Serbian Tribology Society

SERBIATRIB '19

16th International Conference on Tribology

Faculty of Engineering University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

RESULTS OF EXPERIMENTAL RESEARCH PHYSICAL-CHEMICAL CHARACTERISTICS OIL FROM ENGINES OF VEHICLES

Sreten PERIC[1*], Radovan RADOVANOVIC[2], Bogdan NEDIC[3], Mihael BUCKO[1]

[1]University of Defence in Belgrade, Military Academy, Belgrade, Serbia, sretenperic@yahoo.com

[2]University of Criminal Investigation and Police Studies, Belgrade, Serbia, radovan.radovanovic@kpu.edu.rs

[3]University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia, nedic@kg.ac.rs

*Corresponding author: sretenperic@yahoo.com

Abstract: *In the study of ways to reduce the friction losses of internal combustion (IC) engines, investigations of losses from elements in the piston assembly, the bearing system, and the valve train system are paramount. Mechanical and thermodynamic losses, wear and the emissions caused by lubricating oil combustion are principally influenced by the tribological behaviour of the piston assembly. The tribological performance of piston rings in reciprocating IC engines can only be fully understood when both lubrication and wear are considered in combination.*

This paper deals with physical-chemical tests that are part of the oil analysis and are used to access the condition of the system. Furthermore, the results of experimental research on the physical-chemical properties of the oil sampled from engines of the vehicles are shown.

Keywords: *engine, engine oil, oil analysis, tribomechanical system, maintenance.*

1. INTRODUCTION

Modern reciprocating internal combustion (IC) engines have to meet today's requirements of lower fuel consumption and very low emissions. To reach these objectives, the trend towards increased specific load and power in engine development assumes greater importance. Smaller and lighter engines will be used increasingly for propulsion systems [1].

It is known that the piston assembly of heavy-duty diesel engines is a significant source of friction. It has been reported that the piston rings account for a significant portion of the total friction losses of an engine [2]. Typical percentages in the literature may vary from 20-30 % [3] up to 50-60 % [4]. Constructive measures such as lowering the tension of piston rings lead to decreased friction losses and wear rates but they also lead to increased oil consumption, emissions, and thermodynamic losses as a result of blow-by [1]. Much theoretical [5-8] and experimental [4, 9-12] work on the piston/cylinder assembly exists in the literature.

Traditional materials and surface treatments may not be adequate to address the issues towards improved reliability, higher performance and reduced oil consumption and emissions [13]. A coating on the piston may offer advantages such as friction reduction and better scuffing resistance and wear protection [14], while reduced clearance due to the coating thickness may improve oil consumption and engine noise.

The tribological conditions within engines as a real tribomechanical system are quite complex and are conditioned to a large extent by the characteristics of used lubricant. Complexities of the conditions are determined by temperature of the elements in contact, current properties of the used lubricant, external load in reference to specific pressures in contact zone, dynamic nature of contact creating.

The piston assembly tribosystem of reciprocating engines is: the cylinder liner, piston and piston rings, lubricating oil, and crankcase air. There are three major sources of engine friction losses: piston rings/cylinder liners, valve train and engine bearing. Among these parts, the cam/tappet contacts, which are the major source of valve train friction, have been thought to operate in both the boundary and elastohydrodynamic regime [15,16].

Lubrication between piston rings and cylinder liner to reduce friction losses is a critical area for improvement [17-19]. Piston, piston rings and cylinder bore are a coupled system with properties governed by the interaction of gases and inertial forces as well as by the lubrication regime (hydrodynamic, mixed, boundary) [20].

The subject of testing in this paper is the experimental determination of property changes of engine oil during operation depending on the dynamic properties of loads.

This part presents the results of testing of physical-chemical properties of engine oil which was sampled from engines of vehicles used in real conditions of exploitation.

Experimental testing of physical-chemical properties included determining: viscosity at 40 and 100°C, determining viscosity index, flash point and TBN (Total base number).

2. EXPERIMENTAL TESTING OF THE PHYSICAL AND CHEMICAL PROPERTIES OF ENGINE OIL

The physical-chemical properties (Table 1) of the engine oil were examined in accordance with standard methods. The analysis was performed using both fresh oil and oil used in the engines of vehicles. Allowed quantities of certain elements in used engine oil and allowed values of deviations in physical-chemical properties of new and used oil are given in Table 2.

Table 1. The tests and standards of tested the physical-chemical properties of oil

Properties	Standards
Kinematic viscosity, mm^2/s	SRPS B.H8.022
Viscosity Index	SRPS B.H8.024
Flash Point (°C)	ISO 2592
Pour Point (°C)	ISO 3016
Water Content, mas.%	ASTM D 95
Total Base Number (TBN), mgKOH/g	ASTM D 2896
Fe Content, %	ASS
Cu Content, %	ASS

Table 2. Allowed values of deviations in physical-chemical properties of oil

Physical-chemical properties of oil and wearing products	Maximum deviation allowed
Viscosity at 40° C (mm^2/s)	20%
Viscosity at 100° C (mm^2/s)	20%
Viscosity index (%)	± 5 %
Total base number (TBN) (mg KOH/g)	decrease to 50%
Flash point (°C)	20 %
Water content (%)	0.2 %
Wear products – Fe content, ppm(μg/g)	100 ppm
Wear products – Cu content, ppm(μg/g)	50 ppm

Table 3. Used engine oil in tested vehicles [21]

Engine oil from engine of A vehicle	
SAE classification	API classification
SAE 15W-40	API SG/CE
Engine oil from engine of B vehicle	
SAE classification	API classification
SAE 30/S3	-

Table 4. Results of zero samples of used engine oil [21]

Physical-chemical characteristic	Type of engine oil	
	SAE 15W-40	SAE 30/S3
Color	3.0	3.0
Density (g/cm^3)	0.88	0.90
Viscosity at 40°C (mm^2/s)	104.8	104.6
Viscosity at 100°C (mm^2/s)	14.1	11.6
Viscosity Index	–	–
Flash Point (°C)	230	240
TBN (mg KOH/g)	10.5	9.8

The results of experimental testing of physical-chemical properties are presented in Table 5. Experimental testing was carried out in accordance with manufacturer specifications and proper standards by using the necessary testing equipment.

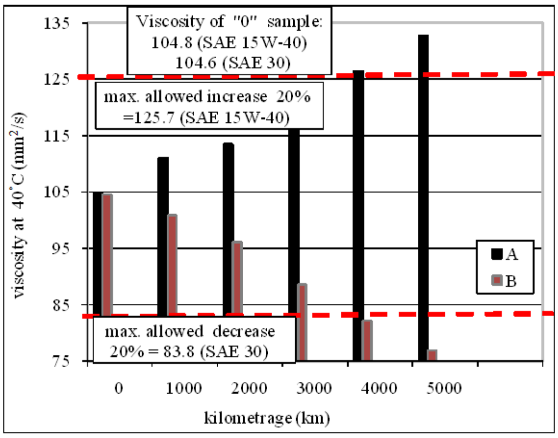

Figure 1. Change of the Viscosity at 40°C [21]

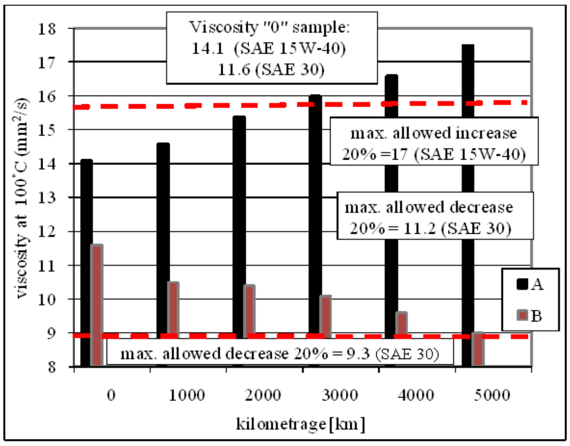

Figure 2. Change of the Viscosity at 100°C [21]

Figure 1 shows viscosity change of the tested oil at 40°C, while Figure 2 – viscosity change at 100°C. An increase in viscosity at 40°C is evident for A vehicle, exceeding the limit of 20%. The decrease in viscosity at 40°C is evident for B vehicle, exceeding the limit of 20%. The increase in viscosity indicates a process of oil oxidation as well or oil contamination with water and dirt, as well as wears products [22]. If a change in the oil viscosity is detected, subsequent analysis of the oil can identify the cause of the disturbance of its properties.

Table 5. Results of testing samples of used engine oil from tested vehicles [21]

Sample		Vehicles A	Vehicles B
Viscosity at 100°C, mm^2/s	0	14.1	11.6
	1	14.6	10.5
	2	15.4	10.4
	3	16.0	10.1
	4	16.6	9.6
	5	17.5	9.0
Viscosity at 40°C, mm^2/s	0	104.8	104.6
	1	111	100.9
	2	113.5	96.1
	3	119.4	88.6
	4	126.4	82.2
	5	132.7	76.9
Viscosiy Index	0	135	100
	1	129	97
	2	122	95
	3	119	91
	4	116	87
	5	112	84
Flash Point, °C	0	230	240
	1	220	193
	2	208	177
	3	205	159
	4	197	143
	5	192	128
TBN, mgKOH/g	0	10.5	9.8
	1	9.1	9.4
	2	7.2	8.4
	3	6.5	7.8
	4	6.1	6.6
	5	5.2	6.2
Fe Content (ppm)	1	98.4	17.9
	2	123	40.9
	3	137	86.7
	4	149	132
	5	165	261
Cu Content (ppm)	1	4.9	3.3
	2	5.9	3.8
	3	6.7	6
	4	7.3	8.1
	5	7.9	9.7

The viscosity index is an empirical number which shows how the viscosity of some oils changes by increasing or decreasing the temperature. High viscosity index shows relatively small tendency of viscosity to change upon influence of certain temperature, as oppose of low viscosity index which shows greater viscosity change with temperature. Change of engine oil viscosity index is shown in the Fig. 3. A decrease in the viscosity index oil is evident for both vehicles, exceeding the limit of 5%.

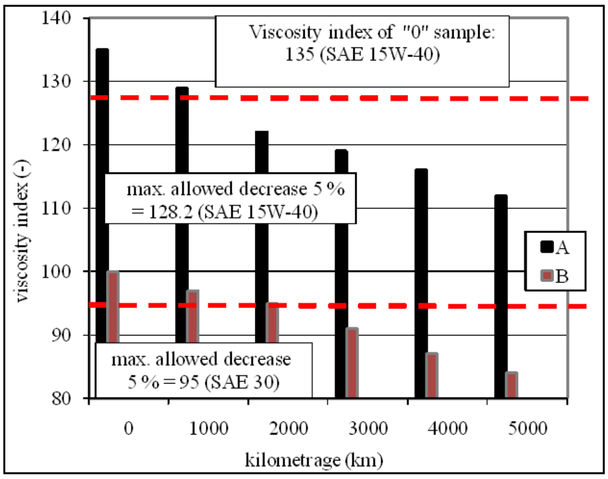

Figure 3. Change of viscosity index [21]

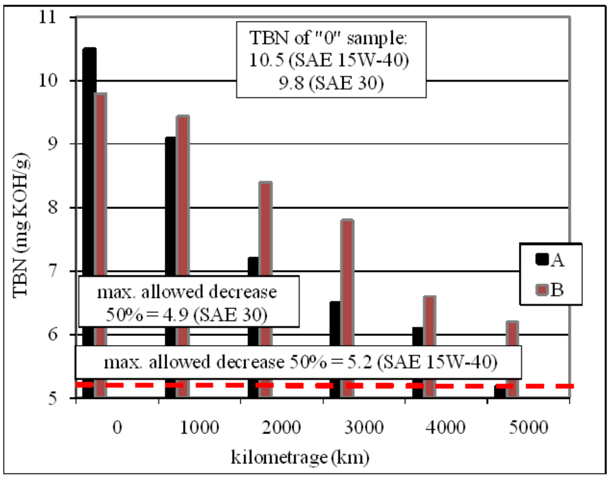

Figure 4. Change of TBN [21]

Total base number is a measure of reserve alkaline additives put into lubricants to neutralize acids, to retard oxidation and corrosion, enhance lubricity, improve viscosity characteristic and reduce the tendency of sludge buildup. TBN is measure of the lubricant alkaline reserve, and mostly is applied to engine lubricants. Combustion acids attack TBN, e.g. sulphuric acid, decreasing as it consumes. Figure 4 shows the change of TBN for engine oils. A decrease of TBN is evident for both vehicles. Up to 5000 km TBN value does not exceed the allowed limit, except for A vehicle.

The flash point is the lowest temperature at which a vapor above a liquid will ignite when a flame is applied under standard conditions. In engine oil, decreases in flash point are usually due to distillate fuel dilution but may also in extreme conditions be a symptom of thermal cracking of the oil. Contamination by residual fuel may not appreciably depress the flash point but can, if the flash point of the fuel is naturally low.

Figure 5 presents the change of flash point for engine oils. A decrease in the flash point is noticeable, and by the end of testing exceeds the allowed limits (20%, Table 2) for B vehicle.

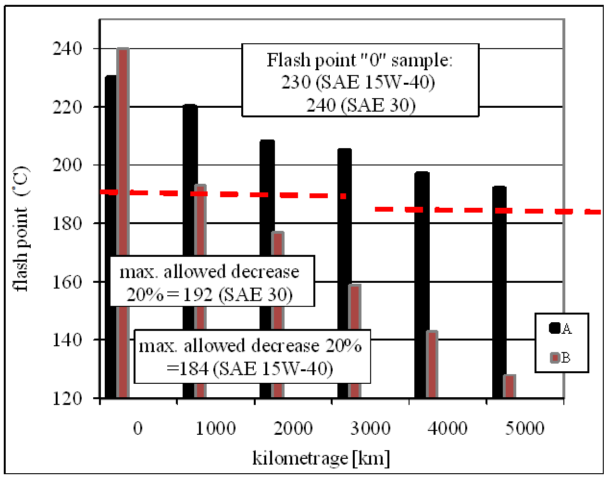

Figure 5. Change of the flash point [21]

An analysis of the metals content of the oil is very important. Metals particles are abrasive, and act as catalysts in the oxidation of oils. In engine oil, the origin of these metals may be from additives, wear, fuel, air and liquid for cooling. Metals from the additives can be Zn, Ca, Ba, or Mg and that indicates the change of additives. Metals originating from wear are: Fe, Pb, Cu, Cr, Al, Mn, Ag, Sn, and they point to the increased wear in these systems. Elements originating from the liquid for cooling are Na and B, and their increased content indicates the penetration of cooling liquid in the lubricant. The increased content of Si or Ca, which are from the air, points to the malfunction of the air filter. Metals such as iron (Fe) and copper

(Cu) were selected for identification because they are typical elements contained in the examined engines. On the basis of changes in their concentration in the oil charge it can be determined their origin from engine elements and the degree of wear.

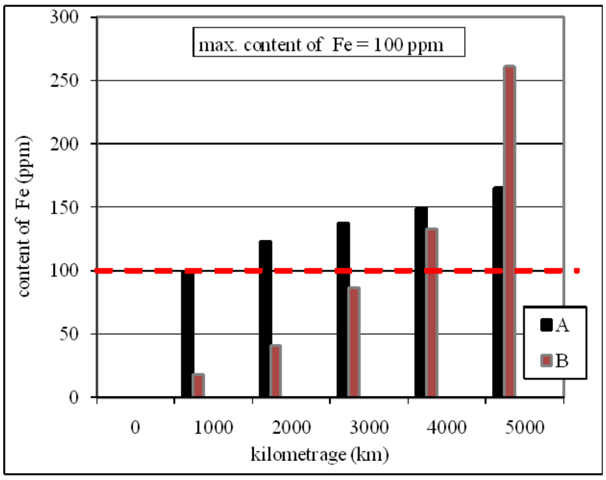

Figure 6. Change of Fe content [21]

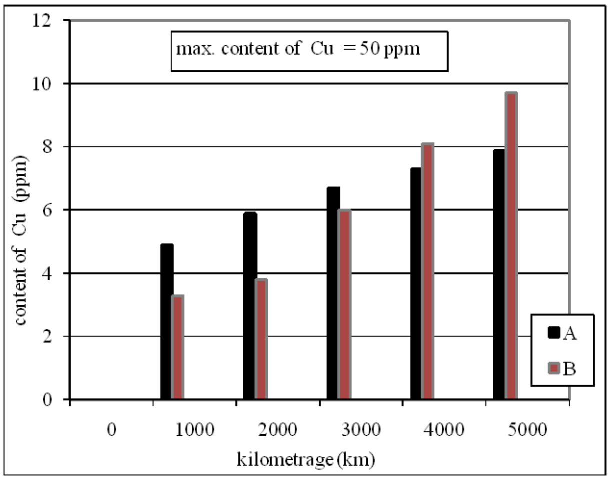

Figure 7. Change of Cu content [21]

The iron and copper content (Figs 6 and 7), because of wear in the oil contents increased progressively throughout. The content of iron is significantly above the allowable limits (100 ppm, Table 2) for A and B vehicles. However, the content of cooper is significantly below the allowable limits (50 ppm, Table 2) for A and B vehicles.

3. CONCLUSION

The engine lubricating oil ageing process is a very complex process during which degradation of the base oil and depletion of its additives take place simultaneously. Oxidative high temperature degradation and contamination by water, ethylene glycol, fuel, soot, and wear metals are the main factors.

By appropriate sampling and testing during exploitation, based on the model presented it is possible to identify the state of system elements and predict its future behaviour in exploitation. The conditions in which the engine elements are found as real tribomechanical system are complex and are determined to a large extent by oil properties. The complexity of the conditions is determined by temperature of elements in contact oil, temperature and properties, external load, that is the specific pressure in the contact zone, the dynamic character of contact.

Results obtained during the tests contain information about physical-chemical properties and products wear.

Based on the experimental investigation and presented results the following conclusions can be summarized:

1. During exploitation, the analysed oil has achieved its primary function and meets the intended replacement interval, which was determined by analysis of characteristic physical-chemical properties, concentration of wear products and tribological properties.
2. The changes in the physical-chemical and tribological properties of the lubricating oil from the vehicle engine are directly dependent on the functional characteristics of all the elements of the tribomechanical system.
3. Testing of physical-chemical and tribological properties of oil in the function of determining the state of engine as a complex tribomechanical system aims to identify mechanisms of change in the system elements.
4. Variation in the oil viscosity is often the first indicator of a global problem of the engine tribomechanical systems. When the oil loses its antioxygenic stability, the oil viscosity increases, and if measures are not taken in due time, this causes the

disturbance of the normal operation of the tribomechanical systems.

5. Metal particles, physical-chemical processes and contaminants, detected through laboratory analysis, is the appropriate base to identify possible disfunctionalities in tribomechanical systems, as well as to determine the life of usage of oil and its functionality in oil systems.
6. Metal particles in oil, regardless of their structure and origin, are a basic cause of tribological degradation process, and on the other side they present a clear indicator of the tribological process intensity and characteristics.
7. The appearance of water in the samples is not found. Water in oil is the main cause for appearance of corrosive processes on the contact surfaces.

REFERENCES

[1] R. Golloch, G. P. Merker, U. Kessen, S. Brinkmann: Functional Properties of Microstructured Cylinder Liner Surfaces for Internal Combustion Engines, Tribotest journal, Vol. 11, No. 4, pp. 307-324, 2005.

[2] N. G. Demas, R. A. Erck, G. R. Fenske: Tribological evaluation of piston skirt/cylinder liner contact interfaces under boundary lubrication conditions, Lubrication Science, Vol. 22, No. 3, pp. 73-87, 2010.

[3] T. Rabute, T. Tian: Challenges involved in piston top ring designs for modern SI engines, Journal of Engineering for Gas Turbines and Power, Vol. 123, No. 2, pp. 448-459, 2001.

[4] G. Ryk, Y. Kligerman, I. Etsion: Experimental investigation of laser surface texturing for reciprocating automotive components, Tribology Transactions, Vol. 45, No. 4, pp. 444-449, 2002.

[5] M. Priest, D. Dowson, M.C. Taylor: Predictive wear modeling of lubricated piston rings in a diesel engine, Wear, Vol. 231, No. 1, pp. 89-101, 1999.

[6] Y. Hu, H.S. Cheng, T. Arai, Y. Kobayashi, S. Aoyama: Numerical Simulation of Piston Ring in Mixed Lubrication – A Nonaxsymmetrical Analysis, Journal of Tribology, Vol. 116, pp. 470-478, 1994.

[7] T. Tian, I. B. Noordzij, V. W. Wong, J. B. Heywood: Modeling Piston-Ring Dynamics, Blowby, and Ring-Twist Effects, Journal of Engineering for Gas Turbines and Power, Vol. 120, No. 4, pp. 843-854, 1998.

[8] O. Akalin, G. M. Newaz: Piston ring-cylinder bore friction modeling in mixed lubrication regime: Part I – analytical results, Journal of Tribology, Vol. 123, pp. 211-218, 2001.

[9] Y. Wang, S. C. Tung: Scuffing and wear behavior of aluminum piston skirt coatings against aluminum cylinder bore, Wear, Vol. 225-229, part 2, pp. 1100-1108, 1999.

[10] Y. Wang, K. Brogan, S. C. Tung: Wear and scuffing characteristics of composite polymer and nickel/ceramic composite coated piston skirts against aluminum and cast iron cylinder bores, Wear, Vol. 250, pp. 706-717, 2001.

[11] J. J. Truhan, J. Gu, P. J. Blau: The effect of lubricating oil condition on the friction and wear of piston ring and cylinder liner materials in a reciprocating bench test, Wear, Vol. 259, No. 7-12, pp. 1048-1055, 2005.

[12] V. D. N. Rao, D. M. Kabat, D. Yeager, B. Lizotte: Engine studies of solid film lubricant coated pistons, SAE Transactions, Vol. 106, No. 3, pp. 20-33, 1997.

[13] R. Gahlin, M. Larsson, P. Hedenqvist: Me-C: H coatings in motor vehicles, Wear, Vol. 249, No. 3-4, pp. 302-309, 2001.

[14] C. Friedrich, G. Berg, E. Broszeit, E. Rick, J. Holland: PVD Cr_xN coatings for tribological application on piston rings, Surface & Coatings Technology, Vol. 123, pp. 211-218, 2001.

[15] M. Takiguchi, K. Machida, S. Furuhama: Piston friction force of a small high speed gasoline engine, Journal of Tribology, ASME, Vol. 110, No. 1, pp. 112-118, 1988.

[16] R. G. Kapadia, C. H. Bovington, I. lee-Prudhoe: A tribological investigation of lubricant effects on bearing friction and fuel economy for passenger car engines and heavy duty diesel engines, Lubrication Science, Vol. 19, No 1, pp. 11-23, 2007.

[17] A. Ruggiero, A. Senatore: On the role of the engine tribology in the reduction of noise and emissions, in: *Proceedings of the 8th Int. Conference on Urban Transport and the Environment in the 21st Century*, Seville, Spain, (2002).

[18] S. Cho, S. Choi, C. Bae: Frictional modes of barrel shaped piston rings under flooded lubrication, Tribology International, Vol. 33, No 8, pp. 545-551, 2000.

[19] V. D'agostino, D. Guida, A. Ruggiero, A. Senatore: A four stroke engine friction model, in: *Proceedings Aimeta Int. Tribology Conference*, AITC, L'Aquila, Italy, 2000.

[20] V. D'agostino, S. Della Valle, A. Ruggiero, A. Senatore: On the Effective Length of the Top Piston Ring Involved in Hydrodynamic lubrication, Lubrication Science, Vol. 17, No. 3, pp. 309-318, 2005.

[21] S. Peric: *The development of a method of diagnosis the condition from the aspect of physical-chemical and tribological characteristics of lubricating oils of vehicles*, PhD thesis, University of Defence in Belgrade, Belgrade, Serbia, 2009.

[22] A. Takeuchi: Investigation on lubrication condition of piston pin in real engine block with ultrasonic technique, Lubrication Science, Vol. 23, No. 7, pp. 331-346, 2011.