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ASSESSMENT OF THE DEGREE OF DETERIORATION OF TRUNK PISTON ENGINE OIL USED IN THE ENGINE 6AL20/24

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Abstract

The problem of engine oils and lubrication systems of marine diesel engines is an important issue in operation of engines. When considering the problems of exploitation of machines and devices, the lubricating oils are treated as one of the part of engine design, which should perform the functions: control friction between load-bearing surfaces, limit the temperature by carrying away heat from fluid fraction and fuel combustion, reduce corrosion etc. – general protect engine parts. The knowledge of the properties lubricating oils allows for proper selection them for the engine and correct use. During operation, the oil subjects' irreversible process of oil deterioration and it cannot properly fulfil their functions. Therefore important are frequent periodic checks of oil, it means monitoring. The state of the lubricating oil can be characterized by parameters such as viscosity, total base number, acid value, lubricating ability, flash point etc. Changes on these parameters of engine oil during exploitation, cause problems in fulfilling the primary functions of the oil. The target of the paper was the analysis and estimate of properties of trunk piston engine oil – Marinol RG 1240 after various times overwork on the sailing vessel "Dar Młodzieży" on the engine Cegielski-Sulzer 6AL20/24. The results were compared with the values critical and preventive limits and proposed several corrective actions for users the engine 6AL20/24.

Keywords: *engine oil, lubrication system, marine diesel engine, trunk piston engine oil, viscosity, flash point, oil contamination*

1. Introduction

The lubrication system of an engine provides a supply of lubricating oil to the various moving parts in the engine [17]. For proper functioning of the engine, lubricating oil have to fulfill basic requirements: the main function is to enable the formation of a film of oil between the moving parts which reduces friction and wear, assisting in cooling, keeping the compression ratio, reducing corrosion, filling in all micro ridges on the surface of cooperating components, sealing the combustion chamber, dissolving and washing the sediment, suppressing the vibration and decreasing noisiness [10, 12, 16, 17].

Various types of lubricants are available all over the world including mineral oil, synthetic oil, refined oil and vegetable oil [15]. The marine engine oil is a mixture that is produced in a process of crude petroleum distillation. Afterwards some chemical changes may be required to produce the desired properties in the product, special chemicals such as corrosion inhibitors, oxidation inhibitors, anti-wear agents, load-carrying friction modifiers, foam suppressors, demulsifiers, metal deactivators etc. [4, 16].

During exploitation, the oil undergoes the irreversible aging process that is – wearing. The state of lubricate may be characterized by the parameters like viscosity, total base number, acid value, lubricity, acidity and alkalinity, carbon residue, cloud point, composition, density (specific gravity), oxidation stability, pour point, thermal stability etc. [4, 10]. The magnitude and intensity of changes of these physicochemical properties have an impact on operational functions changes of oil, wear of cooperating surfaces and also corrosive action. Constant monitoring of these parameters provides information to the explorers on the oil state, engine condition and facilitates preventing breakdowns [3]. In this article, three properties were elaborated i.e. viscosity, flash point and oil contamination.

2.1. Viscosity

The viscosity of a fluid is a measure of its resistance to flow. It is the measure of internal friction in a fluid, which acts as a resistance to change of molecule position in moving fluid exposed to shear stress [10, 12]. Viscosity is one of the most significant properties of any lubricating oil because the lubrication quality during mixed friction as well as the opportunity to create and maintain hydrodynamic conditions for fluid friction depends on it. Indirectly, it influences efficiency, durability, reliability of engine. Another important feature is that it changes during the exploitation process may increase and decrease. The viscosity of liquid changes along with [4, 5, 8]:

– *temperature* – it increases significantly while the temperature rises. Fig. 1 presents the exemplary graph of viscosity-temperature changes. The rise of temperature causes the increase distance between molecules which results in the decrease of coherence force and accordingly internal friction force [18]. Very often in shipbuilding industry, the knowledge of viscosity changes at different temperature is crucial, in this case, the tables and monograms supplied by oil manufacturers are being used,

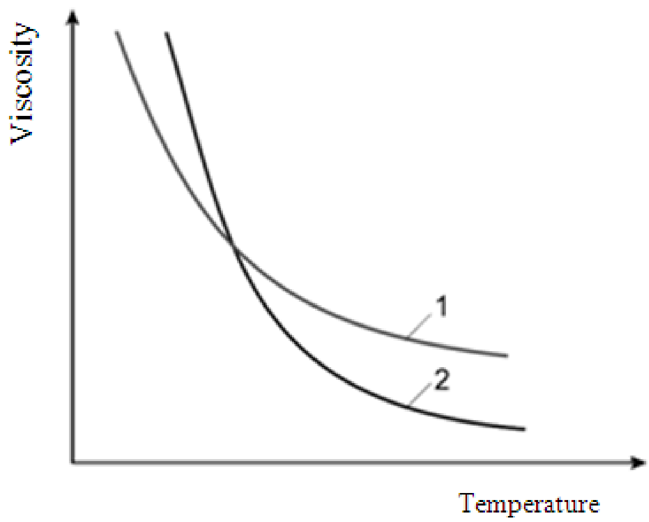

Fig. 1. An example of graph of viscosity-temperature changes; 1 – oil with a low viscosity variation of temperature, 2 – oil with a high viscosity variation of temperature [18]

– *contamination* – the level of viscosity increases along with contamination increase. Contaminated oil is the mixture of solid molecules suspended in liquid – so-called dispersion,
– *water content* (in emulsified state) – the viscosity of oil-in-water emulsion is higher than the viscosity of pure oil.

For engine, it is important not only to choose the type of oil correctly but also to monitor the viscosity. If a change in the oil viscosity is detected, further analysis of the oil can identify the cause of the disturbance of its properties. Every increase or decrease in the viscosity can result in the disturbance of properties of oil. Decreased viscosity can be caused by ingress of fuel into the oil and crack. Increased oil viscosity may be an evidence of its thermal destruction, oxidation, additive decomposition, or contamination with water, coolant, etc. Variation in the oil viscosity is often the first indicator of a global problem of the tribological unit. Tab. 1. lists the limited variations of the viscosity, which are used to monitor engine oil [1, 2, 13].

Tab. 1. Critical and preventive limits for engine oil for the viscosity at 100°C [13]

Limit	Limits for engine oil are indicated for the viscosity at 100°C
Critical (upper)	+20%
Preventive (upper)	+10%
Preventive (lower)	–5%
Critical (lower)	–10%

2.2. Flash point

The *flash point* gives an indication of the presence of volatile components in the oil; and it is the temperature, which oil must reach, under specified test conditions to give off sufficient vapour to form a flammable mixture with air [4]. However, if heating is continued and temperature is reached, the vapours are released rapidly enough to support combustion longer than 5 s. This temperature is called the fire point and for engine oils, it is usually 20-30 higher than flash point [15]. The temperature of flash points for fresh marine oil is in the range of 190-230°C. In case of used oil, the temperature is the indirect measure of fuel presence in oil, which is a significant exploitative matter because fuel compounds the viscosity-lubrication properties of oil, anti-corrosion and resistance to oxidation. There is a customary assumption that the decrease of temperature by approximately 40°C (that is around 5% of fuel in oil) in reference to fresh oil, prejudges its impracticability [9].

2.3. Oil contamination

While operating, the lubricating oil gathers various types of contaminant causing the deterioration of lubrication conditions and decrease of wear process. The simplest definition describes oil contamination as “Every substance that is not oil or an integrated part of oil but occurs in oil” [11].

The process of oil contamination depends on time, type, structure, and technical state of engine, time and conditions of work and also used fuel. In the contamination group of the lubricant, it is possible to distinguish water, air, and other gasses, cooling factors, fuel and the biggest group – solid contaminants – insoluble in n-pentanes, given in mass percentage and defining the content of solid foreign objects. The group of solid oil contaminants consists of airborne dust, soot, coke, ash, consumption products of tribological engine, corrosion products, coating particles, particles of cleaning cloth etc. [9]. Small elements of contamination dispersed in oil create so-called *dispersed systems of macro-objects* [8].

Solid and semi-solid contaminants of motor oil may be the products of different chemical, physical or mixed processes. They can also occur as a result of friction, oxidation, thermo-oxidation, corrosion, condensation of water steam, aging process etc. The presence of solid contaminants in oil is extremely harmful to the engine. It causes disturbance in lubrication systems, increase of tribological wear of cooperating components or even destroying them [7, 8].

3. Engine oil

The research was conducted using motor oil samples of Lotos Company – Marinol RG 1240. The trials differed in terms of overwork in auxiliary engine Cegielski-Sulzer 6AL20/24 of 410 kW placed on sailing vessel “*Dar Młodzieży”*.

Oil samples were collected during the voyage from Gdynia to Barcelona. The operating hours are shown in Tab. 2.

Marine motor oil Marinol RG 1240 is TPEO (*Trunk Piston Engine Oil*) and it is designed for lubrication of marine anhydride light fuel engines. It is formulated on the base of deeply refined,

Tab. 2. Operating hours of tested oils

Samples	Sample 0	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Hours of operation	0	6491	6522	6642	6720	6873

solvent dewaxed and hydrorefined oil distillates received from crude oil. They contain a properly selected package of washing and dispersing additives as well as auto-oxidising, anticorrosion, antirust and anti-wear attributes. The oil fulfils the API CD requirements (*American Petroleum Institute*, category CD) for marine engines.

4. Experiment

The aim of this work was to compare and to assess three basic physio-chemical parameters of oil Marinol RG 1240 after different time of usage.

4.1. Oil viscosity measurement

To test the dependence of viscosity and temperature at –10°C to 100°C range, researchers used the rheometer Haake Mars III of Thermo Scientific Company. The tests were conducted using the cone-plate system. During tests, the parameters of rheometer were as follows:
- shear rate γ = 100 1/s,
- temperature range from –10°C to 100°C, resolution about 0.35°C,
- time of one test t = 5 min.

The viscosity curves dependencies from temperature were determined for each oil in three measuring cycles in full temperature range. For every test, a new oil sample was collected from the container. Designated points of specification constitute the mean value of three measurements.

Motor oil Marinol RG 1240 operates typically of liquids and in all tested samples the viscosity decreases while the temperature rises at whole tested range (Fig. 2).

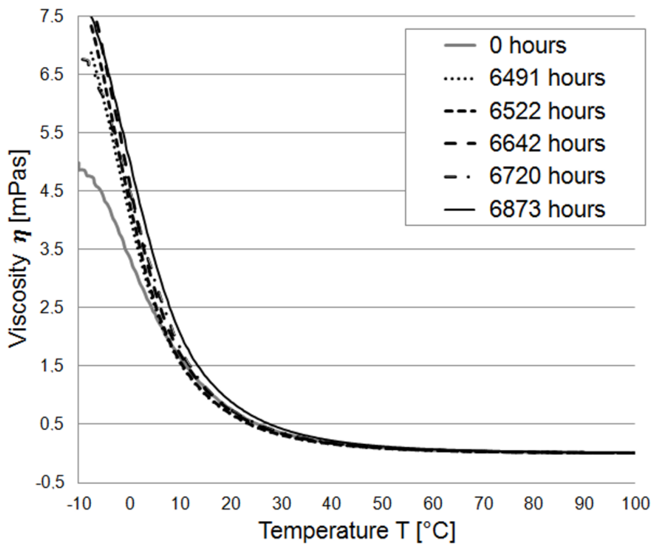

Fig. 2. Graph of viscosity-temperature changes for Marinol RG 1240 after different time of usage

It is difficult to distinguish the differences between characteristics from Fig. 2, thus for the most common temperature levels the results are shown in Tab. 3.

In all tested samples, the viscosity of oil increases along with the consumption. In accordance with the theory, the increase of oil viscosity during the work time might be caused by the presence of water or a large number of contaminants. The biggest discrepancy between fresh oil (sample 0)

Tab. 3. Test results of viscosity-temperature changes

Samples	–10°C	0°C	10°C	20°C	40°C	100°C
	mPas					
Sample 0	4.98	3.318	1.628	0.764	0,1813	0.01181
Sample 1	7.585	3.946	1.462	0.67	0,1693	0.01303
Sample 2	7.36	4.167	1.496	0.686	0.1726	0.01335
Sample 3	7.985	4.46	1.616	0.737	0.1857	0.01338
Sample 4	8.075	4.519	1.778	0.76	0.1855	0.01387
Sample 5	8.123	5.094	2.042	0.886	0.2181	0.01401

and used oil are visible for temperature below 0°C. The disparity for the last trial, which was –10°C, was even 63%. This is extremely important for cold start of engine. For temperature above 0°C, the discrepancies do not exceed 20%. Results obtained for temperature 100°C were compared to Tab. 1. The discrepancy in the percentage regarding fresh oil is subsequently 10.3%, 13%, 13.3%, 17.4%, 18.6%. All of them exceed the warning parameters i.e. 10% and the last sample is close to critical value (20%). Engine users should, as soon as possible, change the oil or refurbish it because its further exploitation may cause the breakdown.

4.2. Flash point measurement

To conduct the measurement, researchers used the ERAFLASH device, which uses the closed-cup method. The temperature measuring range of device lies between –25°C and +420°C. The ignition in the apparatus starts from electric arc and the measure of ignition is the increase of exhaust gasses pressure.

Tab. 4. Test results of flash point

Samples	Sample 0	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Producer
Flash point [°C]	232.1	213.1	211.2	210.5	209.3	207.1	260

The flash point given on manufacturer's specification (260°C) is significantly different from the one that was measured for fresh oil (232.1°C). That difference stems from the methods for determination because the oil manufacturer uses PN-EN ISO 2592 standard "*Indication of flash point and combustion – Cleveland open cup method*" however, during tests the ASTM D6450 standard was used "*Standard Test Method for Flash Point by Continuously Closed Cup*". The flash point designated by closed cup in apparatus is always few degrees lower that the results obtained in apparatus with open cup. Therefore, the temperature designated during the tests will be used as an indicator.

For subsequent oil trails, the flash point decreases and after 6873 of operating hours it is 207.1°C (25°C decrease). In accordance with guidelines presented in 2.2. point, the oil is exploitable. Attention should be drawn to the fast decrease of flash point between collected samples. Until 6491st operating hour, the temperature dropped 0.0029 °C/h on average. However, between 6491st and 6873rd it drops 0.0157 °C/h, which is five times faster. If the situation continues, it might be said that the oil will not be exploitable just after next 956.75 operating hours that is approximately forty days.

4.3. Oil contamination measurement

Testing the contamination content in oil Marinol 1240 was conducted using the spectrometer Spectroil Q100 in accordance with ASTM D 6595 standard. During the first phase of research, every sample series of collected oil was tested three times on spectrometer and then the content of each element was averaged. The content of elements was presented in ppm (parts per million). After averaging, the results were put into the table, which enables conducting the analysis. Spectroil Q100 gives the possibility to test 22 elements; however, author presented only the ones whose change is significant to tested oil (Tab. 5).

Tab. 5. Test results of oil contamination

Samples	Ca	Cd	Cr	Cu	Fe	K	Mg
Sample 0	4786.143	0.000	0.000	0.000	1.927	0.836	16.806
Sample 1	5124.333	0.403	2.320	4.690	11.860	4.513	21.023
Sample 2	5195.333	0.513	2.187	4.435	12.750	4.047	21.397
Sample 3	5353.000	0.495	2.620	4.862	12.850	3.820	22.010
Sample 4	5495.333	0.513	2.407	5.367	13.460	4.773	22.240
Sample 5	5550.667	0.447	2.410	5.460	14.030	6.377	22.404
Samples	Mn	Na	P	Pb	Si	Zn	Mo
Sample 0	3.081	3.941	415.749	0.000	15.367	625.063	4.639
Sample 1	2.010	118.470	655.800	4.093	19.660	595.370	6.197
Sample 2	1.950	120.460	728.100	5.430	20.960	610.603	6.100
Sample 3	1.860	125.648	760.100	5.648	21.393	612.560	6.590
Sample 4	1.980	129.750	830.900	5.593	23.130	622.407	6.343
Sample 5	1.930	136.048	886.800	8.363	23.242	657.777	5.770

Due to different ranges, the separate analysis of each element content was conducted [6, 14, 19]:

– *Chromium* – the content in fresh oil equals zero, it occurs in used oils (the range is 2.1-2.6 ppm) and it originates from wear of engine components such as piston, cylinder liners or piston rings,
– *Zinc* – the component in used oils increases along with each trial, it originates from wear of galvanized surfaces e.g. filter cores. It occurs in fresh oil (625.063 ppm). This indicates that Zinc is a component of improver which has anticorrosion properties and which increases the wear resistance,
– *Phosphorus* – a component of improver in fresh oil 415.749 ppm. Phosphorus provides anticorrosion and antibacterial properties, reduces the friction, and makes metal surfaces chemically inert. However, its concentration level extremely increases (on average 0.6 ppm per hour while the engine is operating), it may originate from fuel or lubricant,
– *Cadmium* – is the wear product which content oscillates approximately 0.47 ppm, originating from bearing or plating,
– *Silicon* – originates from antifoaming additive of oil and that is why it occurs in fresh oil (15.367 ppm). In used oils, its content increases, for last collected sample by more than 50 % in comparison to fresh oil. It may originate from fuel presence, bearing wear, pistons, cylinder liners or air intake,
– *Magnesium* – is an improver (16.806 ppm), increases the corrosion resistance, improves thermal stability, dispersion capabilities and enhances alkali reserve of oil. The amount of magnesium increases along with usage (in the fifth trail by 5.5 ppm). It may originate from seawater or bearing wear,
– *Manganese* – minor additive that provides protection for the engine components. Its content decreases along with usage,
– *Copper* – the product of usage whose content in fresh equals 0 ppm, after exploitation, it increases to approximately 5.46 ppm, it may originate from sea water or wear of bearings, wire system, and sealing or cooler pipes,

- *Molybdenum* – the component of improver (4.639 ppm) which ensures antioxidant properties of motor oil, in used oil it may originate from piston rings wear,
- *Lead* – the lead content in fresh oil equals zero. It occurs in used oil (8 ppm). It may originate from bearing wear or lubricants presence,
- *Potassium* – over seven-time increase for oil samples with the longest operating time in engine. It originates from seawater presence,
- *Sodium* – is a minor improver of oil (3.941 ppm), its amount increases to over 136 ppm. It may indicate the presence of seawater in oil,
- *Calcium* – is a major improver (4786.143 ppm). It improves cleaning properties, dispersion capability, and resistance to overheating. In used oil, it occurs as the contaminant originating from water,
- *Iron* – significant product of usage, its content increased over seven times in comparison to fresh oil. It originates from cylinder liner, piston rings, valves, gears, shafts, bearing, rust crankshaft, water. The extensive presence of iron may cause oil degradation, insufficient lubrication, breaking the oil film, abnormal operation temperature, and decrease of oil pressure.

5. Conclusion

During exploitation, oil experiences high temperature and high pressure, air, combustion products, fuel, water or other usage products of cooperating components, which causes irreversible changes of oil properties and also its contamination. The state of lubricant may be characterized by parameters like viscosity, flash point, and contamination content. The magnitude and intensity of changes of these parameters have the impact on changes of operating functions of oil and also engine wear.

This work includes the analysis of oil Marinol RG 1240 after different time of usage in marine engine. The increase of viscosity along with oil usage and the presence of elements like sodium, magnesium and potassium may suggest the presence of water in oil, which may be caused by the breakdown of coolers or pipe system of heating steam, leaks caused by faulty cooling process of pistons, incorrect use of centrifuges etc. Contrary, the decrease of flash point and large amount of phosphorus and silicon indicate the presence of fuel in tested oil. In this case, it is suggested to take action in terms of control over fuel spray injection and sealing and also control over oil cleaning process (centrifuge, filters). The results should be treated as a very serious warning for engine users of the necessity of oil change or refurbish.

The analysis of fresh oil enabled identification of improver types used by manufacturer of motor oil Marinol RG 1240 and these are detergents and dispersants (Ca, Mg), oxidation and corrosion inhibitors (P, Zn) and lubricate additives (P, Mo). The results confirmed information given by oil manufacturer.

Frequent oil controls may prevent engine breakdowns because oil is a valuable medium of information about the processes and causes of wear of tribological engine systems. The adequate monitoring of lubricants facilitates the increase of durability, exploitation periods, reduction of engine failure frequency and consequently reduction of its exploitation costs.

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