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LABORATORY STUDIES AND COMMERCIAL TESTS OF A POLYMERIC AGENT FOR REDUCTION OF THE POWER CONSUMPTION ON AN OIL PIPELINE

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Results of laboratory experiments and a method for estimating the efficiency of the VIOL polymeric additive for reduction of the hydrodynamic resistance in an petroleum pipeline are presented.

The effect of reducing the hydrodynamic resistance of turbulent flows by polymeric additions at small concentrations discovered almost half a century ago by English chemist Thomes (Thomes's effect) has not only theoretical but also great practical value in pipe transport of liquids [1]. After numerous laboratory experiments carried out in the 1960s-1970s [2] Conoco Company started commercial application of CDR-101 agent in the trans-Alaska pipeline in 1979. At present this oil pipeline and some others use the more effective CDR-102 additive.

In this country hydrodynamic properties of various polymers have been studied under laboratory conditions. High-molecular-weight oil compounds (resins and asphaltenes), surfactant solutions, and a number of synthetic polymeric samples have been tested [3, 4] as resistance-reducing agents. However, at present there are no data on successful tests in oil pipelines. In our opinion, this can be explained partly by the absence of a reliable method for estimation of the hydrodynamic efficiency of the polymer when passing from laboratory experiment to commercial practice and, as a result, the absence of large-scale production of the agent itself.

In most cases, while studying the behavior of polymer solutions, researchers consider just the flow turbulence, which is a necessary condition for manifestation of the effect, and express their experimental results as a function of the Reynolds number, neglecting the shear stress τ_w on the tipe wall. At present it is generally accepted that every polymer sample has a threshold shear stress τ_{th}, starting from which the polymer operates as a resistance reducing agent. Therefore, taking this experimental fact into consideration, a sufficient condition for the onset of Thomes's effect in a turbulent flow can be written as the inequality $\tau_w > \tau_{th}$. Therefore, when studying hydrodynamic properties of synthesized polymer samples, we paid special attention to their conformity with Lamly's time criterion $u_*^2\theta/\nu \geq 1$, where $u_* = \sqrt{\tau_w/\rho}$ is the dynamic velocity and θ is the relaxation time of the polymer. From this criterion a minimum (threshold) shear stress necessary to initiate the effect can be found:

$$\tau_{th} = \frac{RT}{M\,[\eta]}. \tag{1}$$

Thus, a decrease in the friction in an oil pipeline can be achieved only with addition of polymeric solutions satisfying the relation

$$M\,[\eta] > \frac{RT}{\tau'_w}, \tag{2}$$

where τ'_w is the shear stress on the wall of a particular pipeline.

It follows from inequality (2) that the efficiency of the additive depends not only on its molecular mass but also on the quantity $[\eta]$, which characterizes the thermodynamic compatibility of the polymer with the solvent. Petroleum is a multicomponent system, whose properties are determined by the relative content of saturated, cyclic,

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TABLE 1. Decrease of the Hydrodynamic Resistance of VIOL Solutions, $\tau_w = 105$ Pa, $TD = 293$ K

Solvent	*DR* of solutions at various concentrations, kg/m^3				Re × 10^{-3}	[η], m^3/kg
	0.02	0.03	0.05	0.1		
Toluene	0.70	0.70	0.68	0.66	13.0	1.2
Heptane	0.63	0.65	0.71	0.70	18.0	1.1
Cyclohexane	0.58	-	0.62	0.62	7.5	0.9
50% decanol + 50% heptane	-	-	0.54	0.55	3.5	0.8
Petroleum ($\tau_w = 315$ Pa)	0.19	-	0.36	0.42	3.0	0.6

TABLE 2. Decrease of the Hydrodynamic Resistance of VIOL Solution in Heptane ($C = 0.05$ kg/m^3) at Various Shear Stresses

τ_w, Pa	2.5*	9.0	19.0	29.0	55.0	105.0
Re	5000	6000	10000	14000	20000	28000
DR	0.32	0.55	0.63	0.66	0.69	0.70

and aromatic hydrocarbons contained in it and by the presence of polar compounds, containing heteroatoms in their structure. Results of a laboratory study of a sample of the VIOL polymer with hydrocarbon structure are given in Table 1. They show its high hydrodynamic efficiency in solvents of various chemical character. Experiments in this study were carried out with a turbulent flowmeter [5]. Its design is similar to that of a capillary viscometer, in which a turbulent flow with a controlled shear stress is produced. The effect was evaluated from the formula $DR = \Delta\lambda/\lambda_s$. High values of the intrinsic viscosity and molecular mass ($M = 3\cdot10^6$) of the sample (measured with an Ubbelode viscometer and an MOM 3180 ultracentrifuge) allowed a maximum effect to be achieved in most solvents at concentrations lower than 0.1 kg/m^3.

Since high efficiency of the sample studied was obtained at stresses substantially exceeding the actual loads in petroleum pipelines, it was necessary to study the dependence of the effect on the shear stress (Table 2). All the results given in Table 2, except for the first column, are obtained for a tube with a diameter of $1.7\cdot10^{-3}$ m. The shear stress $\tau_w = 2.5$ Pa was achieved for a tube with a diameter of $3.2\cdot10^{-3}$ m with turbulence.

Table 2 shows that the effect increases with the shear stress and at sufficiently large loads it becomes a "plateau" of maximum values. The value of *DR* at $\tau_w = 2.5$ Pa, which is larger than $\tau_{th} = 1$ Pa of the sample obtained from formula (1) and smaller than the actual $\tau'_w = 3$ Pa in the Aleksandrovskoe-Anzhero-Sudzhensk pipeline, is of greatest practical interest. The hydrodynamic efficiency of a petroleum solution of VIOL at $\tau_w = 3$ Pa cannot be found experimentally in a laboratory turbulent flowmeter. At so small a shear stress and the kinematic viscosity of the petroleum $\nu = 5\cdot10^{-6}$ m^2/sec in a tube with a diameter of $1.7\cdot10^{-3}$ m there is a well developed laminar flow. The transition of petroleum systems to turbulence in a turbulent flowmeter occurs at stresses much larger than 3 Pa. Therefore, in our studies the main criterion for predicting the behavior of the additive in a pipeline was satisfaction of inequality (2) at $[\eta] = 0.6$ m^3/kg and $\tau'_w = 3$ Pa.

High values of the hydrodynamic resistance reduction effect obtained experimentally for model hydrocarbon systems at small stresses and low concentrations of VIOL and the validity of inequality (2) for petroleum solutions of the polymer allowed the additive to be commercially synthesized at Tomsk Petrochemical Plant and to be tested in a pipeline. In a pipeline section with a diameter of 1.22 m and a length of $7\cdot10^4$ m, at a shear stress of 3 Pa, a volume flowrate of 1.7 m^3/sec, and Re = $0.35\cdot10^6$, the friction loss was reduced by 21%. The concentration of the additive was 0.04 kg/m^3.

Comparison of the test results for VIOL and CDR-102 shows that their production characteristics are similar. The somewhat higher effect [2] from CDR-102 can be explained by higher shear stresses ($\tau''_w = 9$ Pa) in the trans-Alaska pipeline.

Thus, the present laboratory studies and successful commercial tests of the VIOL additive allow the conclusion to be made that its efficiency is high and that the energy-saving technology can be used in petroleum transportation.

NOTATION

DR, hydrodynamic resistance reduction effect; λ_s and λ_p, hydrodynamic resistances of the solvent and the polymer solution; $\Delta\lambda = \lambda_s - \lambda_p$, change in the hydrodynamic resistance; τ_w, shear stress on the pipe wall; τ_{th}, threshold stress of the polymer sample; u_*, dynamic velocity; ν, kinematic viscosity; ρ, density; θ, relaxation time; R, gas constant; T, temperature; M, molecular mass of the polymer; $[\eta]$, intrinsic viscosity; Re, Reynolds number.

REFERENCES

1. A. Kh. Mirzadzhanzade, A. G. Gumerov, and Z. P. Shul'man, Inzh.-Fiz. Zh., **59**, No. 2, 329 (1990).
2. W. R. Beaty et al., Oil Gas J., **80**, No. 32, 96-102 (1982).
3. A. Kh. Mirzadzhanzade, I. G. Bulina, A. K. Galyamov, et al., Inzh.-Fiz. Zh., **25**, No. 6, 1023-1026 (1973).
4. Yu. P. Belousov, Antiturbulence Additives for Hydrocarbon Liquids [in Russian], Moscow (1986).
5. I. L. Povkh, V. G. Pogrebnyak, and A. I. Toryanik, Inzh.-Fiz. Zh., **37**, No. 4, 581-588 (1979).