Scientific and Applied Aspects of Regulating of High-Viscosity Oil

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Abstract

Pipeline transportation of oil is considered to be one of the basic and cost-effective ways of their delivery to the place of consumption. Moreover, in the case of using electricity, the higher the viscosity of the transported oil is, the more power consumption is. For pipeline transport, it is characterized the movement of the oil in an isothermal mode, in which it changes its rheological properties, moving from a Newtonian fluid at high temperatures of the transported flow to a non-Newtonian one. In Russia, it has not been created a sufficiently rigorous theory of motion of highly viscous flows so far. The complex of the researches on the development of theoretical foundations, the technology of use of the Rotary-Pulsating Acoustic Apparatus (RPAA), creating a high-intensity acoustic field, indicate the possibility of their use in the processes of production, preparation, transportation and processing of high-viscosity oils1,2. The article contains important theoretical background of characteristics and problems of pipeline transport of highly paraffinic crude, the notions of "anomaly of viscosity of (structural) viscosity", "thixotropic liquids", "viscoelastic fluid". In the materials of the article there are the most currently known effective ways of transporting High-Viscosity Oils (HVO), among which it is considered how to use different physical fields as a method of influence on HVO. It has been considered the causes of the structural viscosity on the example of oil OGPE "Yelkhoneft" of PLC "Tatneft" at different temperatures and processed on the developed by the authors RPAA with different duration of exposure. Special attention is given to the dynamic tests for the subsequent measurements of the deformation process.

Keywords: Acoustic Impact, Dynamic Viscosity, Flow Curves, Heavy Oils, Non-Newtonian Systems, Rheology, Thixotropy, Viscosity, Viscoelasticity, Viscoelastic Fluid

1. Introduction

Currently, in the world, there is a tendency of increasing the share of viscous and highly-hardened oil in total volume of the produced oil[1,2]. In the pipeline transport, there arise serious problems in crystallization of n-paraffins and increase of the oil viscosity. The feature of pipeline transport of highly paraffinic oils is that at the ground temperatures at the pipeline laying depth, they have an abnormal viscosity (when the viscosity depends on the shear rate). The notion "anomalies of viscosity" is that the "effective" viscosity as a certain conditional characteristic defined as the ratio of shear stress to shear rate or the

dynamic parameter is widely used in rheology and allows to consider the non-Newtonian oils as the systems with variable viscosity, the magnitude of which depends on velocity (stress) of shear. The most frequent cause of the anomaly of disperse systems is a structurization (aggregation of particles of the dispersed phase into the three-dimensional structure)[3,4]. Thixotropic are fluids, for which, at a constant speed of rotational viscometer, the shear stress and effective viscosity decrease with time, due to the gradual destruction of the internal spatial structure of these fluids, which can be restored after a certain period of time[5]. The emergence of thixotropic properties is connected with the presence of complex macromolecular

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compounds having liability to structure formation in high-viscosity oils. Such compounds are resins, asphaltenes and paraffin Hydrocarbons (HC). In addition to the structure formation in fluids, the known are the other causes of manifestation of anomalies of viscosity when flowing: Orientation of asymmetrical particles of the dispersed phase in the stream; deformation of particles aggregates of the dispersed phase in the stream; deformation of the solvate shells of particles of the dispersed phase.

2. Experimental Body

Before presenting the main results of the studies, it is necessary to define the term "viscoelastic fluid" and offer the methodology of research[6]. Viscoelastic are the fluids, which have both the properties of a liquid and a solid, then the viscosity and elasticity are two sides of a material's ability to respond to an applied shear stress. If the sample is viscoelastic, then a certain amount of shear energy, temporarily stored in the elastic deformation, will be manifested by initiating the sample flow into a state of rest. For carrying out the researches it was used the rotational viscometer Rheotest RN 4.0, which allows to work in two modes: 1. To define the shear rate and determine the resultant shear stress (research with controlled shear rate, or CR – Controlled Rate test); 2. To set shear stress and determine the resulting shear rate, the study with controlled stress or CS – Controlled Stress test. The second measurement mode, CS test, allows us to investigate the viscoelastic properties of the fluid. Particular attention is drawn by dynamic test with an oscillating shear stress for subsequent measurements of the deformation process. Figure 1 shows the results of dynamic testing of a number of typicalbodies[5,6]. When perfect solid body is being tested, shear stress and strain are in phase: The maximum shear stress and maximum deformation. In the case of the Newtonian fluid, deformation advances shear stress by 90°. This can also be expressed in terms of the angle of phase shift δ = 90°. For viscoelastic fluids, the phase angle is within the range of $0<\delta<90°$. In the process of the dynamic testing, given a certain amplitude changes in shear stress $\tau 0$ and the oscillation frequency, it is determined the phase angle δ and maximum deformation γ_0. Using the obtained data, it is necessary to determine the complex viscosity μ^*, which reflects the total dynamic resistance to shear. It can be decomposed into two components - the stored (imaginary) viscosity μ'' (elastic component) and dynamic viscosity μ' (viscous component):

$$\mu^* = \frac{\mu_0}{\gamma_0} . \omega, \mu = (\mu_0 / \gamma_0 . \omega) . \sin\delta; \mu = \frac{\mu_0}{\gamma_0 . \omega} . \cos\delta \quad (1)$$

Where ω - angular velocity.

It should be noted that in the actual viscoelastic fluids, the complex viscosity and phase angle δ are dependent on frequency. Therefore, the tests require to pass a certain frequency range and obtain the dependence of the measured values of μ^* and δ on frequency (Figure 1).
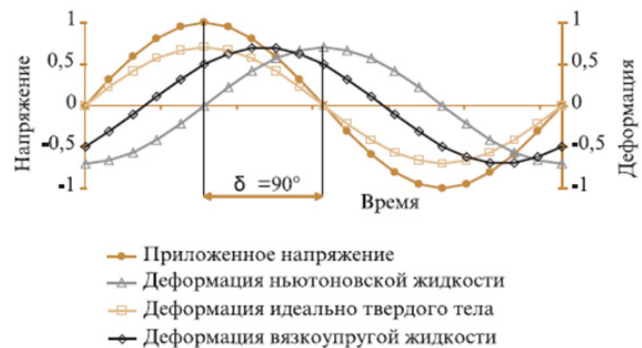

Figure 1. The results of dynamic tests for a number of bodies in atypical CS mode stress time strain applied stress strain of Newtonian fluid Strain of perfect solid strain of viscoelastic fluid.

For extraction and pipeline transport of the oils with abnormal properties, it is required a detailed information about the features of their rheological behavior in different temperature and shear conditions. Regulation with rheological characteristics of oils will reduce the costs of their transportation[7]. The main parameter affecting the transportation of oil is primarily viscosity, i.e. property of oil to resist movement of one part relative to another. The strength of the shear resistance is proportional to the velocity gradient in the direction of normal to the flow of fluid, which is expressed by Newton equation F = ηS (v_2 −v_1) / (y_2 - y_1), (2) where F - the outer tangential force; η - coefficient of friction or viscosity; S - area of liquid layers; (v_2 −v_1) / (y_2 - y_1) - the difference in velocity of the liquid layers separated by distance (y_2 - y_1).

The viscosity of the oil depends mainly on the content of asphaltenes, resins and high-hardened paraffinic hydrocarbons and water. Joint transportation of few oils can lead to the formation of hard degradable oil disperse systems (SSS)[7–9]. When pumping heavy oil, hydraulic

resistance sharply increases, oil pumpability deteriorates, the cost of installing additional pumping equipment increases. Therefore, one carries out an intense search for the most effective ways of transporting high-viscosity oil. Most known effective ways of transporting high-viscosity oils at present can be divided into several groups:

- Methods based on pumping oil through wallow-viscosity layer, which can be created by adding surfactants to the water;
- By reducing the oil-freezing point through the introduction of various surfactants or physical impact;
- Ways in which the improvement of the rheological properties of the oil and pipeline transport efficiency is achieved by the introduction of:
  - Low viscosity hydrocarbon solvents;
  - Inorganic and organic substances or composite compounds.
- Introduction of special soluble polymer additives, opposing the formation of turbulence in the flow of fluid (laminizing stream), in the case of uneconomical use of large diameter pipes, in the following cases:
  - With increasing transmission capacity;
  - Complicated geographic allocation and characteristics of the environment;
  - When the need in transmission capacity appears in a certain season or even is irregular.

The use of fields (acoustic, electromagnetic, magnetic and vibrational) as a method of physical impact on the SSS allows for a short period of time to reach the limit level of destruction of the crystal structure of the paraffinic hydrocarbons. Various studies[2,3,9] show the effectiveness of vibro-jet magnetic treatment to improve the rheological and low-temperature properties of different types of oils. Using magnetic treatment allows to re-structure petroleum associate in the right direction without visible external energy costs, at the same time it is relatively easy to achieve the effect of order in supramolecular structure. However, industrial tests of magnetic treatment using a special device - the magnet activator, have revealed the negative effects along with the positive ones. The reason is that the change of the rheological properties of oils by the magnetic effects is estimated by the ratio of the content of benzene and alcohol-benzene resins. For oils with a high content of neutral benzene resins after magnetic treatment it is observed a decrease of the rheological

characteristics and for oils with higher content of alcohol-benzene resins - quite the contrary. Decrease of oil viscosity by ultrasound has long been known. It is found that as a result of ultrasound, solid wax particles are heated, whereby the viscosity of the oil decreases. The initial stage of the study of the rheological oil properties is to determine the dependence of its dynamic viscosity of the applied shear stress. The basis of determining the dynamic viscosity by measuring the flow time of the fluid through the capillary tube is Poiseuille formula: $\eta = \pi R r^4 \tau / 8 V L$, (3) where P - the pressure at which the liquid outflow from the capillary; V - the volume of fluid flowing through the capillary; τ - the flow time of the liquid in the volume; L - length of the capillary; r - the radius of the capillary.

With decreasing temperature, high viscosity oil products may have anomaly of viscosity, the so-called structural viscosity. At the same time, their flow ceases to be proportional to the applied voltage, i.e. they are non-Newtonian fluids. The reason of the structural viscosity is the content of Resin-Asphaltene Substances (RAS) and n-paraffins. The force which is necessary for the destruction of the supramolecular structure of non-Newtonian fluids is called elastic limit. It is known that the viscosity is defined as a function of shear stress τ and shear γ. The relationship between the stress and the shear rate, so-called flow curve, for Newtonian fluids is a straight line. The viscosity of non-Newtonian fluids is dependent on many parameters (temperature, pressure, shear rate, etc). To evaluate the rheological characteristics of the oil, it is used dependences of viscosity on shear stress, these rheological dependences are graphically in the coordinates $\acute{\eta} - \tau_r$ (dynamic viscosity - shear stress).

The crude of OGPE "Elkhovneft" of "Tatneft" has been researched. According to the terms of the density in Figure 2 (0.907 g/gm^3), the studied oil refers to heavy and we can assume that it will have arheological behavior of significant deviations from the behavior of Newtonian fluids. Determinations were carried out at 20° C and 40° C. Figure 1 shows rheological data at 20^0 C for both the original oil and the oil treated in the Rotary-Pulsating Acoustic Apparatus (RPAA) with different duration (for 1, 3 and 5 minutes). Based on these data, it has been constructed the curves of dependency of the dynamic viscosity on the shear stress for both the original oil and for samples treated oil using RPAA for 1, 3 and 5 minutes.
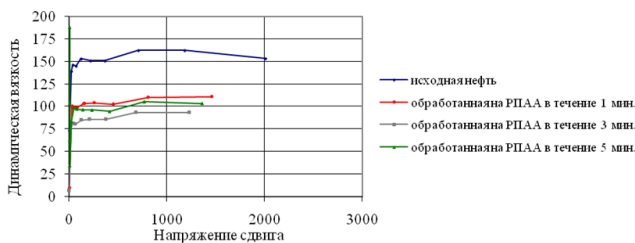
Figure 2. The dependence of the dynamic viscosity on the shear stress (20° C) shear stress.

Dynamic viscosity original oil treated using RPAA for 1 min. treated using RPAA for 3 min. treated using RPAA for 5 min.

Further, the rheological data are presented at 40^0 C for both the original oil and the oil treated in the rotary-pulsating acoustic apparatus for 1, 3 and 5 minutes). It has been made curves of dynamic viscosity at 40^0 C of shear stress for both the original oil and for samples of treated oils using RPAA for 1, 3 and 5 minutes (Figure 3). The presented flow curves in Figures 2 and 3 shown on Newtonian nature and demonstrate the complexity of the rheological behavior under external strain. There is a non-linear behavior of the dynamic viscosity depending on shear rate. With increasing shear stress, the viscosity decreases evenly.
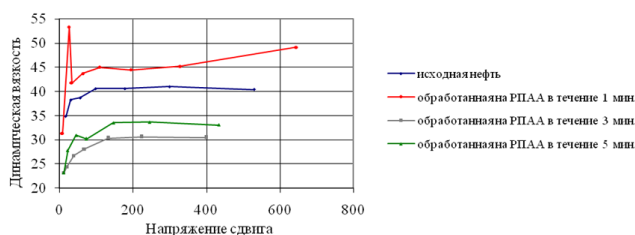

Figure 3. The dependence of the dynamic viscosity at 40° C on the shear stress shear stress.

Dynamic viscosity original oil treated using RPAA for 1 min. treated using RPAA for 3 min. treated using RPAA for 5 min.

The rate range of the shear of non-Newtonian flow from 1 to 1321 s^{-1}, in which the measurements has been taken, includes virtually all of the rates of technological processes, ranging from the movement of oil in bottom hole formation zone to pipeline transportation of oil. For all flow curves, one can identify such an area on which an increase in the shear rate leads to a transition of the system to fluid state, being independent on the applied

shear stress. In this state an irreversible deformation of the oil due to mechanical action in motion begins. As it follows from the above data, with increasing the temperature from 20 to 40° C, the investigated oil acquires properties similar to Newtonian fluid. The tendency of increase in viscosity with increasing shear rate is also preserved according to the temperature (at a temperature of 40^0 C to a much lesser extent than at 20° C). Analyzing the data obtained after refining the oil at RPAA, we come to a conclusion about the positive acoustic effects on the oil. Oil viscosity at 20° C[10] is reduced after being treated to 26-35% at RPAA depending on the processing time. Optimal treatment time is 3 minutes. The data obtained at 40^0 C are analogous, the viscosity reduction is 24-32%. Further studies of the acoustic impact conducted with heavy oil of kinematic viscosity at 40° C-70.5 cSt at OGPE "Yelkhovneft".

The results of studies of the effect of the acoustic impact on the kinematic viscosity at 40° C, heavy original oil, cSt are: 1-70.5; 2-57.5; 3-52.5; 4-50.0. Processing oil with the help of RPAA reduces its viscosity by 18-29%, depending on the duration of treatment. The maximum duration of treatment using RPAA is 3-5 minutes.

3. Summary

1) Treatment using RPAA leads to reduction of oil viscosity; the effect of the acoustic impact on the viscosity depends on the temperature of its determination. So, the viscosity at 20^0 C is reduced after treatment in RPAA by 26-35% and viscosity by 40^0 C - 24-32%, depending on the treatment time. 2) The maximum RPAA processing time is 3-5 minutes. 3) With viscosity increase in the original oil, effect of viscosity reducing is significantly decreased. Thus, for original oil with kinematic viscosity of 37 cStat 40^0 C, acoustic effect reduces the viscosity by 24-32%, while the original oil with a kinematic viscosity of 70.5 cStat 40° C – by 18-29%, depending on the RPAA processing time. Reduction of oil viscosity will reduce the costs of its transportation. 4) It has been offered a wave acoustic model, the essence of which is that the wall of the rotor disc creates a compression wave in the liquid-discharge-compression. 5) The designed rotary pulsating acoustic apparatus is capable of making highly stable emulsions with a disperse particle size of 0.03-0.1 micron. 6) It has been carried out the tests of the developed rotary-pulsating acoustic apparatus in the process of creating a

stable water-fuel emulsions for use in boilers and thermal power plants. It has been found that the use of water-fuel emulsions containing up to 10% of water, saves fuel due to the completeness of combustion. 7) It has been found that under certain modes of operation (number of revolutions 2500-3500), the rotary pulsation apparatus can perform the opposite task: Not crushing the dispersed particles, but their coalescing. 8) The research has established the feasibility of using the RPAA in the production of water-oil emulsions and insulating materials[7, 8, 9, 11].

4. Conclusion

The complex of the researches on the development of theoretical bases, technologies and devices of intensive evaporation and also the rotary-pulsating acoustic apparatus that creates high-intensity acoustic field has showed the possibility of their use in the processes of production, preparation and processing of heavy oil and natural bitumen. The results have showed the effectiveness of using the developed technologies and devices in the development of resources of heavy oil and natural bitumen. Particularly high positive effect can be expected from the use of the rotary-pulsating acoustic apparatus in the process of enhanced oil recovery, the primary processing of heavy oil feedstock and the creation of water-fuel emulsions. To carry out such studies, it has been designed a rotor with diameter of 400 mm, which can create a very intense acoustic field. It can be expected that the use of the RPAA with the rotor in the development of deposits of heavy oils and natural bitumen will prove to be particularly useful.

5. The Conflict of Interests

The author confirms that the data do not contain any conflict of interest.

6. Acknowledgements

7. References

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