APPLICATION OF NANOTECHNOLOGY IN OIL AND GAS INDUSTRY(EOR)

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Abstract:- *Use of Nanotechnology (nanotech) in petroleum industry involves the technique of manipulating the matter on an atomic , molecular and super molecular scale. Nowadays, use of nanotechnology in Enhanced Oil Recovery techniques are gaining more attention throughout the globe as the proved oil reserves are declining and the oil price is hiking day by day. Major characteristics of nanoparticles which is a part of nanotechnology is its ability to combine itself with other substances to perform high grade Enhanced Oil Recovery. Nanotechnology can be referred when we need to fix and fulfill the weakness of traditional ways and invent new mechanisms for Enhanced oil recovery to continue the oil production. Nanotechnology can be used to characterize the type of reservoir and also change its characteristics by using nanofluids. This paper deals with the certain ways that involves the use of nanotechnology to increase the enhanced oil recovery. This paper shows how different substances like nanofluids, nanocatalysts, nanoemulsions and phenomenon like disjoining pressure, IFT reduction and Asphaltene Precipitation can effect the Enhanced Oil Recovery Techniques. There are hindrances that arise in Enhanced Oil Recovery process. They are low sweep efficiency, costly techniques, possible formation damages, transportation of Enhanced Oil Recovery agents to the offshore field etc. on which extensive research needs to be done.*

Key Words: Nanoparticles (NPs), Enhanced Oil Recovery, Nanofluids, nanoemulsions, disjoining pressure, IFT Reduction, nanocatalysts.

1. INTRODUCTION

Nanotechnology has become the thrill word of the last decade. The precise manipulation and management of matter at dimensions of (1-100) nanometers have revolutionized several industries as well as the Oil and Gas business. Its broad impact on quite more than one discipline is creating it of accelerating interest to involved parties. The nanotech applications have punctured through completely different petroleum disciplines from Exploration, to Reservoir, Drilling, Completion, Production and processing & industrial refinery. As an example, Nano-sensors are developed at a great speed to reinforce the resolution of the subsurface imaging resulting in advanced field characterization techniques.

Nanotechnology conjointly strikes the stage of production staggeringly to reinforce the oil recovery via molecular modification and manipulate the interfacing characteristics. Moreover, in an exceedingly} very similar fashion, it provides novel approaches to improved post production processes. Solely only a few publications were able to research paper the newest accomplishments in numerous petroleum engineering domains. This research paper provides an outline of the newest Nano-technological solutions within the O&G business and covers the recent probing developments that are dispensed round the world and paves the path for several researchers and organizations who have an interest in the integration of those technological advancements.

2. LITERATURE REVIEW

- **Water-based mud:** The key fluid of the water base mud depends on the kind of well conditions that exists and additionally on the assorted formations of the well being drilled and thus the water base mud will use H2O, seawater, brine, saturated brine for its base fluid. The solids (clays) react with the water and chemicals within the mud and are known as active solids. The activity of those solids should be controlled so as to permit the mud to function properly. The solids that don't react inside the mud are known as inactive or inert solids (e.g. Barite). Other inactive solids are generated by the drilling method. The major disadvantage of employing water WBM muds is that the water in these muds causes instability in shales. Shale consists primarily of clays and instability is basically caused by hydration of the clays by mud containing water. Shales are the common rock types encountered whereas drilling for oil and gas and provides rise to a lot of issues per meter drilled than the other kind of formation. The interaction of mud-shale resulted within the introduction of a WBM that mixes K-Cl (KCl) with a compound known as partially-hydrolyzed polyacrylamide – KCI PHPA mud. PHPA helps stabilize shale rock by coating it with a protecting layer of chemical compound or a polymer.

- **Oil Based mud:** Oil Based mud: Oil-based muds are similar in composition to water-based except that the continual section is oil in these kind of drilling fluids. OBM's don't contain free water that may react with the clays within the shale rock. OBM not solely offers wonderful wellbore stability however they additionally provide sensible lubrication, temperature stability, a reduced risk of differential sticking and low formation damage potential. Oil-based muds so lead to fewer drilling issues and cause less formation harm than WBM's and they are therefore very talked-about in bounded areas. Oil muds are but costlier and need a lot of careful handling (pollution control) than WBM's. Full-oil muds have a really low H2O content (<5%) whereas invert oil emulsion muds (IOEM's) could have anyplace between fifth and fiftieth water content. In invert oil emulsion mud (IOEM) water could compose an oversized proportion of the quantity, however oil continues to be the continual section. (The water is spread throughout the system as droplets). In recent years the key oil in OBMs has been replaced by synthetic fluids like esters and ethers. Oil primarily based fluids do contain some quantity of water however this water is during a discontinuous type and is distributed as separate entities throughout the continual section.

- **Natural nanomaterials:** Nanomaterials that are belong to resource of nature are outlined as natural nano meter. As per examples virus, protein molecules as well as antibodies originated from nature are some natural nano structured materials. additionally, following are few examples, mineral like clays, natural colloids, like milk and blood (liquid colloids), fog (aerosol type), gelatin (gel type), mineralised natural materials, like shells, corals and bones, Insect wings and opals, Spider silk, Lotus leaf and similar(Nasturtium,). Gecko feet, volcanic ash, ocean spray etc.

- **Artificial Nonmaterial:** Artificial nanoparticles are those that are made deliberately through a well-defined mechanical and fabrication method. The samples of such materials are carbon nanotubes, semiconductor nanoparticles like quantum dots etc.

- **Disjoining Pressure:** The NPs within the nanofluids will make a self-assembled wedge-shaped film on contact with oil section. The wedge film acts to separate the oil droplets from the rock surface, thereby recovering additional oil than antecedently attainable with standard injection fluids. The wedge-shaped film is created because of the existence of a pressure, referred to as structural disjoining pressure.

- **Nanoemulsions:** A nanoemulsion may be a reasonably emulsion that's stabilised by NPs, which demonstrates an excellent ability to beat the challenges encountered with standard emulsions stabilised by surfactants or colloidal solids.

- **Nanocatalysts:** Nanocatalysts are often outlined as nano-sized metal particles used as catalysts that occur throughout steam injection into significant oil reservoirs.

- **Nanofluid:** A nanofluid is solely outlined as a base fluid with NPs that have a mean size of less than a hundred nm in colloidal solution. The key fluid will be any liquid like oil, water or gas. Generally, nanofluids formed by adding numerous NPs in water or brine are accustomed improve water flooding recovery.

1. APPLICATION OF NANOTECHNOLOGY IN ENHANCED OIL RECOVERY

Oil recovery operations are divided into 3 stages: primary, secondary, and tertiary.

Primary production of oil results from the displacement energy that naturally exists in an exceedingly reservoir, like solution-gas drive, gas-cap drive and natural water drive, etc. Secondary recovery processes are waterflooding and gas injection. Tertiary processes use miscible gases, chemicals and or thermal energy to displace extra oil after the secondary recovery method. There are some mechanistic distinctions between secondary and tertiary processes. The injected fluids in secondary processes supplement the natural energy present within the reservoir to displace oil. The recovery potency primarily depends on the mechanism of pressure maintenance. However, the injected fluids in tertiary processes act with the reservoir rock/oil system. These interactions would possibly lead to lower surface tensions (IFT), oil swelling, oil viscosity reduction, wettability modification, or favourable section behaviour. In some condition, the supposed tertiary method might be applied as a secondary operation. Therefore, the term 'tertiary recovery' fell into disfavour in literature and therefore the designation of "ENHANCED OIL RECOVERY" became additionally accepted. As the production rates of existing fields are declining and also the frequency of recent exploration has become greatly lower within the last decades, the importance of Enhanced Oil Recovery techniques is extremely understood by become greatly lower within the last decades, the importance of Enhanced Oil Recovery techniques is highly understood by oil firms and authorities. It is well-known that there are 3 major classes of accessible Enhanced Oil Recovery oil firms and authorities. it's well-known that there are 3 major classes of accessible Enhanced Oil Recovery technologies.

(1) Thermal methods principally introduce heat into bulky oil reservoirs by numerous methods, such as cyclic steam simulation (CSS), steam flooding and steam-assisted gravity drainage (SAGD), to better the flow ability of the bulky oil or bitumen in reservoirs by ever-changing its physical properties (viscosity and density).

(2) Gas strategies utilize organic compound mainly hydrocarbon gases (CH4, C3H8 or natural gas) or non-hydrocarbon gases (N2, or CO2) that dissolve in oil. During this approach, the injected gas will improve oil recovery by decreasing oil viscousness and by increasing oil volume.

(3) Chemical methods principally involve the utilization of long-chained molecules known as polymers to extend the effectiveness of waterflood, or the use of detergent-like surfactants to assist lower IFT that usually prevents crude oil droplets from travelling through a reservoir.

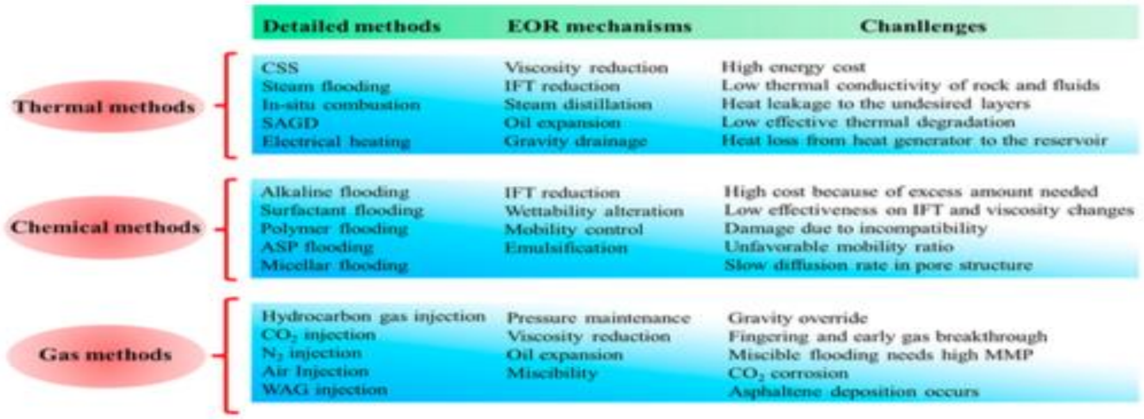

Fig 1: Enhanced Oil Recovery types and mechanisms

In brief, these Enhanced Oil Recovery strategies tend to recover additional oil from reservoir by varied mechanisms such as IFT reduction, wettablility alteration, mobility management, modification of physical properties and gravity evacuation. However, it can also be seen from Figure 1, that every one of these conventional Enhanced Oil Recovery processes face some damages, and losses of chemicals. Therefore, more cost-effective, additional economical, and vital challenges. For instance, for gas strategies, the injected gas usually quickly penetrates through reservoirs from injection wells to production wells, leading to an oversized quantity of residual crude oil remaining uncovered in reservoirs due to the high mobility magnitude relation of injected gas and oil. Moreover, chemical processes are usually restricted by the high price of chemicals, possible formation damages, and losses of chemicals. Therefore, more cost-effective, additionally efficient, and environmentally friendly Enhanced Oil Recovery strategies are greatly required. Nanoparticles (NPs) provide novel pathways to handle the unresolved challenges. NPs are outlined as particles with size ranges from 1 nm to 100 nm and show some helpful characteristics as Enhanced Oil Recovery agents when put next to the offered injection fluids employed in the conventional Enhanced Oil Recovery processes like gas, water and chemicals:

Ultra-small size: one among the foremost vital challenges to chemical processes is pore plugging and injected chemicals trapped in porous media that lead to reducing formation permeability and increasing the injection price. Normally used NPs, like SiO2, TiO2 and Al2O3, are within the order of 1 nm–100 nm (Figure 2), which is smaller compared to pore and throat sizes. Thus, they'll simply flow through porous media without severe permeability reduction and turning into a blockage that will increase the Enhanced Oil Recovery effectiveness of the injection fluids. Additionally, because of ultra-small size of NPs, they have the flexibility to penetrate some pores wherever conventional injection fluids are unable to. Thus, NPs will contact additional sweptback zones, and increase the macroscopical sweep potency.

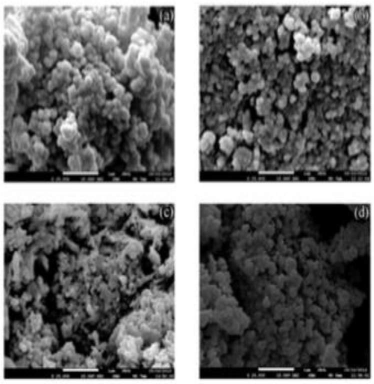

Fig 2: FESEM image of commonly used nanoparticles; TiO_2, Al_2O_3, NiO, SiO_2

Very high surface to volume ratio: because of their tiny particle size, NPs have a really high surface to volume magnitude relation (Figure 3). The big surface area will increase the proportion of atoms on the NP surface. Figure 3 explains the idea of the increasing surface area with decreasing size of the particles. At every step in Figure 3, the identical mass and volume of the sample, however a better surface area results with every smaller size.

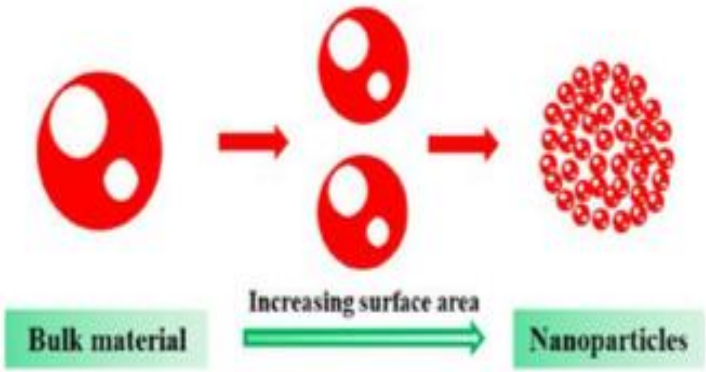

Fig 3: A Schematic diagram of NPs with high surface to volume ratio

Low prices and atmosphere friendliness: One concern of exploitating chemicals on the work field scale is that the injection price. As a result of the cost of NPs is sometimes cheaper than chemicals, NPs are often applied widely for Enhanced Oil Recovery at oilfields. Moreover, most of the Nanopolymers used are environmentally friendly materials when compared to chemical substances or compounds. For instance, most of the silica NPs are silicon dioxide, that is the main element of sandstone rock. In short, NPs are extremely price effective and environmentally friendly.

Due to the aforesaid characteristics of NPs, they supply several potential solutions to the prevailing challenges encountered by conventional Enhanced Oil Recovery strategies.

3.1 Enhanced Oil Recovery

3.1.1 Nanofluids

The Enhanced Oil Recovery mechanisms of nanofluids have already been investigated in literatures , that in the main includes disjoining pressure, pore channels plugging, viscosity increase of injection fluids, IFT reduction, wettability alteration and preventing asphaltene precipitation. The schematic of the Enhanced Oil Recovery mechanisms of nanofluids is shown in Figure 4.

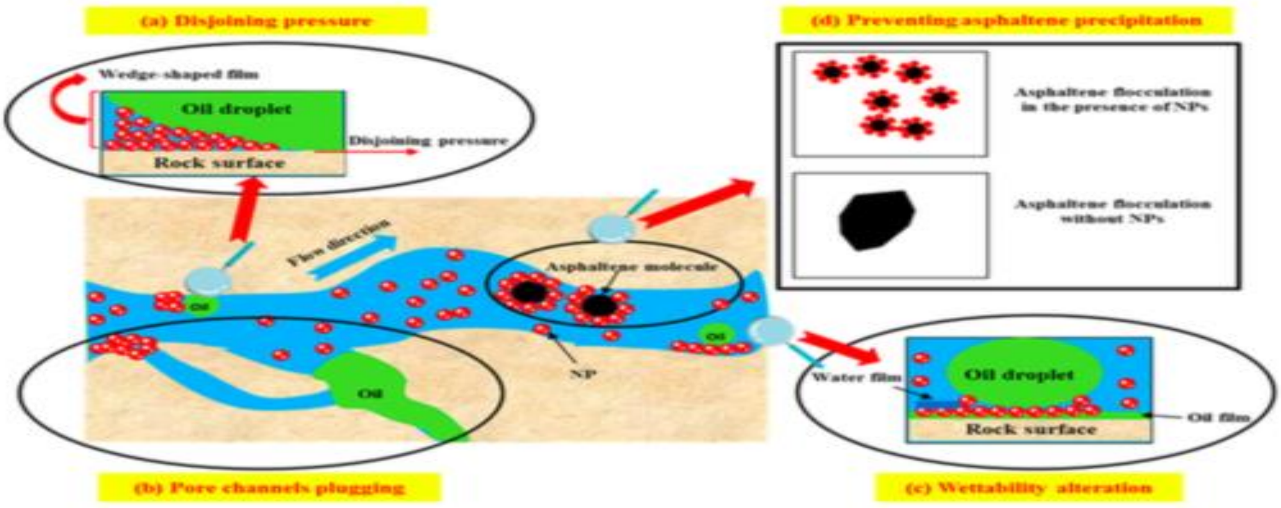

Figure 4: Enhanced Oil Recovery mechanism of nanofluid

3.1.1.1 Disjoining Pressure

The generation of the structural disjoining pressure is diffusion. Driven by a injection pressure of nanofluids, the injected nanofluids exert a pressure forcing the NPs within the confined region forward, and that they tend to rearrange themselves in evenly ordered layers. This arrangement will increase the entropy of the nanofluids because of the huge freedom of the NPs within the nanofluids. The results of this arrangement exerts extra disjoining pressure at that interface exceeding it with that within the bulk liquid. This conclusion was established by the simulated form of the meniscus profile within the wedge region in each in the presence and also the absence of NPs.

3.1.1.2 Pore Channels Plugging

Pore channel plugging is caused by 2 mechanisms: mechanical traping and logjamming (Figure 5). Mechanical traping happens as a result of the diameter of injected elements is larger than pore channels that they flow through (Figure 5a). Generally, pore channels are in microscale, thousand-fold larger than NPs. Therefore, NPs are able to penetrate pore channels without mechanical traping. However, it's noted that some metal NPs might block pore channels because of their massive size. Thus, before these NPs are injected into reservoirs, the evaluation method must be conducted to insure the practicability of enhancing oil recovery.

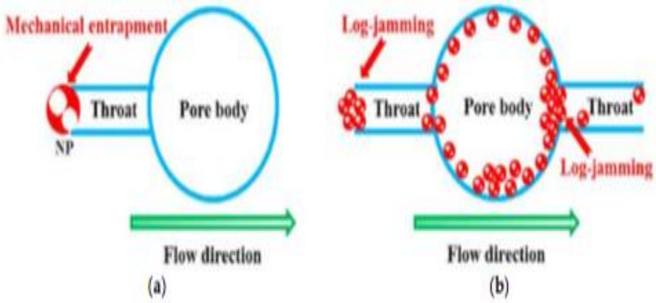

Figure 5: Mechanisms causing pore channels plugging: (a) mechanical entrapment (b) log-jamming

Log-jamming is plugging of pore channels that are larger than every NP. The time a nanofluid flows from pores to throats, the narrowing of flow space and also the differential pressure will result in a velocity(v) increase of the nanofluid. The tiny water molecules can flow quicker than the NPs inflicting accumulation of NPs at the doorway of the pore throats (Figure 5b). In some cases, plugging of pore throats because of log-jamming is helpful to boost the performance of nanofluid flooding. It can be seen from Figure 4b that, within the extremely tiny pore throat, Logjamming leads to NPs accumulation and blockage of the pore throat. The pressure builds up within the adjacent pore throat, propelling the oil entrapped within the pore throat. Once the oil is freed, the encircling pressure drops and therefore the plugging step by step disappears and the NPs begin to flow with the water. This could be thought of as temporary log-jamming. This development is especially ruled by the concentration and size of NPs, rate of flow and therefore the diameters of pore throats.

Decreasing the mobility magnitude relation or mobility ratio of Injected Fluids:

One of the vital parameters for Enhanced Oil Recovery processes is mobility ratio or mobility magnitude relation. The mobility ratio can be obtained by the following expression,

$$M = \frac{\lambda_i}{\lambda_o} = \frac{k_{ri} / \mu_i}{k_{ro} / \mu_o} = \frac{k_{ri}\mu_o}{k_{ro}\mu_i}$$

Where, λi and λo are injected fluids and oil mobilities, respectively. kri and kro are the relative permeabilities of the injected fluids and oil, severally; μ and μ are the effective viscosities of the injected fluids and oil, respectively. As per the equation, a better mobility ratio or mobility quantitative relation exists throughout the displacing processes as a result of the viscosity of a conventional injected fluid, like water, carbon dioxide or chemical, which is commonly less than that of oil. The high mobility ratio or mobility quantitative relation simply causes viscous fingering of injected fluids inside oil, poor conformity, and poor sweep potency. The mobility ratio or mobility quantitative relation is reduced by viscous reduction of oil section or viscosity improvement of injected fluids. Nanofluids will solve the top mentioned complexity because adding NPs in conventional fluids can increase the effective viscousness of injected fluids. Shah and Rusheet found that the viscousness of nanofluids (1% CuO NPs in gas section carbon dioxide) was one hundred forty times larger than that of CO2. The viscousness of a nanofluid is influenced by many factors, like shear rate, temperature and NP concentration. For instance, the viscosity of the SiO2 nanofluid will increase with decreasing shear rate. The increasing rate of its viscosity at lower temperature is more than that at higher temperature.

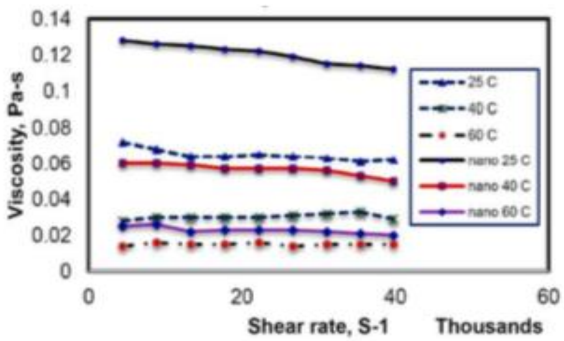

Fig 6: Influence Parameter of Viscosities of SiO2 Nanofluids

For nanocellulose nanofluids, the shear dependence of viscosity is usually subjected to 2 distinct stages. The moment when shear rates are low, viscosities decrease linearly with shear rates within the 1st stage, suggesting a pronounced shear-thinning behavior. As shear rates increase, a transition happens at the second stage; i.e., shear viscosities increase with shear rates. It's believed that nanocellulose is rearranged to create the ordered networks once again and leads the viscous property to recover. Moreover, the viscousness of nanofluids will increase with increasing NP concentration and brine salinities. The kind of NPs conjointly affects the viscousness of nanofluids. At the identical concentration, the viscousness of the SiO2 nanofluid is more than that obtained by the Al2O3 nanofluid. Iron Ferric or ferrous oxide can also increase the viscousness of the injected fluids inflicting the rise within the sweep potency.

3.1.1.3 IFT Reduction

Recently, some experiments were conducted to check the IFT values between fossil oil or crude oil and various metal nanofluids. For example, Adel et al. compared the consequences of SiO2 and Al2O3 nanofluids on IFT at ambient pressure and temperature. They found that the IFT clearly decreased the moment when either of them was made to dissolve in into brine. The SiO2 nanofluid had a lower IFT value than the Al2O3 nanofluid. Therefore, SiO2 nanofluid had the potential to provide additional oil from reservoirs. Alomair et al. furthered to check the power of 3 NPs (Al2O3, SiO2 and NiO) to cut back IFT between the fossil fuel and nanofluids. They found that the SiO2 NPs resulted within the lowest IFT value and NiO had all-time low reduction on IFT. The most important reason for the IFT reduction is high adsorption of NPs and NiO had all-time low reduction on IFT and it modifies oil and water surface.

3.1.1.4 Preventing Asphaltene Precipitation

Some Enhanced Oil Recovery techniques, like carbon dioxide miscible flooding, could cause vital asphaltene precipitation because of special reservoir conditions, that results in wettability alteration, formation permeability reduction, and transportation pipelines blockage, etc. Therefore, a way to prevent asphaltene precipitation is important for these Enhanced Oil Recovery techniques to enhance oil recovery. Some researchers verified that NPs have the tendency to solve the asphaltene issues effectively and not cause environmental hazards (Figure 4d). For instance, Abu Tarboush and Husein found that NPs had the ability to stabilize asphaltene precipitation. From the data gained, Alomair et al. tested the mixed SiO2-Al2O3 nanofluids on asphaltene precipitation and ascertained that because the nanofluid concentration showed inflation, asphaltene precipitation was delayed more. Recently, Kazemzadeh et al. conducted a number of experiments to work out on how SiO2, NiO, and Fe3O4 NPs prevented asphaltene precipitation by a micromodel. Some studies have investigated the results of assorted factors, like asphaltene and water content, temperature and contact time on the asphaltene adsorption onto NP surfaces. The results showed that the extent of asphaltene adsorption onto the NPs enhanced with increasing the contact time. Actually, massive amounts of asphaltene were adsorbed onto the NP surface in a very short amount of time . The asphaltene adsorption was inflated with the rise of asphaltene content and also with the decrease of temperature and the quantity of existing water.

3.2.1 Nanoemulsions

A nanoemulsion is that type of quite emulsion that's stabilised by NPs, that demonstrates a nice ability to beat the challenges encountered with standard emulsions stabilised by surfactants or colloidal solids. Actually, nanoemulsion drops fall within the same droplet lengthscale as a microemulsion, however they're a kinetically controlled system which will retain their morphology with the amendment in oil volume fraction. Therefore, nanoemulsions will stand up to harsh conditions (high temperatures, pressures, shear and salinity) to stay stable in reservoirs and have a wider application range as compared with microemulsions. Additionally, the high viscousness of nanoemulsion will effectively manage mobility ratio or mobility quantitative relation throughout flooding, which is very important for improving significant oil recovery, instead of polymers that are comparatively giant and have high retention on reservoir rocks. Finally, nanoemulsions are very tiny to penetrate through pore throats without without abundant retention. Therefore, they're suited to large-scale applications in field scales.All these these benefits of nanoemulsion contribute to boost oil recovery and attract good interest for researchers and oil corporations. the foremost generally used NPs for emulsions are Si NPs. The wettability of those NPs are often adjusted by the number of silanol groups on their surface. The NPs are often made deliquescent with high share (over 90%) of silanol groups on the surface, and consequently they tend to form stable oil-in-water (o/w) emulsions. On contrary hand, once the Si particles are solely coated about10% on their surface by silanol groups, they're hydrophobic and yield water-in-oil (w/o) emulsions. moreover, when the nanoparticles are alone part coated with silanol groups(e.g., 70%), they become particles with “intermediate hydrophobicity;” the stable emulsion kind they generate depends on the oil polarity, i.e., formation of o/w emulsions are favored with non-ionic oils whereas w/o emulsions are most popularly used with polar oils. The phenomena of emulsification are determined in some micromodel experiments throughout nanofluid flooding processes. The most important reasons for the impact of NPs on emulsion are mentioned by some studies. pictures obtained by an optical microscope showed that the uniform size of the NPs generate a compact, well-structured mono layer at the aqueous/non-aqueous section interface to create the emulsion is very stable even below high temperatures. additionally, to get w/o or o/w emulsions by exploiting NPs, the Si NPs will be accustomed stabilize critical carbon dioxide in-water emulsion and water-in-supercritical CO2 emulsion. The nanoemulsions will be used for enhancing oil recovery, particularly for CO2 flooding or CO2 sequesteration as a result of they'll maintain stable underneath harsh reservoir conditions.

3.2.3 Nanocatalysts

Compared with coventional catalysts, nanocatalysts have many benefits. Nanocatalysts can be brought to use in order to conduct upgrading in bulky oil reservoirs changing bitumen to lighter byproducts by some chemical reactions. These reactions are known as aquathermolysis. The presence of nanocatalysts, like nickel and iron, catalyzes the breaking of carbon-sulfur bonds among asphaltenes, increasing saturates and aromatics within the bulky oil, which may be represented as follows:

R-S-R (organic sulphur compound) + H2O → CO + H2S + lighter compound

The created CO reacts with water throughout the H2o-gas shift reaction and produces Hydrogen(H). These reactions occur within the temperature range of the thermal ENHANCED OIL RECOVERY processes (200 to 300 °C). The created Hydrogen(H) molecules attack the unstable and unsaturated molecule of oil and manufacture lighter and saturated molecules by means of hydrogenolysis. moreover, one in all the many mechanisms of aquathermolysis is to decrease bulky oil viscousness. Shokrlu et al. found that nickel NPs with concentration of five hundred ppm resulted in viscousness reduction from 2700 mPa• s to 1900 mPa• s. This result of NPs on viscousness was conjointly discovered by Clark et al. after they used metal ionic solutions as catalysts in an aquathermolysis method. The most important reason for this development is that the larger specific surface area of nanocatalysts causes a lot of reactivity compared to micron-sized catalysts. that is to mention, larger the surface area of the nanocatalysts leads to a rise within the contact area of oil with the nanocatalysts and higher interaction between them.

4. CHALLENGES AND OPPORTUNITIES FOR FUTURE RESEARCH

Although NPs are proven to be potential candidates because the agent in several Enhanced Oil Recovery processes, most of them are restricted to laboratory analysis and not appropriate for field scale applications. many challenges still stay before these nano-assisted Enhanced Oil Recovery strategies are often utilized in sensible field applications:

(1) Preparation of nanofluids faces many technical challenges. NPs continuously tend to combine at the results of the strong Vander Waals interactions beneath the tough reservoir conditions. Therefore, the biggest technical challenge is to come up with a homogenized suspension of NPs.

(2) At present, most of the research remains targeted on nanofluid flooding method. The mechanisms of different nano-assisted Enhanced Oil Recovery strategies mentioned during this research paper and also the interaction among NPs, rock properties and initial reservoir fluid throughout these processes don't seem to be clearly understood.

(3)Though some experiments were conducted to check metal NPs and establish their ability as Enhanced Oil Recovery agents. However, the studies that attempt to investigate their benefits over SiO2 NPs still have some divergences among themselves. Moreover, the research on mixture nanofluids continues to be in its early stage. The shortage of enough experimental analysis on nanofluid mixtures hinders their wide application in Enhanced Oil Recovery processes.

(4) Reaching a elementary understanding different nano-assisted Enhanced Oil Recovery strategies requires performing correct calculation and comprehensive modeling, that still remains a challenge. However, it's still lack of appropriate theoretical investigation and mathematical models to accurately describe these processes as the nano-assisted Enhanced Oil Recovery strategies involving complicated procedures and unclear mechanisms.

REFERENCES

1. Xiaofei Sun *, Yanyu Zhang, Guangpeng Chen and Zhiyong Gai: Application of Nanoparticles in Enhanced Oil Recovery: A Critical Review of Recent Progress, 11 March 2017.
2. Dr. Mukul M. Sharma: "A new family of Nanoparticle Based Drilling Fluids"
3. E.M Zeynaly-Andabily, H. Chen, S.S. Rahman: "Management of Wellbore Instability in Shales by Controlling the Physical-Chemical Properties of Muds"
4. Manohar Lal: "Shale Stability: Drilling Fluid Interaction and Shale Strength"
5. Rahul Patel, Abhimanyu Deshpandey, Haliburton; Use of nanoparticles in cementing operations; 14th june, 2011.

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