Increasing the efficiency of pipeline transport of viscous oil based on rheological features

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ABSTRACT: This article discusses existing methods for increasing the efficiency of pipeline transport of viscous oils. In more detail, the authors considered a method for transporting viscous oil using various additives. It is known that the rheological properties of oil are the basic initial data for the selection of a rational method of transportation. In this regard, an analysis of rheological models of viscous fluids is presented. Also, this paper considers the calculation of the effectiveness of the use of additives and their influence on the rheological properties of viscous oil. Taking into account the parameters of the studied pipeline, an anti-turbulent additive was chosen. This additive reduces the coefficient of hydraulic resistance and increases the throughput of the pipeline. The results of experimental studies of the rheological properties of viscous oil are presented. Based on the results of the experiments, the authors obtained the dependence of the shear stress on the shear rate in the temperature range of 10-30 °C at different concentrations of the additive used and without it. Taking into account the obtained dependences, conclusions were drawn about the presence of non-Newtonian properties in the investigated oil. In addition, an analysis is made of the change in the rheological model when the concentration of the additive and the temperature of the transportation change. Based on the results of the studies, the authors performed the selection of the optimal pumping regime for the investigated oil.

1 INTRODUCTION

Currently, the issue of increasing the efficiency of pipeline transport of viscous and high-viscosity oils is discussed in the works of many scientists.

The rheological properties of hard-to-recovery oil are the main initial data for the solution of design and operational tasks in field development and further pipeline transport. In this regard, the task of studying the rheological properties of high-viscosity oil is topical.

For the correct choice of technological regimes of various processes of extraction, transportation and processing of oil, it is necessary to know the rheological properties of the oil, as well as oil products and working fluids involved in these processes (Martinez-Palou, 2011).

For the efficient pumping of viscous oil, several basic methods are used (Hart, 2014):

- oil heating;
- using of hydrocarbon diluents;
- hydrotransport;
- construction of loopings and inserts;
- increasing of the number of pumping stations (PS) along the pipeline;
- Increasing of the station capacity;
- Using of additives.

Figure 1. Head capacity curve of the pipeline, transporting oil with the anti-turbulent additive at various concentrations and without it.

The most common method for transporting viscous oil by pipelines is to pump preheated oil. This method consists in preheating oil before the enter to the main oil pipeline. Then oil heating stations are installed on the route at a certain distance, where the oil is heated (Nikolaev, 2016).

Previously, the authors conducted studies on the use of the M-FLOWTREAT grade C anti-turbulent additive in sections of a pressure oil pipeline (Nikolaev et al. 2019).

According to the results of the study, the head-capacity curves of the pipeline pumping oil without additives and with an additive concentration of 10, 20 and 30 g/t were obtained (Figure 1).

In this paper authors provided theoretical and experimental studies of methods for transporting high-viscosity oil. They also got necessary rheological dependencies and calculated effectiveness of using additive.

2 METHODOLOGY

The rheological properties of oil are the main source data for solving design and operational problems in the development of the field and further pipeline transport.

The initial data is a pipeline, the route of which runs under conditions of water-flooded and marshy area and eternal congelation along the territory of the Yamalo-Nenetskiy and Khanty-Mansiisk Autonomous District of the Tyumen Region. In addition to the Arctic climate, the construction area is characterized by unique geological and hydrological conditions. It is not rational to increase throughput only by heating, in order to avoid environmental impact (Nikolaev et al. 2018). In this regard, the authors have suggested the use of additives. An analysis of the using the various additives in domestic and foreign practice was made.

The additives used by the type of commodity form. We can divide additives into two groups: dispersion and gel (Muratova, 2014).

Additives of the first type are a suspension of the polymer in various liquids that do not enter into a chemical reaction with it. Alcohols, glycols and their esters are usually used as such liquids. The content of the active polymer in these additives reaches 25%. Such anti-turbulent additives include Necadd 447, Liquid Power, FLO XL, FLO MXA, M-FLOWTREAT, Alfacauchuk-S, Koltek PTN 3170, TurbulentMaster 8010.

Gel additives (CDR 102, FLO, Necadd 547, Viol, X-PAND, HIPR) are made in the form of a polymer solution in any hydrocarbon liquid (gasoline, kerosene, etc.). The active polymer in such additives contains about 10%.

The use of gel additives is especially beneficial for pipelines, where the processes of speed of their dissolution are important. These can be short pipelines of offshore fields, loading and shipping terminals.

Recently, work has been underway on the development and implementation of suspension-emulsion additives, designed for use in oil and gas production in field pipelines.

Due to the variety of physicochemical properties of the pumped oil and oil products through pipeline systems, in each case the use of chemical reagents is an individual feature of the pipeline.

Taking into account the parameters of the studied pipeline, an anti-turbulent additive was chosen, which reduces the coefficient of hydraulic resistance and increases the throughput of the pipeline (Avksentiev. 2017, Khudyakova et al. 2018).

The effectiveness (%) of anti-turbulent additive in a stationary mode of operation of the pipeline (Nikolaev et al. 2018):

$$DR = \left[1 - \frac{\Delta P_f}{\Delta P_0} \cdot \left(\frac{Q_0}{Q_f} \right)^{2-m} \cdot \left(\frac{\nu_0}{\nu_f} \right)^m \right] \cdot 100\% \quad (1)$$

where f and 0 correspond to the flow of crude oil with and without additives; ΔP = friction pressure loss, kg/cm²; Q = volume flow rate, m³/h; ν = kinematic viscosity with average temperature, m²/c; m = criteria of flow mode. Turbulent in zone hydraulically smooth pipe m = 0,25, zone of mixed friction m = 0,123.

One of the main tasks of rheological research is to determine the correlation between the forces acting on the investigated fluid and the deformations caused by these forces.

Fluids called Newtonian are described by the following equation:

$$\tau = \mu \cdot \dot{\gamma} \quad (2)$$

where τ = the shear stress, Pa; μ = the coefficient of dynamic viscosity, Pa c; $\dot{\gamma}$ = the velocity gradient, c⁻¹.

The hypothesis of linear correlations between shear stresses and the velocity gradient proposed by Newton is not valid for all liquids.

Liquids whose rheological behavior differs from the equation are called non-Newtonian. Non-Newtonian fluids are divided into three groups (Mirzajanzade. 1999, Rogachev. 2000):

1. nonlinearly viscous fluids (shear stress is a nonlinear function of shear rate);
2. liquids with unsteady rheological characteristics (the functional relationship between shear stress and shear rate depends on the time or process history);
3. viscoelastic fluids (exhibit elastic restoration of shape after stress relief).

The studied oil sample can be attributed to nonlinearly viscous liquids.

A general classification of rheological models of nonlinearly viscous fluids proposed by various researchers was given in (Mirzajanzade. 1999.).

3 RESULTS AND DISCUSSION

Experimental studies were carried out at the Center for Engineering Surveys (Mining University), on a Kinexus ultra + rotational rheometer. The principle of operation of the Kinexus ultra + rotational rheometer is to apply an adjustable shear strain to the test sample in order to measure the flow properties.

As a result of experimental studies, the main rheological dependencies were obtained. The obtained dependences show the presence of non-Newtonian properties in oil transported without additives (Figure 2) and in oil samples transported with an additive of 20 g/t (Figure 3) in the temperature range 10-30 °C.

Figure 2. The dependence of shear stress on shear rate without additive.

Figure 3. The dependence of shear stress on shear rate with an additive concentration of 20 g/t.

During data processing the authors obtained the following dependences for a sample of oil transported without the use of an anti-turbulent additive:

Sample heating to 10°C:

$$\tau = 13,863\dot{\gamma}^{0,3057} \quad (3)$$

Sample heating to 15°C:

$$\tau = 12,5\dot{\gamma}^{0,3123} \quad (4)$$

Sample heating to 20°C:

$$\tau = 10,197\dot{\gamma}^{0,3161} \quad (5)$$

Sample heating to 25°C:

$$\tau = 8,4988\dot{\gamma}^{0,3168} \quad (6)$$

Sample heating to 30°C:

$$\tau = 1,7589\dot{\gamma}^{0,5857} \quad (7)$$

According to the results of dependences (3-7) and according to the data in Table 1, the oil corresponds to the Ostwald - de Waal model. During the pumping oil without using an additive, the oil sample belongs to nonlinearly viscous liquids and shows the presence of non-Newtonian properties when heated to 30 °C.

During data processing, authors obtained the following dependences for oil sample transported with an anti-turbulent additive with a concentration of 20 g/t.

Sample heating to 10°C:

$$\tau = 7,7621\dot{\gamma}^{0,3052} \quad (8)$$

Sample heating to 15°C:

$$\tau = 0,0931\dot{\gamma} + 0,8074 \quad (9)$$

Sample heating to 20°C:

$$\tau = 0,0435\dot{\gamma} + 0,0241 \quad (10)$$

Sample heating to 25°C:

$$\tau = 0,0318\dot{\gamma} + 0,0372 \quad (11)$$

Sample heating to 30°C:

$$\tau = 0,0232\dot{\gamma} + 0,0183 \quad (12)$$

According to the obtained dependence 8 and the data of Table 1 the oil corresponds to the Ostwald - de Waal model. According to the obtained dependence of 8, the oil corresponds to the Shvedov-Bingham model. But we can notice that it has a transitional form. According to dependences 9-12, it is clear that when transported with an additive of 20 g/t and when heated to 20 °C, oil acquires Newtonian properties.

Table 1. The results of calculating the effectiveness of anti-turbulent additive «M-FLOWTREAT» brand C.

Stage	Rate of additive, g/t	Output pressure, kgf/cm ²	Inlet pressure, kgf/cm ²	Volume flow rate, m ³ /h	Effectiveness DR, %	Increase in capacity, %
1	-	63.8	2.8	535.00	-	-
2	10	63.7	2.4	610.24	21.59	14.06
3	20	53.9	3.2	700.50	49.86	30.93
4	30	47.7	2.6	734.79	59.08	37.34

4 CONCLUSION

Based on the results obtained during the studying of viscous oil samples at various concentrations of additive from 0 to 20 g/t and heating oil samples from 10°C to 30°C, the following conclusions and recommendations can be made:

At a certain content and temperature of oil, its properties change slightly. Therefore, increasing the cost of regulation of the temperature and the content of the additive is not rational, because efficiency during pumping does not change significantly.

With an increase in additive concentration and temperature, oil with non-Newtonian properties begins to correspond to the model described by Newton.

The optimal mode for pumping this oil is pumping at 20 °C with an additive concentration of 20 g/t. Moreover, increasing in additive concentration will not lead to efficiency improvement.

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