World Tribology Congress 2013
Torino, Italy, September 8 – 13, 2013

Evaluation of oil drain interval for buses in urban traffic with respect to local operating conditions

Zoran Timotijevic[1)*], Slavko Bacevac[1)] and Simona Corsi[2)]

[1)] Petroleum Industry of Serbia, Lubricants Division
Milentija Popovića 1, 11070 Belgrade, Serbia
[2)] Gazpromneft Lubricants Italia S.p.A., Tecnical Department
Via Francesco Benaglia, 13-00153 Roma, Italy
[*]Corresponding author: zoran.timotijevic@nis.eu

1. Introduction

Motor oil quality decreases during exploitation due to of various factors. Since each of these factors has a different effect on oil characteristics, it is understandable that the exact oil drain interval cannot be determined in advance.

The oil drain interval for public transport buses (in most cities) is recommended by the motor manufacturer (OEM). These recommendations are mandatory for the end-users within the motor's warranty period. The recommendations are a result of extensive motor tests, which simultaneously analyses the motor condition and oil condition. However, it is obvious that not all motors operate under the same exploitation conditions. Also, it is important to keep in mind that there are no two motors with the same design characteristics and equal external load. Thus the optimal oil drain interval is specific to concrete exploitation conditions and can be extended beyond the maximum, recommended by the vehicle manufacturer.

2. Objectives

Oil drain interval is determined by motor manufacturer (OEM) and is designed to provide maximum motor protection under a wide variety of conditions. In this study, the motor manufacturer (MAN) has defined the maximum drain interval of **45,000 km**. These recommendations are based on appropriate oil level quality (API CI-4) and the low sulfur fuel (S <10 ppm).

While a majority of equipment owners follow those guidelines, there is a growing trend to extend oil drain interval beyond the OEM recommendations. The recommended oil drain interval can be optimized and extended, if we take into account the specific operating conditions. The key objective of this study is to estimate the optimal oil drain interval for buses in urban traffic with respect to local operating conditions. This goal can be achieved by establishing an appropriate oil analysis program.

3. Experimental work

According to the decision of municipal authorities, public urban transport in Belgrade (Serbia) is organized through a separate public utility service - City Transport Company Belgrade. This company is also responsible for the maintenance of nearly 920 vehicles.

The bus maintenance service and the oil supplier have jointly implemented the project of determining the optimal oil drain interval. The testing program is based on monitoring oil quality during exploitation, fuel quality and basic motor parameters. Oil quality and fuel quality have been assessed based on laboratory analyses of their key features. During the testing process, three-way communication was achieved – among the maintenance service, oil supplier and laboratory.

Diesel motor. The vehicle fleet of the transport company includes several bus types. The majority of buses are articulated type buses, equipped by MAN's diesel motors. At the same time, they are in the service conditions typical for the city of Belgrade (Serbia). The project includes 5 buses, on various transport lines. All buses are equipped with a six-cylinder diesel motor, with the characteristics shown in Table 1.

Table 1 Diesel motor characteristics (Source: OEM)

Model	**MAN D2866 LUH 24**
Number of cylinder	6 (horizontal in-line)
Rated Power	228 kW@1900 rpm
Max. torque	1250 Nm@1300 rpm
Idling speed	500 rpm
Oil fill quantity	33 lit
Emissions category	EURO 3
EGR	External

Driving conditions. The bus lines were so selected to reflect the typical conditions of public transport in Belgrade. This includes the following: geographic terrain configuration, traffic jam, number of traffic lights, circular tours, short relations, heavy loads (number of passengers), low speed, "running in place", stop-go conditions , acceleration, sudden braking, etc. Features of a typical bus line is presented in Table 2.

Table 2 Typical bus line (Source: End-user)*

Length of line	22.710 km
Number of bus stations	35
Number of traffic lights	19
Average speed	20,64 km/h
Fuel consumption	65,22 l/100 km
Number of passengers per day	32.181

** Average values*

Motor oil. All motors are filled with Ultra High Performance Diesel (UHPD) motor oil, SAE 10W-40, recommended and approved by OEM. This oil allows extended oil drain intervals in turbo-charged diesel motors, under heavy duty conditions in different applications.

The oil meets the following specifications: API CI-4/CH-4/CG-4/CF-4; ACEA E4/E7 (2008); MAN M3277; Daimler MB-228.5; VOLVO VDS-3;

Fuel. Following the OEM recommendations, adequate fuel quality was provided: diesel fuel, with sulfur content lower than **10 ppm.** Fuel quality was controlled by end-users during project implementation.

Sampling frequency. Motor oil sampling was conducted in line with the procedures which ensure representative sample. The sampling point was located immediately before the oil filter. Samples were placed in adequate containers and marked with a label which contained the following data: bus number, motor type, total mileage, sampling date, mileage made after the last sampling, oil type and contact person.

Sampling frequency is determined, based on the expected trend in key oil characteristics. Taking into consideration the buses' daily work regime and monthly mileage made, a sampling period of **10,000 km** was established. This sampling period was verified by end-users in previous similar research.

Accredited laboratory. Laboratory analyses of oil samples were conducted within 48 hours after sampling. Having in mind the importance of reliable test results, a laboratory with long experience and high references was included in the project. Of course, it is understood that the laboratory is accredited in accordance with the ISO 17025 standard.

Based on the obtained results, the accredited laboratory issues a Report on Testing which includes three sets of information: a) general information about the tribomechanical system, b) test results in a table format, c) comments about the measured values.

4. Result and discussion

The oil samples were tested according to ASTM standards, in order to evaluate the lubricant composition, remaining service life and level of degradation. Data obtained from laboratory tests were subjected to a double analysis. The first analyses is applies to an individual sample. The second one is applies to many samples and their statistical distribution (trend analysis). In the first case, the results were analyzed against the basic values. Basic values are the original characteristics of zero sample. It is important to point out, that the basic values do not match the data in Product Data Sheet (PDS). In some cases, oil producers change the additives, but do not update PDS promptly. For this reason, an error may occur during the result interpretation. Having that in mind, the basic values are obtained from laboratory tests of fresh oil.

Key Characteristic. During the test implementation, the key features are observed in the function of mileage made. This study implies the Kinematic Viscosity at 100°C, Total Base Number (TBN), Total Acid Number (TAN) and metal particles content as the key indicators of the motor oil condition. Oil color and sediments were visually monitored. Also, oil quantities added in motor during the exploitation test, have been registered.

Limit Values. The limit values are the control points for the measured values. They make possible the criteria for evaluation of oil condition to be implemented in the analysis. The limits are set at two levels - the warning and critical. Warning limits define values that can endanger the performance of the motor. The critical limits indicate the real possibility of reduction in motor performance, and in extreme cases, permanent damage.

The warning and critical limit are defined on bases of OEM recommendations, as well as the long experience of the end-user and oil supplier (statistic processing of previously conducted analyses). During the limit definition process, the impact of the following specific factors was analyzed: a) The age of the motor, b) The driving conditions c) The climate conditions.

Table 3 Limit values (Base Point: Zero Sample)

Characteristic	Test	Warning	Critical
Viscosity, 100°C	ASTM D 445	+ 15%	+ 20%
TAN, mgKOH/g	ASTM D 664	+ 0,8	+ 1,0
TBN, mgKOH/g	ASTM D 2896	- 50%	- 75%
Zinc, Zn	WDXRF *	+10 ppm	+20 ppm
Silicon, Si	WDXRF *	+ 15 ppm	+ 20 ppm
Iron, Fe	WDXRF *	+100 ppm	+120 ppm
Lead, Pb	WDXRF *	+ 30 ppm	+ 50 ppm
Tin, Sn	WDXRF *	+ 10 ppm	+ 15 ppm
Aluminum, Al	WDXRF *	+ 25 ppm	+ 30 ppm
Silver, Ag	WDXRF *	+ 5 ppm	+ 10 ppm

** In-house method*

In this study, limits are defined relative to the value of the zero samples. Table 3. presents the limits, in the expected trend.

Test Results. The data of laboratory analysis are systematized in a unique database. Data are classified according to the sampling date and/or mileage made. This type of data organization allows the long-term trend analysis. In addition, a cross-sectional analysis of two or more characteristics was conducted.

Viscosity at 100 °C. Viscosity analysis was conducted by the standard ASTM D445. The obtained values (cSt), as a function of the mileage made, are presented in Figure 1. Compared to the zero sample, the limit values for Viscosity at 100 °C are equal: Warning Limit -5% ; +15%, Critical Limit -10% ; +20%.

In the initial exploitation phase, a slight decrease in viscosity is evident. This trend is the result of remaining fuel from previous interval. Flash point analyses were carried out in order to determine the quantity of that fuel.

These ad-hoc analyses did not indicate an alarming quantity of fuel nor the need for any additional tests.

In the second exploitation phase, after 20.000 km, a slight increase in viscosity is evident. This increase results from the presence of oil pollutants – soot, solid particles, incomplete combustion residue, oil oxidation products, etc... In most cases, oil pollutants represent high viscosity dispersions.

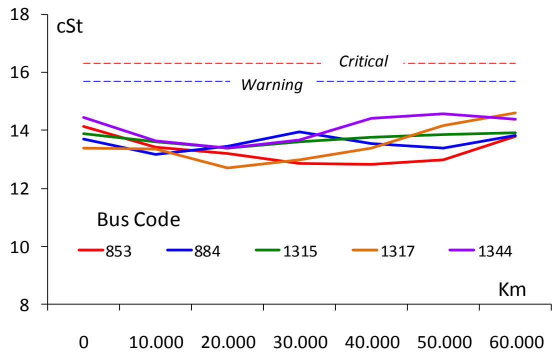

Figure 1 Viscosity at 100 C vs Oil Service Interval

The measured viscosity values are within the range of "normal values". Neither warning nor critical viscosity limits referred to in Table 3. were achieved during the testing process.

Total Base Number. TBN represents the additive alkalinity reserve in motor oil (mg KOH/g). The TBN is generally accepted as an indicator of the oil's ability to neutralize hazardous combustion products in diesel motors. The warning limit is equal to 50% of the value of TBN in the zero samples. (Critical limit: -75%).

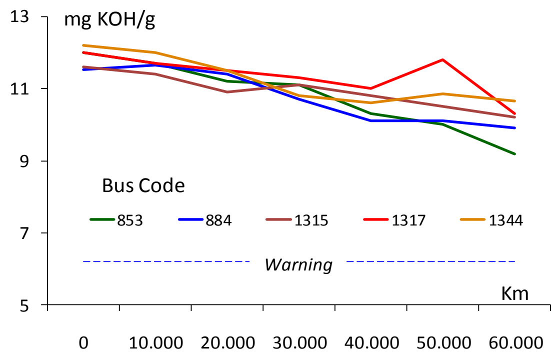

Figure 2 Total Base Number vs Oil Service Interval

TBN analysis was conducted by the ASTM D 2896 standard. The values obtained in terms of mileage made are presented Figure 2. A slight decrease in the TBN is evident during the exploitation process. The fall in the TBN ranges from 15% to 25%, compared to the value of zero sample. Minimal TBN values at the end of the exploitation period remain within the range of allowed limits. A stagnation, or slight increase in the TBN in some motors, is the consequence of refilling small quantities of fresh oil, to compensate for oil losses (leakage, evaporation ...).

Trend analyses, which are based on the extrapolation of obtained values, indicate that the TBN will remain within the allowed limits, even upon the observed exploitation period (**60.000 km**).

Total Acid Number. In the implemented testing program, TAN was observed as the indicator of the motor condition and oil oxidative degradation. This is of high importance, since a sudden increase in the TAN indicates abnormal working conditions (motor overheating, additive package destruction, fuel penetration, presence of sulfur, etc.). In such cases, it is required to stop the testing immediately analyze the cause of the sudden growth.

Data on TAN and TBN are analyzed simultaneously. It is often the case that TBN and TAN graphs' section determines the critical limits of both characteristics. However, this approach was not applied in this study and limits were set based on a statistical analysis of previously conducted tests (Table 3).

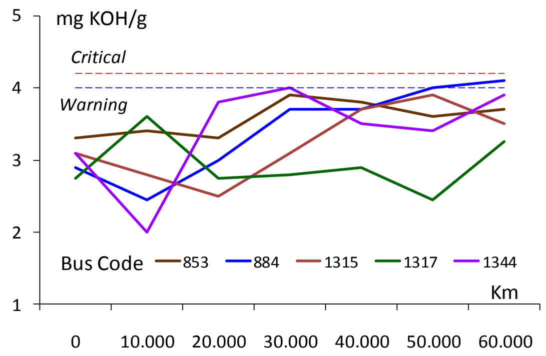

Figure 3 Total Acid Number vs Oil Service Interval

TAN analysis (mg KOH/g) was conducted according to the ASTM D 664 standard. The results are presented in Figure 3. In the initial exploitation phase, a steady level of TAN is evident. After having made 20.000 – 25.000 km, there is a slight increase in the TAN due to the acid products resulting from oil oxidation. The TAN values, achieved at the end of testing, are very close to the critical limit.

Metal particles content. The quantity of metal particles in oil samples is the key parameter for evaluating the motor condition and oil condition. Metal particles occur as the result of motor wear (Fe, Pb, Cu, Cr, Al, Mn, Ag, Sn etc.) and additive depletion (Zn, Fe, Ca, Ba, Mg, S, P, etc.) The rapid increase in the content of metal particles in the oil indicates a serious disturbance in the motor.

Limit values of metal particles are set based on OEM recommendations and statistical results obtained in the previously conducted tests. Over the course of several years, the end-user analyzed the content of metal particles in waste oil during regular motor service. The obtained statistical indicators served for the purpose of setting the metal particles limit. Limit values obtained in such a manner are provided in Table 3.

Identification of the metal particles and their quantity were determined by Wavelength Dispersive X-ray Fluorescence (WDXRF) Spectrometry. The test, according to in-house method, identifies metal elements in oil as microscopic particles, in parts per million (ppm).

During the testing, content of the following metals was analysed: Iron (Fe), Aluminium (Al), Copper (Cu), Magnesium (Mg), Lead (Pb), Tin (Sn) and Silicon (Si).

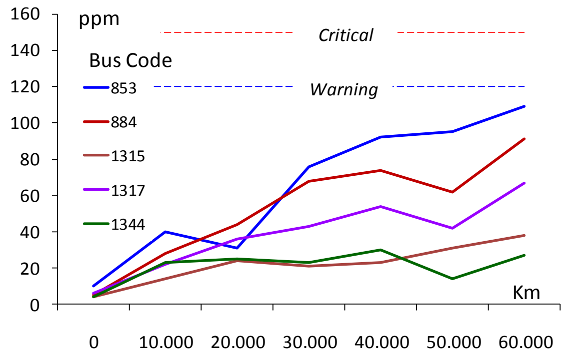

Figure 4 Iron (Fe) Content vs Oil Service Interval

The test results for iron and aluminium are presented in Figure 4. and 5., respectively. Iron particles content indicates steel wear, originating from rings, shafts or cylinder walls. Fe content has a growing trend and it has 109 ppm at the end of end of the exploitation testing. It is significantly below the allowable limits (150 ppm, Table 3) for all vehicles.

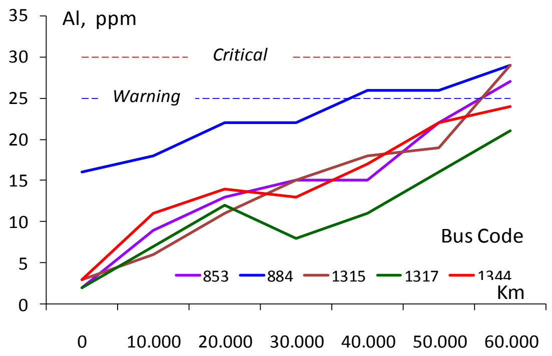

Figure 5 Al - Content vs Oil Service Interval

Content of aluminium indicates the wear of pistons, valves, seals, plain bearings … At the end of the exploitation test, the aluminium particles content approaching critical limits and determines the end of the drain interval (last sampling at 60.000 km).

Refill of fresh oil. The oil level in the motor crankcase was checked during regular daily bus inspections. Possible oil losses, resulting from leakage, combustion or evaporation, were recovered by a refill of fresh oil. The quantity of added oil during the total exploitation period is in the range of 0.4% to 0.5%, compared to the total volume of oil. These quantities are within the acceptable limits, recommended by OEM.

5. Conclusion

It is possible to utilize all lubrication potential of oil to its maximum by determining the optimum of oil drain interval. This Study has shown that specific operating conditions of the motor have the most significant impact. With reference to buses in public transport, the optimum interval may exceed the interval recommended by the OEM even by 30% (**from 45.000 to 60.000 km**).

The conducted research has shown that laboratory analysis of the key oil characteristics can serve as a basis for determining the optimum time for oil change. The achieved effects are reflected in the reduction of the total number of oil replacements and reduced time for motor service. In this way, the availability of public transport buses is increased, leading to higher productivity.

In addition to money savings by reducing the quantity of fresh oil, significant savings of natural resources in urban environments is achieved. Decrease in the quantity of used oil, directly affects the quantity of generated hazardous waste, as well as on the costs for hazardous waste management. If effects of hazardous waste reduction are considered in the long term, this might be the most important benefit.

However, if there is a need to express numerically all savings, which result from this project and similar projects, it is necessary to multiply – oil volumes, oil drain interval, number of kilometers in a month, number of months in a year, number of buses in the city... Finally, all that should be reduced by 30%. It seems that every percentage is very important.

6. References

[1] Jankovic V., Bacevac S., Furman T., “The analysis of biodiesel application in public transport vehicles and other possibilities of application”, Journal of processing and energy in agriculture, 2007, vol. 11, iss. 3, pp. 142-142

[2] Marbach H. W., Frame E. A., “Investigation of Portable Oil Analysis Requirements for Army Application”, Report of U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI), November 1999, San Antonio, Texas

[3] Lee P.M., Priest M., "Influence of gasoline engine lubricant on tribological performance, fuel economy and emissions", IMechE Oxford, 1-12 December 2007, London, pp. 235-246

[4] Sikora G., Miller H., "The analysis of changes in total base number and the flash point in the exploited engine oil", Journal of KONES Powertrain and Transport, Vol. 19, No. 3, 2012

[5] Randles, S.J., “Formulation of Environmentally Acceptable Lubricants”, 49th STLE Annual Meeting, May 1-5, 1998, Pittsburgh.

[6] Strunk, J.W., White E.B., “The elements of style”, 4th ed. New York: Longman 2000.