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A Study of Diesel Particulate Filter Impact on Engine Oil Quality

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Abstract

The paper presents the results of analyzes based on which the setting of change intervals of Castrol SLX, SAE 0W-30 synthetic engine oil used in D5 diesel engines of Volvo cars was verified. ACEA oils of A5/B5 specification recommended for engines complying with EURO 4 emission standards, ie oils from vehicles with DPF, were analyzed. Also, ACEA engine oils of A3/B3 specification, which were taken from cars complying with EURO 3 emission standards (ie without DPF) during service inspections, were analyzed. Based on the results of evaluation of a large scale of oil samples, it has been proved that the engine oil was contaminated with diesel during the DPF filter regeneration process. In some cases, contamination by fuel was so high that the oil viscosity was reduced to half its original value. Therefore, it was recommended to shorten the oil change interval. No significant degradation or contamination was detected in the monitoring of the condition of oils taken from EURO 3 engines.
KEY WORDS: *change interval, engine oil, lubricant, diesel particulate filter (DPF), dilution with diesel, common-rail systems*

1. Introduction

The introduction of European EURO directives to reduce diesel engine emission limits has not only brought technical changes in engine technology or exhaust aftertreatment technology [1,2], but also in the development of lubricating oils.

EURO 4 emission limits include all monitored pollutants in the exhaust, ie CO, NOx, unburned hydrocarbons and soot levels. EURO 4 emission limits are approximately half the EURO 3 limits. With the introduction of EURO 4, the reduction of nitrogen oxides and solid particle concentrations in exhaust emissions has proven to be problematic for diesel engines. For these reasons, some systems that effectively reduce the pollutant content of diesel engines have been introduced. The nitrogen oxides in the exhaust gas are reduced with a urea solution to inert nitrogen, these are selective catalytic reduction (SCR) systems. Another option for reducing NOx are exhaust gas recirculation (EGR) systems. Reducing the solid particles amount in the exhaust is the task of various collection devices in the exhaust system. The best known are diesel particulate filter (DPF) or continuous regenerative particle capture (CRT). These filters trap solid particles from the flue gas. The soot-clogged filters are then regenerated by burning, which is supported by catalytic oxidation [3,4]. DPF are very sensitive to clogging with small ash particles from the burned fuel, and especially from the burned engine oil. Therefore, the more strict Euro 4 emission limits also affected the composition of engine oils. The next-generation engine oil formulations are engineered to be used in engines equipped with sensitive particulate filtering and other catalysts. The new generation of engine oils has reduced sulphate ash (SA) level and reduced levels of phosphorus (P) and sulfur (S), which can act as catalyst poisons and reduce the efficiency and durability of these devices. For these oils, the term “low SAPS oil” is used. There was demonstrated the effects of individual lubricant additives on the resulting ash properties controlling DPF pressure drop, including ash packing density and permeability. Ash consisting primarily of calcium sulfates to exhibit significantly increased flow resistance as opposed to ash primarily composed of zinc phosphates [5]. Also Manni et al. [6] investigated the impact of lubricating oil formulations on efficiency and durability of DPF. Authors used for the test a passenger car diesel engine retrofitted with a continuously regenerating DPF. The different oil additives gave a contribution to DPF deposits mostly depending on their ash content.

Diesel particulate filter requires periodic regenerations under high-temperature conditions in the exhaust pipe in order to oxidize the accumulated soot. A common strategy to produce high exhaust gas temperature is to inject late post-injections after the main injection [7]. However, this practice may dilute the engine oil. The oil is contaminated with fuel particularly in the event of a DPF regeneration interruption, eg due to a change in driving conditions when: a) the vehicle no longer runs at steady speed with the engine in low to moderate load mode, b) at medium to higher engine speeds.

Paper of Thornton at al. [8] assesses the oil dilution impacts on an engine operating in conjunction with DPF, oxides of nitrogen (NOx) storage, SCR emission control system, and a 20% biodiesel fuel blend. The presence of bio-components in the fuel has significant impact on multidirectional hastening of engine lube oil destruction processes. The processes taking place in an engine lubricant, influence adversely the limited possibilities of bio-components evaporation from engine lube oil and contribute to initiation of accelerated, deeper engine lube oil oxidation and degradation [9].

Ye [10] evaluated the impact of post-injection strategy on emissions, combustion and lubricant dilution with a common-rail turbocharged direct-injection diesel engine at moderate speed and low load. Among other things, it was found that the unburned hydrocarbons were found to be the primary source for lubricant dilution. Also the article of Gołębiowski et al. [11] presents the influence of the presence of a diesel particulate filter (DPF) on the level of changes of physical and chemical parameters in engine oils during their service life. In testing lubricant oils statistically significant differences in diesel fuel content were noticed. The presence of fuel in lubricating oil also reduces its viscosity and lubricity [12].

The paper assesses the impact of operation of Volvo Euro 4, which is equipped with a DPF system and Euro 3 (without DPF) on the quality of Castrol SLX, SAE 0W-30 engine oil.

2. Materials and Methods

Volvo vehicle manufacturer recommends authorized service centers to fill combustion engines with Castrol SLX engine oil, SAE specification 0W-30. ACEA performance characteristics vary with the recommended periodic maintenance and engine oil change intervals. For a shorter maintenance interval of 20,000 km, the A3/B3 specification is recommended (for D5244T engines meeting EURO 3 emission standards) and for the maintenance interval of 30,000 km, the A5/B5 specification (for EURO5 D5244T engines). The engines complying with EURO 4 emission standard are equipped with DPF system for regenerative soot capture. The basic characteristics of new engine oils are shown in Table 1.

Table 1

The basic characteristics of new engine oils Castrol SLX Profesional Longtec, SAE 0W-30

	Castrol SLX Professional LongTec, SAE 0W-30	
Specifications ACEA	A3/B3	A5/B5
Kinematic viscosity at 40°C	72 mm^2s^{-1} (cSt)	55,3 mm^2/s (cSt)
Dynamic viscosity at 40°C	60,4 mPa·s (cP)	46,7 mPa·s (cP)
Density at 15°C	839 $kg \cdot m^{-3}$	844 $kg \cdot m^{-3}$
Colour	amber colour	amber colour

Samples of engine oils from Volvo's diesel engines were taken during a periodic inspection of vehicles in a service station just after the engine stopped at a temperature of about 65 ° C to a 500 ml sampler. The sampler was filled to 2/3 of its volume. The sampling was carried out via the engine oil sump outlet. The area around the outlet was thoroughly cleaned first. In order to provide a representative oil sample for analysis, a portion of the oil around the drain plug was discharged into the collection container.

In total, 22 samples of worn-out engine oils from EURO 4 diesel engines were taken during periodic inspections in service center. Five oil samples were taken from EURO 3 diesel engines.

Fourier transform infrared spectrometry (FTIR spectrometry) was used in the paper to monitor thermo-oxidative degradation of engine oil, reduction of additives level and intrusion of contaminants (coolant, soot, fuel) to oil.

Engine wear processes were monitored by the LNF Q200 Laser Particle Analyzer. With this type of device, the number of wear particles in 1 ml of oil was determined and particles larger than 20 µm were assigned to individual wear classes based on the shape characteristics. Dynamic viscosity at 50°C was also monitored with this analyser. Viscosity is considered a key factor of the quality of lubrication by oil and engine manufacturers.

3. Results and Discussion

Based on the evaluation of a large sample of worn-out engine oils (see Table 2) taken from Volvo cars of EURO 4 emission category, ie. equipped with the DPF, the main problem was defined as the dilution of lubricating oil with diesel oil with rapeseed oil methyl ester (RME). The presence of RME in the lubricant was confirmed by FTIR spectrometry - the spectral band of the carbonyl group C = O in the region of 1750 cm^{-1} (see Fig. 1). Dilution of oil with fuel in some cases was so high that the viscosity was reduced to half of its original value (see Table 2). However, a change of this parameter is allowed for about ±20% of the original value of the new engine oil [13].

Wolak et al. [14] confirm in their study that the dilution of oil with unburned fuel is a problem that appears particularly in vehicles in urban driving conditions where the DPF regeneration cycle is slowed down. Due to the incomplete DPF regeneration cycle, up to 26.0-34.6% intruded into the crankcase of the engine. According to Wei et al. [15], the following three factors primarily affect the life of motor oils in passenger cars in urban traffic: engine idle time, engine operating time and number of starts [16].

Table 2

Data on A5/B5 specification of engine oil samples and their dynamic viscosity values

Diesel engine D5244T4 - EURO4					
Sample code of engine oil	Number of days since oil change	Mileage [km]	Type of vehicle	Dynamic viscosity [mPa·s]	Viscosity change [%]
1	413	36,590	V70 08-	32.95	-29
2	99	14,617	V70 08-	47.4	-14
3	358	25,819	XC 70 08-	38.04	-19
4	344	18,092	XC 70 08-	28.46	-39
5	266	31,404	XC 70 08-	37.04	-21
6	354	14,764	XC 70 08-	28.07	-40
7	80	19,699	XC 90	35.04	-25
8	318	30,021	XC 70 08-	42.48	-9
9	430	15,580	XC 90	40.65	-13
10	241	29,239	S 80	61.98	+12
11	286	32,212	S 80	46.07	-1
12	360	17,360	XC 60	23.14	-50
13	370	27,658	XC 90	41.48	-11
14	381	26,014	XC 90	32.73	-30
15	390	20,946	XC 90	36.03	-23
16	337	20,666	XC 90	43.46	-7
17	385	11,603	XC 90	35.63	-24
18	551	14,042	XC 70 08-	24.93	-47
19	177	30,230	XC 70 08-	37.99	-19
20	392	18,241	S 80	24.69	-47
21	226	29,521	XC 90	46.59	0
22	371	16,592	XC 70 08-	36.64	-22

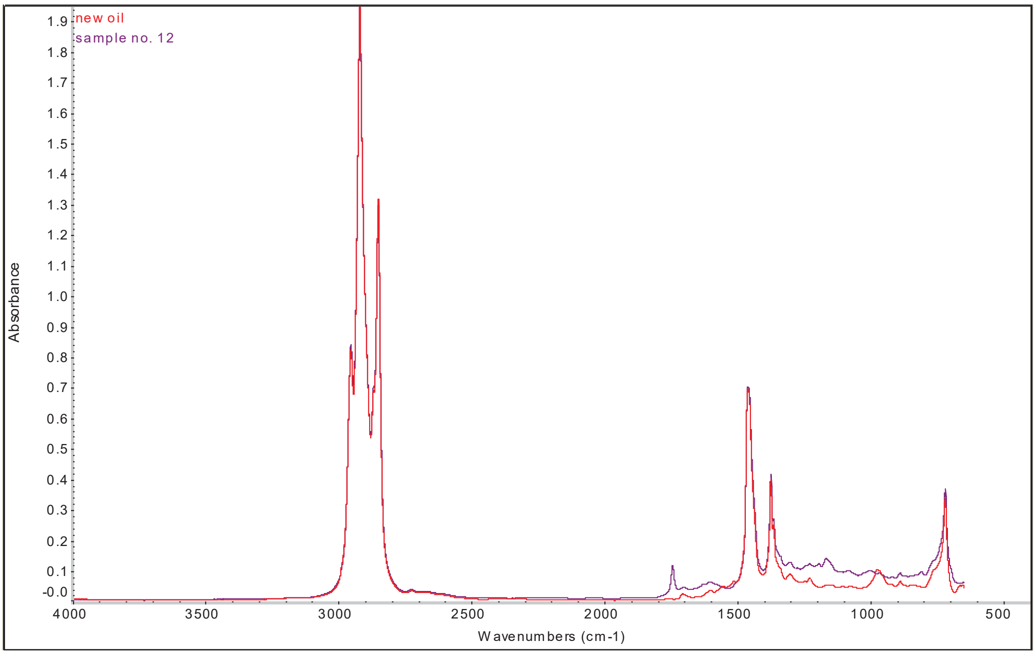

Fig. 1 Spectrogram of new engine oil SAE 0W-30 and engine oil (no. 12) contaminated with diesel

The basis of the problem with the dilution of the Castrol SLX engine oil in the D5 EURO 4 diesel engine is also in the process of regenerating the particulate filter, ie. increasing the fuel dose and its injection (two injections before the exhaust valves are opened). The filter regeneration interval depends on the way of driving and the prevailing load of the engine and it ranges from 500 to 1000 km of driving. The regeneration cycle lasts 10–30 minutes. Therefore, the amount of fuel injected into the space above the piston before opening the exhaust valves is considerable. The fuel injected theoretically shall evaporate into the particulate filter, where it shall start burning, and the increased temperature shall ensure the combustion of solid particles. However, the RME biocomponent has a higher boiling point (358 ° C) compared to diesel, ie. non-evaporated droplets of this biocomponent reach the walls of the cylinder and then pass through the piston rings into the crankcase. This causes dilution of the engine oil and consequent decrease of its viscosity. As a result, the lubricating film may tear at engine load, which may cause increased engine wear.

Car service also reported cases when the fuel accumulation in the engine oil sump was so high that it was sucked through the crankcase ventilation lines into the engine system and then into the space above the piston. This resulted in engine stoppage due to piston-liquid-cylinder head contact, or in self-ignition of liquid and thus impossibility to control engine speed.

An increased content of abrasive particles in the oil charge was also detected by the LNF Q200 laser particle analyzer in the analyzed oil samples contaminated with fuel. Due to the limited scope of this paper, the results of the laser particle analysis of the engine oil sample no. 5 are presented in Fig. 2.

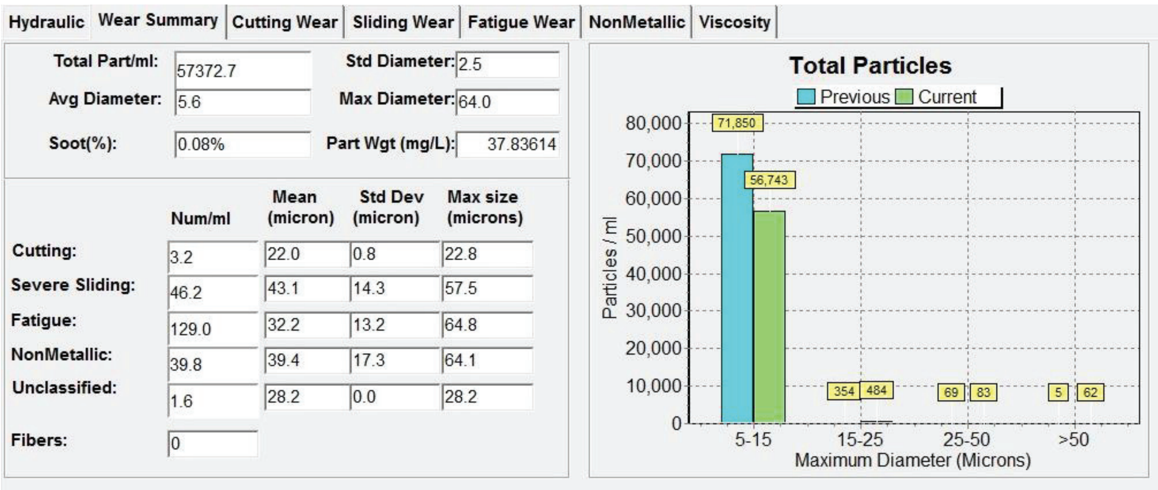

Fig. 2 Demonstration of output from laser wear analysis

Since the problem of RME accumulation has been recorded in all oil samples taken from EURO 4 specification engines, the issue of shortening the service interval of these vehicles (currently the engine oil is changed after 30,000 km or after 12 months) has to be addressed.

In newer cars, the problem of accumulating fuel in the lubricant during DPF regeneration is already solved by installing modern injection systems. These systems are able to divide fuel injection into multiple cycles. Another option is to operate with an additional injector located in the exhaust pipe.

No significant degradation or contamination was detected in the monitoring of the condition of oils taken from EURO 3 engines. Only an oil sample that exceeded the recommended exchange interval has shown a viscosity increase of about 20% (see Table 3).

Table 3

Data on A3/B3 specification of engine oil samples and their dynamic viscosity values

Diesel engine D5244T4 - EURO3					
Sample code of engine oil	Number of days since oil change	Mileage [km]	Type of vehicle	Dynamic viscosity [mPa·s]	Viscosity change [%]
1	395	9,871	V7000-07	60.54	+5
2	337	14,449	V7000-07	43.16	+2
3	432	19,160	V7000-07	64.92	+10
4	238	16,694	XC 70-0-07	63.52	+7
5	371	21,936	S 60	70.21	+21

The increase in viscosity results from the increase of the amount of soot penetrated into the engine oil and of the thermo-oxidation reaction products. No increased amount of abrasive metals that would indicate adverse frictional ratios between the co-operating components of the engine has been recorded.

4. Conclusions

Based on the evaluation of a large sample of worn out engine oils taken from Volvo cars fitted with the D5244T4 diesel engine of EURO 4 emission class, ie. those equipped with the diesel particulate filter (DPF), the dilution of the engine oil with fuel containing the RME biocomponent has appeared to be a major problem. The contamination of oils with RME was in some cases so high that the viscosity was reduced to half the value of the new oil. With these older Volvo cars, the essence of the lubricating oil problem related to fuel lies in the DPF regeneration process. The cars are equipped with a common-rail injection system which injects four doses of fuel into the combustion chamber before the exhaust valves are opened in order to regenerate the DPF. The injected fuel does not evaporate completely due to the high boiling point of the RME. It reaches the walls of the cylinder and then penetrates the crankcase through the piston rings to dilute the engine oil and reduce its viscosity. Reduced viscosity results in increased engine wear. Reduced viscosity was recorded for all lubricants tested - even 50% in some cases. For these types of cars, the engine oil exchange interval needs to be shortened.

When assessing the condition of oils taken from D5244T engines of EURO 3 specification, no significant degradation or contamination was recorded. This type of car is not equipped with DPF. No increased amount of abrasive metals has been shown to indicate adverse frictional ratios between the co-operating components of the engine.

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