | Biosolar | Dexlite | Pertamina Dex |
|----|--------------|----------|---------|---------------|
|    |              | Without  | With    | Without       | With          | Without | With |
| 1  |              | 14,6%    | 14,1%   | 18,4%         | 18,5%         | 15,3%   | 16,0% |
| 2  |              | 13,8%    | 13,1%   | 18,0%         | 17,1%         | 14,8%   | 14,7% |
| 3  |              | 13,7%    | 13,0%   | 17,5%         | 16,5%         | 14,5%   | 14,3% |
| 4  |              | 13,7%    | 12,7%   | 16,8%         | 15,5%         | 14,3%   | 14,2% |
| 5  |              | 13,6%    | 12,5%   | 16,1%         | 13,7%         | 14,0%   | 14,1% |

![Table 1: Result of exhaust gas opacity test](image)
Based on the data from the opacity test results above, it can be seen that for diesel fuel the average opacity using a centrifugal particulate matter reducer was 13.9% and those with the tool were 13.1%, respectively. It means that the use of centrifugal particulate matter reducers can decrease the exhaust gas opacity level by 5.75%. It is in line with the research from Daniel et al who conducted a trial using the Diesel Particulate Trap. They found that the exhaust gas opacity of diesel engines can be lower with the use of particulate traps [14]. For the type of Dexlite fuel, the exhaust gas opacity without centrifugal particulate matter reducer obtained an average of 17.4% and the results with the tool application were 16.3%, respectively. It indicates that there was a decline of 6.3%. The fuel type of Pertamina Dex gained the results of the exhaust gas opacity level at an average of 14.6% without the use of particulate reducer and 14.7% with the use of the tool. So, the opacity level of the exhaust gas opacity with the use of a particulate reducer had increased by 0.6%.

3.2. Result of fuel consumption testing
The fuel consumption testing on diesel engines was to know the difference of the fuel consumption level with and without the use of a centrifugal particulate matter reducer. The sampling technique was done by measuring fuel consumption every 30 seconds. There were 10 samples taken for each condition. The volume of fuel in the measuring cup was set at 1000 ml.

Table 2: Result of fuel consumption testing

| Time (second) | Biosolar | Dexlite | Pertamina Dex |
|--------------|----------|---------|---------------|
|              | Without Tool (ml) | With Tool (ml) | Without Tool (ml) | With Tool (ml) | Without Tool (ml) | With Tool (ml) |
| 0            | 0         | 0       | 0             | 0              | 0               | 0              |
| 30           | 40        | 60      | 30            | 30             | 35              | 30             |
| 60           | 70        | 120     | 60            | 70             | 70              | 70             |
| 90           | 110       | 160     | 100           | 110            | 110             | 110            |
| 120          | 150       | 200     | 140           | 140            | 140             | 150            |
| 150          | 180       | 240     | 170           | 170            | 180             | 180            |
| 180          | 220       | 270     | 210           | 210            | 220             | 220            |
Based on the results of the fuel consumption test above, it was known that the average fuel consumption for 300 seconds at the initial volume of 1000 ml of the diesel-engine inspection train without the use of a centrifugal particulate matter reducer with Bio-solar type fuel consumed 36% of fuel at the average and the use of centrifugal particulate matter reducer was 42%. With the use of centrifugal particulate matter reducers, fuel consumption has increased by 7.7%. The test results on the diesel fuel consumption for Biosolar contradicted with the results of the fuel consumption test conducted by Ihda which showed a decrease in fuel consumption after using a particulate reducer [17]. In the use of Dexlite type fuel, it is known that the fuel consumption without the use of a centrifugal particulate matter reducer got the average of 35% and the same of 35% with the centrifugal particulate matter reducer. There is no difference in fuel consumption with and without the use of centrifugal particulate matter reducers. The test results for the use of Pertamina Dex fuel without the use of a centrifugal particulate matter reducer was 35% for the average fuel consumption and 37% with the centrifugal particulate matter reducer. It means that there is an increase in the amount of fuel consumption after using the centrifugal particulate matter reducer by 2.7%.

In this fuel consumption test, the results showed that the use of a centrifugal particulate matter reducer increase fuel consumption for the use of biodiesel and Pertamina Dex. It can be caused by an obstructed exhaust gas flow rate that affects the flushing process in the combustion chamber. The new gas is blocked that affects the combustion process [19] [20] [21].

![Figure 4](image.png)

**Figure 4:** Chart of exhaust gas opacity and fuel consumption

In the percentage graph, it can be seen that the fuel consumption of Bio-solar is the highest if it is compared to Dexlite and Pertamina Dex diesel fuels after using the centrifugal particulate matter reducer. The type of Dexlite diesel fuel does not change the level of fuel consumption, either before or after using the particulate reducer. For diesel fuel, the Pertamina Dex type also increased fuel consumption after using the centrifugal particulate matter reducer. The percentage of exhaust gas opacity for Biosolar and Dexlite diesel fuels tends to decrease. Unlike Pertamina Dex, exhaust gas opacity has increased after the use of centrifugal particulate matter reducers.
4. Conclusions
Based on the research results above, it can be concluded that the use of centrifugal particulate matter reducer in the inspection train diesel engine can reduce the exhaust gas opacity level for the use of Bio-diesel and Dexlite diesel fuels by 5.75% and 6.3%, respectively. For the use of Pertamina Dex type fuel with the use of a centrifugal particulate matter reducer, the exhaust gas opacity increases by 0.6%. The fuel consumption with the use of the centrifugal particulate matter reducer for Bio-solar and Pertamina Dex fuels increase by 7.7% and 2.7%, respectively. Meanwhile, fuel consumption has not experienced any changes for Dexlite fuel.

References
[1] C. Wicaksono, Akhwan and A R Putri 2018 Analisa Daya Dukung Gardu Traksi Kranji Pada Pengoperasian Kereta Bandara Soekarno – Hatta, J. Perkeretaapi. Indones., vol. II, no. 1, pp. 76–82.
[2] G. Amaral et al. 2017 Analisis Shifting Penggunaan Moda Kendaraan Bermotor Ke Kereta Api Terhadap Penurunan Emisi Gas Rumah Kaca (CO2, CH4, dan N2O) Studi Kasus : Daerah Operasional VIII Surabaya, J. Tek. Lingkung., vol. 6, no. 2, pp. 1–15, 2017, doi: 10.1017/CBO9781107415324.004.
[3] I Mahyudin, K P Serpong, T Selatan, and K Kereta 2012 Kendali Propulsi Krde Untuk Mendukung Atp, INSINAS, pp. 99–108, 2012.
[4] E Coda Zabetta, M Hupa and S Niemi 2006 Bio-derived fuels may ease the regeneration of diesel particulate traps, Fuel, vol. 85, no. 17–18, pp. 2666–2670, doi: 10.1016/j.fuel.2006.04.018.
[5] S Iskandar and D Djunda 2018 Analisis Emisi Gas Buang Kendaraan Bermotor di Kota Makassar, Teknologi, vol. 19, no. 1, pp. 1–10, 2018.
[6] G Saracco, N Russo, M Ambrogio, C Badini, and V Specchia 2000 Diesel particulate abatement via catalytic traps, Catal. Today, vol. 60, no. 1, pp. 33–41, 2000, doi: 10.1016/S0920-5861(00)00314-X.
[7] A Budiyono 2001 Pencemaran Udar : Dampak Pencemaran Udar Pada Lingkungan, Dirgantara, vol. 2, no. 1, pp. 21–27.
[8] D Cappenberg 2017 Pengaruh Penggunaan Bahan Bakar Solar, Biosolar Dan Pertamina Dex Terhadap Prestasi Motor Diesel silinder tunggal, J. Konversi Energi dan Manufaktur UNJ, vol. 2, no. Oktober 2017, pp. 70–74.
[9] “2 Hal yang Harus Diperhatikan Saat Memilih Bahan Bakar Solar - Otomotif Tempo.”.
[10] E Megawati and A M M Huda 2019 Analisa Blending Solar Cn-48 Dengan Pertadex Cn-53, PETROGAS, vol. 1, no. 51, pp. 30–35.
[11] W Suyanto, B. T. Siswanto, and M. Wakid 2015 Fuel Characterization on Diesel Engine, J. Penelit. Saintek, vol. 20, no. 1, pp. 29–44.
[12] H B Wahjono and F Rozaq 2018 High Speed Diesel (HSD), J. Perkeretaapi. Indones., vol. II, no. 1, pp. 47–55.
[13] M Muliatna, D V Wijanarko and Warju 2017 Uji Efektivitas Diesel Particulate Trap (Dpt) Berbahan Dasar Kuningan Dan Glasswool Terhadap Reduksi Opasitas Gas Buang Mesin Diesel Multi Silinder I, Otopro, vol. 13, no. 1, pp. 35–43.
[14] A D Lesmana, I P Kristanto, P Studi, T. Mesin, and U. Kristen 2003 Perancangan Diesel Particulate Trap Untuk Menurunkan Opasitas Gas Buang, pp. 1–6.
[15] M J A Frendianto 2013 Pengaruh penggunaan DPT berbahan kuningan dan stainless steel terhadap opasitas/kepekatan asap Isuzu Panther tahun 2000, vol. 02, pp. 40–47.
[16] S R Ariyanto and Warju, “Rancang Bangun Diesel Particulate Trap (DPT) Untuk Mereduksi Opasitas, Konsumsi Bahan Bakar, dan Tingkat Kebisingan Mesin Isuzu C190,” J. Rekayasa Mesin, vol. 01, no. 03, pp. 19–28, 2014, [Online]. Available: https://jurnalmahasiswa.unesa.ac.id/index.php/jurnal-rekayasa-mesin/article/view/8910/8907.
[17] I F Nisa and Warju 2019 Pengaruh Variasi Bentuk Exhaust Manifold Pada Diesel Particulate Trap Berbahan Dasar Kuningan dan Wire Mesh Stainless Steel Terhadap Performa Mesin Diesel 4 Langkah, J. Tek. Mesin, vol. 7, no. 3, pp. 65–72.

[18] K Bahan, B Dan, E Gas, M Diesel, and P Mw 2017 Analisis pemakaian bahan bakar high speed diesel dan biodiesel (b30) terhadap konsumsi bahan bakar dan emisi gas buang mesin diesel pltl 1.4 mw, vol. 18, no. 2, pp. 30–41.

[19] R A Trisna and Warju 2019 Efektivitas Muffler Tipe Resonant, Three Pass Tube dan Off-Set Tube Terhadap Reduksi Konsumsi Bahan Bakar Pada Mesin Bensin Multi Silinder, J. Pendidik. Tek. Mesin, vol. 09, no. 1, pp. 128–133.

[20] A Sanata 2011 Pengaruh Diameter Pipa Saluran Gas Buang Tipe Straight Throw Muffler Terhadap Unjuk Kerja Motor Bensin Empat Langkah, ROTOR J., vol. 4, no. 1, pp. 32–39.

[21] Y Fan and Z Ji 2019 Three-pass mufflers with perforated inlet/outlet tubes, Appl. Acoust., vol. 156, pp. 217–228, doi: 10.1016/j.apacoust.2019.07.018.