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Experimental Investigation of the Effect of Fuel on Engine Oil Life

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The fuel content of engine oil is a significant factor affecting its degradation processes, lubricating properties and overall service life, especially in the case of modern internal combustion engines equipped with turbocharging, direct injection and exhaust gas recuperation systems. This study analyzes the dilution of engine oil with fuel in diesel and gasoline engines of vehicles with different degrees of wear, represented by the number of kilometers driven. The main objective of the research is to identify the relationship between the fuel concentration in the oil and changes in its physicochemical properties, as well as the potential impact of this phenomenon on the service life of the lubricant and the suitability of the set replacement intervals. The fuel content was quantified using precise quantitative spectrometric analysis, which allowed comparing engine oil samples taken under different operating conditions, including hot and cold starts, urban and highway operation. The results obtained show that vehicles with higher mileage and higher frequency of cold starts exhibit significantly higher rates of oil dilution by fuel, which directly affects the reduction of its viscosity and lubricating ability. The findings of this study provide important insights for the development of recommendations in the field of engine maintenance, especially with regard to optimizing engine oil change intervals, in order to prevent excessive wear and damage to engine components due to lubricant degradation.

Keywords: Oil, Viscosity, Fuel, Durability, Reliability, Contamination

1 Introduction

Engine oils in both modern internal combustion and hybrid powertrains are facing increasing demands to reduce friction, extend service intervals while maintaining wear protection. One of the key factors that directly affects the performance and life of engine oil is the interaction with the fuel. Penetration of unburned fuel into the engine oil - a significant risk that is especially intensified during cold starts, short runs and hybrid modes of operation. Simulation studies and experimental investigations published in the last three years indicate that oil-fuel dilution can reach up to 10-20% by volume in certain operating scenarios such as frequent cold starts or urban operation [1,2]. The consequence is a significant reduction in viscosity, loss of lubricity and accelerated degradation of additives such as antioxidants or detergents. Especially sensitive to this effect are modern engines with direct fuel injection, where high injection pressures increase the risk of fuel leakage through the piston rings into the crankcase [3,4]. Hybrid powertrains, in turn, suffer from frequent switching between electric and combustion modes, which increases the frequency of cold starts and reduces the time required for fuel residues to evaporate from the oil [5,12]. Other studies also point to the type of fuel used as alternative blends E5, E10, E85. These fuels alter both the exhaust gas composition and the physicochemical reactions in the oil, which is manifested by a more rapid decrease in the total plug number (TBN) and a higher presence of metallic wear particles [6,7,10,13]. This study aims to summarize the current knowledge on the effect of fuel on engine oil life and to identify the key mechanisms of lubricant degradation in different engine types and operating regimes. Emphasis will be placed on realistic measurements of oil dilution by fuel and the effect of operating conditions on oil cartridge life.

2 Material and Methods

Due to the complexity of the operating conditions and their direct impact on the degradation of the oil fill, it was necessary to design a methodology that takes into account the variability in mileage, powertrain type and also vehicle design features such as the presence of a diesel particulate filter (DPF). For the evaluation, samples of 5W30 Longlife engine oil were selected from a number of vehicle types that varied in mileage, type of internal combustion engine, type of emission system and operating conditions. In this way, it was possible to capture a comprehensive picture of the actual rate of oil degradation in different situations. Particular attention was paid to vehicles with diesel engines equipped with a DPF system, where more frequent exhaust system re-generations occur, increasing the risk of dilution of the oil charge by the fuel. This phenomenon is one of the main factors influencing the life and effectiveness of the lubricating film. The sampling and analysis methodology was designed to ensure the highest possible level of objectivity and repeatability. Samples were taken under standardised conditions at a single workshop, emphasising the same sampling procedure and recording key operational data. Subsequently, these samples were analysed for their physical and chemical properties to evaluate the influence of various operational factors on the degradation of the oil fill. [Tab. 1] lists the motor vehicles from which the oil samples were sourced, the type of fuel used, the presence of a diesel particulate filter (DPF) and the number of kilometres driven.

Tab. 1 *Evaluated oil samples*

SAMPLE	VEHICLE	FUEL	DPF	MILEAGE [km]
1	NEW OIL 5W30 LL	-	-	0
2	VW Touareg 3.0 TDI	diesel	yes	8150
3	Škoda Superb 1.6 TDI	diesel	yes	13980
4	Seat Leon 2.0 TDI PD	diesel	no	6992
5	Škoda Fabia 1.2 HTP	petrol	no	3105
6	Landrover Discovery 4,4 V8	petrol	no	9652
7	VW GOLF 1.9 TDI	diesel	no	6622
8	Škoda Rapid 1.2 TSI	petrol	no	25206
9	BMW 535 d	diesel	no	23812
10	VW GOLF 1,2 TSI	petrol	no	17390
11	AUDI A4 1.8 T	petrol	no	7918
12	Škoda Octavia III 2.0 TDI CR	diesel	yes	24128
13	VW Polo 1,2 TSI	petrol	no	16292
14	Toyota Auris 1.6 VVTi	petrol	no	11205
15	Peugeot 308 1.6 HDI	diesel	yes	21215
16	Peugeot 208 1.2 Puretech	petrol	no	3916
17	Peugeot 208 1.4 VTi	petrol	no	10600
18	Peugeot 3008 1.0 ETC	petrol	no	13318
19	Peugeot 208 1.2 EB	petrol	no	17420
20	Peugeot 308 1.6 VTi	petrol	no	7392
21	Citroen C4 1,6 HDI	diesel	yes	26218
22	Peugeot 508 1.6 ECB	petrol	no	5202
23	Peugeot 207 1.6 HDI	diesel	yes	13042
24	Peugeot 3008 1,6 THP	petrol	no	14027
25	Škoda Octavia 2.0 TDI	diesel	no	16983
26	VW Passat 1.6 TDI	diesel	yes	16512
27	Volvo XC60 2.0 D	diesel	yes	20937
28	Renault Megane 1.5DCI	diesel	yes	21816
29	Škoda Octavia III 2.0 TDI	diesel	yes	17908
30	Peugeot 5008 1.6 HDI	diesel	yes	19812
31	Škoda Superb 1.6 TDI	diesel	yes	32015

2.1 Reference oil sample

The service station where the sampling was carried out uses 5W30 Longlife engine oil. This oil is developed for a generation of state-of-the-art engines. It is suitable for both diesel and petrol engines, including engines with particulate filters. The first step in the engine oil life analysis is to determine the parameters of a new unused engine oil. The engine oil parameters given by the manufacturer are listed in [Tab. 2]. The parameters given by the manufacturer were verified by measurements which were subsequently used in the measurements of the samples taken. The measured values are given in [Tab. 3].

Tab. 2 *Parameters given by the manufacturer for the oil 5W30 LL*

Parameter	Measurement Method	Unit	Value
Density at 15°C	ASTM D4052	g/ml	0.851
Kinematic viscosity at 40°C	ASTM D445	mm²/s	70
Kinematic viscosity at 100°C	ASTM D445	mm²/s	12.0
Viscosity index	ASTM D2270	-	169
Flash point	ASTM D93	°C	202

Tab. 3 *Parameters measured for 5W30 LL*

Parameter	Measurement Method	Unit	Value
Density at 15°C	DIN 53015	g/ml	0.842
Kinematic viscosity at 40°C	ASTM D445	mm²/s	69.81
Kinematic viscosity at 100°C	ASTM D445	mm²/s	12.10
Viscosity index	calculated value	-	172
Flash point	STN 65 6212	°C	206

From the values shown in the table it can be seen that the measured values are not completely identical with the values given by the manufacturer, since in some cases a different measurement method was used. The measured values and their difference are within 2%, therefore it can be stated that the measured values are identical to the values given by the manufacturer.

The samples for the measurements were always taken in a standardised way. When the engine reached operating temperature it was stopped and then the drain plug was released, at which point an oil sample was taken. Everything was carried out in one workshop with the date and mileage accurately recorded on the oil filler. Laboratory measurements have shown that as little as 5% fuel dilution can reduce viscosity by 25-30%, significantly reducing lubricant film protection and increasing the risk of wear [1,11]. Moreover, at 5% fuel content in the oil, both PHEV and gasoline car users have reported a reduction in viscosity and a recommendation to keep the dilution below 2-3% . Technical recommendations of standards-standards (e.g., ASTM) suggest that a concentration above 4% is a warning signal indicating the need for diagnostics or oil change. Studies in June 2024 confirmed that high-pressure injection during injection (e.g., for DPF re-generation) can result in unburned fuel seeping through the piston rings into the crankcase [3,12]. These simulations also identify the sensitivity of the system to the geometry of the piston rings and apply designs to opti-malize them. Oil measurements from vehicles driven mainly on short urban routes have shown that gasoline engines exhibit a more pronounced drop in viscosity and higher levels of fuel in the oil than diesel engines.

The amount of fuel in each sample was determined using infrared spectrometry with a FieldLab 58 comprehensive measuring device. Since infrared spectrometry evaluates the fuel content of the oil in percent by weight, it was necessary to convert the 5 percent by volume to percent by weight according to formula 1 and 2. Formula (1) represents the cut-off value for spark-ignition engines and formula (2) for compression-ignition engines.

$$W = \emptyset \cdot \frac{\rho_p}{\rho_o} = 5 \cdot \frac{0{,}750}{0{,}842} = 4.4\% w/w \tag{1}$$

$$W = \emptyset \cdot \frac{\rho_p}{\rho_o} = 5 \cdot \frac{0{,}840}{0{,}842} = 4.9\% w/w \tag{2}$$

Where:
W…Ingredient content [% w/w];
∅…Ingredient content [% v/v];
ϱ_p…Fuel density [g/ml];
ϱ_o…Density of oil [g/ml][8].

Before each measurement, each sample had to be homogenized first, for which the Hei-dolph Hei-MIX Reax 2 was used. After mixing, bubbles formed in the oil samples, complicating the actual measurements, so the samples had to be placed in a Branson 200 ultrasonic cleaner afterwards.

For viscosity measurements, the SpectroVisc 300 viscometer was used, which is a benchtop semi-automatic kinematic temperature viscometer optimized for the analysis of used and new lubricants. It complies with ASTM D445, D446, D7279, IP 71 and ISO 3104 requirements. Using this meter, kinematic viscosity values were measured at 40°C and 100°C, and dynamic viscosity was calculated from the measured values. Kinematic viscosity at 100°C and dynamic viscosity at 40°C were evaluated because the same engine oil is always used and the values are related to each other. The viscosity should not deviate from the viscosity of the new oil by ±10%.

In order to be able to evaluate the measured data, it is necessary to determine the limits within which the viscosity can vary. The limit values are calculated in the following formulae.

Lower kinematic viscosity limit at 100°C:

$$12{,}1 \cdot \frac{\mathbf{90}}{\mathbf{100}} = 10.89 \text{ mm}^2\cdot\text{s}^{-1} \tag{3}$$

Upper kinematic viscosity limit at 100°C:

$$12{,}1 \cdot \frac{\mathbf{110}}{\mathbf{100}} = 13.31 \text{ mm}^2\cdot\text{s}^{-1} \tag{4}$$

Lower limit of dynamic viscosity at 40°C:

$$58{,}94 \cdot \frac{\mathbf{90}}{\mathbf{100}} = 53.05 \text{ mPa}\cdot\text{s} \tag{5}$$

Upper limit of dynamic viscosity at 40°C:

$$58{,}94 \cdot \frac{\mathbf{110}}{\mathbf{100}} = 64.83 \text{ mPa}\cdot\text{s} \tag{6}$$

3 Results and Discussion

3.1 Viscosity

Fig. 1 and Fig. 2 show the values sorted according to the mileage of the sample. It can be seen from the measured values that the change in viscosity is not directly proportional to the mileage. Hence, the viscosity of the engine oil itself is affected by several parameters. Therefore, it is not possible to develop a degradation curve for viscosity. It is possible to evaluate samples that are within the limits, but also those that are not. Above we have calculated the limiting values. None of the engine oil samples showed an increased viscosity above the upper limit value. Oils with a viscosity below the limit value should no longer be used and should be replaced immediately.

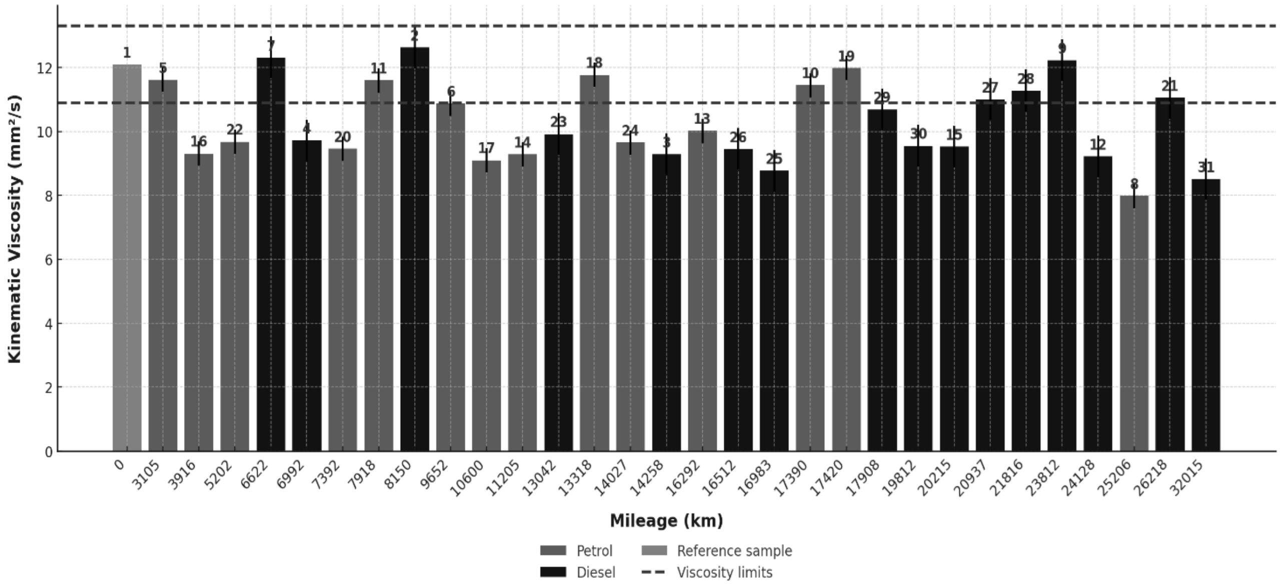

***Fig. 1** Measured values of kinematic viscosity at 100°C*

Based on measurements of the kinematic viscosity of engine oil at 100°C in individual samples, it can be stated that more than half of them exceeded the ±10 % tolerance of the reference viscosity of new oil (12.10 mm²/s). This is mainly a decrease in viscosity, indicating potential oil deterioration due to fuel dilution, thermal ageing or contamination. The most significant drop was observed for sample 8, where the viscosity dropped by up to 34%, which already represents a risk of loss of lubricity and increased wear of the mo-tor. Samples taken from petrol engines generally showed a greater fluctuation and drop in viscosity than from diesel units, corresponding to the more frequent problem of unburnt fuel ingress during cold starts or short runs. In contrast, several diesel samples maintained viscosity within the allowable range, indicating a more stable thermal regime and less aggressive conditions. Based on these findings, regular monitoring of the oil condition, especially at extended drain intervals, may be recommended and if viscosity deviations above ±10% are detected, oil changes and possibly deeper diagnostics of the combustion and injection system condition should be considered.

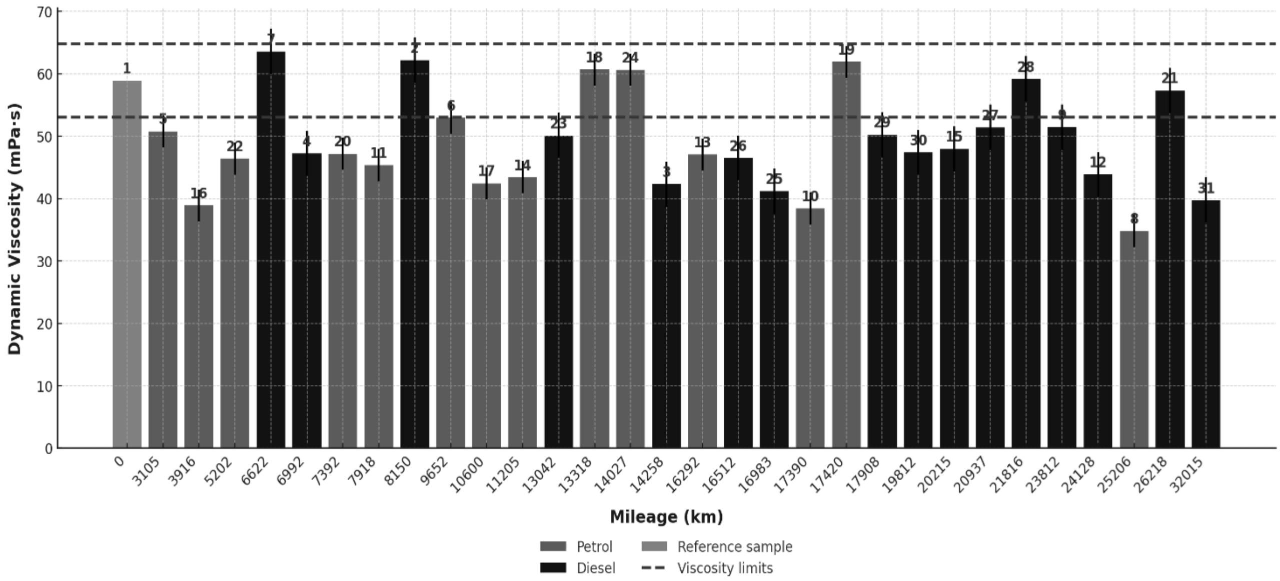

***Fig. 2** Measured values of dynamic viscosity (calculated) at 40°C*

The kinematic viscosity was also measured at 40°C, from which the dynamic viscosity was subsequently calculated. Based on the analysis of the dynamic viscosity of the engine oil, expressed in units of mPa-s, it is evident that the viscosity fluctuates over a relatively wide range with time and mileage. The reference value of dynamic viscosity (sample 1) is 58,94 mPa-s, with several samples showing deviations exceeding the acceptable limit of ± 10 % during operation. Such a deviation was observed in particular for samples 16, 8, 10 and 25, where the dynamic viscosity dropped by more than 30 %, which may be an indication of significant oil dilution - most often by fuel or oxidation during ageing. Sample 8 (34.81 mPa-s) is the lowest of all, representing a drop of more than 40 % from the reference, and may indicate a risk of reduced protection of the moving parts of the engine. Conversely, some samples (e.g. 7, 18, 19, 24, 28) maintained or even slightly increased their viscosity, which may be related to the operating mode (longer runs, diesel engine, less cold starts).

In general, the dynamic viscosity of the investigated oil in some cases exceeded the no-furnace operating limits, which may negatively affect engine lubrication and wear. For dynamic viscosity, a tolerance of ±10 % is assumed as a maximum to maintain reliable lubrication properties. With this in mind, it is evident that more samples have exceeded this threshold and therefore in such cases, immediate oil change or more thorough diagnosis of the cause of degradation should be considered. To ensure optimum engine life and reliable function, we recommend regular monitoring of dynamic viscosity, especially at extended servo intervals.

3.2 Fuel content

The amount of fuel in each sample was determined using infrared spectrometry with a FieldLab 58 comprehensive measuring device. The measured fuel content values were compared with the floating point for control. The measured values of the flash point are given in Fig. 3. The cut-off value for the fuel content in oil was calculated above and was set to 4.4% w/w for spark ignition engines and 4.9% w/w for compression ignition engines.

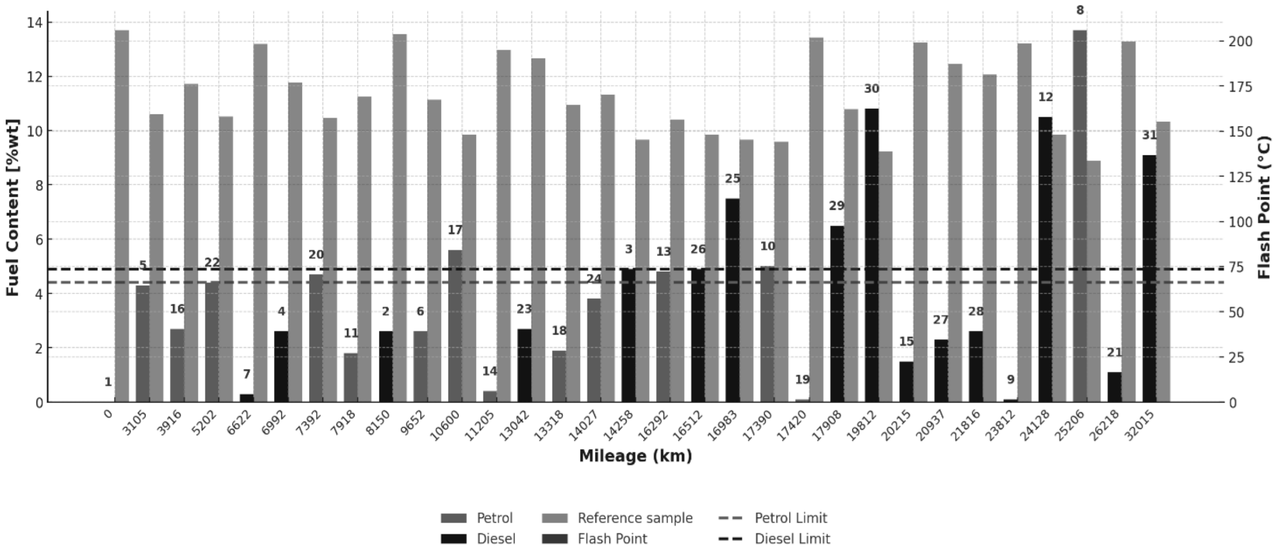

Fig. 3 *Measured values of fuel content in the samples*

Based on the extended analysis of engine oil samples, which includes data on fuel content (%w/w), flash point, viscosity and mileage, several important conclusions can be drawn regarding the condition and quality of the oil under real operating conditions.

The most significant factor influencing oil quality is the unburned fuel content, which has increased significantly in several cases. The fuel content of up to 5 % by weight is considered to be within the safe limit. However, several samples (e.g. samples 8, 12, 30 and 31) exceeded this value by a factor of several times, with the highest value reaching up to 13,7 %. This phenomenon directly correlates with a significant drop in flash point (down to 133,5 °C), which reduces the safety of the lubricating film and indicates dilution of the oil charge. This excessive fuel content also leads to a decrease in viscosity, which has been confirmed in several samples. For example, sample 8, which had the highest fuel content (13,7 %), also showed the lowest viscosity (7,98 mm²/s), a decrease of more than 34 % compared to the reference value. Such oil dilution significantly reduces the ability of the oil to protect the engine against wear, especially at high loads or higher temperatures.

In terms of flash points, a number of samples fell below the 160 °C threshold, which is considered to be a risk - especially for samples with high fuel content. This trend is evident, for example, in samples 3, 10, 25, 30 and 8, where the combination of high fuel content and low flash point significantly degrades the oil properties.

Interestingly, gasoline engines are more likely to suffer from high fuel oil dilution than diesel engines in this sample, which is consistent with expectations - gasoline engines are more likely to suffer from oil dilution during short runs, cold starts, and when the engine is not sufficiently warmed up.

Overall, a number of the samples analysed show signs of oil degradation due to fuel leakage, which is accompanied by a reduction in viscosity and flash point. Such characteristics significantly reduce the protective function of the oil and pose a potential risk to engine reliability and durability. In these cases, it is advisable to proceed promptly with an oil change and to consider the causes of dilution (e.g. improper driving habits or faults in the injection system or imperfect DPF regeneration). To maintain safe operation, we recommend monitoring the fuel content of the oil and monitoring the flash point as an additional indicator of oil deterioration.

When analysing engine oil parameters with emphasis on fuel content, flash point, viscosity and drive type, it is important to take special account of samples from diesel engines equipped with a DPF (diesel particulate filter). The data show that a number of samples from diesel engines show elevated unburnt fuel content - in particular samples 26, 29, 30, 31 and 12. In the case of sample 30 (diesel), the fuel content was as high as 10,8 %, which is extremely high. This may be due to frequent or unsuccessful filter regeneration, during which additional fuel is injected into the cylinders, which may subsequently leak into the oil charge.

Conversely, some diesel samples (e.g., 15, 21) maintained low fuel content (<1%), high flash point, and viscosity within the standard. These cases suggest that this is due to the implementation of an optimized DPF rege-neration strategy, which is an additional injector in the exhaust that is used to raise the temperature in the exhaust manifold, and there is no need to increase the amount of fuel injected into the combustion chambers, resulting in the elimination of fuel contamination of the oil charge.

4 Conclusion

Based on the measurements and analyses performed, it can be concluded that the dilution of engine oil with fuel is a significant factor influencing lubricant life and overall reliability of the internal combustion engine. The results obtained show that, especially in the case of vehicles with spark-ignition engines running mainly on short distances and with frequent cold starts, there is a significant decrease in oil viscosity and an increased concentration of unburned fuel in the oil charge. These negative phenomena have also been confirmed by foreign research, which states that fuel content in the oil above 4-5% by weight represents a threshold value that should be followed by lubricant change or injection system diagnostics [1]. Diesel engines equipped with a DPF system are susceptible to similar degradations, especially when frequent or unsuccessful regeneration of the filter results in secondary fuel injection. These findings are supported by practical observations which suggest that even long-life oils may not meet the declared service life under severe conditions [4,11]. It is therefore desirable to apply advanced monitoring methods such as infrared spectrometry and periodic viscosity monitoring, especially for extended service intervals or hybrid operations. The results of this study can serve as a basis for optimising service schedules and developing intelligent diagnostic systems that enable predictive maintenance of vehicles. Oil film protection is key to reducing wear and ensuring long-term powertrain functionality - which can be aided not only by appropriate lubricant selection, but also by dynamically adapting drain intervals to real-world operation.

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