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SEARCHING FOR THE CAUSES OF ABNORMALLY FAST DEGRADATION OF ENGINE OIL IN A DIESEL COMBUSTION ENGINE

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Abstract: Today, modern tribodiagnostics offers sophisticated analyzes of motor oils with fast and accurate results. However, finding the causes of some undesirable processes of engine oil degradation often requires long-term monitoring of the operating facility. In this case, it was a problem of diesel engine oil in the Citroën Jumpy 2.0 HDi service minibus, which has been in use by the Department of Mechanical Engineering (Armed Forces Academy of General M. R. Štefanik, Demänová) for more than 13 years. The fuel system (conditioners of injectors) on this vehicle has also been monitored for a long time in the period 2019-2021, an article about it was also published in the journal Science & Military (No. 2 / Vol. 14/2019). The cadets of the Deptartment of mechanical engineering Armed Forces Academy of General M. R. Štefanik, were also involved in the diagnostic process. In parallel with the fuel system, the quality of the engine oil was regularly monitored in the time interval 20.1.2020 - 22.4.2021 at a start of 2185 km from the last oil change. During this monitoring, a very rapid degradation of engine oil was found in some parameters, which is atypical during normal vehicle operation. This article discusses the measured results and possible causes of this adverse event.

Keywords: Tribology; Tribodiagnostics; Engine oil; Diesel engine; Engine oil parameters; Carbon black content.

1 INTRODUCTION

From the point of view of maintaining competitiveness on the market, very high demands are placed on today's high-performance motor oils. These are technologically very complex products with a number of parameters that must meet performance parameters under different load conditions. Despite the time and mileage declaration of the service life interval from the manufacturer, there may be cases where there is an accelerated degradation action and the associated risk of premature wear.up to the crash limit engine. The service life of the engine oil is determined by a set of operating factors (eg. cold starts, number of starts, operator's approach to gradually warm up the engine to operating temperature, technical condition of the engine, vehicle load, length of operating distances, operation in difficult terrain, operation in dusty environment etc.). It is the operation of technology in the Armed Forces of the Slovak Republic that is significantly influenced by the above factors. Therefore, in order to maintain the combat capability and reliability of military equipment, it is necessary to pay increased attention to monitoring and evaluating the degradation of motor oil. [1]

Lubricating oil is often exposed to unforeseen operating conditions that affect its service life. We know 3 general criteria that determine the reason for changing the lubricating oil. These include the degradation of the base oil, the loss of additives and impurities in the lubricating oil. The degradation of the base oil itself can be caused by the ongoing oxidation process, thermal degradation (hot spots) and chemical degradation. The choice of lubricating oil, the choice of base oil and suitable additives, or the loss of additives also have a certain influence on the degradation of the lubricating oil. [2]

Additives are added to base oils to reduce destructive processes and improve beneficial properties. For example, antioxidant additives help slow down the oxidation rate. Detergent additives help prevent deposits and sludge. Anti-wear additives are added to some engine oils to form a layer on metal components and prevent wear. The depletion of additives is one of the main reasons why engine oil loses its effectiveness and must be changed. Although all engine oils deteriorate over time, synthetic oils last longer than conventional oils and provide improved protection against wear and deposits. [3]

2 OBJECT DIAGNOSTIC MONITORING

The request for tribodiagnostic monitoring came from the vehicle operator, ie from the Dept. of Mechanical Engineering AOS Lipt. Mikuláš, which has been using the vehicle since 2008 to fulfill transport tasks. The vehicle is subject to high requirements in terms of functionality and reliability.

2.1 Fuel system problem

The problem with the fuel system has been solved since 2019 - the diagnostics revealed an uneven supply of fuel through the injectors due to their clogging with carbon. The initial solution to the problem was an intensive cleaning treatment of the fuel system by using cleaning additives for diesel. This cleaning process has had positive effects on the fuel system. Injector values have approached an almost ideal, i.e. uniform fuel supply (Graph 1).

However, this can be a problem for the operation of the oil change, as the fuel additives are characterized by high cleaning effects and aggressiveness. The influence of the cleaning system of the fuel system therefore has a negative impact on the quality of the oil filling. And this is what the next part of the article discusses. This was a specific operating stage of the vehicle (from 20.1.2020 to 22.4.2021 at the start of 2185 km since the last oil change), when the fuel (diesel) was significantly concentrated with cleaning additives VIF Super Diesel Additive for winter and summer operation of he vehicle. (Fig. 2). Additive preparations were continuously added to the fuel at each refueling of the vehicle in the maximum recommended doses, resp. in slightly exceeded quantities (the manufacturer does not consider an overdose to be harmful to the engine and fuel system).

Company car tested (Armed Forces Academy of General Milan Rastislav Štefánik, Department of Mechanical Engineering, Demänová): Citroën Jumpy 2.0 HDi

Engine 2.0 HDi specification:

- Power (kW): 88 kW
- Horsepower: 120 hp
- Horsepower: 118 bhp
- Rev. at Max Power: 4000 / min
- Torque: 300 Nm
- Torque (lb-ft): 221 lb-ft
- Rev. at Max Torque: 2000 / min
- Displacement: 2 l
- Displacement: 1997 cc
- Number of Cylinders: 4
- Number of Valves per Cylinder: 4
- Bore: 85 mm
- Stroke: 88 mm
- Compression Ratio: 17.6: 1
- Common Rail Diesel System

INCLUDE PICTURE "http://shared.autorubik.sk/upload/2014/06/citroen_ew7j4.jpg" \ * MERGEFORMATINET

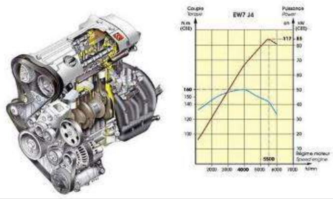
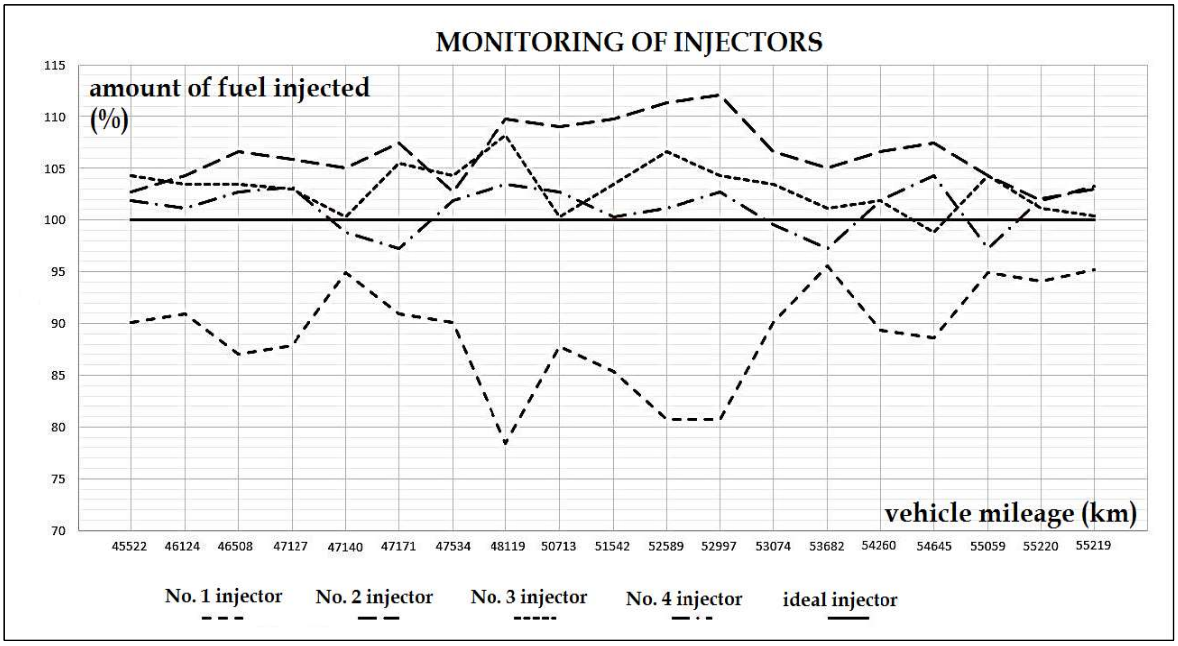


Fig. 1 Monitored vehicle Citroën Jumpy 2.0 HDi
Source: authors [5, 6].

Fig. 2 Additives added to diesel
Source: authors.

VALVOLINE Syn Power XL III Full Synthetic SAE 5W-30
ACEA C2, C3, A3 / B4
BMW LL-04MB 229.31; 229.51VW 504.00, 07.00Porsche C30

Fig. 3 Engine oil specification
Source: authors.



Graph 1 Condition of injectors in the period 13. 5. 2019 - 22. 4. 2021 during the start of 9998 km
Source: [4].

Table 1 Current quality of VALVOLINE Syn Power XL III 5W-30 oil filling in the period 20. 1. 2020 to 22. 4. 2021 at the start of 2185 km

vehicle operation	1/21/2020 *	8/13/2020	9/7/2020	9/8/2020	9/9/2020	2/2/2021	4/22/2021	allowed values	results for vehicle operation
	engine oil change at 53035 km	route: AOS - Bratislava and back	route: AOS - Bratislava and back	route: AOS - Nitra and back	route: AOS - Trebisov and back	route: AOS - Sučany and back	route: AOS area - AOS area		
	mileage of the car: 0 km	mileage of the car: 647 km	mileage of the car: 1225 km	mileage of the car: 1610 km	mileage of the car: 2024 km	mileage of the car: 2185 km	mileage of the car: 2185 km		
oil parameter	total mileage of the car: 53035 km	total mileage of the car: 53682 km	total mileage of the car: 54260 km	total mileage of the car: 54645 km	total mileage of the car: 55059 km	total mileage of the car: 55220 km	total mileage of the car: 55220 km		
Glycol (%)	0	0	0	0	0	0	0	max. 0	passes
Oxidation (abs /0,1)	19,2	22,1	25,1	20,5	21,9	24,2	32,4	max. 40	passes
Soot (% wt)	0	0,49	0,53	0,61	0,64	0,70	0,71	max. 3	passes
Sulfation (abs /0.1)	23,9	24,4	24,5	23,7	23,9	24,6	26,7	max. 40	passes
TBN parameter (mg.KOH/g)	8,1	7,1	5,8	6,9	6,7	6,0	3,5	min. 3	passes
Water content (ppm)	239	112	133	76	217	119	221	max. 5000	passes
Kinematic viscosity at 40 ° C (mm^2/s)	72,7	79,5 (+ 9,3%)	79,4 (+ 9,2%)	79,4 (+ 9,2%)	81,1 (+ 11,6%)	83,8 (+ 15,3%)	80,05 (+ 10,11%)	max. difference ± 20% compared to the new sample	passes
Kinematic viscosity at 100 ° C (mm2/s)	12,4	13,3 (+ 7,3%)	13,2 (+ 6,5%)	13,2 (+ 6,5%)	13,5 (+ 8,9%)	13,8 (+ 11,3%)	13,3 (+ 7,3%)	max. difference ± 20% compared to the new sample	passes

* Reference (new) engine oil comparison sample VALVOLINE Syn Power XL III 5W-30.

2.2 The problem with fast engine oil degradation

Oil sampling of the Citroën Jumpy 2.0 HDi was carried out during operation, usually after returning from business trips. The oil sample of the Dutch manufacturer VALVOLINE (Fig. 3) was subsequently subjected to analysis by modern instruments in the tribodiagnostic laboratory of the Department of Mechanical Engineering (Fig. 4).

Fig. 4 Tribodiagnostics laboratory
Source: authors.

The kinematic viscosity of the oil sample was evaluated with a Spectro Visc Q-3050 optical-electronic instrument.

Chemical parameters were evaluated with a Fluid Scan Q-1000 FTIR method. Infrared spectrometry with Fourier transformation (FTIR spectrometry) is an optical non-destructive analytical method, which is providing quick and complex information about the state of used lubricant. One of the FTIR spectrometry advantages in comparison to the classical methods, the contamination by foreign substances does not occur. It is also possible to discover the change of sample quality caused by mixing with another oil type or another working liquid, or such fact exclude. They are devices working on emission interference principle, which in comparison with dispersion devices measuring the interferogram of emission modulated beam after the transit through the sample. These devices are requiring application of Fourier mathematical method (cosines) transformation, in order to get classical spectral record. [7]

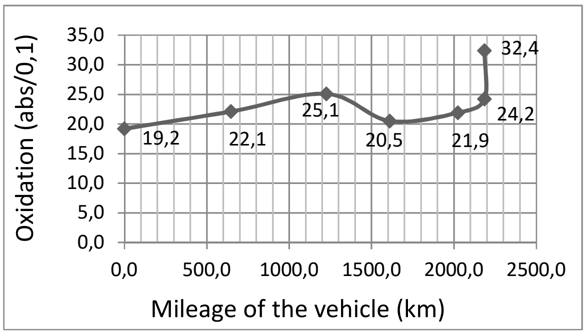
$$I(d) = \int_{-\infty}^{\infty} I(\tilde{v}) \cos(2\pi d \tilde{v})\, d\tilde{v} \qquad [7]$$

I - emission intensity,
d - way difference of patterned rays,
v ~ - wave number (1 /λ)

One of the methods ascertaining the properties changes of worn or otherwise devalued lubrication oil, fuel or another mixture by help of FTIR spectrometry it is a technique of used and new liquid spectrums subtraction. [7]

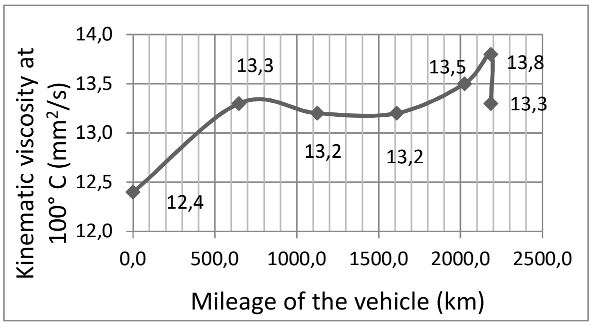
Table (Table 1) contains the measured data - the course of the change of individual physico-chemical parameters of the engine oil depending on the mileage operation of the vehicle. After passing each route, seven tribodiagnostic measurements of the oil sample were performed. In the following section, the individual diagrams show the most significant degradation changes of the monitored physico-chemical parameters of the engine oil.

The primary physical parameter - the kinematic viscosity of the oil during the monitored operating interval was within the allowed values, did not exceed the allowed range ± 20 percent compared to the reference sample (Graph 2).

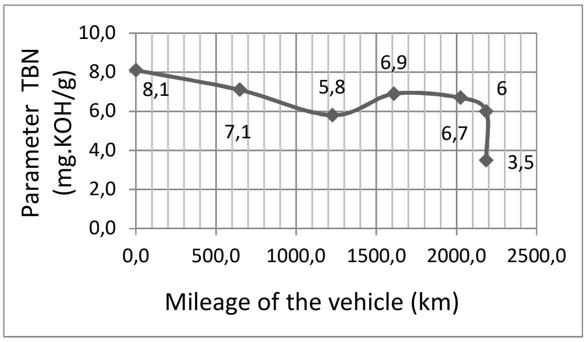


Graph 2 Kinematic viscosity profile at 100 °C
Source: authors.

Engine oil showed quite good oxidative stability during the observed interval (Graph 3). Apart from the last measurement, no significant increases and decreases in oxidation were recorded.

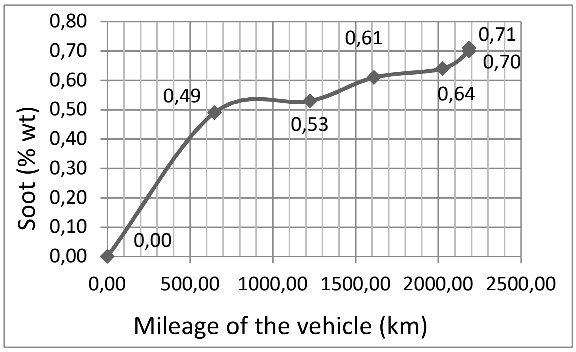


Graph 3 Oxidation process in engine oil
Source: authors.



Graph 4 Course of the TBN parameter in engine oil
Source: authors.

Engine oil maintained a relatively stable base reserve TBN (total base number) during the reporting interval (Graph 4). However, the last measurement showed a significant decrease to 3,5 mg/KOH and a dangerous approach to the permitted minimum value of 3 mg/KOH. This parameter, which affects the corrosivity of lubricating nodes, proved to be the least stable in the oil filling after the 2185 km run-in (as is traditional) and significantly worsened the overall chemical picture of the oil filling.



Graph 5 The course of carbon black content in engine oil
Source: authors.

Regular measurements showed a significantly increasing soot content during the entire operating interval (Graph 5). This phenomenon is given the most attention in this article.

Soot is burned when diesel is burned in diesel engines. Most of the soot leaves the combustion chamber with exhaust gases, but some of them also gets into the engine oil. If an EGR valve is installed in the engine, part of the exhaust gases return to the cylinder, thus increasing the amount of soot that penetrates the engine oil. Soot generated in the engine can cause hard sludge, high lubricant viscosity or oil gelling. The carbon black is made of almost pure carbon, which is hard, has sharp edges and causes blackening of the oil. The limit value for the carbon black concentration in the oil is 3% wt. The large amount of soot in the engine oil not only causes an increase in its viscosity and thus wear of the engine. It can also result in depletion of dispersants. The soot then accumulates into larger dimensions and there is a risk of clogging of the oil filter and failure of the oil supply to the entire system. [8]

Although in tribodiagnostics the maximum value of carbon black content is allowed at the level of up to 3 % wt, the value of 0,71 % wt is very high after only 2185 km. This probably also points to the cleaning effects of the added additives in the fuel, which significantly release carbon deposits in the working space of the engine and subsequently get into the oil charge. The intensive cleaning procedure of the fuel system with the help of cleaning additives in the fuel has, with a certain probability, resulted in a significantly faster degradation of the oil filling than under normal vehicle operating conditions. In practice, the impact of cleaning agents on the quality of the oil should have only a negligible impact, but the measured values show that the new oil filling recorded a very significant increase in soot content and kinematic viscosity during the first 2185 km. The increased carbon black content can be attributed to the cleaning effect of the additives in the diesel, which gets into the oil especially during cold starts. The carbon deposits in the combustion chamber of the engine were dissolved while operating and subsequently entered into the oil charge. The result has just been an increasing concentration of carbon black in the engine oil. The soot in the form of solid particles, due to their thickening effect, also caused a decrease in the fluidity of the oil, i.e. there was a gradual increase in the kinematic viscosity. Figuratively, the comparison that the oil level after the first 2185 km showed results, as in normal circumstances at a range of several times more kilometers, or as a vehicle with a heavily worn engine (the vehicle reached a total start-up of only 55220 km at the end of the measurement - considers with negligible engine wear).

Even after a relatively low mileage, the 13 - year - old engine was characterized by high working space (carbonation), as evidenced by clogged injectors at the beginning of the cleaning treatment, as well as rapid oil degradation during cleaning. The cleaning process in the monitored period was significantly helped by the operation of the vehicle over long distances (in the order of hundreds of kilometers), mainly on highways, where the engine operated for a long time at high speeds and engine operating temperature.

The other monitored oil parameters did not show any special deviations from the standard course of degradation. It is also worth mentioning the water content parameter, which was lower during operation than with the new oil filling, precisely due to the operation of the vehicle, mainly over long distances, where the water evaporated from the oil filling.

However, during the last measurement (after a longer service downtime), a sharp, almost step change in all physicochemical parameters was recorded (Graph 2-5), which also indicates a significant increase in engine oil degradation. In this case, the oil degraded significantly even during a long downtime.

3 CONCLUSION

The tribodiagnostic analysis of the oil level, despite the low start-up (2185 km), provides important information for the vehicle user, especially the fact about the end of the oil level's life in the near future. In previous random sampling of the oil (when no cleaning agents had yet been added to the fuel), the degradation of the engine oil was not as significant as during this cleaning stage. An important factor in the significant degradation of oil was also the time aspect - the age of the oil (20.1.2020 - 22.4.2021).

It follows from the above that the vehicle operator should, as far as possible, pay due attention not only to the fuel system but also to the engine lubrication system. The relative cleanliness of the systems can be ensured mainly by using quality media and regular replacement of filter components. It is also recommended to add additives to the fuel on a regular basis. However, in the case of more intensive cleaning processes (as in this case), it is also necessary to monitor the quality of the engine oil or to change the oil preventively before the vehicle manufacturer prescribes it. In such cases, it is recommended to change the engine oil after starting the vehicle for 5000 km (max. 7000 km), or after a time of max. 2 years.

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