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A Mini Review of the State-of-the-Art Development in Oil Recovery Under the Influence of Geometries in Nanoflood

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ABSTRACT

The global demand for oil and petroleum products is experiencing a significant increase, while the number of newly discovered oil reservoirs is relatively low. This emphasises the critical need for innovative techniques to enhance the rate of oil recovery in order to meet global demand. The implementation of nanotechnology in enhanced oil recovery (EOR) yields numerous advantages, including cost savings in production and improved oil recovery. Additionally, it is critical to investigate the geometrical behaviour of the reservoir, as this information is vital for determining the maximum oil recovery rate. This review highlights the significance of nanotechnology through the utilisation of various geometries to determine the rate of hydrocarbon recovery. Furthermore, this paper also addresses the obstacles associated with achieving maximum oil recovery and provides suggestions for future research in this field. The review concludes with its key finding, which indicates that an examination of reservoir geometry utilising nanofluid in the presence of electromagnetic waves can significantly improve the rate of hydrocarbon recovery.

1. Introduction

The global economic crisis began in the early 2000s because of a continuous decrease in oil extraction from current fields, coupled with waning interest in discovering new oil reserves. With

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declining production from existing sources and reduced investment in alternative energy development, the global financial downturn commenced around 2000. To overcome these obstacles, the oil industry must develop innovative strategies Increasing oil recovery from existing fields [1]. Conventional oil reservoirs and unconventional oil reservoirs have substantial oil deposits or residual oil in place that requires certain procedures or methods to actualize maximum oil recovery.

Classic oil reserves are well-known and very simple to produce oil from naturally drilling techniques. These reservoirs are made up of three parts: a porous rock formation (reservoir rock) that stores the oil, an impermeable cap rock that traps the oil and an aquifer that provides pressure support. Because of their complicated geological and reservoir characteristics, unconventional oil resources are more difficult to produce. Unlike conventional reservoirs, oil in unconventional reservoirs is trapped in low-permeability rocks, making it difficult for it to flow to the wellbore. Shale oil, tight oil and heavy oil/bitumen deposits are examples of common unconventional oil reservoirs [2].

Oil fields normally undergo 3 production strategies mainly the primary, secondary and enhanced oil recovery which accounts for about 5-15%, 10-15% and 10-20% of original oil in place. The secondary injection, basically water and Immiscible gas injection are basically pressure maintenance methods. The EOR methods are those that change the characteristics of oil and rock by injection chemicals or application of heat. Depending on the reservoir parameters, EOR can recover an additional 10–20% of OOIP [3]. There are three types of EOR:

i. Miscible flooding
ii. Chemical flooding
iii. Thermal techniques

Miscible flooding can be used to recover oil, but it is dependent on various factors, including reservoir characteristics, fluid parameters and injection method. It has been discovered that applying the miscible flooding technique in EOR can recover between 10 and 40% of the OOIP from a reservoir, with higher recovery rates possible in some particular instances [4].

Chemical flooding is a type of EOR in which chemicals are pumped into the reservoir to help transport oil towards the producing wells. Chemical flooding can help recover varying amounts of oil, depending on factors such as the type of chemicals and its concentration, rock and fluid properties and injection strategy. Several studies have demonstrated that chemical flooding can recover between 5 and 20% of a reservoir's OOIP, with some projects even achieving greater recovery rates [5]. Thermal methods entail heating the reservoir to make the crude oil less viscous, allowing it to flow and be extracted more easily. The amount of oil recovered by thermal EOR is determined by various factors, including the type of thermal technology used, the reservoir characteristics and the injection strategy. According to various research findings, thermal EOR can recover between 10% and 70% of a reservoir's OOIP. Although thermal EOR technologies make it easier to extract more oil from reservoirs, they have several drawbacks and restrictions [6].

All the restrictions such as low rate of oil recovery and heavy experimental cost necessitated the development of new, more robust recovery methods; thus, researchers included nanotechnology in the EOR method to determine the maximum oil recovery from production wells. Nanotechnology has demonstrated that it can boost oil recovery by altering reservoir fluid characteristics, making them thicker and making standard EOR procedures more effective [7]. The use of nanofluids in the oil and gas industry has grown significantly over the last decade. By boosting heat transmission and minimizing thermal resistance between the fluid and the reservoir, nanofluids can also be employed to improve thermal EOR procedures such as steam injection. This could lead to higher oil recovery rates [8]. Although the use of magnetic nanoparticles in EOR is still a relatively new topic, it has made significant progress in recent years. Several studies have demonstrated that adding magnetic nanoparticles to the injected fluid significantly increases the amount of oil that can be extracted from the reservoir. As a result, magnetic nanoparticles are a viable technique for future EOR applications [9].

Mathematical modelling is an excellent technique for EOR studies since it has various advantages over experimental studies. Mathematical model provides the prediction of oil recovery in the reservoir and gives the hypothetical explanation of the properties of the oil reservoir which helps in the experimental studies to recover more oil in real condition. In conclusion, mathematical modelling is an important tool for EOR research and it has various advantages over experimental studies. However, an experimental team should support models in order to ensure validity and accuracy. -Engineers and geologists employ advanced reservoir modelling and simulation techniques to determine the maximum oil recovery from a certain reservoir. These models consider reservoir features, fluid behaviour, well placement, production techniques and the use of appropriate recovery technologies [10,11].

The flow geometry in unconventional oil reservoirs is critical to influencing oil recovery efficiency. Unconventional reservoirs, such as shale oil and tight oil formations, have distinct characteristics that necessitate careful attention in order to maximize oil output. The structure and distribution of fluid flow pathways within the reservoir rock is referred to as flow geometry and it has a substantial impact on the oil recovery process [12]. Permeability and porosity distributions in unconventional reservoirs are frequently complicated and heterogeneous. Engineers use complex reservoir simulation models that account for flow geometry and other reservoir parameters to improve oil recovery in unconventional reservoirs. These models aid in assessing the efficacy of various production tactics, including well spacing, fracking design and fluid injection, in order to maximize oil recovery [13].

According to the authors, the structure of the flow in the reservoir can affect how well the injected fluids move. Fluids may flow through the reservoir and around the oil in reservoirs with high aspect ratios, which implies the channels are lengthy and narrow, lowering displacement efficiency. When selecting an effective EOR approach, researchers highlighted the need to understand the geometries of low-permeability reservoirs. They speculated that novel procedures that account for the complex geometries and variances in low-permeability reservoirs may be required to extract the oil [14]. Based on the research reviewed above, an assessment of the impact of nanoflooding utilising different geometries for predicting oil recovery in EOR is required. There are some reviews published in the literature on the uses of oil recovery, but to the best of our knowledge, a review on nanoflooding utilising different geometries has not yet been published, which could attract academics to study this interesting topic. In addition, Figure 1 depicts the review's flow chart.

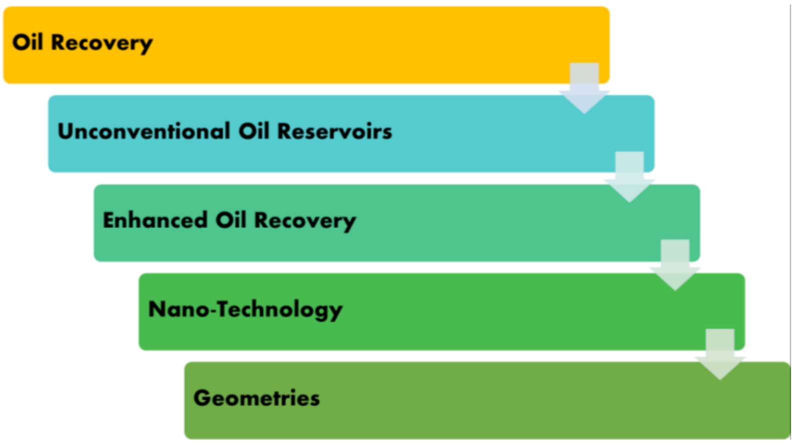

Fig. 1. Flow chart of the review

2. Importance of Nanoflooding in EOR

2.1 Nanotechnology

The amount of energy consumed globally is anticipated to have increased by 50% by 2050 [15]. These forecasts were created prior to the coronavirus pandemic, which had a huge impact on the unanticipated decline in global oil supply. Furthermore, conventional technologies are incapable of recovering the maximum amount of oil from existing reservoirs [16,17]. Because oil supplies were originally regarded as the best energy source for industry, this is a big issue that must be addressed. According to the literature, about 2 million barrels (0.3 million metric tonnes) of crude oil and 5.0 million barrels (0.8 million metric tonnes) of heavy oil will remain in reservoirs following traditional recovery methods [18]. As the global need for energy develops, new methods must be developed to extract as much oil as possible from reservoirs. This needs the development of novel methods for extracting additional oil from reserves [20-24]. To tackle these obstacles, researchers use nanotechnology in EOR to extract as much oil as possible from reservoirs.

In conclusion, Nanotechnology has the potential to increase oil recovery, improve refining catalysis and monitor reservoir parameters in the petroleum industry. These applications can lead to increased efficiency, higher yields and less environmental damage, but further research and development is required to fully reap the benefits.

2.2 Nanotechnology in EOR

Nanotechnology is attractive for improving oil recovery but using it in the oil industry is tough because it has special properties. It makes water less likely to stick to surfaces, helping trapped oil move faster. It also causes sand to stick together more easily and reduces surface tension. Nanoparticles (NPs) have unique chemical, thermal and physical traits and are very small, usually between 1 and 100 nanometres in size. Consequently, they provide novel approaches to address challenges in oil production. From 2010 to 2023, approximately a thousand articles have been published on the topic of utilising nanoflooding techniques to enhance oil recovery. Figure 2 illustrates the visual depiction of the published publications.

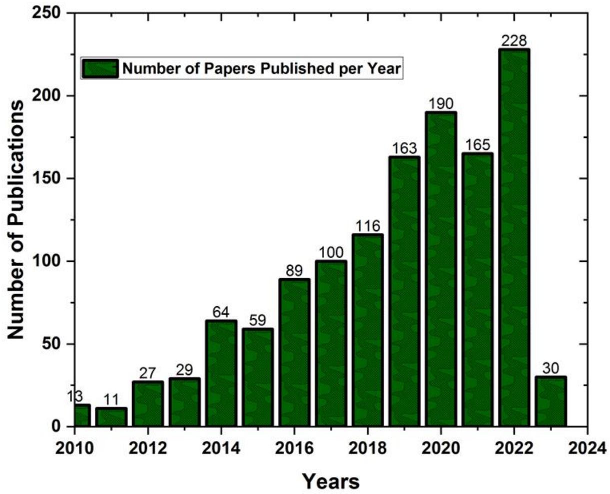

Fig. 2. Publications in EOR that use nanotechnology and their comparison year-wise

According to Figure 2, employing NP is an excellent approach to extracting the maximum amount of oil from reservoirs. Many scientists have used nanomaterials to make thin bitumen and heavy and semi-heavy oils. Experiments show that NP concentration, size and type are all separate parameters that influence how heavy oil loses viscosity [25,26]. NPs have been utilised to regulate mobility in a number of publications; they have performed admirably in decreasing water squeeze, enhancing sweep efficacy and boosting oil recovery [27]. Additionally, microspheres and nanospheres can alter the capillary force and relative permeability of water, changing how water moves through porous media [28]. Also, NPs do not create a negative impact in oil and gas reservoirs with high salinity and temperatures. Adding certain NPs to injection solutions can help EOR in many ways, such as by changing how wet the fluid is, changing how the fluid behaves, making trapped oil move more easily, making sand stick together better and reducing IFT [29].

2.3 Impact of Nanofluids

The use of nanofluids in the oil and gas industry has seen significant growth in the past century. Nanoparticles (NPs) in nanofluids can reduce the interfacial tension (IFT) between oil and water, promoting easier fluid flow and enhancing oil recovery rates. They also help decrease the amount of trapped oil in reservoirs, facilitating more efficient extraction. NPs mitigate capillary forces that retain oil in reservoirs and seal small pores in the reservoir matrix, improving fluid sweep efficiency. Additionally, nanofluids aid thermal enhanced oil recovery (EOR) methods like steam injection by enhancing heat transfer and reducing thermal resistance between the fluid and reservoir, thereby boosting oil recovery rates [30-32].

In further studies, the effect of NP dispersions on base fluid viscosity was observed [33]. The effective dispersion of NPs was seen to enhance the viscosity of the base fluid. In a Newtonian fluid, the viscosity is set by the fluid's composition, pressure and temperature. NPs may be able to change an emulsion's rheological properties from a Newtonian fluid to a non-Newtonian fluid, where the viscosity changes depending on the flow conditions [34-37]. The apparent viscosities of non-Newtonian fluids can be larger or lower than the viscosities of their constituent fluids. The process of making a non-Newtonian fluid with a higher viscosity in situ may lead to a higher sweep efficiency than the injected fluid because of the trapped oil emulsification [34,38,39]. According to the preceding section, the use of nanofluids in EOR is very effective and nanofluids have the potential to boost the oil recovery rate from reservoirs. The increase in oil recovery is attributable to the following features of the nanofluids, which are detailed in the next section.

2.3.1 Mobility ratio

The speed of water in relation to the speed of oil is one of the most crucial aspects of how successfully a flood operates. When mobility exceeds one, it is disadvantageous because water in the porous medium is more mobile than oil; injected water tends to bypass oil, the oil producing wells experience early water breakthroughs. Because water has a lower mobility ratio than oil, it may be displaced and recovered more efficiently. The fluid mobility ratio varies dramatically when NPs are added to a reservoir. As a result, it has been determined that the use of NPs reduces the mobility ratio, allowing for maximal oil extraction [40,41].

2.3.2 IFT reduction

One of the most critical elements determining how fluids travel and spread in porous media is the IFT of crude oil and injected fluid [42]. When IFT is lower, more oil may be extracted from reservoirs. Nanofluids have the unique potential to minimise crude oil IFT and increase oil flow in reservoirs, making their use critical for reducing IFT. Some NP types used for nanofluid flooding in EOR may benefit from IFT lowering [43,44].

2.3.3 Wettability

Wettability is the natural tendency of a liquid to spread on a solid surface. It's important in EOR because it affects the interactions of solids (rock) and liquids (crude oil, brine) in reservoirs. It has been discovered as a crucial factor influencing the amount of residual oil [45]. Researchers Al-Anssari *et al.,* [46] studied the wettability of carbonate rocks using silica nanofluid and observed that they could change the wettability of calcium carbonate surfaces so that they became strongly wet. Tawfik [47] discovered that the pressure gradient inside the nanofluid boosted its wettability by using NPs for fluid dispersion. They discovered that structural disjoining pressure causes enhanced nanofluid spreading, while NP adsorption on the rock surface causes decreased friction.

2.3.4 Rheology

Rheology is the study of the deformation and flow of materials. The rheological characterization of materials offers a comprehensive picture of the viscoelastic flow behaviour of the system [48]. Because rheological reactions are directly related to the final structures of the system, rheology is well known to be incredibly significant for all materials. Understanding a nanofluid's framework is further aided by studying its rheological behaviour [49]. They are indispensable for devising injection fluids for EOR applications and determining the optimal concentrations thereof. It is possible to precisely predict the viscoelastic behaviour of injectants in order to maintain the required mobility ratio in porous media and prevent the viscous cupping phenomenon [50].

2.4 Nanofluid Imbedded in Porous Medium

A nanofluid consists of nanoparticles (NPs) suspended in a base fluid (the liquid phase) to form a two-phase system. Due to their minuscule size and light weight, NPs are buoyant in fluids and defy the force of gravity. Brownian motion enables them to navigate the fluid medium at random. When dealing with weighty particles, a range of surfactants are employed to enhance the suspension of the particles in the base fluid. The totality of the van der Waals forces between them and their Brownian motion randomness determine the stability of NPs. This characteristic is crucial in establishing its significance in fluid formation. When the repulsive forces surpass the attractive forces, particle stability is enhanced and agglomeration is prevented [51,52].

By altering the charge density and zeta potential of the particles, the researchers can stabilise the dispersion in the reservoir. To attain stability, surface coating refers to the process of modifying the surface of NPs. As the nanofluid is injected into the porous medium, a reduction in nanoparticle concentration is caused by a number of mechanisms [53]. NPs remain in porous media because they adhere to the walls of the pores and clog the throats of the pores. NPs can block pore throats in two ways: mechanical entrapment (when nanoparticles are larger than pore throats) and log jamming (when nanoparticles pile up). In the pore channels, the pore throat acts as a bottleneck. As the fluid gets closer to the bottleneck, its speed increases because the flow area shrinks and the pressure rises. Because small molecules of fluid flow faster than nanoparticles, the particles will congregate at the pore's opening [54]. A sensitivity analysis using the reservoir's features determines the factors that affect the flooding of nanofluid in porous media and the reservoir. Each of these factors is discussed in detail in the subsections that follow.

2.4.1 Nanoparticle concentration

The quantity of NPs in the nanofluid has the most significant influence on its ability to be injected into permeable media in order to produce more oil. When NP concentrations exceed a specific threshold of 3%, they remain within porous media, resulting in a reduction in the medium's porosity and permeability due to obstruction of pores and throats [55,56]. In addition, as the quantity of NPs increases, disjoining pressure and Brownian motion also increase. This is because the interparticle forces are strengthening, which leads to a more noticeable change in wettability .When the concentration of NPs goes above the optimal concentration, there will be a higher permeability reduction factor instead of a wettability change, which results in a lower recovery factor [18].

2.4.2 Nanoparticle size

The particle size of NPs should not be excessively large to obstruct pores or become entangled in them, nor too small to cause excessive obstruction. The particle charge density, which is dependent on the particle size, affects the discontinuous pressure. The charge density will be greater for smaller particle sizes, resulting in more pronounced electrostatic repulsion between the particles. Nanoparticles also have an impact on disjoining pressure, in addition to size and charge density. As previously mentioned, as the particle sizes decrease, so does the repulsion force and, as a result, the disjoining pressure between them increases. Although this is the case, particles aggregate more rapidly when they are extremely minuscule. No NPs should be excessively small to cause obstructions or entrapment. As a result, it can be concluded that the size of NPs is crucial in determining the optimum oil recovery rate in EOR [9,57].

2.4.3 Salinity

In porous media, salinity is one of the most significant factors influencing nanofluid transport. In general, NP stability decreases with increasing salinity. An elevation in salinity induces colloid agglomeration, colloidal instability and an increase in the zeta potential of NP. A decrease in Zeta's potential results in an increase in salinity and changes the mass of the solution to colloidal. This is due to the fact that the functionality and stability of disjoining pressure in this environment are preserved due to the absence of modification of NPs [58]. This can be done by changing the particle's surface or adding a surfactant to change the ionic environment and the density of the surface charge. A salinity increases of 10% or greater in nanofluid has no discernible impact on the mobility of NPs; however, it facilitates their adsorption by pebbles. This can be done by changing the particle's surface or adding a surfactant to change the ionic environment and the density of the surface charge. A salinity increases of 10% or greater in nanofluid has no discernible impact on the mobility of NPs; however, it facilitates their adsorption by pebbles [18].

2.4.4 Temperature

Because the temperature inside the reservoir is higher than the temperature on the surface, the nanofluid should be optimized for the conditions of the reservoir before it is injected into the field reservoir. As the temperature goes up, the zeta potential goes down. As a result, NPs colloids get bigger and less stable. The temperature has a very small effect on the retention of NPs on the surface; as a result, there is a slight reduction in the amount of oil that can be recovered. Researchers studied the effect of the temperature in the reservoir and found that as the temperature increased, there was a general upward trend in the displacement efficiency as well as the recovery rate caused by nanofluid injection. This may be the result of a decrease in the IFT or an increase in the intensity of Brownian motion, as well as a reduction in viscosity and particle size as a consequence of an increase in temperature [9].

2.4.5 Size of rock in reservoir

To determine the recovery rate in nanofluid transport, it is necessary to first understand the effect of rock size during the flooding process. NPs may adhere to rocks in various ways, depending on the size of the rock grains. The area of the porous medium's surface is proportional to the grain size. The surface area per unit bulk volume decreases as rock grains become larger. The area of the surface of the porous medium is related to the grain size. If rock grains are larger, it results in a decrease in the surface area per unit bulk volume. The porosity of a larger grain size is greater than that of a smaller one. When the reduction in surface area per unit bulk volume decreases, the retention of the NPs on the rock also decreases. Also, mechanisms like naturally occurring fine entrainment and redeposition can cause abnormal productivity decline [59].

2.4.6 Injection rate

Particle retention in the pores of NPs flowing through porous media has been classified into two types: pore surface deposition and pore throat blocking. The two most common causes of pore throat blocking are mechanical entrapment and log jamming (accumulation). It happens when a single particle is bigger than the pore throat. Bridging occurs when two or more particles become trapped at the pore throat. Throat blockage and bridging plugging are stochastic in nature and cause some of the throat to close off flow. As the injection rate increases, smaller molecules of water accelerate faster than NPs, causing the NP to assemble and block the pore throats. As a result, as the injection rate increases, the effect of nanofluid injection on oil recovery is expected to diminish as NPs assemble at the pore throat. As a result, absolute permeability decreases further and the recovery factor decreases [19,60,61].

2.4.7 Base fluid

In EOR, NPs can be mixed with many different base fluids, such as water, saltwater, ethylene glycol and different gases. Depending on the properties of the NPs and the base fluid, the nanofluids that are made can have a stable suspension, better thermal conductivity, more pressure to separate the particles or a different viscosity [8,62]. The rheological properties of nanofluids demand a thorough understanding of base fluid properties, particularly the mechanisms involved in multiphase flow properties in microporous structures. The interactions of NPs among themselves and between nanoparticles and base fluid describe the stability of NPs in base fluid. The results show that there is a difference in recovery when water or gas is used as the base fluid versus water alternating with gas [63].

In conclusion, to find out oil recovery using nanofluid transport in porous media, the concentration of NPs, size of NPs, salinity, temperature of the reservoir, size of the rock in the reservoir and the use of base fluid are very important and to obtain maximum oil recovery, these factors must be investigated very carefully.

2.5 Benefits of Nanofluids in EOR

Nanofluids are a new type of fluid made up of NPs that are spread out in a base fluid. In the last few years, scientists have investigated the use of nanofluids in EOR. From the above literature, here are some reasons why using nanofluids in EOR is a smart choice:

i. Improved fluid mobility: NPs in nanofluids can lower the IFT between oil and water. This makes fluids move more easily and increases the amount of oil that can be recovered. Reducing the amount of oil left in the reservoir: NPs in nanofluids can also lower the amount of oil left in the reservoir, allowing for more oil to be recovered. This is because NPs can lower the capillary forces that hold oil in the reservoir.
ii. Reduced fluid loss: NPs in nanofluids can also reduce the amount of fluid that leaks into the reservoir matrix. This makes the sweep more effective and increases the amount of oil that can be recovered. This is due to the ability of NPs to plug the small pores in the reservoir matrix.
iii. Enhanced thermal recovery: Nanofluids can also be used to improve thermal EOR methods like steam injection by making it easier for heat to move through the fluid and into the reservoir and by lowering the thermal resistance between the fluid and the reservoir. This can result in higher oil recovery rates.

In order to get a better understanding, Table 1 summarizes the recovery rate obtained by the researchers using nanofluid injection.

Table 1
Oil recovery rate using nanofluid injection

Ref	Year	Oil recovery
[64]	2020	Oil recovery increases to 26%
[65]	2020	The use of SiO_2 nanoparticles suspensions is recommended for oil recovery.
[66]	2020	The oil recovery increase to 15.74% at 100mg/L.
[67]	2020	The oil recovery increase to 24%.
[68]	2020	Additional 12-14.5% oil recovery obtained.
[69]	2020	The oil recovery increase to 10.39-13.08%.
[70]	2021	The optimum oil recovery factor increases to 19%.
[71]	2022	Oil recovery increases from 48.96 – 64.14%
[72]	2022	Oil recovery increases to 15-20%
[73]	2022	The oil recovery increase to 17.2% at 100mg/L.
[74]	2022	The oil recovery increase to 13.8 – 21.6%.

From Table 1, it is observed that the use of nanofluids provides maximum oil recovery, which is very important for the oil and gas industry and attracts researchers to focus their work on using nanofluid injection to find out the way to obtain maximum oil recovery, which is the major challenge now. In conclusion, the use of nanofluids in EOR can offer several benefits, including improved fluid mobility, reduced residual oil saturation, reduced fluid loss and enhanced thermal recovery. These benefits make nanofluids a promising area of research in EOR.

3. Impact of Geometries in EOR

Researchers employed various geometries such as 2D rectangular, hexagonal prism, 3D hexagonal prism, cylindrical and anti-cline shapes in nanofluid flow simulations to predict oil recovery in reservoirs under different boundary conditions and parameters. They discovered that utilizing 3D geometries in heterogeneous models yielded more accurate predictions of oil recovery. different geometries like, 2D rectangular, hexagonal prism, 3D hexagonal prism, cylindrical and anti-cline geometry using nanofluid flow to predict the oil recovery in the reservoirs at different boundary condition and at different parameters and find that the use of 3D geometries at heretogas model provides better oil recovery prediction [75-80]. Figure 3 to Figure 10 provides the details of different geometries along with their mesh analysis which are used to predict the oil recovery rate.

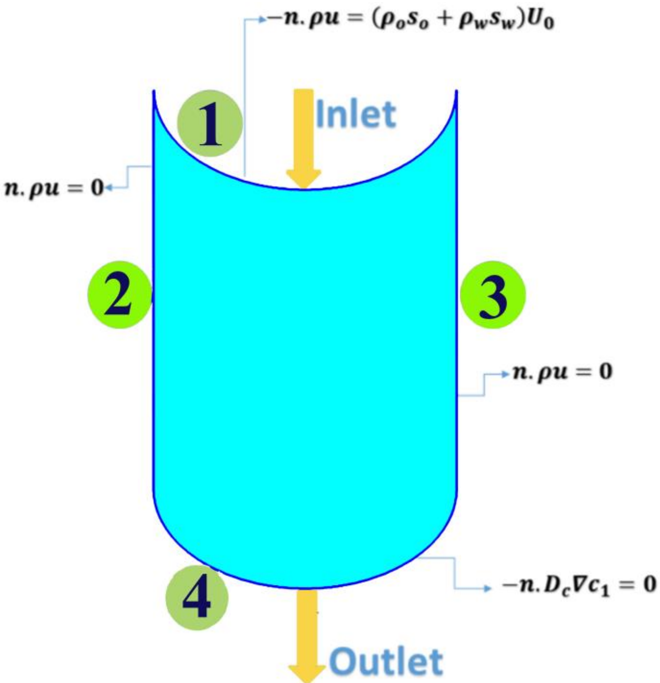

Fig. 3. Anticline geometries used in nanoflooding to predict oil recovery [81]

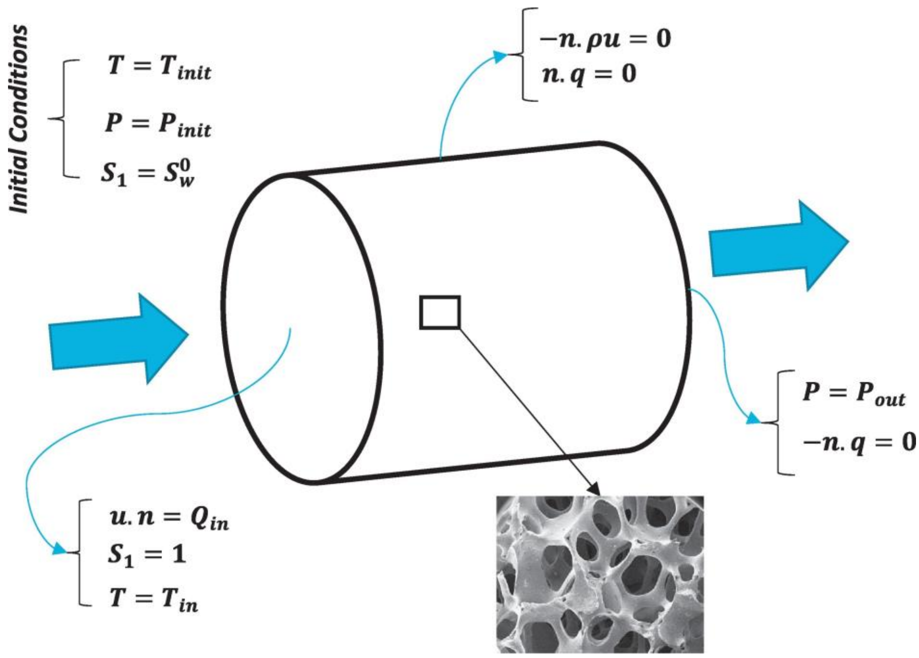

Fig. 4. 3D cylindrical geometries used in nanoflooding to predict oil recovery [82]

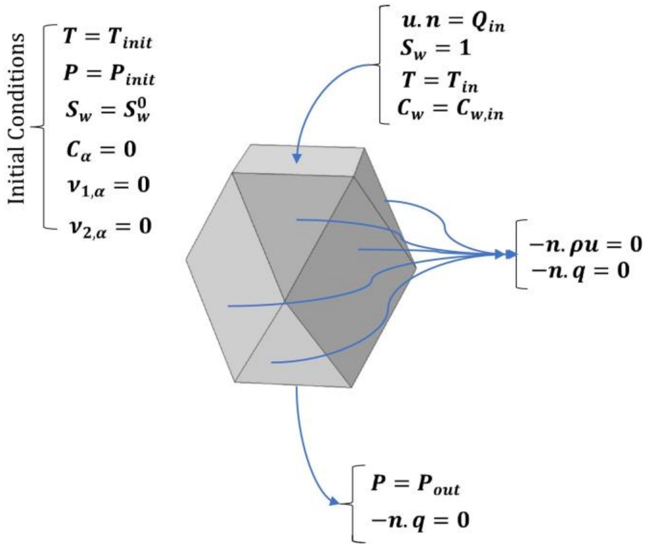

Fig. 5. 3D geometry with boundary condition used in nanoflooding to predict oil recovery [83]

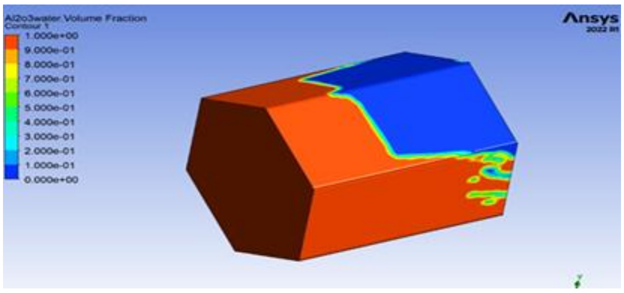

Fig. 6. 3D hexagonal prism used in nanoflooding to predict oil recovery [75]

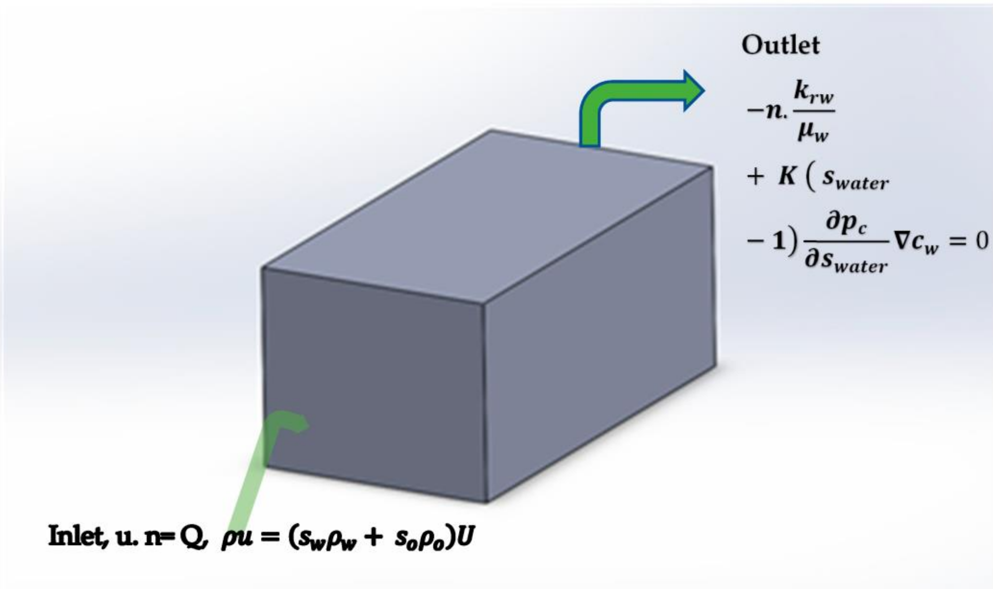

Fig. 7. 3D rectangular prism used in nanoflooding to predict oil recovery [77]

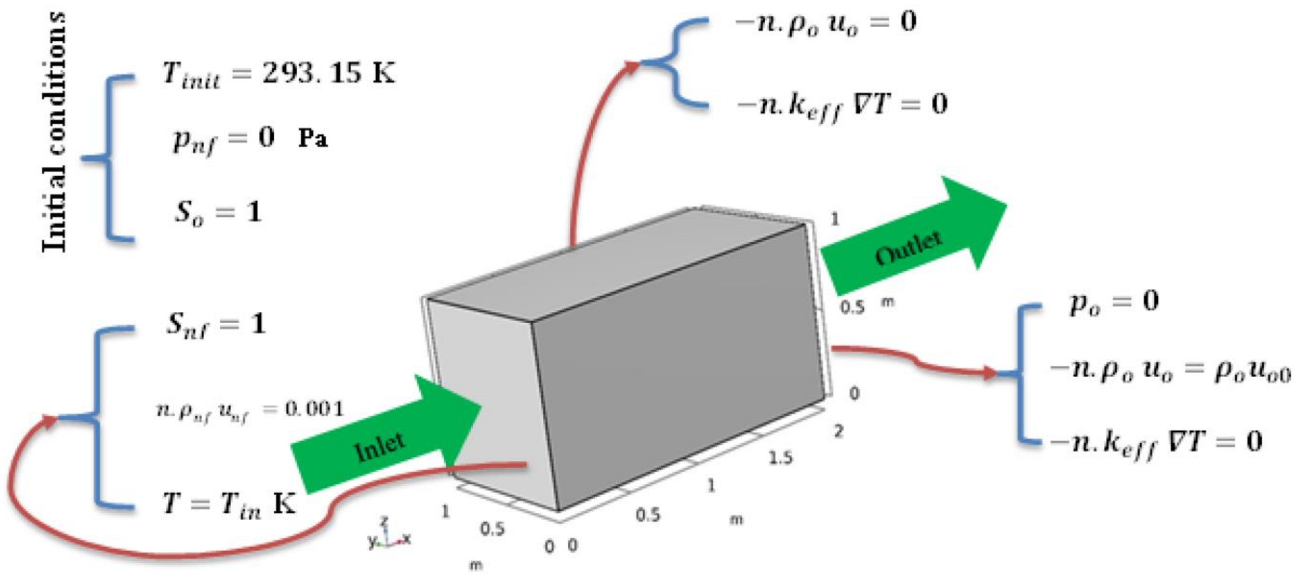

Fig. 8. Rectangular geometries used in nanoflooding to predict oil recovery [80]

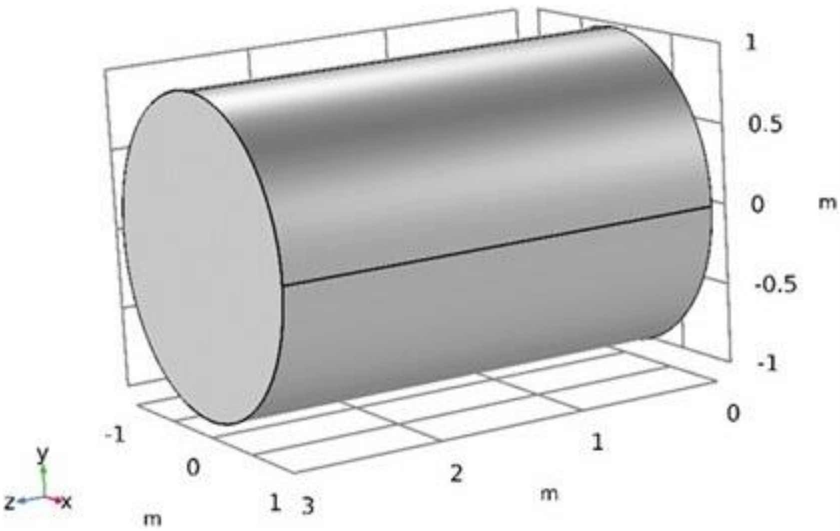

Fig. 9. Different geometries used in nanoflooding to predict oil recovery [78]

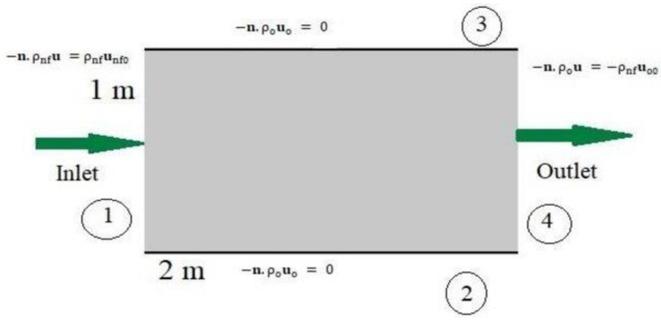

Fig. 10. 2D geometry used in nanoflooding to predict oil recovery [84]

From Figure 3 to Figure 10, in EOR, the word "geometry" refers to the physical properties of the reservoir, like its porosity, permeability and heterogeneity. These shapes can have a big effect on how well the EOR method being used works. Here are some of the effects of geometries in EOR.

i. Porosity: The reservoir's porosity is the amount of empty space in the rock that can hold fluids. High-porosity reservoirs can hold more fluid and are therefore better suited to EOR methods like water flooding or gas injection. Using complex geometries, we investigate the effect of porosity in the reservoir and how it can increase oil recovery.
ii. Permeability: The reservoir's permeability is how easy it is for fluids to move through the rock. High-permeability reservoirs are better for EOR methods like water flooding or gas injection because fluids can get in and out of them more easily. Permeability has a major impact on the reservoir geology. Using complex geometries, we can investigate the flow of oil in the reservoir and increase oil recovery. The reservoir geology is highly affected by permeability. Using complex geometries, we investigate the flow of oil in the reservoir and can increase oil recovery.
iii. Heterogeneity: refers to the variations in porosity and permeability within the reservoir. Highly heterogeneous reservoirs may require tailored EOR methods to account for the variations in fluid flow behaviour. It is also useful to have a 3D-shaped reservoir geometry, which helps to increase the heterogeneity of the reservoir and, as a result, allows for more oil to be recovered.

4. Challenges in EOR

The flow geometry of unconventional reservoirs is of paramount importance in oil recovery due to its ability to regulate fluid movement within the reservoir and impact oil extraction efficacy. A range of flow geometries, including complex, radial and linear configurations, influence the behaviour of fluids within the reservoir rock. This impact is also evident in variables such as pressure distribution, sweep efficiency and flow rates. Unconventional reservoirs differ from conventional reservoirs in that they present unique challenges for oil recovery due to their complex geometry. Hence, it is critical to understand and efficiently handle the intricate geometry of unconventional reservoirs in order to maximise oil recovery. Sustained investigation, in conjunction with technological progressions and enhanced methods of reservoir characterization, continues to be imperative in order to optimise oil extraction from these invaluable yet complex resources.

5. Future Recommendations

Based on the analysis, the subsequent suggestions are made regarding prospective research in the field of oil recovery:

i. In order to optimize the rate at which oil is recovered, it is imperative to thoroughly examine the physical attributes and behaviour of the reservoir. As a result, forthcoming research ought to concentrate on examining the intricate geometry of nanofluid flow in order to determine the reservoirs with the greatest potential for oil extraction.
ii. Furthermore, it has been noted that the incorporation of electromagnetic waves in conjunction with nanofluid flow has the potential to increase the rate of hydrocarbon recovery. As a result, subsequent investigations ought to investigate the effects of electromagnetic waves on the characteristics of fluid flow within the reservoir, given the potential efficacy of such a strategy.

6. Conclusion

In this paper, we provide a state-of-the-art review of the development of nanoflooding using different geometries in EOR. The main results of the review are as follows:

i. The utilization of nanofluid increases the fluid velocity within the reservoir, hence augmenting the extraction of oil.
ii. The presence of nanoparticles inside the reservoir geometry enhances the permeability of both oil and water, resulting in optimal oil recovery.
iii. Furthermore, it has been noted that the utilization of nanofluids within the porous medium enhances oil recovery by an additional 10-15% compared to alternative recovery techniques.
iv. Utilizing complex boundary conditions in heterogeneous reservoirs enhances the pace of oil extraction.

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