Overview of the prospects for the introduction of ultrasonic oil treatment in the main pipeline transport

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Abstract. This paper considers the most common methods of pipeline transport of high solidified oil existing at the moment. The effects of treating oil with magnetic and electric fields are given. The positive and negative effects of ultrasonic treatment in oil transport processes are considered. The totality and quality of the facts requires much more in-depth analysis on a number of issues in this area because with a lot of positive effects are present and negative, which do not allow to implement.

Keywords: high pour point oil, hot pumping, ultrasound treatment, molecules destruction, synergetic effect, pour point depressants.

1. Introduction

Today, according to the International Energy Agency, the share of oil in the world energy balance is reaching a plateau. The same data can be found in the BP report for 2022. In general, this trend is a consequence of the consumption of oil as a fuel source. However, it is worth noting that oil as a source of raw materials for polymers and materials will not lose its relevance for a long time. The oils which include in their composition a significant share of paraffins are of interest in the sales market due to the value of paraffin as a raw material. However, oil with high paraffin content may have a high pour point as a result of the paraffin crystallization process. Apart from Russia this problem is faced worldwide such as in Egypt, China, etc. [1, 2].

2. High pour point oil transportation solutions

There are a lot of approaches to the problem of transport of high solidified oil. According to the principle they can be divided into chemical, physical-chemical and physical. A summary chart of all methods can be seen in Fig. 1 [3, 4].

If you look into the issue of applying these methods, it turns out that, in general, many of the listed methods have not received real distribution. In the case of pumping emulsions, there is a problem with the dehydration of oil after pumping, as well as the transport of water as unnecessary ballast. Some initiatives do not have prospects due to the requirements for the technological process and the high costs of their use. For example, hydrotransport requires a special device for pumping water into the inner layer; barotreatment requires large tanks, coupled with their gradual wear due to metal fatigue in the equipment. A separate important condition is the preservation of the composition of the feedstock without the destruction of high-molecular hydrogens. In general, the pumping method should be relatively simple, economically justified and not change the composition of the oil [3, 4].

At the moment, only three methods satisfy these criteria, each of them has gained its distribution in the world. These are:

1) Transport with solvents.

2) Hot transfer.

3) Addition of pour point depressants.

The first method involves reducing the concentration of paraffins in oil. by mixing with light hydrocarbon solvents. These are diesel fuel, light oils, etc. [3, 4].

The second method involves heating oil to temperatures of 50 °C, this is due to the technical features of the transport of a hot medium, as well as the fact that at this temperature a significant part of the paraffins is in molten form. At the same time, oil heating stations are located along the pipeline route to prevent reaching the pour point [3, 4].

The third method involves the addition of polymer depressant additives to the oil. Their impact is manifested in a decrease in the pour point of oil. The principle of operation is to increase the number of paraffin crystallization centers and change their morphology [3, 4].

The use of the first method is problematic since the dissolution requires the constant presence of light solvents in large quantities. In the case of the Zapolyarye-Purpe pipeline, highly paraffinic oil is mixed with gas condensate and transported in this form. This type is more economically justified. Initially, the pipeline was built exactly as a hot pipeline with all the necessary infrastructure.

The second and third methods are used jointly on the Usa-Ukhta pipeline. Hot pumping is complemented by the addition of a depressant additive DPN-1 to the oil flow. The dosage is 50-150 ppm. Their use together is caused by the relatively high temperature of the setting of oil, while the introduction of the additive should be carried out purely at a temperature when the paraffins are in the molten state, and since the oil is already heated, this operation is much easier to introduce into the technological process [5, 6].

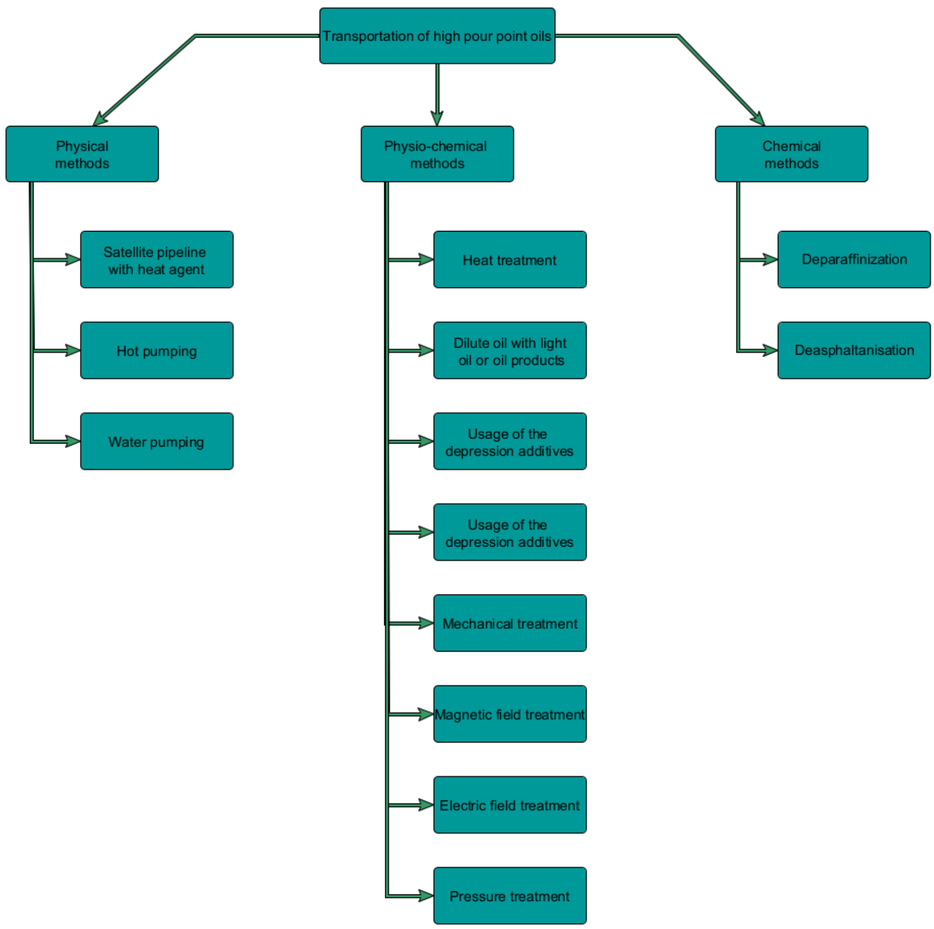

Fig. 1. Methods of transportation [4]

3. Perspective directions of oil treatment

In general, according to the authors, promising areas may be the treatment of oil through the effects of fields of different nature. Such fields can be magnetic, electric and, of course, ultrasonic (acoustic) field. At the moment we can say that there is a scientific basis that allows us to talk about a certain effect on the oil. Oil is considered as a dispersed system.

The influence of a magnetic field according to the work [7] confirms the influence on properties of oil disperse system by means of influence on its structure-forming components. At the same time more centers of crystallization are formed and precipitation of ARPD occurs in the whole volume in the oil, not only on the surface of the pipelines. Also work [8] confirm that a weak magnetic field has almost no effect on the system of oil paraffin, while having a much greater impact on the resin and asphaltene components.

An alternating electric field according to the works affects the rheology of oil with the frequency affecting more than the amplitude of oscillations [9].

Acoustic or ultrasonic impact has contradictory data. If we talk about the mere impact of ultrasound on oil dispersed systems, there is evidence that treatment with ultrasound reduces oil viscosity, lower pour point, changing the composition of precipitation, etc. [10].

The author of the work besides [10] the positive effect after treatment finds the opposite effect for high-paraffin oils, which depends on the content and composition of the paraffin components and does not depend on the content and proportion of tarry asphaltene components. If we talk about the pour point, it turns out that when processing high-paraffin oil with a relatively high pour point, it increases.

Due to the fact that the ultrasonic effect is considered in various conditions and applications within the framework of the main oil transport it is worth considering it as a target for prospective application.

4. Positive and negative effects of ultrasonic treatment

As said, transport of highly pouring oil is carried out mainly in three ways, each of which has its pros and cons. The hot pipeline coupled with depressor additives can be improved by integrating ultrasonic influence. There are enough reasons for such integration to make this idea viable.

In work [11] authors observe synergetic effect of wax deposition inhibitors application at joint treatment of model fluid. Under the model liquid is meant 6 % solution of petroleum paraffin in kerosene.

In the work [10] already discussed above also observed a synergistic effect with a depressant additive of polymeric type, but the effect was also observed on the model mixture, which may also affect the result of the work.

The works [12, 13] consider the use of ultrasonic treatment for destruction of sediments and ARPD on the bottom of tanks and surfaces of oil pumping equipment. This effect is possible due to the appearance of cavitation bubbles at the interface, the process is clearly shown in Fig. 2. Experimental results show that it is possible to clean the surface in this way.

Fig. 2. Cavitation bubble influence on ARPD [12]

This paper [14] considers the use of ultrasound to remove bottom sediments, but in contrast to the simple treatment wax sediment inhibitors were used. The scheme was to circulate oil according to the scheme shown in the figure. The oil was pumped out of the tank, heated, treated with ultrasound and then back into the tank, eroding the sediments.

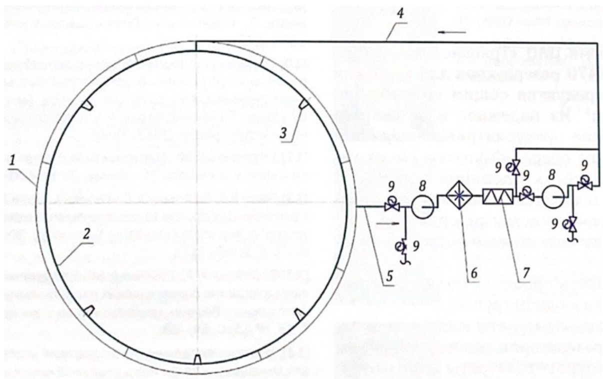

Fig. 3. Scheme itself [14]: 1 – tank to be cleaned; 2 – ring pipe (Dy 100); 3 – hydraulic monitor; 4 – receiving pipe (Dy 150); 5 – discharge pipe (Dy 150); 6 – heat exchanger; 7 – ultrasonic device; 8 – axial diagonal pump (UODN-360-250-250); 9 – electric gate valve

The authors of paper [14] subjected the oil to ultrasonic treatment together with wax inhibitors. The treatment occurred at a frequency of 20 kHz at three different power levels. The efficiency of the treatment was calculated based on the amount of dissolved ARPD mass in the oil. As the intensity increased, the result improved and at maximum power the effect reached a 40 percent increase in mass compared to the untreated oil.

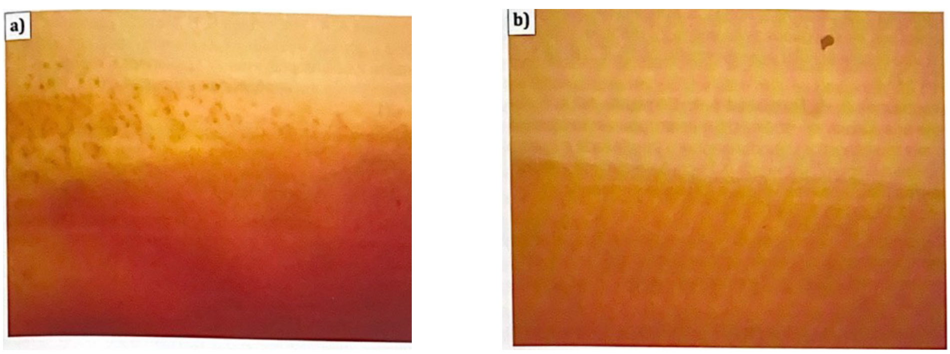

Fig. 4. Effect on paraffins, a) before, b) after [14]

It is important to note that ultrasound contributed to the synergistic effect of the combined effect of ultrasound on the oil, this was observed both visually and in the reduction of viscosity. At the same time, the authors believe that such treatment can reduce the pour point. The result of this treatment is that by changing the dispersion medium of oil paraffins become dissolved in the oil. The result of the internal survey is shown in Fig. 4. In other words, the positive effect of the combined effect of inhibitor additive and ultrasound on highly paraffinic oil has been achieved.

From all the previously described experiments and treatment results, a pattern emerges according to which the combined work of ultrasound and additives should lead to an increase in their efficiency, which is an unambiguous advantage and a compelling reason to introduce such a mechanism into the oil transport system.

On the other side of the question, it was already mentioned above about negative effects of treatment of high-paraffin oil of different composition and in different time range. In this case, in addition to such influence there are other negative effects, which are caused in turn by acoustic cavitation, which is a consequence of occurrence of zones of separation and compression in the liquid volume during the passage of ultrasonic waves [15-17].

Under this reason in the works [17, 18] is considered the possibility of breaking hydrocarbon molecules of great length. The mechanism works according to the principle of occurrence of tensile and compressive forces in the molecules located on the borders of the cavitation bubble, as a result of which the destruction of molecules is observed.

Ultrasonic vibrations when applied to polymer solutions can be accompanied by destruction of macromolecules. Thus, a decrease in structural viscosity was observed for solutions of synthetic polymers (polyacrylates, polystyrene, polyvinyl acetate, nitrocellulose). By the example of polystyrene, it was shown that at different initial values of macromolecules the value of the latter after a long treatment in the ultrasonic field is close to the minimum value of 30000 a. m. Moreover, the efficiency of degradation of polymer macromolecules directly depends on the intensity of the ultrasonic field. The higher it is, the greater the number of cavitation bubbles and the higher the rate of destruction [19, 20].

According to the paper, most depressor additives are solutions of ethylene vinyl acetate (Fig. 5), comb type co-polymers (Fig. 6), or nano hybrid. All of them are in one way or another different variation of polymer. In other words, they are long macromolecules and the impact of ultrasound on them can lead to their destruction and as a consequence, a partial or complete loss of properties [21].

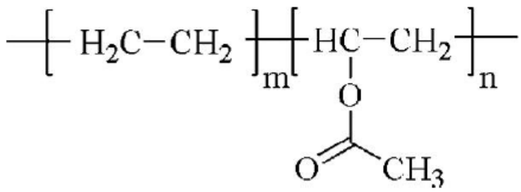

Fig. 5. EVA chemical formula [21]

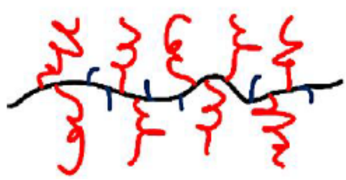

Fig. 6. Comb type PPD structure [21] (red line – alkyl branch, black line – polar group)

When transporting oil, it is also not allowed to change the chemical composition of oil, because paraffin and other macro molecules are valuable components, which are further used for processing. For example, thermal destructive treatment of oil in which oil is heated and treated with pressure, as a result oil flowability is improved and solidification temperature is reduced, but in the process the chemical composition is changed [3, 4].

5. Conclusions

In the course of the article clearly visible experimental evidence of the positive effect of ultrasound on oil reduces viscosity and pour point. Synergistic effect is observed in conjunction with depressor or inhibitory additives in the model liquids and oil. On the other hand, there are many works that speak about changes in the chemical composition of oil, about deterioration of rheological properties and increase of pour point. Indirectly we can talk about the negative impact on polymeric additives.

At this stage, we cannot talk about the possibility of full integration of ultrasonic treatment in the process of oil transport, as there are many negative effects requiring more in-depth study.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

Nikita Lisovskiy is responsible for conceptualization, data curation, investigation and writing-original draft preparation. Nikita Atroscshenko and Yang Chen are responsible for resources, visualization and writing-review and editing.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] "Executive summary." World Energy Outlook 2022. https://www.iea.org/reports/world-energy-outlook-2022/executive-summary (accessed 2023).

[2] "Statistical Review of World Energy." 2023. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

[3] A. A. Korshak and A. M. Nechval, *Design and operation of a gas and oil pipeline*. St. Petersburg, Russia: Nedra, 2008.

[4] G. G. Vasilyev, G. Y. Korobkov, and A. A. Korshak, *Pipeline transportation of oil*. Moscow, Russia: Nedra-Bisnestsentr, 2002.

[5] A. Y. Lyapin, V. O. Nekuchaev, S. K. Ovchinnikov, and M. M. Mikheev, "Investigation of the reasons for decreased efficiency of depressant additives during the pumping of paraffinic oils," *Science and Technologies Oil and Oil Products Pipeline Transportation*, Vol. 10, No. 2, pp. 157–163, Apr. 2020, https://doi.org/10.28999/2541-9595-2020-10-2-157-163

[6] A. Y. Lyapin, V. O. Nekuchaev, A. V. Bakanov, M. M. Mikheev, and P. V. Fedorov, "Increase of depressant additives effectiveness during transportation of paraffin and high pour point oils," *Science and Technologies Oil and Oil Products Pipeline Transportation*, Vol. 11, No. 6, pp. 630–639, Dec. 2021, https://doi.org/10.28999/2541-9595-2021-11-6-630-639

[7] L. A. Artsumovich and S. Y. Lukyanov, *The Motion of Charged Particles in Electric and Magnetic Fields*. Moscow, Russia: Mir, 1977.

[8] G. M. Mokrousov and N. P. Gorlenko, *Physico-Chemical Processes in Magnetic Field*. Tomsk, Russia: Publishing house of Tomsk State University, 1988.

[9] O. V. Belyi, "About molecular modification of liquid hydrocarbon fuels by electric fields," *Transport of Russia: Problems and Prospects*, pp. 13–35, 2010.

[10] R. V. Anufriev, "Influence of ultrasonic treatment on the structural and mechanical properties and composition of oil disperse system," Federal State Budgetary Scientific Institution Institute of Petroleum Chemistry, Siberian Branch, Russian Academy of Sciences, Tomsk, Russia, 2017.

[11] I. V. Prozorova, I. V. Litvinets, G. I. Volkova, A. V. Morozova, and O. A. Kazantsev, "Effect of ultrasonic treatment and polymer additive on structural-mechanical properties of solutions of paraffinic hydrocarbons," in *Proceedings of the Advanced Materials with Hierarchical Structure for New Technologies and Reliable Structures*, 2018, https://doi.org/10.1063/1.5083489

[12] H. Hofstatter, M. Pavlov, and B. Mastobaev, "Application of ultrasound for the destruction of resin-paraffin deposits in pipeline transport of oil," *Storage of Petroleum Products and Transport of Hydrocarbons*, No. 3, pp. 6–9, 2014.

[13] E. V. Shchurova, A. A. Krys, R. A. Khuramshina, and A. R. Valeev, "Removal of asphalt-resin-paraffin deposits from oil storage tanks using ultrasonic treatment," *Storage of Petroleum Products and Transport of Hydrocarbons*, pp. 29–33, 2020.

[14] M. N. Fazlyev, Y. Demyanov, Y. Timirgaliyev, I. Bezymyannikov, Muphtakhov, and E. E. Nurislamov, "Development of innovative energy-saving technology for cleaning tanks by dispersing deposits," *Science and Technologies Oil and Oil Products Pipeline Transportation*, Vol. 11, No. 5, pp. 484–491, Dec. 2021, https://doi.org/10.28999/2541-9595-2021-11-5-484-491

[15] D. Feldman, "Sonochemistry, theory, applications and uses of ultrasound in chemistry," *Journal of Polymer Science Part C: Polymer Letters*, Vol. 27, No. 13, pp. 537–537, Dec. 1989, https://doi.org/10.1002/pol.1989.140271309

[16] K. Semionescu and K. Oprea, *Mechanochemistry of High-Molecular Weight Compounds*. Moscow, Russia: Mir, 1970.

[17] V. A. Kargin and G. L. Slonimsky, *Short Sketches in Physico-Chemistry of Polymers*. Moscow, Russia: Chemistry, 1967.

[18] M. A. Margulis, *Sound-Chemical Reactions and Sonoluminescence*. Moscow, Russia: Chemistry, 1986.

[19] A. A. Berlin, "Mechanochemical transformations and synthesis of polymers," Uspekhi chemi, 1958.

[20] V. A. Kargin, B. M. Kovarska, and L. I. Golubenkova, "Block-polymer on the basis of phenol-formaldehyde resin and nitrile rubber," *DAN SSSR*, Vol. 112, No. 3, pp. 485–486, 1957.

[21] L. Na, M. Guoliang. S. Xianzhi, and T. Shiwei L. Yang, "Advances in the research of polymeric pour point depressant for waxy crude oil," *Journal of Dispersion Science and Technology*, Vol. 39, No. 8, pp. 1165–1171, 2018.

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