

The change in Diesel Engine Oil Properties During Performance

Kafaa F. Abbas

Al Farabi University College, Baghdad, Iraq

Email: kafaa.alani@alfarabiuc.edu.iq

Abstract: Infrared (IR) and differential scanning calorimetric (DSC) analytical tests have been used to study the change in diesel engine oil properties during performance, in addition to the changes in physical and chemical properties.

Two types of diesel engine oils (petroleum base) that are used in bus vehicles were examined in bus diesel engines travelling distances up to 5000 km. The results show the characterization of the oil as the changes in chemical composition and physical properties with the travelling distances increase. Also, the results show the changes that take place in the diesel engine oils during use up to 5000 km depend on choosing the type of oil that bears such heavy duty engines as the bus vehicle, and the period required to change the oil to avoid damage to the different parts of the engine.

Keywords: Diesel oil, internal combustion engine oil, diesel oil aging, diesel oil properties, chemical composition of diesel oil

1. Introduction

Lubrication is a process in which a lubricant is placed between rubbing surfaces to control friction and reduce wear. The manufacture and classification of lubricating oil base stocks, including refined petroleum stocks, are used in internal combustion engines, whether in light or heavy duty engines (HD). These oils consist of a base oil chosen with specifications that suit the place of use. However, these oils do not withstand the operating conditions, especially when exposed to extremely high temperatures (up to 800 °C in the cylinder walls) and pressures (up to 1000 psi in the bearings) in the air environment [1, 2, 3]. Base oils are mixed with chemical additives to improve the specifications, and to enhance oxidation stability, corrosion resistance, wear reduction, friction modification, viscosity–temperature improver and other important performance characteristics to enhance lubrication in extreme environments [4, 5,6] .

The continuous aging of used oil is caused by the action of oxygen in the air, which readily reacts with hydrocarbons. As a result of their oxidation, compounds with the composition of alcohols, aldehydes, organic acids, and resin products are formed, which lead to the formation of double bonds, then cause polymerization. After a long period of use, the oxidation process is accelerated by the high temperature causing thermal decomposition of base oil hydrocarbons and altering viscosity, then the oil turns light and black, and becomes unable to lubricate anything [7, 8].

During service, the properties of oil change and may come to the state that the oil fails to keep the engine performing efficiently and safely. A portion of the heat generated during combustion is eventually transferred to the oil which, with prolonged time of operation, deteriorates the oil properties by firstly reducing the viscosity at high temperature, and secondly by increasing the oxidation rate with a

subsequent formation of organic compounds which may attack bearing materials. Moreover, other reactions may occur between oil molecules that result in asphaltic compounds which contribute to the formation of sludge; water, fuel, soot, residues, metallic wear particles and environmental dirt particles may pollute the oil as a result of combustion, engine wear and filtration. These are actually functions of engine life. For these situations, deteriorating oil should be replaced by new oil [9].

A study of over a 100 hour lube oil aging in different passenger cars diesel engine shows the emissions decrease first up to 50 hr. of oil age, and then increased as the oil ageing up to 100 hr, and the contamination of diesel engine oil with particles, water or by other liquids effect on bearing life through wear, while water can damaging the ball and other roller bearing [10]. .

The effects of water contamination on the filtration of HD diesel engine oils [11], indicates that further work is required before bench tests can be established to predict filter plugging tendencies of water contaminated HD engine oils in service and shows that one of the great indicated on the efficiency of internal combustion engines and largely determine their reliability and durability as well as environmental impact is the wear resistance of friction pairs, which directly depends on the metal physical characteristics of the friction surfaces as well as the physical and chemical properties of engine oils [12].

For these reasons, the researchers went to search for oils that are more resistant to oxidation and bear the difficult conditions that oil is exposed to when used in internal combustion engines. Some of them who worked on the use of synthetic oils such as alpha olefin oil and different types of esters, and some of them went to use vegetable oils to solve problems or blend them with conventional oil.

Synthetic engine oils like esters, poly alpha olefins (PAO) and bio-based lubricants offer several advantages over conventional oil. First, it lasts longer because oil takes longer to break down. It also performs better in extreme temperatures, and needs lower levels of additives compared to conventional motor oils. Most notable are reduced quantities of viscosity improvers because of the inherently high viscosity index (VI) of synthetic oil. A high VI means that synthetic oil retains its viscosity when hot, and lower pour point [13].

In this study, about the changes that occur to the oils used in internal combustion engines such as public transport vehicles (heavy duty engines), it was found that it is a result of continuous use and the nature of use, in addition to environmental conditions, oils are affected quickly, so they need to be replaced for a period of 4500-5000 km, in addition to continuous maintenance and work to replace filters to preserve engine parts.

2. Experimental work

2.1. Field test program

Two double decker buses were selected and subjected to normal maintenance of their depot and have the following specifications:

220 h.p, 2200 r.p.m., 6 cylinders (D-2566 muh) – MAN type.

Oil samples were fully drained from bus vehicles at intervals of 1000 km up to 5000 km for both diesel engine oils (A) and (B). The main properties of fresh diesel oils are listed in Table 1.

Table 1. The main properties of fresh diesel engine oils A & B

The properties	Unit	Diesel oil A	Diesel oil B
Viscosity at 40°C	cst	130	113.02
Viscosity at 100°C	cst	11.99	10.53
Flash point	°C	242	193
Total Acid Number	mg KOH/g	1.7	1.75

The specifications and changes that occurred in diesel engine oils A and B were studied after use for periods of 1000-5000 km. The properties are listed in Tables 2 and 3.

Table 2. The main properties of diesel engine oil A at different running distances

Property	Unit	Testing Method	Distance, km				
			1000	2000	3000	4000	5000
Viscosity at 40oC	cst	ASTM D- 445	130.24	126.11	123.54	121.23	120.05
Viscosity at 100oC	cst	ASTM D- 445	11.84	11.77	11.7	11.04	10.53
Flash point	oC	ASTM D 92	231	230	217	206	181
Total Acid Number	mg KOH/g	ASTM D-664	1.80	2.21	2.55	2.74	3.13

Table 3. The main properties of diesel engine oil A at different running distances

Property	Unit	Testing Method	Distance in km				
			1000	2000	3000	4000	5000
Viscosity at 40°C	cst	ASTM D- 445	113.02	109.22	104.32	98.76	89.05
Viscosity at 100°C	cst	ASTM D- 445	10.53	10.15	8.7	8.3	6.04
Flash point	°C	ASTM-D - 92	193	177	158	142	122
Total Acid Number	mg KOH/g	ASTM-D- 664	1.75	1.93	2.25	2.83	3.35

2.2. Infrared Analysis

The IR spectra of fresh and used diesel engine oils are carried out with PYE Unicom infra-red spectrophotometer SP-300 fitted with a data processor type SP3-050 and PYE printer type PU-8501. The test was done with a KBr cell of 0.02 mm.

2.3. Differential Scanning Calorimetric measurement

10 mg of oil samples were weighted in Aluminum crucibles by heating them at 10oC heating rate in static air to 350°C. Aluminum oxide was used as a reference material. The experimental error was within $\pm 2^\circ\text{C}$.

3. Results and Discussion

The infrared spectrum for each of the diesel engine oils A and B is shown in Figures 1, 2. As for Figure 3, it shows the intensities and the changes in absorption bands that occurred in the oils during use up to 5000 km. The different chemical groups and their corresponding IR absorption spectra are listed in Table No. 4.

Table 4. The IR absorption spectra and their corresponding chemical groups.

Absorption band ,cm ⁻¹	Chemical group	Reference
1600	Aromatic compounds	14
1300 – 1160	Oxygen, sulfur and nitrogen hetero-compounds	15
980	Naphthenic compounds	15
850-820	Substituted aromatic compounds	15
720	(CH ₂) _n where n≥4	15
668	P=S of the ZnDDPH	15

The change in the absorption bands increase as the running distance increases, and the changes occur within the same oil and between the different oils. It is possible to compare the stability of the different chemical groups, also.

3.1 diesel engine oil A

The absorption spectrum at 720 cm⁻¹ shows the degradation of long-chain paraffinic compounds into compounds of smaller chain, and the absorption spectrum at 1300-1150 cm⁻¹, which is related to compounds that contain heterogeneous atoms. There was an increase at a low rate with the increase of the traveled distance up to 5000 km. Then, a rapid change occurred, which indicates a rapid degradation of the oil components as shown in Figure 1. It was also noticed that the rate of change in the absorption spectrum at 1600 cm⁻¹ for aromatic compounds, and the spectrum at 850-820 cm⁻¹ for aromatic compounds that contain substituted groups are less than what occurs in paraffinic compounds.

This indicates that the aromatic compounds and the naphthenic compounds are more stable compared to the various paraffinic compounds. After 5000 km, a rapid change occurred, which indicates that the oil has changed completely, Figure 2.

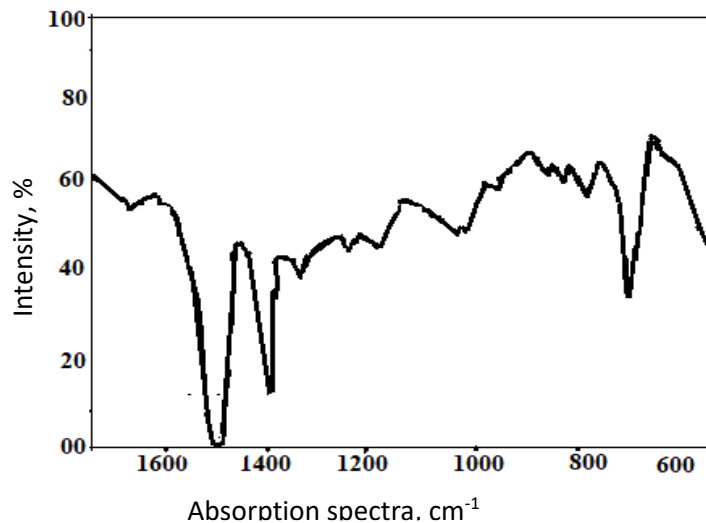


Figure 1. Infrared spectrum of diesel engine A

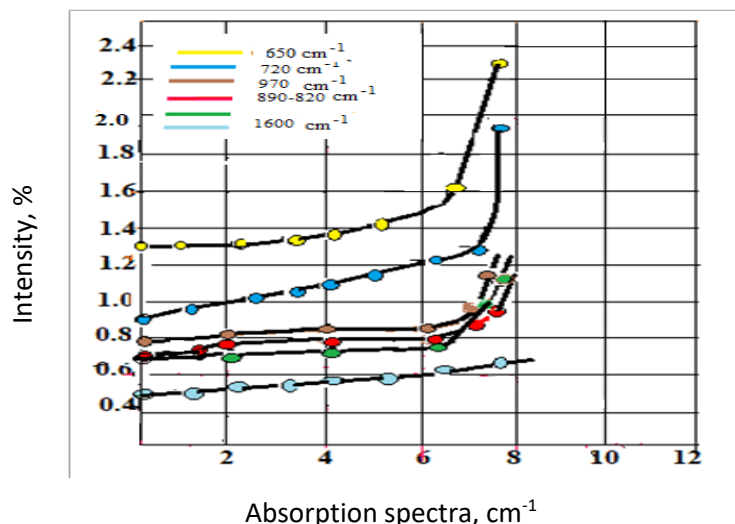


Figure 2. The change in the absorption spectra with increasing traveling distance for diesel engine A

3.2 diesel engine oil B

The absorption spectra at 750 cm^{-1} and $1300\text{-}1150\text{ cm}^{-1}$ show the degradation of the long paraffinic chains into smaller ones. This increased at a rapid rate as soon as the oil was used, then became slower with the increase in the distance of travel. The rate of chemical change in absorption spectra for shown aromatic compounds, 970 cm^{-1} for naphthenic compounds, and $850\text{-}820\text{ cm}^{-1}$ for substituted aromatic compounds were higher than that observed with paraffinic and heteroatom compounds as shown in Figure 3.

The absorption spectrum at 664 cm^{-1} for P=S of Zinc-dialkyldithiophosphate (Zn-DDP) in paraffinic, aromatic, and naphthenic compounds has shown a smooth and slow change rate with increasing running distance that indicates a good stability of Zn-DDP additive.

From the above observations we can say that the stability of diesel engine oil A is higher in stability than diesel engine oil B during performance in a diesel engine while traveling up to 5000 km, Figure 4.

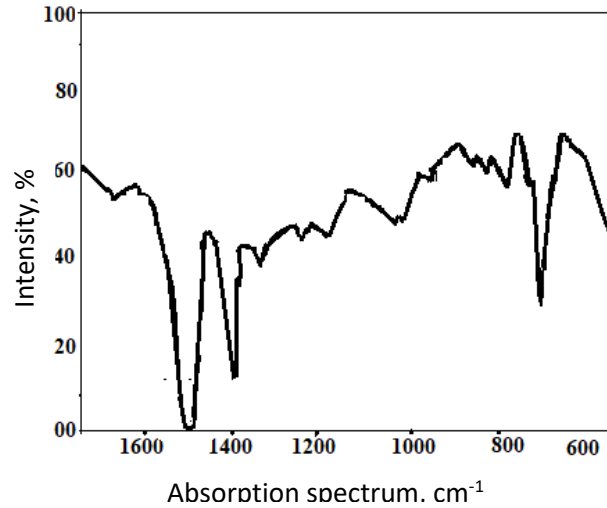


Figure 3. Infrared spectrum of diesel engine B

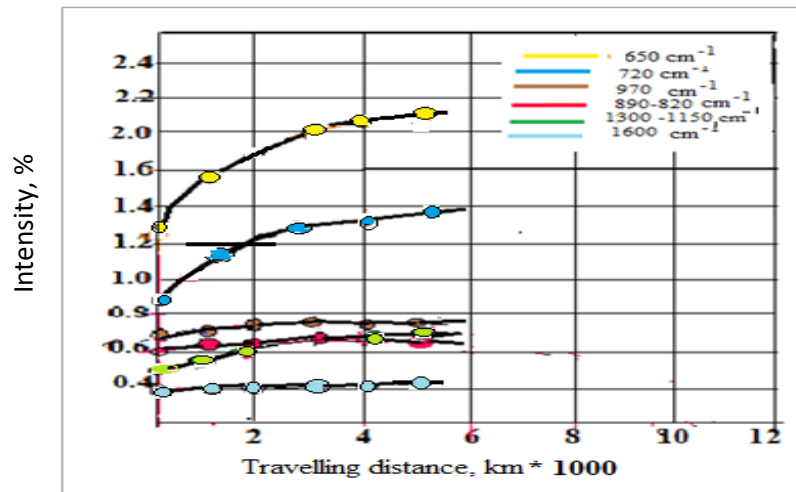


Figure 4 . The change in the absorption spectra with increasing traveling distance for diesel engine B

3.1. Differential scanning Calometric (DSC) analysis for used diesel engine oils

Thermo-oxidation stability of diesel engine oil during performance could be estimated by plotting the initial degradation temperature (T_i) against the running distance. Such a plot for diesel engine oil A and diesel engine oil B has been obtained by DSC analysis and is presented in figure 5.

In comparison between the two plots, it can be concluded that the thermo-oxidation stability of diesel engine A is higher in stability than diesel engine B. This higher stability is characterized by an induction period up to 4000 km traveled. The induction period was followed by a slow decrease in oil stability up to 5000 km. Then there continued to decline in stability.

On the other hand, diesel engine oil B shows no induction period. Its degradation started early. The stability declined at a higher rate from the first 1000 km, then a lower rate of decline was observed at the interval of 1000-3000 km, while a sharp decrease was observed after 3000 km. The degradation temperature (T) at 5000 km was 187°C. This finding was agreed with the results of infra-red spectroscopic analysis.

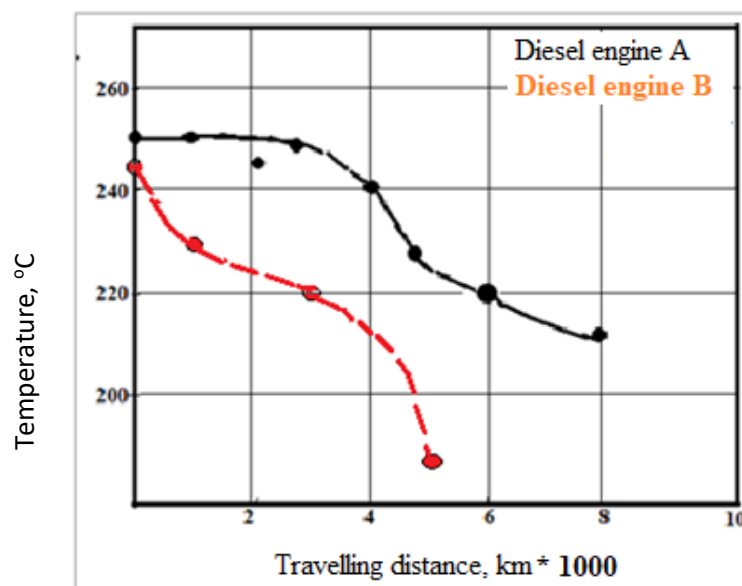


Figure 5. Differential Scanning Calometric (DSC) curves for diesel engine oils **A** and **B**

4. Physical and chemical properties

4.1. Viscosity

Figure 6 shows a comparison of the viscosity measured at 40 °C for both types of oils at a distance of 5000 km, as the graphic shows the rapid change in the viscosity of oil B with an increase in the distance traveled, which indicates the loss of the oil's ability to lubrication at the distance of 2000 km. While oil

A showed more resistance, and its loss of lubrication was gradual, up to a distance of 5000 km. We also notice the same behavior of the viscosity of the diesel engine oils at a temperature of 100 °C. Figure 7.

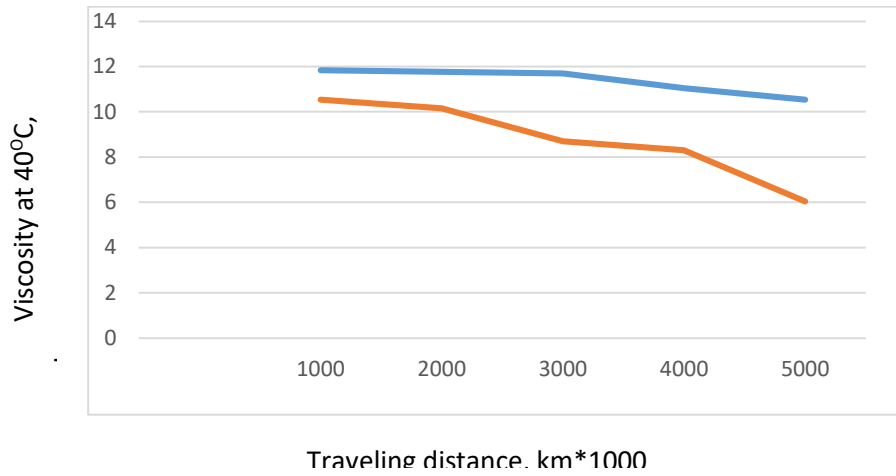


Figure 6. Comparison in Viscosity at 40 °C for diesel engine Oils A and B

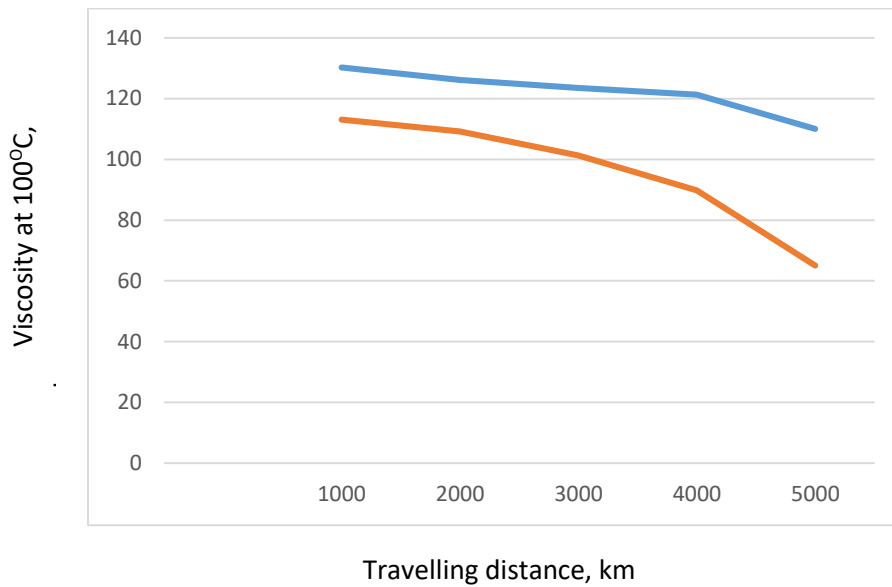


Figure 7. Comparison in Viscosity in centistock at 100 °C for diesel engine Oils A and B

4.2. Flash point

From Figure 8, we notice in both diesel engine oils A and B a decrease in the degree of flash point with the increase in the distance traveled as a result of the degradation of the oil inside the engine, and that the diesel engine oil A showed a gradual degradation and breakdown of the components, while diesel engine oil B was faster in degradation, but in both cases the degradation produces as light materials and compounds that lower the degree of flash point.

4.3 Acidity

Acidity is considered one of the important specifications that indicate the unfitness of the oil for use if it exceeded the permissible limit because of the corrosion it causes to the equipment as a result of the formation of organic and mineral acids. Figure 9 shows that there is an increase in the acidity of both oils with increasing distance traveled.

In the case of diesel engine oil A, we notice the increase appearing from the beginning of use, but gradually, while diesel engine oil B, the increase is rapid, and in both cases, the increase in acidity continues to a distance of 5000 km.

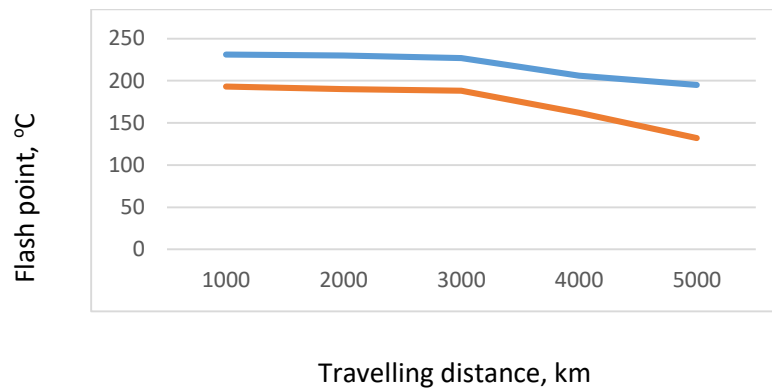


Figure 8. Comparison in flash point for diesel engine Oils A and B

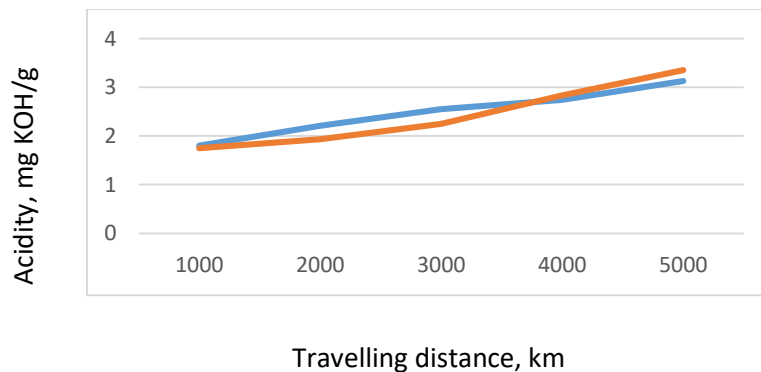


Figure 9. Comparison in the acidity for diesel engine Oils A and B

5. Conclusion

Because diesel engines must withstand higher peak combustion chamber forces than gasoline-powered engines, more durable construction features are used. They include heavier pistons and stronger crankshafts, valve trains, and gear trains.

Infra-red and differential scanning calorimetry (DSC) can predict the stability and aging tendency of diesel engines at travelling distances.

The improvement in the quality and composition of engine oils helped the engine reach high durability milestones.

- Changing the oil filter as infrequently as twice a year.
- In heavy duty diesel engines, the required oil must be high in quality.
- The usage period for diesel engine oil in bus engines must be in the range of 4500-5000 km to keep the engine safe.
- Environmental pollution may play a role in accelerating oil degradation.

Acknowledgment

The researcher thanks and appreciates everyone for the facilities and assistance, whether by allocating the bus and those in charge of changing oils during use or examining and analyzing the samples.

References

- [1] Liston, T.V. "Engine lubricant additives. What they are and how they function". *Lubrication Eng.* (1992), 48, P: 389–397.
- [2] Nehal S. Ahmed and Amal M. Nassar, "Lubrication and Lubricants" *Tribology – Fundamentals and Advancements book*, chapter 2. June (2022), ISBN: 978-953-51-1135-1, DOI: 10.5772/56043.
- [3] Function of Lubrication, Tansi International College, Awk, <https://tansicollege.edu.ng>, files, home school.
- [4] James R. Dickey. "Lubrication and Lubricants, Kirk- Othmer Encyclopedia of Chemical Technology, first published: 17 June (2005). [Http://doi.org/10.1002/0471238961](http://doi.org/10.1002/0471238961).
- [5] "Lubricant Additives: Use and Benefits", Technical Committee of Petroleum Additive Manufactures Europe, Aug. (2016) / ATC document 118
- [6] Wei, L. and et al. "Discussion on the influence of driving parameters of civilian cars on motor oil degradation. *Proc. IMechE Part J.* (2019), 233, P: 281–288.
- [7] IDZIOR, M. "Aging of engine oils and their influence on the wear of an internal combustion engine." *Combustion Engines.* (2021), 185(2), P: 15-20. <https://doi.org/10.19206/CE-138033>].
- [8] Marie Sejkorová & et al. "Study of the Effect of Physicochemical Degradation and Contamination of Motor Oils on Their Lubricity". *Coatings* (2021), 11(1), 60; <https://doi.org/10.3390/coatings11010060>
- [9] Wilfried J. Bartz. "Engine Oils and Automotive Lubrication". (2019), Page 435. CRC Press, <http://www.crcpress.com>. Book
- [10] Andrews, G., Abdel Halim, S., LI, H. "The influence of lubricating oil age on oil quality and emissions from IDI passenger car diesels" . *SAE Technical Paper* (1999). 1999-01-1135. <https://doi.org/10.4271/1999-01-1135>, 01 March (1999). ISSN: 0148-7191, E-ISSN: 2688- 3627.
- [11] R.Overton and W.N. Roger." Heavy Duty Diesel Engine Oil Filterability" *SAE Transaction Vol. 93*,

Section 2: 840222—840402 (1984), pp. 754-764. Published By:
SAE International.

- [12] Vladimir Baskov & et al , “Assessing the influence of operating factors on the properties of engine oil and the environmental safety of internal combustion engine”. *Transportation Research Procedia*, Elsevier (2020), Volume 50, P: 37-43. DOI: [org/10.1016/j.trpro. \(2020\).10.005](https://doi.org/10.1016/j.trpro.2020.10.005).
- [13] Stephen 8- Boyde., “Esters from: Synthetics, Mineral Oils, and Bio-Based Lubricants”, *Chemistry and Technology*, 13 Feb (2020). 3rd edition. CRC Press
<https://www.routledgehandbooks.com/doi/10.1201/9781315158150-3>. Book
- [14] S. L. Sarowha, I. D. Singh, D. L. Garg. *Indian Journal Technol.* (1985). 23, 451.
- [15] H. H. Abu El Naga, A.E.N. Salem. *J. Thermal Analysis*, (1986). 31, 747.