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Nanotechnology in Oil and Gas Industry

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ABSTRACT

Nanotechnology is the study of nanoscale phenomena, the practice of nanoscale engineering, and the use of materials at the nanoscale. It has become a ground-breaking applied technology in the past few decades. Several aspects of society have been impacted by nanotechnology, leading to increased productivity and lower cost production of high-quality goods. Nanotechnology plays a significant role in the oil and gas industry by enhancing various processes. It is used for better oil recovery, real-time monitoring, innovative materials, drilling fluids, and reservoir characterization. Almost every oil & gas company is heavily investing in nanotechnologies to enhance oil recovery, to improve equipment reliability, to reduce energy losses during production, and to provide real-time analytics on emulsion characteristics. This paper explores how nanotechnology is transforming the oil industry and enhancing its performance.

KEYWORDS: *nanotechnology, nanomaterials, oil and gas industry, petroleum industry*

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INTRODUCTION

Scientists and engineers have entered the enormous field of study known as nanotechnology to explore and improve material qualities at the atomic level. Successful applications of nanotechnology in many facets of life have boosted the effectiveness of product development and use. Nanomaterials are the building blocks of nanotechnology, and the impacts of the nanoscale are what give them their unique properties.

In secondary and tertiary oil recovery operations, nanotechnology has the potential to significantly improve oil recovery and address problems caused by formation damage during water and gas reservoir flooding. Nanotechnologies can improve fluid phase separation, subsurface porous media qualities, coatings for reservoir components, and enhance the functionality of manufacturing system sensors and controls. Nanoparticles have gained significant attention in the oil and gas sector due to their unique properties and potential applications. Integrated circuit technology that are lighter, with reduced size, and superior than ever before have been made possible by nanotechnology.

Over the past two decades, global energy consumption has been gradually increasing. Over the next 30 years, global energy demand is projected to rise as high as almost 60%, a challenging trend that may be met only by revolutionary breakthroughs in energy science and technology. Breakthroughs in nanotechnology open up the possibility of moving beyond the current alternatives for energy supply by introducing technologies that are more efficient and environmentally sound. Nanotechnology could be used to enhance the possibilities of developing unconventional and stranded gas resources. Nanotechnologist is concerned with building new structures and substances by manipulating molecules and atoms on this scale. In oil and gas applications, nanotechnology could be used to increase opportunities to develop geothermal resources by enhancing thermal conductivity, improving down hole separation, and aiding in the development of noncorrosive materials [1]. Research in nanomaterials has brought many performance enhancements to the materials used in oil and gas well drilling, cementing, production, and enhanced oil recovery (EOR). Research in petroleum well drilling, design,

stimulation, and reservoir production management has demonstrated that nanoparticles can make industrial materials tougher [2].

WHAT IS NANOTECHNOLOGY?

Technologies impact every aspect of our modern society. There are many ways in which our society and technology are interlinked. Nanotechnology has the potential to provide huge benefits, just like any useful technology.

The term "nano" means something small, tiny, and atomic in nature. The application of the term in science led to a field called nanotechnology. Nanotechnology refers to the characterization, fabrication and manipulation of structures, devices or materials that have one or more dimensions that are smaller than 100 nanometers. It may be regarded as an area of science and engineering where phenomena that take place at the nano-scale (10-9m) are utilized in the design, production, and application of materials and systems. It is an emerging area of that integrates chemistry, biology, and materials science to create new properties that can be exploited to gain new market opportunities [3].

Nanotechnology deals with the characterization, fabrication, and manipulation of biological and nonbiological structures smaller than 100 nm. Dimensions between approximately 1 and 100 nanometers are known as the nanoscale. As indicated in Figure 1 [4], the nanoscale is so small that we cannot see it with a light microscope. It is the scale of atoms and molecules. Nanotechnology involves the creation and application of materials and devices at the level of molecules and atoms. It may be regarded as the science that is conducted, researched, investigated, and experimented at the nanoscale. Nanotechnology is a multi-disciplinary field that includes biology, chemistry, physics, material science, and engineering. It is the science of small things—at the atomic level or nanoscale level. The past three decades has witnessed an increased interest and funding in nanotechnology. This has led to rapid developments in all areas of science and engineering [5].

- Richard Feymann, the Nobel Prize-winning physicist, introduced the world to nanotechnology in 1959 and is regarded as the father of nanotechnology. Nanotechnology involves the manipulation of atoms and molecules at the nanoscale so that materials have new unique properties. Nanomaterials are expected to have at least one dimension (length, width, height) at the nanoscale of 1 – 100 nm. One nanometer is a billionth of a meter, too small to be seen with a conventional lab microscope. Nanomaterials include nanofilters, nanosensors, nano photocatalysts, and nanoparticles. Nanomaterials are known as nanoparticles when they have nanoscale length, width, and height. Figure 2 portrays a technique for the preparation of nanoparticles [6].

Today, nanotechnology is part of our daily lives. Nanotechnology will leave virtually no aspect of life untouched. Its usages include everything from safer food processing to more efficient drug-delivery systems to powerful computer chips. Three steps to achieving nanotechnology-produced goods are [7]:

1. Scientists must be able to manipulate individual atoms.
2. Next step is to develop nanoscopic machines, called assemblers, that can be programmed to manipulate atoms and molecules at will.
3. In order to create enough assemblers to build consumer goods, some nanomachines called replicators, will be programmed to build more assemblers.

Nanotechnology is trending among scientists and engineers. Here are some underlying trends one should look for [8]:

1. Stronger Materials: The next generation of graphene and carbon devices will lead to even lighter but stronger structures.
2. Scalability of Production: One big challenge is how to produce nanomaterials that make them affordable. Limited scalability often hinders application.
3. More Commercialization: In addition to transforming the automotive, aerospace, and sporting goods fields, nanotechnology is facilitating so many diverse improvements: thinner, affordable, and more durable.
4. Sustainability: One main goal of the National Nanotechnology Initiative, a US government program coordinating communication and collaboration for nanotechnology activities, is to find nanotechnology solutions to sustainability.
5. Nanomedicine: There will be a mindboggling impact of nanotechnology on medicine, where advances are being made in both diagnostics and treatment areas.

Applications of nanotechnology are found in a wide range of industries, including engineering, medicine, microelectronics, manufacturing, biology, chemistry, energy, and agriculture, and life sciences. Figure 3 shows some applications of nanotechnology [9]. Although nanotechnology has been successfully

applied in various industries, its use in the oil and gas sector is still limited.

NANOTECHNOLOGY IN OIL AND GAS

Among the numerous energy sources, crude oil remains one of the most treasured, valued, and predominant natural resources on the planet earth. Although demand on crude oil is increasing worldwide, discovering new oil reservoirs is difficult. Thus, researchers and oil companies must extract the remained oil in the matured reservoirs using efficient technologies. Nanotechnology is the current most attracted valuable technology [6].

Due to their special qualities, nanoparticles are useful in various applications in the oilfield, such as sensing or imaging, improved oil recovery (EOR), gas mobility control, drilling and completion, produced fluid treatment, and tight reservoir applications. Chemical processes have been facilitated in the oil and gas industries, from upstream to downstream, using materials with special size-dependent characteristics. Oil and gas field operations may be classified into two distinct sectors: upstream and downstream. The upstream sector pertains to the exploration and production of oil, while the downstream sector is primarily concerned with the refining, processing, purification, marketing, and distribution of the resulting products. The complexity of the O&G operation is shown in Figure 4 [10].

Apart from the wide range of uses, such as structural nanomaterials, nanofluids, and nanosensors, nanotechnology also has prospective applications in upstream oil activities. The upstream oil business appears to have a promising future for nanotechnology if it can adopt notable breakthroughs from various industries. The upstream oil & gas industry could receive a great boost under the impulse of innovations in the field of nanotechnology.

APPLICATIONS OF NANOTECHNOLOGY IN OIL AND GAS

Nanotechnology has a wide range of uses, and its use in drilling fluids, innovative materials, real-time monitoring, reservoir characterization, well stimulation, cementing, wettability, enhanced oil recovery. and better oil recovery has shown tremendous promise. Figure 5 shows some of the applications of nanomaterials in O&G industry [11]. It is a rapidly growing field that has many applications in the oil and gas industry, including the following [12-14]:

- *Drilling:* The drilling process, as the name suggests, is creating a hole in the ground to reach the desired depth. Figure 6 shows a typical oil drilling [15]. Nanotechnology has shown promise in addressing major problems and improving drilling effectiveness. It has played a crucial role in the advancement of drilling tools and materials. Nanoparticles can improve the rheological properties of drilling fluids, which can help reduce fluid losses, stabilize the wellbore, and ensure safe drilling. They can also be used to create nano drilling mud, which is often used in deep wells. Drilling fluids play a critical role in guaranteeing drilling success by improving oil recovery and cutting down on the time needed to achieve early oil production. They are comparable to blood in the physical makeup of the human body throughout the drilling operation. The primary function of additives is to improve the fundamental characteristics of drilling fluids. The variety of fluid additives available is a reflection of the complex drilling–fluid systems that are currently being used to enable drilling in increasingly difficult subsurface conditions. When nanoparticles are added to a fluid, the mixture becomes a nano-fluid. The incorporation of nanoparticles into drilling fluids has produced upgraded fluids with better features, including improved lubricity, thermal stability, and filtering capacities. Electrical and thermal conductivity are essential factors in drilling operations. It is necessary to use a thermally conductive drilling fluid to effectively remove heat from the drill bit.
- *Enhanced Oil Recovery* (EOR): This is a tertiary technique that involves the application of different methods for the purpose of increasing the amount of crude oil that can be extracted from a hydrocarbon reservoir. The use of nanoparticles in EOR is one of the most important fields of application as it provides larger amounts of oil during the extraction, thus ensuring a faster return on investment. Important EOR mechanisms include injection fluid viscosity increase, asphaltene precipitation and prevention, interfacial tension, and wettability changes. Different techniques using nanotechnology are being considered and very promising appears to be the use of nano-robots for real time insight into the well pad. By adding some sensors inside the robots, very important information will be obtained. Nanoparticles can be used to change the surface tension and viscosity of reservoir fluids. They can also be used to create more efficient and eco-friendly chemical-enhanced oil recovery (CEOR) compounds. EOR could also be guaranteed by the use of nanoparticles dispersed in suitable fluids. One of the main problems in the oil & gas industry is the use of materials capable of withstanding highly corrosive environments.

Different nanofluids are used in EOR techniques such as chemical, thermal, miscible, polymer, and microbiological flooding. Nanoparticles are added to fluids to create nanofluids. EOR techniques have been employed to extract the residual percentage of original oil from areas that are not amenable to water flooding. Figure 7 shows the categories of enhanced oil recovery technologies [6].

- *Oil Well Cementing:* Cement is needed in the oilfield for casing cementation in order to provide mechanical support, protection from corrosive fluids, and sealing. Cement set accelerators are essential in the cementing of oil wells by speeding up the transition from the liquid phase to the solid phase. Conventional cement-set accelerators, such as inorganic salts like calcium chloride ($CaCl_2$), are known to increase cement permeability while shortening the set time. The expenditures associated with the waiting on cement phase can be reduced through careful cement design. Nano silica has the potential to be used in a variety of oil and gas well cementing scenarios, such as cementing in lower temperature zones. Nano silica also addresses cement's problems with gas migration. The cement becomes more susceptible to pore pressures from the formation. Using a cement viscosity enhancer, using cement-set accelerators, regulating cement density, embedding nanosensors in cement, incorporating nanoparticle additives that promote microcrack self-healing, and controlling cement density will improve cement integrity.
- *Reservoir Characterization:* The characterization of reservoirs and improved oil recovery have benefited from nanotechnology. Improved technologies have been made available to characterize reservoirs through nanoparticle tracers and nanoscale imaging techniques. This has enabled the identification of the best drilling sites and increased productivity. While introducing nanoparticles into reservoirs, worries regarding the environmental impact surface.
- *Water Treatment:* Both upstream and downstream sectors employ a lot of water in accomplishing its activities, such as in drilling fluids, enhanced oil recovery/improved oil recovery (EOR/IOR), and in oil refinery processes. Treatment of contaminated water is essential but increasingly difficult due to the negative environmental effects of industrial water pollution. Using nanomaterials for water treatment and purification processes demonstrates appealing qualities. The nanofiltration separation process can be used to purify and desalinate injected water for EOR processes, water produced in oil fields, and water used in refineries. Comparing nanofiltration membranes are more efficient than the traditional technologies at eliminating pollutants from small adjourned oil droplets and dissolved substances. Water from the oil sands process, which is mostly produced during the oil sands production process, can also be cleaned using reverse osmosis and nanofiltration membranes.
- *Environmental Remediation:* One of the most significant predicaments confronting contemporary society is the pervasive environmental pollution and degradation stemming from various origins. Numerous conventional methods are being employed to tackle this predicament. One crucial area in which nanotechnology can have a significant impact is environmental stewardship, which addresses issues such as pollution, resource efficiency, and renewable energy production. Nanotechnology has presently being investigated for its potential deployment as a potent tool in combating environmental pollution. Nanosensors are essential for accurately tracking how human activity affects the environment and for enabling early intervention in the form of care, treatment, and prevention. Businesses that use nanotechnology have the ability to produce biodegradable, environmentally friendly materials, which could help reduce pollution. The utilization of nanoremediation techniques presents a promising avenue for the detection and treatment of contaminants in various environmental matrices such as water, soil, sediment, and air. The nanoremediation technique encompasses the utilization of reactive materials to facilitate the detoxification and conversion of contaminants. It must be emphasized that this process is not only essential for the preservation of ecological well-being but also for the overall health of the general public.
- *Disinfection:* The drilling process for oil and gas can significantly enhance microbial activity due to the use of chemicals that are biodegradable and serve as a food source for microorganisms. This process poses a risk of introducing potentially harmful microbes to the environment. Nanotechnology is used to introduce a method of disinfecting the environment in order to combat the current and anticipated hazard. Nanomaterials possessing antimicrobial properties have the potential to be utilized for the purposes of disinfection and microbial control. The

functionalization of carbon nanotubes has been shown to enhance their antimicrobial activity, thereby increasing their capacity for disinfection.

- *Desalination:* This process constitutes a mere 1 % of the global water consumption; yet it is an energy-intensive process, with the majority of operational expenses attributed to energy consumption. Given the significant impact of climate change, there is a pressing need to develop sustainable desalination processes that address the issues of brine discharge, greenhouse gas emissions, and energy consumption per unit of freshwater produced. Nanotechnology can play a crucial role in achieving specific energy consumption reduction.
- *Wettability*: This refers to a fluid's capacity to occupy a porous solid surface while other immiscible fluids are present. It is directly tied to how fluids interact with the solid or one another. The term "wettability alteration" describes how a surface's affinity for a specific phase changes. The upstream oil and gas sector finds wettability alteration (WA) of reservoir rock to be an appealing issue for increasing hydrocarbon production. Wettability modification is an essential component of improved oil recovery (EOR) procedures in the context of oil recovery. In order to improve the effectiveness of oil recovery, the wettability of the reservoir rock is altered from its original state. It has been observed that nanoparticles modify the wettability of the surface under study by altering the reservoir rocks' surface roughness. In other words, adding nanoparticles may increase surface roughness, which will reduce the contact angle and increase the system's wettability.
- *Oil Well Exploration:* Petroleum geologists are capable of conducting exploration, a process that involves utilizing various techniques to locate hydrogen resources beneath the earth's surface. In spite of the utilization of current sophisticated methods for oil recovery, such as thermal approaches, gas injection, water flooding, and chemical flooding, a significant amount of oil and gas may remain unrecovered. To overcome these technological challenges and effectively explore unconventional oil and gas sources, it is imperative to employ unconventional methods and exceptional materials. Cements in well construction are also witnessing numerous advances in the implementation of nanoparticle designs. The integration of nanoparticles and smart fluids can yield an exceptionally efficient sensor capable of operating effectively in demanding environments, while delivering accurate measurements of temperature, pressure, oil flow rate, and stress in deep wells. Scientists are currently engaged in the development of nanosensors capable of performing reservoir characterization, identifying various fluid types, and monitoring fluid flow. Cement set accelerators are important chemical additives in oil well cements. They offer the possibility of shortening the time duration it takes for the cement to transition from liquid into the solid phase.

BENEFITS

Nanotechnology applications are rapidly expanding in various fields because of its unique qualities, such as a large surface area. It provides huge potential in addressing technology challenges related to the upstream oil and gas industry with nanomaterials and devices. Nanotechnology is becoming increasingly popular in the oil and gas industry. Other benefits include the following [12]:

- *Improved Performance:* Adding nanoparticles to drilling fluids can considerably improve their performance and solve some of their current problems. Different drilling fluid systems have shown the benefits of using nanoparticles in drilling fluids. Usually, drilling fluids are weighted to maintain a positive overbalance against the pore pressure of the formation. When designing drilling fluids for harsh conditions, particularly those with temperatures above 120 °C, nanoparticles have demonstrated promise.
- *Waste Management:* Solid waste materials encompass substances generated through human activities to fulfil their needs and subsequently introduced into the environment. Industrial and urban waste contribute hazardous organic and inorganic pollutants to water, soil, and air. Conventional technologies struggle to effectively eliminate these pollutants. Common biological and physicochemical methods are unable to remove all of the toxic and nonbiodegradable materials found in wastes. Modern technologies, such as nanotechnology, emerge as a crucial solution to address this issue.
- *Increased Productivity:* Through increased productivity and superior products created at lower overhead costs, which boosts demand, nanoparticles has had a clear and significant impact on society in many fields. Nanoparticles are therefore crucial to contemporary lifestyles. Nanotechnology has shown that nanoparticles outperform similar macro- and micro-materials in

terms of their chemical, physical, thermal, mechanical and tribological capabilities.

- *Sensing and Imaging:* Nanoparticles can be used to create temperature and magnetic sensors, as well as imaging techniques. For example, magnetic nanoparticles can be used as contrast agents to monitor and surveil reservoirs.
- *Miniaturization:* Some of the possible benefits of nano-materials are the outcome of miniaturization, while others are the result of change in the property of the material.

CHALLENGES

The widespread adoption of nanoparticles in the oil and gas field is impeded by several challenges that require attention. These challenges include cost, durability, compatibility, safety, and regulation. A major challenge in the oil & gas industry is the use of materials capable of withstanding highly corrosive environments. Nanotechnology is still in the early stages of application in the oil and gas industry, and there are some challenges to overcome. Other challenges include the following [12,14]:

- *Temperature:* Most recently discovered oil and gas formations are situated in high-pressure and high-temperature conditions. Exploration and production under such environments are costly and challenging. The rheology of drilling fluids is considerably impacted by the elevated temperatures. For instance, clay swelling, flocculation, and sodium ion replacement in bentonite mud, frequently used in drilling, cause increased yield stress at higher temperatures. High temperatures can also destroy polymeric additives in drilling fluids, diminishing viscosity and performance and creating new difficulties for drilling operations. Nanomaterials must be able to withstand the high-temperature and high-pressure conditions of the downhole environment. Deep oil wells and steam injectors have difficulties due to uncontrolled heat loss, which can result in problems including clogging, the deposition of paraffin and asphaltenes, and poor steam quality. For example, the strength of cement can decrease dramatically at temperatures above 150 °C.
- *Environmental Impact:* In commercial drilling, managing drilling fluid waste is a major environmental concern, and actions are being taken to mitigate the effect of drilling activities utilizing non-aqueous fluids on the metal content of marine sediments. It is common knowledge that drilling mud pits at drilling rigs can contain sizable concentrations of hazardous heavy metals. Nanotechnology can make the O&G industry considerably greener.
- *Injection of Nanofluids:* The continual injection of nanofluids into the water stream is, in fact, a major problem in the enhanced oil recovery (EOR) process. This raises concerns over potential injectivity loss in the injector well due to numerous types of formation damage. Consequently, it is imperative that the assessment of flow assurance in the laboratory is given top priority to avoid and minimize any formation damage related to nanoparticle injection
- *Collaboration:* Nanotechnology is characterized by collaboration among diverse disciplines. It is crucial to promote cooperation between regulatory agencies, business, and academia to guarantee the appropriate and long-term integration of nanotechnology in the oil field. A thorough examination of potential hazards and environmental effects, as well as the formulation of rules and standards for the use of nanomaterials, would all be made easier by collaboration.
- *High Cost*: The production and use of nanoparticles can be expensive, thereby limiting their commercial adoption in the oil and gas industry. The application of nanotechnology is limited due to the fact they are so expensive to produce and maintain. The price of nanoparticles continues to be an important factor, and lowering it will be essential for their widespread use and commercialization in the industry.
- *Degradation:* Nanoparticles are susceptible to degradation in the harsh downhole environment, which can limit their effectiveness and longevity. Using nanoparticles for EOR requires them to travel deep into the reservoir and remain stable in the harsh downhole environment.
- *Incompatibility:* Achieving compatibility between nanoparticles and other fluids and materials used in the oil and gas industry can be challenging, particularly for nanoparticles designed for specific applications.
- *Safety*: In spite of the numerous potential benefits of incorporating nanoparticles into the oil and gas sector, concerns regarding their safety and environmental impact persist. Nanomaterials and their biodegradability have raised concerns regarding long-term consequences and safety. Nanoparticles can pose a safety hazard if not handled properly, as they can be easily inhaled or ingested. It is necessaryto proceed with caution and conduct additional research to fully comprehend both their potential benefits and risks. Some of the most widely studied

nanomaterials in the oil and gas sector are nanosilica and metallic oxide nanoparticles; they have various effects on human beings and the environment.

- *Regulation:* The use of nanoparticles in the oil and gas industry is a relatively new, and there are few regulations governing their use, leading to uncertainty and delays in commercialization.

CONCLUSION

Nanotechnology has stood strong in the oil and gas industry, with many applications that have gone from laboratory and simulation studies to successful trial applications in the field. It will continue to influence the future of the oil and gas sector by embracing ongoing research, development, and responsible application, enhancing drilling operations, boosting sustainability, and fostering overall industry advancement. Prominent oil corporations are currently engaged in a thorough examination of the potential implementation of nanoparticles and nanotechnology within the oil and gas sector. The oil and gas field is expected to see a successful expansion in the application of nanotechnology in different areas. More information about nanotechnology and nanomaterials in oil & gas industry can be found in the books in [16-22] and the following related journals/magazines:

- Nanotechnology
- Nanoscale.
- Nano: The Magazine for Small Science
- Micro and Nano Technologies
- Nanotechnology News
- Nature Nanotechnology
- Current Research in Nanotechnology
- American Journal of Nanotechnology & Nanomedicine
- Nanomedicine: Nanotechnology, Biology and Medicine
- Journal of Nanotechnology
- Journal of Nanoparticle Research
- Journal of Bioelectronics and Nanotechnology
- Journal of Nanoscience and Nanotechnology,
- Journal of Micro and Nano-Manufacturing
- Journal of Nanoengineering and Nanomanufacturing
- Nanotechnology and Precision Engineering
- South African Journal of Science
- International Journal of Petroleum and Petrochemical Engineering
- Journal of Petroleum Science and Engineering
- Petroleum
- Petroleum Research
- Energy Reports
- Oil & Gas Journal

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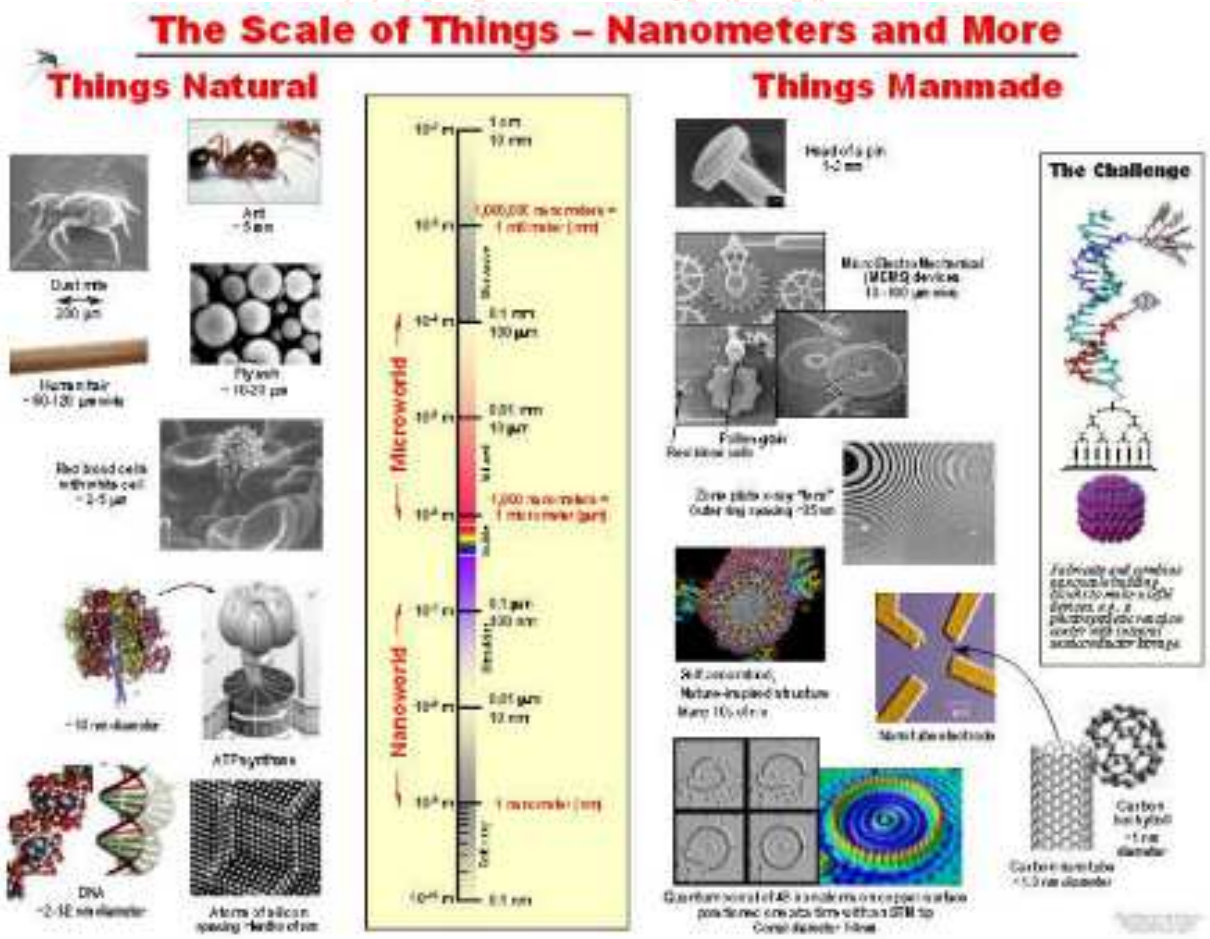

Figure 1 Indicating the relative scale of nanosized objects [4].

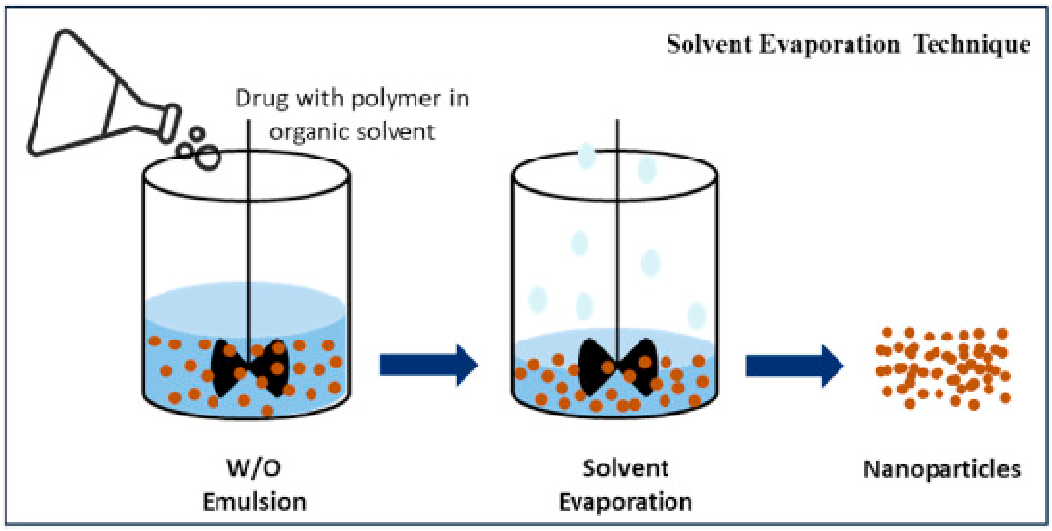

Figure 2 A technique for the preparation of nanoparticles [6].

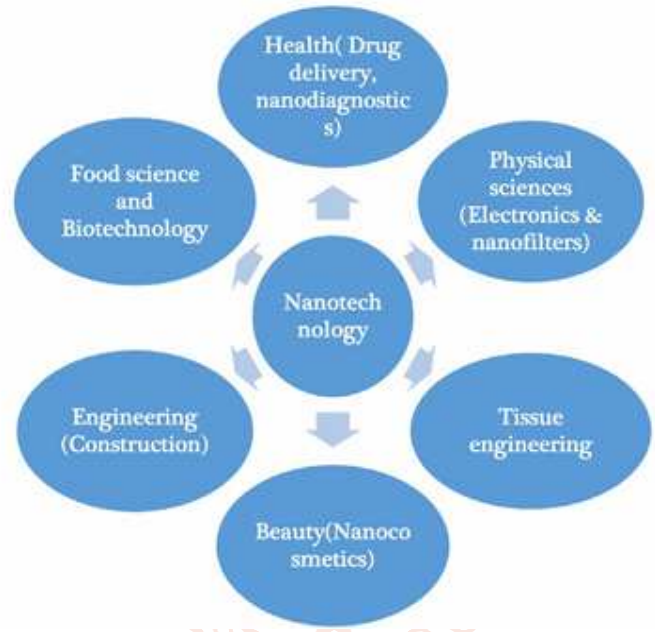

Figure 3 Some applications of nanotechnology [9].

Figure 4 The complexity of the O&G operation [10].

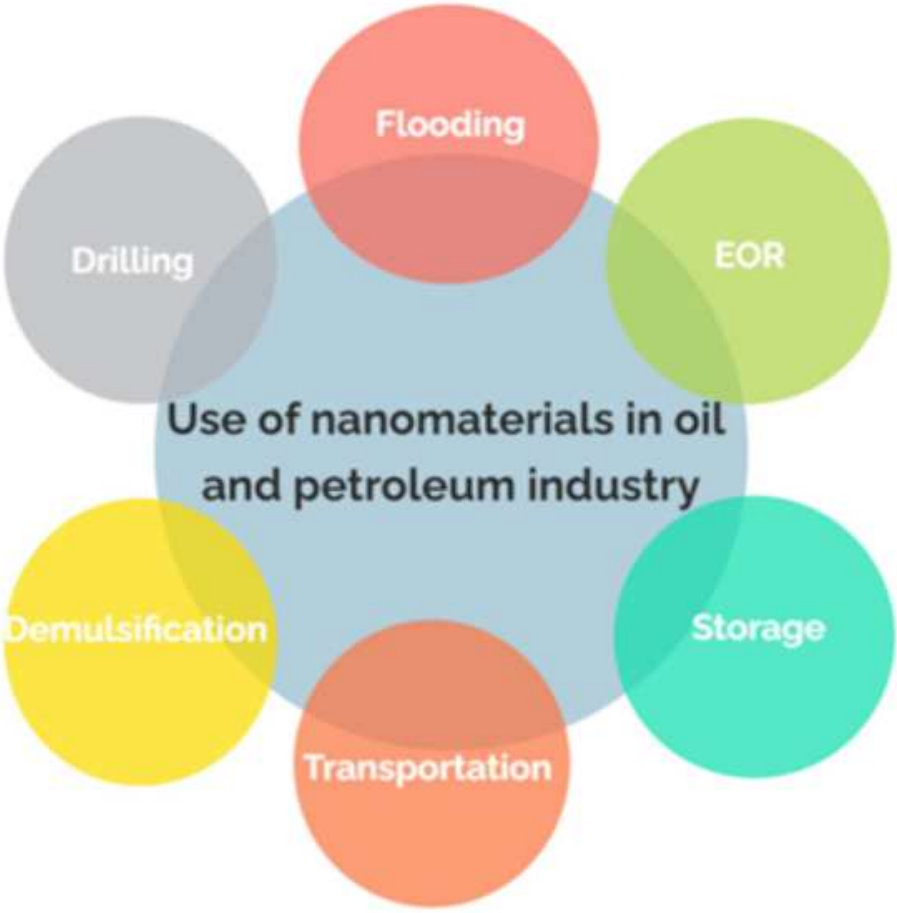

Figure 5 Use of nanomaterials in O&G industry [11].

Figure 6 A typical oil drilling [15].

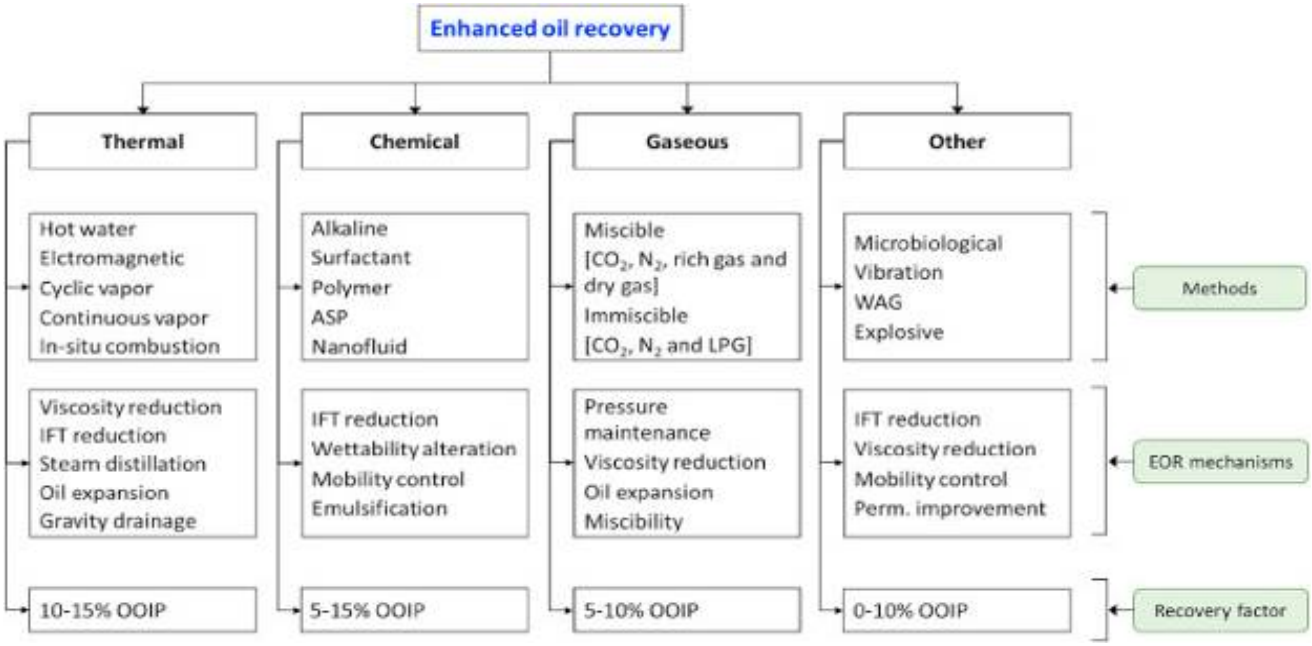

Figure 7 Categories of enhanced oil recovery technologies [5a].