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Review

Biotechnology in the petroleum industry: An overview

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A R T I C L E I N F O

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A B S T R A C T

A significant quantum of crude oil is trapped in reservoirs and often unrecoverable by conventional oil recovery methods. Further downstream, the petroleum industry is facing challenges to remove sulfur, metal, nitrogen as well as undesirable organic compounds from the crude.

Conventional secondary recovery methods such as water and gas injections helped to increase the productivity of the well, while chemical and physical refinery processes such as hydrodesulfurization, desalting, and high-pressure high-temperature hydrotreating remove most inorganic impurities. The increasing demand for oil in the world coupled with very stringent environmental laws piled economical and technical pressure upon the refinery industry to further improve crude oil recovery as well as reduce sulfur, metal and nitrogen concentration to the low ppm levels.

In the search for economical and environmentally friendly solutions, growing attention has been given to biotechnology such as the use of microbial enhanced oil recovery (MEOR). MEOR is an alternate recovery method that uses microorganisms and their metabolic products. In addition, the emerging field of crude oil refining and associated industrial processes such as biodesulfurization, biodemetallation, biodenitrogenation and biotransformation are also covered.

This review aims to provide an overview on MEOR and biorefining relevant to the petroleum industry and highlights challenges that need to be overcome to become commercially successful. Literature pertaining to laboratory experiments, field trials and patents are included in view of industrial applications and further developments.

Contents

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1. Introduction

Most economies rely currently on products from crude oil, and inadequate oil resources can jeopardize a countries development and elevate living costs. With the increased consumption of oil by developing countries has increased the demand and price for oil in the world market. The forecast of global energy use by the OECD (Organisation for Economic Co-operation and Development) and Non-OECD countries between 2006 and 2030 (USA EIA, 2009) shows an increase of 15.5% and 73% respectively for oil with the existing energy resources. With the steady increase in demand for oil, the prospective alternatives are exploration of new sources of energy or utilization of enhanced oil recovery (EOR) techniques in poor performing and depleted oil wells.

Different EOR processes are currently employed in the oil industry for the extraction of trapped oil. The EOR method used depends on the characteristics of the crude oil in the oil reservoir. EOR processes fall under the broad classification of thermal (steam flood, combustion and hot water injection), chemical (injection of polymers, surfactants and alkali) and gas injection (CO_2, N_2 and flue gas) (Sen, 2008). In the thermal recovery process heat is added to the reservoir to decrease the oil viscosity and/or to vaporize the oil. The natural temperature of oil reservoirs reported in literature varies from 10 °C in the on average 27 m deep Canadian Athabasca oil sands (Harner et al., 2011) to 124 °C (Brown, 2010) with the majority between 40 and 80 °C (Li et al., 2002; Hao et al., 2004; Ghojavand et al., 2012; Zhang et al., 2012a). Reservoir temperature will rise by 10s–100s of degree Celsius depending on the method used, reservoir characteristics, prevailing heat transport mechanism, duration and temperature of heat supply. The application of thermal techniques, particularly fire flooding, can, however, produce polar compounds such as carbenes and carboids which are incompatible with asphaltenes and capable of causing blockages of the pores and channels through which the oil must move during recovery (Speight, 1999). In the chemical recovery process chemicals are used to extract oil from pores in the oil-bearing rocks and alter its characteristics. The gas injection method utilizes various types of gases miscible or immiscible to displace oil to the extraction point. The major drawbacks of thermal and chemical methods are the high energy requirement and chemical costs. In the case of gas injection, availability of gases at high pressure needs to be considered. Recently in the US there is an increasing trend towards thermal and gas injection EOR projects compared to chemical methods (Alvarado and Manrique, 2010).

A promising alternative oil recovery approach is microbially enhanced oil recovery (MEOR). This has been suggested as early as 1926 by Beckman (Donaldson et al., 1989) and involves the use of microorganisms to enhance oil production. The MEOR constitute injection of microorganisms with essential nutrients into the oil well, and under favorable environmental conditions microbial population grows exponentially and their metabolic products mobilize the residual oil. With the availability of favorable microbes in-situ, injection of nutrients is feasible as reviewed by Gao and Zekri (2011). These microbes are capable of producing a broad range of metabolic products, and their growth and effects depend on factors such as: (1) porosity and permeability, pressure, temperature, dissolved solids, pH and salinity of the reservoir, (2) nutrients provided to the bacteria and (3) specific type of microorganisms injected into the reservoir (Doghaish, 2008; Wang et al., 2008). Metabolic products and applications of microbes in oil reservoirs are given in Fig. 1.

Biotechnological applications can be further extended to MEOR from oil sands (Harner et al., 2011) and the petroleum refinery industry, where microorganisms may be used in refining crude oil (biorefining, Fig. 2). MEOR from oil sands is still in the research

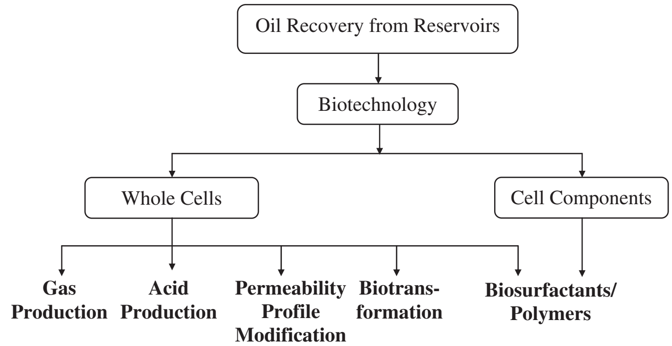

Fig. 1. Potential applications of biotechnology in the recovery of oil from reservoirs.

stage due to its novelty and unique environmental challenges (low water availability, high hydrocarbon concentration) (Harner et al., 2011).

This review aims to provide an insight and critically discuss the potential and commercial applications of biotechnology in the petroleum industry with particular focus on oil recovery from reservoirs and downstream biorefining.

2. Oil recovery from reservoirs

The majority of energy requirements in the world are currently met by non-renewable fossil fuels. The dwindling rate of discovery of new oil fields makes it necessary to maximize the oil recovery from existing or abandoned fields (Brown and Vadie, 2000; Kerr, 2000; Mehta and Gair, 2001; Giles, 2004).

Primary recovery is the first oil that is produced under natural pressure, which causes the oil to flow from the site of formation to the surface. It is the least expensive method of production and accounts for 20% of original oil in place (OOIP) in reservoirs worldwide (Sandrea and Sandrea, 2007). Secondary recovery is used when there is a fall in the reservoir's natural pressure. The pressure is commonly increased by either water or gas injection. These methods are more expensive than the primary recovery (Table 1) and accounts for additional recovery of 45–50% of OOIP (Sandrea and Sandrea, 2007). It is estimated that approximately 58% of total oil available in the USA is unrecoverable by deploying current technologies (Table 2) and offers a large potential to improve or develop new oil recovery methods. Tertiary or EOR methods include thermal and chemical processes applying solvents, surfactants, micro-emulsions (Santanna et al., 2009), starch/cyclodextrin based synthetic polymers (Leslie et al., 2005) and microbiologically produced polymers such as Xanthan gum (McInerney et al., 2003) to produce an additional 7–15% of OOIP (Sandrea and Sandrea, 2007). From the techniques available or currently under development, MEOR is environmentally friendly

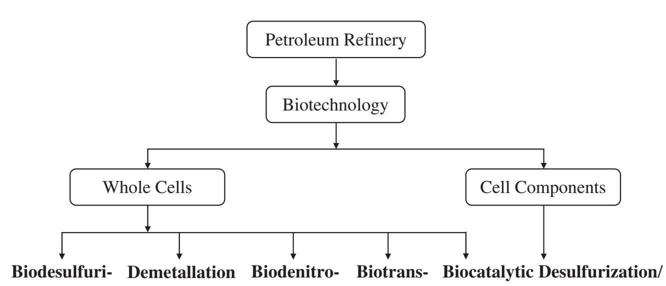

Fig. 2. Potential applications of biotechnology in petroleum refinery.