Institute of Mathematics, Physics and Chemistry

Department of Chemistry

Laboratory of fuels, oils and lubricants

Laboratory exercise

Measurement of dynamic viscosity of lubricating oil by Höppler method and determination of viscosity index WL

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EXERCISE SHEET

<table>
<tr><td rowspan="3">1</td><td colspan="3">Relation to subjects: Marine Power Plant Operation/28</td></tr>
<tr><td>Specialty/Subject</td><td>Learning outcomes for the subject</td><td>Detailed learning outcomes for the subject</td></tr>
<tr><td>MPPO – Chemistry of fuels and lubricants.</td><td>EKP3
K_U014, K_U015, K_U016.</td><td>SEKP12 – Determination of selected quality indicators of petroleum products;</td></tr>
<tr><td>2</td><td colspan="3">Purpose of the exercise:
teaching the student how to independently perform viscosity measurements and determination of WL viscosity index of lubricating oils;</td></tr>
<tr><td>3</td><td colspan="3">Prerequisites:
the student is trained in the occupational health and safety regulations on a laboratory stand, which he confirms with his signature on the appropriate form, knows the concept of viscosity and its types and units, the Höppler method of dynamic viscosity measurement, knows the concept of the WL viscosity index and the method of its calculation, the method of converting a given viscosity into other types of viscosity, operational importance of viscosity and viscosity index, and the boundary values of these performance parameters for lubricating oils;</td></tr>
<tr><td>4</td><td colspan="3">Description of the laboratory workplace:
ultrathermostats, Höppler viscometers, seconds, a set of hydrometers, a thermometer, a special cylinder used for density measurements, a station for washing measuring apparatus and laboratory glass with extraction gasoline, samples of lubricating oils or other petroleum products;</td></tr>
<tr><td>5</td><td colspan="3">Risk assessment *:
contact with a petroleum product heated to 100°C, contact with extraction gasoline used to clean measuring devices and laboratory glass - probability of thermal burns with hot oil and fire hazard due to the presence of flammable gasoline vapour – (very low risks due to efficient ventilation and low concentration of volatile gasoline vapours).
Final assessment – SMALL THREAT
Safety measures required:
a. lab coats,
b. health and safety cleaning products, cleaning cloths, paper towels,
c. petroleum products waste container (for disposal),
d. container for waste gasoline beakers (for regeneration);</td></tr>
<tr><td>6</td><td colspan="3">The course of the exercise:
a. Reading the workplace manual (appendix 1) and familiarizing with the laboratory kit for the exercise,
b. Measuring the viscosity of the lubricating oil or other petroleum product at 40°C and 100°C and calculating the WL based on the measurements (in the case of testing lubricating oils);</td></tr>
<tr><td>7</td><td colspan="3">Exercise report:
a. Develop an exercise in accordance with the instructions contained in the workplace manual,
b. On the basis of the carried-out viscosity measurements and the calculated WL, determine the quality and operational suitability of the tested oil by comparing the determined parameters with the permissible values in operation,</td></tr>
</table>

	c. On the basis of the obtained results, determine the operational reasons for the changes in the condition of the oil and therefore make a diagnostic conclusion on the last engine. If necessary, propose appropriate corrective actions;
8	**Archiving of research results:** Submit a written report on the performed exercise to the teacher.
9	**Assessment method and criteria:** a. EKP1, EKP2 – tasks given for independent solution and development: mark 2.0 – the student has no basic physicochemical and operational knowledge regarding the viscosity of petroleum products and WL of lubricating oils and the ability to solve simple tasks in this field; mark 3.0 – has basic physicochemical and operational knowledge regarding the viscosity of petroleum products and WL of lubricating oils, as well as the ability to calculate and solve simple tasks in this field; mark 3.5-4.0 – has extended physicochemical and operational knowledge regarding the determined performance parameters of the analyzed petroleum products and the ability to solve complex tasks in this field; mark 4.5-5.0 – has the ability to use complex physicochemical and operational knowledge for partial evaluation of the quality and operational suitability of the analysed petroleum products due to the determined performance parameters and the ability to make operational decisions on this basis. b. EKP3 – control works: mark 2.0 – does not have the ability to analyse and evaluate the results of the performed analyses and determinations and to draw conclusions; mark 3.0 – has the ability to analyse the obtained results, interpret the laws and phenomena, transform formulas, and interpret charts and tables; mark 3.5-4.0 – has the ability to broaden the analysis of results, apply laws, construct monograms and charts; mark 4.5-5.0 – has the ability to comprehensively analyse the obtained results, make generalizations, detect cause-and-effect relationships and make the right operational decisions.
10	**Literature:** 1. Krupowies J., Wiznerowicz Cz.: Pomiar lepkości dynamicznej oleju smarowego metodą Höpplera oraz wyznaczanie wskaźnika lepkości WL. Instrukcja stanowiskowa do ćwiczenia, AM, Szczecin 2013. 2. Barcewicz K.: Ćwiczenia laboratoryjne z chemii wody, paliw i smarów. Wyd. AM w Gdyni, Gdynia 2006. 3. Podniało A.: Paliwa oleje i smary w ekologicznej eksploatacji. WNT, Warsaw 2002. 4. Przemysłowe środki smarne. Poradnik. TOTAL Polska Sp. z o.o., Warsaw 2003. 5. Urbański P.: Paliwa i smary. Wyd. FRWSzM w Gdyni, Gdańsk 1999. 6. Krupowies J.: Badania zmian parametrów fizykochemicznych silnikowych olejów smarowych eksploatowanych na statkach Polskiej Żeglugi Morskiej. WSM w Szczecinie, Studia nr 27, Szczecin 1996. 7. Krupowies J.: Badania zmian właściwości oleju obiegowego okrętowych silników pomocniczych. WSM w Szczecinie, Studia nr 40, Szczecin 2002. 8. PN/EN/ISO standards for the testing of petroleum products. 9. Oil product catalogs of oil companies. 10. Dudek A.: Oleje smarowe Rafinerii Gdańskiej. „MET-PRESS”, Gdańsk 1997. 11. Baczewski K., Biernat K., Machel M.: Samochodowe paliwa, oleje i smary. Leksykon, Wydawnictwa Komunikacji i Łączności, Warsaw 1993.

	12. Herdzik J.: Poradnik motorzysty okrętowego. Wydawnictwo TRADEMAR, Gdynia 1995.
10	Notes

APPENDIX 1 – MANUAL

1. SCOPE OF THE EXERCISE

- getting acquainted with the workplace instructions for the exercise,
- performing the measurement of the dynamic viscosity of the lubricating oil using the Höppler method at the temperature of 40ºC and 100ºC,
- calculation of the viscosity index (WL),
- evaluation of the operational suitability of the tested oil on the basis of confrontation with the limit values of viscosity.

2. THEORETICAL INTRODUCTION TO THE EXERCISE

2.1. Viscosity

The term liquid viscosity is understood as internal friction, causing, in the conditions of laminar flow, resistance to the sliding of the layers relative to each other, resulting from the cohesive forces between the liquid molecules. Using the Newton's formula, the dynamic viscosity can be determined by the following equation:

$$\eta = \frac{F}{S} \cdot \frac{dv}{dy}$$

where:

$\frac{F}{S}$ – tangential shear stress as the ratio of the force (F) acting on the surface (S) in a plane parallel to the direction of liquid flow,

$\frac{dv}{dy}$ – gradient of the velocity of the liquid film, as the drop in velocity (v) over the thickness of the layer (y).

Viscosity is a temperature and pressure dependent property. For petroleum products, these dependencies are of great practical importance.[*/]

The influence of pressure on the viscosity of petroleum products is of great practical importance, because in some friction nodes pressures from several to tens of thousands of MPa are generated. For example, in the bearings of the crankshaft of an internal combustion engine, the unit pressures are about 20 MPa, in the piston pin bearings from 50 to 80 MPa, and in the gears, the pressure in the meshing area is several hundred or even several thousand MPa.

The reason for the increase in viscosity with increasing pressure is the proximity of liquid molecules and the increase in intermolecular interactions.

[*/] The temperature dependence of viscosity is discussed in the viscosity index

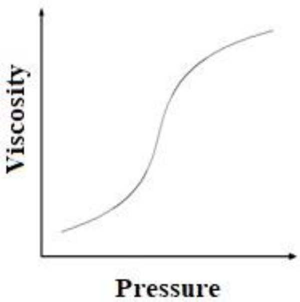
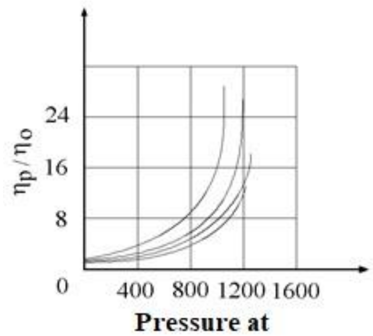


Fig. 1. General dependence of viscosity on pressure changes

Figure 1 shows a schematic view of the effect of pressure on oil viscosity. In the high-pressure range, around several thousand MPa, the effect of intermolecular repulsion is marked and the curve approaches asymptotically to a certain constant value. The increase in viscosity as pressure increases also depends on the temperature. At higher temperatures, this relationship is smaller than at lower temperatures. For petroleum products, the individual character of this relationship is of particular importance, as it is determined by the differences in the group composition of hydrocarbons and the content of additives. Figure 2 shows these different relationships.

Water in an emulsified form, which is quite a common case in shipbuilding, also has a significant impact on the viscosity of petroleum products. However, the viscosity of the emulsion is always higher than that of the pure petroleum product.



η_p – the viscosity of the oil under pressure *P*
η_o – the viscosity of the oil under pressure *at*

Fig. 2. Dependence of lubricating oil viscosity on pressure acc. to Gurewicz

In shipbuilding practice, the importance of fuel viscosity when using heavy fuels is related to a number of factors. Primarily viscosity is decisive for possibility of pumping fuel and pumping capacity. The quality of cleaning in the fuel system depends on the viscosity. It also determines the correct operation of fuel pumps, in which the fuel acts as a lubricant. Viscosity has a decisive influence on the quality of fuel atomization and combustion. The maximum and minimum injection viscosity values are provided by the manufacturers of marine engines. The maximum viscosity at the injection temperature is from 21 to 30 mm^2/s, while the minimum viscosity is 2 mm^2/s, and the optimal one is from 12 to 17 mm^2/s. One of the important activities of a marine engineer in the operation of the engine room is the regulation of the viscosity of the fuel in the process of its cleaning and in the fueling of the engine. Temperature dependency is then used, which is an automatically or manually regulated parameter.

Viscosity in relation to lubricating oils is their most important property. It determines the possibility of creating and maintaining conditions of hydrodynamic fluid friction. It also has a serious influence on the lubrication of elastohydrodynamic and mixed friction. Thus, the type and losses of friction, as well as the efficiency, durability and reliability of the lubricated device, depend on the viscosity. In combustion engines, viscosity determines the degree of sealing of the piston in the cylinder, the efficiency of engine cooling and the possibility and speed of starting the engine without heating.

As in the case of fuels, the quality of cleaning and pumping efficiency depend on the viscosity of the lubricating oil.

Oil viscosity significantly affects the engine's operating results, including the specific fuel consumption and the wear of mating parts. If it is too small, it may seize. If the oil viscosity is too high, its inflow to distant lubrication points may be interrupted, resulting in seizure and an increase in engine power losses due to increased internal frictional resistance, as the internal friction coefficient of the oil is directly proportional to its viscosity – according to the hydrodynamic theory of lubrication. The critical minimum oil viscosity is considered to be equal to 3 mm^2/s. It is more difficult to determine the upper viscosity limit as this value is different for different engines. During operation, the viscosity changes compared to the stickiness of fresh oil – it may decrease or increase.

The decrease in viscosity occurs as a result of fuel entering the crankcase ("pouring injectors") and unburned light fuel residues, which are scraped off with the oil from the cylinder bearing surface. The increase in viscosity of the oil is due to the increasing amount of impurities that accumulate in it over time. This is because the contaminated oil is considered to be a dispersion mixture, i.e., a mixture of solid particles suspended in a liquid. As the impurities increase the volume of the dispersed phase by increasing their size and number in the oil, they therefore increase the viscosity of the dispersion mixture.

2.2. Viscosity index

The viscosity index is a quantity that characterizes changes in viscosity depending on changes in temperature. It is a dimensionless quantity investigated in a conventional manner, which was introduced by Dean and Davis in 1929 for lubricating oils only. Due to the necessity to fulfil new functions by the oil in a wide range of temperatures, this index is of great importance when assessing lubricating oils, especially engine oils. The smaller the changes in viscosity of the lubricating oil with temperature, the greater its viscosity index and the better the quality and suitability of the oil. The concept of the viscosity index was introduced due to the large difference in the dependence of viscosity on temperature for various types of lubricating oils. The reasons for this are differences in the group composition of hydrocarbons, their structure and the presence of other types of compounds. The essence of the issue is that the viscosity of the petroleum product always decreases with the temperature increase, but the course of this relationship is always different, it is individual. This means that two different oils with the same viscosity at t_1, temperature have different viscosities at t_2 temperature. So far, it has not been possible to establish a general relationship between viscosity and temperature variation. These changes are caused by changes in the distance between molecules. It is tantamount to changes in the interaction. Fig. 3 presents exemplary curves of the dependence of oil viscosity on temperature.

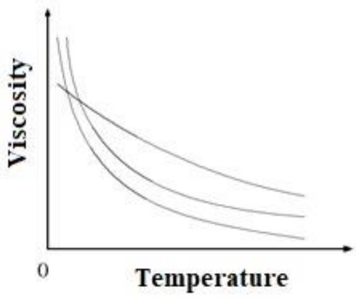


fig. 3. Dependence of oil viscosity on temperature

In shipbuilding practice, it is often necessary to recalculate the viscosity at different temperatures. In such a case, appropriate tables or nomograms, which are usually found on board the ship, should be used. However, it should be remembered that there are usually slight differences between these materials (from different sources). This is due to the need to rely on a certain average course of the viscosity-temperature dependence in the preparation of the above-mentioned materials. The above errors and inaccuracy to a certain extent eliminate the use of the oil viscosity index.

However, the theoretical and practical significance of the viscosity index is limited by the narrow range of applied measurement temperatures (40ºC and 100ºC). Therefore, it cannot characterize the behaviour of oils at temperatures significantly different from those indicated above for which it is determined.

The viscosity index is empirical because it determines the temperature dependence of the viscosity in relation to two groups of reference oils, namely the H-series oils obtained from Pennsylvania crude oil, which are assigned a viscosity index value of 100, and the L-series oils from California crude, for which the index the viscosity was assumed to be 0. The higher the value of the oil viscosity index, the better its operational properties (lower viscosity dependence on temperature changes). The WL values of oils used for marine engines should not be less than 90.

3. Performing the exercise

3.1. Determination of the viscosity of petroleum products

There are several types of viscosity: dynamic, kinematic and relative. The SI unit of dynamic viscosity η is 1 Ns/m^2 (equal to 1 Pa · s).

The reciprocal of the dynamic viscosity of a liquid is referred to as flowability $\rho = \frac{1}{\eta}$.

The kinematic viscosity ν of a liquid is the ratio of the dynamic viscosity of a liquid to its density at the same temperature:

$$\nu = \frac{\eta}{\rho}$$

The SI unit of kinematic viscosity is [m^2/s].

Determination of viscosity is carried out using devices called viscometers. These cameras can be divided depending on the principle of their operation:

1. capillary viscometers for determining the time of liquid flow through capillaries – Ostwald-Pinkiewicz and Vogel-Ossaga viscometer;
2. Engler viscometer - the measurement of liquid viscosity consists in determining the relative outflow time of a precisely defined volume of liquid;
3. Viscometers where the viscosity is determined on the basis of the falling velocity of a solid (ball) - the Höppler method or the decay of solid body vibrations in the tested liquid - the Gurewicz method and ultrasonic viscometers.

Determination of viscosity with a Höppler viscometer

The inner wall of the downpipe – 1 (Fig. 4) of the viscometer and all other parts (2, 3, 6, 7) before and after each measurement, thoroughly wash with gasoline, ethyl alcohol and dry with a warm air stream (from a dryer). Then, after closing the lower opening of the drop tube with a plug – 2 and tightening it lightly with the cap nut – 3, fill the tube with the test sample to a height of 25 mm below its upper edge. The product should be poured carefully along the wall to avoid bubbles. Using tweezers, insert a suitable ball into the tube (the diameter of which is selected on the basis of Table 1).

Close the downpipe from the top with a metal plug – 4 so that the tested product flows out through the capillary of the plug – 5 and fill it up to a height of 3 mm below the upper edge. Then put on the plug cover – 6 and tighten the cap nut – 3. In the case of marking at temperatures above 20°C, do not tighten the cap nut until the measurement temperature is reached. After determining the required temperature in the viscometer's mantle (after 15 minutes), start the measurement. For this purpose, the ball should be brought to the upper position by turning the mantle through the angle of 180°. After the mantle is rotated vertically by 180°, lock the viscometer and when the lowest ball level reaches the upper line A on the drop tube, turn on the timer and turn it off when the same point on the ball reaches the lower line B. Record the ball drop time in seconds. The final result will be the arithmetic mean of at least three measurements, which do not differ by more than those specified in Table 1.

Table 1

Exemplary physical parameters of the balls

No	Diameter d [mm]	Mass m [g]	Density ρ_k [g/cm^3]	Constant K_k [mPa · cm^3/g]	Minimum fall time [s]	Projected viscosity at maximum ball fall time [mPa· s]	measurement error [%]
1	15.805	4.6139	2.223	0.0095770	60	0.6 ÷ 5	±2.0
2	15.630	4.4499	2.225	0.075556	60	03 ÷ 30	±0.5
3	15.560	16.0830	8.144	0.12182	30	25 ÷ 250	±0.5
4	15.000	14.3950	8.148	1.2114	30	250 ÷ 2 500	±1.0
5	13.500	9.9351	7.722	10.554	30	2 500 ÷ 25 000	±1.0
6	10.000	4.0399	7.716	40.00	30	8 000 ÷ 80 000	±1.5

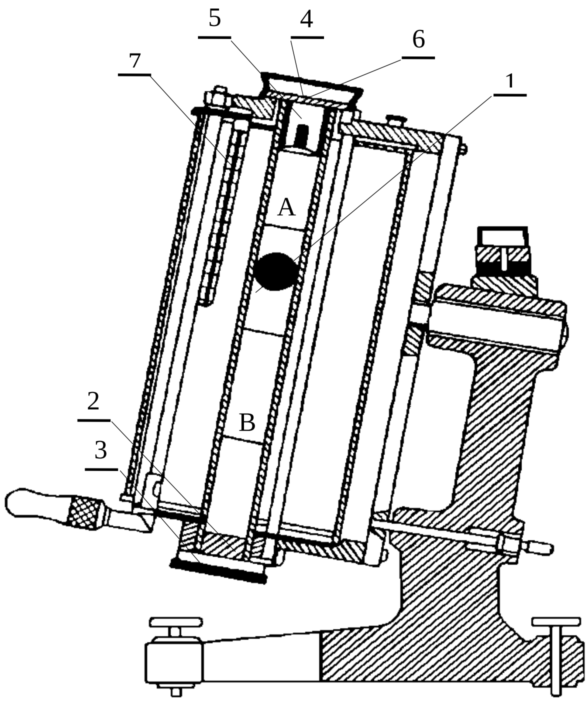


Fig. 4. Höppler viscometer: 1 – downpipe, 2 – plug, 3 – cap screw,
4 – metal plug, 5 – capillary in the plug, 6 – plug cover, 7 – thermometer

Elaboration of the results

Calculate the dynamic viscosity η_t from the following formula:

$$\eta_t = K_k (\rho_k - \rho_c) \cdot \tau$$

where:

η_t – dynamic viscosity [mPa· s],
K_k – constant of the ball [mPa·cm^3/g],
ρ_k – ball density [g/cm^3],
ρ_c – density of the tested product at the measurement temperature [g/cm^3],
τ – fall time of the ball [s].

Converting dynamic viscosity to kinematic viscosity

$$\nu = \frac{\eta_t}{\rho_c}$$

where:

ν – kinematic viscosity [mm^2/s],
η_t – dynamic viscosity [mPa·s],
ρ_c – test product density [g/cm^3].

3.2. Calculation of the viscosity index

Viscosity index WL is a unitless number that defines the dependence of the kinematic viscosity of the tested oil on temperature in relation to two oils adopted as standards, the viscosities of which at 100ºC are the same as the viscosity of the tested oil at 100ºC. The higher the value of the viscosity index, the lower the dependence of the viscosity on temperature. The principle of calculating the viscosity index is to determine its numerical value on the basis of the previously known kinematic viscosity of the tested oil at 40°C and 100°C (method I – for oils with a standard viscosity index up to 100 and method II – above 100), using formulas and tables.

3.2.1. Calculation of the viscosity index for oils with WL ≤ 100

Viscosity index WL is determined from the following equation:

$$WL = \frac{\nu_L - \nu_{\nu_{40^\circ}}}{\nu_L - \nu_H} \cdot 100 = \frac{\nu_L - \nu_{\nu_{40^\circ}}}{\nu_D} \cdot 100$$

where:

ν_L – kinematic viscosity at 40°C of the reference oil of the L series (WL = 0), having at the temperature of 100°C the same kinematic viscosity as the tested oil [mm^2/s];

$\nu_{\nu_{40^\circ}}$ – kinematic viscosity of the tested oil at 40ºC [mm^2/s];

ν_H – kinematic viscosity at 40°C of the reference oil of the H series (WL = 100), having at the temperature of 100°C the same kinematic viscosity as the tested oil [mm^2/s];

ν_D – differences between the kinematic values of the reference oils of the L and H series [mm^2/s].

Note!

1. For an oil whose kinematic viscosity at 100ºC is within the limits of 2 – 70 mm^2/s ($\nu_{\nu_{100^o}}$), the value ν_L and ν_D or ν_H should be read from Table 2. If the kinematic viscosity at 100ºC for the tested oil is greater than 70 mm^2/s ($\nu_{\nu_{100^o}}$), then values ν_L and ν_D should be calculated from the following equations:

$$\nu_L = 0{,}8353\left(\nu_{\nu_{100^o}}\right)^2 + 14{,}67 \cdot \nu_{\nu_{100^o}} - 216$$

$$\nu_D = 0{,}6669\left(\nu_{\nu_{100^o}}\right)^2 + 2{,}82 \cdot \nu_{\nu_{100^o}} - 119$$

where:

$\nu_{\nu_{100^o}}$ – kinematic viscosity of the tested oil at 100ºC [mm^2/s].

Elaboration of the results

Take a whole number as the value of the oil viscosity index.

3.2.2. Calculation of the viscosity index for oils with WL > 100

The viscosity index is determined from the following dependencies:

$$N = \frac{\log \nu_H - \log \nu_{40^o}}{\log \nu_{100^o}}$$

$$WL = \frac{Anty \log N - 1}{0{,}00715} + 100$$

where:

$\nu_{\nu_{40^o}}$ – kinematic viscosity of the tested oil at 40ºC [mm²/s],

$\nu_{\nu_{100^o}}$ – kinematic viscosity of the tested oil at 100ºC [mm²/s],

ν_H – kinematic viscosity at 40ºC of H series reference oil (WL = 100), having at a temperature of 100°C the same kinematic viscosity as the tested oil [mm²/s].

Note!

1. For an oil whose kinematic viscosity at 100°C is within the limits of 2 ÷ 70 mm²/s, the value ν_H should be taken from Table 2.
2. If the kinematic viscosity of the oil at 100°C is greater than 70 mm²/s the value ν_H should be calculated from the equation:

$$\nu_H = 0.1684 \left(\nu_{\nu_{100^o}}\right)^2 + 11.85 \cdot \nu_{\nu_{100^o}} - 97$$

where:

$\nu_{\nu_{100^o}}$ – kinematic viscosity of the tested oil at 100ºC [mm²/s].

Table 2

Values ν_L , ν_D i ν_H [mm^2/s] for oils
with kinematic viscosity at 100ºC(ν_{100^o}) within 2 ÷ 70 mm^2/s

ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$	ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$
2.00	7.994	6.394	1.600	6.00	57.97	38.19	19.78
2.10	8.640	6.894	1.746	6.10	59.74	39.17	20.57
2.20	9.309	7.410	1.998	6.20	61.52	40.15	21.38
2.30	10.00	7.944	2.056	6.30	62.32	41.13	22.19
2.40	10.71	8.496	2.219	6.40	65.18	42.14	23.03
2.50	11.45	9.063	2.390	6.50	67.12	43.18	23.94
2.60	12.21	9.647	2.467	6.60	69.16	44.24	24.92
2.70	13.00	10.25	2.548	6.70	71.29	45.33	25.96
2.80	13.80	10.87	2.937	6.80	73.48	46.44	27.04
2.90	14.63	11.50	3.132	6.90	75.72	47.51	28.21
3.00	15.49	12.15	3.334	7.00	78.00	48.57	29.43
3.10	16.36	12.85	3.540	7.10	80.25	49.61	30.63
3.20	17.26	13.51	3.753	7.20	82.39	50.69	31.70
3.30	18.18	14.21	3.971	7.30	84.53	51.78	32.74
3.40	19.12	14.93	4.196	7.40	86.66	52.88	33.79
3.50	20.09	15.66	4.428	7.50	88.85	53.98	34.87
3.60	21.08	16.42	4.665	7.60	91.04	55.09	35.94
3.70	22.09	17.19	4.909	7.70	93.20	56.20	37.01
3.80	23.13	17.97	5.157	7.80	95.43	57.31	38.12
3.90	24.19	18.77	5.415	7.90	97.72	58.45	39.27
4.00	25.32	19.56	5.756	8.00	100.0	59.60	40.40
4.10	26.50	20.37	6.129	8.10	102.3	60.74	41.57
4.20	27.75	21.21	6.546	8.20	104.6	61.89	42.72
4.30	29.07	22.05	7.017	8.30	106.9	63.05	43.85
4.40	30.48	23.92	7.560	8.40	109.2	64.18	45.01
4.50	31.96	24.81	8.156	8.50	111.5	65.32	46.19
4.60	33.52	25.71	8.806	8.60	113.9	66.48	47.40
4.70	35.13	26.63	9.499	8.70	116.2	67.64	48.57
4.80	36.79	27.57	10.22	8.80	118.5	68.79	49.75
4.90	38.50	28.53	10.97	8.90	120.9	69.94	50.96
5.00	40.23	28.49	11.74	9.00	123.3	71.10	52.20
5.10	41.99	29.46	12.53	9.10	125.7	72.27	53.40
5.20	43.76	30.43	13.32	9.20	128.0	73.42	54.61
5.30	45.53	31.40	14.13	9.30	130.4	74.57	55.84
5.40	47.31	32.37	14.94	9.40	132.8	75.73	57.10
5.50	49.09	33.34	15.75	9.50	135.3	76.91	58.36
5.60	50.07	34.32	16.55	9.60	137.7	78.08	59.68
5.70	52.64	35.29	17.36	9.70	140.1	79.27	60.87
5.80	54.42	36.26	18.16	9.80	142.7	80.46	62.22
5.90	56.20	37.23	18.97	9.90	145.2	81.67	63.54

Table 2 cont.

ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$	ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$
10.00	147.7	82.87	64.86	14.00	263.3	135.4	128.0
10.10	150.3	84.08	66.22	14.10	266.6	136.8	129.8
10.20	152.9	85.30	67.56	14.20	269.8	138.2	131.6
10.30	155.4	86.51	68.90	14.30	273.0	139.6	133.5
10.40	158.0	87.72	70.25	14.40	276.3	141.0	135.3
10.50	160.6	88.95	71.63	14.50	279.6	142.4	137.2
10.60	163.2	90.19	73.00	14.60	283.0	143.9	139.1
10.70	165.8	91.40	74.42	14.70	286.4	145.3	141.1
10.80	168.5	92.65	75.86	14.80	289.7	146.8	142.9
10.90	171.2	93.92	77.33	14.90	293.0	148.2	144.8
11.00	173.9	95.19	78.75	15.00	296.5	149.7	146.8
11.10	176.6	96.45	80.20	15.10	300.0	151.2	148.8
11.20	179.4	97.71	81.65	15.20	303.4	152.6	150.8
11.30	182.1	98.97	83.13	15.30	306.9	154.1	152.8
11.40	184.9	100.2	84.63	15.40	310.3	155.6	154.8
11.50	187.6	101.5	86.10	15.50	313.9	157.0	156.9
11.60	190.4	102.8	87.61	15.60	317.5	158.6	158.9
11.70	193.3	104.1	89.18	15.70	321.1	160.1	161.0
11.80	196.2	105.4	90.75	15.80	324.6	161.6	163.0
11.90	199.0	106.7	92.30	15.90	328.3	163.1	165.2
12.00	201.9	108.0	93.87	16.00	331.9	164.6	167.3
12.10	204.8	109.4	95.47	16.10	335.5	166.1	169.4
12.20	207.8	110.7	97.07	16.20	339.2	167.7	171.5
12.30	210.7	112.0	98.66	16.30	342.9	169.2	173.7
12.40	213.6	113.3	100.3	16.40	346.6	170.7	175.8
12.50	216.6	114.7	101.9	16.50	350.3	172.3	178.1
12.60	219.6	116.0	103.6	16.60	354.1	173.8	180.3
12.70	222.6	117.4	105.3	16.70	358.0	175.4	182.5
12.80	225.7	118.7	107.0	16.80	361.7	177.0	184.7
12.90	228.8	120.1	108.7	16.90	365.6	178.6	187.0
13.00	231.9	121.5	110.4	17.00	369.4	180.2	189.2
13.10	235.0	122.9	112.1	17.10	373.3	181.7	191.5
13.20	238.1	124.2	113.8	17.20	377.1	183.3	193.8
13.30	241.2	125.6	115.6	17.30	381.0	184.9	196.1
13.40	244.3	127.0	117.3	17.40	384.9	186.5	198.4
13.50	247.4	128.4	119.0	17.50	388.9	188.1	200.8
13.60	250.6	129.8	120.8	17.60	392.7	189.7	203.0
13.70	253.8	131.2	122.6	17.70	396.7	191.3	205.3
13.80	257.0	132.6	124.4	17.80	400.7	192.9	207.7
13.90	260.1	134.0	126.2	17.90	404.6	194.6	210.0

Table 2 cont.

ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$	ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$
18.00	408.6	196.2	212.4	24.00	683.9	301.8	382.1
18.10	412.6	197.8	214.8	24.20	694.5	305.6	388.9
18.20	416.7	199.4	217.3	24.40	704.2	309.4	394.8
18.30	420.7	201.0	219.7	24.60	714.9	313.0	401.9
18.40	424.8	202.6	222.2	24.80	725.7	317.0	408.8
18.50	429.0	204.3	224.7	25.00	736.5	320.9	415.6
18.60	433.2	205.9	227.2	25.20	747.2	324.9	422.4
18.70	437.3	207.6	229.7	25.40	758.2	328.8	429.5
18.80	441.5	209.3	232.3	25.60	769.3	332.7	436.6
18.90	445.7	211.0	234.7	25.80	779.7	336.7	443.0
19.00	449.9	212.7	237.3	26.00	790.4	340.5	449.8
19.10	454.2	214.4	239.8	26.20	801.6	344.4	457.2
19.20	458.4	216.1	242.3	26.40	812.8	348.4	464.4
19.30	462.7	217.7	245.0	26.60	824.1	352.3	471.8
19.40	467.0	219.4	247.6	26.80	835.5	356.4	479.1
19.50	471.3	221.1	250.2	27.00	847.0	360.5	486.6
19.60	475.7	222.8	252.9	27.20	857.5	364.6	492.9
19.70	479.7	224.5	255.2	27.40	869.0	368.3	500.6
19.80	483.9	226.2	257.8	27.60	880.6	372.3	508.3
19.90	488.6	227.7	260.9	27.80	892.3	376.4	515.9
20.00	493.2	229.5	263.7	28.00	904.1	380.6	523.5
20.20	501.5	233.0	268.5	28.20	915.8	384.6	531.2
20.40	510.8	236.4	274.4	28.40	927.6	388.8	538.8
20.60	519.9	240.1	279.8	28.60	938.6	393.0	545.7
20.80	528.8	243.5	285.3	28.80	951.2	396.6	554.5
21.00	538.4	247.1	291.3	29.00	963.4	401.1	562.3
21.20	547.5	250.7	296.8	29.20	975.4	405.3	570.1
21.40	556.7	254.2	302.6	29.40	987.1	409.5	577.6
21.60	566.4	257.8	308.6	29.60	998.9	413.5	585.3
21.80	575.6	261.5	314.1	29.80	1011	417.6	593.4
22.00	585.2	264.9	320.2	30.00	1023	421.7	601.6
22.20	595.0	268.6	326.4	30.50	1055	432.4	622.3
22.40	604.3	272.3	332.0	31.00	1086	443.2	643.2
22.60	614.2	275.8	338.4	31.50	1119	454.0	664.5
22.80	624.1	279.6	344.5	32.00	1151	464.9	686.0
23.00	633.6	283.3	350.3	32.50	1184	475.9	708.0
23.20	643.4	286.8	356.6	33.00	1217	487.0	730.2
23.40	653.8	290.5	363.3	33.50	1251	498.1	752.8
23.60	663.3	294.4	369.0	34.00	1286	509.6	776.8
23.80	673.7	297.9	375.7	34.50	1321	521.1	799.9

Table 2 cont.

ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$	ν_{100^o}	ν_L	ν_H	$\nu_{D=L-H}$
35.00	1356	532.5	823.4	55.00	3126	1066	2060
35.50	1391	544.0	847.2	55.50	3180	1082	2098
36.00	1427	555.6	871.2	56.00	3233	1097	2136
36.50	1464	567.1	896.5	56.50	3286	1112	2174
37.00	1501	579.3	921.8	57.00	3340	1127	2213
37.50	1533	591.3	946.8	57.50	3396	1143	2253
38.00	1575	603.1	972.3	58.00	3452	1159	2293
38.50	1613	615.0	998.3	58.50	3507	1175	2332
39.00	1651	627.1	1024	59.00	3563	1190	2372
39.50	1691	639.2	1052	59.50	3619	1206	2413
40.00	1730	651.8	1079	60.00	3676	1222	2454
40.50	1770	664.2	1106	60.50	3734	1238	2496
41.00	1810	676.6	1133	61.00	3792	1254	2538
41.50	1851	689.1	1162	61.50	3850	1270	2579
42.00	1892	701.9	1191	62.00	3908	1286	2621
42.50	1935	714.9	1220	62.50	3966	1303	2664
43.00	1978	728.2	1250	63.00	4026	1319	2707
43.50	2021	741.3	1280	63.50	4087	1336	2751
44.00	2064	754.4	1310	64.00	4147	1392	2795
44.50	2108	767.6	1340	64.50	4207	1369	2858
45.00	2152	780.9	1371	65.00	4268	1386	2882
45.50	2197	794.5	1403	65.50	4329	1402	2927
46.00	2243	808.2	1434	66.00	4392	1419	2973
46.50	2288	821.9	1466	66.50	4455	1436	3018
47.00	2333	835.5	1498	67.00	4517	1454	3064
47.50	2380	849.2	1530	67.50	4580	1471	3110
48.00	2426	863.0	1563	68.00	4645	1488	3157
48.50	2473	876.9	1596	68.50	4709	1506	3204
49.00	2521	890.9	1630	69.00	4773	1523	3250
49.50	2570	905.3	1665	69.50	4839	1541	3298
50.00	2618	919.6	1699	70.00	4905	1558	3346
50.50	2667	933.6	1733				
51.00	2717	948.2	1769				
51.50	2767	962.9	1804				
52.00	2817	977.5	1839				
52.50	2867	992.1	1875				
53.00	2918	1007	1911				
53.50	2969	1021	1947				
54.00	3020	1036	1984				
54.50	3173	1051	2022				

4. DEVELOPMENT OF THE EXERCISE

1. Compare the obtained results with the catalogue viscosity.
2. Calculate by what percentage the viscosity of the tested oil differs from the viscosity of the fresh oil.
3. Compare the calculated deviation with the value of allowable deviations provided by oil manufacturers and determine whether the tested oil, due to its viscosity, is suitable for further use.
4. What diagnostic conclusion is the result of the study.
5. On the basis of the calculated value of the WL viscosity index, evaluate the operational suitability of the tested oil.
6. In tables 3 – 6 at the end of the manual, warning values are given for the basic physicochemical parameters of some oils from the following companies: Elf, Castrol and Mobil as well as limit values recommended by manufacturers of marine engines.

5. THE FORM AND CONDITIONS FOR PASSING THE LABORATORY EXERCISE

1. passing the so-called "entry" before starting the exercise.
2. submission of a correct written report on the completed exercise, which should contain:

   - short theoretical introduction,
   - operational significance of the measured parameter,
   - processing of the obtained results according to the position manual.

3. final credit for the test at the end of the semester.

I. Example of task with solution

The Höppler method was used to measure the viscosity of Marinol RG 1530 oil taken from the cycle of an anhydride motor at a temperature of 40° and 100 °C. Using the data below, calculate the Viscosity and Viscosity Index of this oil. On the basis of the obtained measurements and calculations, determine the operational suitability of the tested oil.

Data:

- the density of the oil measured at 19.6 °C is 0.891 g/cm^3,
- the temperature coefficient of density for this oil is $\alpha = 0.000647$ g/cm$^3 \cdot °C$ (Table 1 of the exercise manual – Density Measurement ...);
- the mean time of the ball flow in the normal direction when measured at 40 °C is 115.8 s;
- mean flow time of the ball in the reverse direction when measured at 40 °C was 116.1 s;
- the density of the ball used to measure the viscosity at 40 °C is 8.144 g/cm^3;
- the ball constant for the normal direction is 0.12106 mPa·cm^3/g;
- the ball constant for the reverse direction is 0.12071 mPa·cm^3/g;
- the mean time of the ball flow in the normal direction when measured at 100 °C is 96.35 s;
- the mean time of the ball flow in the reverse direction when measured at 100 °C is 96.4 s;
- the density of the ball used to measure the viscosity at 100 °C is 2.225 g/cm^3;
- the ball constant for the normal direction is 0.075556 mPa·cm^3/g;
- the ball constant for the reverse direction is 0.07474 mPa·cm^3/g;

Calculations:

Before starting the viscosity calculations, the oil density should be converted from the temperature of this density measurement with a hydrometer, into the temperature of viscosity measurement, i.e., 40° and 100°C, according to the dependence:

$$\rho^{t_1} = \rho^{t_0} - \alpha(t_1 - t_0)$$

where:

ρ^{t_1} – oil density at temperature t_1 [g/cm^3],

ρ^{t_0} – oil density at temperature t_0 [g/cm^3],

α – temperature coefficient of density [g/cm$^3 \cdot$ °C].

thus, the density of the tested oil at 40 °C is:

$$\rho^{40} = 0.891 \text{ g/cm}^3 - 0.000647 \text{ g/cm}^3 \cdot °C(40°C - 19.6°C) = 0.878 \text{ g/cm}^3$$

while the density at 100 °C is:

$$\rho^{100} = 0.891 \text{ g/cm}^3 - 0.000647 \text{ g/cm}^3 \cdot °C(100°C - 19.6°C) = 0.839 \text{ g/cm}^3$$

Calculation of the viscosity of the oil tested at 40°C

The dynamic viscosity determined by the Höppler method at 40°C is calculated from the formula:

$$\eta = K_{n/o}(\rho_k - \rho_c)\tau$$

where:

η – dynamic viscosity of the oil [mPa·s],
K_n – ball constant for normal direction [mPa·cm^2/g],
K_o – ball constant for the reverse direction [mPa·cm^2/g],
ρ_k – ball density [g/cm^3],
ρ_c – the density of the tested oil at the temperature of its viscosity measurement [g/cm^3],
τ – fall time of the ball [s].

for the normal direction, the viscosity is:

$$\eta_{K_n}^{40} = 0.12106 \text{ mPa} \cdot \text{cm}^3/\text{g} \left(8.144 \ \frac{g}{\text{cm}^3} - 0.878 \ \frac{g}{\text{cm}^3}\right) \ 115.8 \ s = 101.86 \text{ mPa} \cdot s$$

for the reverse direction, the viscosity is:

$$\eta_{K_o}^{40} = 0.12071 \text{ mPa} \cdot \text{cm}^3/\text{g} \left(8.144 \ \frac{g}{\text{cm}^3} - 0.878 \ \frac{g}{\text{cm}^3}\right) \ 116.1 \ s = 101.83 \text{ mPa} \cdot s$$

the mean value of the dynamic viscosity determined at 40 °C is:

$$\eta_{sr}^{40} = \frac{101.86 \text{ mPa} \cdot s + 101.83 \text{ mPa} \cdot s}{2} = 101.845 \text{ mPa} \cdot s$$

Then we convert the dynamic viscosity into the kinematic viscosity from the dependence:

$$\nu = \frac{\eta}{\rho_c}$$

where:

ν – kinematic viscosity [mm^2/s],
η – dynamic viscosity [mPa·s],
ρ_c – tested oil density [g/cm^3].

so

$$\nu^{40} = \frac{101.845 \text{ mPa} \cdot s}{0.878 \ g/\text{cm}^3} = 116.03 \text{ mm}^2/\text{s}$$

Conclusion:

The kinematic viscosity of the tested oil at 40°C is 116.03 mm^2/s, and the viscosity of Marinol RG 1530 fresh oil, according to the manufacturer's data, should be in the range 110 – 112 mm^2/s. Thus, the viscosity of the tested oil increased by 4.53%, which proves that this oil is suitable for further use, because the acceptable changes in viscosity in relation to the viscosity of fresh oil are ±25%.

Calculation of the viscosity of the oil tested at 100 °C

The dynamic viscosity determined by the Höppler method at 100 °C is calculated from the formula:

$$\eta = K_{n/o}\left(\rho_k - \rho_c\right)\tau$$

therefore, for the normal direction it is:

$$\eta_{K_n}^{100} = 0.075556\ \text{mPa}\cdot\text{cm}^3/\text{g}\ \left(2.225\ \frac{g}{\text{cm}^3} - 0.839\ \frac{g}{\text{cm}^3}\right)\ 96.35\ s = 10.09\ \text{mPa}\cdot s$$

and for the reverse it is:

$$\eta_{K_o}^{100} = 0.075474\ \text{mPa}\cdot\text{cm}^3/\text{g}\ \left(2.225\ \frac{g}{\text{cm}^3} - 0.839\ \frac{g}{\text{cm}^3}\right)\ 96.40\ s = 10.08\ \text{mPa}\cdot s$$

the mean value of the dynamic viscosity determined at 100 °C is:

$$\eta_{sr}^{100} = \frac{10.09\ \text{mPa}\cdot s + 10.08\ \text{mPa}\cdot s}{2} = 10.085\ \text{mPa}\cdot s$$

Then we convert the dynamic viscosity into the kinematic viscosity from the relationship

$$\nu = \frac{\eta}{\rho_c}$$

so:

$$\nu^{100} = \frac{10.085\ \text{mPa}\cdot s}{0.839\ g/\text{cm}^3} = 12.02\ \text{mm}^2/\text{s}$$

Conclusion:

The kinematic viscosity of the tested oil at 100°C is 12.02 mm^2/s, and according to the manufacturer's data, the viscosity of fresh Marinol RG 1530 oil should be within the range of 11 – 12 mm^2/s. The viscosity of the tested oil increased by 4.55%, which proves that this oil is suitable for further use because the acceptable changes in viscosity are ±25%.

Calculation of the viscosity index – WL

Viscosity index WL is determined from the following equation:

$$WL = \frac{\nu_L - \nu_{\nu_{40^\circ}}}{\nu_L - \nu_H}\cdot 100 = \frac{\nu_L - \nu_{\nu_{40^\circ}}}{\nu_D}\cdot 100$$

where:

ν_L – kinematic viscosity at 40ºC of L series reference oil (WL = 0), at 100ºC having the same kinematic viscosity as the tested oil [mm^2/s] – (Table 2 of the manual);

$\nu_{\nu_{40^\circ}}$ – kinematic viscosity of the tested oil at 40ºC [mm^2/s];

ν_H – kinematic viscosity at 40 °C of the reference oil of the H series (WL = 100), having at the temperature of 100 °C the same kinematic viscosity as the tested oil [mm^2/s] – (Table 2 of the manual);

ν_D – differences between the kinematic viscosities of L and H series reference oils [mm^2/s] – (Table 2 of the manual).

From table 2 of the manual, for the case where the viscosity of the tested oil at a temperature of 100 °C is: $\nu^{100} = 12.0\ \mathrm{mm^2/s}$, we read the data to calculate WL.

Data: $\nu_L = 201.9\ \mathrm{mm^2/s}$, $\nu_L - \nu_H = \nu_D = 93.87\ \mathrm{mm^2/s}$,

and the previously calculated oil viscosity at 40 °C $\nu_{\nu_{40^\circ}} = 116.03\ \mathrm{mm^2/s}$, so:

$$\mathrm{WL} = \frac{201.9\ \mathrm{mm^2/s} - 116.03\ \mathrm{mm^2/s}}{93.87\ \mathrm{mm^2/s}} \cdot 100 = 91$$

The WL viscosity index of the tested oil is 91 and according to the applicable limits for marine engine oils, it cannot be lower than 90, therefore it meets the requirements in this regard.

Final conclusion:

Due to the parameters determined, the tested oil is suitable for further use, and a slight increase in its viscosity suggests that the oil is used in a well-functioning engine and the oil service life is not very long.

Parameters of currently used beads for viscosity measurement

BALL FOR MEASURING VISCOSITY OF OILS AT 40ºC

Ball mass	**– 16.1671 g**
Ball density	**– 8.137 g**
Constant K for the normal direction	**– 0.087758 mPa · cm^3/g**
Constant K for the reverse direction	**– 0.087581 mPa · cm^3/g**

BALL FOR MEASURING VISCOSITY OF OILS AT 100ºC

Ball mass	**– 4.44 g**
Ball density	**– 2.225 g**
Constant K for the normal direction	**– 0.075556 mPa · cm^3/g**
Constant K for the reverse direction	**– 0.075474 mPa · cm^3/g**

II. Tasks and questions to be completed by the student

Tasks

1. The analysis of the used Marinol RG 530 oil taken from the main crosshead engine cycle showed that its kinematic viscosity at 40 °C is 143.99 mm^2/s, and base number BN 12.28 mg KOH/g of oil. Fresh oil parameters are as follows: kinematic viscosity at 40 °C – 110 – 112 mm^2/s, and BN 5 mg KOH/g of oil. Based on the above-mentioned assess the operational suitability of the tested oil and provide the reasons for changes in its parameters.
2. The viscosity and flash point of Marinol RG 2040 oil from the auxiliary engine circuit were determined. The following results were obtained: the kinematic viscosity of the oil is 145.15 mm^2/s, and closed crucible flash point 159°C. Fresh oil viscosity at the temperature of 40°C is within 158 – 170 mm^2/s. Determine the operational suitability of this oil and provide the reasons for changes in its parameters.
3. The viscosity, viscosity index and flash point of the Marinol RG 1530 oil were determined from the run-down of the auxiliary engine. The following results were obtained: the kinematic viscosity of the oil is 134.18 mm^2/s, and the viscosity index WL = 95, closed crucible flash point 202 °C. Fresh oil viscosity at the temperature of 40 °C is within the limits 110 - 112 mm^2/s. Determine the operational suitability of this oil and provide the reasons for changes in its parameters.
4. For Castrol Hyspin AWS68 hydraulic oil, enter the classification and the numerical code in the name.
5. For Marinol RG 2040 oil, state what classification is it and what the numbers in the name mean.

Questions

1. What is viscosity, what are its types and units?
2. What are the methods of measuring viscosity and how is the kinematic viscosity of a lubricating oil determined?
3. Explain the operational importance of viscosity as one of the basic operational parameters of lubricating oils.
4. What factors influence the viscosity?
5. How does the viscosity of an engine oil change during operation and what are the reasons for this?
6. What are the viscosity change limits for circulating oils in trunk piston engines?
7. What is the WL viscosity index of lubricating oils, what is it and what are its values for mineral and synthetic oils?
8. How is the WL of lubricating oils determined?
9. What is the viscosity classification of motor oils and what are its criteria?
10. Specify the viscosity grades for the circulating oils of trunk piston engines, crankcase oils of crosshead engines and cylinder oils.
11. Provide the rules of viscosity classification for non-engine oils (hydraulic, gear, turbine).

Auxiliary tables

Table 3

Warning values for the basic physicochemical parameters of some Elf oils

Markings	Disola M3015 Disola M4015	Aurelia XT4040
Kinematic viscosity at 40°C [mm^2/s]	+30% –20%	+30% – 20%
Base number [mg KOH/g]	> 8	> 15
Flash point in a closed cup [ºC]	> 180	> 180
Water content [%]	< 0.3	< 0.3
Content of impurities insoluble in n-pentane [%]	< 2	< 2

Table 4

Warning values for the basic physicochemical parameters of some Castrol oils

Markings	Castrol MPX 40 Castrol MLC 40	Castrol MXD 303
Kinematic viscosity at 40°C [mm^2/s]	± 25%	± 25%
Base number [mg KOH/g]	– 50%	–50%
Flash point in a closed cup [°C]	> 180	> 180
Water content [%]	< 0.2	< 0.2
Content of impurities insoluble in n-pentane [%]	< 2	< 4

Table 5

Warning values for the basic physicochemical parameters of some Mobil oils

Markings	Mobil 312	Mobil 412	Mobil 442
Kinematic viscosity at 40°C [mm^2/s]	min mm^2/s max 143 mm^2/s	min 102 mm^2/s max 218 mm^2/s	min 102 mm^2/s max 218 mm^2/s
Base number [mg KOH/g]	– 50%	– 50%	– 50%
Flash point in a closed cup [ºC]	> 190	> 190	> 190
Water content [%]	< 0.2	< 0.2	< 0.2
Content of impurities insoluble in n-pentane [%]	< 2	< 2	< 2

Table 6

Limits for the basic physicochemical parameters of lubricating oils recommended by Western manufacturers of marine engines

Compression ignition engines			Kinematic viscosity [mm^2/s] at 100°C		Flash-point FP	Max water content	Contaminant content	BN
manufacturer	type	model	min	max	[ºC]	[% weight]	[% weight]	[mgKOH/g]
1	2	3	4	5	6	7	8	9
Daihatsu	four-stroke	all	–20%	+30%	180	0.1% vol.	2.5	3.0 for fuel (MDO) 5.0 for fuel (LMFO) 10.0 for fuel (HFO)
Deutz-MWM	four-stroke	D/TBD 234 TBD 604 B S/BAM 816	9 (SAE 30) 11 (SAE 40)	+25%	190	0.2	2.0	min 50%
	four-stroke	D/TBD 440 S/BAM 628 TBD 645 R/S/BVM 640	9 (SAE 30) 11 (SAE 40)	+25%	190	0.2	2.0	min 60%
Krupp MaK	four-stroke	all	80 at 40°C (SAE 30) 130 at 40°C(SAE 40)		180	0.2	2.0	min 15* min 18**,*** min 50% for fuels MDO/MGO
MAN B&W	four-stroke two-stroke	20/27 to 58/64	±1 degree SAE		185	0.5	1.5	min 50%* min 70%**
MTU	four-stroke	all	9,0 (SAE 30) 10,5 (SAE 40)	+25%	190	0.2	2.5	min 50%
Wartsila	four-stroke	VASA 46	11.5 for 40°C 95	19 for40°C 212	170	0.3 (0.5)	2.0	50% min 15
Sulzer	two-stroke (oil cooling of the pistons)	RTA 84 C/M/T 72, 62, 52 48, 38	–10%	+20%	180	0.5	0.5	min 5
	two-stroke (water cooling of the pistons)	RTA 84, 76, 68, 58 and all RND, RLA i RLB	–10%	+20%	180	0.5	0.5	min 5
	four-stroke	Z40, ZA40, ZA40S	–20%	+30%	180	0.5	2.5	min 60%
	four-stroke	type-A andS20	–20%	+30%	180	0.5	2.5	min 50%
Yanmar	four-stroke	all	–20%	+30%	180	0.3% vol.	2.0	4 (for fuel MDO) 15 (for fuel HFO)

* engines with separate cylinder oil circuit, fuelled by HFO,
** HFO fuelled engines without separate circulation of cylinder oil,
*** applies to the MaK 453 C engine.