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Review article

In-situ heavy and extra-heavy oil recovery: A review

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HIGHLIGHTS

- A review of the existing in-situ heavy oil recovery techniques is presented.
- Various aspects of traditional recovery methods are systematically discussed.
- The in-situ catalytic upgrading and recovery of heavy crude oil is elaborated.
- Standards and methodologies are summarized to establish the technological criteria.

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ABSTRACT

Due to the growing global energy demand and increasingly limited availability of conventional or easy-to-produce crude oils, extensive attention is being paid to the exploitation of unconventional heavy and extra-heavy oils. However, their inherent properties, characterized by high viscosity and poor mobility, coupled with the complex reservoir configuration, make the desired recovery processes very challenging. Although several *in-situ* recovery techniques have been employed in oil reservoirs worldwide, most of them are still suffering from low sweep and displacement efficiencies, high capital investment, potential formation damage and negative environmental footprints.

This paper aims to provide a comprehensive review of the existing *in-situ* heavy oil recovery techniques, which fall into three categories of thermal injection, chemical injection and gas injection. Different aspects including the fundamental principles, main features, applicability, and limitations of these recovery processes are elaborated sequentially to illustrate the current technology status. Underlying mechanisms causing the relatively low recovery factors will also be pinpointed. Furthermore, this paper focuses on the technology using novel and active catalysts for simultaneous heavy oil upgrading and recovery, especially in the case of metallic nanocatalysts. Rationales, advantages and challenges regarding this *in-situ* catalytic upgrading technology will be extensively described for their potential implementation in fields. It is noteworthy that many recovery techniques are still limited to the laboratory scale with needs for further investigations. Therefore, this paper also covers the evaluation standards and analytical methodologies of heavy and extra-heavy oil recovery to establish experimental screening criteria. In the end, economic and environmental aspects of the *in-situ* catalytic upgrading technology have been briefly discussed. The objective of this review is to present a wide range of expertise related to the *in-situ* heavy oil recovery processes, and to introduce the *in-situ* catalytic upgrading technology as an effective and environmental friendly heavy oil recovery process.

Contents

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1. Introduction

Projection of the oil demand by the Organization of the Petroleum Exporting Countries (OPEC) will reach 111.1 million barrels per day by 2040, with a 23.1% increment compared to current data [1]. Meanwhile, the consumption of conventional light oils has resulted in declining reserves of these resources. As fossil fuel will remain to be the main energy source for the coming decades, there is an urgent need to exploit alternative fossil resources. Therefore, substantial efforts have been devoted to the effective production of heavy and extra-heavy (i.e., natural bitumen or oil sands) oils from reservoirs, which account for ca. 70% of total world oil reserves [2,3].

Compared to the production of conventional oils, heavy oil recovery is more problematic due to the inherent properties, such as high viscosity or even immobility, high carbon/hydrogen (C/H) ratios and high heteroatom contents [4,5]. Complex formation configuration could also add additional difficulty in the oil production. Notwithstanding, the key mechanism for effective recovery has been identified to be the oil viscosity reduction and the resulting improved oil mobility. With this in mind, according to the temperature-viscosity correlation, various external energy sources are supplied to heat up the heavy oils, which eases their flow and extraction from the underground. Traditionally, oil production is divided into three steps: primary, secondary and tertiary recoveries. In the production of heavy oils, primary and secondary recoveries are dominated by cold production and water flooding, as in the cases of Canadian oil sands, Venezuelan heavy oils and UK Continental Shelf. These recovery methods are however either limited to relatively shallow reservoirs or only effective to lighter heavy oils [6]. To realize a high recovery factor, tertiary recovery, or more widely known as enhanced oil recovery (EOR), is rather critical and necessary to extract more oils left behind by the primary and secondary recoveries.

Until recently, a variety of EOR techniques have been proposed and developed, which can be conveniently classified into thermal, chemical and gas injection [6,7]. Among these methods, thermal injection is recognized as an effective one with high recovery factors up to 70% of the original oil in place (OOIP). Typical thermal recovery includes steam-assisted gravity drainage, cyclic steam stimulation and *in-situ* combustion. However, these technically successful methods are still challenged both economically and environmentally because of high cost of heat supply along with excessive carbon dioxide (CO_2) emission and costly post-treatment and maintenance [8]. Chemical and gas injection are also, to some extent, commercially viable, especially the CO_2 flooding, which is gaining considerable interest recently due to its potential for CO_2 sequestration. Unfortunately, these methods are often suffering from poor mobility control and severe viscous fingering, resulting in insufficient sweep and displacement efficiencies. Due to the high interfacial tension (IFT) and distinct viscosity contrast between displacing fluid and oil, particularly in terms of bitumen or oil sands, these techniques are usually ineffective and far from commercial expectations [4]. The above-mentioned obstacles thus have become the driving forces behind the desire for a better recovery solution.

Simultaneous recovery and upgrading of heavy oils in reservoirs using thermal recovery along with injection of active catalysts are emerging as a promising technology that combines the advantages of both thermal recovery and *in-situ* catalysis [9–11]. Growing interests are being dedicated to investigate the feasibility of applying active catalysts for *in-situ* heavy oil recovery, especially metallic nanoparticle assisted recovery method [12]. The integration of nanotechnology with enhanced heavy oil recovery could provide a novel pathway and have the potential to achieve higher recovery efficiency and better recovery factor. In this review, a chapter will specially focus on different aspects of the nanoparticle-assisted recovery in detail compared to other recovery methods.