Investigation of rheological properties of water-in-oil emulsions

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Abstract. This work is dedicated to the study of flow curve characteristics obtained from rotational viscometer for oil and water-in-oil emulsions at different temperatures and water content. Within the framework of this study an approach of carrying out was developed. Assessment shows that the formation of crude oil structures occur at a temperature lower than the reservoir temperature. It was also established that reason for the the observed effects is the formation of paraffin crystals due to the sharp increase in viscosity. Experimental studies of mixtures showed that by increasing the water content up to the point of phase inversion the viscosity anomaly of water-in-oil emulsions become more evident. The determined rheological curves for direct and reversed feeds of emulsion specify the existence of hysteresis loop in the water content of respective phase inversion, which is a characteristic of non-Newtonian / anomalous fluids.

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Keywords: rheological curves, viscosity, water-in-oil emulsions, water cut, shear stress.

Introduction

The work of the well/downhole pump equipment largely depends on the composition and properties of the mixture of crude oil (NB crude oil would be referred to as oil in throughout this article), gas and water lifted to the surface. When moving in underground pipes pressure is lost on friction. This is caused by the large increase in viscosity properties of reservoir fluids, physicochemical processes of formation of different combinations of both the oil and mixture of oil components, gas and water phases. Notable characteristic effect on the effectiveness of the uplift of downhole products is the formation of water-in-oil emulsions - mixtures of water and oil at different thermodynamic conditions. Despite the importance of the question and the great number of publications dedicated to the studying of properties of water-oil-dispersed systems [1,2,3,4,5], only few sources contain information about the properties of produced "natural" emulsions, forming in units of well and submersible pump equipment. Therefore, the results of the studies, which are given in this article, make a unique contribution to scientific knowledge dedicated to the studying of properties of stable high-viscosity water-in-oil emulsions.

The current state of the domestic oil industry is characterized by the increase in water-cut of well/downhole products and the reduction of well efficiency. Increase in the water phase content in the well/downhole products provoke series of complications, one of which is the formation of steady high-viscosity water-in-oil emulsions.

Analysis of references (or literature sources) as well as experimental studies [6] show that, when the water-cut of well/downhole products is within the range of 50 - 80% the formation of steady water-in-oil emulsion with an anomalously high viscosity is most probable.

It has been shown by many researchers that oil with increased composition of asphaltene, resin (or tar) and paraffin possess structure-mechanical properties. The occurrence of viscosity anomalies is characteristic of such oils, i.e. their viscosity is not constant, but depends on the acting shear stress. In relation to this, oil falls in the class of Newtonian liquids [7]. Rheological properties, inherent of Newtonian fluids including viscosity anomalies at given flow conditions can cause the occurrence of water-in-oil emulsions. Thus, for example, with increase shear stress applied to the water-in-oil emulsion, globules of its dispersed phase deform (elongate, changing their form from spherical to elliptical), which eases the flow of emulsion and leads to reduction of its effective viscosity [8].

Knowledge of rheological properties of the produced oil (or water-in-oil emulsion) is necessary when selecting equipment and determining the optimal drive of well production, including electric submersible pump as well as when substantiating the methods and technology directed towards increasing the efficiency of oil production processes.

Approach

Rheological studies were conducted on a rotational viscometer Rheotest RN 4.1. The experiment included determination of the dependence of oil viscosity on shear stress, as well as that of shear stress on shear rate at different temperatures within the range of 15 - 60 degrees Celsius. Mechanical method of dispersion was used for the preparation of water-in-oil emulsions with the help of a paddle mixer, which allows simulating the process of mixing oil and water in steps of the electric submersible pump. The prepared and measured portions of the oil and water were poured into a volumetric container and mixed for 40 minutes at 2000 rev/min (revolutions per minute) on a laboratory mixer IKA EUROSTAR Power Control Visc 6000. The time of mixing was chosen experimentally depending on the dispersity of water globule [6]. Rheological flow curves of the water-in-oil emulsion were drawn at the same temperatures as those for the prepared oil sample.

Body

This article presents results of studies on rheological properties of oil from deposits of the tourn-fammenian stage, as well as its water-in-oil emulsions. The studied oil falls under the class of low viscosity oils with a viscosity in reservoir conditions of 7.3 mPa*s. In terms of density the oil is in the category of medium density oils; the density of the separated oil varies from 859 to 877 kg/m^3, averaging 868 kg/m^3.

The oil is resinous - 11 - 28% resin, sour - 1.6 - 3.0% sulfur, paraffinic - 0.1 - 4.1% paraffin. The physicochemical characteristics of degassed oil are given in table 1.

Table 1. Physico-chemical characteristics of degassed oil sample

Parameter	Average value
Density at 20 °C, kg/m^3	868
Viscosity, mPa·s	
at 20 °C	16,17
at 50 °C	5,67
Molar mass, g/mole	213,0
Mass composition, %	
Sulphur	2,62
Silica gel resins	18,86
Asphaltenes	3,28
Paraffins	1,74
Water	0,75-95,6
Melting point temperature of paraffin, °C	53,3

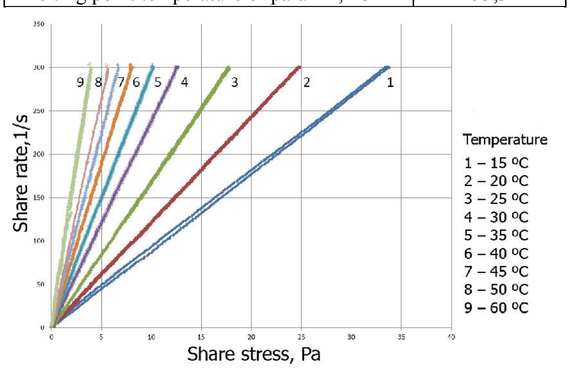

Figure 1. Rheological curves for direct and reversed feeds (hysteresis loop) of oil at different temperatures

The different characteristics of deformation for the sample under investigation are shown from the stress rate/velocity of oil and shear stress (fig. 1). At a temperature of 20 degrees Celsius and more, the oil behaves practically like a non-Newtonian fluid. By decreasing the temperature to 15 degrees Celsius, the anomalous properties of the oil become more prominent: viscosity begins to decrease with increase in stress rate.

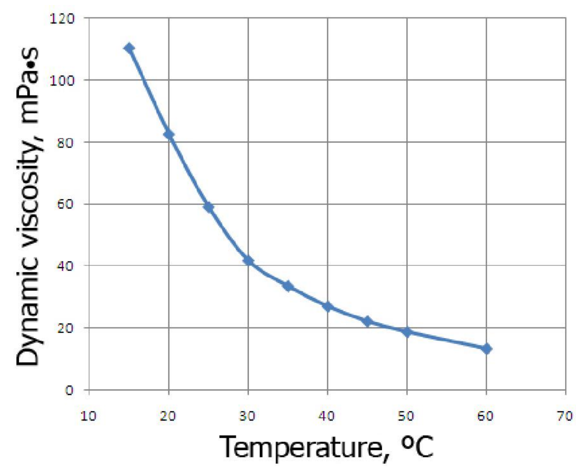

Figure 2. Dynamic viscosity of oil and temperature relations

The existence of paraffin oil in the sample under investigation results to high dependence of its viscosity on temperature. By increasing the temperature paraffin crystals are formed, wherein, the viscosity of the oil sharply increases [9, 10]. Thus, crude oil in Turna-famennian stage contains 2% of paraffin. Studies show that reducing the temperature with reservoir from 24 to 15 degrees Celsius the viscosity increases by almost two (fig. 2).

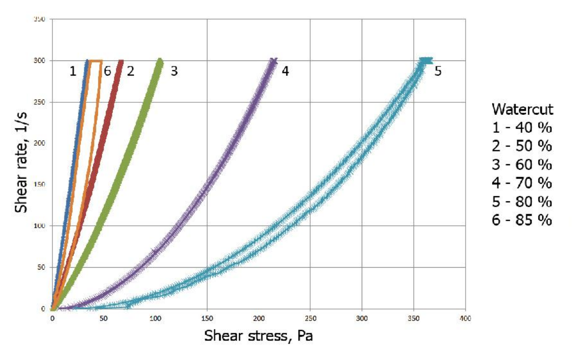

Figure 3. Rheological curves for direct and reversed feeds (hysteresis loop) of water-in-oil emulsions at different water contents

Results for the rheological studies of reversed type water-in-oil emulsions show that increasing water content up to the point of phase inversion the viscosity anomaly of water-in-oil emulsion becomes more prominent, in our case by increasing the water content to 80% (fig. 3). Moreover, the rheological curves for direct and reversed feed study of water-in-oil emulsion form a hysteresis loop which is characteristic of non-Newtonian fluids with thixotrophic properties.

Conclusion

1) Results for the study on structural and mechanical properties of oil showed that the formation of structures occur at a temperature lower than 20 degrees Celsius. This is related to the existence of asphaltene-resin-paraffinic substances in the oil. Notwithstanding, the oil under study is not related to high-viscosity and heavy oils.

2) Significant increase of emulsion viscosity occurs up to a content of 80% aqueous phase indicating that the point of phase inversion exceeding the densest packing structure forming globules of water phase. This indicates formation of water globules on the the surface layer consisting of natural surface-active substances (SAS), which give emulsions high stability.

3) The presented results on the rheological properties of water-in-oil emulsions give possibility of increasing the operational efficiency of well equipment.

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