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Abstract. The article presents a study on the change in kinematic viscosity with the temperature for three samples of synthetic used oil (SAE 5W-30). Samples were taken after a 10,000 km run on the occasion of periodically changing oil from three engines with close cylindrical capacities (one diesel engine – VW 1.9 TDI, one gasoline engine – Audi 1.8 Turbo and one spark engine – Audi 1.8 Turbo, working with GPL). Comparatively, viscosity measurements were made for the same oils before being introduced into the engines. The kinematic viscosity was measured experimentally using the Brookfield viscometer from 5 to 5 degrees Celsius. To eliminate the errors, the measurements were made under the same conditions for all samples, being repeated three times, the values taken into consideration for a given temperature being made up of averages of the three measurements.

1. Introduction

In automotive industry, friction behaviour is the most critical factor in some component systems design and performance and it is influenced by a large number of variables, including geometry of components, materials, components interaction and many other operating conditions. Automotive engineers use a variety of materials to maximize performance in all areas, often combining five to twenty different material ingredients to form complex composite friction materials [1], [2].

In the operation of internal combustion engines for road vehicles, all types of friction are encountered: dry, semi-dry, liquid and semi-liquid. Thus, when starting the engine, the crankshaft journals rest on the oil film in the bearings, and when the resistance of the film is insufficient, the metallic contact between the bearings and the bearing liners also appears. With the increase of the crankshaft speed, the transition from the semi-liquid friction zone to the liquid friction zone is obtained. Between the piston and cylinder assembly, even during normal operation, a friction to the limit or even semi-dry friction is performed.

The main role of lubrication is to remove the direct contact between the surfaces of the relative moving parts, thereby reducing the mechanical work of friction, heating and wear of the parts.

The viscosity and the greasiness, which confer the oil its lubrication properties, ensure the existence of an oil film between the moving parts. When the thickness of the oil film is relatively high (up to 0.6μm), liquid (hydrodynamic) lubrication is performed which ensures optimum operating conditions with minimum energy consumption to overcome friction and achieve a reduced wear of the parts. The temperature of the oil at which normal operation is ensured is in the range of 75 ... 90 ^{0}C.

As the main function of the oil is the hydrodynamic lubrication of the relative moving parts, the oil must be sufficiently viscous to withstand high relative loads. On the other hand, the oil must have a low viscosity (especially at start-up) to consume as little of the power developed by the engine. An oil is better the more it maintains its viscosity with changing the temperature and pressure regime.

When choosing the oil, it must be taken into account that it satisfies the lubrication functions, maintains its initial physico-chemical properties for a duration of the engine's life as long as possible, that it is has little sensitivity to the variation of the ambient temperature and is relatively cheap [3].

2. Literature review

Fossil fuels such as gasoline and diesel fuel, being sourced from non-renewable resources, are depleted day by day. It is obvious that these conventional fuels become insufficient in the coming decades [4], [5]. To counter this shortcoming, current research focuses on reducing the use of conventional fossil fuels and gradually replacing them with alternative biofuels. We are talking about biodiesel and bioethanol which are used in combination with diesel and petrol respectively, in increasing proportions.

For example, currently, most of the Otto engines that supply vehicles are powered by a mixture of 10-15% ethanol and gasoline, and the so-called "biofuel engines" are designed to operate with pure hydrated ethanol (93% ethanol and 7% water) or with the mixture called E85, which consists of 85% ethanol and 15% gasoline. Furthermore, in Brazil, FFV (Flex Fuel Vehicles) vehicles are designed to use a mixture of ethanol and gasoline in any proportion [6], [7].

It is worth noting that the impact of bioethanol on the lubrication properties of oils is completely different from that of gasoline. This is due to the fact that bioethanol has a higher tendency to enter the engine oil bath due to its higher evaporation temperature than gasoline [8]. The percentage of bioethanol in the oil can lead to significant degradation of the properties and performances of the oil. Bioethanol is miscible with water, but immiscible with oil, which can lead to the formation of a bioethanol-water-oil emulsion, an emulsion that can cause dangerous wear of the engine or even its disengagement [9]. As a result, the oil should be replaced at well-established time intervals. It has been observed that even a dilution in a small proportion of the oil can lead to the degradation of its physico-chemical properties (among others - the viscosity), which plays a very important role in the overall lubrication system [10], [11].

Changes in the viscosity of the oil as a result of ethanol or gasoline contamination are obviously undesirable, as they affect the efficiency of the oil and change the thickness of the oil film. The viscosity of synthetic oil has been found to decrease significantly when diluted with a mixture of bioethanol and gasoline [12].

As for the diesel engine, the effect of fuel contamination on oil performance is underestimated compared to the effects caused by soot or water contamination. The fuel enters the engine oil through the internal leaks of the injectors. The presence of fuel in the diesel engine oil can reduce the viscosity of the oil, accelerate its oxidation and increase the wear due to the decrease of the oil film thickness. Contamination of oil with diesel fuel can also cause deposits of unwanted substances that reduce the functionality of the oil [13].

The effect of the presence of diesel fuel in oils on their viscosity is significantly different from mineral oils to synthetic oils. Mineral oils can lose their properties even at a dilution of 1%, the limit for synthetic ones being reported at 7%. On the other hand, the existence of sulfur in diesel fuels can play a role in reducing wear and friction losses due to their good lubrication properties [14].

Soot is formed due to incomplete combustion of hydrocarbons in the combustion chamber. Soot contains ash, carbon particles and unsaturated hydrocarbons. Unsaturated hydrocarbons are acetylene and polycyclic aromatic hydrocarbons having only carbon (C) and hydrogen (H) elements and at least one carbon-carbon double or triple bond. All these components have a high level of acidity and volatility [15]. Soot contains 90% carbon, 4% oxygen, 3% hydrogen, and the rest is nitrogen, sulphur and metal particles [16].

The presence of soot particles is much more common in diesel engines than in gasoline engines. This is due to the different combustion mechanism in the two types of engines. Soot particles are both discharged into the atmosphere and absorbed by the oil. This contamination reduces the engine life.

Research shows that the viscosity of oils used in diesel engines increases due to oxidation and contamination with soot particles. Dilution with diesel fuel slightly affects the viscosity of the oil. As a result, the effect of increasing the viscosity of the oil due to contamination with soot particles is somewhat counteracted by the dilution effect with diesel. Hence the conclusion that there are no noticeable changes in the values of the viscosity of diesel oil after a certain period of operation [17].

3. Theoretical considerations

The physico-chemical properties of motor oils depend to a large extent on the type of the basic element (petroleum or synthetic elements), the technology used in the manufacture and the type and nature of the additives introduced into the base oil. The lubrication and flow characteristics of the oils are greasiness and viscosity.

Greasiness is the ability of the oil to adhere to the metal surfaces and to form on them an oil resistant film that prevents the direct contact between the moving parts. This eliminates the dry friction, ensures the lubrication to the limit and avoids the wear and the grip.

Viscosity is the property of the oil to oppose the flow (relative motion of the constituent particles). The viscosity level of the oil significantly influences the lubrication capacity of the moving parts, depending on the temperature and speed, the friction coefficient as well as the loss of power due to friction.

Both the greasiness and the viscosity of the oil have a great influence on the wear during the thermal engine start-up process. Due to the smoothness of the parts, the parts are covered with an oil film (during the previous operation), and the viscosity ensures the quick access of the oil to the moving parts.

The temperature has a major influence on the viscosity of the oil, the higher the temperature, the less the oil becomes viscous and flows more easily. At low temperatures, however, the alkanine hydrocarbons form a crystalline network that causes the oil to freeze, i.e. the total loss of flow capacity.

The decrease in oil viscosity leads to:

- reducing losses due to friction;
- reducing fuel consumption;
- easier starting of the engine;
- engine operation at very low temperatures.

The increase in viscosity leads to:

- decrease in oil consumption;
- better sealing between the piston, the segments and the cylinder.

It is preferable that the engine oil have a slight variation of the viscosity with the temperature. Also, the oil lubrication system must be adapted to the different viscosities of the oil, and the tests of the engine must be made with oils with different viscosity characteristics.

Thus, the optimum oil for a particular engine is the one with the minimum viscosity, but high enough to ensure the formation of the oil film on the metal surfaces and the sealing of the piston-segment-cylinder mechanism.

4. Experimental research. Equipment and procedures

Next we will present a study on the change in kinematic viscosity with the temperature for three samples of synthetic used oil (SAE 5W-30). Samples were taken after a 10,000 km run on the occasion of periodically changing oil from three engines with close cylindrical capacities (one diesel engine – VW 1.9 TDI, one gasoline engine – Audi 1.8 Turbo and one spark engine – Audi 1.8 Turbo, working with GPL). Comparatively, viscosity measurements were made for the same oils before being introduced into the engines. The kinematic viscosity was measured experimentally using the Brookfield viscometer from 5 to 5 degrees Celsius. To eliminate the errors, the measurements were made under the same conditions for all samples, being repeated three times, the values taken into consideration for a given temperature being made up of averages of the three measurements.

Because the viscosity measurements were made at different temperatures, the oil samples had to be pre-heated. The heating was done on a thermostatic electric hob (Figure 1).

In order to determine the qualitative changes of the used oils, they were compared with new oil. The measurements were carried out using a Brookfield rotary viscometer model DV-E (Figure 2).

Figure 1. Overall view of the thermostatic electric hob

Figure 2. Overall view of the Brookfield rotary viscometer model DV-E

The device performs the measurement with an accuracy of +/- 1% of the full measurement scale for the selected pair of parameters: type of spindle and measuring speed.

Its operation consists of rotating a shaft which is inserted into the fluid to be tested, by means of a calibrated spring. The viscosity of the fluid is measured by the deformation of the spring. The rotary transducer is the one that produces the deformation through a torque signal. The measurement range of this viscometer is in [mPa/s] or centipoise [cP] and depends on the speed of rotation of the axis, the shape and size of the axis, the container where the axis determines its rotation and the full-scale torque held by the calibrated spring.

The units of measurement fall within the CGS system and are expressed in [cP] or in the SI system, in [mPa · s]. Within the Brookfield DV-E viscometer, viscosity is displayed in centipoise or [mPa/s]. The torque is displayed in units of measure such as [dyn/cm] or [Nm] which in both cases are displayed as a percentage on the viscometer display [18].

5. Results and conclusions

The most desirable tests of viscosity changes of motor oils are tests that reflect the real conditions of their work in car engines. Our measurements allow observing changes in viscosity of these liquids during the temperatures interval between ambient temperature and 100 °C.

The following charts present the variation of dynamic viscosity (η[cP]) with temperature for the three samples of used oil, from the three types of engines mentioned above. The measurements were made from 5 to 5 °C. For a comparative study, the values of dynamic viscosity as a function of the temperature of new oils of the same type were also determined.

At a first overview, it can be observed that the variation of the viscosity with temperature for all the samples is an exponential one, without exception.

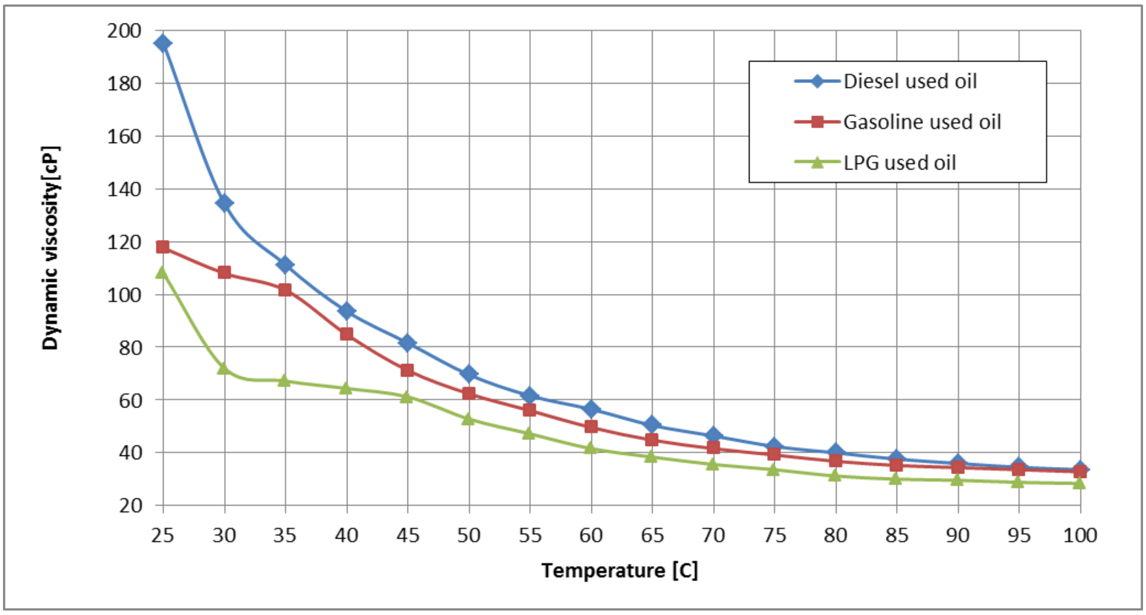

Figure 3. Dynamic viscosity vs temperature for the three used oil samples

In addition, Figure 3 shows comparatively the behaviour of the waste oils for the three types of engines, noting that, at relatively low temperatures, the viscosity of the oil used in the diesel engine is higher than of the oils in the gasoline and LPG engines. This is due to the fact that the oil in the diesel engine is mainly contaminated with soot, the dilution with diesel being less intense, which, overall, leads to an increase in the viscosity of the used oil.

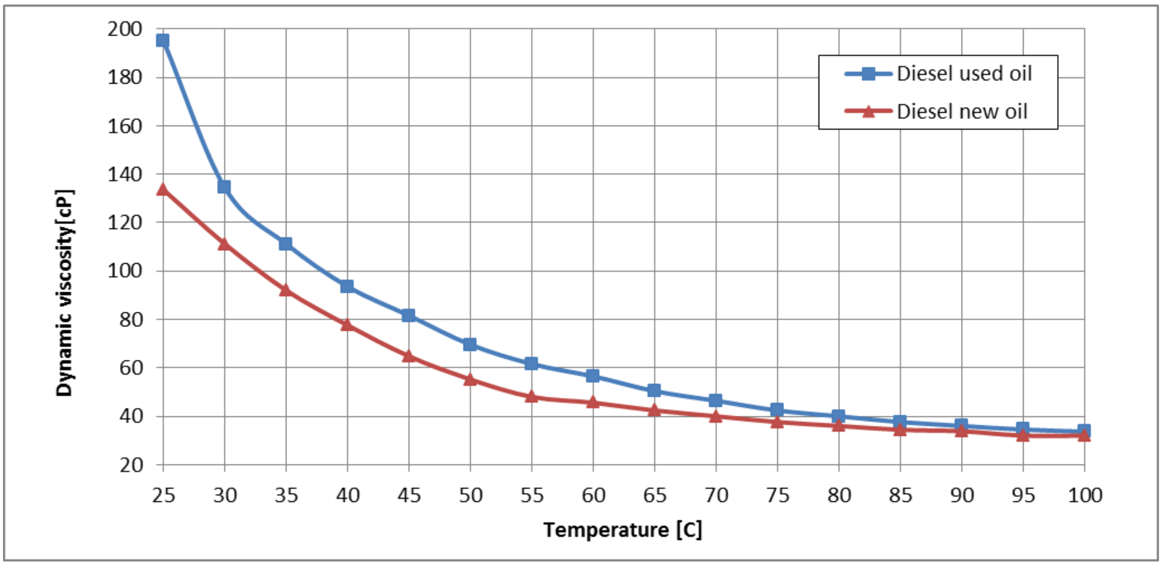

Figure 4. Dynamic viscosity vs temperature for diesel used and new oils

In Figure 4 it can be observed that, during most of the temperature range, the viscosity of the used oil in the diesel engine is higher than that of the new oil of the same type. Only in the field of high temperatures the viscosity values tend to equalize. The chart comes to certify the theory presented above.

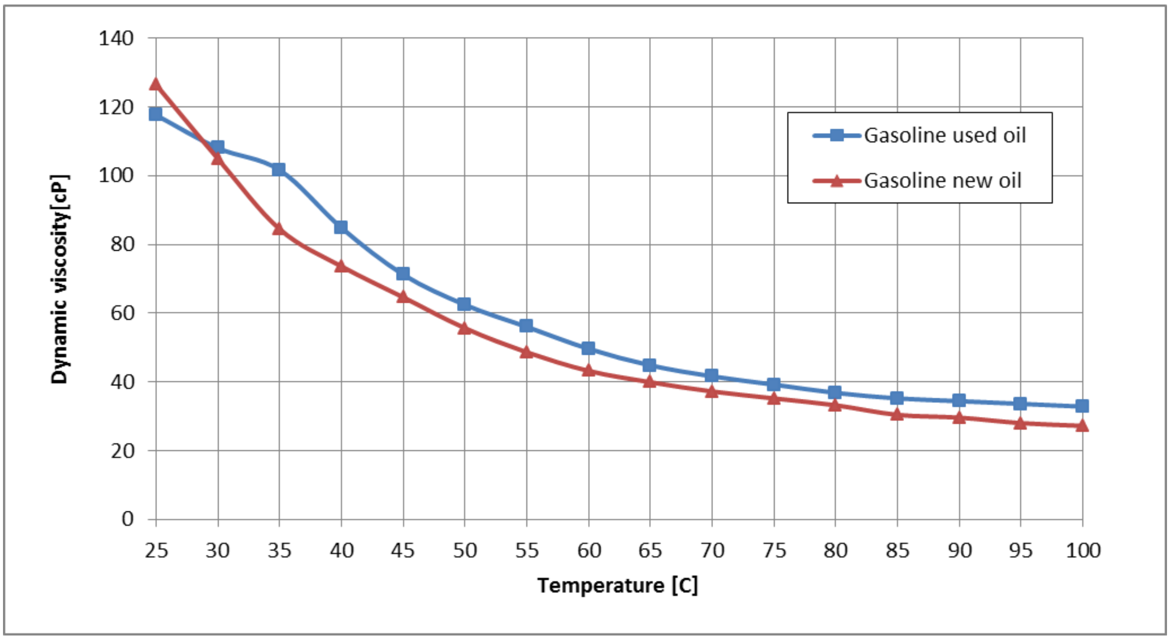

Figure 5. Dynamic viscosity vs temperature for gasoline used and new oils

Regarding the oil used in the gasoline engine, it can be seen, from Figure 5, that the viscosity of the used oil at temperatures close to that of the environment is lower than that of the new oil, and as the temperature increases the values change.

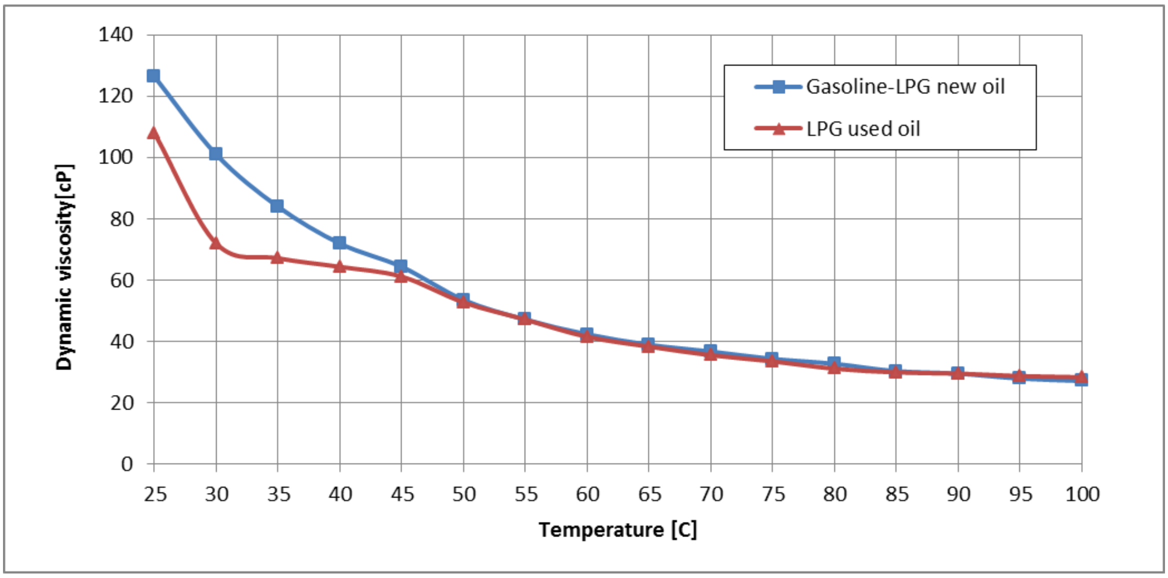

Figure 6. Dynamic viscosity vs temperature for LPG used and new oils

From Figure 6 it can be concluded that the used oil utilised in the LPG engine has a much lower viscosity, at relatively low temperatures, than the new one, and as the temperature increases, the viscosity values are equalized. The explanation is that the used oil is excessively diluted with gasoline, especially in the cold start phase of the engine, knowing that LPG-powered engines use gasoline at the start-up phase.

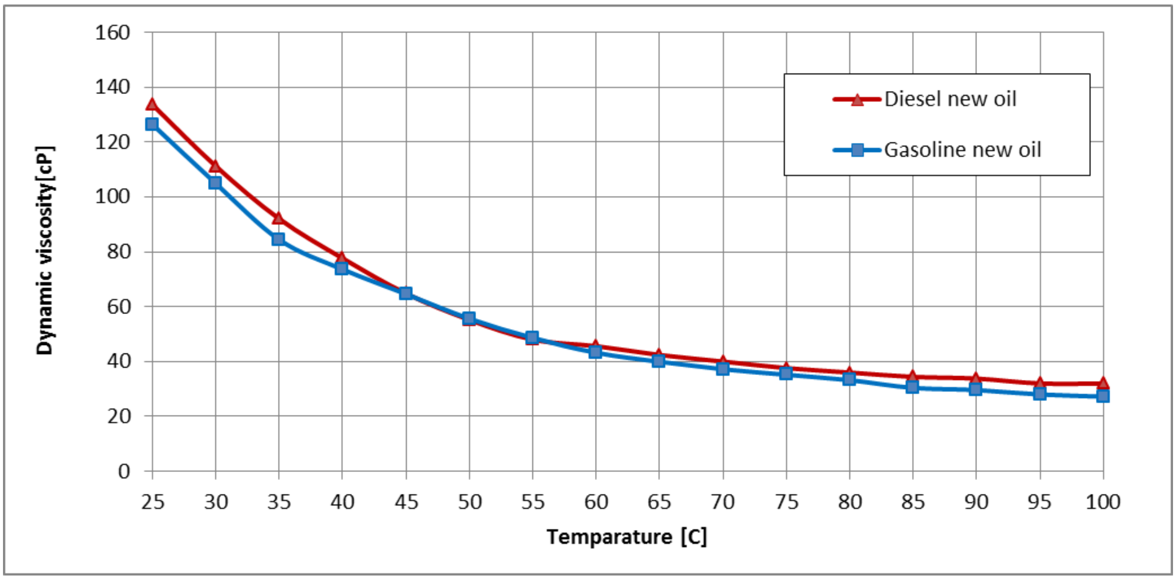

Figure 7. Dynamic viscosity vs temperature for diesel and gasoline new oils

Figure 7 shows the comparison between the evolution with the temperature of the viscosity of new oils for diesel and gasoline engines. There was also no distinct variation of the viscosity of the new oil for LPG because it is similar to the one used in the gasoline engines. Similar evolution is observed for the two types of oils.

Final conclusions:

The effect of fuel contamination on the performance of oil is normally underestimated compared to the other contaminants such as soot and water.

Fuel normally enters the engine oil through internal leakage of the injector and contaminates the oil. The presence of fuel in the engine oil can create several issues such as reduction of viscosity.

The presence of soot particles is more common in diesel engines than in gasoline engines.

It can be observed that the viscosity of the oils increased during the ageing process by the oxidation process and the addition of CB (carbon black, soot) contamination as expected.

Diesel contamination slightly reduced viscosity of the oils due to the fuel dilution.

As diesel decreases the viscosity and CB particles increase viscosity of oil, there was no notable change in the viscosity of oils which were contaminated with both CB and diesel fuel. In addition, at higher temperatures there was no significant difference in the viscosity of oil samples with various contaminants.

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