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APPLICATION OF NANOTECHNOLOGY IN ENHANCED OIL RECOVERY

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Abstract: Responding to the growing demand in the oil industry is possible in two ways: by finding new hydrocarbon resources or by increasing extraction from existing oil reservoirs. Increasing production efficiency by modifying EOR methods is quite obvious while the process of exploring new oil fields is declining and many oil fields are in the final stages of production; Because in many reservoirs of the world about two-thirds of the oil in situ cannot be extracted by conventional methods.

Recovery mechanisms in EOR operation can also be enhanced using nanotechnology. Nanotechnology-assisted EOR processes depend on several factors: mobility control using viscosity-increasing solutions, altering the rock wettability, reducing the interfacial tension (IFT), and lowering the oil viscosity using nanocatalysts. The efficiency depends on how the process behaves at both the macro and micro scales.

The microscopic efficiency considers the displacement of the fluids at a poral scale and measures how effective the displacing agent is in mobilizing oil and rocks to make contact. In this regard, the geometry of the pores, capillary pressure, viscous forces, rock wettability, and rheological behavior play a major role.

The macroscopic efficiency is the relationship between the connected reservoir volume being swept by the injected fluid and the volume of oil originally in the reservoir and parameters affecting this factor are: the rock heterogeneity and its anisotropy, the absolute permeability, the mobility ratio, and the gravitational segregation.

Downstream processes such as petroleum refining are employed to extract up to 40% more gasoline in catalytic cracking units than their predecessors. In upstream operations, the first application of nanotechnology was the development of nano-enhanced materials.

Nanotechnologically enhanced oil recovery processes involve (a) the addition of nanoparticles in the displacing agent enhancing its rheological properties, which are known as nanofluids; (b) the use of nanoparticles as stabilizing agents in the formation of nanoemulsions; and finally, (c) active nanoparticles working as nanocatalysts injected to perform in-situ upgrading operations in the porous medium before extraction.

Keywords: *Nanotechnology, EOR, Nanoparticles, Nanoemulsions, Nanofluids, Nanocatalysts*

1. INTRODUCTION

The growing demand in the oil and gas industry and responding to it has made the use of Enhanced Oil Recovery (EOR) methods from oil reservoirs an inevitable necessity, given the development of nanotechnology and its significant share in the oil industry and various fields such as exploration, drilling, enhanced oil recovery, refining, and distribution.

Recently, nanotechnology with the improvement of reservoir geomechanics and surface tension modification along with the improvement of oil reservoirs has the potential to change and modify the usual EOR methods and has attracted the attention of many researchers on a laboratory and industrial scale. An industrial scale has been used to identify the effect of injecting fluids at high temperatures into heavy oil reservoirs or generating heat inside the reservoir by thermal on-site as well as non-thermal methods to increase extraction.

Conventional EOR methods from heavy oil reservoirs are divided into two general categories of thermal and non-thermal methods .Some of the methods that have been successful so far are:

a) Thermal EOR, which involves applying heat to a reservoir, such as injecting water vapor, to reduce the viscosity of heavy oil and improve its ability to flow through the reservoir.
b) Injection of gases such as natural gas, carbon dioxide, and nitrogen that expand in the reservoir and cause oil to move to the wellhead. Injecting other gases that dissolve in the oil and reduce its viscosity can also make it easier for the oil to move inside the reservoir.
c) Injections of chemicals, such as surfactants, are used to reduce surface tension and prevent oil droplets from forming as the oil passes through the reservoir.

However, each of these methods is abandoned due to high cost or in some cases poor performance and efficiency in reservoir extraction.

The operation of wells includes all activities that lead to its production, maintenance, and increase. Certainly, the use of nanotechnology can facilitate and accelerate operations and ultimately lead to increased production from reservoirs. (Pourali – Pirmoradi, 2010)

2. VARIOUS APPLICATIONS OF NANOTECHNOLOGY IN THE OIL AND GAS EXPLORATION AND PRODUCTION INDUSTRIES

2.1. Application of nanotechnology in the exploration process

One of the applications of nanotechnology in the exploration process is the use of small sensors made of fiber optics to measure pressure, temperature, oil flow, and sound waves in oil wells. Another application is to inject nanosensors into the tank and receive more detailed information about the structure of the reservoir and also use of nanosensors in seismic imaging.

2.2. Application of nanotechnology in drilling operations

It involves the addition of some nanomaterials to drilling cement, which results in a uniform distribution of the cement mixture and thus uniformity of cement properties. Adding calcium silicate nanoparticles to drilling cement improves the application of cement at high temperatures (deep wells and geothermal wells), Addition of some nanomaterials causes, stability of cement quality, removal of excess water, having a suitable specific gravity, initial compressibility, and proper timing, stronger cement coating, lower permeability and permeability of cement, inhibition of gas migration, prevention of fluid waste and proper insulation of layers. Construction of more durable drilling equipment (especially drilling rigs) using nanocrystals as coating and improvement of thermal and compressive strength of drilling rigs, as well as the use of nanomaterials in better absorption of oil residues from drilling mud and the use of nanoparticles (zinc oxide, to absorb H_2S from drilling fluids and use compounds), nano-lubricant, and other applications of nanotechnology in drilling operations for oil and gas wells, are in drilling and lattice operations.

The combination of chemical EOR agents with different nanomaterials has shown increased recovery efficiencies in rock formations that had otherwise reached their operational limit (Asrilhan, 2005; Suslick et al., 2009).

However, the potential advantages of the application of nanomaterials in oil recovery should also be carefully considered from an environmental point of view. Some concerns have been raised since the same features that make nanotechnology so attractive to oil recovery processes might also harm the environment and human health. These include the potential long-term side effects associated with medical applications as well as with the biodegradability of nanomaterials being used(Raffa – Druetta, 2019; Holsapple et al., 2005; Balshaw et al., 2005; Tsuji et al., 2006; Borm et al., 2006; Powerset al., 2006).

Even though during the last years many nanomaterials have been inserted into the market, the amount of information over their impact on the environment is minimal. For instance, there is almost no information about the associated risks in the manufacturing, usage, and final disposal of nanomaterials (Hashemi et al, 2014). Focusing on EOR techniques, it has been shown that a percentage of the nanoparticles will remain underground and deposited in the rock formation, remaining for many years, and this could cause the contamination of groundwater sources. Thus, one of the desirable properties of these nanoparticles should be high durability and recyclability in a cost-effective process to decrease their impact on the environment (Hashemi et al., 2014)

2.3. Application of nanotechnology in equipment protection

The total cost of corrosion, which is imposed annually in the world of the oil and gas industry, is about millions of dollars that were spent on corrosion of surface plumbing and equipment, and also spent on in-well pipes. As one of the biggest concerns in the oil and gas industry, corrosion of equipment, coating, fabrication of parts using nanotechnology can increase the strength, stability of the equipment, and reduce their depreciation.

Nanomaterials can be used in many sectors of the oil and gas industry. By making several materials at the nanoscale, equipment that was lighter, more stable, and more powerful than conventional equipment (Taghavizadeh & Hashemizadeh, 2014). The use of nanostructured materials in this area by using nanocomposites, nanocomposite coatings, nanoparticles, and nano-lubricants can be divided into the following will be mentioned. Nanocoatings have a higher coefficient of thermal expansion, hardness, and toughness compared to micrometer coatings. They are more resistant to corrosion, abrasion, and erosion (Taghavizadeh & Hashemizadeh, 2014)

2.4. EOR using nanosurfactants

Surfactants refer to substances that reduce surface tension. These materials can be divided into biosurfactants, nanosorfactants, and polymeric surfactants based on the structure and method of production. When these materials are dissolved in the solvent, they form structures with nanoscale to micrometer dimensions. These materials are often composed of a hydrophilic head and a hydrophobic tail, and depending on the nature of their tail into categories: non-ionic or uncharged, anionic or negatively charged, cationic or positively charged, and amphoteric, both positively charged and amphoteric. Has a negative charge, they are divided (Towler et al., 2017).

2.5. EOR using nanoparticles

Among the important applications of nanoparticles in this field is the use of nanomaterials to facilitate the separation of oil and gas inside of reservoir and nanosensors inside the reservoir rock. These nanoparticles when combined with rocks containing crude oil they drop their shipments and recycle crude oil.

According to studies, one of the main applications of nanoparticles is to change the wettability of reservoir rocks. The wettability of a reservoir rock fluid system is defined as the ability of a fluid to spread on the rock surface in the presence of another fluid. Wettability not only determines the initial distribution of fluid but is also a major factor in how fluid flows in the reservoir and plays an important role in oil and gas production. In general, hydrophilic reservoir rock is preferable to the oil-friendly reservoir rock. Because the reservoir rock is oil-friendly, the oil tends to stick to it and thus reduces production.

When the well is being operated, due to the damage to the formation, the reservoir rock may become oil-friendly, in which case the wettability of the reservoir rock can be well improved by using nanoparticles. For this purpose, the effect of nanofluids on the wettability of carbonate rock as one of the main factors in enhanced oil recovery has been investigated in studies, and ZnO_2, TiO_2, $CaCO_3$, and SiO_2 nanoparticles are used in this regard (Nazari Moghaddam et al., 2015).

2.6. Improvement in place of heavy oils with the help of nanocatalysts

Nanocatalysts are used to upgrade heavy oil in situ and convert them to lighter compounds to reduce the viscosity of the fluid inside the porous medium and its ease of movement towards production wells can be used as an effective method to increase the extraction of heavy oils (Hashemi et al., 2012; Hashemi et al., 2014). Hydrogen and colloidal catalyst can be injected simultaneously through a well; In another method, the first hydrogen is injected and after a sufficient time for complete hydrogen penetration into different areas of the tank, the catalyst mixture is injected. After the injection operation, sufficient time is given for the injected mixture to contact the tank oil and to perform the necessary reactions to improve the heavy oil position through the hydrogenation process. By successive sampling of the oil produced by the well and according to the temperature, pressure, and porosity of the formation, the suitability of the viscosity of the produced oil for its economic production will be measured (Owen).

The time required for the injected mixture to come into contact with the tank oil, called the "catalytic wetting" time, varies from less than one day to hundreds of days, depending on the tank conditions and the properties of the heavy oil (Owen).

2.7. Use of nanoparticles in solvent flooding operations to increase chemical EOR

In reservoirs that for various reasons, including environmental and technical issues, the type of reservoir structure and the probability of sand production, high content Asphaltene and permeability, porosity, it is not possible to use thermal methods to increase oil extraction/(EOR), chemical improvement of oil recovery coefficient may be a suitable method. The main mechanisms for increasing the extraction/(EOR) of heavy oil in flooding operations with solvent-based emulsions include control of mobility, reduction of oil viscosity, and emulsification.

Fluid flow control is one of the most important factors in the extraction of hydrocarbon fluids. In this case, the front of the injected fluid must move as evenly as possible so that it can penetrate the formation properly. To improve this process, researchers have succeeded in producing nanoparticle-based surface and non-permeable agents that can improve the flow rate in extraction and production operations. In this case, nanoparticles are needed that:

1) Do not stick to the body of the formation matrix in any way.
2) It can be detected in very low concentrations.
3) Can cause the deformation of the fluid inside the cavity.
4) Can change the surface tension between hydrocarbons and saline water or between the fluid and the surface of the reservoir rock (Onyekonwuand Ogolo, 2010).

Researchers at MIT have also discovered that the addition of water-repellent magnetic nanoparticles, when mixed with oil and eventually using a strong magnet, can easily separate the oil-water mixture. The exploitation of oil reservoirs plays a very important role. This process must take place outside the oil recycling tanks to prevent contamination of the environment by nanoparticles. According to Zhan's research, this process, which uses ferrofluids fluids that contain magnetic nanoparticles has shown very positive results. In this process, a mixture of water and fluid is passed through the canal and outside the canal, a suitable magnet is placed to guide it to the desired location so that the separation operation can be done in a very suitable way.

2.8. Use of nanoparticles to improve polymer flooding operations

Some polymers have excellent properties and solubility to improve injection properties in oil reservoirs. Polymers are widely used in EOR operations. Such compounds act as modifiers of the rheological properties of the reservoir fluid to improve the continuous phase viscosity and thus the mobility ratio and flooding efficiency to ultimately increase the recovery rate and oil production rate. Polymer systems must be able to withstand the conditions in oil reservoirs.

In addition, the polymer used must be completely soluble, have high viscosity at low concentrations of the solution, and have low surface tension and good mobility control relative to the oil phase. The polymer used must also be economical. To solve the problems related to conventional polymer systems, the use of chemically bonded nanoparticles has recently attracted a lot of attention. Flooding with water is one of the most successful and common methods of secondary recycling. Improving the control of water movement and oil movement in low permeability areas is of great importance in this type of operation. For this purpose, cohesive particles are injected into the reservoir as a blocking agent, as a result of which high permeability areas are blocked and low permeability pathways are exposed to flood (Al-Manasir et al., 2009).

2.9. Effect on viscosity

Other applications of nanotechnology include changing the viscosity of injected fluids into the oil phase, including water, CO_2, or surfactant solutions in the form of intelligent fluids (Saidur et al., 2011). Viscosity remains largely intact, so researchers are always trying to reduce their viscosity by using enhanced oil recovery methods.

One of the effective factors in increasing the enhanced oil recovery is the viscosity of the fluid that is injected into the reservoir to move the oil, which is usually less than the viscosity of the oil. The addition of nanoparticles can adjust the viscosity of the injected fluid to the optimum level and improve the movement in the reservoir, thus increasing the oil extraction efficiency. The results of studies Shah Rusheet, (2009) showed that the viscosity of carbon dioxide with the addition of 1% of CuO (Copper Oxide) nanoparticles and a small amount of distributor is approximately 140 times the viscosity of ordinary carbon dioxide; Therefore, by spraying such nanoparticles in the propellant carbon dioxide fluids, the desired mobility and high sweeping efficiency can be achieved, which leads to more oil extraction from the reservoir.

Shah Rusheet (2009), performed two experiments to investigate the effect of nanoparticles on reducing the viscosity of heavy oil. The first group uses CO_2 nanofluid consisting of carbon dioxide gas as a base fluid and nanoparticles of CuO and polydimethyl cyclohexane (PDMS) as a distributor and the second group uses VRI nanofluid consisting of viscosity reducing fluid (VRI) as a base fluid, CuO nanoparticles and polydimethyl cyclohexane (PDMS) as distributors.

Core flooding experiments performed by injecting carbon dioxide on a sample of Berea core, once alone and again with copper oxide nanoparticles, showed that injecting carbon dioxide alone resulted in 58% of oil recovery, while with the use of CuO nanoparticles this amount can be increased up to 71%. The results also show that with the increase of PDMS and CuO nanoparticles in the carbon dioxide-based injection fluid, the density and viscosity of the injection fluid decreases, which reduces the mobility of the injection fluid and increases the sweeping efficiency, which ultimately improves oil recovery. The use of PDMS and CuO nanoparticles can also significantly reduce the viscosity of heavy oil and facilitate oil flow (Shah Rusheet, 2009).

To investigate the effect of nanoparticle size on viscosity reduction, heavy oil samples were compared with different concentrations of iron particles in micro and nano sizes at different temperatures. The results showed a greater reduction in the viscosity of nanoparticles than microparticles (Shokrlu – Babadagly, 2010). This effect can be considered due to the larger specific surface area of nanoparticles, which leads to their greater reactivity compared to microparticles; In other words, the larger the particle surface, the greater the contact of the particle surface with the oil phase, resulting in better interaction between the two phases.

2.10. Effect on the surface tension of the injected fluid

The addition of nanoparticles to the surfactant solution changes the rheological properties and increases the effect of the surfactant solution in the enhanced oil recovery operation. Munshi et al., (2008) showed that the presence of nanoparticles reduces the amount of surface tension at the oil and surfactant interface, which can be attributed to the presence of nanoparticles at the interface.

The primary purpose of using surfactants in extraction and production operations from reservoirs is to reduce surface tension and improve fluid separation operations, correct reservoir wettability, and convert it from petroleum to hydrophilic mode, which facilitates the separation of hydrocarbon fluid from the formation and also reduces the viscosity of the oil. At the same time, this causes the diameter increase and space between the layers to swell and increase using the width of the long surfactant chains, which in turn blocks the fluid filtration pathways. Also, large surfactants are absorbed due to improper structure in the initial intervals of the formation or have an inverse effect on wettability. Therefore, some properties of these materials reduce their effect in reducing capillary pressure. While the goal is to reduce capillary pressure and increase the permeability of the formation in enhanced oil recovery. Today, the use of nano surfactants due to their smaller size and the higher active surface has improved the process of using these materials.

When the dimensions of these materials are in the nanometer range, their ability to penetrate the formation cavities and their active surface area increase significantly. These materials widely affect the surface tension n of the reservoir fluid and reduce its viscosity. In this case, the fluid whose viscosity is reduced inside the reservoir and well, is lighter and flows better in the exit path of the well, and is separated from other materials in the well. Studies show that surfactants affect nanocomplexes and complex compounds in wells and alter reservoir structure. In this case, the ability of the surfactant to penetrate between the layers of the formation is very important (Tari – Alipour, 2013).

2.11. Effect on emulsions

One of the most effective methods to reduce the viscosity is emulsification, but the methods currently used for emulsification are too expensive or have poor performance for large-scale use. The use of nanoparticles can be considered as a solution to these problems. Nanoparticle-stabilized emulsions have attracted the attention of many researchers due to their many special properties and advantages over conventionally stabilized emulsions by surfactants or colloidal particles. Oil-in-water and water-in-oil emulsions stabilized with silica nanoparticles of various sizes have been investigated. Surfaces stabilized with water/oil emulsions are generally used in the oil industry. Emulsions are also produced with solid particles called stabilizers, but due to the presence of solid particles in the form of colloidal particles with micron size and easily trapped in rock cavities, they are rarely used in the oil industry. Nanoparticles have useful properties for enhanced oil recovery operations in the oil industry. Drops of emulsions stabilized with them, due to their small size, easily pass through the cavities and flow through the reservoir rock without much return. In addition, these emulsions can remain stable for several months without coagulation.

They are also able to withstand the harsh conditions of the reservoir due to the irreversible adsorption of nanoparticles on the droplet surface. In addition, the high viscosity of nanoparticle-stabilized emulsions can contribute to the degree of mobility during flooding operations, thus providing a durable way to move highly viscous oils from beneath surfaces (Zhang et al., 2010)

The results of Berea core flooding experiments indicate that oil recovery in nanofluid flooding in pure form is slightly better than nanofluid flooding followed by water flooding, which is related to the breakthrough time delay due to the formation of a viscous crude oil emulsion.

Studies on the equilibrium and stability of emulsions stabilized by colloidal particles and nanoparticles showed that the particle concentration is a key parameter in controlling the stability of emulsions so that increasing the particle concentration increases the volume and stability of the emulsion. The results also show that the average size of emulsion droplets decreases with increasing concentration, which allows more particles to be placed on the joint surface (Zhang et al., 2009)

The results of studies on supercritical CO_2 emulsions in water by Dick Son et al; and supercritical CO_2 water emulsions by Adkins et al; are of particular interest for other enhanced oil recovery processes to produce CO_2 water emulsions, they mixed water consisting of 1 to 50% by weight of silica nanoparticles with CO_2 at 25 °C and pressures varying between 34 and 700 bar. The results showed that the stability of emulsions increases with increasing nanoparticle concentration. Adkins et al., (2007) showed that water emulsions in CO_2 can be stabilized with hydrophobic silica particles with a diameter of less than 10 nm.

Water emulsions in CO2 consist of highly stable nanoparticles and form a compact layer of nanoparticles at the droplet water/CO_2 interface and have the ability to overcome many limitations such as the ability to withstand high temperature and salinity conditions that surfactants-stabilized emulsions face. Zhang et al. (2009) studied stabilized water/oil emulsions using surface-modified silica nanoparticles. The results showed that these emulsions remained stable for weeks at room temperature and above; The reason for this was attributed to the presence of surface-modified nanoparticles by polyethylene oxide polymer.

2.12. Use of nanoemulsions

Nanoemulsion is one of the smart fluids that can recover the remaining crude oils at the bottom of the reservoir rock. Nanoemulsion, which is a family of emulsions with droplet sizes in the range of 50–500 nm, has attracted a lot of attention in recent years due to its unique properties and characteristics. The presence of very small droplets of scattered phases in them has caused the phenomenon of separation of phases in this family from materials does not occur in the short term (Nalbandi – Khalili, 2013). Nanoemulsions contain chemicals used in petroleum fields and have a wide range of applications in good operations to prevent sedimentation, acid leaching, and sediment removal. One of the important properties of nanoemulsions, which is of great interest for use in petroleum fields, is the excellent resistance of these materials against sedimentation and cream formation, which can be attributed to the lack of separation of phases in storage tanks or chemical feed lines related.

The droplet size of nanoemulsions is smaller than the pore entry pores in sandy beds and reservoir rocks, which means that the emulsion can penetrate very well without the need for fluid filtration (Nalbandi and Khalili, 2013).

Nanoemulsions, have successfully been developed in laboratories, and the upcoming challenge is to develop techniques for cost-efficient industrial-scale production techniques (Engeset, 2012). They can be designed to be compatible with reservoir fluids/rocks and be environmentally friendly (Cocuzza et al., 2012). Some newly developed nanofluids have shown extremely improved properties in applications such as drag reduction, binders for sand consolidation, gels, wettability alteration, and anticorrosive coatings (Chaudhury, 2003; Esmaeili, 2011). In heavy oil reservoirs where EOR thermal production processes are usually utilized, the application of nanotechnology yielded several breakthroughs.

2.13. Use of nanofilters

Nanotechnology has provided new insights into improved oil extraction. This technology helps to separate oil and water more efficiently. More oil can be released using nanoscale materials in oil fields. Water and petroleum products do not mix, but they can be severely contaminated and difficult to separate. There are various methods for separating water from oil, which are not cost-effective due to high operating costs, low efficiency, and large equipment. To solve this problem, a combination of carbon nanotubes and microtubules can be used.

A filter surface that has both superhydrophobic and superoleophobic properties is suitable for separating water and oil. Such a filter can be produced by stacking multi-walled carbon nanotubes on a stainless steel mesh. Carbonated materials have oleophilic properties and therefore carbon nanotubes have high oleophilic properties due to their capillary properties. Research has also shown that increasing surface roughness causes hydrophobicity. Therefore, the fabrication of a nanotube mesh in which carbon nanotubes are placed vertically can be used to separate water from oil.

One of the advantages of this nanotube filter is that it separates water from oil and oil compounds with high efficiency. Another advantage of this filter is that it works easily using gravity and does not require a suction device. This filter is used to recycle oil spilled into the sea and separate saline water from crude oil from oil wells whose oil is mixed with saline water.

2.14. Use of nanogels and nanocomposite gels

One of the factors that reduce oil production is the production of excess water. Increased water production, along with the limited processing capacity of operating facilities, reduces production efficiency and even abandons wells. On one hand, the process of removing the produced water costs a considerable amount of money, and on the other hand, the unprincipled disposal of this water causes many problems in terms of environmental issues. One of the most common reasons for the increase in water and gas production in oil wells is the decrease in reservoir pressure due to production, resulting in a decrease in the gas-oil contact level and an increase in the water-oil level.

One of the common chemical methods to prevent the production of excess water in oil and gas wells is the use of polymer gels, which today due to low initial cost and chemical stability and low sensitivity to bacterial degradation, etc. have been considered. Gels are used to close gaps and high-permeability areas that play an important role in producing excess water.

In general, in the gel injection process, first, the gelatin solution is injected into the formation and after the formation of the gel inside the formation, the well returns to the production circuit. Today, one of the most practical types of polymer gels is polyacrylamide-chromium acetate polymer gel. The mentioned advantages, including low cost, are the reason for using these gels.

The disadvantages of these gels are low mechanical strength due to the application of mechanical stresses during the injection process through the pump and also when entering the formation. These mechanical stresses can lead to the breaking of polymer chains and a significant reduction in the molecular weight of the polymer. Therefore, the gelatin solution, which contains a polymer and a lattice agent and solvent, cannot reach significant strength inside the formation. As a result, when the well returns to the production circuit, the gel system formed with low strength is easily removed from the porous medium and practically cannot have the desired performance in reducing the permeability in the formation.

These gels are vulnerable to water formation. Because the water formation due to having a large amount of monovalent and divalent ions reduces the strength and disintegration of the gel structure. For this reason, today, by adding mineral particles at the nanometer scale to the structure of the polymer (composites), they improve its strength and temperature properties (Bahramiyan et al., 2010).

Polymer nanocomposites are a new generation of materials that contain a matrix (polymer and a small percentage) less than 10% by weight (of a nanometer reinforcer) that are blended conveniently. The very small and very high contact surface with less load improves the desired properties and issues related to common amplifiers, such as weight gain, surface defects, and processing problems are less seen in them.

These gelling systems consist of a water-soluble polymer and one or more of the main crosslinking agents. Also, these polymers can be injected into tanks with conventional pumps due to their water-like viscosity. They transform and play their role as path reducers or blockers. In this method, due to the similarity of water viscosity and polymer gels, the cost of injection into the well is much lower than other methods. Also, the penetration depth of this type of gel is much higher than cement due to structural similarity with water; On the other hand, the strength and durability of this type of gels are more than ten times in comparison with ordinary gels and similar conditions (Tari et al., 2013).

To overcome the limitations in the use of existing polymer gels, new nanogels based on polyacrylamide clay (MMT) were developed and their properties were tested experimentally and used for polymer flooding. These nanogels showed good results in thermal, resistance, and mechanical tests compared to ordinary polymer gels. These nanogels can be classified from aqueous solution with a low concentration to an elastic solid or can be used as a crack-blocking agent or a variety of deflectors (Miyahi – Miahi 2013).

2.15. Use of nanosensors, nanorobots, and nano detectors

One of the most important operations in the operation of wells is to record accurate information about the condition of wells such as pressure, temperature, and flow at the well or the bottom of the well. Ensuring the correct operation of measuring instruments is of particular importance (Pourali – Pirmoradi, 2010).

Special types of reliable and inexpensive sensors are being developed from fiber optics to measure pressure, temperature, oil flow, and acoustic waves in wells. These sensors have received a great deal of attention due to their advantages such as small size, safety against electromagnetic interference, ability to operate at high temperatures and pressure, and harsh environments. Most importantly, it is possible to replace and exchange these sensors without interfering with the oil production process and at a reasonable cost. New sensors are very cost-effective in terms of production and take more accurate measurements (Pourali – Pirmoradi, 2010).

The technology of these sensors is expected to improve oil production by providing accurate and reliable measurements and reducing the risks associated with oil exploration and drilling. The use of nanorobots and their effect on reducing graphing error is another advantage of nanotechnology (Miyahi – Miahi 2013).

Nanorobots which are equipped with nanosensors, can be used to measure formation properties, mud properties, and the environment around the well. Nanorobots are made in such a way that they are equipped with sensors and transmit information to the surface through electromagnetic waves.Nanorobots have the ability to monitor the well at any time and can continuously measure the properties of the formation and send its information to the surface of the earth (Rostaei et al, 2010).

With the help of this technology, the environmental effects affecting the graphing operation can be reduced or minimized, which will lead to more accurate knowledge and evaluation of reservoir engineers of the static and dynamic behavior of the reservoir. It is also possible to better detect and study the movement and displacement of injected fluids in reservoirs using nano detectors (Miyahi – Miahi 2013).

2.16. Use of nanocatalysts

Improving in situ oil and converting it to lighter compounds to reduce the viscosity of the fluid in the porous medium and its ease of movement towards production wells can be used as an effective method to increase the extraction of heavy oils.

Hydrogen and colloidal catalyst can be injected simultaneously through a well. In the other method, hydrogen is injected first and after a sufficient time for the complete penetration of hydrogen into different areas of the reservoir, the catalyst mixture is injected. After the injection operation, sufficient time is given for the injected mixture to come into contact with the reservoir oil and to perform the necessary reactions to improve the heavy oil in situ through the hydrogenation process.

By successive sampling of the oil produced by the well and according to the temperature, pressure, and porosity of the formation, the suitability of the viscosity of the produced oil for its economic production will be measured. The time required for the injected mixture to come into contact with the reservoir oil, called the "catalytic wetting" time, varies from less than one day to hundreds of days, depending on the reservoir conditions and the properties of the heavy oil (Mohammadi – Ghajari, 2013).

3. Results

Increasing production efficiency by modifying EOR methods while the exploration of new oil fields is declining and many oil fields are in the final stages of production is quite obvious. Because in many reservoirs of the world about two-thirds of the oil in situ cannot be extracted by conventional methods. There are many methods for increasing extraction from oil reservoirs, which are divided into two general categories of thermal and non-thermal methods.

The results of various researches indicate that the use of nanotechnology can be effective and practical in increasing oil extraction from reservoirs. Nanoparticles can increase the enhanced oil recovery by changing the wettability of the reservoir rock, affecting the viscosity, changing the surface tension of the injected fluid, and affecting the emulsions. Nanoemulsions can also recover crude oil remaining at the bottom of the reservoir rock. Nanoemulsions contain chemicals used in petroleum fields and have a wide range of applications in good operations to prevent scale formation, acid leaching, and sediment cleaning and removal.

One of the factors that reduce oil production is the production of excess water. There are various methods for separating water from oil, which are not cost-effective due to high operating costs, low efficiency, and large equipment. To solve this problem, a combination of carbon nanotubes and microtubules can be used. It is also possible to use polymer gels, which have been considered today due to their low initial cost, chemical stability, low sensitivity to bacterial degradation, and so on. Nanocomposite gels are used to close gaps and high permeability areas that play an important role in the production of excess water.

Improving in situ oil and converting it to lighter compounds to reduce fluid viscosity in the porous medium and facilitate its movement towards production wells can be an effective way to increase the extraction of heavy oils, for which nanocatalysts can be used. Also, nanosensors, nanorobots, and nano detectors can be used to record detailed studies of the condition of wells such as pressure, temperature, and flow at the well or the bottom of the well.

4. CONCLUSION

With the review of nanotechnology, the many capabilities, and applications of using nanofluids in increasing enhanced oil recovery, increase oil efficiency between 5–35% in addition to the efficiency with the main fluid. Due to their small size, nanoparticles can pass through the cavities, they cause very little sediment in the reservoir and spread easily into the core, so the permeability decreases shortly after they cause flooding. Studies on the application of nano to increase the enhanced oil recovery of hydrocarbon reservoirs are mostly theoretical and laboratory and need to be used and developed on a field scale. The expansion and development of this research on a field scale can bring various successes to the oil and gas industry. Economic studies of the use of this technology will also reveal the possibility of doing so on a practical and field scale.

Nanofluids are obtained from the distribution of nanoscale particles in ordinary fluids, which are used as the base fluid for the dispersion of nanoparticles. In recent years, with the development of nanoscience, the use of nanoparticles in various sectors of the oil industry has been considered. With the help of nanofluids, the separation of oil and gas inside the reservoir can be facilitated and the oil extraction rate can be increased compared to current methods. By adding nanoparticles to a fluid, its properties such as density, viscosity, thermal conductivity, and specific heat can be optimally adjusted.

One of the important applications of nanoparticles is to facilitate the separation of oil and gas inside the reservoir.GP Nanotechnology Company in Hong Kong is one of the pioneers in the development of silicon carbide, a nano-sized ceramic powder. Using these powders, very hard materials can be produced. This mixture will damage the reservoir wall in the well eliminate and increase oil extraction capacity.

Some polymers have very good properties and solubility to improve injection properties in the oil reservoir. Polymers are widely used in EOR operations. Such compounds act as modifiers of properties of reservoir fluid rheology to improve continuous phase viscosity resulting in mobility ratio and flooding efficiency are taken to eventually increase the recycling rate and oil production rate. Polymer systems must have the ability to tolerate the conditions in the oil reservoir.

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