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INFLUENCE OF ULTRASOUND AND HEAT TREATMENT ON THE RHEOLOGICAL PROPERTIES OF UST-TEGUSSKOE OIL

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The effect of ultrasound and heat treatment on the dynamic viscosity, pour point, density, acidity, interphase tension at the water interface, and chemical composition of Ust-Tegusskoe oil is investigated. It was revealed that the plastic viscosity of the treated oil was diminished by a factor of 1.7 and the pour point by 32°C after ultrasonic treatment. Maximum depression of the pour point is obtained after ultrasonic treatment at 80°C and pressure of 1 atm in a helium medium.

The percentage of so-called difficult-to-extract reserves – low shallow penetrable collectors, high-viscosity oils, and oil-gas fields – is increasing in Russia and other oil-producing countries of the world. During the last 30 years of the previous century, the percentage of difficult-to-extract reserves in Russia had increased by almost three times [1]. According to prognosis of the structural dynamics of the reserves, the percentage of difficult-to-extract reserves will exceed 70% by 2015. Considering that average depletion of active oil reserves may exceed 80% by that time, it will be primarily the difficult-to-extract reserves that will be refined in the near future [2].

The action of physical methods (for example, acoustic) on oil to change its structural-mechanical properties is one of directions taken to improve the recovery efficiency of difficult-to-extract reserves. The effect of ultrasonic (US) vibrations during extraction of oil makes it possible to ensure increased penetrability of the near-face zone of seams, dewaxing, and acoustic degassing, and reduced viscosity of the oil [3, 4]. A number of US-instruments and procedures applicable to the transport of oil have been developed [5, 6]. US treatment prevents precipitation of paraffins and formation of resin and asphaltene deposits, and increases the percentage of light fractions during sublimation of the crude. A procedure calling for combined use of ultrasound, for example, together with chemical reagents, is promising [7, 8]. The advantage of US-treatment as compared with many other methods is ecological safety for the interior of the earth and the ambient environment.

The subject of the investigation was crude from the Ust-Tegusskoe field, the physicochemical characteristics of which are presented in Table 1.

The fraction of the total mass of asphaltenes contained in the oil resid was determined by Gold's "cold" method [9], the resinous substances by the chromatographic method [10], and the paraffin hydrocarbons by the method of complexing with carbamide in accordance with the procedure outlined in [9, 10].

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TABLE 1

Dynamic viscosity η at 20°C, mPa·sec	Pour point T_p, °C	Content, wt.%		
		oil (including normal hydrocarbons)	resins	asphaltenes
363	–5.6	63.1 (3.0)	35.7	1.2

TABLE 2

Sample number	Dynamic viscosity η, mPa·sec	T_p, °C	Treatment conditions (method of treatment, temperature, duration, pressure, medium)
Initial	363	–5.6	–
1	201	–8	US, 20°C, 120 sec, 1 atm, air
2	186	–6.6	US, 20°C, 480 sec, 1 atm, air
3	195	–6.7	US, 20°C, 120 sec, 1 atm, helium
4	197	–6	US, 20°C, 120 sec, 10 atm, helium
5	197	–12	US, 20°C, 480 sec, 1 atm, helium
6	199	–7	US, 20°C, 480 sec, 10 atm, helium
7	207	–36	US, 80°C, 120 sec, 1 atm, helium
8	213	–32	US, 80°C, 120 sec, 10 atm, helium
9	197	–35.5	US, 80°C, 480 sec, 10 atm, helium
10	208	–38	US, 80°C, 480 sec, 1 atm, helium
11	228	–30	HT, 80°C, 120 sec, 1 atm, air
12	243	–33	HT, 80°C, 480 sec, 1 atm, air

The Krystall instrument [11] (raying of a sample with infrared light in a narrow wave band) and processing of the measurements with a built-in microprocessor with screen-displayed information were used to determine the pour point T_p of samples. The accuracy of the measurement was ±0.2°C. The acid number in the oil was determined by the method of potentiometric titration (GOST 11362–96), the density of the oil by areometers (GOST 3900–85), the interphase tension of the oil σ on the water interface at 20°C by measuring the volume of the drops forced-out by a micrometric sensor [12], and the rheological characteristics of the oil on a Brookfield DV-III ULTRA rotary viscosimeter at 20°C.

The rheological parameters of the oils were calculated from Bingham's formula [13]:

$$\tau = \tau_0 + \eta D,$$

where τ is the shear stress in Pa, τ_0 is the shear stress at the yield point in Pa, η is the coefficient of dynamic viscosity in Pa·sec, and D is the shear rate per second.

The oil (sample volume of 200–300 ml) was ultrasonically treated in a steel reactor using an MSP 1/24 transducer connected to a 4-kW MUG 4/18-27 generator. Elastic vibrations were introduced to the sample by a rod waveguide with an effective end 20 mm in diameter; the vibration amplitude of the emitter was 5–10 ∝m at a frequency of 22 kHz. Prior to the US-treatment and after its completion, the sample was thermostated for 20–30 min at 20°C.

The IR-spectra of the initial crude and treated samples were plotted on a Nicolet-5700 IR Fourier spectrometer.

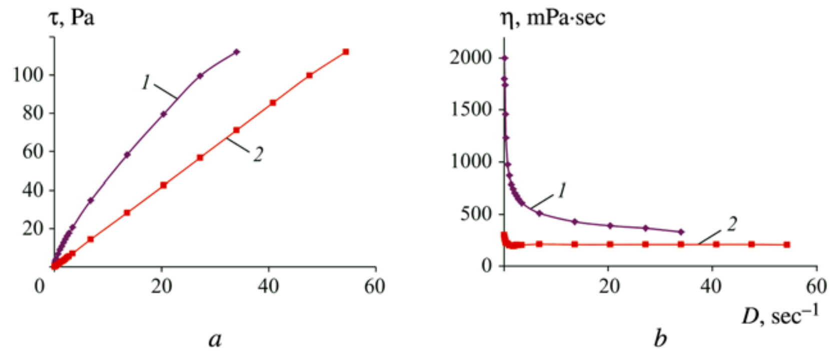

Fig. 1. Dependence of shear stress τ (*a*) and viscosity η (*b*) on shear rate *D*: *1*) initial crude; *2*) sample 10.

TABLE 3

Sample number	Dynamic viscosity η, mPa·sec	
	Shear rate, sec^{-1}	
	0.1	0.34
Initial	2000	1230
2	100	180
3	100	180
5	100	180
6	100	210
7	100	210
8	100	210
10	200	180
12	300	270

The rheologic parameters and pour point of the Ust-Tegusskoe oil determined after US-treatment and heat treatment (HT) are presented in Table 2.

US-treatment of the oil investigated in an air medium under atmospheric pressure resulted in a reduction in dynamic viscosity by a factor of 1.7 as compared with the initial oil (samples 1, 2). The pour point of samples 1 and 2 was substantially lowered, the depression being 2.4 and 1°C, respectively.

The viscosity-temperature characteristics of samples 3–6 are essentially identical: the dynamic viscosity was reduced by 45–49%, and depression of the pour point amounted to 0.4–6.4°C, irrespective of the treatment time, pressure, and medium.

A significant drop in the pour point of the oil investigated was observed after US-treatment at 80°C (see Table 2). Maximum pour-point depression was 32.4°C for sample 10. The viscosity depression of samples 7–10 is somewhat lower, however, than that for samples 3–6 (treated in a US-field at 20°C). A reduction in viscosity is observed for samples 11 and 12 – after heat treatment at 80°C for 120 and 480 sec (by a factor of 1.6 and 1.5, respectively).

US-treatment ensures not only a reduction in the viscosity and pour point, but also variation in the form of the rheologic curves (see Fig. 1) for all samples treated. Proportionality between shear stress and shear rate is observed for the treated oil, but not for the initial oil. The character of the dependence of viscosity on shear rate varies accordingly: a relationship characteristic of non-Newtonian liquids is observed for the initial oil; and, the relationship for the treated oil in the region of low shear rates corresponds to a thixotropic liquid, and to a Newtonian liquid at high shear rates.

Experimental data on the influence exerted by heat and US-treatment on the dynamic viscosity of the oil at shear rates of 0.1 and 0.34 sec^{-1} are presented in Table 3. The effect of US-treatment on the rheologic properties is more significant in the region of low shear rates: the dynamic viscosity of the oil exposed to sonic waves is virtually an order lower as compared with the initial oil. At a high shear rate, the effect due to the US-treatment is less expressed.

These investigations demonstrated that the density, acid number, and interphase tension of the oil at the interface with water remain essentially constant after US-treatment. No change is also revealed in the chemical composition of the oil after the US-treatment, suggesting identity between the IR-spectra and the values of the spectral coefficients calculated from the initial oil and treated samples.

Conclusions. US-treatment contributes to a 1.8–1.9 reduction in the viscosity of the oil investigated, and the depression of the pour point reaches 32.4°C. The maximum drop in pour point is attained after US-treatment of the oil at 80°C. The US-treatment does not alter the density, acid number, interphase tension, and chemical composition.

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