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RELAXATION EFFECTS IN THE PROPAGATION OF SHOCK WAVES IN ANOMALOUS OILS

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Experimental results are presented from a study of the propagation of wave pertubations in anomalous oils exhibiting relaxation phenomena.

Nonequilibrium phenomena occurring in anomalous oils [1, 2] containing a substantial quantity of paraffinous and resinous fractions necessitate the use of rheologically complex models to describe their flow [3]. The viscoelastic and thixotropic properties of the oil have a significant effect on wave processes and make it necessary to allow for them in examining transient conditions in hydraulic lines.

The structure and dynamics of propagation of pressure perturbations in anomalous oils at different temperatures was studied on a shock tube of a design similar to that used in [4]. The tube was developed by the Institute of Thermophysics of the Siberian Branch of the Soviet Academy of Sciences to study wave processes in gas—liquid systems. The shock tube consists of a high-pressure chamber (HPC) and was connected in the experiment to a diaphragm block. The pressure in the HPC was created by means of a special cylinder and was recorded by two regulators. The working part of the tube, 1654 mm long and 33 mm in diameter, was equipped with three LKh 601 piezoceramic pressure transducers with a resonance frequency no lower than 50 kHz. The lower limit of the frequency-independent characteristic was 20 Hz. Shock waves with an intensity up to 1.5 MPa were created by the rupture of membranes made of aluminum foil. The structure and profile of the pressure change during propagation in the oil were recorded by two C8-3 recording oscillographs. The operation of the oscillographs was synchronized with the aid of a special triggering sensor. The working part of the tube was completely covered by a silicone sleeve and connected to a cryostat, ensuring the prescribed temperature conditions in the range from 0 to 60°C.

The tests were conducted on resinous and paraffinous oils at temperatures of 10-40°C. Special rheological investigations conducted under kinetic and dynamic conditions established that these oils exhibit anomalous viscosity characteristics and relaxation effects

TABLE 1. Rheological Characteristics of the Oils

t, °C	Paraffinous oil			Resinous oil		
	τ_0, Pa	η, Pa·sec	relaxation time, msec	τ_0, Pa	η, Pa·sec	relaxation time, msec
10	30	0,109	240	117	4,26	870
15	26	0,063	5	80	2,91	40
20	17	0,041	3	40	2,10	21
30	0	0,027	1	0	0,083	0,4
40	0	0,015	—	0	0,35	—

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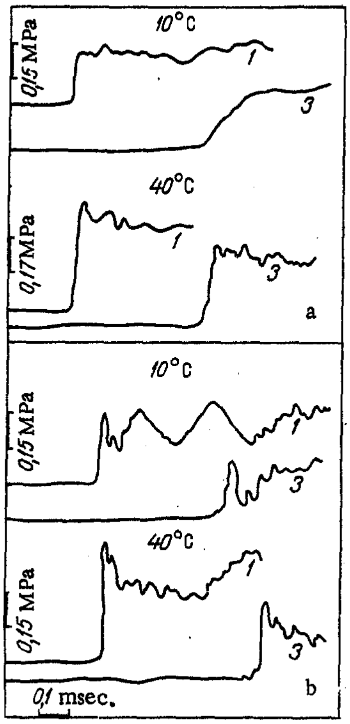

Fig. 1. Structure and dynamics of propagation of shock waves in a resinous (a) and a paraffinous (b) oil with $P_{spp} = 0.8$ MPa.

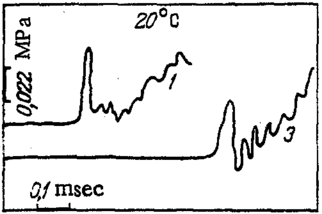

Fig. 2. Structure and dynamics of propagation of shock waves in a paraffinous oil with gas bubbles with $P_{spp} = 1.2$ MPa.

in the temperature region below 20°C. Table 1 shows rheological characteristics of samples of the oils in which we studied wave processes. The viscosity characteristics of the resinous oil are several times greater than those of the paraffinous oil. The relaxation time for these oils depends slightly on the temperature and changes within the range 10^{-1}-10^{-3} sec. These figures are quite comparable with the characteristic times of the transient processes being studied, but several new effects were observed here that were not seen earlier [5], since the tests in the latter work were conducted in the temperature range $t \geqslant 20°C$. In this range, these systems behave as normal viscous liquids with very short relaxation times of 10^{-4}-10^{-5} sec. We should especially point out the fact that all of the oils used in the tests may contain up to 3-4% gas in the finely dispersed state under industrial conditions, which fundamentally alters the character of pressure-wave propagation. This was demonstrated for gas—liquid systems consisting of a viscous liquid and air bubbles [6]. Thus, the oils we tested we carefully degassed beforehand by vacuum treatment with heating in a special chamber.

As was established earlier by rheologically nonsteady investigations [2], the resinous oil has mainly viscoelastic properties. This is shown well by oscillograms depicting the propagation of a shock wave of finite duration. The oscillograms are shown in Fig. 1a for different temperatures. The pressure was recorded on two D-1 and D-3 transducers spaced 0.625 m apart. The presence of relaxation in the resinous oil, due only to its viscoelastic properties, leads to additional dissipation and dispersion which in turn cause strong damping of the initial pressure pulse $P_{spp} = 0.80$ MPa to 0.23-0.26 MPa. As it propagates, two very important phenomena occur which are characteristic only of relaxing systems. The expansion of the front of the shock wave on the D-3 transducer at 10°C with respect to the time scale corresponds fully to the relaxation time determined in dynamic tests — $(2\text{-}3) \cdot 10^{-2}$ sec. Also, the pressure pulse is amplified compared to its value at the first D-1 transducer, which is attributable to the elastic properties of the oil. These effects disappear completely with an increase in the temperature of the oil in the shock tube to 40°C, the structure and form of propagation of the shock waves become similar to viscous systems, and the intensity of the shock wave doubles.

The character of propagation of shock waves in the paraffinous oil is completely different from the effects described above. With a temperature $t \leqslant 20°C$ in this oil, two properties compete with each other: viscoelasticity and thixotropy. Figure 1b shows shock wave propagation in such systems at 10°C, when relaxation effects are manifested, and at 40°C, when the relaxation time becomes so short (10^{-4}-10^{-5} sec) that it has almost no effect on the processes in question. In the anomalous region (10°C), the initial, irregularly-shaped shock wave is changed to an oscillating structure and, as it propagates (at D-3), leaves almost as a solitary wave. However, due to strong dissipation, the initial intensity of the shock wave $P_{spp} = 0.8$ MPa decays to 0.3 MPa. The upper frequency of the oscillating waves does not exceed 5 kHz, which is much lower than the resonance frequency of the pressure transducers used. With an increase in temperature to 40°C, all anomalous and relaxation effects disappear due to the melting of the paraffinous fractions in the oil, and the shock waves accordingly propagate as in viscous systems.

The presence of gas bubbles in the oil (Fig. 2) leads to strong dissipation of the shock wave even in the viscous region, and the initial pressure pulse $P_{spp} = 1.2$ MPa decays to 0.049 MPa. This is in full agreement with the test data in [4] for gas—liquid systems. The emergence of a solitary wave is seen as early as the first pressure transducer, and a cavitation region is created as the wave propagates. Thus, the presence of gas in the oil, even in small amounts (to 5%), may have both a positive and a negative effect during rapid transitional processes in pipes.

A detailed mathematical analysis of the evolution of shock waves in anomalous oils with relaxation properties and gas bubbles was made in [5] and makes it possible to predict nonsteady transitional processes in hydraulic systems involved in oil extraction and transport.

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