UDC 622.276
MRNTI
DOI 10.56525/YNLA7808

STUDY OF RHEOLOGICAL PROPERTIES OF PARAFFIN OIL MIXTURE

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Abstract. In experiments on cavitation effect on oil, rheological properties (density, dynamic viscosity coefficient, oil composition, freezing point and shear stress on the wall) of high-viscosity, low-freezing oils from the Kalamkas and Karazhanbas fields, as well as high-freezing paraffinic oils from the Uzen and Zhetybay fields were studied. The ratio of oils in this case is: Zhetybay-Uzen - 65%, Karazhanbas-Kalamkas – 35%. From a ready mixture of oils in the volume of 10 liters, in accordance with the sampling method according to GOST 2517-85, a sample of oil in the amount of 0.5 liters is taken for the initial analysis of the mixture of oils according to the measured values. Then the ready mixture of oils, heated to the required temperature, is loaded into the receiving tank of the unit and mixed with a mixer to obtain a homogeneous mixture. The mixed oil mixture is pumped by a gear pump and fed to the cavitation unit. In this case, the movable rod regulates the oil pressure at the inlet to the confuser and changes the cavitation mode. After the oil passes through the diffuser, a sample of oil is taken for analysis using a special device. The processed oil is again fed to the receiving tank and then sent for secondary processing using a gear pump. The ultimate shear stress of oils before and after cavitation at different temperatures was determined. It was found that at temperatures below 30 ^oC and above, oils are Newtonian fluids. Pseudoplastic fluids have rheological characteristics that do not depend on time, and for such fluids, the yield point is not detected.

Key words: cavitation; rheological properties; oil composition; draining time.

Introduction

Cavitation (from Latin cavitas) is the occurrence in a liquid and the subsequent instant (in thousandths and millionths of a second) collapse of vapor-gas cavities (caverns) as a result of created pressure differences, accompanied by hydrodynamic shocks similar to a point explosion. In this case, as established for water, the local temperature of the collapsing cavern can reach up to $6 \div 10 \cdot 10^3$K, and the pressure up to $(5,06\text{-}10,1) \cdot 10^5$ kPa, which corresponds to the parameters of low-temperature plasma. As a result of a large number of force effects of collapsing bubbles in the processed medium, deep chemical and physicochemical transformations and changes in its properties occur. For example, cavitation action leads to partial splitting of water molecules and a change in pH. Thus, the basis of all technological effects of cavitation application is its destructive action [1].

According to the method of cavitation formation, the following types are distinguished:

- wave, arising as a result of excitation in the system of high-frequency ultrasonic vibrations;
- hydrodynamic, associated with a violation of the continuity of the liquid due to an instantaneous decrease and increase in pressure in a moving liquid flow;

- thermal, the excitation of which is associated with a local increase in temperature.

Cavitation has shown itself, first of all, as a negative phenomenon, leading to the destruction of the propeller shafts of ships, pumps, turbines. A large number of studies have been devoted to these issues [2-4]. And only with the advent of standard ultrasonic equipment, with the help of which it is possible to excite cavitation in a liquid medium due to a wave pressure difference, did this type of energy impact result in practical application in such technological processes as emulsification, dispersion of suspensions, homogenization, depolymerization, etc. [5-7].

In the early 60s, the first work appeared [5], in which it was shown that ultrasonic treatment of oil leads to a change in its viscosity.

In the 70s, laboratory studies were conducted at the Institute of Oil and Natural Salts Chemistry of the Academy of Sciences of the Kazakh SSR [6-8], as a result of which it was clearly proven that under the influence of ultrasound, the viscosity and freezing point of oils decrease, which can have a beneficial effect on its transportation through pipelines in the cold season. But, apparently, due to the lack of equipment for ultrasonic processing of large volumes of oil, required for the introduction of this method into industry, work in this direction did not receive further development. In this regard, further efforts were directed at studying the possibility of using hydrodynamic devices for emulsification. Devices with different operating principles were designed and underwent bench tests: slot, resonator, vortex [7]. It was established that for emulsification of reagents and processing of finely dispersed suspensions, the most effective are ultrasonic hydrodynamic emitters of the vortex type. The principle of their operation consists in converting the continuous movement of liquid under pressure into vortex oscillating flows, which have a cavitation-cumulative destructive effect on the liquid medium being processed. They provide a high degree of dispersion of reagents up to 80% – 20 microns, simple in design and reliable in operation, and the energy consumption for obtaining the same technological effects is 10–15 times lower than when using ultrasonic generators.

Materials and research methods

In experiments on cavitation effects on oil, the rheological properties (density, dynamic viscosity coefficient, oil composition, freezing point and shear stress on the wall) of high-viscosity, low-freezing oils from the Kalamkas and Karazhanbas fields, as well as high-freezing paraffinic oils from the Uzen and Zhetybai fields were studied.

The experiments were conducted on a laboratory-type hydrodynamic cavitation unit with a capacity of 3.5 m^3/hour. The unit is designed to operate in a closed mode, i.e. the processed oil is re-processed in a very short period of time. At the beginning of the work, a mixture of oils in the volume of 10 liters is prepared, which is necessary for cavitation treatment. For this, the containers containing low-freezing oil from the Kalamkas and Karazhanbas fields are shaken well for 10-15 minutes, and oils with a freezing point of 30 °C are additionally heated to a temperature of 40-45 °C. This is a necessary condition for uniform distribution of oil components in the container. Then, in a previously prepared clean container, a mixture of oils is prepared, consisting of four oils from the Zhetybai, Uzen, Kalamkas and Karazhanbas fields. The ratio of oils in this case is: Zhetybai-Uzen - 65%, Karazhanbas-Kalamkas – 35%. From the finished oil mixture in the volume of 10 liters, in accordance with the sampling method according to GOST 2517-85, a sample of oil in the amount of 0.5 liters is taken for the initial analysis of the oil mixture by the measured values. Then the finished oil mixture, heated to the required temperature, is loaded into the receiving tank of the unit and mixed with a mixer to obtain a homogeneous mixture. The mixed oil mixture is pumped by a gear pump and fed to the cavitation unit. In this case, with the help of a movable rod, the oil pressure at the inlet to the confuser is regulated and the cavitation mode is changed. After the oil passes through the diffuser, a sample of oil is taken for analysis using a special device. The processed oil again enters the receiving tank and is then sent for secondary processing using a gear pump.

The number of samples of selected oil for analysis is selected depending on the specified test modes. Analysis of the original and cavitation-treated oil is carried out at a temperature of 20 to 40 °C. Based on the analysis of oil samples, their rheological characteristics are determined (pour point, dynamic and kinematic viscosity, ultimate shear stress). The pour point (or loss of fluidity) of oil was determined according to GOST 20287-91. The analyzed oil was preliminarily subjected to heat treatment and then cooled to a temperature at which it lost mobility. Having added 3 degrees to the resulting temperature, we take it as the temperature of loss of fluidity of oil.

Determination of kinematic viscosity and calculation of dynamic viscosity were carried out in accordance with GOST 33-2000 (ISO 3104-94). The method is based on measuring the time of liquid outflow under the influence of gravity in a glass viscometer. Two types of capillary viscometers were used for the analysis: VPZh-2 with a constant C = 0.8853 mm^2/s^2 and VPZh-4 with a constant C = 0.3606 mm^2/s^2.

Results and Discussion

It is known that one of the most important properties in the characteristics of oils is density. For its measurement, the areometric method of analysis according to GOST 3900-47 was used. Determination of the density of oils was carried out in a temperature range from 20 to 40 °C. It was found that the density of oils fluctuates between 0.84 and 0.9 g/cm^3. In oils that have undergone cavitation treatment, a slight change in density is observed compared to the original oil. Further study of the analysis of oils shows a change in their rheological properties after cavitation treatment. Tables 1, 2 show comparative characteristics of the mixture of oils from the Kalamkas, Karazhanbas, Uzen, Zhetybai fields. The values of density, kinematic and dynamic viscosity, pour point in the temperature range of 20-40 °C were obtained.

Table 1- Comparative characteristics of the oil mixture before and after cavitation treatment

Indicators	**A mixture of oils from the Uzen, Zhetybai, Karazhanbas, and Kalamkas fields**			
	before	**after**	**before**	**after**
Density 20ºC	0,8816	0,8805	0,8876	0,8795
30ºC	0,8785	0,8930	0,8684	0,8691
35ºC	0,8679	0,8721	0,8632	0,8643
40ºC	0,8604	0,8635	0,8601	0,8604
Kinematic viscosity, cSt	-	-	-	-
30ºC	150,54	104,57	93,87	70,81
35ºC	54,05	49,65	44,35	39,60
40ºC	31,83	30,12	32,87	30,32
Freezing point, ºC	+24	+18	+24	+21
Mechanical impurities, %	0,0156	-	0,0156	-
Water, %	0,0871	-	0,0871	-

Table 2- Comparative characteristics of the oil mixture before and after cavitation treatment and the process of restoring the rheological properties of oils to their original characteristics

Indicators	**A mixture of oils from the Uzen, Zhetybai, Karazhanbas, and Kalamkas fields**				
	before	**after 6 days**	**before**	**after 6 days**	**after 8 days**

Density 20ºС	0,8805	0,8822	0,8795	0,8820	0,8815
30ºС	0,8730	0,8915	0,8691	0,8725	0,8735
35ºС	0,8621	0,8685	0,8643	0,8621	0,8642
40ºС	0,8635	0,8641	0,8604	0,8621	0,8610
Kinematic viscosity, cSt	-	-	-	-	-
30ºС	104,57	127,5	70,81	86,7	82,3
35ºС	49,65	51,3	39,6	47,2	44,3
40ºС	30,12	31,8	30,32	33,8	33,2
Freezing point, ºС	+18	+21	+21	+24	+21
Mechanical impurities, %	-	-	-	-	-
Water, %	-	-	-	-	-

Comparisons of the rheological characteristics of oils before and after cavitation treatment, taking into account the factors affecting oil (temperature and pressure) show a decrease in the kinematic and dynamic viscosity, pour point of the mixture of oils after cavitation treatment. At the same time, the influence of the rheological properties of oils is noticeably manifested at temperatures close to the pour point, when the process of crystallization of paraffins begins with the appearance of their viscoplastic properties. Repeated experiments revealed a decrease in kinematic viscosity from 150 to 82 cSt at a temperature of 30°C and a decrease in the freezing temperature by 5°C.

The study of the mechanism of action and the essence of the change in the rheology of oils under the influence of cavitation gives grounds to believe that when oil moves in the cavitation area, the structure of oils is destroyed under the influence of shock waves of liquid bubbles, the collapse of which creates high pressures. Thus, the effects on the surface of high-molecular compounds of paraffins, as well as on the structure of asphaltenes and resins, affect the process of formation of crystallization centers of paraffins, liquefy the viscoplastic medium and reduce the freezing point of oil. A significant change in the rheological properties of oils under the influence of cavitation, as was previously noted, is observed at oil processing temperatures close to the freezing point of oil. With an increase in the oil processing temperature, a noticeable decrease in oil viscosity also occurs. It follows from this that a change in the temperature regime of oil processing within the range from 25 to 40 ° C does not have a significant effect on the development of the cavitation process [8]. Taking into account the analysis of experimental data, optimal modes and parameters of cavitation development were determined. At the same time, the analyzed characteristics of oils are improved. The kinematic viscosity decreases to 40%, and the pour point decreases by 5 °C.

Tables 1, 2 show the results of a comparative analysis of the obtained experimental data. Tables 1, 2 show the temperature dependences of the kinematic viscosity of the Karazhambas – Kalamkas (35%), Zhetybai – Uzen (65%) oil mixtures before, after and 6 days after cavitation treatment. Tables 1, 2 shows a significant decrease in kinematic viscosity at a temperature of 30 °C. The effect of viscosity reduction after 6 days decreases, the temperature dependences of the kinematic viscosity of a mixture of 4 Kalamkas-Uzen-Karazhambas-Zhetybai oils. Tables 1, 2 show the temperature dependences of the kinematic viscosity of the original mixtures of 4 oils after cavitation treatment. In tables 1, 2 show the viscosity change curves of the mixture of 4 oils after cavitation, 8 days and 16 days after treatment, respectively. Tables 1, 2 show the dependences of the kinematic viscosity of the mixtures of Uzen, Kalamkas, Zhetybai and Karazhambas oils on temperature.

The results obtained for calculating the volume of oil mixtures from the Zhetybai, Uzen, Kalamkas and Karazhanbas fields depending on the drain time are shown in Fig. 1.

As can be seen from Fig. 1 for the oil mixture of the Zhetybai-Uzen, Kalamkas-Karazhanbas fields in the ratio of 65% and 35%, respectively, the draining time is practically independent of the temperature change, and cavitation treatment plays a significant role. For low-viscosity oil with simultaneous heating and draining from the tank, as shown in the figure, the draining time changes slightly (Fig. 1), the difference is 3-4 minutes. This is apparently due to the preservation of the mass of oil due to its property: a slow change in density with increasing temperature. With an increase in oil viscosity, the draining time, with partial heating and simultaneous draining compared to the draining time of initially completely heated oil, decreases and the nature of the drain is linear.

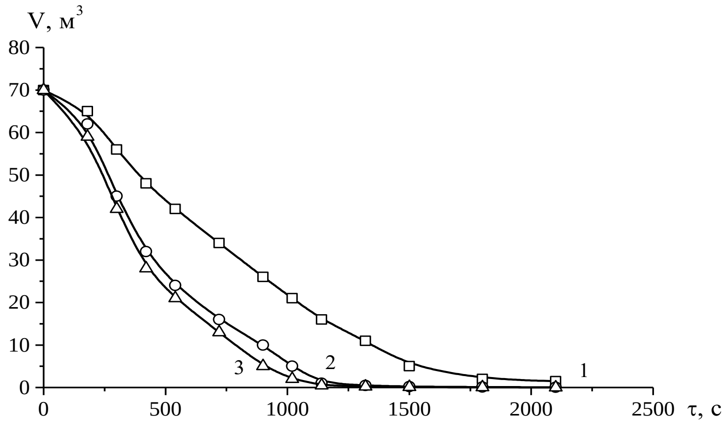

Figure 1 – Change in the estimated volume of oil mixtures from the Zhetybay, Uzen, Kalamkas, and Karazhanbas fields in a tank depending on the draining time.
1 - initial oil mixture, the ratio of oils is: Zhetybay-Uzen - 65%, Karazhanbas-Kalamkas - 35%; 2 - the same oil after cavitation treatment, τ = 10 minutes; 3 - the same oil after cavitation treatment, τ = 15 minutes. System temperature is 30°C

Also in the work [2] it is shown that the decrease in the volume of oil in the tank does not reach zero over time, i.e. there is no complete draining or the tank needs to be washed. As is known, the total time for draining oil from a railway tank is made up of: the time of heating (in winter), the time of draining and the time of washing out the oil sediment. The authors of the work [3] proposed electric induction heating for the simultaneous draining and heating of oil from the tank. In this case, less time is required for heating, which leads to an increase in the productivity of oil draining.

Conclusion

The results of laboratory experimental and thermal-hydraulic calculations of the use of cavitation technology show the need to implement cavitation technology for pumping high-freezing, high-viscosity oils. At the same time, the results of experimental studies and thermal-hydraulic calculations indicate the following circumstances:

- when using cavitation technology, they are performed on the basis of the rheological properties of the oil mixture obtained in laboratory conditions. In the conditions of industrial operation of the oil pipeline, various situations arise caused by mixing low-freezing and high-freezing oil in different proportions, instability in the hydraulic mode of operation of pumping stations, fluctuations in productivity, pressure pulsations in the main oil pipeline, etc., which must be taken into account when implementing cavitation technology. In this regard, the implementation of cavitation technology requires large-scale pilot tests to take into account various factors arising during the operation of the oil pipeline;

- undoubtedly, the use of cavitation technology is a promising direction in economic and environmental terms. However, the application of cavitation technology in industrial conditions poses the following tasks: 1) cavitation technology requires the processing of the oil mixture to improve its rheological properties in an industrial unit, which leads to the manufacture of a special unit with the necessary equipment and the use of a certain capacity; 2) depending on the percentage of low-freezing and high-freezing oils in the composition of the oil mixture, the effect of cavitation treatment may be different; 3) the improvement of the rheological properties of the oil mixture during cavitation treatment remains unchanged for a certain period of time, after which the process of restoring the rheological properties of the oil mixture begins. Therefore, in order to implement cavitation technology, it is necessary to develop, on the basis of pilot tests, technological regulations for the use of cavitation technology in industrial conditions, taking into account a variety of production conditions; - it is possible that the use of cavitation technology leads to some complication of the technology of pumping high-freezing oils due to the need to maintain a stable ratio of volumetric contents of low-freezing and high-freezing oil mixtures in a certain range, ensuring stable operation of the cavitation treatment unit, etc.

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ИССЛЕДОВАНИЕ РЕОЛОГИЧЕСКИХ СВОЙСТВ ПАРАФИНО-НЕФТЯНОЙ СМЕСИ

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Аннотация. В экспериментах по исследованию воздействия кавитации на нефть были изучены реологические свойства (плотность, динамический коэффициент вязкости, состав нефти, температура замерзания и напряжение сдвига на стенке) высоковязких, низкозамерзающих нефтей с месторождений Каламкас и Каражанбас, а также высокозамерзающих парафинистых нефтей с месторождений Узень и Жетыбай. Соотношение нефти в данном случае составляет: Жетыбай-Узень – 65%, Каражанбас-Каламкас – 35%. Из готовой смеси нефтей объемом 10 литров в соответствии с методикой отбора проб по ГОСТ 2517-85 отбирают пробу нефти объемом 0,5 литра для первоначального анализа смеси нефти по измеренным значениям. Затем готовая смесь нефти, нагретая до необходимой температуры, загружается в приемный бак установки и перемешивается миксером до получения однородной смеси. Перемешанная нефтяная смесь перекачивается шестеренчатым насосом и подается в кавитационную установку. В этом случае подвижный стержень регулирует давление нефти на входе в конфузор и изменяет режим кавитации. После прохождения нефти через диффузор с помощью специального устройства отбирается проба масла для анализа. Обработанное масло снова подается в приемный резервуар, а затем направляется на вторичную переработку с помощью шестеренчатого насоса, были определены предельное напряжение сдвига нефти до и после кавитации при различных температурах. Было установлено, что при температурах ниже 30°С и выше нефти представляют собой ньютоновские жидкости. Псевдопластичные жидкости обладают реологическими характеристиками, которые не зависят от времени, и для таких жидкостей предел текучести не определяется.

Ключевые слова: кавитация; реологические свойства; масляный состав; время слива.

ПАРАФИН-МҰНАЙ ҚОСПАСЫНЫҢ РЕОЛОГИЯЛЫҚ ҚАСИЕТТЕРІН ЗЕРТТЕУ

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Аннотация. Кавитацияның мұнайға әсерін зерттеу эксперименттерінде Қаламқас және Қаражанбас кен орындарынан жоғары тұтқыр, төмен температурада қататын мұнайлардың, сондай-ақ Өзен және Жетібай кен орындарынан жоғары температурада қататын парафинді мұнайлардың реологиялық қасиеттері (тығыздығы, тұтқырлықтың динамикалық коэффициенті, мұнайдың құрамы, қату температурасы және қабырғадағы сдысу кернеуі) зерттелді. Бұл жағдайда мұнайдың арақатынасы: Жетібай-Өзен – 65% және Қаражанбас-Қаламқас – 35% құрады. МемСТ 2517-85 бойынша сынама алу әдістемесіне сәйкес көлемі 10 литр мұнайдың дайын қоспасынан өлшенген мәндер бойынша мұнай қоспасын бастапқы талдау үшін көлемі 0,5 литр мұнай сынамасын алады. Содан кейін қажетті температураға дейін қыздырылған мұнайдың дайын қоспасы қондырғының қабылдау цистернасына салынып, біртекті қоспаны алғанға дейін араластырғышпен араластырылады. Аралас мұнай қоспасы беріліс сорғымен айдалады және кавитациялық қондырғыға беріледі. Бұл жағдайда жылжымалы штанга конфузордың кіреберісіндегі мұнай қысымын реттейді және кавитация режимін өзгертеді. Мұнай диффузордан өткеннен кейін арнайы құрылғының көмегімен талдау үшін май сынамасы алынады. Өңделген май қайтадан қабылдау резервуарына жіберіледі, содан кейін беріліс сорғысы арқылы қайта өңдеуге жіберіледі, әр түрлі температурада кавитацияға дейін және одан кейін мұнайдың сдысуының шекті кернеуі анықталды. 30°С-тан төмен және одан жоғары температурада мұнайдың Ньютон сұйықтықтары екендігі анықталды. Псевдопластикалық сұйықтықтар уақытқа тәуелді емес реологиялық сипаттамаларға ие және мұндай сұйықтықтар үшін аққыштық шегі анықталмайды.

Түйін сөздер: кавитация; реологиялық қасиеттері; май құрамы; төгу уақыты.