Application of Technology of Hydrodynamic Cavitation Processing High-Viscosity Oils for the Purpose of Improving the Rheological Characteristics of Oils

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Abstract. There is investigated the technology of hydrodynamic cavitational processing viscous and high-viscosity oils and the possibility of its application in the pipeline transport system for the purpose of increasing of rheological properties of the transported oils, including dynamic viscosity shear stress in the article. It is considered the possibility of application of the combined hydrodynamic cavitational processing with addition of depressor additive for identification of effect of a synergism. It is developed the laboratory bench and they are presented results of modeling and laboratory researches. It is developed the hardware and technological scheme of application of the developed equipment at industrial objects of pipeline transport.

1. Introduction
Viscous oils (VO) and high-viscous oils (HVO) concern to hardly recoverable types of hydrocarbons and differ from conventional oils by hyper dynamic viscosity in natural conditions and by composition [1]. In the total structure of reserve stocks of the Russian Federation the share of VO and HVO on the basis of the Ministry of Energy of the Russian Federation grounds to 2014 has reached 30% of Russia's total. The most part of stocks is concentrated in the Volga-Ural and West Siberian petroliferous basins and the Volga and Urals regions contain about 70.8 per cent of the Russian reserves [2].

The feasibility analysis of the transport system VO and HVO has demonstrated its low efficiency characterized by a low transport speed, by the necessity of pre-treatment and continued support of high temperature oil, and a short operational resource of the system in conditions of low ambient temperatures. Widespread methods of pre-processing to achieve big speeds of transportation and improvement of rheological properties of oils are:
- thermal heating
- addition of additives and thinners
- application of electromagnetic radiation

Thermal heating is the most widespread and effective method, but at the same time and the most expensive method of processing, as by heating of oil is used natural gas as fuel. Thus for the heating of 1 million tons of VO on 1 °C will require about 241 thousand rubles and 100 thousand m³ of natural gas on the basis of 2016. In the conditions of the low prices of oil and the economic instability, it is very actual to research and to develop new power - and resource-saving methods of increase of efficiency of transport [3].

The authors have investigated a possibility of application of hydrodynamic cavitation processing of VO and HVO for the purpose of a break of complex hydrocarbogenic chains, decreasing of the dynamic viscosity and tension of shift. According to foreign scientists, such as Hemmit F, Daley J., from the American society of mechanical engineers, hydrodynamic cavitation processing has economic prospects and high efficiency.
2. Research
The cavitation phenomenon occurs at the moment of approaching the values of pressure of liquid to value of pressure of saturated steam of liquid in the process of which there are copious bubbles (cavities) filled with the dissolved gas. The collapse of cavities is characterized by sharp jumps of temperature and pressure, and the distribution of energy wave contributes to the destruction of nearby carbon chains and molecular compounds. Number of bubbles can vary from $10^4$ to $10^6$ m$^3$ [4].

Figures 1 and 2 shows simulation of the hydrodynamic cavitation process due to pipeline section change by means of ANSYS/FLUENT software. The obtained data and dependences have been taken into consideration when conducting laboratory tests.

![Figure 1](image1.png)

**Figure 1.** Distribution of a thermal field during cavitation
Zone 1 – a preheat zone, zone 2 – a zone of cold boiling, zone 3 – flow and thermal field stabilization.

![Figure 2](image2.png)

**Figure 2.** Pressure wave propagation vectors

The simulation has showed that in the process of passing a liquid through a narrowing phase occurs the local temperature increase. The cavitational equipment created by the simulation results is presented at Figure 3.
The energy of the collapsing cavitation bubble, which was spherical, determined by the formula (1):

\[ E = \frac{4}{3} \pi P_{r_k} R_{\text{max}}^3 \]  

where \( R_{\text{max}} \) – the radius of a cavitation cavitation cavity before a collapse which is calculated by the formula (2):

\[ \frac{dR_{\text{max}}}{dt} = \sqrt{\frac{2(p_n - p_{r_k})}{3 \rho}}. \]  

We will write down the total energy emitted at a collapse of cavitation cavities through number of cavitation cavities (3):

\[ N = K \cdot V, \]  

\( K \) – concentration of cavitation cavities \((1/m^3)\)
\( V \) – the volume of fluid without cavitation \((m^3)\)

Considering formulas 1-3, we will write down the formula of the energy released due to collapse of cavities at the developed cavitation (4):

\[ E = K \cdot V \cdot \pi \cdot \frac{85.33 \cdot p_n}{g \cdot v} \left( \frac{29 \cdot \rho \cdot g}{p_n} \right)^{1.9} \cdot \int_0^t \left[ \frac{2(p_n - p_{r_k})}{g \cdot v_{av}} \left( \frac{29 \cdot \rho \cdot g}{p_n} \right)^{1.5} \right] \cdot \frac{p_n}{3 \rho} \]  

where \( t = 0.915 \cdot R_{\text{max}} \sqrt{\frac{\rho}{p_{r_k}}} \) - rayleigh times of a full collapse, sec.

It is demonstrated the laboratory setup at the Figure 4. The testing process the following equipment involved these: centrifugal pump by head 50 m and flow rates up to 70 p/a, cylindrical tubes with a diameter of 3 cm², temperature sensors and pressure, the cavitation equipment [5, 6]. During the tests was processed about 200 litres of high viscosity of the Usinsk oil \( \rho = 945 \text{ kg/m}^3 \) and \( V = 150 \text{ mPa•s} \).
Figure 4. Laboratory setup.

Figure 5 shows that complex processing of oil has high efficiency,

Figure 5. The dependence of the viscosity from depressor additive and time.

3. Conclusion
Using the findings by cavitation processing of oil with the use of additives, by the authors was developed a hardware-technological scheme on installation of the cavitation equipment at Figure 6.
The author’s analysis and calculations show that the method of cavitation of cavitation processing improve the rheological properties of VO and HVO is effective and promising [7]. The feasibility of application of complex processing of oil in pipeline transport system consists in the following:

- increase of reference temperature of heating of high-viscosity oil;
- reduction of viscosity of oil
- reduction of the spent energy of traveling heaters and fuel consumption;
- improvement of rheological properties of oil at the expense of a rupture of carbonaceous communications.

The applied technology can be used on trade or technological pipeline systems with diameters up to 300 mm and viscosity of oils transporting 150-200 mPa·s.

References

[1] Shiryaev A M and Zholobov V V 2015 J. Science and Technology 24 60-68
[2] Ilyin E G and Ivantsova S G 2014 J. Crude oil pipeline 6 67-70
[3] Vyboyschik M A and loffe AV 2015 J. JSC Rosneft 36 45-52
[4] Vengerov A A and Brand A E 2014 Oil cavitation treatment to prevent formation of paraffin deposits J. Natur. and intellect. resource. of Siberia. 15 36-37
[5] Tarasenko M A and Brand A E 2014 Reducing oil viscosity by a method of hydrodynamic J. Natur. and intellect. resource. of Siberia. 15 44-45
[6] Brand A E, Vershinina S V, Vengerov A A and Mostovaya N A 2015 Applying the technology of hydrodynamic cavitation treatment of high-viscosity oils to increase the efficiency of transportation IOP Conf. Ser.: Mater. Sci. Eng, 93 012005
[7] Vershinina S V, Brand A E and Mostovaya N A 2015 Application of hydrodynamic cavitation treatment of high-viscosity oils for the purpose of increase of efficiency of transportation J. Higher Educ. Instit. News. Oil and Gas 4 97-101
[8] Valuev D.V. Malushin N.N.,Valueva, A.V. Dariev, R.S. Mamadaliev R.A., Traditional technology of chromium-tungsten steels facing, its disadvantages and suggestions for their eliminations, J. IOP Conference Series: Materials Science and Engineering. 127 (2016) p. 1-7