H.O. Sirenko, I.V. Sulyma, N.V. Shmaltser

Problems of Selection of Lubricants for Ethylene High-Pressure Compressors. 3. Investigation of Viscous-and-Thermal Properties of Lubricants

Vasyl Stefanyk Precarpathian National University, 57 Shevchenko Str., Ivano-Frankivsk, 76018, Ukraine

The viscous-and-thermal properties of naphtene and polyglycol oils and compositions on their basis have been studied. The investigate lubricants for high-pressure ethylene compressors have estimated according to a complex criterion which is included the co-relation of viscosity of oils for two temperatures; relative and interval temperature coefficient of viscosity and three coefficients of an adequate equation of approximation of dependence the logarithm of viscosity on the logarithm of temperature. A comprehensive assessment made it possible to complite the lubrication efficiency rows.

Key words: lubricant**,** ethylene compressors, relative temperature coefficient, interval temperature coefficient, logarithm of viscosity.

Introduction

It is known, that viscous-and-thermal characteristic of oils, which are used in high-pressure compressors, is one of the important operating properties of lubricant [1-6]. This determines by such basic reasons:

• For oils of one chemical group antiwear and antiseizure characteristics increase when viscosity increases. And also viscosity increases when pressure increases. For naphtene oils when pressure increases from 0.1 to 100 MPa, viscosity increases by 10-20 times.

• When temperature increases viscosity decreases, pressure influence on viscosity becomes less noticeable.

• Thus, value of viscosity change when pressure changes depends on composition, structure of molecule and **temperature.**

I. Experimental

Testing of viscosity-and-thermal characteristic **were** **c**arried out on the viscosimeter ВПЖ-4 using standard methods.

Viscous-and-thermal properties of machines, naphtene, polybutene, polyglycol and others oils for ethylene high-pressure compressors were evaluated by:

• indexes of dynamic η_t and kinematic v_t viscosities in the diapason of the temperature 20-100°C with the viscosimeter VPZh-4 (Tabl. 1);

• thermal coefficients – correlations of viscosities at t_1 and t_2:

$$C_t = \frac{v_{t_1}}{v_{t_2}} \qquad (1)$$

where v_{t_1}- kinematic viscosity at 45°C **(C₁)** or at 50°C (C₂);

v_{t_2}- kinematic viscosity at 90°C (C₁) or at 100°C (C₂);

(*for polybutenes $C_1 = v_{45^0}/v_{100^0}$);

• thermal coefficient of viscosity

$$TCV_1 = \frac{v_{t_1} - v_{t_2}}{v_{t_2}} \text{ or } TCV_2 = \frac{(v_{t_1} - v_{t_2})k}{v_{t_3}} \qquad (2)$$

for instance: for oils with low viscosity and medium viscosity

$$TCV_2 = \frac{v_{0^0} - v_{100^0}}{v_{50^0}} \qquad (3)$$

for oils with high viscosity

$$TCV_2 = \frac{v_{20^0} - v_{100^0}}{v_{50^0}} \cdot 1,25; \qquad (4)$$

in this work was used coefficient

$$TCV_2 = \frac{v_{30^0} - v_{90^0}}{v_{60^0}} \text{ and C=1;} \qquad (5)$$

• interval coefficient of viscosity

$$\Delta T = \frac{v_{t_1} - v_{t_2}}{t_2 - t_1} \qquad (6)$$

in this work was used coefficient

$$\Delta T = \frac{v_{30^0} - v_{90^0}}{t_{90^0} - t_{30^0}}; \qquad (7)$$

• parameters ***a*** and β of curve ***lg*** $v = $ ***a*** $+ \beta$ ***lg*** ***t***,where β – tangent of obtuse angle of incline of straight line ***lg*** $v = \varphi$ (***lg t***), to the axis of abscissas; in the work were used more convenient dependences of viscosity on inverse temperature for finding the acute angle:

$$\mathbf{lg} \, v_i = a_i + b_i \, lg \frac{1}{t}, \qquad (8)$$

H.O. Sirenko, I.V. Sulyma, N.V. Shmalzer

Table 1

Comparable viscous-and-thermal characteristics of oils and lubricating compositions

Oil, additive		Kinematic viscosity at t°C, cs							
		20	30	40	45	50	60	90	100
Risella-33			126	68.5	49	42.4	27.7	10.4	8.8
Risella-17			18.9	13.9	12.3	10.5	7.8	4.1	4.02
Vitorex 334			132	78.9	49.7	42.9	26.3	11.3	9.13
Esso-CHristo			121	68.9	53.8	47.9	28.2	10.6	10.3
5350			131	69.2	42.5	39.3	29.0	11.9	8.7
Vaseline oil			78	50.4	44.6	34.9	23.8	9.9	7.74
NKM-40			80.2	56.6	47.8	39.3	26.8	10.6	9.79
NKM-70			148.4	83.2	65.07	52.72	36.26	15.9	12.82
Polybutene for succynimide additives			16321	7422	5830	3683	1961	374	288
Polybutene Tredkat-99			1799	1475	1074	759	464	146	53.7
Lowmolecular polybutene			61404	13842	12851	7277	1968	172	93.6
Risella-33+ Polybutene for succynimide additives	30		630	300	220	182	108	36.5	30,2
	50		826	405	275	233	139	42.9	34,8
KPL 201		420	258.2	115	89	68	42.8	15.4	11.8
Witco CL 1000		824	378	194	143	104	61.86	23	20.6
Witco CL 1200		880	430	225	184	120	71	26	23
Witco CL 1500		1190	612	300.4	215	158	90	29.5	25
Orites 210 DS		650	462	280	237	186	135	59	46.8
Polyol LG 56			362	224	175	143	98	41.8	36.9
Orites (regen.)			443		226	177.2	130	60.3	49.7
Syntheso D201		800	461	300	245	200	140	62	52
Syntheso D201N		865	615	310	262.4	210	144.2	62.2	50
Syntheso D202		890	634.9	307	264.7	208	138.9	57.9	46
Breox CL 1300			409.9	250	205.4	171	125.8	63.2	52.8
Breox 1400			485	272	221.7	181	127.6	58.2	47.4
KSM			443		232	176.4	138	61	50.86
Laprol 202			44.1	25.8	19.8	16.5	10.7	4.3	3.9
Laprol 602			63.6	43.7	35.3	27.7	19.6	8.4	7.77
Laprol 2002			298	198	163	135	93.1	40.5	38.9
Laprol 503			209	110	76.6	59.6	36.6	12.3	10
Laprol 3003			295	176	143	119	86.2	41.8	35.1
Laprol 2502			417	269	230	182	137	60	53.96
Laprol 3503-2-70			574.6	338	275	228	162	76.7	64.47
Laprol 3503-2-Б5			374	230.5	190	159	115	58.9	49.29
PVBE+Risella, %									
100 -			12227	5799	4239	3021	1970	720	
50 50			970	483	360.5	304	197	68.7	
- 100			126	68.5	49	42.4	27	10.4	8.8

where $b_i = \dfrac{lg\frac{v_{t_1}}{v_{t_2}}}{lg\frac{t_1}{t_2}}$, $i = 1,2,3;$ (9)

As criterions of assessment of viscous-and-thermal properties were chosen:

1) b_1 for $t_1 = 30°C$, $t_2 = 90°C$;
2) b_2 $t_1 = 30°C$, $t_2 = 60°C$;
3) b_3 $t_1 = 60°C$, $t_2 = 90°C$;
4) mean arithmetical $\overline{b} = \dfrac{\sum_{i=1}^{n} b_i}{n}$;   (10)
5) mean quadratic $\overline{b_q} = \sqrt{\dfrac{1}{n}\sum_{i=1}^{n} b_i^2}$ (11)

6)   mean quadratic deviation from the mean arithmetical

$$S_{n-1} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(b_i - \overline{b})^2} \quad (12)$$

Oils with less value of indexes C_t, TCV and ΔT havegood viscous-and-thermal properties.

Declivity of viscous-and-thermal characteristic of oil was found by the tangent of acute angle of incline of straight line $\lg\eta = f\left(lg\frac{1}{T}\right)$ to the axis of abscissas: less value of coefficient b, less changes viscosity from temperature. This parameter was used as substitution to less definable index of viscosity.

Viscous-and-thermal characteristics of naphtene and polyglycol oils [7] and polibutene [8] for lubrication of ethylene high-pressure compressors

Oils	Viscous-and-thermal coefficients					
	C_1	TCV_2	ΔT	b_1	b_2	b_3
Naphtene:						
Risella-33	4.72	3.32	1.86	2,245	1,861	2,903
Risella-17	2.93	1.89	0.25	1,279	1,274	1,555
NKM-70	5.23	3.74	3.07	2,303	2,022	1,783
NKM-40	4.47	2.60	1.16	1,838	1,581	2,278
Esso-Christo	5.08	3.19	1.83	2,215	2,099	2,414
Vitorex-334	4.40	4.57	2.00	2,233	2,322	2,081
5350	4.41	4.11	1.99	2,187	2,176	1,997
Polybutene:						
Polybutene for succynimide additives (M=860)	20.27[*]	8.18	265.8	3,443	3,065	4,070
Polybutene Tredkat-99(M=460)	20.0[*]	3.56	27.55	2,283	1,956	2,844
Risella-33+50% of polybutene (M=860)	7.02	5.64	13.05	2,693	2,572	2,900
Risella-33+30% of polybutene (M=860)	4.87	5.05	1.99	2,214	2,468	1,781
Polyglycol:						
KSM	3.80	2.77	6.37	1,804	1,681	2,014
Orites-210 DS	4.02	2.60	3.72	1,873	1,574	2,384
Laprol-2502-2-70	3.83	2.61	5.95	1,765	1,610	2,030
Glicerin	8.27	6.61	6.25	2,931	2,783	3,190
Mineral:						
Compresorna 12(M)	5.67	3.68	3.55	2,255	2,004	2,702
Vaseline	4.47	2.86	1.13	1,872	1,715	2,140
Indusrtrial-20	3.53	2.57	0.83	1,686	1,607	1,821
Aviacijna MS-20	6.44	3.75	14.9	2,448	2,009	3,197
Oils	Viscous-and-thermal coefficients					
	$\bar{b}$		$\bar{b_q}$		S_{n-1}	
Naphtene:						
Risella-33	2.336		2.376		0.5270	
Risella-17	1.403		1.407		0.1420	
NKM-70	2.369		2.3899		0.3848	
NKM-40	1.899		1.921		0.352	
Esso-Christo	2.243		2.247		0.1593	
Vitorex-334	2.212		2.214		0.1219	
5350	2.12		2.122		0.1067	
Polybutene:						
Polybutene for succynimide additives (M=860)	3.526		3.549		0.5076	
Polybutene Tredkat-99(M=460)	2.361		2.389		0.5447	
Risella-33+50% of polybutene (M=860)	2.722		2.725		0.1659	
Risella-33+30% of polybutene (M=860)	2.154		2.1729		0.3474	
Polyglycol:						
KSM	1.833		1.838		0.1684	
Orites-210 DS	1.944		1.972		0.4096	
Laprol-2502-2-70	1.802		1.809		0.2124	
Glicerin	2.968		2.973		0.2060	
Mineral:						
Compresorna 12(M)	2.320		2.338		0.3536	
Vaseline	1.909		1.917		0.2149	
Indusrtrial-20	1.705		1.707		0.1082	
Aviacijna MS-20	2.551		2.598		0.6007	

Results of calculations of coefficients C_1, TCV_2, ΔT and b_1, b_2, b_3, $\bar{b}$, $\bar{b_q}$, S_{n-1} for naphtene, polyglycol and polybutene oils and glicerin are adduced in Tabl.2.

Coefficients C_1, TCV_2, ΔT are conditional and are used for estimation and comparison of viscous-and-thermal properties of one level viscosity oils, for coefficients b_1,

b_2, b_3, $\bar{b}$, $\overline{b_q}$, S_{n-1} this estimations can be used for more wide diapason of viscosity.

II. Result and discussion

1. Analysis of results, which are adduced in Tabl. 1 and Tabl. 2 shows, that for naphtene oils Vitorex-334, Esso-Christo, 5350, Risella-33, NKM-40 with similar viscosity kinematic viscosity equals at 90°C 10,4-11,3 cs and at 45°C 47,8-53,8 cs coefficient C_1 varies from 4,4 to 5,08; TCV_2 – from 2,6 to 4,57; ΔT – from 1,16 to 2,0 cs/°C; b_2 – from 1,838 to 2,245; b_2 – from 1,581 to 2,322; b_3 – from 1,997 to 2,903; $\bar{b}$, – from 1,899 to 2,243; $\overline{b_q}$ from 1,921 to 2,247; S_{n-1} from 0,1219 to 0,5270.

Decreasing of viscosity of oil Risella (comp. Risella-33 and Risella-17) from 10,4 to 4,2 cs (at ~60%) at 90°C and from 49,1 to 12,3 cs (at ~75%) at 45°C leads to decreasing of coefficients: C_1 from 4,72 to 2,93 (at~62%); TCV_2 – from 3,32 to 1,89 (at~43%); ΔT – from 1,86 to 0,25 cs/°C (at~87%); b_1 – from 2,245 to 1,379 (at~35%); b_2 – from 1,861 to 1,274 (at~32%); b_3 – from 2,903 to 1,555 (at~46%); $\bar{b}$ - from 2,336 to 1,403 (at~40%); $\overline{b_q}$- from 2,376 to 1,407 (at~41%); S_{n-1} from 0,5270 to 0,1420 (at~70%).

Decreasing of viscosity of oil NKM (comp. NKM-70 and NKM-40) at ~33% at 90°C and at ~43% at 45°C leads to decreasing of coefficients: C_1 at ~15%; TCV_2 at ~31%; ΔT at ~62%; b_1 at~20%; b_2 at ~22%; b_3 at ~18%; $\bar{b}$– from 2,369 to 1,899 (at~20%); $\overline{b_q}$- from 2,3899 to 1,9210 (at~20%); S_{n-1} from 0,3848 to 0,3520 (at~8,5%).

For the statistic copolymer of propylene and ethylene oxides of oils KSM, Orites-210 DS and Laprol-2502-2-70 with similar viscosity these coefficients change little.

For polybutene and mineral oils coefficients C_1, TCV_2, ΔT vary in wide bounds, coefficients b_1, b_2, b_3 are comparable with naphtene and polyglycol oils.

Thus we can introduce mean sum of each coefficient for generalized assessment of viscous-and-thermal characteristic of oils (Tabl. 2).

By this estimation we have a row of oils by viscous-and-thermal properties

effectiveness increases

a) by C_1 polybutene > glycerin > mineral > naphtene > polyglycol;
b) by TCV_2 glycerin > polybutene> naphtene > mineral > polyglycol;

c) by ΔT polybutene > polyglycol> glycerin > mineral > naphtene;

d) by b_1 glycerin > polybutene > mineral > naphtene > polyglycol;

e) by b_2 glycerin > polybutene > naphtene > mineral > polyglycol;

f) by b_3 glycerin > polybutene > mineral > naphtene > polyglycol;
g) by average of sum of C_1, TCV_2, ΔT

polybutene > glycerin > mineral > polyglycol > naphtene.

Assessment of viscous-and-thermal properties of oils by mean sum of coefficients b_1, b_2, b_3 (that is by $\bar{b}$ and $\overline{b_q}$), which takes account of declivity of dependence $v = f(T)$ at different temperature sections (parts) gives another row of oils by viscous-and-thermal properties (in order of high estimation):

effectiveness increases

a) by $\bar{b}$ glycerin > polybutene > mineral> naphtene > polyglycol;

b) by $\overline{b_q}$ glycerin > polybutene > mineral > naphtene > polyglycol;

c) by S_{n-1} polybutene > mineral > polyglycol> naphtene > glycerin;
d) by mean sum of coefficients $\bar{b}$, $\overline{b_q}$, S_{n-1}

glycerin > polybutene > mineral > naphtene > polyglycol.

Dependences of viscosity from temperature and pressure which are represented in Fig. 1- Fig. 3 [4; 7], confirm preferences of polyglycol oils. In Fig. 1 dependence of dynamic viscosity η (cp) for initial naphtene (1) and glycol (3) oils and these oils in saturation state (2 i 4 accordingly) from temperature is represented.
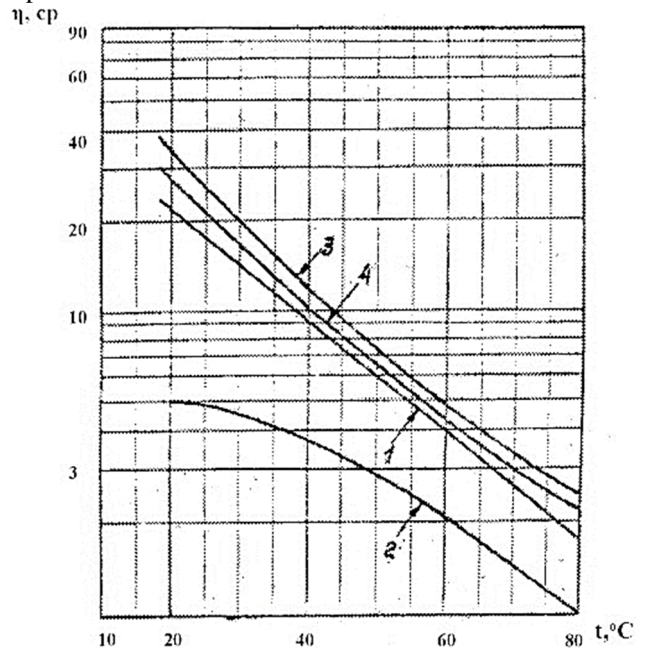

Fig. 1. Dependence of dynamic viscosity of initial oil (1,3) and of oil in saturation state by ethylene (2,4) on the temperature:
1,2-naphtene oil SAE-40 (Risella-33);
3,4-polyglycol oil Orites 125 DS (Orites 88 DS) [4; 7]

In fig. 2 and fig.3 relation of dynamic viscosity from pressure of naphtene oil Codex H23, polyglycol Orites 88DS (modern Orites 125 DS), Ucon 75H 1400, Orites 210 DS (modern Orites 270DS) and polybutene Orites L66 (modern Orites 125 MS) and Orites L100 (modern

Orites 270 MS) oils (t= 50° 80°C) are shown. Polybutenes have enough high temperatures of flashing (t$_{fl.}$)[8], which increase when molecular mass increases (M):

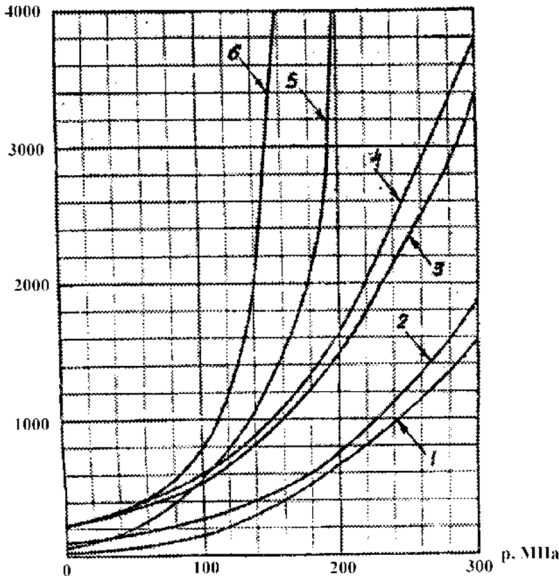| M	660	700	780	940	1410	1520
t$_{fl.}$,°C	280	325	360	>500	>500	>500

Fig. 2. Relation of viscosity of oils from pressure (at t=50°C):
1 – naphtene oil Codex H23; 2 – polyglycol oil Orites 125 DS (Orites 88DS); 3 – polyglycol oil Ucon 75H 1400; 4 – polyglycol oil Orites 270 DS (Orites 210 DS); 5 – polybutene oil Orites 125MS (Orites L 66); 6 – polybutene Orites 270 MS (Orites L 100) [4; 7]
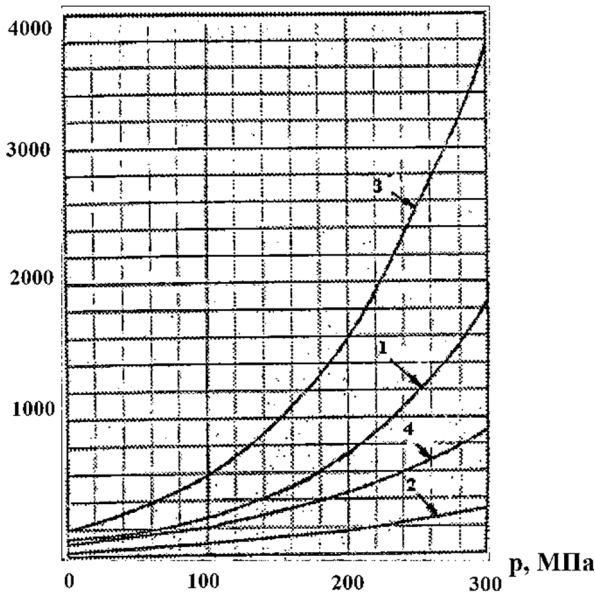
Fig. 3. Relation of dynamic viscosity of polyglycol oil with pressure at 50°C (1,3) and 80°C (2,4):
1,2 – Orites 125 DS (Orites 88 DS); 3, 4 – Orites 270 DS (Orites 210 DS) [4; 7]

In Fig. 3 dependences of dynamic viscosity on pressure for polyglycol oils Orites 125 DS (Orites 88 DS) and Orites 270 DS (Orites 210 DS) at t=50 i 80 °C are represented.

Comparing of naphtene oils by viscosity shows that oils with low viscosity have more acute viscous-and-thermal characteristic than oils with high viscosity. (Fig.4).
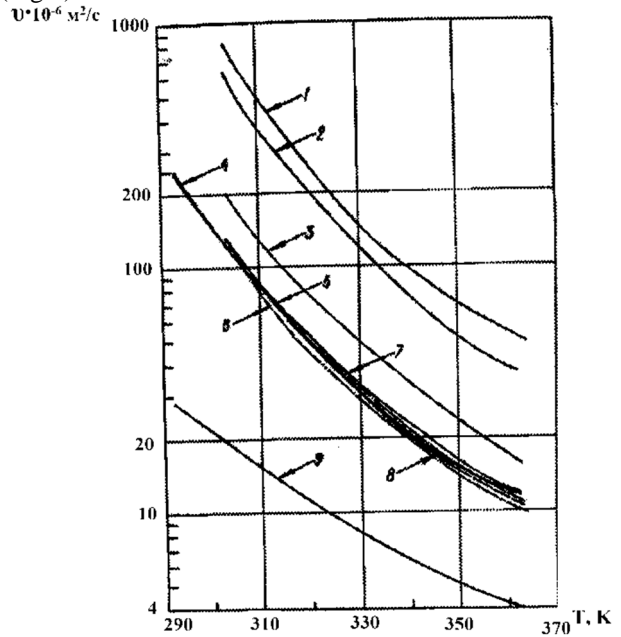

Fig.4. Viscous-and-thermal characteristic of naphtene oil:
1 – Risella -33 + 50% of polybutene "Tredkat-99"; 2 – Risella 33 +30% of polybutene for succynimide additives; 3 – NKM-70; 4 – Risella 33; 5 – X (Japan); 6 – Vitorex-334; 7 – NKM-40; 8 – 5350; 9 – Risella-17.

Viscous-and-thermal characteristic of polyglycols: Laprol-202; Laprol-602; Laprol-1002; Laprol-2002; Laprol-503; Laprol-3003; Polyol LG-56; Laprol-5003; Laprol-1503; Laprol-2502; Syntheso-D 201; Orites-270 DS (regenerative); Syntheso-D 201 N; Laprol-3503-2-70; Laprol-3503-2-65 are represented in the Fig. 5.

This information is adduced in Tabl. 1 and coefficients of viscous-and- thermal characteristic are calculated.

Viscous-and-thermal characteristic of statistic copolymer of propylene and ethylene oxides of oils KSM, Orites-210 DS and Laprol-2502-2-70 with similar viscosity is represented in Fig. 6.

Conclusions

1. Studying of viscous-and-thermal properties of naphtene and polyglycol oils and choosing characteristics that the most complete characterize these properties.

2. For the first time, an estimation of the viscous-and-thermal properties of lubricating oils and compositions on their basis was made for the lubrication of surfaces of solids of dynamic contact of friction units designed for high and high-pressure ethylene compressors, according to a complex criterion:

- the ratio of viscosity of oils for two temperatures;
- relative temperature coefficient of viscosity;
- interval temperature coefficient of viscosity;
- three coefficients of an adequate equation of approximation of the logarithm of viscosity dependence on the logarithm of temperature for three temperature intervals: on 30° to 90°C, on 30° to 60°C, on 60° to 90°C.

3. The comprehensive assessment of the viscosity and temperature properties of these lubricating oils and compositions of lubricating oils behind the root-mean-square and arithmetic mean of these coefficients and the root-mean-square deviations from the arithmetic mean of these coefficients was represented. which made it possible to compile 11 rows of the efficiency of the lubricating oils

10 – Laprol-2502; 11 – Syntheso-D 201; 12 – Orites-270 DS (regenerative);

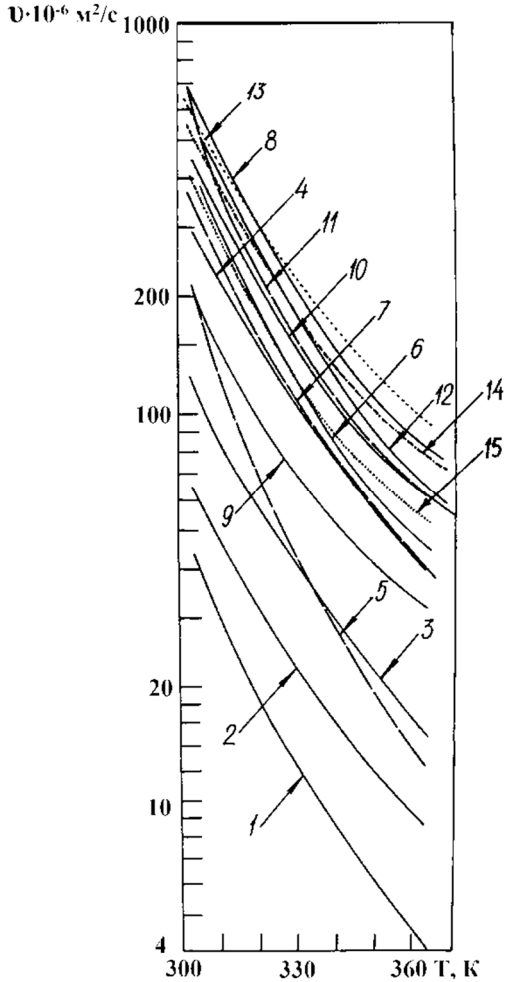13 – Syntheso-D 201 N; 14 – Laprol-3503-2-70; 15 – Laprol-3503-2-B5.

Fig. 6. Viscous-and-thermal characteristic of synthetic oils:

1 – Orites -210 DS; 2 – KSM; 3 – Laprol 2502-2-70; 4 – Glycerin; 5 – Esso-Christo

Fig. 5. Viscous-and-thermal characteristic of polyglycols:

1 – Laprol-202; 2 – Laprol-602; 3 – Laprol-1002;
4 – Laprol-2002; 5 – Laprol-503; 6 – Laprol-3003;
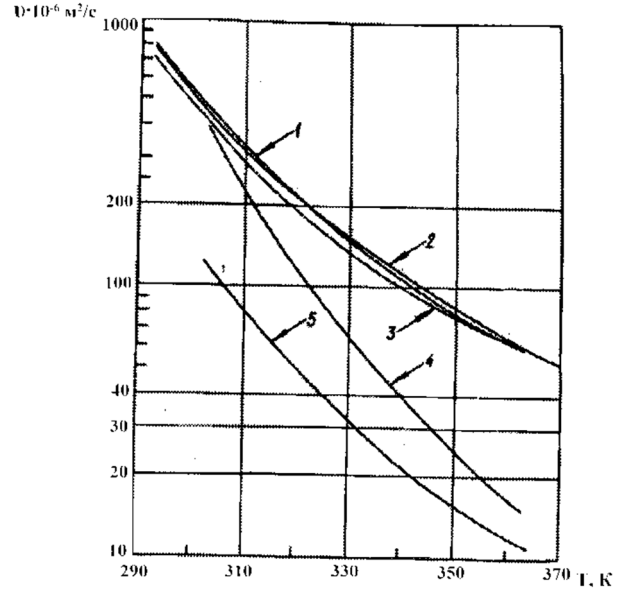7 – Polyol LG-56; 8 –Laprol-5003; 9 – Laprol-1503;

Sirenko H.O. – Profesor, Doctor of Technical Sciences? Professor of Department of General and Applied Chemistry;
Sulyma I.V. – Masters, Assistant chemist of LLC "Karpatnaftohim";
Shmalster N.V. – Masters, Ph.D. student of Department of General and Applied Chemistry.

[1] H.A. Sirenko, R.V. Hrinevych, I.I. Novikov, Thes. of the Rep. of the all-union Scient. and Techn. Confer. "Tribonica and antifriction material science" (NPY, Novochekassk, 1980), p. 156. (in Russian).

[2] H.A. Sirenko, I.I. Novikov, V.P. Zakharenko, A.M. Zavoyko and etc., Grease for high-pressure ethylene compressors: A.S., 1063105 USSR, MKI S 10 M1/28 / - No 3263977; Declaring. 23.03.81, (47), (1983). (in Russian).

[3] A.M. Zavoyko, I.I. Novikov, H.A Mirenko and etc, Chemical and petroleum engineering, (1), 19 (1984) (in Russian).

[4] A.M. Zavoyko, I.I. Novikov, H.A. Mirenko, A.H. Platonov, On the selection of oils for the production of high-density polyethylene (NiiTechim, Moskva, 1987) (in Russian).

[5] H.O. Sirenko, Science Zb. "Bulletin of the All-Ukrainian scient. and prof. Assoc. of M. Mikhnovsky, (9),1 (1998) (in Ukrainian).

[6] H.O. Sirenko, O.V. Kuzyshyn, F,V, Zavoiko. Problems of selection of lubricants for ethylene high-pressure compressors. 1.Statement of a question lubricants // Problem of Tribology, (4), 149 (2003).

[7] Advertising information of ELF Aquitaine (France) at the exhibition "Neftegazekspo-79",

(TSINTIKHIMNEFTEMASH, Moskov, 1979), (18/12), p.3 (in Russian).

[8] Polybutene – Polyvis // Bulletin «Cosden Petroleum Corporation». – Translation No. P-121, (VNIINEFTEKHIM, Lviv, 1964), p.3 (in Russian).ослинних олив // Тези допов. **V** регіональної конференції молодих вчених та студентів з. **41 (2003)**.

Г.О. Сіренко, І.В. Сулима, Н.В. Шмальцер

Проблеми вибору мастил для етиленових компресорів високого тиску. 3. Дослідження в'язко-температурних властивостей мастил

[1]*Прикарпатський національний університет імені Василя Стефаника, вул. Шевченка, 57, м. Івано-Франківськ, 76018, Україна*

Вивчено в'язко-температурні властивості нафтових та полігліколевих олив та композицій на їх основі. Досліджені мастила для етиленових компресорів високого тиску оцінюються за складним критерієм, що включає співвідношення вязкостей олив за двох температур; відносний і інтервальний температурний коефіцієнти в'язкості та три коефіцієнти адекватного рівняння апроксимації залежності логарифму в'язкості від логарифму температури. Комплексна оцінка дозволила скласти ряди ефективності олив.

Ключові слова: мастило, етиленові компресори, відносний температурний коефіцієнт, інтервальний температурний коефіцієнт, логарифм в'язкості**.**