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Nanoparticle technology for heavy oil in-situ upgrading and recovery enhancement: Opportunities and challenges

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HIGHLIGHTS

- Overview the recent application of nanoparticles in oil upgrading and recovery.
- Overview the oil quality enhancement by using nanoparticles.
- Overview the challenges facing nanoparticle applications.
- Overview the available recovery mechanism of nanoparticles.
- Proposal of the possible applications of nanoparticles in wettability alteration.

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ABSTRACT

With more than 170 billion barrels of estimated oil sands reserves in Canada, Canada has the third largest oil reserves in the world. However, more than 80% of oil sand's reserves are located deep underground and could not be accessed by surface mining. Nonetheless, a number of in-situ recovery methods have been developed to extract heavy oil and bitumen from deep reservoirs. Once produced, bitumen is transferred to upgraders converting low quality oil to synthetic crude oil. However, in the present context, heavy oil and bitumen exploitation process is not just high-energy and water intensive, but also it has significant environmental footprints as it produces significant amount of gaseous emissions and wastewater. In addition, the level of contaminants in bitumen requires special equipment, and has also environmental repercussions.

Recently, nanotechnology has emerged as an alternative technology for in-situ heavy oil upgrading and recovery enhancement. Nanoparticle catalysts (nanocatalysts) are one of the important examples on nanotechnology applications. Nanocatalysts portray unique catalytic and sorption properties due to their exceptionally high surface area-to-volume ratio and active surface sites. In-situ catalytic conversion or upgrading of heavy oil with the aid of multi-metallic nanocatalysts is a promising cost effective and environmentally friendly technology for production of high quality oils that meet pipeline and refinery specifications. Further, nanoparticles could be employed as inhibitors for preventing or delaying asphaltene precipitation and subsequently enhance oil recovery. Nevertheless, as with any new technologies, there are a number of challenges facing the employment of nanoparticles for in-situ catalytic upgrading and recovery enhancement. The main goal of this article is to provide an overview of nanoparticle technology usage for enhancing the in-situ catalytic upgrading and recovery processes of crude oil. Furthermore, the article sheds lights on the advantages of employment of nanoparticles in heavy oil industry and addresses some of the limitations and challenges facing this new technology.

Contents

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1. Introduction

There is no doubt that the world is facing formidable challenges in meeting energy demands as the available conventional energy supplies are decreasing due to several factors [1], such as enormous growth of world population, competing demands from a variety of users, increasing industrialization and motorization of the world, and increasing technical development and living standard. Therefore, it is necessary to look for alternative energy supplies that can be produced from natural resources.

Various natural energy resources have been explored; including biomass, vegetable oils, biodiesel, etc. [2]. These resources are believed to be environment-friendly fuels [3], but they are costly and insufficient in meeting energy demands. Further, usually these types of fuels need to be formulated to meet the relevant properties of conventional fuels [3]. Most importantly, they require advanced attention to evaluate their advantages, disadvantages and specific applications. These facts have led to an increased demand on the upgrading and recovery of unconventional oil in order to meet current and future energy needs

Accordingly, due to an increase interest in alternative energy resources and utilization of fossil fuels, like unconventional crude oil, Alberta oil sands have now become an important source of alternative energy resources [4]. Actually, the International Energy Agency (IEA) has predicted that, by the year 2030, about 60% of the total worldwide energy growth will be met by fossil fuel sources such as heavy oil, coal, and natural gas [5]. Nonetheless, due to its high viscosity, low hydrogen to carbon ratio and high sulfur and nitrogen content, there are a number of challenges associated with bitumen recovery and upgrading in the present context. These challenges need to be surmounted to make it a sustainable and economically feasible alternative [6–10].

Among the challenges to be solved are the reduction in costs associated with the production and transportation of oil sands and the improvement of synthetic crude quality to meet stringent market specifications with less environmental footprints [11]. Nanotechnology is a rapidly growing technology with considerable potential applications and benefits [12]. It provides unprecedented opportunities to develop more cost effective and environmentally friendly heavy oil upgrading and recovery processes. Interest in using nanotechnology in heavy oil processing is driven from the unique physical and chemical properties of the nano-scale particles [13]. In the world of nanotechnology, a nanoparticle acts as a whole unit in terms of its transport behavior and properties, and its diameter is sized between 1 and 100 nm. In other words, as the size of a particle reduces to nanoscale (i.e., 1–100 nm) the properties begin to change dramatically as the percentage of atoms at the surface of a material becomes significant, a phenomena which is attributed to the large surface area to volume ratio [14]. Quantum confinement, surface plasmon resonance, high adsorption affinity, enhanced catalytic activity, good dispersion ability and intrinsic reactivity are just some of the unique properties associated with nanoparticles [15].

Nowadays, because of these properties nanoparticles are used in vast areas of engineering applications, such as heavy oil upgrading [16–18], fuel cell technology [19,20], polymer nanocomposites [21–23], catalysis [24–26], and wastewater treatment [27–29], to name only a few. However, there are uncertainties associated with nanoparticles applications, which should be deeply explored.

Among the potential applications enumerated for nanoparticles are in oil and gas industry, specially upgrading and recovery enhancement of heavy feedstocks by nanoparticle catalysts [30]. In addition to its high surface area, these catalysts should maintain ultra-dispersion ability and high catalytic activity. The ability to engineer desired surface functionalities of nanoparticles by tuning its characteristics as well as the possibility of its in-situ preparation makes nanotechnology an attractive unique option for heavy oil upgrading and recovery. In addition, owing to their small size and transport behavior, nanoparticles can be employed in-situ within the reservoir environment where upgrading and recovery are needed [11,31].

Extensive research was performed ranging from synthesis of nanocatalysts to pilot plant application for ex-situ and in-situ upgrading processes at the University of Calgary. However, there is still long way to investigate all aspects of these nanocatalysts properties and performances. Here, we briefly review what are known about nanoparticles and their behavior as adsorbent/catalysts for heavy oil upgrading and recovery as well as possible challenges for future implementations. We also discuss state-of-the-science knowledge and instrumentations related to nanocatalysts implementation for upgrading and recovery of Athabasca bitumen. It should be noted here that a comprehensive discussion of the applications of nanotechnology to heavy oil upgrading and recovery is beyond the scope of this article. The main objectives here are to discuss the opportunities and challenges of using nanoparticles as adsorbent/catalysts in the upgrading and recovery of heavy oil.

2. In-situ prepared ultradispersed nanoparticles

Placement of catalysts inside the porous media is one of the important steps to apply the idea of "underground refinery" for