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Advanced nanomaterials in oil and gas industry: Design, application and challenges

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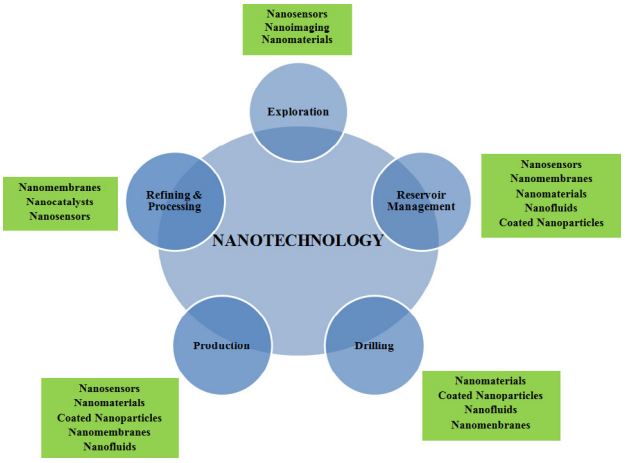
HIGHLIGHTS

- Synthetic protocols for nanoparticles used in oil and gas industry.
- Surface functionalization for nanoparticles used in oil and gas industry.
- Application of nanoparticles in enhancing hydrocarbon exploration and production.
- The potential of nanoparticles in refining and fuels production.
- Challenges and prospects of nanomaterials in oil and gas industry.

GRAPHICAL ABSTRACT



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ABSTRACT

The increase of global energy consumption and the growing demand of fossil fuels as predominant energy resources have greatly improved the advancement of new technologies in hydrocarbon recovery processes. New class of materials, such as nanoparticles has been widely studied in an effort to ensure simpler and more economical oil exploration and production processes, especially in challenging and harsh reservoirs environments. The unique physical and chemical properties of nanomaterials have lead to their application in almost all oil and gas aspects, such as exploration, reservoir characterization, drilling, cementing, production and stimulation, enhanced oil recovery (EOR), refining and processing. This review article presents comprehensive discussion on the most recent development of nanomaterials and their roles in new or enhanced applications in oil and gas industry. Here, the synthetic strategies and functionalization of some of the most common nanomaterials used in oil and gas industry, i.e. metallic and metal oxide nanoparticles, carbon nanotubes and magnetic nanoparticles are summarized. Their applications in different types of oil and gas processes are also discussed. Finally, an outlook on the current challenges and some prospects for the future applications is also highlighted.

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Contents

1. Introduction

Nanotechnology has revolutionized the perspective of today's scientists and engineers towards smart materials. The study and application of very small materials (1–100 nm) has become one of the fastest growing research areas in wide variety of science and engineering fields. Advancement in nanotechnology has enabled researchers to fabricate collection of various unique and enhanced nanomaterials, nanodevices and nanotools that can be used in many fields including electronics, aerospace, medical and biomedical, smart materials and manufacturing, pharmaceutical, photography, energy, etc. [1–10]. This is generally due to their unique size-dependent physical and chemical properties that are often not observable in their bulk counterparts [11]. In bulk materials, the number of atoms at the surface is significantly smaller than the number of atoms in the bulk. Therefore their physical and chemical properties are mostly constant regardless of their sizes. However, when the size of a particle is reduced to near or less than the wavelength of conduction electrons, several properties such as magnetism, optical behavior, thermal resistance, chemical and catalytic activities, melting point and internal pressure are altered. This is due to the surface/volume ratio becomes exponentially larger and the number of atom on the surface becomes significant with regards to the amount of atoms in the bulk [12]. This allows researchers to utilize these unique properties for many different applications. In addition, nanotechnology also offers not only cost-effective and cost-efficient industrial processes but also a precise design and manipulation of atoms and molecules as well the as full control on their unique properties [6].

In the past few decades, rapid advancement of nanotechnology has lead to the application of various nano-sized materials and nanoparticle-based devices and tools for oil and gas industry. In addition, the high global demand for energy and the remaining major challenges in the application of current conventional procedures have forced researchers to embark on the search for more economical, efficient and environmentally sound techniques to extract more hydrocarbons. In a recent review article by Kong and Ohadi, a summary of major challenges in petroleum industry has been comprehensively discussed [12]. These challenges lie from the early stage of exploration such as reservoir mapping, reservoir managements and drilling processes, to the production and post-production processes such as refining and processing. Recent advancement of nanotechnology enables researchers and engineers to potentially solve industrial problems in almost all aspects of oil and gas industry, from upstream to midstream to downstream. For instance, new nanoparticles based sensor technology can be used to probe key valuable information about deep reservoir properties which enables one to solve the complex structure and the nature of reservoir rocks and their interaction with trapped fluids. This is important in many different aspects of petroleum engineering field since it can be used to design suitable exploration and production plans. In a work by Wang et al., metallic nanoparticles have been used in geochemical exploration to delineate ore deposition [13]. In drilling processes, drilling equipments and platforms can be made with better resistance towards water and corrosion, better durability, wear- and shock-resistant, and enhanced thermal conductivity by coating them with a special type of nanoparticles [12]. Furthermore, another emerging application of nanotechnology in oil and gas industry called "nano-fluid" has also been reported. According to literatures, nanofluids can be used in a wide range of applications such as drilling, cementing, and enhanced oil recovery (EOR) [14–18]. Recently, nano-sized silica particles were used to stabilize the formation of liquid CO_2 foam for CO_2 EOR processes which can facilitate the improvement of oil production [19]. Moreover, iron oxide based nanocatalyst for *in-situ* aquathermolysis process to upgrade the quality and improve the productivity of heavy and extra heavy oil [20]. Various types of nanocatalysts have also been used in this regard [21–23].

Because of these great technological and industrial potencies, considerable efforts and innovations have been applied to the design and characterization of nanomaterials, particularly for oil and gas applications. Therefore, the development of nanotechnology and its contribution in oil and gas industry will be highlighted and discussed in this review article. In the first part of this review, synthetic protocols for nanomaterials that are commonly used in oil and gas application as well as their functionalization strategies are briefly discussed. This study will greatly serve to underscore the key role of chemistry on the fabrication of suitable nanomaterials and their applications in petroleum industry. Furthermore, recent progress on relevant nanotechnological studies and their