Cavitation method of intensification of processing of hydrocarbon raw materials

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Abstract. The article describes the success of research and application of wave methods in the process of processing hydrocarbon raw materials. A promising direction for intensifying the processing of hydrocarbon raw materials is wave technologies implemented on the basis of physical principles: electrical, magnetic, radiation, acoustic, cavitation, microwave, vibration, laser effects. The hydrodynamic cavitation unit and the instrumental-technological scheme of the unit are presented. Two main groups of hypotheses are presented - thermal and electrical. The studies on the change in the physicochemical and rheological characteristics of oil during its processing in a rotary impulse apparatus are shown.

1 Introduction

In recent decades, hard-to-recover oil reserves have attracted more and more attention in Kazakhstan. In this regard, it is relevant to develop innovative methods for stimulating production, which can significantly increase the oil recovery factor (ORF) from already developed formations. The introduction of methods for intensifying oil production at the enterprises of the oil and gas complex of the Republic of Kazakhstan is carried out quite intensively, but the choice of one method or another requires a scientifically based approach [1]. And also the traditional ways of solving the problem of increasing the depth of oil refining - the use of new technological, structural and technical solutions, the development of new types of catalysts, reagents, etc. As a rule, this requires capital investments, much more time and is feasible, mainly at the design stage and when new installations are put into operation [2]. A promising direction for intensifying the processing of hydrocarbon raw materials are wave technologies implemented on the basis of physical principles: electrical, magnetic, radiation, acoustic, cavitation, microwave, vibration, laser effects. Explosive energy, low-density plasma, barrier discharge, and ionizing radiation are also used. Explosive energy, low-density plasma, barrier discharge, and ionizing radiation are also used. From year to year, the number of publications demonstrating the success of research and application of wave methods in the process of processing hydrocarbons and the use of petroleum products increases [3–7]. However, approaches, terminology, methods and assessments are often very different, and some studies are duplicated due to lack of awareness. Therefore, the purpose of this work is to analyze the literature on oil processing using the cavitation method.

As known, wave methods for influencing hydrocarbon raw materials are divided into two main groups, electromagnetic and mechanical. Electromagnetic effects are carried out by electric, constant and alternating electromagnetic fields. Mechanical action is carried out by means of acoustic waves (including ultrasound), cavitation, vibration jets, impulse shocks, in cavitation mills, due to elastic low-frequency vibrations created by a column of pumped liquid, etc.

According to domestic and foreign experts, the most promising method of influencing oil is exposure to physical fields (magnetic, ultrasonic (US), vibration, etc.), which lead to the destruction of the structures of oil associates and reduce the viscosity of oil. The use of elastic mechanical vibrations in petrochemical technology is In many cases, it provides an extremely high intensity of the technological process, which is not achievable with the help of other methods.Analysis of studies on the use of cavitation for the intensification of various technological processes shows that this method is promising. The category of the most effective techniques that improve the rheological properties of viscous oils and petroleum products should include complex methods of exposure, for example, combining the introduction of a solvent or reagent and cavitation treatment of oil, which will increase the effect obtained from each method separately. In the phase of the acoustic wave discharge or due to a local decrease in pressure when flowing around a solid, cavities (cavitation bubbles) are formed in the liquid, which are filled with the saturated vapor of this liquid. In the compression phase, under the action of increased pressure and surface tension forces, the cavity collapses, and the vapor condenses at the interface. A gas dissolved in the liquid diffuses into the cavity through the walls of the cavity, which is then subjected to strong adiabatic compression. At the moment of collapse of the cavitation cavity, the pressure and temperature of the gas can locally reach significant values (according to the calculated data, up to 100 MPa and 10,000 K, respectively) [8–10]. After the collapse of the cavity, a spherical shock wave propagates in the surrounding fluid, which rapidly decays in space. When pulsed tensile stresses are generated in a liquid, cavitation nuclei present in it (stable vapor and gas bubbles of small sizes) begin to grow, forming a cavitation cluster, the shape and size of which is determined by the initial size spectrum of cavitation nuclei, the nature of the applied stress, and boundary conditions. Liquid vapors, dissolved gases, as well as substances with high vapor pressure can penetrate into the cavitation cavity, and ions or molecules of nonvolatile dissolved substances cannot penetrate. The energy released during the collapse of the cavity is sufficient for the excitation, ionization and dissociation of water molecules, gases and substances with high vapor pressure inside the cavitation cavity. Erosion of a solid (destruction of the surface), cleaning of surfaces, dispersion of solid particles, dissolution, extraction, emulsification, homogenization, foaming are carried out mainly due to two characteristic manifestations of cavitation: shock waves and cumulative streams formed during the collapse of cavitation bubbles. Cumulative streams destroy the surface layers and the surface of a solid due to the kinetic energy of the liquid. Small particles of a solid, the sizes of which are commensurate with the cross-section of cumulative jets, are carried away by them and make an additional contribution to the process of destruction of the surface layers and the solid particles themselves in the liquid.

In industry, for cavitation action on a liquid, hydrodynamic, electrodynamic, piezoelectric, magnetostrictive and mechanical cavitation generators are used. In the ultrasonic range, the most common are piezoelectric and magnetostrictive cavitation generators. These electroacoustic transducers use a direct magnetostrictive and piezoelectric effect in alternating magnetic and electric fields [11].

2 Results and discussion

Under the influence of high-intensity cavitation for a long time, C – C bonds in paraffin molecules are disrupted, as a result of which changes in the physicochemical composition (decrease in molecular weight, crystallization temperature, etc.) and the properties of oil products (viscosity, density, flash point, etc.) occur.).

To break the bonds in the molecules of hydrocarbon compounds, it is necessary to provide a multifactor energy impact in a pulsed form on a complex multicomponent system, which is oil and oil products. According to the author, [12] of the work, such an effect is realized in rotary pulsed apparatuses (RIA), where the dissociation energy of the C - H bond fluctuates depending on the molecular weight and structure of the molecule, within 322–435 kJ / mol, the dissociation energy of the C– bond C - 250–348 kJ / mol. When the C – H bond is broken, hydrogen is detached from the hydrocarbon molecule; when the C – C bond is broken, the hydrocarbon molecule is broken into two unequal parts. During cavitation treatment of hydrocarbon raw materials, the destruction of molecules occurs, caused by microcracking of molecules and ionization processes.

As a result of these processes, “activated” particles accumulate in the system: radicals, ions, ionic-radical formations. This method allows you to increase the fuel combustion ratio, save fuel oil and reduce harmful emissions of NOx and CO_x into the atmosphere during their combustion.

3 Materials and methods

The cavitation method with the use of hydrogen as a donor can be used to improve the physicochemical, operational characteristics of heavy oils, such as atmospheric and vacuum residues. On the other hand, the very high local temperature resulting from the collapse of the bubbles can activate dispersed metal nanoparticles, and hence cracking or hydrogenation reactions can be catalyzed by the heavy oil cavitation process. The authors of [13] in a home-made laboratory hydrodynamic cavitation unit (Figure 1) numerically investigated the formation of a vapor phase in a cavitation chamber, as well as changes in the characteristics of a fuel oil sample in the presence of gasoline as a donor of hydrogen and metal nanoparticles. The results showed that adding 0.01 L / L gasoline to a 10-minute cavitation cracking process at 80 ° C and atmospheric pressure can reduce the viscosity of the heavy oil by about 20%. In addition, the presence of iron nanoparticles can increase the rate of hydrogenation or cracking reactions in the heavy oil cavitation upgrade (HCUP) process in the presence of a hydrogen donor.

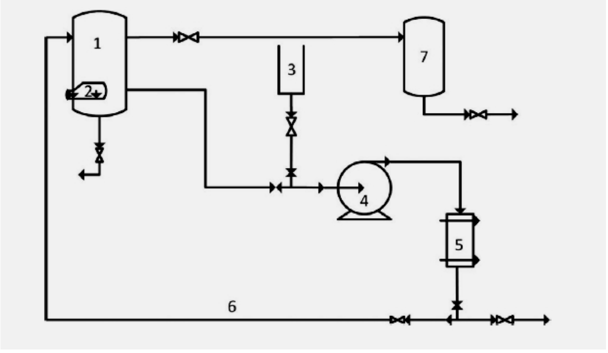

Fig. 1. Hydrodynamic cavitation unit. 1 - reservoir; 2 - heater; 3 - spare container; 4 - pump; 5 - cavitation chamber; 6 - recirculation pipe; 7 - container for light fractions.

Oil shale consists of two parts: a solvent-soluble fraction of low-molecular substances captured by a network and a solvent-insoluble fraction consisting of a covalently crosslinked network, which leads to a low extraction rate [14, 15]. For this type of extraction, it is advisable to use the method of cavitation with ultrasonic energy, when exposed to the latter, intensive mixing occurs in the system. The resulting microjets cause disruption of covalent interactions and enhance the penetration of solvents into various regions of multiphase systems. Solvent selection and ultrasonic parameters play an important role in improving the extraction yield. Haddadin [16] studied the influence of ultrasonic parameters such as frequency, ultrasound power and operating parameters such as extraction temperature, extraction time and type of solvent. All of these parameters have shown a significant impact on oil yield.

4 Conclusions

The authors of [16] proposed to reduce the viscosity of bitumen and other heavy oils by cavitation treatment as an ecological alternative in comparison with the use of solvents or heat treatment. In this work, the effect of acoustic cavitation at various frequencies (from low to high frequencies) on rheological changes and the quantitative composition of metal and asphaltenes in bitumen was investigated. When carrying out the experiment under different conditions of sonication, frequency and energy consumption, it was shown that treatment of bitumen with ultrasound under different conditions of frequencies and acoustic power reduced the H / C ratio.

These results showed higher aromatic hydrogen content and lower aliphatic hydrogen content in bitumen treated under different sonication conditions of frequency and intensity. Asphaltenes were characterized using ICP-MS and TXRF, lower metal content was revealed. The reduced metal content may be due to a decrease in asphaltene formation as a result of sonication of bitumen.

The most important component of the raw material base of the oil industry are reserves of heavy and bituminous oils. However, during their transportation, a number of problems arise, the main of which is viscosity, which reduces the speed. The following methods are used to lower the viscosity: thermal heating, electromagnetic radiation, and ultrasonic vibrations.

According to study [17], the most promising method is complex oil treatment, that is, at the first stage, a depression additive is added, then oil transported through the pipeline enters the physical field of action (cavitation treatment) (the apparatus and technological scheme of the installation is shown in Figure 2).

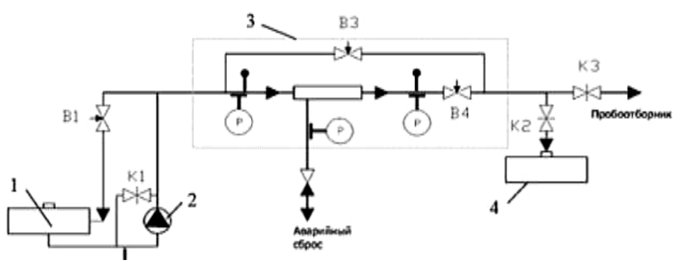

Fig. 2. Hardware - technological scheme of the installation. 1 - initial tank, 2 - pump, 3 - working area, 4 - receiving tank (tank farm).

When using the complex method, the percentage of use of thermal heating of oil decreases. Using this method, one can abandon oil heating to 50 degrees, and the preliminary benefit will be a reduction in heating costs in the region of 15-17%. The authors believe this method is relevant, safe and cost effective.

At the moment, scientists are classifying the processes that occur under the influence of ultrasound, but are carried out without the influence of the latter, with a lower speed and reactions that do not go without ultrasonic vibrations (Table 1) [18].

Table 1. Types of reactions.

Reactions under the influence of ultrasound and without exposure to ultrasound	Ultrasound-influenced reactions
Hydrolysis of carboxylic acid esters	Redox reactions, which are carried out in aqueous solutions between solutes and products of ultrasonic splitting of water, arising in cavitation bubbles and passing into solution after their collapse
Dimethyl sulfate hydrolysis	Reaction between dissolved gases and substances with high vapor pressure inside cavitation bubbles
Decomposition of diazo compounds	Chain reactions in solution, which are initiated by non-radical products of water splitting, but by some other substance present in the system and splitting in a cavitation bubble.
	Sound-chemical reactions in non-aqueous systems.
	Explosion initiation in liquid and solid explosives.

Promtov et al. [19] investigated changes in the physicochemical and rheological characteristics of oil during its processing in a rotary impulse apparatus. Highly paraffinic oil of the following composition was taken for analysis: paraffin concentration - 20.57%, asphaltenes - 1.08%, resins - 8.14%, mechanical impurities - 0.038%, sulfur - 0.25%, water was not detected. After hydroacoustic treatment the oil had the following parameters: paraffin content 19.98%; asphaltenes 0.97%; resins 7.92%; mechanical impurities 0.059%; sulfur 0.3%; water - n / a.

The results of the study show a decrease in the viscosity of thixotropic oils without heating, which has a beneficial effect on the consumer and transportable properties of the pumped product due to the destruction of the native structure of the CCE, dispersion of solid paraffin crystals, as well as the uniform distribution of chemicals in ultra-low concentrations over the entire flow section.

Thus, cavitation treatment can be considered as one of the promising methods of oil treatment from an economic and environmental point of view. Since when using this method, it is not necessary to use expensive chemical reagents that lead to environmental pollution.

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