Emerging Nanotech Applications in the Oil Industry

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Abstract— With the introduction of nanotechnology, energy industries envisage a potential revolutionary change in the field of exploration, development and production. Research by universities into such areas as nanosensors, nanomarkers and nanobots to provide valuable data regarding the reservoir are of great focus due to their large potential return on investment, but have yet to yield substantive products. By contrast, efforts into drilling applications of nanotechnology such as drilling fluids are less known. Nanotechnology can revolutionize the additive properties by tuning particle characteristics to meet certain environmental, operational and technical requirements. Nano-technology produces nanomaterials that are ultra-fines in nature, usually smaller than ordinary micro particles and thus has very high specific surface area with enormous area of interactions. Recent research has indicated that nanomaterials have unique properties for a broad range of applications in the field of oilfield exploration and drilling , where fluid loss control, borehole stability, cementing quality of a well, remediation of damaged reservoirs, hydrocarbon recovery efficiency, oilfield wastewater treatment, high-temperature tolerance and viscosity modification are of interest. This paper presents an extensive literature review of assessing the applications of nanotechnology and nanomaterials in the field of oilfield exploration and drilling, investigating the existing problems in the application of nanomaterials in oilfield exploration and drilling , and evaluating the potential technical and economic benefits that nanotechnology and nanomaterials might provide to petroleum development and production. This paper will also discuss results from projects which utilize carbon nanotubes (CNT), nanosilica and other nanochemistries to achieve and enhance the performance of drilling fluids.

Key words: Nano-sensors, Nanotechnology, Nano-materials, Oil field exploration, Oil field drilling, Carbon nanotubes, Drilling Fluids

I. INTRODUCTION

Nanotechnology continues to gain momentum in the areas of academics as well as applied research. Generally, material is said to be a nanomaterial if one of its dimension is less than 100 nm. Because of the large increase in the surface area to volume ratio, nanomaterials display different chemical and physical properties compared to their macro- or micron-sized counterparts. For instance, opaque substances become transparent (copper) and inert materials become catalysts (platinum). This enables niche application of nanomaterial.

The global demand for energy is anticipated to continue to increase over the next few decades with the expectation that the world's energy consumption will increase substantially in the near future. Although the use of alternative energy sources, such as nuclear and renewable energy will increase in the coming years, the increase will be relatively small and the main role of the alternative energy sources, at least for the next two decades, will be to complement and supplement, rather than replace, the use of hydrocarbons. Accordingly, meeting the World's growing energy demand will be a major challenge in the coming decades and will only be possible with revolutionary breakthroughs in the oil and gas industry's core science and engineering.

Breakthroughs in nanotechnology have the potential to move the industry beyond the current alternatives for energy supply by introducing technologies that are more efficient and more environmentally sound. Recently, the oil industry has been approaching nanotechnologies as a potential solution to the above mentioned challenges, calling for the same breakthrough effects that this relatively new branch of science has been gushing over the last century in Aerospace, biology and medicine. Nano technologies have the potential to introduce revolutionary changes in several areas of the oil and gas industry, such as exploration, drilling, production, enhanced oil recovery, refining and distribution. For example, nanosensors might provide more detailed and accurate information about reservoirs; specially fabricated nanoparticles can be used for scale inhibition; structural nanomaterials could enable the development of petroleum industry equipment that is much lighter and more reliable and long-lasting; and nanomembranes could enhance the gas separation and removal of impurities from oil and gas streams. Other emerging applications of micro and nano technologies in the petroleum industry are new types of "smart fluids? For enhanced oil recovery (EOR) and drilling. In short, there are numerous areas in which nanotechnology can contribute to more efficient, less expensive, and more environmentally sound technologies. This paper presents an extensive literature review of assessing the applications of nanotechnology and nanomaterials in the field of oilfield exploration and drilling, investigating the existing problems in the application of nanomaterials in oilfield exploration and drilling , and evaluating the potential technical and economic benefits that nanotechnology and nanomaterials might provide to petroleum development and production. Additionally this paper will also discuss results from projects which utilize carbon nanotubes (CNT), nanosilica and other nanochemistries to achieve and enhance the performance of drilling. Also recent developments in research in areas of significance to the oil and gas industry are briefly reviewed. The potential opportunities and challenges that face future trends of nanotechnology applications in the oil and gas industry are also discussed.

II. MATERIALS AND METHODS

The true nano-revolution relies on the full exploitation of the bottom-up approach, i.e., the creation of smart materials by exploiting their self-organizational capacity. The ultimate breakthrough of the nanotechnologies will be the extensive integration between the top-down and the bottom-up approaches: currently, very few serious plans about cooperation have been set forth, despite the numerous theorized roadmaps about convergence. Yet, there is a wide consensus that the future of nanotechnology lies in the integration of biological tools and systems into nanotechnological design and manufacturing. Many companies are spending considerable financial resources in researching a specific area of nanotechnology called Carbon Nano Tubes (CNTs). Carbon nanotubes are made by carbon atoms forming hollow, open-ended cylinders that have a diameter between 0.4 and 1.8 nm and vary in length up to several hundred nanometers, depending on the production methodologies. Electrons flow through these nanotubes 10 times faster than they do through CPUs silicon circuits, they can carry up to 100 times the current and dissipate up to 20 times the heat. Carbon nanotubes can also act as either conducting or semiconducting material for use in data storage [5], while scanning probe microscopes may eventually be used as a tool for data transfer.

Another nanotechnology material, called graphene, has long been regarded as one of the most promising technologies to emerge. The latest development produce a continuous layer of pure grapheme which could be used to conduct electricity across flexible, transparent touchscreens based on a sheet of carbon just one-atom thick that can be folded like paper [16]. The same material can also be used to make displays lighter and more power-efficient. In the following a brief overview of the existing applications and near future improvement of nano-related "products" in different industrial sectors is presented and discussed with the aim of underlying similarities and thus possible applications to the oil industry.

III. Results

A. Single-Walled-Carbon-Nano Tube (SWNT)/ Si-Lica Nano hybrids:

These particles represent very promising materials: if delivered at the O/W interface, they would react with and modify the oil properties to increase oil mobilization. At the moment, the research is analysing the potential benefits derived by the application of nanomaterials, nanofluids and nanomembranes to the oil industry. In the following a more detailed overview of the recent progresses in research and application in key oil and gas sectors is provided.

B. Sensors:

Nanomaterials are excellent tools for the development of sensors and imaging-contrast agents due to the significant alterations in their optical, magnetic and electrical properties along with their ability to form (electrically and/or geometrically) percolated structures at low volume fractions [11]. Such nanomaterials, when combined with smart fluids, can be used as extremely sensitive downhole sensors for temperature, pressure and stress even under extreme conditions. The ultimate evolution of devices for prospection is represented by nanorobots, which should really provide an effective mapping of the reservoir. Nowadays, nanorobots still remain a dream, shared by the medical and oil sectors. But advances in nanosensor miniaturization are occurring rapidly and numerous theoretical and experimental investigations about the flow of multiphase fluids containing nanoparticles in porous media enrich the recent technical literature [14].

C. Coatings:

Significant work is underway toward the transition of smart/multifunctional polymer coatings from laboratory curiosities toward the identification of commercial applications. Intelligent or smart coatings, which may combine the shielding aspect with sensor or actuator functions, rely on their capabilities to respond to physical, chemical or mechanical stimuli by developing readable signals. Nanomaterials are expected to be used not only as advanced functional materials, but also as an integral part of complete smart structures composed of various elements including sensors, actuators, and control devices. Some of the key challenges in more advanced research areas are the understanding of corrosion protection mechanism imparted by conducting polymers and the advancement of micro/nanocapsulation as a means to impart self-healing [2]. Nano-coated, wear-resistant probes, made of tungsten carbide or boron nitride, enhance the lifespan and efficiency of the drilling systems, thus inducing remarkable cost savings. The same applies to the nano-layered corrosion inhibitors in pipes or tanks, which act through the creation of a permanent molecular layer on the surface of metals, thus eliminating or hampering corrosion induced by HCl or H2S.

D. Nanofluids And Nanomaterials For Drilling And Completion:

Drilling and completion sectors are other two oil branches where the benefits of nanofluids and nanomaterials application are already tangible. Nanotechnology has opened the door to the development of a new generation of fluids defined as "smart fluids" for drilling, production and stimulationrelated applications. Thanks to the exceptionally high surface to volume ratio, nanofluids and nano-based additives exhibit major interaction with the surrounding environment even at very low concentrations. Such smart fluids will further enhance drilling by adding benefits such as wettability alteration, advanced drag reduction and sand consolidation [3]. One specialized petroleum laboratory has developed an advanced fluid mixed with nanosized particles and superfine powder that significantly improves the drilling speed and can eliminate formation damage in near wellbore zone. Synthesis of a new class of elastomeric composites filled with carbon nanotubes or other strongly anisotropic nano-objects, stronger, tougher and more resistant drilling tools and apparatus will be manufactured in the coming years. At the same time, these tools will ensure a significant weight reduction and the potential to originate self-sensing elements to be interrogated for the real-time monitoring of the most critical parts. Another important technique in the development of super-hard materials is the use of nanostructured dispersed-hardened materials [15]. The superiority of physical-mechanical properties of diamond poly-crystalline nanocomposites [15], boron nitride nanocomposites [6] and WC/Co/diamond nanocomposites [9] in comparison with their traditional counterparts.

First generation of nanotech applications for improving hydraulic fracturing are represented by nano-structured metal composites, combined by magnesium, aluminium and other alloys, which offer both strength at lower weight and the ability to "dissolve" away under certain conditions. Another example is the proppant produced by Oxane Materials, constituted by nano-structured ceramic material which is as strong as but lighter as ceramic proppant. A possible solution for mitigating fine migration problems is represented by the commercialized nanocrystals for treating hydraulic fracture proppant packs to fixate formation fines. The mechanism of fixation of the formation fines depends on the high surface forces of the nanoparticles, such as Van der Waals and electrostatic forces, which also attach the nanoparticles to the surface of proppant during fracpacking and fracturing treatments.

E. Nanomembranes:

Inspired by the success of zeolites, which are materials capable of separating small gases such as oxygen and nitrogen, a new generation of largescale, lightweight and sturdy nanomembranes is being developed and deployed. These nanomembranes will significantly enhance the exploitation of tight gas by providing efficient methods for removing impurities, separating gas streams and enabling GTL production. By exploiting methods common in the microelectronics industry, the cost of manufacturing highly uniform and reproducible membranes is quite competitive [11]. Nanoporous and nanoparticular materials are also very promising to manage the environmental, health and safety risks deriving from the presence of CO2 and H2S in hydrocarbon mixtures.

F. Viscoelastic-Surfactant Stimulation Fluids:

Viscoelastic surfactant (VES) fluids have been widely used in the oil industry as completion and stimulation fluids. The surfactants structurally arrange to form rod-like micelles that increase VES fluid viscosity for regular fracturing and frac-packing fluids. However, high fluid leak-off and low viscosities at elevated temperatures have limited VES fluids for hydraulic fracturing and frac-packing applications. This paper will introduce a nanotechnology application for maintaining viscosity at high temperatures and controlling the fluid loss of VES fluid, without generating formation damage. The nanometer-scale particles studied display unusual surface morphologies and have high surface reactivity. These nanometer-scale particles, through chemisorption and surface charge attraction, associate with VES micelles to stabilize fluid viscosity at high temperatures; and produce a pseudo- filter cake of viscous VES fluid that significantly reduces the rate of fluid loss and improves fluid efficiency. When internal breakers are used to break the VES micelles, the fluid will dramatically lose its viscosity and the pseudo-filter cake will then break into nanometer-sized particles. Since the particles are small enough to pass through the pore throat of producing formations, they will be flowed back with the producing fluids, and no damage will be generated. The results of rheology leak-off and core flow tests will be presented for the VES fluid systems at temperatures 150°F and 250°F.

G. Treatment Of Effluent:

A substantial amount of oily wastewater has been generated from oil and gas exploration and production activities, and it contains a great number of harmful substances such as suspended solids, organics, heavy metal ions, and so on, which will cause severe environmental pollution when discharged arbitrarily without any treatment. Therefore, it is necessary to purify this wastewater so that it can be reused to save water resources. However, conventional oily wastewater treatment methods have several disadvantages, including low efficiency, high cost, and corrosion and recontamination problems. Additionally, they are not effective in removing smaller oil droplets and emulsions [8]. So a new technique for wastewater treatment should be developed. A tubular UF module equipped with poly-vinylidene fluoride membranes modified by inorganic Nano-sized alumina particles was used to purify oily wastewater, and the membrane water permeations of the UF process were analyzed [10]. The experimental results showed that the oil content was reduced to less than 1 mg/L, suspended solids content was reduced to less than 1 mg/L, and the median diameters of solid particle were less than 2 μm, which indicated that the quality of the permeation water could meet the requirement for oilfield injection or drainage. The retentions of chemical oxygen demand were more than 90%, and the total organic carbon was more than 98%. The SEM images showed that the nanometre alumina.

IV. DISCUSSION

With the rapid development of nanotechnology, Nano-materials have been gradually infiltrating to every respect of oilfield, and they will play an essential role in the preparation of new oilfield agents. Unfortunately, there are many problems in the applications of nanotechnology and Nano-materials in the field of oilfield exploration and drilling.

An interesting and extremely efficient property which could be exploited at the nanoscale is the shape memory effect. Nanoparticles based on specific alloys or polymeric composites maximize the efficiency of the shape memory phenomenon, with the triggering of the shape change occurring as a result of changes in temperature, moisture intake or pH [4]. The subsequent improvement should be the nanosensors or nano-sensors clusters localization. Under this respect, the special electrical, optical and magnetic properties of nano-materials make them well suited for use as injected sensors and contrast agents. Several possible applications and exploitation schemes are currently under study with nano-devices injected into a reservoir. The position of the nano-devices could be measured at predesigned time delays by suitable crosswell or surface-based electro-magnetic procedures or seismic methods in the case of nano-devices behaving like acoustic pingers incorporated novel paramagnetic nanoparticles into proppant structures [7]: this smart proppant could help in mapping the fracture efficiency using detectable contrast agents.

It is very easy to generate agglomerates for Nano-materials during use, and the grain sizes will increase greatly. Only by stirring can hardly disperse these agglomerated particles into Nano-meter scale again, so these Nano-materials will lose their unique properties, even resulting in failure of preparation of novel oilfield exploration and drilling agents. Therefore, the agglomerate Problem of Nano-materials remains to be solved in future, and the stability of Nano-materials should be improved. There are few researches on the mechanism of Nano-materials in oilfield exploration and drilling, and some aspects are seldom involved. A breakthrough in their application cannot be made until the fundamental research of Nano-materials is appreciated. Nowadays, the cost effectiveness of most Nano-materials is too low. In the field application, the desired results cannot be achieved with only a little dosage of Nano-materials, but excessive dosage will raise the cost. So, low cost and industrial production are the key factors for extensive application of Nano-materials in the field of oilfield exploration and drilling. With the development of nanotechnology, many potential solutions will emerge for the above problems, and Nano-materials will be applied in broader field of oilfield exploration and drilling. Meanwhile, further development of nanotechnology and oilfield exploration and drilling technique will be promoted.

Several innovative materials and solutions could support the development of nanosensors. For example, as far as the scaffold is concerned, organic building materials are very good at self-assembly, but the most reliable and highperformance molecular machines may be constructed out of diamondoid materials, the strongest known substances. Building diamondoid nano-robots will require both massive parallelism in molecular fabrication and assembly processes and programmable positional assembly, including mole-cularly precise manufacture of diamond structures using molecular feedstock [13]. Positionally controlled single-atom covalent bonding (mechano-synthesis) has been achieved experimentally for hydrogen and silicon atoms [12], but presently only computational simulations support the same expectation for carbon atoms and diamond structures.

Based on the available technology the path to “slightly” smart nanosensors is shorter and could introduce significant advantages for reservoir investigation. 100-1000 nm diameter passive nanoobjects could be flushed with the injection fluids through the pores of the reservoir rocks to determine the formation characteristics. No active components (sensor, data storage or transmission, 3D location, power) would be on-board, but the presence of a proper structure (multi-wall nanowires, core-shell particles,) interacting with the reservoir could retrieve threshold information (maximum temperature and/or pressure, maximum pH, salinity,). The magnetic (through a magnetic core) or electrical (as in the case of Carbon nanotubes) conductivity of such nano-dust could be exploited for recovering information. Using a core-shell structure, for example, the quantity of oil present in a Reservoir could be assessed based on the amount of material lost or retained during the travel time, or the extreme conditions (temperature, pressure, salinity gradient) at which the nanoparticles were exposed and for how long, could be determined. The idea could be to pump nano-sensors in the reservoir periodically so as to regularly monitor changes in the well/field conditions.

In turn, this could result in improved production efficiency and trouble managing [7].

Evolution of nanotechnology application for reservoir monitoring: The petroleum sector dreams of a nanosensor able to provide direct (in-situ) and reliable information about the system under analyses. Nowadays, this represents one of the most complicated and transversal challenge faced by oil industry because it requires strong technical improvements in many different disciplines. In fact, the exploitation of injected nanosensors into the reservoir is subject to the satisfaction of the following technological requir-ements: emplacement and recovery, protection in harsh environments (through a proper shell or coating), 3-D location, sensors powering, data storage and retrieving.

As far as the power is concerned, many nano-based tools are currently under development. Several options exist: a nano-battery operated system, a system able to scavenge the necessary energy in situ or a mixed solution. This last alternative is even more intriguing and some encouraging results have been obtained, particularly for the biomedical field.

The greatest challenge is concerned with the possibility of increasing the efficiency of hydrocarbon production, both by improving the current EOR methodologies and by developing alternative technologies. According to current researches and technical literature, the newgeneration nano-agents should both affect the properties of the injected fluid, in terms of viscosity, density, thermal conductivity and specific heat and modify the fluid-rock interaction properties, for example in terms of wettability.

Innovative water nano-filters have to be specially designed both to ensure uniform pore throats and the ability to recovery tens of billions of tons of oil; this aspect is also very important, since the flow capacity of currently employed biomedical filters would not be adequate for the purpose. To provide an evidence of the impact of such a nanotechnological breakthrough, it should be considered that the reservoir rocks of the are characterized by a mean pore radius of 1-10 nm, which is comparable with molecular sizes [1].

V. CONCLUSION

Well drilling, fracturing and cementing as well as new generation membranes for gas separation can already rely on nanotech solutions. Other technologies will require further elaboration before direct use. Different types of applications of nanotechnology have been emerging such as Surfactant Structure Fluids, Prevent fine migrations, drilling fluids, completion fluids, work over fluids, environmentally friendly stimulation fluids, profile control agents, heavy oil thinner, oily Effluent treatment materials etc. So it shows great promise for upstream sectors of petroleum industry. The cost effectiveness of most nanomaterials is too low. In the field application, the desired results cannot be achieved with only a little dosage of Nano-materials, but excessive dosage will raise the cost. So, low cost and industrial production are the key factors for extensive application of Nano-materials in the field of oilfield chemistry. With the development of nanotechnology, many potential solutions will emerge for the above problems, and Nano-materials will be applied in broader field of oilfield chemistry. Meanwhile, further development of nanotechnology and oilfield chemistry technique will be promoted.

Currently, relevant efforts are being made to design nano-sensors for reservoir characterization and monitoring and to produce nano-fluids for improving EOR processes. Very promising results have been obtained from laboratory experiment, but field tests are still extremely limited. The future of nanotechnology seems to be bright. Nevertheless, several issues are to be considered and the following actions should be taken to transform a big opportunity into reality: favour multi-disciplinarity, improve convergence between the top-down and the bottom-up approaches (namely, miniaturization and the creation of smart materials by exploiting their selforganisational capacity), and, finally, consider the usual long-term research and investment time frame for targeting business properly.

VI. REFERENCES

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