The use of nanoparticles to enhance oil recovery

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Abstract. The article describes the actual problem of the introduction of nanotechnology in various fields of activity and existing technologies of the oil industry. The expediency of using nanotechnology to increase oil recovery, in the production of metal alloys to increase their strength characteristics and corrosion resistance, insulating coatings to reduce heat losses, lubricants that reduce wear of mating surfaces, in laboratory studies is shown. The results of the application of various nanotechnologies in the oil industry are presented.

1 Introduction

The improvement of nanoscale structured materials is one of the most interesting innovative aspects bringing technological progress to many industries. Developments in the field of nanoparticle technologies mainly concern materials science with the possibility of obtaining new metal alloys that provide high strength, low weight and high resistance to corrosion and abrasion. However, these materials can appear in various forms, from solid to liquid, with the possibility of having special combinations with nanoparticles.

The extractive oil and gas industry could get a big boost from the momentum of nanotechnology innovations based on processes that expose equipment materials to extreme working conditions. In addition, nanotechnology developments related to suitable modeling tools make it possible to characterize interfacial phenomena between minerals and fluids (wettability, etc.), which leads to a better understanding of the mechanisms of hydrocarbon extraction. Currently, oil and gas production increases the need to improve nanotechnology to better characterize the organic matter content in nanopores of oil and gas-containing rocks [1-6].

Almost every oil and gas company actively invests in nanotechnology to improve oil recovery, improve equipment reliability, reduce energy losses during production, provide real-time analysis of emulsion characteristics, and develop highly efficient products (for example, high-performance lubricating oils are of great importance in the oil industry).

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2 Methods and materials

The use of nanoparticles to enhance oil recovery is one of the most important applications, as they provide more oil during production, thereby providing a faster return on investment. Various methods using nanotechnology are being considered, and the use of nanorobots to study the formation in real time seems very promising. These tiny robots will be able to provide operators with useful information for better drilling operations, such as dynamic adaptation of additive mixtures or operating pressure [7-11].

The EXPEC Advanced Research Center has implemented some important work on the use of nanorobots in oil and gas reservoirs, the design of reservoir robots used as nanoreporters. The main difficulty lies in adapting the physical and chemical properties of nanorobots in order to pass through tiny pores, but some experiments have yielded good results. By adding some sensors inside the robots, you can get very important information.

To increase oil recovery, the use of solid nanoparticles of various metals dispersed in liquids to improve certain properties in technological solutions can also be guaranteed. Such nanofluids can be created in such a way that they are compatible with fluids and rocks of the productive formation and at the same time do not pose a danger to the environment.

Experiments using various nanoparticles such as magnesium oxide, aluminum oxide, zinc oxide, zirconium oxide, tin oxide, iron oxide, nickel oxide, hydrophobic silicon oxide and silane-treated silicon oxide have shown an increase in hydrocarbon production. The effects arising from the use of these substances are associated with a change in the wettability of rocks, a decrease in the viscosity of oil, a decrease in interfacial tension, a decrease in the coefficient of mobility and a change in permeability. Another example of the use of nanoparticles (in order to increase the efficiency of oil production) as an additive during operation was presented by the University of Alaska, where some researchers identified important characteristics guaranteed by the use of metal nanoparticles dispersed in supercritical CO_2, responsible for reducing the viscosity of heavy oil with a subsequent increase in extraction efficiency [12-16]. The figure (Figure 1) shows a scheme of chemical flooding with the use of nano-containing solutions to increase oil recovery.

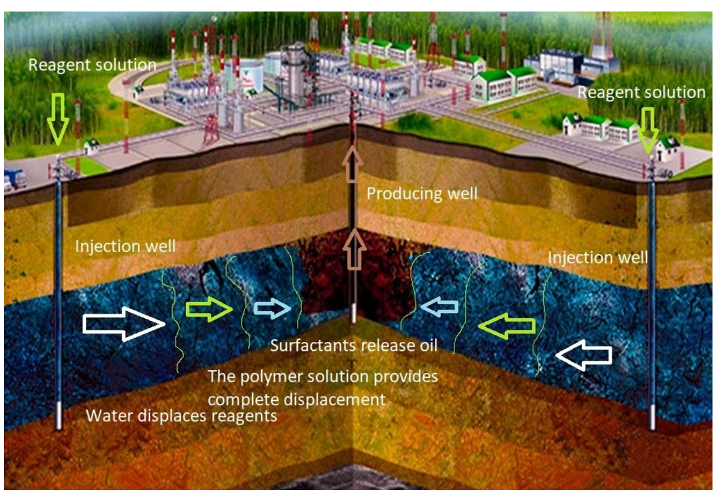

Fig. 1. A scheme of chemical flooding to increase oil recovery.

3 Results and Discussion

One of the main problems in the oil and gas industry is corrosion and the need for corrosion-resistant materials. The use of acidic crude oil highlights this problem by shortening the service life of equipment, especially pipelines and heat exchangers. The need to solve these problems has led to research in the field of nanotechnology in order to develop nanostructured coatings capable of increasing corrosion resistance. For example, Saudi Aramco has carried out important research in this area by completing a product development program called “Application of nanotechnology for structural repair of destroyed heat exchangers on site.” Thus, the goal is to develop products capable of reducing corrosion damage and downtime due to maintenance. In aggressive environments with corrosion and high wear, the use of a protective film is difficult. A few years ago, electroplated “engineered hard chrome" (EHC) was used to protect the surface. EHC was preferred over cadmium (Cd) or zinc-nickel (ZnNi) galvanic metals because they have low wear resistance and are quickly removed. Highlighting the toxicity of chromium, which negatively affects the health of workers, it has recently been proposed to overcome EHC. In this regard, Integran offers electroplated nanocrystalline cobalt, called Nanovate CoP, which represents an innovative and cost-effective overcoming of EHC.

In the figure (Figure 2) the results of typical corrosion tests are shown.

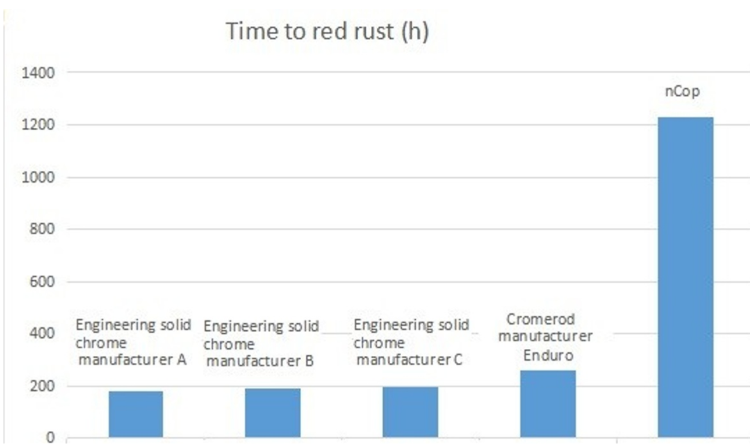

Fig. 2. Time to red rust after exposure for ncap (Nanogate Cap) compared to Enduro's Chrome Os and Engineering Solid Chrome (EHC) from another industrial supplier.

Another very important problem is heat loss during oil and gas treatment operations. It is estimated that about 50% of the supplied heat is lost in the equipment, which significantly reduces the efficiency of the process. Research in this area leads to the development of aerogel solutions that insulate the surface of equipment. The use of nanotechnology in this field makes a great contribution, as evidenced by the implementation of innovative products such as Nansulate by Industrial Nanotech, Inc. Nansulate and provides very low thermal conductivity through the use of a nanocomposite called Hydro-NM oxide mixed with acrylic resin and performance additives. The test results of thermal insulation solutions are shown in the table (Table 1).

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Table 1. Experimental tests on the Nansulate.

Measured parameters	Uncoated wall	Coated wall nansulate	Change, %
Heat flow, J	32.003	20.8605	-34.8
Heat transfer coefficient, J/(m^2·K)	1.6179	1.2544	-22.5
Thermal resistance, (m^2·K)/J	0.6181	0.7972	+28.9

The use of nanoparticles in addition to specific mixtures brings innovation to various industries, allowing the development of new high-performance products that will positively affect the relevant industry. One of the most important innovations is the use of a new generation of anti-wear lubricating oils. The most promising nanomodifiers of lubricants and antifriction materials are currently carbon group nanomodifiers - fulleroid materials. This is due to a set of physico-chemical properties inherent in this new allotropic modification of carbon, in which the chemical bond of carbon is represented by a mixed character of hybritization. The multifunctional effect of fullerene materials in the friction zone is provided by the effect associated with a decrease in temperature in the friction zone, since these materials have high thermal conductivity and the ability to form their own grid on the surface (Figure 3).

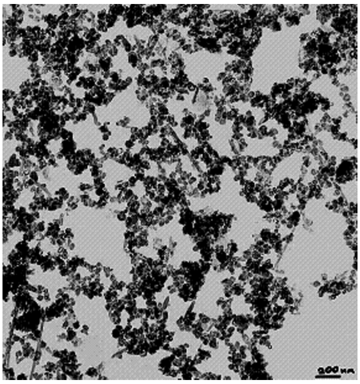

Fig. 3. Formation of a fractal mesh structure of a fulleroid material in the friction zone.

The consequence of a decrease in temperature in the friction zone is the preservation of the physico-chemical and physico-mechanical characteristics of both the lubricating medium and the friction surfaces of materials. Due to the increased sorption capacity of fullerene materials to hydrocarbons, they are able to retain a shell of adsorbed molecules of lubricant components and deliver them to the friction zone when they are depleted in the tribocontact zone due to desorption with a metal surface with increasing temperature. Thus, adhesive wear of rubbing metal surfaces is prevented.

At the run-in stage, the effect of a nanomodifier can significantly reduce the time to achieve equilibrium roughness due to rapid microabrasive wear of working surfaces. This leads to a decrease in the exposure time to elevated temperatures of local temperature flashes, leading to the destruction of the lubricant. The presence of a fulleroid material in the lubricant helps to reduce abrasive wear caused by the appearance of solid metal oxides in tribo-stresses. Oxides are formed due to the presence of molecular oxygen (O_2) in the lubricant. However, the fulleroid material is a good O_2 sorbent, and the sorption is in the nature of chemical absorption, which in the tribocontact zone at maximum temperatures ends with a reaction of $C + O_2 = CO_2$, which leads to a general decrease in O_2 in the oil volume, and, as a result, to a slowdown in the growth of oxide films to thicknesses capable of self-separation due to differences in the coefficient of thermal expansion.

As shown in various papers, experimental results indicate a marked improvement in tribological characteristics (low wear and increased load-bearing capacity). The lubricating effect of various nanoparticles used as additives depends on the material category and mainly concerns the properties of typical nanoparticle materials.

The opportunity provided by nanoparticles concerns the analysis of emulsions extracted from wells in real time. This is due to the introduction of nanoparticles, which are then restored. One of the largest companies in this field is MAST Inc., which develops instruments for determining the spectroscopic characteristics of particles during extraction operations. The particles contain a magnetic core and are coated with sensitive substances that detect the presence of sulfur, water or gas. Experience with magnetic sensors has led to the development of methods for observing them also in a completely opaque stream.

The importance of this technology is growing rapidly after the intensive use of hydraulic fracturing, which provides more resources and new development in oil exploration. However, hydraulic fracturing can also have a significant impact on the environment and therefore requires significant efforts related to environmental monitoring. In this regard, the use of nanosensors makes it possible to develop methods for maintaining the purity of groundwater in the immediate vicinity of the well.

4 Conclusion

The oil and gas industry has always been a leader in the application of new technologies in exploration and production, processing of hydrocarbons and production of petroleum products. The introduction of nanotechnology in the oil and gas industry will change the perception of the economic prospects of the hydrocarbon economy and will make it possible to correctly assess the direction and effectiveness of investments in the development of new knowledge about the oil and gas system. After analyzing a number of studies, it can be concluded that the use of nanotechnology can improve oil recovery and equipment reliability.

Nanotechnology plays an important role in the development of the oil industry. Research in the field of nanoparticles is developing so actively that it is impossible to predict all new directions of application of nanotechnology. However, even the results that are already known today allow us to talk about many new directions in the technology of oil and gas field development.

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