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Analysis of Viscosity of Oil and Depressor Additives to It

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ABSTRACT: The article provides a detailed analysis of the rheological properties of high-viscosity oils and the efficiency of using pour point depressants to optimize their transportation. The article considers the non-Newtonian characteristics of heavy oils, their influence on the processes of pumping through pipeline systems, and modeling methods that allow predicting the behavior of oil under various conditions. Particular attention is paid to the analysis of viscosity changes with variations in shear stress and temperature conditions, as well as to the assessment of the influence of pulsating and oscillating flows on the efficiency of transportation. The article presents results based on the use of the Powell- Eyring, Sutterby, Williamson, and Meter models, which demonstrate the importance of preliminary analysis and adaptation of engineering solutions to the specifics of high-viscosity oils.

KEYWORDS: heavy oils, high-viscosity oils, rheological properties, non-Newtonian fluids, pour point depressants, flow modeling, viscosity, pipeline transportation, rheological models.

I. INTRODUCTION

In the modern oil industry, issues related to the extraction, transportation and processing of heavy and highly viscous oils occupy a special place. High oil viscosity is a significant technical obstacle that increases energy costs for pumping through pipelines and reduces the efficiency of all processes, from extraction to refining. For this reason, the regulation of oil viscosity using chemical additives such as depressants plays a key role.

Depressant additives are designed to reduce the temperature of the onset of paraffin crystallization, which is important to prevent the formation of paraffin plugs in oil pipelines during the transportation of oil in the cold season. They also help reduce viscosity, thereby facilitating the process of its pumping and reducing overall processing and transportation costs.

The effectiveness of pour point depressants depends on many factors, including their chemical nature, concentration in oil, and the characteristics of the oil itself, such as its composition and operating temperature conditions. Analysis of oil viscosity and the effect of various pour point depressants on it requires a deep understanding of these processes, which is the subject of our study. In this article, we will review modern approaches to studying oil viscosity and analyze the effectiveness of various pour point depressants, based on the latest data from laboratory and industrial studies.

II. MATERIALS AND METHODS

Heavy and highly viscous oils play a key role in the global energy industry, primarily due to the depletion of easily accessible oil reserves. These oils have a complex chemical composition, high density and viscosity, which poses challenges for their production, transportation and processing. They usually have a low API gravity (less than 20°) and contain large amounts of asphaltenes, resins, paraffins and metals such as vanadium and nickel, which significantly increases their viscosity and requires the use of specialized technologies to optimize their transportation [1].

The rheological properties of such oils vary depending on temperature, pressure and the presence of water, which can form emulsions, further increasing the viscosity. As temperatures decrease, the viscosity of these oils increases, which requires the use of heating methods, the addition of solvents or the use of surfactants to ensure their transportation [2].

As for the classification of fluids according to their rheological properties, they can be divided into Newtonian and non-Newtonian depending on the changes in viscosity with variation in shear stress [3-5]. Newtonian fluids are characterized by constant viscosity under the same conditions of temperature and pressure, and they follow Newton's fundamental law of internal friction.

$$\tau = -\mu \frac{d\vartheta}{dy} = \mu\gamma \qquad (1.)$$

where: τ is the internal friction stress, Pa; μ is the dynamic viscosity, Pas ; ϑ is the shear (flow) velocity of the liquid, m/s; y is the coordinate on the axis perpendicular to the direction of flow (shear), m; $\gamma = \frac{d\vartheta}{dy}$ is the velocity gradient, s $^{-1}$.

Non-Newtonian fluids, such as oil, do not obey Newton's law of internal friction [3]. Their structure depends on the interaction of particles and changes under the influence of external forces and deformation rate, which is studied by rheology. Rheological properties are determined experimentally using rheological curves, which reflect the relationship between the velocity gradient (γ) and the shear stress (τ).

Rotational viscometers are used to plot rheological curves, where the rotation of the cylinder causes a shift in the liquid in the intercylinder space and the formation of tangential stresses measured through torque [4]. The characteristics of pseudoplastic and dilatant liquids are often described by a power dependence, which allows for an accurate assessment of their rheological properties.

When developing pipeline systems, studying the parameters of liquid flow helps to increase transport efficiency [6, 7]. The rheological properties of oil depend on its unique composition, which requires preliminary analysis for calculations and design [8,9].

Predictive models help to simplify the calculations of hydrodynamic parameters such as velocity and flow rate, minimizing energy costs during transport. The Powell- Eyring, Sutterby, and Williamson models provide an accurate description of the rheological properties of pseudoplastic fluids, although their application depends on the range of shear rates [10].

The Navier-Stokes equation is not suitable for non-Newtonian fluids due to their complex rheological characteristics. Adapted models that take these features into account are used for accurate engineering calculations [11].

III. RESULTS

Transportation of highly viscous oils is also carried out using diluents, heat treatment, hydrotransport with a water layer or emulsions. Stabilization of emulsions is achieved by using reagents such as sulfonol NP-1, which ensure the stability of emulsions at low temperatures and their decomposition at elevated temperatures [12-15].

In order to increase the efficiency of oil transportation, it is necessary to minimize energy costs, prevent the formation of deposits and reduce hydraulic resistance. Chemical reagents are also used to prevent corrosion caused by salts contained in oil.

Table 2 presents reagents and compositions for transporting high-viscosity oils. Sodium alkylbenzenesulfonates (0.005-0.015%) are actively used to reduce the viscosity of oils, reducing interfacial tension and improving pumping conditions [16].

Table 2.
Compositions of substances used for the transport of high-viscosity oils

Reagent	Compound	Content,%	Purpose of the impact and features of application
Alkylbenzenesulfonates	Sodium alkylbenzenesulfonates	0.005-0.015	Transport of high-viscosity oils
Gas-water mixture	Gas mixture	2.4-4.7	Transport of paraffinic oil, the mixture is introduced at 45-60 ^{0}C
	surfactants	95.3-97.6	

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	Thermal well water is the basis	60	
	Demulsifier DN-1	8	
Gas condensate with surfactants	Gas condensate	32	Transport of highly paraffin oils
	surfactants	0.25-3.05	
Hexametaphosphate with additives:			
1	Sodium hexametaphosphate	45	Hydrotransport of viscous oils
	Ethoxylated alcohols	18.8	
	KMC	36.2	
2	Sodium hexametaphosphate	45	Concentration of the composition 3.2 g/l
	Ethoxylated alcohol	60	
	KMC	8	
3	Sodium hexametaphosphate	45	Concentration of the composition 2.8 g/l
	Oxyethylated alcohols OS-20	0.4	
	KMC	6	
4	Sodium hexametaphosphate	26.4	Concentration in water (sea) 0.312%
	Ethoxylated alcohols	31.6	
	KMC	6	
5	Sodium hexametaphosphate	3	Concentration in water (sea) 0.312%
	Oxyethylated alcohol OS-20	1	
	KMC	0.4	

A gas-water mixture, including thermal well water (60%), surfactants (95.3-97.6%) and demulsifier (8%), is used to transport paraffin oil at a temperature of 45-60°C. The gas mixture promotes the melting of solid paraffins, while surfactants stabilize emulsions, preventing their destruction during transportation.

Compositions based on gas condensate with the addition of surfactants (0.25-3.05%) are intended for the transportation of highly paraffinic oils. Gas condensate (32%) dissolves solid paraffins, which reduces the viscosity of oil and increases its fluidity, ensuring more efficient pumping through pipelines.

Hexametaphosphate with additives is used in several variations of composition and concentration for hydrotransport of viscous oils. Its content in compositions is 26.4-45%, supplemented with oxyethylated alcohols (0.4-60%) and carboxymethylcellulose (6-36.2%). Such compositions stabilize emulsions and prevent their destruction, especially in seawater conditions, where the concentration of the composition can reach 0.312%.

IV. DISCUSSION

Analysis of data on synthetic reagents for transporting high-viscosity oils shows that their development is aimed at improving fluidity, reducing viscosity and pour point.

Table 3.
Synthetic reagents used for oil transport

Reagent	Compound	Content, %	Purpose of the impact and features of application
Hydroxyethylated acids	Hydroxyethylated fatty acids of fraction C_{17}-C_{20}		Transport of viscous oils , emulsion stability during hydrotransport
Dialkylamidodithio - phosphate	Dialkylamidodite phosphate		Reducing the viscosity and pour point of oil
Disolvan-411 with additive	Disolvan-4411	50 (g/t)	Hydrotransport of viscous oils
	Hypan	10 (g/t)	
Demulsifier	Demulsifier DN-1 in combination with a low-viscosity diluent nonionic surfactants containing 6-13 hydroxyethyl groups, and surfactants containing GS-GIS in alkyl	0.15	Improving the rheological properties of high-viscosity oil, the amount of diluent depends on the properties of the oil.
Polypropylene	Polypropylene M-(2-3) 10^3	60-95	Transport of high-viscosity oils - creation of a peripheral ring flow

Polymer type additive with additive	Polymer type additive	5-40	Transport of highly viscous oils - reduction of pour point
	Derivative of 1,3 dioxane	92	
Thinner with additive	Gasoline or kerosene fraction	8	Transport of highly viscous oils in the form of a coarsely dispersed phase in a low-viscosity diluent
	Asphalt resin product (0.01-1.0% of the oil mass)	60	
PAA	metasilicate + PAA	60	Hydrotransport of high-viscosity oils
PAA	Sodium metasilicate + PAA	22	Concentration of the composition 32.5 g/l
	SulfonolNP-1 or NP-3	14	
sulfonol NP-3+ diolvan-4411	Sodium metasilicate + sulfonol NP-3 + diolvan-4411	60	Concentration of the composition 10 g/l

Hydroxyethylated fatty acids (C_{17}-C_{20}) stabilize emulsions during hydrotransport, preventing their destruction and sedimentation of heavy components. Dialkylamido dithiophosphate reduces the viscosity and pour point of oil, changing its rheological properties, which makes it universal for paraffinic oils.

V. CONCLUSION

Hypane- based compositions stabilize the flow and prevent paraffin deposition, which is important for pipelines in difficult climatic conditions. Demulsifiers such as DN-1, in combination with diluents and surfactants with hydroxyethyl groups, effectively improve oil fluidity, reducing its viscosity. Polymer additives containing 1,3-dioxane derivatives prevent the formation of paraffin structures and reduce the pour point.

Diluents, such as gasoline or kerosene fractions with the addition of asphalt-resinous products, facilitate the transportation of oil by reducing hydraulic resistance. Compositions based on sodium metasilicate, PAA and sulfonols (NP-1, NP-3) provide a decrease in viscosity and flow stabilization, adapting to transportation conditions.

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