

Implementation of linear elevator with high riding quality based on Scurve profile

Cite as: AIP Conference Proceedings **2415**, 030009 (2022); <https://doi.org/10.1063/5.0092879>
Published Online: 15 December 2022

Saba A. Othman, Jamal A.-K Mohammed and Farag Mahel Mohammed



ARTICLES YOU MAY BE INTERESTED IN

[Study and comparative for cooling methods of thermoelectric cooling elements for hypothermia treatment](#)

AIP Conference Proceedings **2415**, 030012 (2022); <https://doi.org/10.1063/5.0093135>

[Influence of shot peening on the corrosion and fatigue behavior of Al 6061](#)

AIP Conference Proceedings **2415**, 060001 (2022); <https://doi.org/10.1063/5.0092305>

[The effect of biolubricants oil on the dynamic performance of rotor bearing system](#)

AIP Conference Proceedings **2415**, 040003 (2022); <https://doi.org/10.1063/5.0092281>



APL Quantum

CALL FOR APPLICANTS

Seeking Editor-in-Chief

Effect of Soot Particles on lubricating Oils Degradation in Compression Ignition (CI) Diesel Engine

Mohammed A. Fayad^{1,a)}, Hayder A. Dhahad²⁾, Farag Mahel Mohammed³⁾

¹ *Energy and Renewable Energies Technology Center, University of Technology, Baghdad, Iraq*

² *Mechanical Engineering Department, University of Technology, Baghdad, Iraq*

³ *Electromechanical Engineering Department, University of Technology, Baghdad, Iraq*

^{a)} *Corresponding author: Mohammed.A.Fayad@uotechnology.edu.iq*

Abstract: The performance of the engine oil is affected over time by the different parameters such as combustion products such as soot particles, carbon, unburned fuel, and unburned hydrocarbon (UHC). The engine oil degradation was analysed by using Transmission Electron Microscopy (TEM), Thermogravimetric Analysis (TGA) and Fourier Transform Spectrometry (FTIR). In this work, it is indicated that the number of primary particle (n_{po}) increased with long time of engine operation (30 days) compared with short period of engine operation (10 days). Besides, the size of primary particle (d_{po}) is bigger by (33nm) from combustion of 30 days on engine operation with respect to the 10 and 20 days by 28 nm and 31 nm, respectively. The high levels of presence soot particles in the engine oil are need a higher temperature for degradation. Further, it is found that the 400 °C is the maximum temperature for weight loss in case of fresh oil, while goes to 450 °C for used oil (soot in oil). From FTIR results, the concentration of soot contamination in lubricating oil increased with long time of engine operation.

Keywords - Soot particle, lubricating oil, TGA, degradation, contamination, diesel engine.

1. INTRODUCTION

To meet strict standard emissions regulation, designers are working in modify diesel engine. Higher loading by engine from these changes is result in an increasing the soot emissions and unburned fuel. Small proportion of soot primary particles, soot agglomerates and unburned hydrocarbon (HC) is transferred from the engine cylinder to the lubricating oil [1, 2]. The formation of soot particles is initiates from pyrolysis of unburned HC via high heat produced during fuel combustion [3, 4]. The nanoparticles of soot emissions is formed from the alkynes (from the decomposition of fuel) like acetylene (C_2H_2) and heavy PAH (Polycyclic Aromatic Hydrocarbons) [5]. It is mentioned that the higher engine conditions (load and speed) increases the soot production and reduces the residence time available for soot oxidation [6, 7]. The soot accumulation in the engine oil is the main reason for wear mechanism, especially when engine equipped with exhaust gas recirculation (EGR) technology. The lubricating oil is penetrated by foreign material arises in the combustion chamber such as soot particles and fuel-borne organometallic additives [8]. Liang et al. [9] and by McGeehan et al. [10] studied the influence of soot particles on increases the wear mechanism and reduce the oil viscosity. Also the engine oil properties are changed when contaminate with harmful soot particles and causes in wastage of billion tonnes of lubricants per year, participating in critical impact to human wellbeing and environmental pollution [11-13]. It is stated that more than 5% of soot emissions can transferred from combustion cycle to the engine oil [14]. Soot particles emitted from diesel engine have twofold effect on environmental and human health [15]. The contamination of soot particles and unburned fuel in lubricating oil is getting interest by researchers over time due to the direct effect on the viscosity, friction coefficient and film thickness as well as engine oil life [16, 17]. Green et al. [17] and Gautam et al. [18] stated that used TGA technique to analysis the soot concentration in the lubricating oil. It is reported that higher level of soot concentration in combustion cycle increases the wear mechanism between engine components [19].

Smaller size of particles has vital role in an increasing the contamination of engine oil in the crankcase due to possibility of these particles enter between cylinder wall and piston during the combustion cycle [20, 21]. It is documented that the soot composition is different between soot in the engine oil and combusted from the engine [22]. The soot particles are transported within the sump oil either via reciprocating action of the piston rings or

through scraping the remaining soot on the cylinder wall [6, 17]. In previous work, it is reported that the increases engine wear and rheological performance affected by amount of soot particles [23]. They also concluded that the amount of soot interaction can be effect on engine oil thickening and abrasive wear as well as this can be occurred because of the presence soot particles. Earlier experimental works by Li et al. [24] and La Rocca et al. [25] have suggested several techniques on how soot agglomerates can be extracted from engine oil. Clague et al. [22] proposed a new method to prepare a suitable sample of soot agglomerates from lubricating oil for Transmission Electron Microscopy (TEM). It is reported in the literature that the initial coefficient of friction reduced by 10% when the graphite contaminate with engine oil at 10 mass% with respect to the fresh engine oil [26]. The Thermogravimetric (TGA) analysis is widely accepted technique used to investigate the soot oxidation and determines the thermal stability of a substance as a percent by weight. In addition, it is also employed to assess the amount of soot content in the lubrication oil. In the literature, only limited data are available the contamination of soot agglomerate in the lubricating oil. The purpose of this study is to investigate how the soot particles can effect on engine oil degradation for 10, 20, 30 days of engine operation. Further, analysis the chemical and physical (number and size) properties of soot primary particle in the engine oil for different time of diesel engine operation.

2. EXPERIMENTAL TESTS AND EQUIPMENT

2.1 Research Engine Specifications and Conditions

The tests were carried out using research four-cylinder direct injection (DI) diesel engine equipped with exhaust gas recirculation (EGR) system. The research engine specifications were 110 and 125 mm for bore and stroke respectively, with compression ratio 17:8. The engine speed was ranged from 900 to 2500 rpm, with indicated mean effective pressure (IMEP) is less than 6 bar. The main engine parameters of torque and engine speed were controlled via electric dynamometer. Further, the exhaust temperature and oil temperature were measured by using E-type of thermocouples and these values are recorded during the experimental tests. During all tests, the engine speed was constant of 1800 rpm, with fuel injection pressure was kept constant at 650 bar and IMEP fixed at 5 bar for 20 hours per day. The high rate (30%) of EGR was used for all tests to increase the level of soot particles may be accumulated in the engine oil. Further, the engine is filled with clean lubricating oil (type SAE 5W/30). The chemical degradation and colour change occurs in the engine oil due to the chemical reaction between combustion by-products and oil as illustrated in Figure 1. It can be noticed that the trend of contamination in the engine oil starts growing with 20 and 30 days (Figure 1) of engine operation. The engine starts running the real test for 10, 20 and 30 days and 20 hours per day. The oil sample is drawn from engine sump before test (fresh oil) and at end of the each test period (used oil) based on the method by La Rocca et al. [25] (Figure 1).

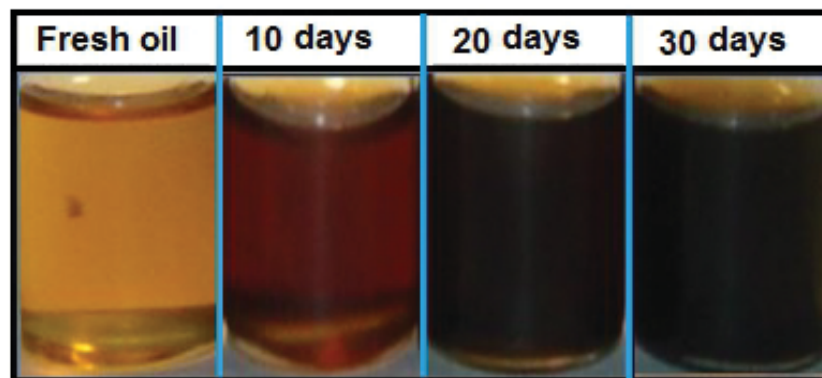


FIGURE 1. A picture of engine oil samples for different days of engine operation.

2.2 Fuel and Equipment

The main properties of conventional diesel fuel used during the test are presented in Table 1. The engine was fed by diesel fuel which supplied by Al-Doura Refinery. High resolution about 2 Å of transmission electron

microscopy, TEM with Phillips CM-200 microscope, was carried out over the tests to investigate the parameters of soot particles in the engine oil (Figure 2). TEM is a proper system to tracking soot particles and provides accurate measurement of the number of primary particles (n_{po}) and size of primary particles (d_{po}) of soot agglomerates [27-29].



FIGURE 2. A picture of transmission electron microscopy (TEM).

TABLE 1. Specifications of tested fuels [21, 30].

Properties	Diesel fuel
Chemical formula	$C_{16}H_{34}$
Derived cetane number	51.8
Latent heat of vaporization (kJ/kg)	242
bulk modulus (MPa)	1410
density at 15 °C (kg/m ³)	844.3
Calorific value (MJ/kg)	45.80
Falsh & Fire point (°C)	65-70
Water content by coulometric KF (mg/kg)	40
kinematic viscosity at 40 °C (cSt)	2.77
Stoichiometric air fuel ratio	14.4
lubricity at 60 °C(μm)	312

Thermogravimetric Analysis with model Perkin Elmer 2012 (TGA) is commonly used estimate the soot concentration as a percent by weight as shown in Figure 3. A sample pan is hangs from a precise optical balance situated in the head of TGA. The oil sample (20 mg) is put in the pan and then resides within a platinum furnace to measure the soot content in the engine oil. When testing, the pan resides within a platinum furnace which is encased in a glass chamber that is pneumatically lifted to seal against a glass sphere as pictured. The oil sample is heated under inert and atmospheric conditions (i.e. nitrogen or helium) from ambient temperature to 750 °C to quantify its oxidisable content and evaporative. Heating the oil sample in a nitrogen-rich atmosphere to remove all of the volatile materials at around 600 °C until the weight of the sample levels off. Thermal breakdown of engine oil is occurring in three phases. The oil sample starts at 300 °C in nitrogen environment and then replaced by air at 550-580 °C. The temperature further increased allowing the oil to oxidize until the weight again stabilizes. The last phase is occur once oxygen is present in the sample's atmosphere and the temperature remains above 750°C until

no organic compounds left at this point. The steps and details of the TGA operation used during the test are listed below:

1. 20 mg of Sample Size
3. Initial Purge Gas-Nitrogen (Program Steps)
4. 50°C for 1 min for Isothermal
5. Heat the sample to 850°C during 100 °C/min
6. Cool from 850°C to 400 °C during 100 °C / min
7. Heat to 400°C to 850°C during 100 °C/min
8. Isothermal at 850°C (for 10 min)
9. At 100°C/min, cool from 850°C to 50°C
10. For 10 min, isothermal at 850 °C



FIGURE 3. Thermogravimetric Analysis (TGA).

Fourier Transform InfraRed, FTIR with Model 2030, spectrometer was used to measure the level of soot contamination in the engine oil (liquid sample) by measure the sample spectrum. Permanently, it is used to measure the soot level in lubricating oil. The light emitted covering all relevant signals for lubricant analysis. Spectral range was from 4000 to 600 cm^{-1} with a resolution of 4 cm^{-1} at room temperature [31].

3. RESULTS AND DISCUSSION

3.1 Level of Soot Particles Concentration in the Engine Oil

Figure 4 show the effect of soot contamination level in the engine oil for different engine operating 10, 20 and 30 days and high rate of EGR (exhaust gas recirculation). According to the results, the engine oil increases the degradation by soot in oil with increasing the time of engine operation. The sample of soot agglomerates in the engine oil was analysed by Transmission Electron Microscopy (TEM) as shown in Figure 5. The method used to

extracted soot from oil and analysed by TEM is presented in La Rocca et al. [25]. Different number and size of primary particles comprised together to form chain-like and clusters of spherules of the final shape of soot agglomerates (Figure 5). It is reported that the soot particles are agglomerated together forming irregular clusters of soot agglomerates in engine oil [25, 32]. It can be observed that the number of primary particles increased in the engine oil with increasing the time days of engine operation and high rate of EGR as presented in Figure 4. It is stated that the present high rate of EGR technology leads to increases the soot emissions in diesel engine [33, 34]. Further, the soot particles are contaminated the engine oil more in sample of soot in engine oil for 30 days. This could be due to increases the soot formation during engine combustion processes for long time of hours, which in turn increases the potential chance to penetrate some of these soot to the oil sump and contaminate the lubrication. The soot agglomerates composed from 30 to 40 particles are higher for all engine operation conditions (Figure 4). It is thought that the soot particles enhanced further aggregation and agglomerations between soot particles result in more increase in the total number of primary particles that to entered to the oil sump. Another reason could be due to the soot aggregates and likelihood of collisions between particles occurred after leave the combustion process.

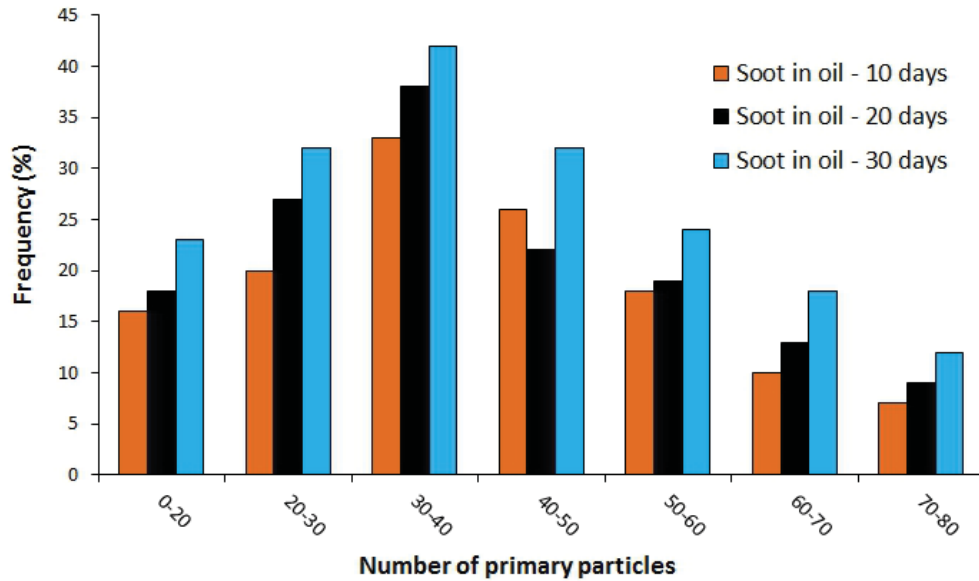


FIGURE 4. Number of primary particles (n_{po}) for soot in oil under different engine operation days.

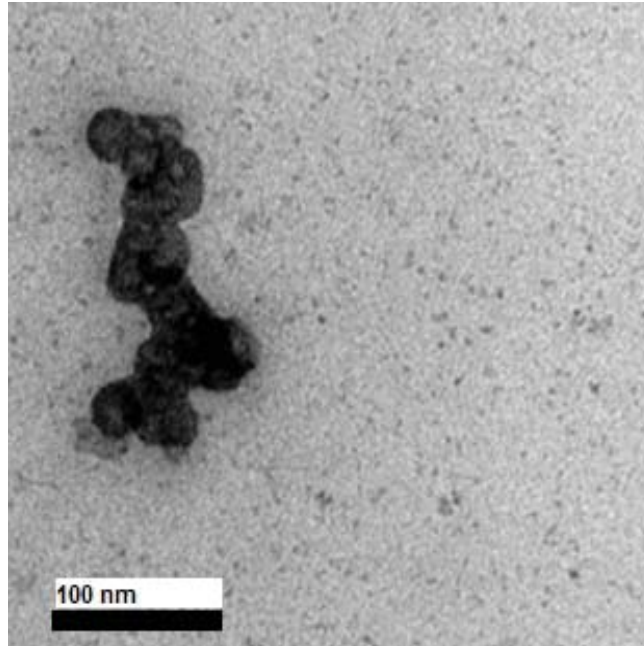


FIGURE 5. A sample TEM image of soot agglomerates in the engine oil.

From TEM image, more than 150 primary particles were selected to calculate the average size of primary particles (d_{po}). The size of primary particles for soot in oil under different engine operating days is presented in Figure 6. It was found that the size of primary particle in engine oil is higher with engine operating 30 days by 33 nm compared to the 20 and 10 days by 31 nm and 28 nm, respectively of engine operation. The main reason to justify this is because of the increase the number of soot primary particles inside combustion process [35, 36], which increases the collision between particle to form bigger size of primary particles. It also suggested that several of unburned hydrocarbons, carbon and graphite layers resulted from combustion process are form another layer turn around the soot particles to increase the average size of primary particles. It is documented that the soot particle in engine oil contains a higher ratio of carbon compared to the soot particle emitted from the exhaust [37]. The increase temperature with time of engine operating (from 10 to 30 days) could be increase the growing of polycyclic aromatic hydrocarbon (PAH). The react and/or attach PAH with each other also contributes in forming larger size of soot primary particle (Figure 6). The coagulation between single primary particle with other spherical primary particle is occurs to growing the size of particle. This phenomena of soot coagulation is agreements with previous experimental studied in literatures [12, 38].

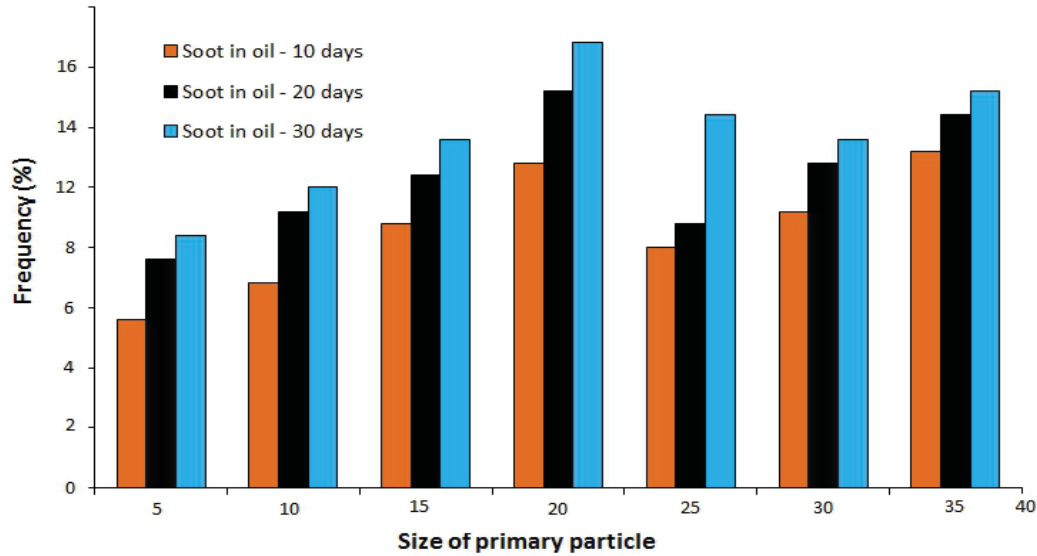


FIGURE 6. Primary particles size distributions for soot in oil for different days operation.

3.2 Thermogravimetric Analysis (TGA)

Figure 7 shows the effect of temperature on engine oil degradation for fresh oil and used oil using Thermogravimetric Analysis (TGA) for different engine operation days. It is shown how used oil needs a higher temperature for its degradation, probably due to the presence of soot particles in the engine oil. The maximum rate of weight goes from around 400 °C for fresh oil to 450 °C for used oil, which coincides with typical soot pyrolysis temperatures. For weight losses, used oil needs about 30°C more for degradation than fresh oil (Figure 7). It is shown that used oil at 460 °C has been completely pyrolyzed. Further, it can be seen that the used oil losses the weight faster than fresh oil over range of temperatures. From TGA results, it can be noticed that soot particle increases the contamination in engine oil with increase the engine operation time as presented in Figure 7. The weight losses increased with long time of engine operation (30 days) compared with 10 days. This is due to the increases soot particles formed and contamination in the engine oil. In addition, the aging of engine oil this can be noticed in Figure 1 when engine oils become a thick black colour and losing their clarity, especially in case of 20 and 30 days of engine operation.

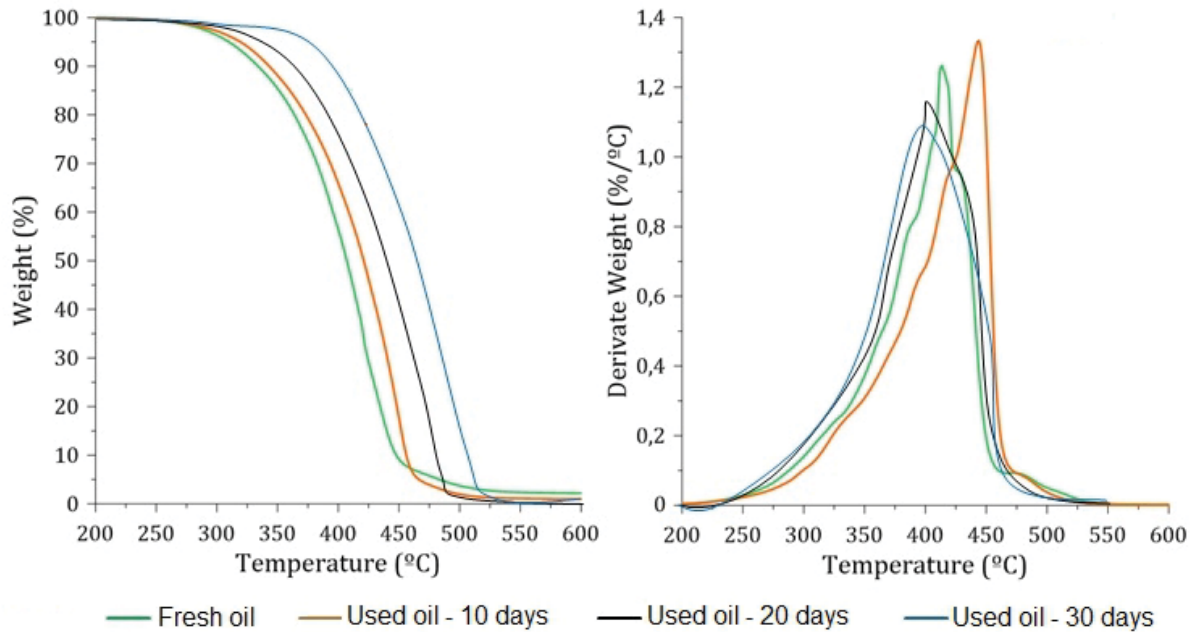


FIGURE 7: TGA results obtained for fresh oil and used engine oil collected from oil sump for different engine operating days.

3.3 Level of Soot Particles in the Engine Oil

During the warm-up of the engine, incomplete combustion can lead to a series of by-product of soot particles, substances, and unburned fuel dissolving in the engine oil. The soot samples were collected from the lubricating oil in crankcase for different engine operating days. The soot particles contamination in the engine oil doesn't exhibit a specific IR absorption therefore its treated differently. The two typical spectra of in-service oil highlighting various different signals correlating were shown in Figure 8 with changes exhibited by the oil during operation. The ASTM E2412 method was depends in this test to analysis the used oil. Figure 8 shows modern analytical technique of soot level in engine oil by Fourier Transform Spectrometry (FTIR) for used oil and fresh oil. The fresh oil was analysed by FTIR spectrum to obtain a baseline FTIR trace. It is clear that the soot contamination level of used oil was slightly higher than fresh oil. This is indicated by subtracting the fresh oil spectrum form used oil spectrum (called difference spectrum). According to Figure 8, it can be noticed that the soot in used oil causes a vertical shift in the bassline of the spectrum (affected by amount of soot present and size of soot particle size). This is due to absorption and scattering of light in the region around 2000 cm^{-1} (this region is used to assess the level of soot in oil sample). It can be observed from Figure 9 that two peaks in rang 1600 cm^{-1} and 1300 cm^{-1} due to aromatic C=C stretching and symmetric and symmetric modes, respectively. Clearly, there are small differences in the peak positions of the band due to a little soot contamination with lubricating oil. However, it is difficult to distinguish the degradation of oil properties for short time of engine operation because the soot particles take long time to dissolves in lubricating oil. In contrast, the increasing engine operating days leads to increase the soot level in the engine oil as shown in Figure 9. This could due to increase the degradation of engine oil with increasing the level of soot particles in the engine oil compared than to the fresh oil. The main reason for that is the direct react of soot particles with engine oil via time and reduced the engine oil life. The solid soot particles can be more effect on engine parts due to increase the friction and reduce the anti-ware mechanism for engine parts.

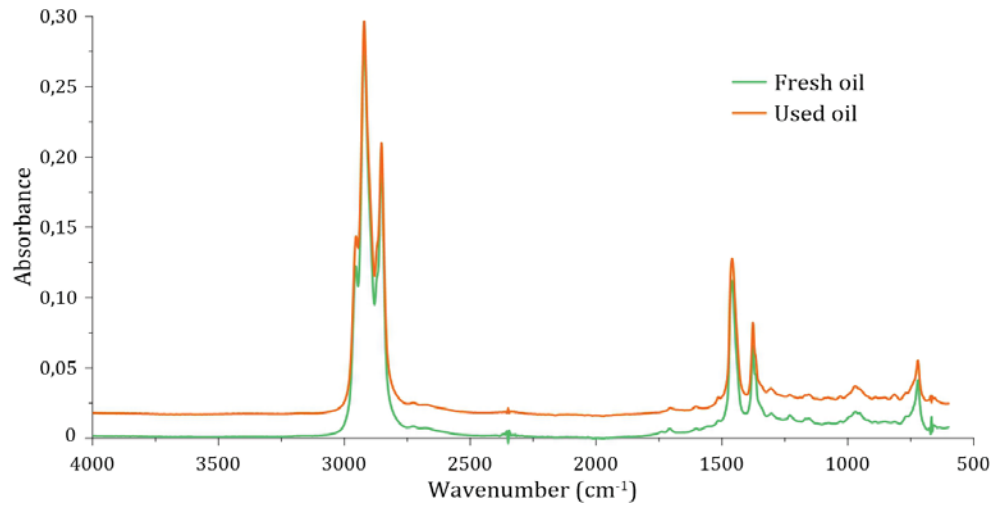


FIGURE 8. FTIR spectrum seen in fresh engine oil and used engine oil.

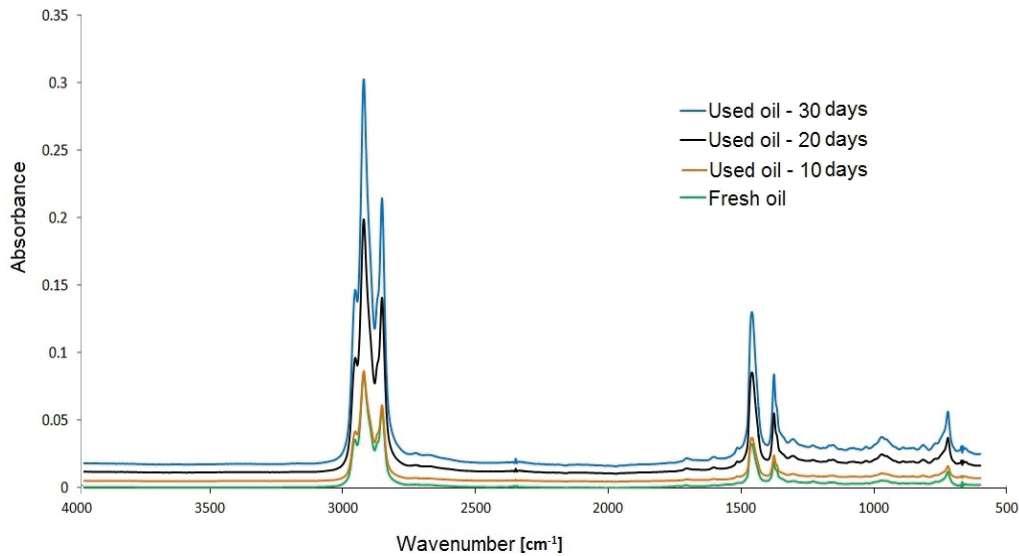


FIGURE 9. FTIR spectrum seen in fresh engine oil and used engine oil for different engine operating days.

4. CONCLUSIONS

The influence of level soot primary particle on the degradation of engine oil properties for 10, 20 and 30 days of diesel engine operating is experimentally investigated in this study. The samples of engine oil are analysed by different instruments to detect the behaviour of soot agglomerates in the engine oil. It can be concluded that mean size and number of primary particles of soot agglomerates in engine oil were increased with 30 days of engine operation. The d_{po} is larger by 33nm from 30 days of engine operation compared than those emitted from 10 and 20 days of engine operation by 28 nm and 31 nm, respectively. This indicates that soot particle will be high effect on the engine components. It was observed that the weight losses of engine oil increases with increasing the soot particles in the engine oil. Furthermore, the obtained FTIR results revealed that the level of soot particles increase more with 30 days of engine operating compared than to the 10 and 20 days. These results provide further understanding about analysis the effect of soot particles on the degradation of engine oil.

ABBREVIATIONS

DI = direct injection

d_{po} = size of primary particle

EGR = exhaust gas recirculation

FTIR = fourier transform infrared

HC = hydrocarbon

TEM = transmission electron microscopy

IMEP = indicated mean effective pressure

PM = particulate matter

n_{po} = number of primary particles

TGA = thermal gravimetric analysis

REFERENCES

1. Yu, M., Zhang, J., Joedicke, A., Reddyhoff, T., *Experimental investigation into the effects of diesel dilution on engine lubrication*. [Tribology International](#), 2021. **156**: p. 106828.
2. Liang, X., Wang, Y., Wang, Y., Zhao, B., Zhang, Z., Lv, X., Wu, Z., Cai, X., Wang, K., [Combustion and Flame](#), 2020. **217**: p. 77-84.
3. Dhahad, H.A., Fayad, M.A., [Fuel](#), 2020. **279**: p. 118384.
4. Kitamura, T., Ito, T., Senda, J., Fujimoto, H., [International Journal of Engine Research](#), 2002. **3**(4): p. 223-248.
5. Heywood, J.B., USA: McGraw-Hill, 1988: p. ISBN 0-07-100499-8.
6. Daido, S., Kodama, Y., Inohara, T., Ohyama, N., Sugiyama, T., [JSAE review](#), 2000. **21**(3): p. 303-308.
7. Fayad, M.A., *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 2019: p. 1-11.
8. Vincent, M.W., Richards, P.J., Rogers, T.J., SAE Technical Paper, 2000.
9. Liang, X., Wang, Y., Wang, K., Wang, Y., Zhang, H., Zhao, B., Lv, X., *Proceedings of the Combustion Institute*, 2020.
10. McGeehan, J.A., Rynbrandt, J.D., Hansel, T.J., SAE Technical Paper, 1984.
11. Gómez-Rico, M.F., Martín-Gullón, I., Fullana, A., Conesa, J.A., Font, R., [Journal of Analytical and Applied Pyrolysis](#), 2003. **68**: p. 527-546.
12. Fayad, M.A., Tsolakis, A., Martos, F.J., [Renewable Energy](#), 2020. **149**: p. 962-969.
13. Fayad, M.A., Dhahad, H.A., [Fuel](#), 2021. **286**: p. 119363.
14. Eastwood, P., John Wiley & Sons Ltd. UK., 2008.
15. Fayad, M.A., Fernández-Rodríguez, D., Herreros, J.M., Lapuerta, M., Tsolakis, A., [Fuel](#), 2018. **229**: p. 189-197.
16. Esangbedo, C., Boehman, A.L., Perez, J.M., [Tribology International](#), 2012. **47**: p. 194-203.
17. Green, D.A., Lewis, R., [Proceedings of the Institution of Mechanical Engineers, Part D Journal of Automobile Engineering](#), 2008. **222**(9): p. 1669-89.
18. Gautam, M., Chitoor, K., Balla, S., Keane, M., SAE Technical Paper, 1999.
19. Oungpakornkaew, P., Karin, P., Tongsri, R., Hanamura, K., [Wear](#), 2020. **458**: p. 203407.
20. Pulkhabek, W.W., *Engineering fundamentals of the internal combustion engine*. 2004.

21. Fayad, M.A., [Thermal Science and Engineering Progress](#), 2020: p. 100621.
22. Clague, A.D.H., Donnet, J.B., Wang, T.K., Peng, J.C.M., [Carbon](#), 1999. **37**(10): p. 1553-1565.
23. George, S., Balla, S., Gautam, V., Gautam, M., [Tribology international](#), 2007. **40**(5): p. 809-818.
24. Li, S., Csontos, A., Gable, B., Passut, C., Jao, T., SAE Technical Paper, 2002: p. 01-1672.
25. La Rocca, A., Di Liberto, G., Shayler, P.J., Fay, M.W., [Tribology International](#), 2013. **61**: p. 80-87.
26. Al Salihi, H.A., Fayad, M.A., Slepchenkov, M., Shunaev, V. *Laser Physics, Photonic Technologies, and Molecular Modeling*. 2020. International Society for Optics and Photonics.
27. Lapuerta, M., Martos, F. J., Martín-González, G., [Journal of colloid and interface science](#), 2010. **346**(1): p. 23-31.
28. Lapuerta, M.B., R.; Martos, F. J., [J. Colloid Interface Sci.](#), 2006. **303**: p. 149-158.
29. Fayad, M.A., Tsolakis, A., Fernández-Rodríguez, D., Herreros, J.M., Martos, F.J., Lapuerta, M., [Applied Energy](#), 2017. **190**: p. 490-500.
30. Fayad, M.A., [SN Applied Sciences](#), 2019. **1**(9): p. 1088.
31. Zhang, J., Yang, Y., Zhang, X., Guan, J., Zheng, L., Li, G., [Industrial Lubrication and Tribology](#), 2019. **72**(5): p. 549-555.
32. la Rocca, A., Di Liberto, G., Shayler, P.J., Parmenter, C.D.J., Fay, M.W., [Tribology International](#), 2014. **70**: p. 142-147.
33. Aldajah, S., Ajayi, O.O., Fenske, G.R., Goldblatt, I.L., [Wear](#), 2007. **263**: p. 93-98.
34. Tsolakis, A., [energy & fuels](#), 2006. **20**: p. 1418-1424.
35. Su, D.S., Jentoft, R.E., Müller, J.-O., Rothe, D., Jacob, E., Simpson, C.D., Tomovic, Z., Müllen, K., Messerer, A., Pöschl, U., Niessner, R., Schlögl, R., [Catalyst Today](#), 2004. **90**: p. 127-132.
36. Bonatesta, F., Chiappetta, E., LaRocca, A., [Applied Energy](#), 2014. **124**: p. 366-376.
37. Bannister, C.D., Chuck, C.J., Bounds, M., Hawley, J.G., Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2011. **225**(1): p. 99-114.
38. Fayad, M.A., Herreros, J. M., Martos, F. J., Tsolakis, A., [Environmental Science & Technology](#), 2015. **49**(19): p. 11967-11973.