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Nanotechnology and Nonmaterial Applications in Oil Industries in Recent Years: A Review

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A B S T R A C T

Several disciplines recognize nanotechnology's revolutionary potential, including nanoelectronics, nanobiomedicine, and nanodevices. Surprisingly, the oil and gas industry's upstream exploration and production sector has shown limited enthusiasm. Increased oil recovery and the use of unconventional resources are vital for success, but recessions, particularly during low crude oil prices in the 19th century, pose additional challenges. In response, significant attention has turned to applying nanotechnology to overcome these industrial barriers. Recently, government agencies and the global oil sector have boosted investments in exploration, drilling, production, treatment, and wastewater management. Notably, nanosensors provide precise reservoir monitoring, while nanofluids with advanced nanoparticles significantly enhance oil production. Moreover, nanocatalysts have improved the efficiency of petrochemical and oil refining operations. Research found that using CNTs and Iron Oxide at specific weight ratios yields the highest Oil Recovery Factors of 31% and 28%, respectively. Additionally, nanomembranes facilitate the efficient separation of oil, water, and air, aiding in the purification of oil and air while removing contaminants from wastewater. Functional nanomaterials are also driving a shift in device design and manufacturing, ensuring more innovative, reliable, and durable products. This article examines the latest advancements in nanotechnology and potential nanomaterial applications in the petroleum sector. Collaborative research and infrastructure investments are paving the way for transformation. As technology progresses, it holds the potential to make processes more efficient, cost-effective, and environmentally sustainable.

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1. Introduction

Since 2014, when there was an excess of oil, the world has faced a price crisis. As a result, several countries have chosen to reduce production or even close industries when costs become too high to sustain operations. Colombia is among these nations. Due to investments in new techniques and technology, the Colombian oil and gas industry has been transformed to enhance transportation and production efficiency. Because of their minimal size (ranging from 1 to 100 nanometers), nanotechnology has recently become an intriguing area of research in oil and gas as well as the extra danger of pore obstruction, hence avoiding formation damage. At the nanoscale, remarkable properties such as dispersibility, excellent thermal and chemical stability, and a high surface-area-to-volume ratio become attainable.

As particle size decreases, surface functional groups are less inhibited, significantly enhancing the reactivity of particles with nanometric dimensions. In other words, because the surface atoms of nanomaterials are not surrounded by other surface atoms, they are free to interact with other molecules [1]. The field of nanotechnology was established in the late 1980s, it has been dedicated to developing new platform technologies to tackle challenging problems. Nanotechnology has integrated numerous scientific fields, including chemistry, biology, electronics, mechanics, physics, and materials science. Nanomaterials' distinctive optical, electrical, and mechanical characteristics of particles, rods, sheets, or crystals with sizes between 1 and 100 nm make them useful in various industrial contexts. Investigating the physical properties of novel nanomaterials explores opportunities to develop ideas and hypotheses that expand the boundaries of knowledge in both scientific and technological fields. Leveraging the unique properties of nanomaterials has enabled significant advancements and enhanced performance across a range of fields, such as microelectronics, manufacturing, biology, chemistry, energy, and agriculture [2–4]. Nanomaterials, which became achievable by the rise of nanotechnology as a key driver in interdisciplinary research, offer potential solutions for the oil and gas industry to address real-world challenges in oilfield development, especially in improving recovery efficiency. During the last five years, the oil and gas industry has demonstrated an increased interest in nanotechnology. Research on the practical applications of nanotechnology in improved oil recovery has been extensively documented in many publications and reviews [5, 6]. Researchers have studied the mechanisms of enhanced oil recovery (EOR) and investigated how nanochemistry, particularly the use of polymer-coated nanoparticles, influences its effectiveness [7]. Oil companies are increasingly investing resources in the research and development of nanotechnology. These efforts are being carried out both in the organization as well as in collaboration with educational institutions. In 2008, corporations like Schlumberger, TOTAL, Shell, and BP, among others, joined forces to establish the Advanced Energy Consortium (AEC) to collaborate with research institutes to develop and implement nanotechnology in the oil and gas industry.

Additionally, ExxonMobil, Chevron, and Halliburton are actively exploring nanotechnology both in laboratory settings and through oilfield application studies. These companies are researching to advance the use of nanotechnology in the industry [8]. Nanofluids for EOR utilize the unique properties of nanoparticles to improve oil recovery, though challenges related to nanoparticle retention must be addressed. In refining processes, nanocatalysis holds the potential for increasing catalytic activity, but the safety and stability of nanoparticles are critical considerations. Nanoparticles used for oil spill remediation provide effective cleanup solutions, but sustainable disposal methods remain an ongoing research attention. Nanomaterials designed for corrosion protection aim to extend equipment lifespan, though ensuring compatibility with existing coatings can present challenges. Nanoparticle-based sensors offer the advantage of real-time monitoring, but ensuring reliable performance requires careful attention to calibration and maintenance. The industrial applications of molecular nanomaterials are outlined in Table 1, which provides a summary of the information.

Table 1: The industrial use of molecular materials summarized.

Manufacturing	Molecular Nanomaterials	Options	Ref.
Construction Industry	Nano-TiO_2 CNT, nano-MgO, nano-smectite-based clay	Increase cement sample photocatalytic properties. To strengthen cement composite.	[9] [9,10]
Textile Industry	Nano-TiO_2, nano-ZnO	More effectively absorbing and dissipating UV radiation.	[11]
	CNT-reinforced polymer composite fibers	Reduce weight and increase strength.	[12]
Water Treatment Industry	CNTs	Industrial wastewater biological treatment.	[13]
Agriculture Industry	Carbon nanotubes, nano oxides of Cu, Ag, Mn, Mo, Zn, Fe, Si and Ti	Develop nanopesticides and nanofertilizers	[14]
Food Industry	ZnO nanoparticle with polystyrene film	For food packaging	[15,16]
	Silver nanoparticles and nanocomposites	Improved food safety with antibacterial agents	[15,16]
Aeronautics Industry	Fe_3O_4 nanopowders	Making multifunctional structural composites	[17]
Medicinal Industry	siRNA containing nanoparticles	To enable genetic disease and cancer drug delivery systems	[18]
Environmental Industry	TiO_2 and ZnO nanoparticles	Used to degrade air and water organic pollutants.	[19]
Cosmetics Industry	TiO_2 and ZnO nanoparticles Polycaprolactone (PCL) nanocapsules	Sunscreen non-prescription drugs. Encapsulate cosmetic ingredients.	[20] [20]
	Silver nanomaterials	Consumer product preservative.	[20]
Machinery Industry	Nano-titanium nitride	Boost material strength, hardness, and fracture toughness.	[21]
Oil and Gas Industry	Air-suspended Ni-Fe nanoparticles	Injected into hydrate formation to penetrate cavities and penetrate the reservoir.	[22]
Computer Industry	Nanotube/carbon nanotube	Nanotubes are used to make smaller transistors and electronics.	[23]
Medicine and Computer Industries	Fullerene	Fullerene is particularly useful for controlled drug release for cancer and other diseases. It's helpful in solar cells, diodes, and semiconductors. Fullerene may be used in nanomedicine and pharmaceuticals.	[24–28]

Using developed nanoparticles is one of the available and effective methods that can be used to explore and identify hydrocarbons in petroleum reservoirs through various procedures and mechanisms, as stated in Table 2. Utilizing nanoparticles can lead to significant improvements in photo contrasts and sensors by altering their optical, electrical, and magnetic properties. These nanoparticles can be considered excellent instruments compared to their "bulk counterparts," which are nanoparticles that have not undergone any changes. Both El-Diasty and Ragab (2013) and Rezaeyan *et al*. (2018) come to the same conclusion [30,32]. More specifically, using nanosensors within the pore spaces of nanodusts can provide valuable information about reservoir characterization, fluid flow monitoring, and fluid type identification.

Table 2: Synopsis of the applications of nanotechnology in the fields of exploration and reservoir characterization.

Nanomaterial	Determination	Ref.
Superparamagnetic iron oxide (SPIO) NPs	Self-confirmed, targeted tumor MR imaging is possible.	[29]
Nano-optical fiber	It detects oilmicrobes and reservoir pressure and temperature.	[30]
WO_3 NPs-based sensor	It selectively measures H2S concentrations from 0 to 200 ppm with a detection limit of 1 ppm.	[31]
Hyperpolarized silicon NPs	An innovative nanosensor measures and images hydrocarbon reservoirs.	[32]
Magnetic (Fe_2O_3) NPs	It detects fracture, fluid contact, hydrocarbon bypass, and flood front.	[33]

This report examines recent advances in nanotechnology, highlighting relevant innovations in processes essential to oil and gas production. Upstream drilling, well completion, manufacturing processes, nanomembrane separation, water treatment, and the role of water in flooring are some of the essential topics discussed in the report, which address a broad audience of readers.

2. Nanomaterials in Oil Industry Applications

Nanotechnology is a relatively new and precise technology performing operations at the nano-scale. From the Latin term, we get the word "nano," which translates as "dwarf." The nanometer equals 103 millionths of a meter, 1n = 109 meters. Nanometers are the most minor units of a given unit [34]. In enhanced oil recovery (EOR), nanoparticles (NPs) have many benefits, however, instability, agglomeration, and aggregation can block pore channels and induce rapid sedimentation, leading to limited oil recovery. NP surface modification can address these challenges, and a detailed overview of the leading modification techniques and their impact on both the efficiency of enhanced oil recovery (EOR) and the microscopic properties of NPs is essential to inform future research [35]. Due to utilizing nanoparticles as carriers for both small and large molecules, the development of nanotechnology has garnered substantial scientific attention over the past ten years. A wide variety of polymers is used in the production of nanoparticles. As nanotechnology continues to evolve, it will give rise to nanomaterials with advanced properties and functionalities, improving the life quality of people in various aspects, such as public health, environmental protection, electronics, and beyond. These advancements will have a significant impact across multiple areas [34, 35]. Nanomaterials have transformed the oil industry by offering innovative solutions across various sectors. Their unique properties and adaptability have greatly improved drilling, completion, oil recovery, and environmental practices within the industry [91, 92].

2.1 Enhanced Drilling and Completion

Nanomaterials serve multiple functions in drilling and completing operations, especially in challenging environments or complex formations like high-temperature deep wells. Their versatility enables the achievement of multiple objectives simultaneously. The inclusion of nanomaterials in drilling and completion fluids provides several advantages, enhancing overall performance and efficiency [36]. Fig 1. summarize the enhancement:

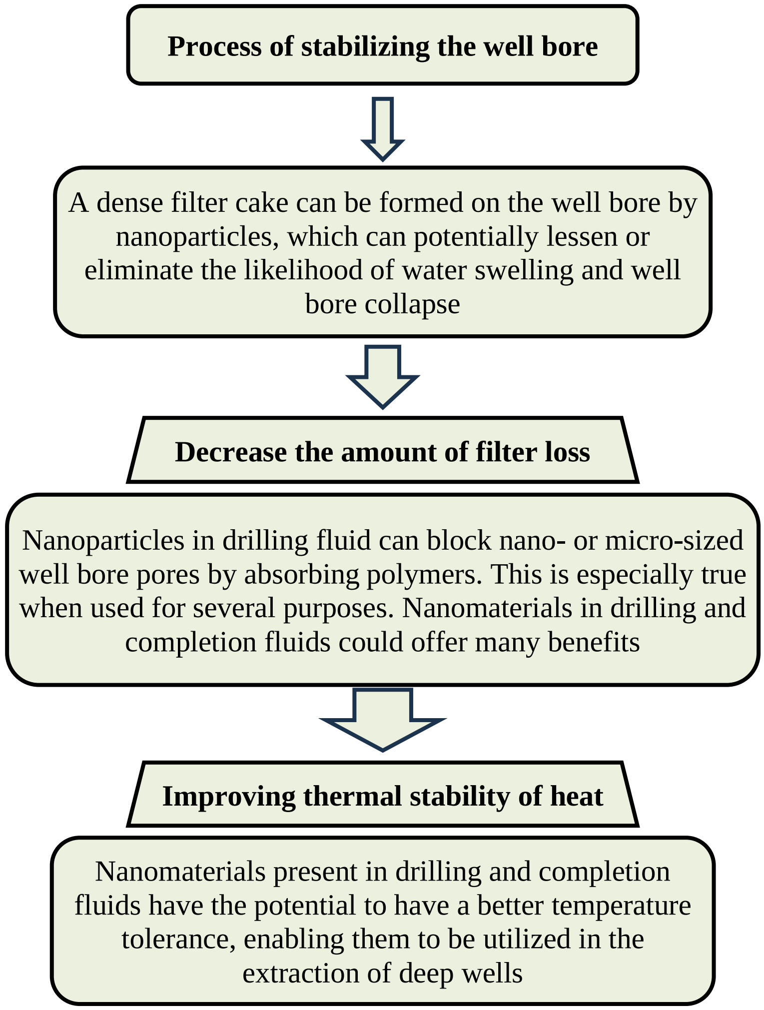

Figure 1: Maximizing Efficiency: Harnessing Nanomaterials for Enhanced Drilling and Completion in Challenging Environments - An Illustrative Diagram.

To achieve the benefits mentioned earlier, research on drilling based on nanoparticles has concentrated chiefly on incorporating nanomaterials into drilling fluids. Hoelscher *et al*. [37] researched to investigate the effects of physical properties of nanomaterial-based drilling fluid on the Marcellus and Mancos shale formations. The findings indicated that the tiny pores within the shale could be physically blocked, leading to a significant reduction in the shale's permeability. These findings highlight the potential of nanomaterials to improve wellbore integrity in such formations. The result was a reduction in the pressure difference, which ultimately led to an increase in the force of the shale. By utilizing silicon dioxide particles that are easily accessible commercially, Salih and his colleagues discovered that the rheological and filtration functions of water-based drilling muds could be improved. This advancement was made possible by applying silicon dioxide particles [38]. One such drilling mud, created by Amanullah and colleagues, is based on nanomaterials and has adjustable rheological characteristics. It is possible to use this drilling mud both during and after the drilling process [39]. In this study, it was shown that the incorporation of cellulose nanoparticles (CNPs), nanocrystals of cellulose, and microfibrillated cellulose (MFC) are two examples of materials that can improve the rheological and filtration characteristics of drilling fluids derived from bentonite water (CNCs). The CNC-based system outperformed the MFC-containing system regarding rheological properties, temperature stability, fluid loss volume, and filter cake thickness. It was comparing the two different approaches that allowed this to be accomplished. The core-shell paradigm has been proposed for water-based fluids containing CNC and bentonite. Include some examples of how nanoparticles can be applied to drilling fluids using Table 3.

Table 3: Drilling fluids incorporating nanoparticles.

Considered NP	Enhanced parameters	Ref.
Aluminum oxide Copper oxide Magnesium oxide	enhance rheological properties,improvement of filtration characteristics	[40]
Copper oxide	Plug shale nanopores, Hole stability improvement	[41]
CNT–polymer nanocomposite	Enhancing rheology Increase wellbore stability Enhancing HPHT drilling filtration	[42]
Iron oxide	Improving drilling fluid lubrication Improving filtration characteristics	[43]
Nanoclay	Rheology improvement for synthetic-based drilling fluids, Electrical resistivity reduction	[44]

2.2 Advanced Oil Recovery

The residual oil was effectively recovered using enhanced oil recovery (EOR) techniques in regions where water flooding proved insufficient. EOR procedures encompass a variety of methods, including chemical, thermal, microbiological, and gas techniques, which can be classified as either miscible or immiscible. Conventional chemical EOR methods typically involve the polymers usage, surfactants, and alkaline substances. These materials improve the efficiency of oil sweep and displacement, improving the recovery of residual oil. Nanofluid technology has the potential to enhance production levels beyond what traditional chemical (EOR) methods can achieve. Furthermore, it can boost the effectiveness of injection processes, sparking global interest [45]. However, employing nanofluids involves various considerations, including the capillary number, the wettability of the reservoir surface, and the properties of the nanomaterials used. The use of molecular dynamics simulations, Miranda *et al*. [46] assessed the molecular behaviour of nanofluids diffusing through the reservoir, the impact of reservoir surface wettability, and the mobility and stability of functionalized silica nanoparticles. Contrarily, for the hydroxylated nanoparticles, the data demonstrated that the oil/nanoparticle interface exhibited the shortest interfacial tension (0.913N/m). Functionalized silica nanoparticle mobility and stability, reservoir surface wettability effect, and molecular behaviour of nanofluids diffusing through the reservoir have all been studied. The results showed that hydroxylated nanoparticles exhibited the lowest interfacial tension at the oil/nanoparticle interface, measuring 0.913N/m. Of all the nanoparticles tested, those altered with polyethylene-glycol (PEG) showed the most substantial contact angle for salt concentrations. It is recommended to carry out further experiments and explore additional nanoparticles as potential candidates for nanofluids. Using nanoparticle dispersions, Zhang *et al*. carried out studies related to EOR technologies [47] using the water-wet Berea sandstone with a single-glass capillary structure. Although silica nanoparticle suspensions would dissolve in highly salty water, their study demonstrated that the resulting nanofluids could be helpful in such an environment. In addition, compared to brine solution, the crude oil recovery achieved with nanofluids can be around three times higher. Previous research has suggested that nanofluids could displace crude oil, and this phenomenon could be explained by the disjoining pressure mechanism [48]. Various nanoparticles were employed to extract any remaining oil from the environment using an EOR compound (Table 4 Summarization).

Table 4: EOR agent was used by various nanoparticles to recover the remaining oil.

Type ofNP	Concentration /wt%	Additional Oil Recovery Factor /%	Fluids	Porous Media	Ref.
Silica	0.1–3	19	Brine Water	Sandstone rock Micromodel	[49]
Nano Clay	0.1–1	5	Brine Water	Sandstone Core	[50]
Carbon Nanotubes	0.01–0.1	31	Nanofluid	Glass beads	[51]
Iron Oxide	0.01–0.64	28	Brine Water	Glass beads	[52]
Titanium Dioxide	2–2.5	4.2	Water	Glass micromodel	[53]
Graphene Nanosheets	0.005–0.01	15.2	Brine Water	Sandstone Core	[54]
Ferric oxide Chitosan	0.01–0.03	10.8	Sea Water	Carbonate sand Packs	[55]
Zinc Oxide	0.1	10.4	Brine Water	Sand Packs	[56]
Multi-Walled Carbon Nanotubes	0.1–0.3	18.5	Nanofluid	Glass beads	[57]
Silica / Graphene	0.01–0.1	14	Brine Water	Glass micromodel	[58]

2.3 Heavy Oil Extraction

The production of heavy oil, extra-heavy oil, and bitumen has increased consistently in recent years to satisfy the growing demand. The production of these oils is more complicated and expensive than conventional oil due to their high density, viscosity, and heteroatom content [59]. The use of nanotechnology has created new opportunities for enhancing recovery methods in the heavy oil sector. In the proposed system, heavy oils can be treated with nanoparticles, including metal oxides, to improve their efficiency. While this may lessen the expenses of refining and ground transportation, it also can increase the heavy oil recovery. The in situ upgrading process also maintains the contaminants' concentration in the reservoir, which includes sulfur, vanadium, iron, and nickel. Disposing of these minerals, a waste product of oil production helps lessen their environmental impact [60]. Among the many benefits of nanocatalysts for in situ up-gradation are their ability to react inside porous media on the spot, reducing environmental concerns and making heavy oil more manageable to work with. Despite their small size, nanocatalysts offer exceptional catalytic performance because of their large specific surface area. Immobilizing these nanocatalysts enhances the probability of reactants coming into contact with them. Unlike fixed bed catalysts, nanocatalysts may have more extraordinary residence times for conversion within the medium. Nanocatalysts may provide higher conversion rates instead of catalysts in a fixed bed.[61]. In addition, nanoparticles can be utilized to improve heavy oil recovery by deploying nanofluid flooding [62] or emulsions used for stabilizing in EOR procedures [63]. Ehtesabi *et al*.[62] studied the chemical properties and impacts of TiO_2 nanoparticles on heavy oil recovery from sandstone cores. Nanoparticle stability across a range of salinities was verified by zeta potential and UV-Vis measurements. Core flood experiments with two pore volumes of TiO_2 nanofluids pre-injected may lead to a recovery rate roughly 1.5 times higher than water flooding. A shift from oil-wetting to water-wetting rock wettability is among the many possible causes of the improved recovery. As an additional end-of-life (EOR) option, emulsion flooding shows promise for some heavy oil reservoirs that have been produced, especially those that are limited to thermal recovery because of environmental and technical constraints [64,65]. Pei *et al*.[63] found that adding nanoparticles makes the emulsion much thicker and more stable. A thickened emulsion with favorable mobility considerably improves sweep efficiency, leading to increased heavy oil recovery. Fig. 2 shows the rules that control how surfactants and nanoparticles interact in porous media. Nanoparticles not only enhance the mechanism that controls the composition of surfactants, but they also improve their performance.

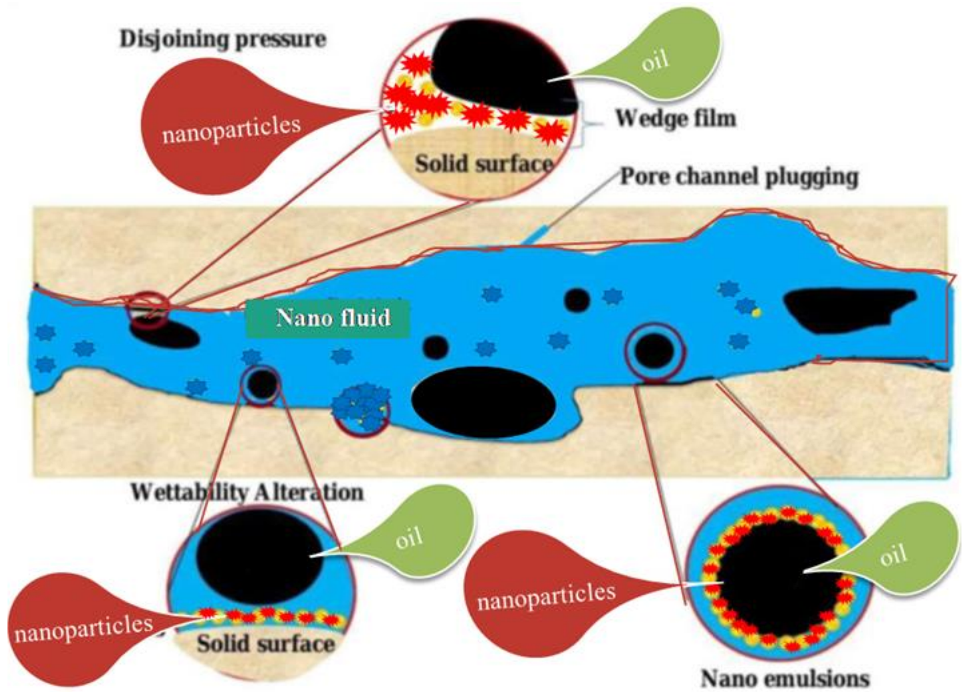

Figure 2: Nanoparticles and surfactants in environments with pores.

2.4 Water Treatment and Purification

In the oil and gas industry, both upstream and downstream processes involve water usage. Activities such as drilling, oil refining, and improved oil recovery are examples of operations that contribute to water pollution [66]. The remediation of contaminated water is becoming increasingly challenging, and the environmental consequences of this polluted water are a major concern. Numerous physical, chemical, and biological procedures, such as adsorption, flocculation, chemical precipitation, and membrane treatment, can efficiently treat wastewater from the oil industry. On the other hand, nanomaterials offer potential for water treatment and purification. In comparison to traditional adsorbents, cellulose nanofibers or nanocrystals provide several benefits, including a large specific surface area, affordability, and minimal environmental impact [67]. Cellulose nanoparticles can effectively remove organic pollutants and heavy metal ions when used as adsorbents. Their pollutant-binding efficiency can be further improved through surface functionalization. For instance, incorporating succinic acid groups into cellulose nanocrystals (CNCs) has been shown to significantly enhance their ability to bind lead and cadmium ions in aqueous solutions [68]. This method can remove various organic solvents, heavy metal ions, crude oil, and nanocomposites made of cellulose. Zheng *et al*.[69] developed organic aerogels that combined silane-treated PVA with cellulose nanofibrils (CNF) and found that they could absorb a wide range of substances, including organic solvents, heavy metal ions (like Pb^{+2} and Hg^{+2}), and crude oil. Korhonen *et al*. [70] enhanced cellulose nanofibril aerogels for oil absorption by adding a titanium dioxide layer, which is both hydrophobic and oleophilic. This modification allows the aerogels to absorb oil effectively, and after the oil is removed, the material can be recycled, burned, or cleaned for reuse. Chitosan-silica composite aerogels that are both hydrophobic and nanoporous were effectively synthesized by Ma *et al*. [71]. Additionally, composite aerogels containing 20 g/g of chitosan can be recycled up to 10 times, with an oil absorbency of up to 30 g/g, making them both efficient and environmentally friendly. The study also discussed nanocomposite membranes and magnetic nanocomposites, including those that integrate both organic and inorganic components. Fig. 3 presents various common nanocomposites, highlighting their structures and the unique properties that distinguish them.

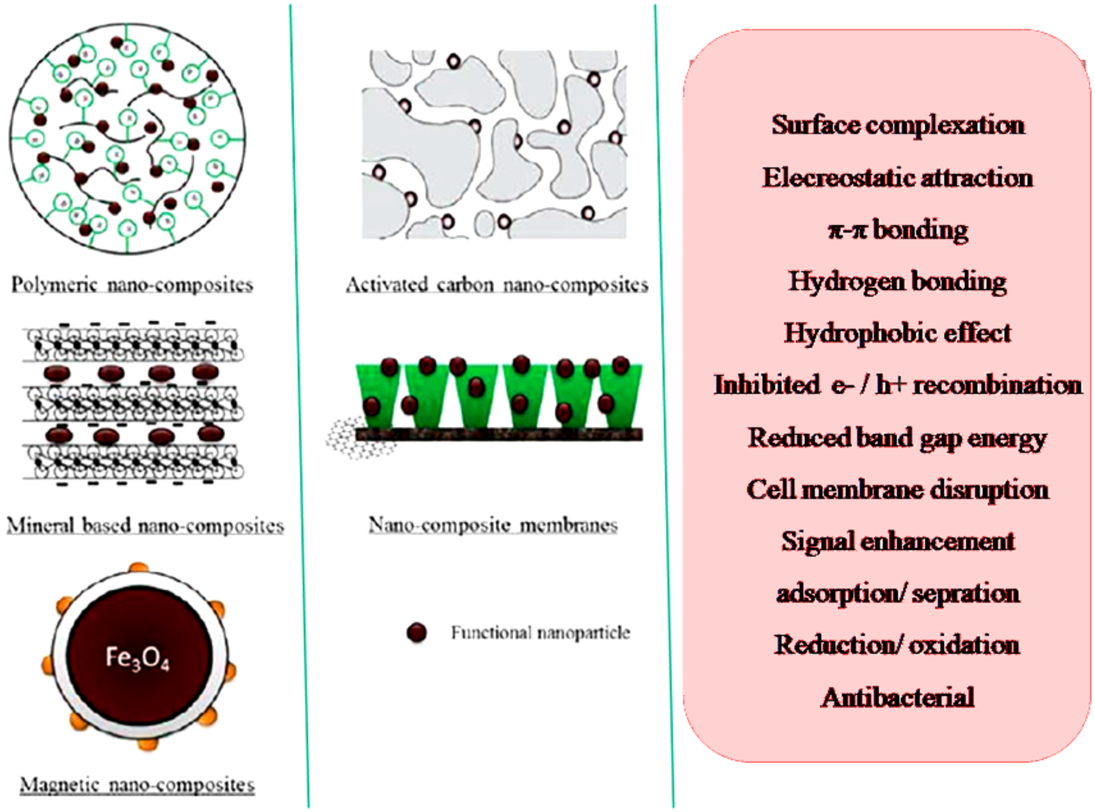

Figure 3: Illustration of environmental nanocomposites and nanotechnology features.

2.5 Nanomembranes for Separation and Purification

In the oil and gas industry, nanomembranes are essential for both upstream and downstream operations. They play a critical role in oil-water separation, oil purification, enhancing gas separation, and the collection and storage of carbon dioxide. Nanofiltration membranes are also widely used in wastewater treatment. A highly efficient oil-water separation membrane has been developed using a nitrocellulose (NC) membrane featuring micro- and nano-sized pores [72,73]. Water-removing" membranes with underwater superoleophobicity and oleophilic properties can effectively filter out oil and debris. These membranes repel oil while allowing water to pass through, making them ideal for oil-water separation and purification tasks. These membranes enable the rapid separation of water from oil/water mixtures, including hexane, petroleum ether, crude oil, and others this offers a significant advantage when compared to materials considered to be "oil-removing,". Based on the findings of the experiments, it was determined that the membranes can function at a separation efficiency higher than 99 percent. He *et al*. Cross-linking cellulose nanofibres with polyamide-amine-epichlorohydrin (PAE) created a cellulose nanofibre aerogel filter demonstrating super-hydrophilic and underwater superoleophobic performances. The produced aerogel filter ultimately retained none of the tested oils, including peanut, mineral, hexadecane, and canola oil. In addition, emulsions containing no oil-water surfactant achieved a separation efficiency of 98.6%. The prepared aerogel filter could effectively separate oil and water[48]. Nanomembranes can be categorized into inorganic, organic, hybrid, and synthetic types, depending on the materials used in their composition. Fig. 4 illustrates these classifications. Applications in water remediation utilize these different categories to address various contamination challenges [86-90].

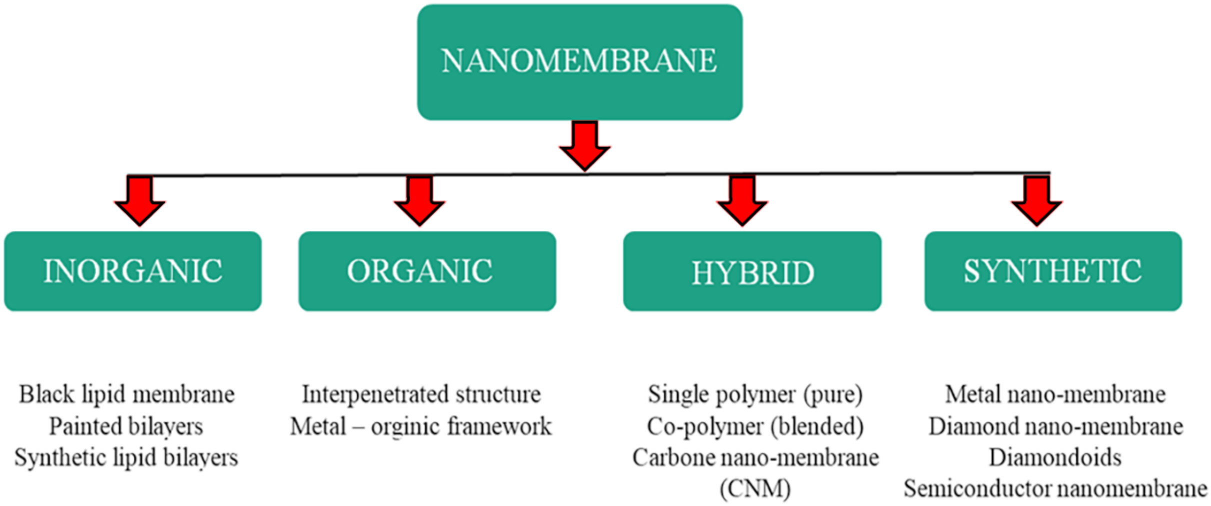

Figure 4: Broad classification of nanomembranes.

2.6 Innovative Catalysts and Anti-Corrosion Solutions

The distinctive catalytic properties and high aspect ratio of many nanomaterials have made them valuable as catalysts, especially metallic nanoparticles, which are widely used. Manipulating the optical, magnetic, or electrical properties of these catalysts, these variables provide responsive characteristics, allowing for enhanced control and adaptability in chemical reactions. One of the most widely used chemical processes catalyzed by metal nanoparticles is the Fischer-Tropsch process. This process involves a sequence of chemical reactions that convert carbon monoxide and hydrogen into liquid hydrocarbons. Various metals, such as ruthenium, iron, nickel, and cobalt, have been reported to catalyze the Fischer-Tropsch process effectively [74]. The synthesis and stability of nanoparticles are the primary difficulties that require attention for the Fischer-Tropsch process. Top-down and bottom-up techniques are two categories that can be used to classify the synthesis methods for nanocatalysts. The bottom-up approach involves reducing metal oxides using either a solvent or gas reductants, such as carbon monoxide and hydrogen sulfide. These techniques enable precise control over particle size and maintain crystals with specific internal geometries [75]. Yan *et al*. [76] studied various varieties of polyvinylpyrrolidone, a substance used to stabilize palladium (Rh), ruthenium (Ru), platinum (Pt), and cobalt (Co) (Co). By using the Fischer-Tropsch reaction, we tested the PVP-Co catalyst's catalytic activity and found that it was on par with the supported Co catalyst. An additional obstacle that must be overcome when employing nanocatalysts to carry out the Fischer-Tropsch reaction is the stability of particles. Fan *et al*. [77] scattered iron or cobalt nanoparticles in polyethylene glycol (PEG) catalyzed the Fischer-Tropsch reaction, resulting in a relatively high reaction rate. Due to the ferromagnetic properties of iron nanoparticles, the catalyst can be salvaged following the reaction. Utilizing carbon catalysts of nano-scale size, Li *et al*. [78] reported that developing an innovative technology reduced the excessive viscosity of heavy oil. This involves using nano-sized carbon to break the carbon-sulfur bonds when heated by microwaves. Simultaneously, the viscosity of the treated heavy oil was reduced by four percent compared to the untreated system. Fig. 5 demonstrates the application of nanotechnology in organic coatings to enhance corrosion protection specifically, demonstrating how nanoparticles, such as carbon nanotubes or metal oxides, are included into the matrix of the coating in order to enhance the barrier properties, mechanical strength, and other characteristics, such as the ability to self-clean or eliminate corrosion [79-85,92].

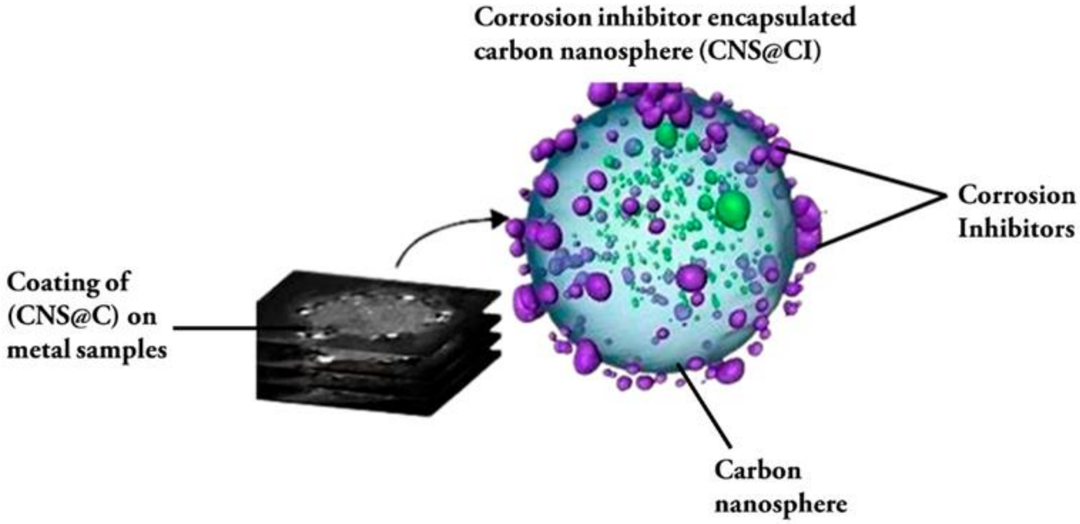

Figure 5: Nanotechnology in corrosion protection coatings [79].

3. Future Prospects and Challenges

The future of the oil industry depends on the continuous need for nanomaterial applications. Nanotechnology holds great promise however, challenges such as cost-effective manufacturing, optimal dispersion, and environmental compatibility must be addressed. Concentrated research, collaboration, and the adoption of innovative approaches will be key to developing more sustainable and effective practices in the oil industry.

4. Challenges and Opportunities

While the possibilities are great, the challenges are many. Overcoming these barriers from cost-effective manufacturing to ensuring proper and environmentally compatible dispersion will be necessary. Cooperation between researchers, industry, and regulatory agencies will be crucial to overcoming these barriers. Fostering a collaborative environment can harness collective knowledge and resources, enabling us to overcome challenges together. The transformational impact of nanotechnology on the oil industry highlights human intelligence and points us toward an efficient and sustainable future. Having reached the brink of a new technological age, embraced challenges and learning from setbacks is of utmost importance. By unlocking the full potential of nanomaterials, we can usher in an era where the oil industry operates between cutting-edge technology and environmental stewardship. This journey creates a brighter tomorrow for generations to come.

5. Conclusions

As stated in the previous sentence, nanotechnology has had a deniably revolutionary impact on the oil business. Redesigning significant applications ranging from oil exploration to renewable energy has been the focus of recent research investigating the widespread application of nanotechnology. This comprehensive report examines advances in drilling, advanced oil recovery, heavy oil extraction, water purification, Nanomembranes, catalyst purification, and anti-corrosion techniques. Whereas we provide a comprehensive review of current research developments, this report remains an essential resource for researchers. Significant research breakthroughs will drive innovation, introduce new approaches to nanomaterials, and expand our ability to create materials with properties that are on par with those of other materials. The results were illustrated by some previous studies that used different types of nanoparticles such as Silica, Nano Clay, Carbon Nanotubes, Iron Oxide, Titanium Dioxide Graphene Nanosheets, Ferric oxide Chitosan, Zinc Oxide, Multi, Walled Carbon Nanotubes, Silica / Graphene. Type and concentration wt% of NP along with additional oil recovery Factor %, and Fluids Porous Media also reported. It was found that using Carbon Nanotubes and Iron Oxide at a wt ratio of 0.01-0.1 and 0.01-0.64 wt % gives the highest Oil Recovery Factor % 31 and 28 respectively. Furthermore, exploring the different applications of existing nanomaterials will allow them to integrate into previously unexplored areas in the oil industry.

Conflict of Interest

The authors declare that they have no conflict of interest.

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