

Influence of Temperature and Water Content on the Viscosity of some Oil Types

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This paper presents results of the studies concerning the influence of temperature and reservoir water content on the viscosity of oil. Experiments using five types of oil originating from various areas of Romania were made. We evaluated their dynamic viscosity by using currently available empirical models. When comparing the values obtained, large discrepancies are observed. Thus, for proper high precision design computations, we recommend additional direct measuring of this physical property of oil.

Keywords: oil, reservoir water, viscosity

Viscosity is one of the main physical properties of fluids, and is defined as the property of fluids to oppose flowing, due to tangential friction. Viscosity is in fact the main characteristic that differentiates perfect or ideal fluids (with zero viscosity) from real fluids (with non-zero viscosity), which represent the two types of models used in fluid dynamics. There is no closed-form expression for viscosity; it is expressed as the coefficient of proportionality between the tangential tension τ and the speed gradient normal to the flow direction dv/dn :

$$\tau = \mu \frac{dv}{dn} \quad (1)$$

where:

μ is the dynamic viscosity;

v is the speed and n is the flow direction.

Expression (1) is known as Newton's law (or Newton's hypothesis). Some fluids widely used in technical or practical applications satisfy relation (1) (for example, water, pure mineral oils and other fluids). However, for numerous other fluids viscosity decreases with the deformation speed, which can be a temporary or permanent condition. A quantity used in practice is the cinematic viscosity, defined as:

$$\nu = \frac{\mu}{\rho} \quad (2)$$

where ρ is the density of the fluid.

In general, viscosity quickly decreases with temperature and to a lesser extent increases with pressure. For example, these influences are apparent for crude oil, where information about viscosity is important, as it affects the flow through the porous medium, in the reservoir and the extraction and transportation pipes and in refining [1].

Various empirical relationships that express the dependence on temperature of the dynamical viscosity of oil and petroleum products are presented in the literature [2, 3]. These models include:

$$\mu = A \exp \frac{B}{T} \quad (3)$$

where A and B are experimentally determined coefficients; (3) is known as Andrade's relationship [2]; and

$$\mu = \mu_0 e^{-C(T-T_0)} \quad (4)$$

where C is a constant that can be computed given the viscosity at a certain reference temperature, and μ_0 is the dynamic viscosity at that same temperature T_0 [3].

The empirical character of these equations results in a series of errors in the computed values, which makes the experimentally determined values more reliable.

Experimental part

The experiments were run in the General Hydraulics Laboratory of the Oil-Gas University Ploiesti. A rotating viscosimeter was used (RHEOTEST 2) corresponding to the device with two coaxial cylinders shown in figure 1. The analyzed substance is placed in the annulus space of the above cylinders. The external cylinder of radius R is fixed and is the recipient of the analyzed probe [4].

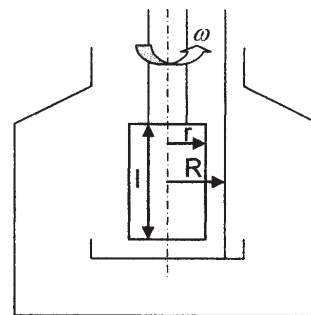


Fig. 1. Schematic of the Rheotest viscosimeter [4]

The external cylinder is introduced in a recipient containing a temperature-controlled liquid, for regulating its temperature. The interior cylinder of radius r and length l rotates around an axis with constant angular velocity ω . Dynamical viscosities can be then obtained using specific equations [4] with values for the parameters as obtained from measurement, tables or the device construction. The analyzed probes were taken from oil collecting reservoirs belonging to a set of extraction facilities in Romania. Oils of various qualities were used during the experiments, including very viscous oils which pose special problems during extraction, transportation and refining. The probes contained 10 mL of substance to be analyzed. We analyzed five Romanian types of oil, identified by a number between 1 and 5. The main properties of the analyzed oils are presented in table 1, which shows that probes 1 and 2 have higher densities compared to probes 3, 4 and 5. The data

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Table 1
PHYSICAL AND CHEMICAL PROPERTIES OF THE ANALYZED OILS

Type of oil	Temperature	Density	Kinematic viscosity	Dynamic viscosity	Congelation point	Content of paraffin
	°C	kg/m ³	10 ⁻⁶ m ² /s	10 ⁻³ Pa.s	°C	%
Oil 1	20	900	490.8	441.7		7.18
	30	-	297.3	-		
	40	-	231.1	-		
	50	-	151.7	-		
	60	-	107.1	-		
Oil 2	15	944.08	-	-	32	
	23	939.2	1016.725	954.909		
	56	919.7	104.676	96.271		
Oil 3	20	851	-	-	33	13.2
	30	830	44.39	36.845		
	40	823	15.736	12.951		
	50	816.1	10.678	8.714		
	60	809.1	8.992	7.275		
Oil 4	20	858	-	-	36	9.39
	30	837	95.851	80.230		
	40	830	15.507	12.871		
	50	823.1	9.821	8.083		
	60	816.1	7.915	6.459		
Oil 5	20	891.5	-	-	37	14.45
	30	885	54.328	48.082		
	40	878.6	33.328	29.281		
	50	872.1	21.692	18.917		
	60	865.6	16.170	13.997		

Table 2
VISCOSITY VARIATION FOR OIL 1

Dynamic viscosity, 10 ⁻³ Pa.s								
Temperature, °C	Content of reservoir water, %							
	5	10	15	20	30	40	50	60
0	8239	8898	9106	9416	4993	6277	12880	9507
10	2847	2568	2918	3264	1783	2354	4756	3170
20	911	1011	951	1040	674	852	954	1100
30	416	446	436	476	555	406	433	470
40	190	228	198	238	159	164	257	220
50	167	110	109	110	89	95	164	165
60	67	66	67	65	57	63	110	110
70	45	44	44	43	40	50	88	73

from table 1 are provided from oil field where they were obtained in particular conditions.

Results and discussions

Experiments followed by calculations were performed in order to study the influence of temperature and water content in the reservoir on some types of oil. The results obtained by processing the experimentally obtained data are presented in tables 2...6. The tables contain the viscosity values for the oils numbered 1...5, corresponding to different temperatures and mass fractions of reservoir water, expressed in [%].

Table 2 shows that for low temperatures the viscosity of oil 1 exhibits two maxima obtained at 20% and respectively

50% of reservoir water. For higher temperatures, the variation of viscosity with the reservoir water content is insignificant, in particular for water content smaller than 50%.

Table 3 shows that the viscosity of oil 2 increases with the increase of water concentration (at temperature 0°C) in the reservoir and it attains a maximum at 20% water content. For temperatures between 10°C and 30 °C, the viscosity increases monotonically with the water content, while for temperatures above 40 °C the viscosity has a maximum at 20% water content.

Table 4 shows the dependence of viscosity on water content of the reservoir which exhibits a maximum for 50% water content at 30 °C, two maxima of 20% and 65% at 35

Table 3
VISCOSITY VARIATION FOR OIL 2

Temperature, °C	Dynamic viscosity, 10 ⁻³ Pa.s			
	Content of reservoir water, %			
	0,9	20	40	60
0	6677	11770	-	-
10	2180	4542	8099	15472
20	672	1641	2490	4018
30	333	915	1172	1546
40	176	289	260	240
50	91	149	122	103
60	61	83	53	55

Table 4
VISCOSITY VARIATION FOR OIL 3

Temperature, °C	Dynamic viscosity, 10 ⁻³ Pa.s				
	Content of reservoir water, %				
	<1	20	50	65	70
30	-	-	1045	836	-
35	483	508	182	808	71
40	239	28	40	-	37
45	26	13	-	26	14
55	15	11	21	18	8

°C, and a significant decrease of the viscosity with the increase in water content at 40°C; for higher temperatures, the variation of viscosity with the reservoir water content is relatively small. We also note the important decrease of viscosity with the increase in temperature above 40°C for pure oil; the decrease starts at even smaller temperatures for oil with impurities.

Table 5 shows a similar behavior of viscosity with the water content at different temperatures for oil 4 as for oil 3, which can be easily motivated by the fact that the two oils have similar physical properties.

Table 5
VISCOSITY VARIATION FOR OIL 4

Temperature, °C	Dynamic viscosity, 10 ⁻³ Pa.s			
	Content of reservoir water, %			
	0,9	20	50	65
30	-	-	1046	837
35	484	509	182	808
40	240	290	-	-
45	27	15	41	27
55	17	11	22	19

Table 6 shows that the viscosity of oil 5 reaches a maximum value for 50% water content, regardless of the temperature. We also note the important decrease of viscosity, independent of the salt water content, for temperatures higher than 35°C.

Table 6
VISCOSITY VARIATION FOR OIL 5

Temperature, °C	Dynamic viscosity, 10 ⁻³ Pa.s			
	Content of reservoir water, %			
	0,6	20	50	70
35	66	262	559	71
40	11	28	89	37
45	9	17	61	14
55	7	12	46	10

Tables 7 through 11 present the dynamic viscosities for oils 1...5, computed using the Andrade model in (3) and the model in (4). The errors between the experimentally obtained values and those computed with relations (3) and (4) are obtained using the formula:

$$\varepsilon = \frac{|\mu_{\text{exp}} - \mu_{\text{c}}|}{\max(\mu_{\text{exp}}, \mu_{\text{c}})} 100 \quad (5)$$

where:

ε is the percent error,

μ_{exp} is the experimentally determined dynamic viscosity;

μ_{c} is the computed dynamic viscosity.

These errors are also shown in tables 7 through 11.

The analysis of the obtained data shows that in almost all cases the experimentally determined values are higher than the computed ones. Although the error intervals are rather large for both models, the Andrade model is apparently more reliable for a given type of oil. The error bars increase with the increase in temperature, which can be motivated by the exponential decrease of viscosity with temperature.

Table 8 shows that for oil 2 the error intervals shrink and their distribution becomes more compact; the error is not monotonically increasing with temperature, as minima are obtained for a temperature of 40°C for model (4), and 40°C / 50 °C respectively for the Andrade model. However, this observation is not valid when the water content is below 1%.

Table 9 shows that for oil 3, which is a relatively light oil (with low density), the computed viscosity values are very small at high temperatures, especially when the oil contains reservoir water. The corresponding errors have large values, and for the Andrade model the computed viscosity values are mostly larger than the experimentally obtained ones.

Table 10 shows that for oil 4, which is also a light oil, the results are similar to the ones for oil 3.

Table 11 shows that the results for oil 5 are similar to those of oils 3 and 4, except that only one computed value of viscosity is larger than the experimentally obtained one.

Results from the literature suggest that the water-oil emulsion forms when the percent of water in the oil is at least 74%, and that the viscosity gradually increases with the water content; a reversal of the emulsion takes place when the water percent is 80%, followed by a rapid decrease of the viscosity towards values close to the viscosity of water [5]. The results of our experiments show

Table 7
COMPUTED VISCOSITY AND COMPUTATION ERROR FOR OIL 1

Formula	Temperature, °C	Content of reservoir water, %															
		5		10		15		20		30		40		50		60	
		μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ
(3)	30	313.8	24.6	369.3	17.1	210.2	51.7	357.5	24.8	271.4	51.1	328.2	18.9	212.8	50.8	445.4	5.1
	40	115.9	39	163.4	28.3	106.4	46.3	131.1	48.4	115.8	26.9	135.4	17.6	52.24	79.6	179.9	18.3
	50	38.05	77.2	76.04	30.9	56.11	48.5	51.51	53.2	52.14	41.5	58.85	64.2	13.99	94.5	77.83	64.6
	60	18.93	71.9	37.05	43.9	30.75	54.3	21.33	67.2	24.72	56.9	26.37	57.6	6.74	93.8	35.41	67.8
	70	8.28	81.8	18.82	57.3	17.45	59.9	9.30	78.3	12.14	69.3	12.85	74.1	1.26	98.5	16.86	77.0
	20	625.6	31.4	733.7	27.3	935.2	1.67	-	-	636.7	5.4	884.2	3.63	1742	45.3	1057	3.96
(4)	30	339.9	18.3	209.6	53	299.7	31.3	331.6	30.5	227.4	59	331.8	18.3	638.4	32.2	352.5	16
	40	117.5	38.2	59.89	73.9	96.05	51.5	107.7	55.5	81.2	48.8	124.5	24.3	233.9	8.93	117.6	46.6
	50	40.59	75.7	17.11	84.5	30.78	71.8	33.69	69.4	28.3	68.3	46.74	50.9	85.7	47.8	39.2	76.3
	60	14.03	79.2	4.89	92.6	9.86	85.4	10.74	83.5	10.35	82	17.54	72.3	31.4	71.5	13.07	88.1
	70	4.85	89.3	1.4	96.8	3.16	92.7	3.42	92	3.69	90.6	6.58	86.7	11.5	87.1	4.36	94.1

*the computed viscosity is more than the gauge viscosity

Table 8
COMPUTED VISCOSITY AND COMPUTATION ERROR FOR OIL 2

Formula	Temperature, °C	Content of reservoir water, %							
		0,9		20		40		60	
		μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ
(3)	30	224.0	32.8	633.9	30.8	827.7	29.4	1141	26.19
	40	80.1	54.5	260.2	10.6	295.2	11.81*	350.9	31.6*
	50	30.52	66.3	112.9	24.2	112.2	8.7	116.1	11.3
	60	12.32	79.9	51.5	38.1	45.19	15.81	41.07	26
(4)	20	701.1	4.11	1752	6.37	-	-	-	-
	30	225.5	32.3	676.2	26.1	765.8	34.7	1044	32.5
	40	73.79	58.1	260.9	9.81	235.5	9.53	271.1	1.15
	50	23.84	73.6	100.7	32.4	72.41	41.1	70.4	11.4
	60	7.7	87.4	38.84	53.3	22.26	58.5	18.28	67.1

Table 9
COMPUTED VISCOSITY AND COMPUTATION ERROR FOR OIL 3

Formula	Temperature, °C	Content of reservoir water, %									
		<1		20		50		65		70	
		μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ
(3)	35	-	-	60.31	88.1	-	-	-	-	-	-
	40	-	-	-	-	323.2	87.6*	-	-	-	-
	45	120.6	78.8*	-	-	-	-	807.7	96.8*	19.52	30.6*
	55	32.78	53.5*	3.22	70.7	61.85	65.3*	791	97.7*	5.82	29.5
(4)	35	-	-	-	-	31.58	82.6	261.7	67.6	-	-
	45	118.1	77.9	1.632	87.9	-	-	-	-	19.13	29.2
	55	28.84	42.2	0.005	99.9	0.16	99.2	2.52	85.9	5.16	37.5

Table 10
COMPUTED VISCOSITY AND COMPUTATION ERROR FOR OIL 4

Formula	Temperature, °C	Content of reservoir water, %							
		0,9		20		50		65	
		μ	ϵ	μ	ϵ	μ	ϵ	μ	ϵ
(3)	35	-	-	67.95	86.6*	-	-	-	-
	45	213.6	87.2*	-	-	6.51	84.1	757.3	96.4*
	55	57.23	70.8*	4.73	58.9	0.28	98.7	712.3	97.3*
(4)	45	118.7	77	1.68	88.7	5.53	86.5	265.9	67.1
	55	29.08	92.5	0.006	99.9	0.17	99.2	2.71	85.6

Table 11
COMPUTED VISCOSITY AND COMPUTATION ERROR FOR OIL 5

Formula	Temperature, °C	Content of reservoir water, %							
		0,6		20		50		70	
		μ	ε	μ	ε	μ	ε	μ	ε
(3)	35	1.37	97.9	46.44	82.2	130	76.7	100.1	28.7*
	55	0.86	87.4	6.90	41.2	29.64	34.8	2.34	74.5
(4)	45	4.34	49.3	3.04	82.5	14.02	76.9	19.64	26.2
	55	1.75	74.4	0.04	99.6	0.35	99.2	5.41	43.3

that it is possible that the water-oil emulsion can actually form at lower water content, as a function of the experimental conditions.

Conclusions

Viscosity decreases with temperature, regardless of the type of oil, water content, or computation method.

Viscosity increases with the reservoir water content at low temperatures, exhibiting one or two maxima at typically 50% water content, after which it generally decreases.

This behaviour of viscosity is possibly mainly caused by the inversion of the water-oil emulsion into oil-water emulsion, and by the evaporation of light fractions at high temperature. Additionally, a split or rearranging of the large hydrocarbons molecules is possible.

The computed values for the dynamic viscosity using two of the empirical models described in literature show large differences with respect to the actual measured values. It is thus recommended to take this fact into account when viscosity is a design issue (for example, in reservoir engineering, technology of extraction, transportation of oil and oil products and refining of oil).

The analyzed oils may be classified given their physical characteristics into two categories, light oils and heavy oils. However, our measurements as well as the obtained errors indicate that the variations can also be explained by the difference in the reservoir water salinity, since it is well known that the viscosity of reservoir water increases with the degree of mineralization. Nevertheless, our results may be used as a quick guideline for estimating the viscosity of oils with similar properties.

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