ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 63 2 Number 1, 2015

http://dx.doi.org/10.11118/actaun201563010015

MONITORING OF AGRICULTURAL MACHINES WITH USED ENGINE OIL ANALYSIS

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Abstract

BEKANA DANIEL, ANTONIEV ANTONI, ZACH MARTIN, MAREČEK JAN. 2015. Monitoring of Agricultural Machines with Used Engine Oil Analysis. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 63(1): 15–22.

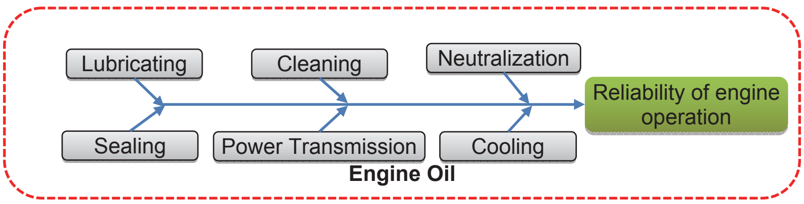
Predictive maintenance has gained wide acceptance as a cost cutting strategy and improve maintenance in modern industry. Condition monitoring by lubricant analysis is one of the basic tools of a predictive maintenance program along with vibration monitoring, performance monitoring and thermography. In many cases, it enables identification of a potential problem before a major repair is necessary and downtime during critical operations can be avoided.
In this paper we analyzed the used motor oil and its remaining resource in agricultural machines.

Keywords: oil analysis, failure, TBN, viscosity, maintenance, agricultural machinery

INTRODUCTION

In dynamic developing economy, companies which produce agricultural machinery try to be competitive in the market by improving the quality of their product so that they can reply to the need of the farmers. While designing these machines it is nursery to pay attention to the lubricants that are necessary to lubricate the friction connections. Engine oil is a multi-functional element and is responsible for a number of tasks and is intended to fulfil a range of complex duties, Fig. 1. It provides lubrication in order not only to reduce friction and thus prevent wear, it provides cooling in order to support the thermal control of the engine, it must seal moving parts, it has to maintain engine cleanliness to ensure freedom of movement of the engine parts and protect against corrosion by neutralising acid components and prevent the formation of these components (SAE J 357, 2006), (Enchev Ev. & T. Delikostov, 2013; Sascha R. 2011).

An example of this machine parts are the engines of tractors or combines. Condition monitoring of this machines is a key to their trouble-free operation and extend their useful life. Lubrication analysis is one of the methods for condition monitoring of machines. The quality of lubricants insures the reliability of machines by reducing the wear rate of machines. Used lubricants carry information about the condition of machines. Used lubricants



1: *Main functions of engine oil (Sascha R., 2011)* analysis is one of the methods for condition monitoring. Condition based maintenance can be achieved using results from condition monitoring which can be lubricants analysis. It can detect wear products and the general condition of internal combustion engine, gearboxes and other friction connections. Intervals of monitoring repair or replacement of agricultural machines can determine easily.

The aim of this research is to analyze the condition of used lubricants from agricultural machines that are utilized in the condition of Bulgarian agriculture.

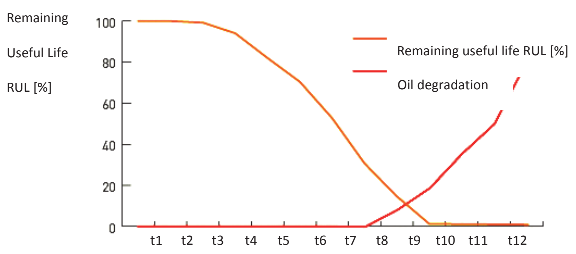
Used Oil Analysis

During exploitation of machines lubricants degrade, because of wear particles contamination, contaminants like coolants (ethylene glycol), high temperature, oxidation and etc. Exhaust gases from burning proses also have a serious effect on used lubricants (engine oil). For example worn out cylinders and piston rings is one of the reasons for contamination which decreases the quality of lubrication. All these factors lead to degradation of lubricants additives and decrease the quality of used lubrication oils Fig. 2.

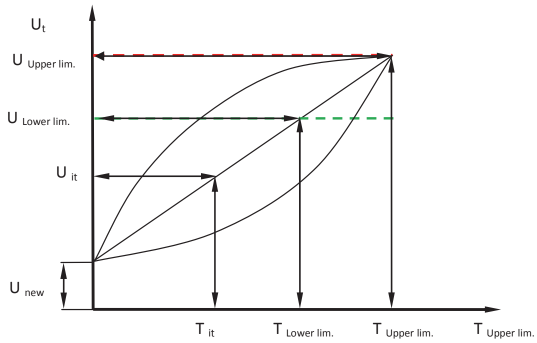
It is obvious that the process of oxidation of lubricants increases slightly until it reaches full exhaustion of additives. At this stage the speed of oxidation gets drastically high. At this stage failure probability gets very high. This event should not happen in agricultural machines exploitation. That's why condition monitoring should be applied in order to avoid sudden (unexpected) failure to occur. One way of condition monitoring for internal combustion engine is monitoring the condition of engine oil, (Roy M. *et al.*, 2010; Jana Andertová *et al.*, 2007; Kangalov P., 2013; Majdan R., Tkáč Z. & Kangalov P., 2013).

In this research used engine oil was analyzed depending on the engine hours in order to determine the condition of the engine and the remaining useful life of the oil. Samples are taken from tractors that are 5 years old or less. The engine oil corresponds to the specification of the tractor producer.

To determine the interval of oil change – Tm.cm, [M. hr.] – motor hours it is necessary to use appropriate extrapolation method that is



2: *Relation between the stability of the oxidation, the lubricant additives and the age of the lubri-cant How (Oil Degrade, 2012)*



3: *Diagram for determining Remaining Useful Life of used engine oil: (Antony A., 2015)*

a realization of certain operation Fig. 3 which according to (Miroshnikov L. V., Bildin A. P. & Pal V. I., 1977) which can give one of the accurate and reliable results for a given condition. Its essence is expressed in the resolution on (Tm.cm. load) function approximating the monitored parameter Ut of the initial value U_H to the limit value U Upper. lim. Based on approximating function can determine the full resource for the controlled indicator (monitored parameter) of used engine oil, provided that $U_t = U_{Upper.\ lim}$. Provided that the diagnosis related to the definition of an integrated diagnostic indicator of used engine oil or the relevant part quality parameter with a certain periodicity $T_{m.cm.i}$, the remaining resource $T_{m.cm.ocm}$ compared with $T_{m.cm.i}$ and concludes suitability of oil at $T_{m.cm.ocm} > T_{m.cm.i}$ or the need to replace the oil provided that $T_{m.cm.ocm} < T_{m.cm.i.}$ Forecasting can be simplified by replacing U Upper. lim with its permissible value-ness by providing growth diagnostic parameter for the period $T_{m.cm.i}$ to T lower lim.

Forecasting on the realization is accepted that the variation of monitored parameters of the relevant quality indicator is characterized by extrapolation function and mean square deviation of the actual modification of the relevant parameter. Extrapolation function is determined by the parameter modification status of the parameter in the past. Any modification of the parameter corresponds to a certain limit and residual resource (RUL) of oil for one of the indicators whose intensity variation is greatest. According to (Miroshnikov L. V., Bildin A. P. & Pal V. I., 1977), (Mitev Iv., 2002) and others, forecasting realization gives more technical and economic effect than the average statistical forecasting. This is achieved at the expense of the greater reduction of the variance of parameters variation of the controlled property, since the forecast instead of mathematical expectation amending the random function used its realization.

Forecasting a realization using the same approximating function, $U_t = U_H + VT^\alpha + Z$ and an average statistical prediction, (Miroshnikov L. V., Bildin A. P. & Pal V. I., 1977).

Rate of change of state V is determined by the parameter modification status of each controlled oil properties, taking into account the load at the time of diagnosis.

In order to determine the remaining lifetime of the parameter with respect to Tm.cm.ocm it is necessary to have a degree of output information consisting the following points:

1) Initial value of the monitored parameter for the given item;
2) Initial load of production exploitation of used engine oil at the monitoring point diagnosis;
3) the size of the parameter of state at the time of diagnosis Uit, which is reported by the used diagnostic tools;
4) Upper limit inadmissible parameter values of state;
5) the exponent of approximating functions of state parameter variation.

The results obtained in the process of survey and post-swarming dependencies was found that after they have approximated the same monotonously decreasing or monotonously increasing character. Typically, as in the integral monitoring parameter for controlling quality indicators correspond to linier characteristics. Based on the graphics and linier character, exponent α will be equal to 1. In this case approximated function shown above looks like the following formula:

$$U(t_m) = U_H + VT_{m.cm.omp}.$$

As it can be seen from the scheme shown in Fig. 3 threshold value of the monitored parameter condition for the corresponding diagnostic parameter in the most general case it can express the equation:

$$U_{upperlim.} = U_H + VT_{upperlim}.$$

Based on equation above we determine the rate of change of the monitored parameter, where in:

$$V = \frac{U(t) - U_H}{T_{m.cm.omp}}.$$

By replacing V in one of the above equation $U_{upper\ lim}$ is calculated.

$$U_{upperlim} = U_H + (U(t) - U_H)\frac{T_{upperlim}}{T_m}.$$

After transforming the above equation, $T_{upper\ lim.}$ is calculated:

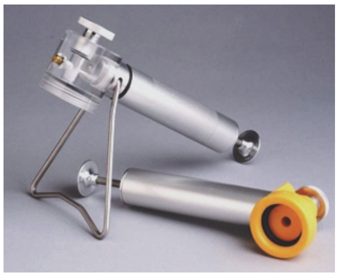
$$T_{upperlim.} = \frac{U_{upperlim.} - U_H}{U_{m.cm} - U_H}T_m.$$

If U_H is equal to zero, $T_{upper\ lim.}$ will have the following equation:

$$T_{upperlim.} = \frac{U_{upperlim.}}{U_{tm}}T_m.$$

This means that it is possible to determine the remaining useful life of used oil from the graphs that are determined from the experimental results of used engine oil.

4: *Lab oil sample containers*



5: *Vacuum pump for oil samples*

The samples are taken in a specific way so that the results from analysis will be authentic. Before tacking the sample the engine must be warm and the oil well mixed. Taking the oil sample is carried out by a vacuum pump Fig. 5 and placed in chemically clean container Fig. 4. These requirements were strictly followed in obtaining samples.

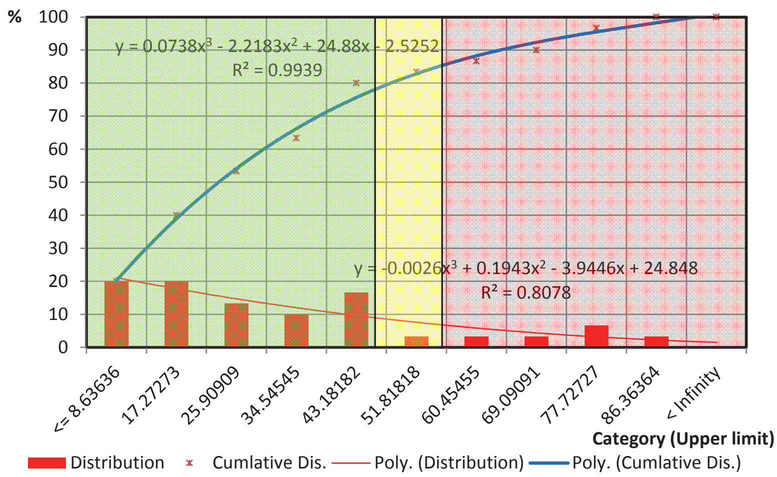
Each sample was labeled so that the data of the machine and type of oil can be identified.

Laboratory samples were processed with several laboratory analyses. Significant results were achieved with the following experiments. First, determining the **general condition of used oil** with SKF Oil Check TMEH1. This instrument measures dielectric constant of the oil. By comparing the values of new and used oil can determine the rate of change of the **dielectric constant** of the used oil. The temperature of the sample must not be higher than 40 ° C. Display of the unit are from 0 to 100, with values from 0–50 correspond to the green sector, the values of 50–60 respectively yellow and the 60–100 red sector. These measurements are comparative, the new oil is taken as standard and the equipment is restated (taken as zero). Depending on the position which the sample takes, three situations are detected, they are:

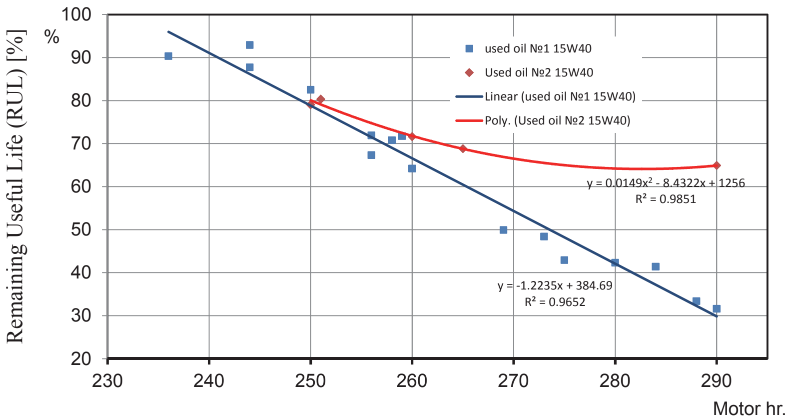
1) The sample is good (green);
2) The oil must be changed in the near future (yellow);
3) The oil must be changed immediately(red);

The results from the measurements are presented in Figs. 5 and 6.

Samples taken from oil type 1 are generally in good condition 0 to 40 units (green sector) Fig. 6 and Fig. 7. This mines they have significant remaining useful life.



6: *Statistical law of distribution of dielectric property of used oil measured with SKF Oil Check TMEH1: 0–50 correspond to the green sector, the values of 50–60 respectively yellow and the 60–100 red sector*

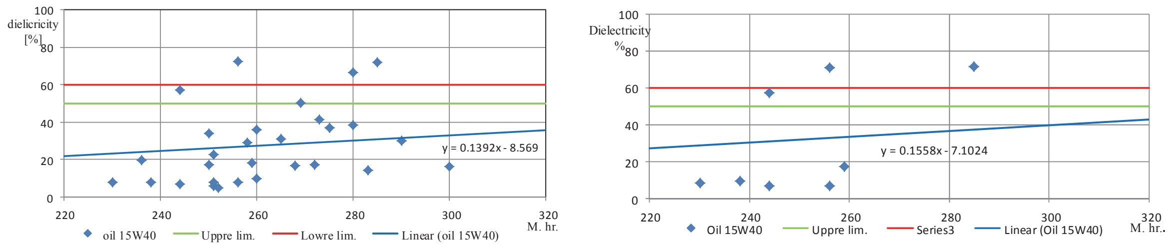


7: *Condition of the used oil*

It was found that agricultural machinery leading factors in monitoring changes in the basic quality indicators of used engine oil are: sulphur content of fuel, load of the engines (velocity and load of machines), their design features and etc. As one of the essential factors influencing the resource of used engine oil and interval of oil change is the ratio between the volume of crankcase volume and the engine power. In this regard, based on the technical characteristics of the tractors analysis were made amending the ratio between regulated quantity of oil to boot from the manufacturer and the power of the corresponding tractor. Based on the **ratio of the quantity of oil in the crankcase to the engine power is defined as coefficient** K_{cm}. After some calculations based on dates from observed tractors, this ratio varies in the range of 0.10 to 0.22, on this basis the corresponding tractors are divided into three groups Tab. I.

I: *Value of K_{cm} used for the research*

Machine type	K_{cm},	Group I	Group II	Group III
	K_{cm} = L/kW	$K_{cm} \geq 0.10$	$K_{cm} \geq 0.12$	$K_{cm} \geq 0.14$
JD 8R	0.122		X	
JD 6030	0.196			X
Case Magnum	0.092	X		
Case Puma	0.096	X		
Case Maxxum	0.182			X
Case JXU	0.128		X	
Case 2388	0.1	X		



(a) (b)

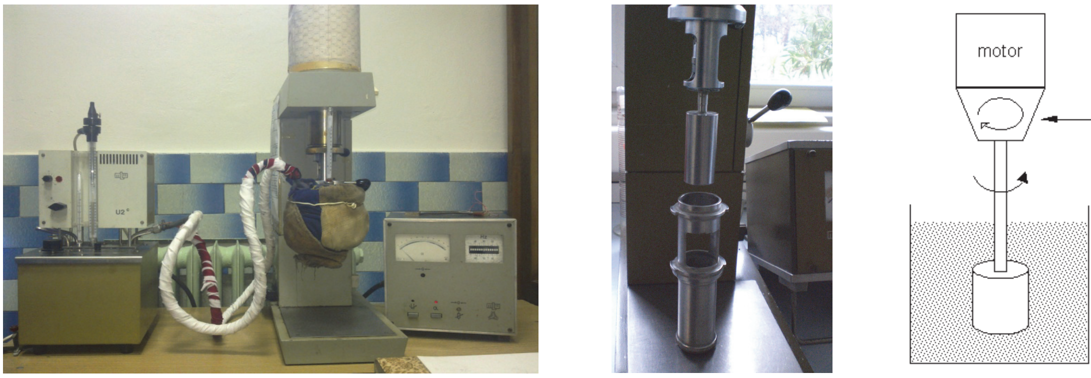
8: *Change of dielectric property of used engine oil for tractors with: a) For all tractors; b) for tractors with 0,12 > K_{cm} ≥ 0,10 in relation with load in Motor hours (M. hr.)*

II: *Determining the remaining lifetime in terms of the dielectric conductivity and coefficient K_{cm} depending on the operating conditions at engine operation load 320 Motor hr.*

No.	Indicator	Engine operation Load			K_{cm}		
		1 group	2 group	3 group	1 group	2 group	3 group
1	Realized resource	42.329	24.918	22.829	42.7536	34.1044	29.9208
2	Rate of change of dielectric pr. % per Mhr.	0.132	0.0779	0.071	0.071343	0.106576	0.093503
3	Realized resource recurs in % for $U_{up.\,lim}$.	70.548	41.529	38.050	71.256	56.84067	49.868
4	Realized resource recurs in % for $U_{low.\,lim}$.	84.658	49.835	45.660	85.5072	68.2088	59.8416
5	Remaining resource $U_{up.\,lim}$.	17.671	35.082	37.170	17.2464	25.8956	30.0792
6	Remaining resource $U_{low.\,lim}$.	7.671	25.082	27.170	7.2464	15.8956	20.0792
7	Remaining resource $U_{up.\,lim}$.	29.452	58.471	61.9503	28.744	43.15933	50.132
8	Remaining resource $U_{low.\,lim}$.	15.342	50.164	54.340	14.4928	31.7912	40.1584
9	Remaining resource $U_{up.\,lim}$.	94.245	187.106	198.241	91.9808	138.1099	160.4224
10	Remaining resource $U_{low.\,lim}$.	49.094	160.527	173.889	46.37696	101.7318	128.5069

The column K_{cm} ≥ 0.10 fall in most machines. This is characterized by that work under heavy load and carries out operations such as plowing, disc cultivation and harvesting. The power from the engine is in the range of 210–330 hp. and the oil in the crankcase 15–25 L.

Based on the presented graphs (Fig. 8) for the different groups in terms of the ratio of the volume of the crankcase of the engine to its power is observed that there is a slight increase in the dielectric conductivity of the oil with increase of the daily load as its change is characterized with different variation of intensity. The pattern of change in dielectric conductivity as a function of load and is analogous to that of dependencies relating to the various groups according to the degree of the load (Tab. II). In tractors with 0.12 > K_{cm} ≥ 0.10 intensity of change of dielectric properties is greatest, such as consumed and residual resource in absolute values differ slightly from those tractors performing energy absorbing operations (heavy load). The remaining two groups where K_{cm}. 2 varies in the range 0.14 > K_{cm} ≥ 0.12 and respectively 0.22 > K_{cm} ≥ 0.14 used resource is 15 and 21% smaller than the first set, between the second and third group difference is 7%. For example, the intensity of change in dielectric conductivity of oil in tractor loaded 320 motor hr. where K_{cm} 1 is 0.12 > K_{cm} ≥ 0.10 against those with coefficient K_{cm} 2 varing in the range of 0.14 > K_{cm} ≥ 0.12 is 20.23%, higher, compared to the coefficient K_{cm} 3 located in the range 0.22 > K_{cm} ≥ 0.14 is 30.01%. The difference between the intensity of change of the controlled parameter in tractors K_{cm}.2 to K_{cm}.3 is 12.26%. Ten percent of the entire set of observations of the used oils have passed the limit of the controllable parameter that is monitored for tractors that have been on major operations, as well as in K_{cm}.1 and have a duration of more load greater than reglamented by the manufacturer (250 M. hr) Fig. 8. The remaining 90% used engine oils are changed in the presence of different remaining resource, which is between oil changing interval 320 M. hr. remaining resource regarding the given limit of the dielectric conductivity respectively tractors relating to the first, second and third group K_{cm}. is 17.24, 25.89 and 30.07. From the above it can be seen that there is a pattern that characterize the monitoring indicator that can be regarded as dielectric properties of the used engine oils in terms of both the extent of the load also in terms of K_{cm}. Typical for K_{cm}.$_2$ and K_{cm3} is intensity of change of dielectric properties compared to group 2 and 3 are related to the degree of the load. This allows us to conclude that in determining the oil changing interval, it is necessary to have a diferentiated approached not only varied according to the load and operation speed of the machines, but in any case it is necessary to take into account their structural features.



A B C

9: *Rotational viscometer RHEOTEST 2 with thermostat*

Three samples are in the yellow sector and it is necessary to change engine oil. Only one sample is in the red sector, compared to the other samples the engine has performed twice as much as the other engines. The condition of the sample is worst and the oil must be changed immediately. All samples from oil type 2 are in good condition and can be used certain time.

The measurements taken by SKF Oil Check TMEH1 are generalized that uses permittivity property of the used oil. It is necessary to investigate which of the oils characteristics (properties) have degraded? Dynamic viscosity is one of the properties of lubricants that can be tested. For this purpose rotational viscometer REOTEST 2 with thermostat was used Fig. 9.

The dual system Rotation Viscometer is a proved and reliable instrument for the investigation of the flow characteristics of used engine oil. REOTEST 2 proves exact measuring values of the rheological characteristics of both Newtonian and non-newtonian liquids. It determines the dynamic viscosity, ascertains the structural viscosity and dilatancy, and measures the plasticity, and surveys the thixotropic and rheopexy. In the production of exact hysteresis curves in practical rheology, the instrument will produce accurate and reliable results from the first series of measurements.

REOTEST 2 can perform measurements of dynamic viscosity in wide diapasons. The rotational viscometer method with coaxial cylinders (Fig. 9c) is mostly used in rheological measurements (Roy M. Mortier & Malcolm F. Fox Stefan T. Orszulik). The cylinder is propelled by 12 level velocity DC electrical motor with two positions so that 24 velocities are obtained which corresponding to the shear moment of the particular fluid.

It is obvious that the viscosity of fluids depends on their temperature and the measurements should be performed with fixed temperature. For this purpose the coaxial cylinder with measuring fluid is placed in a closed vessel for tempering, which circulates through thermostat for fixing the temperature. Depending on the working temperature different fluids are used Tab. III.

III: *The working temperature different fluids*

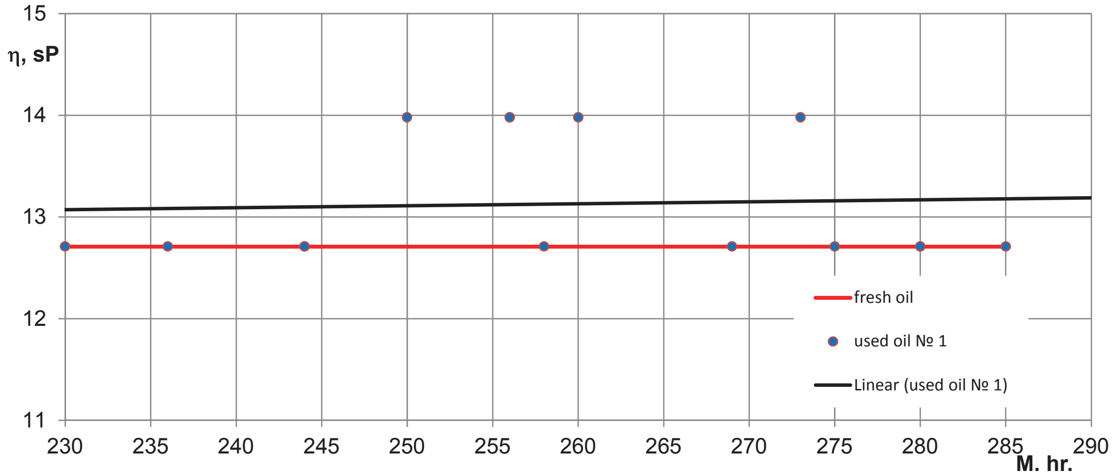
Temperature t°	Tempering fluid
1 – °C	Distilled water
80–160 °C	Glycerin
-60–30 °C	Ethyl or Methyl alcohol

Dynamic viscosities of the used oil samples are determined at 100 °C temperature of glycerin, which is used for fixing the temperature regime. Each measurement was taken after 20 to 30 minutes of tempering the sample. Results are given in Figs. 10 and 11.

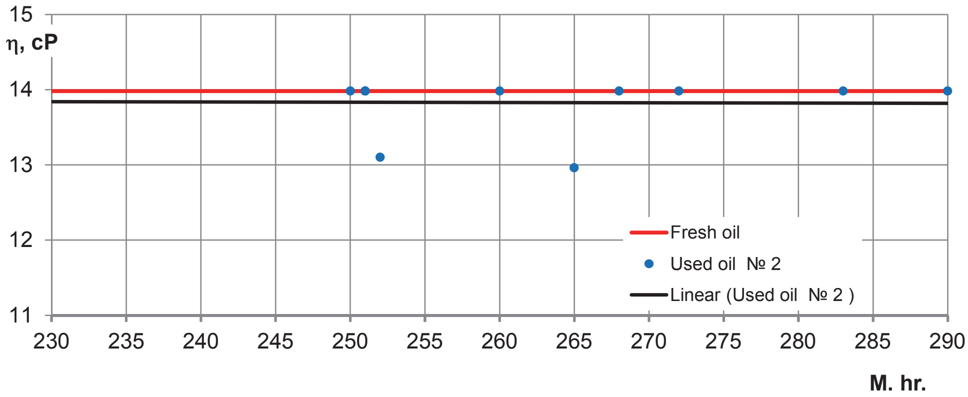
In both cases the dynamic viscosity of the used oil remains in close range compared to the fresh engine oil. The small variation of dynamic viscosity may be due to the presence of soot from burning process of the engine. Measurements show that used oil up to 300 M.hr. does not show significant difference from the fresh oil. This means that there is no need to change engine oil at 300 M.hr.

Another indicator of used engine oil is total base number (TBS, [mg. KON/g]). The role of this indicator is the capacity of lubricants to neutralize the damaging impact of asides (corrosion). This arises from combustion process of the engine, where fuels contain different chemical components with sulfur, nitrogen, carbon and other components. In the survey sample is titrated with an acid solution to measure the alkaline reserve. In the initial period of operation TBN is high after words it decreases. According to some technical refinances ASTM 4739, lower limit to which must not fall below 25% of the value of fresh oil. Results obtained from laboratory test for alkaline reserve are presented in graphical form in the next two charts.

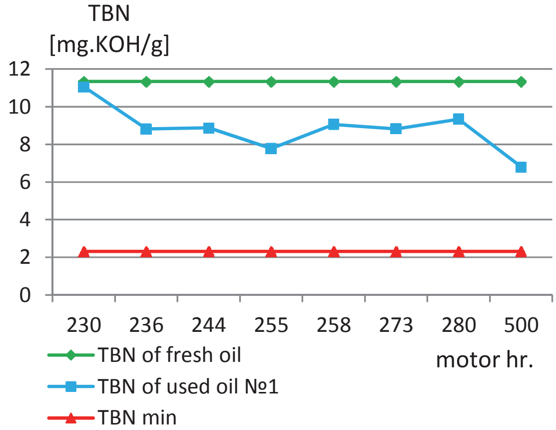
The results show that TBN of the used oil is more than 50% of total base number of the fresh oil. The engine oils that are used in this case can be used (Figs. 12 and 13). Therefore both engine oils have a substantial reserve of TBN which can prove that engines can be utilized more than 300 Motor hours without changing oil.



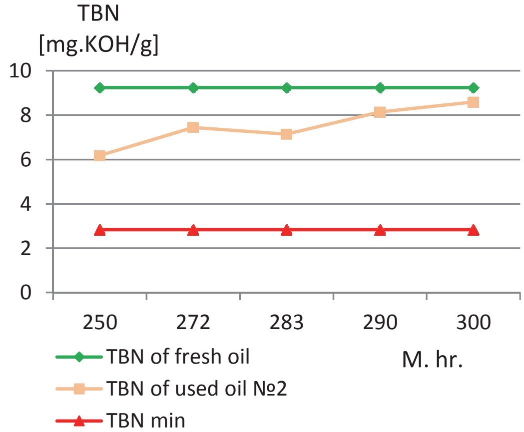
10: *Dynamic viscosity of oil No. 1: η – Dynamic viscosity [sP]; M. hr. – Motor hours*



11: *Dynamic viscosity of oil No. 2: η – Dynamic viscosity [sP]; M. hr. – Motor hours*



12: *Diagram of TBN, sample No. 1*



13: *Diagram of TBN, sample No. 2*

CONCLUSION

This research shows that all used oils are in good condition. The practice of changing engine oil at 250 M. hr. is not justified correctly. All the tractors that take part in this research are in good condition. Reliability of engine operations in this case is achieved with high availability and it is necessary to optimize oil changing period with a farther research by extending the motor hours at which engine oil is changed depending on the specific working condition of each machenery.

Most researches show that oil degradation intensifies after 500 motor hours which in our case the new tractors oil was changed at 250 and there is no inflection point (we don't reach inflection point) which shows that the used oils have remaining useful life. In order to use the oil furthermore it is necessary to intensify the period of monitoring.

Acknowledgement

The research was conducted with the support of the project: CZ.1.02/5.1.00/10.06433 – Acquisition of instrumentation for BAT Centre at Mendel University in Brno. The analytical work was done at the Mendel University in Brno – BAT centrum. FNI 2014-AIF-02-/2018, Research on Performance of Internal Combustion Engine Using Bio-diesel and Developing a System for Diagnosis and Monitoring, Ruse University, Bulgaria.

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