

## **Temperature Dependence of the Viscosity of Hydrocarbon Fractions**

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### **Abstract**

This study deals with the determination of viscosity using the Ubehlode viscosimeter and the HAAKE RV2 rotation viscosimeter. The viscosities of hydrocarbon fractions were measured between  $-20^{\circ}\text{C}$  and  $140^{\circ}\text{C}$ . Diesel fuel, vacuum distillates and asphalt were used as samples. The temperature dependences of Walter, Mehrotra and Umstätter equations were used for the calculation of viscosity values by extrapolation and intrapolation. The calculated viscosities compared with experimental values.

**Keywords:** viscosity, temperature dependence, hydrocarbon fractions

### **Introduction**

The viscosity of liquid hydrocarbon mixtures has an important role in technological practice. It is used in the calculation of heat transfer coefficients, pressure drops, hydraulic properties and rheological and tribological evaluations. Often the viscosity of medium and high viscosity mixtures must be adjusted at particular temperature. Liquid viscosity is one of most difficult properties to calculate with accuracy. No single method is satisfactory for all temperatures and viscosity ranges. The comparison of experimental results with calculated values of hydrocarbon fractions viscosity at particular temperatures may help to select a suitable method.

### **Theoretical**

At saturation pressure, the liquid viscosity variation with temperature follows a law analogous to that of Clapeyron for vapor pressure (Wauquier 1995):

$$\log\left(\frac{\mu}{\mu_0}\right) = B\left(\frac{1}{T} - \frac{1}{T_0}\right) \quad (1)$$

Where

$\mu, \mu_0$  = dynamic viscosity of liquid [mPa.s]

$T, T_0$  = temperature [K]

$B$  = viscosity coefficient

Equation (1) was used by Ducoulombier (Ducoulombier at all 1986). The study deals with the determination of the viscosities of n-alkanes, alkylbenzenes (butyl, hexyl, and octyl), and some alkane mixtures, between 20°C and 100°C and from one to 1000 bars. A phenomenological equation has been derived from the experimental viscosity values.

In order to formulate the dependence of hydrocarbon liquid viscosity on temperature, a number of relations were proposed. The logarithmic values of dynamic or kinematic viscosity that constitute the temperature exponential function are used most frequently:

$$\log(\mu + c) = aT^b \quad \text{or} \quad \log(\nu + c) = aT^b \quad (2)$$

Where

$T$  = temperature [K]

$\mu$  = dynamic viscosity [mPa.s]

$\nu$  = kinematic viscosity [mm<sup>2</sup>.s<sup>-1</sup>]

$a$  = correlation coefficient

$b$  = correction coefficient for the variation of viscosity with temperature

$c$  = viscosity correlation factor

Coefficients  $a$  and  $b$  can be determined from the experimental viscosities of the hydrocarbon compound or mixtures at 40 and 100°C. Walter used equation (2) for kinematic viscosity (Walter 1933) and Mehrotra for dynamic viscosity (Merlotra 1990). Both equations are used in logarithmic form with various values of the  $c$  coefficient. In Walter's equation, the  $c$  value is in the interval from 0.6 up to 0.8, with smaller values for higher viscosities. Merhotra uses the  $c$  coefficient equal to 0.8. The ASTM standard (ASTM D341 2003) is based on Walter's equation and proposes the dependence of the kinematic viscosity of hydrocarbons on temperature by a straight line on graph paper for which the scales are such that:

$$\log \log(\nu + f(\nu)) = a + b \log T \quad (3)$$

where

$$\begin{aligned}
 T &= \text{temperature} && [\text{K}] \\
 \nu &= \text{kinematic viscosity} && [\text{mm}^2 \cdot \text{s}^{-1}] \\
 a, b &= \text{straight line coefficient} && \text{s} \\
 f(\nu) &= 0,7 && \text{for } \nu \geq 1,5 \text{ mm}^2 \cdot \text{s}^{-1} \\
 f(\nu) &= 0,7 + 0,085(\nu - 1,5)^2 && \text{for } \nu < 1,5 \text{ mm}^2 \cdot \text{s}^{-1}
 \end{aligned}$$

The straight line and consequently its coefficients are determined starting from two known viscosity values.

It is known, that the Walter, Mehrotra and ASTM methods apply with accuracy only for viscosities between 1 and 1000 mPa.s or  $\text{mm}^2 \cdot \text{s}^{-1}$ . Umstätter [Umstätter 1940] established an argument of hyperbolic sinus as a parameter for dependence viscosity on temperature by the equation:

$$\arg \sinh \ln \nu = a - b \ln T \quad (4)$$

The viscosity calculation according to equation (4) has not found application in practice. The transformation of a viscosity natural logarithm to a hyperbolic sinus argument is uncomfortable. That is why it is useful to replace the inverse hyperbolic function with a logarithmic function:

$$\arg \sinh x = \ln(x + \sqrt{x^2 + 1}) = a - b \ln T \quad (5)$$

by substituting  $x = \ln \nu$  into equation (5) we will get a logarithmic form for the Umstätter inverse hyperbolic function:

$$U = \arg \sinh \ln \nu = \ln(\ln \nu + \sqrt{(\ln \nu)^2 + 1}) \quad (6)$$

If viscosities at two different temperatures are known (for example 40 and 100°C) the Umstätter function may be used in its logarithmic form for the calculation of viscosity according to relation (4). Acquiring the viscosity value from the Umstätter function at particular temperatures is given by solving the equation:

$$e^U = x + \sqrt{x^2 + 1} \quad \text{where: } x = \frac{e^{2U} - 1}{2e^U}, \quad x = \ln \nu \quad (7)$$

The program compiled from algorithms of the function according to Walter, Mehrotra or Umstätter allows for a comfortable calculation of viscosity at particular temperatures through two viscosities measured at various temperatures.

## Experimental

For the kinematic viscosity measurements we used the Ubelhode viscosometers made by Analys with the constants 0.0998 , 0.3006 in HERZOG Triplex Veriomat thermostats. The dynamic viscosity was measured by the RV2 HAAKE device. We used the measurement MV-I system with the stator diameter of 21mm, a rotor diameter of 20.04 mm and a height of 60 mm. For tempering we used the cryostat MK70 WEB WLW Prüfgeräte Werk.

The results were evaluated in the Visual basic pro EXCEL programs. From the viscosity measurement data at various temperatures the viscosities were calculated based on the relations according to Mehrotra, Waltera and modified equations according to Umstätter. The calculation of viscosity at particular temperatures from the viscosities measured at two various temperatures in the Visual basic pro EXCEL environment had the following algorithm presented in Table 1.

Table 1. Algorithm of the calculation of viscosity at particular temperatures

Mehrotra and Walter Version:	Umstätter Version:
REM LT1 – logarithms of temperature $t_1$	REM LT1 – logarithms of temperature $t_1$
REM LT2 – logarithms of temperature $t_2$	REM LT2 – logarithms of temperature $t_2$
REM $t_1 < t_2$	REM $t_1 < t_2$
REM LT3 – logarithms of temperature $t_3$	REM LT3 – logarithms of temperature $t_3$
$k = 0.434294$	
$LT1 = \text{Log}(273.15 + t_1) * k$	$LT1 = \text{Log}(273.15 + t_1)$
$LT2 = \text{Log}(273.15 + t_2) * k$	$LT2 = \text{Log}(273.15 + t_2)$
$LT3 = \text{Log}(273.15 + t_3) * k$	$LT3 = \text{Log}(273.15 + t_3)$
REM Lv1 – logarithms of viscosity at $t_1$	REM Lv1 – logarithms of viscosity at $t_1$
REM Lv2 – logarithms of viscosity at $t_2$	REM Lv2 – logarithms of viscosity at $t_2$
$Lv1 = \text{Log}(v_1 + 0.8) * k$	$Lv1 = \text{Log}(v_1)$
$Lv2 = \text{Log}(v_2 + 0.8) * k$	$Lv2 = \text{Log}(v_2)$
$W1 = \text{Log}(Lv1) * k$	$u1 = \text{Log}(Lv1 + \text{Sqr}(Lv1^2 + 1))$
$W2 = \text{Log}(Lv2) * k$	$u2 = \text{Log}(Lv2 + \text{Sqr}(Lv2^2 + 1))$
$m = (W1 - W2) / (LT2 - LT1)$	$k = (u1 - u2) / (LT2 - LT1)$
$W3 = m * (LT1 - LT3) + W1$	$u3 = k * (LT1 - LT3) + u1$
$W4 = 10^W3$	$u4 = \text{Exp}(u3)$
$W5 = 10^W4$	$u5 = (u4 * u4 - 1) / (2 * u4)$
REM Viscosity calculated at temperature $t_3$	REM Viscosity calculated at temperature $t_3$
$v3 = W5 - 0.8$	$v3 = \text{Exp}(u5)$

The suitability of models for the calculation of viscosities was tested on various oil products. The properties of the samples of the diesel fuel, vacuum distillates and asphalt are included in Table 2.

Table 2. Properties and composition of used hydrocarbon mixtures

		Diesel fuel	Vacuum distillates			Asphalt
			VD-1	VD-2	VD-3	
<b>Properties:</b>						
Density at 60°C	[kg.m <sup>-3</sup> ]	825,8 <sup>*1</sup>	883	892	901	998
Viscosity at 60°C	mm <sup>2</sup> s <sup>-1</sup>	2.48 <sup>*2</sup>	15.81	24.14	48.82	275 <sup>*3</sup>
Mw		217.7	352	410	473	
Cloud point	[°C]	-10	40	45	48	43.2 <sup>*4</sup>
<b>Composition:</b>						
Saturates	% m/m	69.7	51.4	44.4	41	15.5
Aromatics	% m/m	30.3	45.4	50.7	48.6	58.2
Polar compounds	% m/m		3.2	4.8	10.2	25.3 <sup>*5</sup>

<sup>\*1</sup>–density at 20°C, <sup>\*2</sup>– viscosity at 20°C <sup>\*3</sup>– viscosity at 135°C

<sup>\*4</sup>–Softening Point (ASTM D36 2006)

<sup>\*5</sup> – polar compounds including asphalts

## Results and Discussion

### *Viscosity of Diesel Fuels.*

The viscosity of diesel fuels is one of the characteristics required by the quality norm (EN590 2004). In the event of low temperatures, viscosity influences the characteristics of the fuel in the tank and its transport by fuel pump to the motor cylinders. Fuel viscosity also influences the paraffin hydrocarbons settling at low temperatures. Figure 1 shows the experimentally measured viscosities of diesel fuels at temperatures below 20°C. Viscosities calculated by extrapolation from viscosities measured at temperatures of 15°C and 20°C are also shown. We used the relations (3) and (5). Viscosities were calculated at temperatures shifted higher from an experimentally measured value of temperature by a step of 0.5°C.

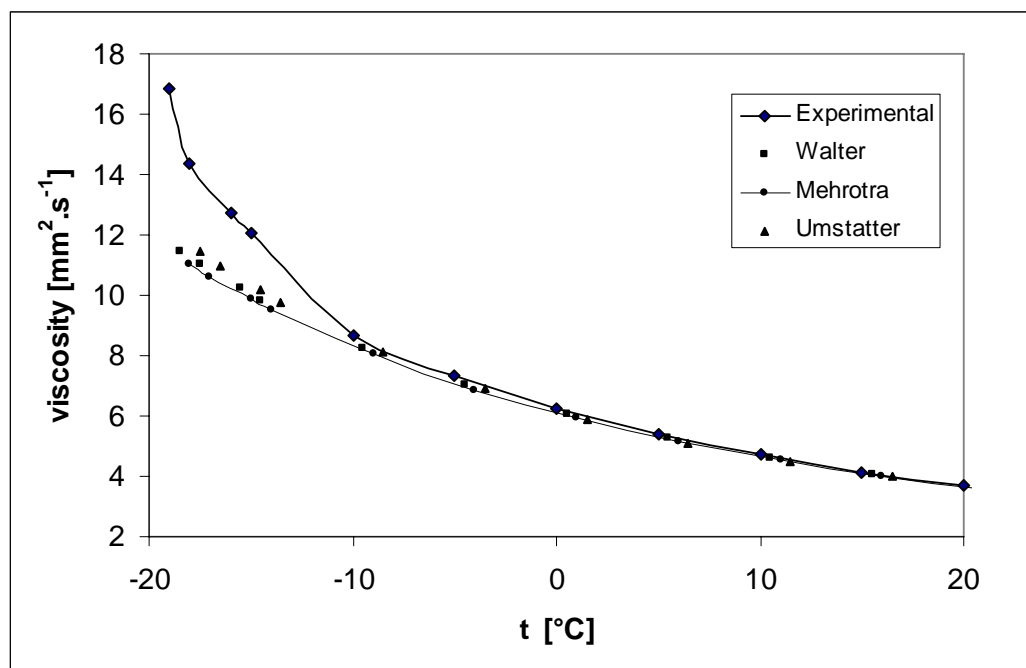


Fig. 1. Dependency of diesel fuel viscosity on temperature

Table 3. Experimental values of Diesel fuel viscosity and differences between experimental and calculated viscosity values ( $\Delta$ )

t	Viscosity experimental	Extrapolation			Interpolation		
		Walter	Mehrotra	Umstätter	Walter	Mehrotra	Umstätter
[°C]	[mm <sup>2</sup> .s <sup>-1</sup> ]	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$
20	3.67 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
15	4.12 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	-0.02	-0.02	-0.01
10	4.72	0.06	0.08	0.05	0.02	0.01	0.04
5	5.42	0.09	0.10	0.08	0.03	0.01	0.06
0	6.24	0.09	0.11	0.07	-0.01	-0.02	0.02
-5	7.36	0.18	0.23	0.13	0.04	0.03	0.06
-10	8.69 <sup>*1</sup>	0.20	0.29	0.10	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
-15	12.06	1.88	2.03	1.69	1.59	1.62	1.54
-16	12.71	2.14	2.30	1.93	1.84	1.87	1.76
-18	14.34	2.88	3.11	2.64	2.56	2.61	2.44
-19	16.82	4.92	5.15	4.62	4.55	4.61	4.41

\*1 – values of viscosities was used for calculation of other viscosities at given temperature

The viscosities depicted in the graph in the interval from -10°C up to 20°C show an equal trend of measured and calculated values. At temperatures below -10°C the experimentally

measured viscosity values distinctively differ from the calculated values. The differences between the calculated values and the experimental values are caused by the phase modification of paraffin hydrocarbons that constitute a fraction of the fuel. The temperature for beginning the extraction of paraffins from the sample of monitored fuel was  $-10^{\circ}\text{C}$ . Below this temperature the crystallized paraffins distinctively influence the viscosity properties of the fuel.

### Viscosity of Vacuum Distillates

For the products on the base of mineral oils, viscosity constitutes the fundamental parameter for quality which distinctively influences its utilization. In fact there are norms establishing viscosity values at particular temperatures for each of these products. Lubricating oils are classified according to the viscosity at  $40^{\circ}\text{C}$  according to the ISO VG classification. The most frequently used temperatures for viscosities are  $40^{\circ}\text{C}$  and  $100^{\circ}\text{C}$ . In this field, the possibility of comparing viscosities calculated by the use of relation (3) and (5) was tested. Figure 2 depicts experimentally measured viscosities of vacuum distillates and viscosity values measured by extrapolation from experimentally measured viscosities at  $50^{\circ}\text{C}$  and  $60^{\circ}\text{C}$ . The Walter function was used for calculation.

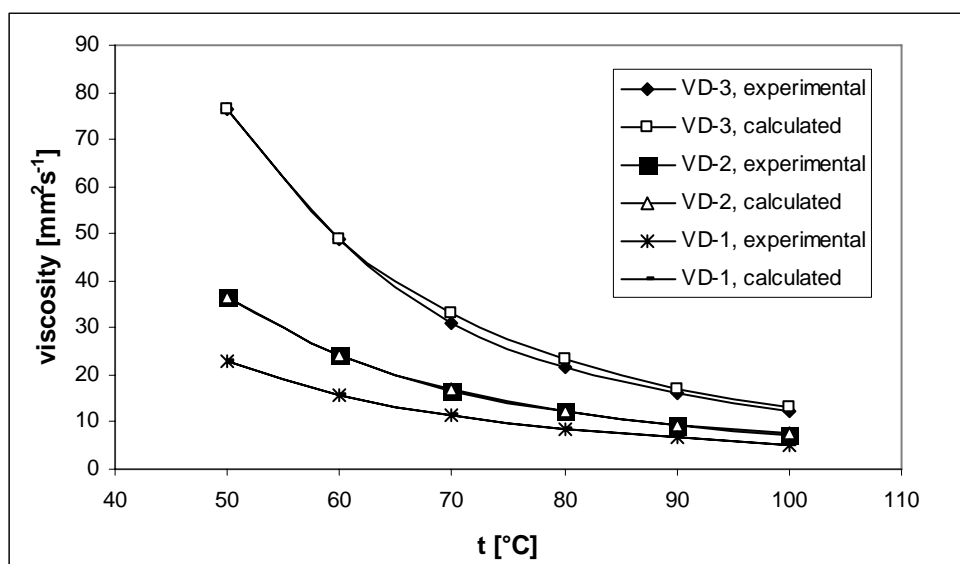


Fig.1. Dependency of vacuum distillates on temperature

The graphic depiction of viscosities shows that in the interval from  $50^{\circ}\text{C}$  up to  $100^{\circ}\text{C}$  the calculated viscosity values differ more significantly from the experimental values in the case of the heavy vacuum distillate VD-3. The suitability of relations (3) and (5) for the

calculation of vacuum distillate viscosities was detected by the same method as in the case of diesel fuels. For calculation, we selected experimental values of viscosities at 50°C and 60°C, and through this calculation the values at higher temperatures were extrapolated. For the calculation of viscosities through interpolation, viscosities at temperatures 50°C and 100°C were selected as the base. The differences between experimental and calculated viscosities are incorporated in tables 4, 5 and 6. From the experimental and calculated viscosities we can see the differences in the relations (3) and (5) are used for the calculation of vacuum distillates viscosities. The value of differences between experimental and calculated values changes irregularly and there is no significant difference between interpolated and extrapolated viscosities values. We monitored the differences in values in the event of the use of Walter, Merhotra or Umstätter equations, however it is impossible to strictly prefer one of the relations.

Table 4. Experimental values of vacuum distillate VD-1 viscosity and differences between experimental and calculated viscosity values ( $\Delta$ )

t	Viscosity experimental	Extrapolation			Interpolation		
		Walter	Mehrotra	Umstätter	Walter	Mehrotra	Umstätter
[°C]	[mm <sup>2</sup> .s <sup>-1</sup> ]	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$
50	22.91 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
60	15.81 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	0.11	0.07	0.22
70	11.42	-0.10	0.00	-0.03	0.14	0.09	0.24
80	8.51	-0.17	-0.05	-0.13	0.07	0.04	0.14
90	6.63	-0.12	0.00	-0.12	0.10	0.09	0.14
100	5.19 <sup>*1</sup>	0.10	-0.08	-0.23	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>

\*1 – values of viscosities were used for the calculation of other viscosities at the given temperatures



Table 5. Experimental values of vacuum distillate VD-2 and differences between experimental and calculated viscosity values ( $\Delta$ )

t	Viscosity experimental	Extrapolation			Interpolation		
		Walter	Merlotra	Umstätter	Walter	Merlotra	Umstätter
[°C]	[mm <sup>2</sup> .s <sup>-1</sup> ]	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$
50	36.52 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
60	24.14 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	-0.01	-0.02	0.11
70	16.76	-0.06	-0.05	-0.08	-0.07	-0.10	0.05
80	12.31	0.07	0.09	0.01	-0.25	0.03	0.14
90	9.37	0.13	0.16	0.04	0.11	0.10	0.15
100	7.21 <sup>*1</sup>	-0.29	0.06	-0.10	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>

\*1 – values of viscosities were used for the calculation of other viscosities at the given temperatures

Table 6. Experimental values of vacuum distillate VD-3 and differences between experimental and calculated viscosity values ( $\Delta$ )

t	Viscosity experimental	Extrapolation			Interpolation		
		Walter	Merlotra	Umstätter	Walter	Merlotra	Umstätter
[°C]	[mm <sup>2</sup> .s <sup>-1</sup> ]	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$
50	76.34 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
60	48.82 <sup>*1</sup>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	0.75	0.68	0.86
70	30.93	-2.04	-2.02	-1.96	-1.14	-1.21	-1.02
80	21.44	-1.87	-1.84	-1.90	-1.02	-1.06	-0.93
90	16.17	-0.96	-1.02	-1.02	-0.21	0.03	-0.17
100	2.37 <sup>*1</sup>	-0.64	-0.59	-0.73	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>

\*1 – values of viscosities was used for calculation of other viscosities at given temperature

*Viscosity of Asphalt*

In practice, asphalts are heated to higher temperatures. This happens when they are pumped, transported and covering material. The viscosity behavior of asphalts at higher temperatures correspond with Newton liquids. Measuring the kinematic viscosity of asphalts at higher temperatures is difficult. Filling the special flow viscosimeters by non-transparent fluids at high temperatures is connected with significant difficulties. The cleaning of viscosimeters is time consuming and a large amount of solvents is used. Rotation viscosimeters of the Searle type can be used for measuring the dynamic viscosity of asphalts at temperatures up to 140°C.

We selected the interval 90°C up to 140°C for measuring the dynamic viscosity of asphalt samples. In this interval we tested the possibility of using relations (3) and (5) to calculate the viscosity of samples at higher temperature  $t_3$  from viscosities measured at lower temperatures  $t_2 > t_1$ . At the same time, these results acquired by extrapolation were compared to the results acquired by interpolation. Figure 3 shows the values of experimentally detected viscosities of the sample and viscosities calculated by the Walter equation. We noticed significant difference between the experimentally established values of dynamic viscosity and the values calculated from viscosities measured at the two lowest temperatures 92.0°C and 97.5°C. A much lower difference was shown between the experimentally measured values calculated by interpolation from the viscosity at the lowest and the highest measuring temperatures (92°C, 138.5°C).

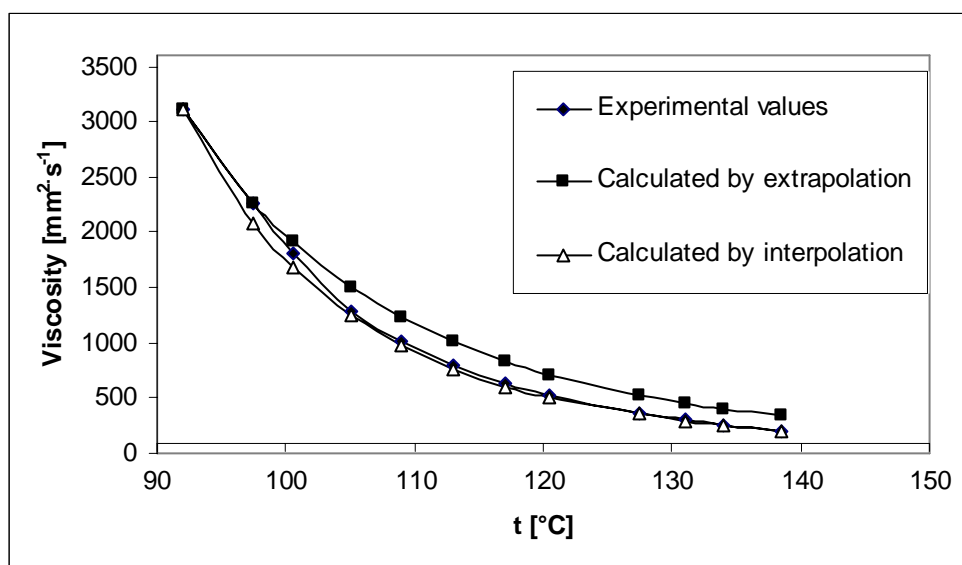


Fig. 3 Dependency of asphalt viscosity on temperature

A comparison of the differences in viscosity calculation through extrapolation and interpolation with the use of Walter, Mehrotra and Umstätter equations is provided by Table 7. Results show that the values of dynamic viscosity calculated by extrapolation are higher than the results established experimentally. On the contrary, the values calculated by interpolation are lower than those experimental values. Differences between experimental and calculated values diminish at values of lower viscosities, i.e., at viscosities measured at higher temperatures. This tendency was observed for the differences calculated by interpolation and extrapolation. Similarly, as in the case of higher hydrocarbon fractions and asphalt, the differences of calculated viscosities were higher in the case of extrapolation. The difference in values of calculated viscosities was insignificant in comparison with the values acquired by various equations. The results according to Walter, Mehrotra and Umstätter equations were identical from the aspect of practical use. The differences between values calculated for the identical temperatures through various methods were always lower than differences between experimental and calculated values.

Table 7. Experimental values of asphalt viscosity and differences between experimental and calculated viscosity values ( $\Delta$ )

t	Viscosity experimental	Extrapolation			Interpolation		
		Walter	Mehrotra	Umstätter	Walter	Mehrotra	Umstätter
[°C]	[mm <sup>2</sup> ·s <sup>-1</sup> ]	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$	$\Delta$
92.0	3109.0 <sup>*1</sup>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
97.5	2261.4 <sup>*1</sup>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	183.2	183.1	181.1
100.5	1817.0	-97.7	-97.7	-97.6	130.4	130.3	128.0
105.0	1285.4	-220.0	-220.0	-219.6	35.4	35.3	33.1
109.0	1019.2	-207.0	-207.0	-206.4	49.0	48.9	47.0
113.0	799.0	-207.6	-207.6	-206.8	37.3	37.2	35.6
117.0	630.1	-202.4	-202.3	-201.2	25.6	25.5	24.4
120.5	529.0	-180.1	-180.0	-179.8	31.0	30.9	30.1
127.5	353.6	-168.8	-168.8	-167.6	-0.9	8.1	7.7
131.0	300.5	-151.2	-241.1	-149.9	9.8	29.8	9.5
134.0	249.1	-151.0	-151.0	-149.7	-3.0	-3.0	-5.1
138.5	205.2 <sup>*1</sup>	-130.5	-130.4	-129.2	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>

\*1—values of viscosities was used for calculation of other viscosities at given temperature

The calculation of viscosity by extrapolation may be carried out by use of viscosities measured at various temperatures. The selection of temperatures influences the reliability of

the calculated values. The Walter equation was used for extrapolation. The influence of the value of experimentally established dynamic viscosities at various temperatures on the reliability of calculated viscosity at higher temperature was established. For comparison, the dynamic viscosity of asphalt 205.2 mPa.s at temperature  $t_3 = 138.5^\circ\text{C}$  was selected as the base. For calculation we used viscosities at temperatures ( $t_1, t_2$ ) of two neighboring experimental points. Table 8. shows that the differences in viscosities from experimentally measured viscosities calculated this way are in a wide interval of values and differ chaotically from the measured values. The reliability of these results is low.

Table 8. Differences  $\Delta = \mu_{\text{experimental}} - \mu_{\text{calculated}}$  for viscosities at  $138.5^\circ\text{C}$

$t_1$	92.0	97.5	100.5	105.0	109.0	113.0	117.0	120.5	127.5	131.0
$t_2$	97.5	100.5	105.0	109.0	113.0	117.0	120.5	127.5	131.0	134.0
$\mu_{\text{calc. at } t_3 = 138.5^\circ\text{C}}$	335.8	202.7	167.3	241.4	213.6	208.2	235.9	200.0	216.1	190.6
$\Delta = \mu_{\text{experimental}} - \mu_{\text{calculated}}$	-130	2.5	37.9	-36.2	-8.4	-3.0	-30.7	5.2	-10.9	14.6

A more suitable and reliable method for the calculation of viscosity by extrapolation involved using an experimentally established viscosity at the temperature  $t_2$  that was close to the temperature  $t_3$ . The distance of another point used in the calculation (viscosity at temperature  $t_1$ ) from the second point (viscosity at the temperature  $t_2$ ) had no essential influence on the reliability of the result. Table 9. shows the differences of experimental and calculated viscosities through viscosities at temperatures  $t_1$  and  $t_2$ . The worst result of viscosity calculated for the temperature  $138.5^\circ\text{C}$  was recorded in the use of viscosities at temperatures  $t_1 = 92^\circ\text{C}$  and  $t_2 = 120.5^\circ\text{C}$ . In this case the difference between experimental and calculated values was 30.7 mPa.s, which corresponds to a relative error rate of 15%. The other results were better and in majority of cases the relative error rate was below 3%.

Table 9. Differences  $\Delta = \mu_{\text{experimental}} - \mu_{\text{calculated}}$  for viscosities at 138.5°C

$t_3$ [°C]	$t_2$ [°C]	$t_1$ [°C]									
		92.0	97.5	100.5	105.0	109.0	113.5	117.5	120.5	127.5	131.0
138.5	134.0	2.64	3.96	3.98	3.28	4.04	4.39	4.69	6.42	6.8	14.6
138.5	131.0	-7.7	-5.2	-5.4	-6.1	-6.0	-5.9	-6.1	-3.4	-10.9	
138.5	127.5	-5.7	-1.7	-1.8	-4.4	0.3	-1.8	-1.6	5.2		
138.5	120.5	-17.8	-9.8	-10.7	-18.6	-15.5	-17.8	-30.7			
138.5	117.0	-13.3	-1.9	-2.3	-12.3	-5.2	-3.0				
138.5	113.0	-17.8	-1.4	-2.0	-19.8	-8.4					

## Conclusion

The comparison of experimentally established viscosities with viscosities calculated at the same temperature provided interesting knowledge for the practical use of the relations according to Walter, Mehrotra and Umstätter. In the case of monitored hydrocarbon fractions, the suitability of the use of individual methods was proven. Used relations were proven to be equal in calculating the viscosity for particular temperatures from two viscosities established at different temperatures. The differences between viscosities calculated from the relations according to Walter, Mehrotra and Umstätter were lower than the difference between the experimentally established value and the calculated value. When evaluating calculated viscosities we noticed the differences in reliability of the results of extrapolated and interpolated values.

In the interval of temperatures at which no phase modifications occur, the logarithmic relations may be used for the calculation of the kinematic viscosity of diesel fuels. In these cases, the differences in the extrapolation between experimental and calculated values of viscosity below 3% relative to the viscosity value were observed. The results acquired by interpolation showed differences below 1%. At low temperatures, below the cloud temperature of fuel sample, the use of the relations for the calculation of viscosity by extrapolation is unsuitable. The relative differences may exceed 30% of the experimental viscosity value.

The kinematic viscosity of vacuum distillates depends in the interval of temperatures from 40°C up to 100°C on the distillation profile. In the lightest VD-1 oil distillation profile,

we observed similar results to the diesel fuels with a reliability of viscosity results. Measuring of these samples was carried out in similar intervals of viscosities but at different temperatures. The similar reliability of extrapolated and interpolated calculated viscosities of VD-1 and VD-2 samples was unexpected. In the extrapolation of calculation of viscosities of VD-1 and VD-2 samples we observed differences between the experimental and calculated values of viscosity below 4% relative to the viscosity value. In the interpolation, these differences were below 2%. The third sample of VD-3 vacuum distillate had the highest viscosity and largest differences between experimental and calculated values of viscosities. In the extrapolation of the VD-3 viscosity calculation sample we observed differences between experimental and calculated viscosity values below 7% relative to the viscosity value. In the interpolation these differences were below 5%.

In the measuring of the dynamic viscosity of asphalt we operated in an interval of temperatures from 92°C up to 138.5°C. The comparison of the suitability of the use of relations for viscosity calculation through extrapolation according to Walter, Mehrotra and Umstätter was carried out through viscosities  $\mu_1$  and  $\mu_2$ , that corresponded with temperatures  $t_1 = 92^\circ\text{C}$  and  $t_2 = 97.55^\circ\text{C}$ . The results of such extrapolated dynamic viscosities at higher temperatures showed large differences from experimentally measured viscosities. The maximum difference was up to 60%. In calculations of viscosities through interpolation from the viscosities measured at the highest and the lowest temperatures of measuring, the largest difference from experimental viscosity was 8%. The differences in individual methods of calculation were insignificant. In further calculations we used the Walter equation. The base of the calculation was established by two subsequent neighboring measured points with coordinates  $t_1, \mu_1$  and  $t_2, \mu_2$  whose viscosity was calculated by extrapolation,  $\mu_3$  at temperature  $t_3 = 138.5^\circ\text{C}$ . The calculated viscosity was compared to the viscosity measured at temperature  $t_3$ . The differences between the viscosities calculated this way were in wider interval of values. They differed chaotically from experimentally measured viscosities. The reliability of results was low. The highest difference from experimental value reached 39%. The selection of experimental points for the calculation of viscosity at higher temperature significantly influenced the reliability of the results. The most reliable results were achieved by use of experimental points  $t_2, \mu_2$  and the  $t_2$  coordinate, which is the closest to the temperature  $t_3$ , at which we want to establish the viscosity value through calculation. It is suitable to test the influence of experimental point  $t_1, \mu_1$  on reliability by use of several viscosities at temperatures lower than  $t_2$ .

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