Influence of acoustic treatment and nature of solvents on viscosity of heavy oils

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Abstract. The article summarizes experimental data on the influence of acoustic treatment and the nature of solvents on the viscosity of oil from the Timan-Pechora and the Volga-Ural oil and gas-bearing basin. A combined treatment of oils, including acoustic exposure to 22 kHz and the addition of a chemical reagent was carried out. It is shown that the introduction of 1.75% wt alkaline solution of isobutyl alcohol leads to a decrease in oil viscosity of the Timan-Pechora oil and gas-bearing basin by 35%. After complex treatment (acoustic exposure for 1 min and the addition of reagent) the viscosity decreased by 60%. The introduction of alkaline chemicals into the oil of the Volga-Ural oil and gas-bearing basin does not lead to a decrease in viscosity. Oil viscosity decreases by 2.1 times after the introduction of 3% wt solvent P-12 (60% toluene, 10% xylene, 30% butyl acetate). Viscosity reduces by further 18% after acoustic exposure. Thus, the maximum viscosity reduction of heavy oils can be achieved by using the combined treatment including of acoustic exposure and addition of the selected chemical reagent.

1. Introduction

A prerequisite for the extraction of hydrocarbon resources in Siberia and the Arctic is to ensure uninterrupted operation of the transport system of the extracted volumes of oil, as well as their products [1]. Oil pipeline transport in the Russian Arctic is developed in several autonomous regions. The length of oil pipelines ranges from 63 to 523 km. For example, when developing the Novoportovskoye field on the Yamal Peninsula (one of Gazprom Neft's strategic projects) along with sea oil transportation, a pressure oil pipeline with a length of more than 100 km is used. To maintain the set temperature of the feed it was designed in the form of two insulated pipelines through which heated oil circulates between shipments.

In the Arctic regions of European Russia where there are already separate trunk oil and gas pipelines a promising way to transport hydrocarbons may be to connect peripheral wells and fields to the main pipelines. Where subsoil development projects are only being developed it is advisable to calculate the competitiveness of pipeline transport in comparison with sea and rail transportation, as well as assess its compatibility and complementarity with these types of transportation.

To date, volumes of hydrocarbon transshipment from offshore terminals in Murmansk, Vitino and Arkhangelsk are limited by the possibilities of delivering fuel to these ports via the Oktyabrskaya Railway. The prospect of the development of pipeline transport in the Russian Arctic, which will also make it possible to fully utilize the capacities of these ports and increase export volumes via the
Northern Sea Route may be connected with the connection of these ports with the onshore fields of the Russian Arctic by main pipelines.

Complications in technological processes of hydrocarbon transport, such as increasing viscosity, loss of fluidity, the formation of asphalt-resin-paraffin deposits on the surface of the equipment that occur when the temperature of the feed stream decreases, increase energy costs and reduce the efficiency of these processes. Methods used to increase the fluidity of oil traditionally include heat treatment, physical and chemical methods, dilution with light oil fractions or solvents of various nature [2-6]. Processing efficiency is often improved when using combined methods of exposure. Currently, the influence of acoustic effects in the ultrasonic wave range on the structural and mechanical properties of disperse systems is actively being investigated. Acoustic treatment technology (AT) is attracting increasing attention due to the simplicity of operation, high technology, low cost and environmental safety. However, the consequences of acoustic exposure to hydrocarbons are ambiguous and depend on the composition of the oil disperse system. So in [7] it was shown that AT of highly paraffin disperse systems leads to an increase in their viscosity and pour point. Treatment of such dispersed systems in the presence of aromatic components or polymer depressant additives eliminates the negative impact of acoustic exposure and also improves viscosity-temperature characteristics [7].

In [9], the effect of ultrasonic treatment on the viscosity and pour point of paraffinic and high-paraffin oils with different contents of tar-asphaltene components was studied. Ultrasonic action on resinous paraffin oil for 15 min allowed to lower the pour point by 16 °C and viscosity by 6 times. The relaxation of the viscosity-temperature characteristics of the oils takes several days, and the petroleum dispersed system is not completely restored, thereby partially preserving the influence of ultrasonic exposure.

The work [10] is devoted to the study of the influence of cavitation on the rheological properties of Azerbaijani oil. Based on the studies, the author claims that cavitation destroys paraffins and supramolecular structures of oil, associates, micelles and helps to reduce their size, which contributes to a decrease in viscosity. The experiments showed that as a result of cavitation processes, the dynamic viscosity of Azerbaijani oil decreased by 9% rel. However, the statement about the destruction of paraffins as a result of cavitation processes in oil is quite bold if we take into account the previously published work [11].

In practice, the rheological characteristics of high viscosity oil are usually reduced by dilution with lighter oil, gas condensate or solvents, but light hydrocarbons may be absent near the field with high viscosity oil and the introduction of organic solvents is not economically viable. Therefore, it is relevant to study complex methods of exposure including dilution of oil and AT the effectiveness of which is higher due to the presence of a synergistic effect.

In [12], the influence of ultrasonic treatment, chemical reagent treatment, and complex effects on deposits of various nature was studied. It is shown that an increase of temperature as a result of ultrasonic treatment has a positive effect on the structural and rheological parameters of the paraffin systems under study.

Thus, the above literature review shows the ambiguity of most studies, in which the fact of changes in the structural and mechanical properties of oil systems is noted, therefore, to determine the nature of the influence of acoustic effects on the behavior of oil disperse systems, additional research is required.

In this paper, we studied the effect of acoustic treatment (AT) and the nature of solvents on the viscosity of oils from the Timan-Pechora oil and gas-bearing basin (TP) and the Volga-Ural oil and gas-bearing basin (VU).

2. Experimental methods and materials
Selected oils differ in component composition and physicochemical properties (table 1).

| Oil | Effective viscosity at 20 °C, $\eta_{20} \text{ mPa.s}$ | $T_{p}$, °C | Content, % wt |
|-----|------------------------------------------------------|-------------|---------------|

Table 1. Viscosity, pour point and component composition of oils.
The chemical reagents used were toluene, an alkaline solution of isobutyl alcohol (IBA), Netrol acid reagent in alcohols, and R-12 solvent (60% toluene, 10% xylene, 30% butyl acetate).

AT of oil systems was performed on a ULTRASONIC TS-4M (1 kW of power) installation. 200-300 g of oil was introduced into the reactor and treated for a predetermined time.

A Brookfield DV-III ULTRA viscometer was used to study the effect of AT and chemical reagents on the rheological characteristics of the initial oils. Measurement processing was performed using Rheocalc software.

Oil viscosity measurements were carried out according to the following methods:

- AT: 300 g of the initial oil was thermostated in the cell of an ultrasonic reactor for 20 min at 20 °C. The oil was then sonicated for a predetermined time. An oil sample placed in a cell of a rotational viscometer then thermostated for 20 min and rheological measurements were performed.

- Effect of a chemical reagent: At first, the initial oil was examined. The oil sample was heated to 50 °C, thermostated for 30 min, then cooled to 20 °C, thermostated for 20 min and measured on a rotational viscometer. To assess the effect of a chemical reagent on the viscosity of oil it was dosed into hot oil and then rheological parameters were measured at various additive concentrations under the same conditions as the initial oil.

- The complex effect of AT and a chemical reagent: the viscosity of the initial oil was measured then acoustic treatment was performed and rheological parameters were measured. The chemical reagent was added and the mixture was kept for 30 min and viscosity measurements were performed. The simultaneous and sequential effect of acoustic treatment and chemicals on oil was studied. With simultaneous influence, a chemical reagent was introduced into the oil, and then acoustic treatment was carried out. With a sequential effect, the oil sample was first subjected to acoustic activation, and then a chemical reagent was added.

3. Results and Discussion

TP oil is characterized by a very high viscosity, the values of which increase significantly with decreasing temperature. Studies have shown that the rheological properties of oil change little after AT: after processing for 1-8 min, a decrease in viscosity of the original oil by 8-10% is observed.

In the presence of 3% wt toluene depression viscosity is 30%. More effectively, the viscosity of TP oil decreases after complex exposure: dilution of 3% toluene and AT for 5 min leads to a decrease in viscosity by 2.1 times (table 2).

**Table 2. Change in the viscosity of VU oil depending on the method of exposure (20 °C).**

| Sample                      | Viscosity, mPa·s |
|-----------------------------|------------------|
| TP                          | 5200             |
| TP + 1 min AT               | 5020             |
| TP + 3% toluene             | 3640             |
| TP + 3% toluene + 2 min AT  | 3640             |
| TP + 3% toluene + 3 min AT  | 3500             |
| TP + 3% toluene + 4 min AT  | 3000             |
| TP + 3% toluene + 5 min AT  | 2476             |
| TP + 3% toluene + 6 min AT  | 2800             |
| TP + 3% toluene + 7 min AT  | 2800             |
| TP + 3% toluene + 8 min AT  | 2950             |
| TP + 3% toluene + 8 min AT_2 days⁸ | 2950 |
| TP + 3% toluene + 8 min AT_3 days⁸ | 3150 |
IBA was added to TP oil in an amount of 0.5-5% wt. The introduction of 1.75% wt IBA reduces the viscosity of TP oil by 35%. The maximum depressant effect of 60% was achieved after the introduction of 1.75% wt IBA and subsequent treatment for 1 min (figure 1). The increase in the time of ultrasonic treatment of the mixture oil + 1.75% wt IBA up to 2 min leads to an increase in viscosity. The processed sample, aged for 3 days, relaxes, but does not reach the initial viscosity values.

Figure 1. Change in effective viscosity (shear rate 20 s⁻¹) of TP oil after AT and dilution with IBA; temperature 20 °C.

VU oil is also characterized by a high content of resins (28.6% wt), asphaltenes (6.1% wt), and a lower acid content (concentration of COOH groups is 0.05%) compared to TP oil. This oil after AT for 2 min shows a decrease in dynamic viscosity by an average of 10% over the entire range of shear rates compared to the viscosity of the original oil. Increasing the processing time to 5 min leads to an increase in viscosity values.

The low content of petroleum acids in this oil precludes its treatment with alkaline solutions to reduce viscosity. To reduce the viscosity of VU oil Netrol acid reagent solutions in methyl, isopropyl, and isobutyl alcohols were used. It turned out that the use of an acid reagent in methanol leads to a decrease in viscosity, however the oil mixture exfoliates over time.

As can be seen from table 3, the introduction of 1 and 2% wt Netrol’s solution in isopropyl alcohol (IPA) (Netrol’s concentration in alcohol of 1% wt) in oil reduces the viscosity by 1.7 and 1.9 times, respectively. The increase in the content of Netrol to 6% wt leads to an increase in dynamic viscosity compared with the initial sample. AT of mixtures of oil + 1% wt and oil + 2% wt solution of Netrol in isopropyl alcohol leads to an additional decrease in viscosity by 10 and 14%, respectively (table 3).

Table 3. Change in the viscosity of VU oil depending on the method of exposure (20 °C).

| Sample                        | Viscosity, mPa·s |
|-------------------------------|------------------|
|                               | No AT | AT, 2 min |
| VU                            | 1121  | 1009      |
| VU + 1% methanol (1% Netrol)  | 703   | 621       |
| VU + 2% methanol (1% Netrol)  | 695   | 598      |
| VU +0.5% IPA (1% Netrol)      | 790   | 694       |
| VU +1% IPA (1% Netrol)        | 672   | 610       |
| VU +2% IPA (1% Netrol)        | 595   | 524       |
VU +0.5% IBA (1% Netrol) 749 622
VU +1% IBA (1% Netrol) 652 628
VU +2% IBA (1% Netrol) 557 520
VU +1% P-12 701 671
VU +2% P-12 559 490
VU +3% P-12 536 441

*Mixture exfoliates*

The effectiveness of ultrasonic treatment increases with the introduction of R-12 solvent into oil (60% toluene, 10% xylene, 30% butyl acetate). For example, dilution of oil 3% wt solvent P-12 leads to a decrease in viscosity by 2.1 times and after acoustic exposure the viscosity decreases by another 18%.

4. Conclusion

The effect of acoustic treatment and nature of solvents on the viscosity of heavy oils has been studied. The addition of chemical reagents into the oils reduces the viscosity. Solvent effectiveness is strongly dependent on the composition of the treated substance. The combined effect of acoustic treatment and solvent results in an additional decrease in viscosity characteristics.

Thus, the maximum decrease in the viscosity of heavy oils can be achieved by using the combined effects of acoustic treatment and a selected chemical reagent.

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