Prospects of Using the Cavitation Technologies in Transportation

A.N. Gurbanov, I.Z. Sardarova

Azerbaijan State Oil and Industry University (Azadlig ave. 16/21, Baku, AZ1010, Azerbaijan)

For correspondence:

Gurbanov Abdulaga / e-mail: qabdulaga@mail.ru

Abstract

The paper explores the aspects negatively affecting the pipeline transportation of heavy oil and reviews the implementation possibility of cavitation processes as an alternative method of solving occurring problems. Based on the laboratory research of abnormal oil from Azerbaijan fields, the parameters and technical upgrade of heavy oil in the system of hydrodynamic cavitation have been studied. Moreover, as a result of carried out experiment, the operation mechanism of cavitation process during reduction of heavy oil viscosity is described and the implementation prospect of this technology in commercial scales is analyzed as well.

Keywords: heavy oil, cavitation, viscosity, pipeline transportation, emulsion, microcracking.

DOI 10.52171/2076-0515_2023_15_04_32_39

Received *09.04.2023*
Revised *15.12.2023*
Accepted *20.12.2023*

For citation:

Gurbanov A.N., Sardarova I.Z.
[Prospects of Using the Cavitation Technologies in Transportation]
Herald of the Azerbaijan Engineering Academy, 2023, vol. 15, no. 4, pp. 32-39 *(in English)*

Nəql zamanı kavitasiya texnologiyalarından istifadə perspektivləri

Ə.N. Qurbanov, İ.Z. Sərdarova
Azərbaycan Dövlət Neft və Sənaye Universiteti (Azadlıq pr. 16/21, Bakı, AZ1010, Azərbaycan)

Yazışma üçün:
Qurbanov Əbdülağa / e-mail: qabdulaga@mail.ru

Xülasə

Məqalədə ağır neftlərin boru kəmərləri ilə nəqli zamanı mənfi təsir göstərən amillər araşdırılmış və yaranan problemlərin həllində alternativ bir metod olaraq kavitasiya proseslərindən istifadə edilməsi nəzərdən kecirilmişdir. Azərbaycan yataqlarından hasil edilən yuksək özlülüklü neftlərin laboratoriya tədqiqatları əsasında, hidrodinamik kavitasiya sistemində ağır neftin modernləşdirilməsinin şərtləri, parametrləri və nəticələri öyrənilmişdir. Bundan əlavə, təcrübələr nəticəsində kavitasiya prosesi zamanı ağır neftlərin özlülüyünün dəyişməsi mexanizmi izah edilmiş və bu texnologiyanın kommersiya miqyasında istifadəsinin mümkünlüyü təhlil olunmuşdur.

Acar sözlər: ağır neft, kavitasiya, özlülük, boru kəməri, emulsiya, mikrokrekinq.

DOI 10.52171/2076-0515_2023_15_04_32_39

УДК 622.692.4

Перспективы использования кавитационных технологий при транспортировке

А.Н. Гурбанов, И.З. Сардарова
Азербайджанский государственный университет нефти и промышленности (пр. Азадлыг, 16/21, Баку, AZ1010, Азербайджан)

Для переписки:
Гурбанов Абдулага / e-mail: qabdulaga@mail.ru

Аннотация

В статье исследованы факторы, оказывающие негативное влияние при транспортировке тяжелой нефти по трубопроводам, и рассмотрено использование процессов кавитации как альтернативного метода решения проблем. На основе лабораторных исследований высоковязких нефтей, добываемых на месторождениях Азербайджана, изучены условия, параметры и результаты модернизации тяжелой нефти в гидродинамической системе кавитации. В результате проведенных экспериментов объяснен механизм изменения вязкости тяжелых нефтей в процессе кавитации и проанализирована возможность использования данной технологии в промышленных масштабах.

Ключевые слова: тяжелая нефть, кавитация, вязкость, трубопровод, эмульсия, микротрещина.

Introduction

In the last two decades, the global oil industry has undergone significant changes that have created a new production and commercial situation. All these processes deeply affect the production, consumption and trade of oil, which, despite serious efforts to increase the share of alternative energy sources, remains the main energy resource and continues to have a significant impact on the development of the global economy [1].

Oil, in turn, is basically a mixture of hydrocarbons, which can be conditionally divided into light and heavy, taking into account its viscosity and density. The viscosity of ordinary light oil varies in the range of 0.001-0.01 Pa4, and the viscosity of heavy oil is higher than 0.02 Pa [2]. For comparison, it can be noted that the viscosity of water is 0.001 Pa.

Crude oil with API density of 22.5 is classified as heavy [3], with API or less belongs to the group of superheavy oils that are heavier than water. On the contrary, the density of tobacco light oil (Brend&WTI) varies between 38° and 40°API.

It should be noted that the extraction, transportation and processing of heavy oil in comparison with light is a more labor-intensive process, since the traditional technologies that exist today were designed mainly for the production of light oil. But despite this, the growing demand for oil and the gradual depletion of deposits of traditional light oil due to long-term operation increases the demand for heavy oil production. The world's heavy oil reserves are mainly accounted for by countries such as Canada, the USA and Venezuela. According to the latest statistics, there is more heavy oil in Venezuela than in the Middle East. Currently, there is enough in Canada to meet its current demand for over 200 years [4].

The composition of heavy oil includes a low concentration of low molecular weight compounds and light fractions against the background of a high volume of asphaltenes, resins and paraffins [5]. There is also a claim that the viscosity of heavy oil varies depending on the volume fraction, chemical structure and physico-chemical properties of asphaltenes. In turn, it is known that oil grades containing significant amounts of asphaltenes and naphthenic acids are prone to the formation of stable oil-water emulsions, which are difficult to separate (water and oil) dispersed systems [6].

In addition, heavy oil also contains large amounts of sulfur, nitrogen, salts and heavy metals such as nickel and vanadium [7].

As it was noted, operations related to heavy oil, in one form or another, face technological and financial problems. One of the main roots of the problem is the high viscosity of heavy oil, which leads to complications at all stages of production. For example, a decrease in the return of oil by the reservoir due to its very low mobility at low temperature.

At the next stage of production, high viscosity negatively affects surface operations, namely complicates the processes of dehydration and desalination of oil.

On the other hand, the transportation of heavy oil, especially through pipelines, is also difficult, since the high viscosity of oil increases the cost of overcoming large friction pressure losses. Given the aforementioned difficulties associated with heavy oil, the development of new resource-saving technologies for its extraction, transportation

Herald of the Azerbaijan Engineering Academy
2023, vol. 15, no. 4, pp. 32-39
Gurbanov A.N., Sardarova I.Z.

and processing is becoming increasingly urgent.

The solutions currently available are based on the use of various technological methods, such as heat treatment, addition of chemical additives, mixing with light hydrocarbons, electrostatic devices and other alternative technologies. All these technologies have a common goal: to reduce the viscosity of heavy crude oil and improve its quality [8].

Setting the issue

The purpose of this article is to show the possibility of using cavitation processes as an alternative method for solving problems associated with the transportation of heavy oil. Although the application of the cavitation phenomenon in various operations with oil has long been studied by scientists, nevertheless, it is too early to talk about the introduction on an industrial scale due to a lack of knowledge, experience and evidence. As it was noted earlier, asphaltenes, resins and paraffins contained in high concentrations in the composition of heavy oil and increasing its freezing point are an integral part of high-viscosity oil. Asphaltenes are polycyclic aromatic highly condensed heavy molecules that are considered as resin compaction products [9]. The molecules of paraffin and resins form some kind of randomly arranged long lattices in the composition of oil, which is why the viscosity does not obey the laws of Stokes, Newton and Poiseuille. Therefore, the system provides significant resistance to shear forces. In addition, the combination of asphaltenes, resins and paraffins in the composition of oil contributes to the creation of conditions for the formation of aggregates of paraffin crystals and their adhesion to the surface, thereby forming asphalt-resin-paraffin deposits (ASPs) in pipes.

Solution methods

Recent studies show the possibility of improving the above rheological and qualitative properties of oil using cavitation technologies. Cavitation is defined as the generation of subsequent growth and destruction of bubbles / cavities of steam or gas in a liquid with a local decrease in pressure to the pressure of saturated vapors of a liquid: as a result of an increase in velocity (hydrodynamic) or the passage of an acoustic wave (acoustic). This is due to the fact that the negative pressure created is higher than the local strength limit of the liquid, since the formation of cavities requires overcoming the forces of adhesion of the liquid. The coupling forces, in turn, vary from fluid to fluid, taking into account the type, composition and frequency.

The more liquid is contaminated with fine particles, the easier it is to initiate cavitation at moderate negative pressures. The collapse of cavitation bubbles is accompanied by bursts of pressure (up to several hundred Mpa) and temperature (several thousand degrees Kelvin), while similar environmental conditions remain unchanged.

The destruction of bubbles occurs at a high rate, which leads to the emergence of millions of foci of high temperature and pressure, in other words, extreme physical and chemical conditions are created. Thus, cavitation can be used to carry out various reactions that require harsh conditions at minimal cost to change the environment. There are several methods of cavitation regeneration, but mainly hydrodynamic and acoustic are used in the oil industry.

Herald of the Azerbaijan Engineering Academy
2023, vol. 15, no. 4, pp. 32-39
Gurbanov A.N., Sardarova I.Z.

Hydrodynamic cavitation is generated when pressure changes due to areas of variable velocity created using the geometry of the system. Examples of such geometry can be constrictions in cranes, throttle valves, valves, diaphragms, valves, pumps, hydraulic turbines, Venturi tubes, etc. Acoustic cavitation is created by changing the pressure in the liquid using sound waves, usually ultrasonic (16kHz-100MHz). Chemical changes associated with cavitation caused by the passage of sound waves are usually called sonochemistry. Ultrasonic cavitation can be used to destroy oil-water emulsions during pipeline transportation of oil. Oil-water emulsions are mainly formed as a result of long-term exploitation of deposits and flooding of reservoirs, as well as with artificial impact on the well-developed zone to increase production. As is known, the composition of oil includes natural emulsifiers, such as colloidal resin solutions, asphaltenes, paraffins, which contribute to the formation of stable oil-water emulsions. Modern methods of oil dewatering include settling in special settling tanks, the use of electric fields, the addition of various chemical reagents, the use of coalescing filters. In the case of heavy oil, which is rich in the content of the above emulsifiers, the separation of water from oil by traditional methods is difficult.

The experiments were carried out on a cavitation impact device, the basis for the creation of which was a high velocity at which the pressure dropped to the value of the saturated vapor pressure, which led to the formation and collapse of cavitation cavities. As a result of exposure to high-energy pulses (high temperature and pressure) of cavitation bubbles, large molecules of heavy oil turn into light hydrocarbon molecules, which leads to a decrease in viscosity after the cavitation zone. The decrease in the kinematic viscosity of Azerbaijani oil when passing through the cavitation zone is shown in Table 1.

Table 1 – Reduction of kinematic energy when passing through the cavitation zone of Azerbaijani oil

Indicators	**Experimental results**					
Viscosity up to the cavitation zone at 20°C, mm^2/s	14,6	12,8	12,3	12,8	13,7	13,9
Viscosity after the cavitation zone at 20°C, mm^2/s	12,8	12,0	11,0	11,5	11,3	12,3
Iodine number before cavitation, g of iodine per 100 g of fractions	0,9	0,9	0,8	0,8	0,7	0,6
Iodine number after cavitation, g of iodine per 100 g of fractions	1,3	1,1	0,95	1,12	1,3	1,2

The results of analyses of heavy oil before and after the cavitation zone give grounds to assert that, due to the rupture of intermolecular bonds of oil, the process of microcracking occurs, as evidenced by an increase in the iodine number (according to GOST-2070-82). It should be noted that the intensity of the occurrence of cavitation and its development in oil are influenced by the pressure of saturated oil vapor, the steepness of the curve of the dependence of saturated oil vapor pressure on temperature, viscosity, surface tension, the amount of dissolved and free gas in oil, the residence time of oil in the zone with reduced pressure, the nature of the flow itself before entering the cavitation zone (laminar or turbulent), etc. Viscosity can have a two-way effect on the cavitation potential of oil. On the one hand, the high viscosity of oil is able to increase the adhesion force of the liquid, thereby preventing the formation of cavitation cavities. On the other hand, high viscosity, creating resistance, can increase pressure losses when narrowing at the entrance to the cavitation device to the places where cavitation occurs, where it is necessary to achieve a saturated vapor pressure value, thereby accelerating the onset of cavitation. In petrochemistry, it is considered that the ratios of paraffin to resin and to asphaltene are the key parameters controlling the stability of paraffin and asphaltene structures in the composition of oil. When the proportion of asphaltenes in relation to paraffin decreases, then due to the increased influence of resins, paraffin crystals form ribbon aggregates that increase viscosity. And since microcracking occurs as a result of cavitation in oil, cavitation can in one way or another change the ratio of paraffin to resin and asphaltene, thereby leading to viscosity variations.

To study this theory, experiments were carried out to change the viscosity depending on the time of cavitation exposure. The experiments were carried out with samples of paraffin and resinous oil from the Shykhbagi and Shirvan deposits, the characteristics of which are given in Table 2.

Table 2 – Characteristics of oils from Shikhbagi and Shirvan fields according to paraffin and tar

Deposits	Kinematic viscosity at 20°C, mm^2/s	Mass fraction		
		Paraffin	resins	Asphaltenes
Shykhbagi	32,48	12,3	15,72	2,35
Shirvan	78,75	4,36	12,21	5,21

Based on the experiments, graphs of the dependence of the kinematic viscosity of oil on the time of cavitation treatment for oil from the Shykhbagi and Shirvan fields were constructed (Figure). As can be seen from the graphs, the viscosity change is divided into two areas. In the first area, cavitation treatment accelerates diffusion, depending on the time of cavitation treatment of oil in the paraffin cavity, intensifies the process of its destruction, i.e. with C or With S, the bonds of heavy oil molecules are broken and free radicals are. The second region begins at the moment of viscosity growth, when already formed free radicals eventually go to recovery, forming heavier molecules as a result of cavitation microflows and turbulence. During this period of time, not only paraffin, but also asphaltene free radicals can act as embryos for the creation of heavy molecules. This means that with an increase in the time of cavitation treatment, the abnormal properties of oil among the molecules of paraffin, resins and asphaltenes can be restored.

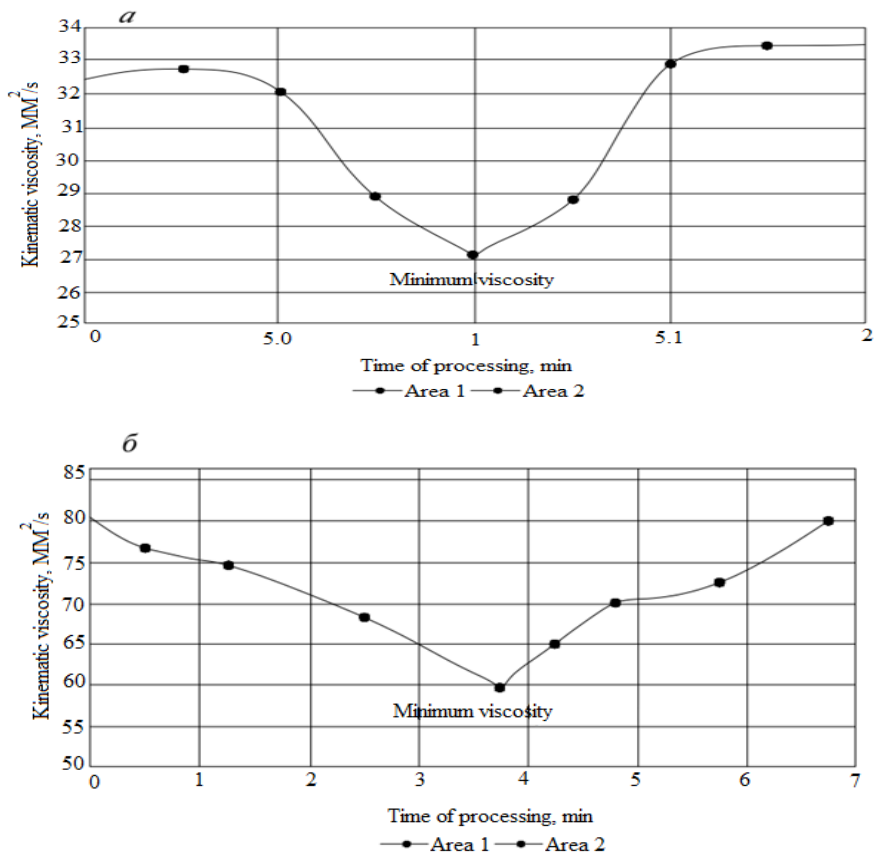

Figure – The change in the kinematic viscosity of the oil of the Shykhbagi (a) and Shirvan (b) fields formed, which leads to a decrease in viscosity

It should also be noted that the effect of cavitation treatment on viscosity reduction was more noticeable on resinous oil of the Shirvan field (25.1%) than on paraffin oil of the Shykhbagi field (16.6%).

Conclusion

Based on the experiments conducted and the study of the effect of cavitation on oil, it can be concluded that each oil has an optimal time of cavitation action, determined by the point of minimum viscosity, after which the viscosity begins to increase. This time interval should be taken into account when applying cavitation to reduce the viscosity of heavy oil. In addition, the most important result of this study from the point of view of the technological process of applying cavitation is that it is sensitive to the characteristics of oil. This means that each oil has a specific development process and before creating a large-scale installation, it is mandatory to perform laboratory tests and experimental studies.

Conflict of Interests

The authors declare there is no conflict of interests related to the publication of this article.

REFERENCES

1. **Yakovlev P.P.** Neft v globalnoj ekonomike i mirovoj torgovle // Mezhdunarodnaya torgovlaya v torgovoya politika, 2018, № 3, s. 100-114 *(in Russian)*
2. **Avvaru B., Venkateswaran N., Uppara P., Iyengar S., Katti S.** Current Knowledge and Potential Applications of Cavitation Technologies for the Petroleum Industry. *Ultrasonics Sonochemistry*, 2018, v. 42, pp. 493-507.
3. **Conaway C.** The Petroleum Industry: A Nontechnical Guide. 1999, Tulsa: Pennwell Publishing Co.
4. **Chiras D.D.** Environmental science, Non-renewable Energy Sources, 9th edition, 2012, Jones & Bartlett publishers.
5. **James G. Speight, Marcel Dekker.** The chemistry and technology of petroleum, 2nd edition, 1991, CRC Press New York.
6. **Qurbanov Ə.N., Quliyev A.S.** 28 May NQCİ-nin Günəşli yatağında texnoloji avadanlıqlar və nəql xətlərində yaranan kondensləşmənin səbəblərinin araşdırılması. Azərbaycan Mühəndislik Akademiyasının Xəbərləri. 2015. № 4. s. 75-85.
7. **Ismajylov G.G., Safarov N.M., Nurmamedova R.G., Aliev S.T.** O vozmozhnosti primeneniya fraktalnogo analiza dlya issledovaniya strukturnyh izmenenij i svojstva vodoneftyanyh emulsij // *Azərbaycan Milli Elmlər Akademiyasının Xəbərləri*, Yer Elmləri, 2013. № 1. s. 76-83 *(in Russian)*
8. **Martinez R., Mosqueira M., Zapata B., Mar E., Bernal C.** Transportation of heavy and extra-heavy crude oil by pipeline: a review. *Journal of Petroleum Science and Engineering*, 2011, 75(3-4), pp. 274-282.
9. **Quintana L., Chavez C., Olaya E.** Sonochemistry: The future of the profitable heavy crude oil operations. Heavy Oil Latin America Conference & Exhibition, 2015.