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1. Introduction

The U.S. Energy Information Administration (EIA) predicts that the global energy consumption will increase by nearly 50% between 2020 and 2050 [1]. This is due mainly to the required industrial development to meet the rapid increase of the world’s population, which is projected to reach about 9.7 billion by 2050, an increase of approximately 1.8 billion between now and then [2]. In 2020, the crude oil was the most-used energy source, accounting for more than 31% of the world’s total primary energy consumption, which includes (oil, natural gas, coal, hydroelectric, nuclear energy, and renewables) as given in Table 1 [3]. In 2021, the crude oil global demand is estimated to reach 108.2 million barrels per day (bpd) in 2045, which represents an increase of 176 million bpd between 2020 and 2045 [4]. Therefore, it is expected that crude oil production will continue to grow to support the predicted increase in energy consumption. Crude oil reserves, however, are depleting, and new discoveries of easy-to-find crude oil fields are becoming more difficult. Hence, improving oil recovery from the existing and depleted mature petroleum reservoirs through advanced recovery techniques has become a vital scheme in the oil and gas industry.

During the primary (natural drive and artificial lift) and secondary (waterflooding and immiscible gas injection) oil recovery stages, roughly one-third of the original oil-in-place can be recovered from mature reservoirs, implying that significant amounts of crude oil are left unrecovered following these two recovery stages. The remaining oil in the reservoirs is attributed to the low oil mobility and poor displacement efficiency, directly related to the high oil viscosity and surface tension, as well

<table>
<thead>
<tr>
<th>Primary energy</th>
<th>Billion bbl (oil equivalent)</th>
<th>Share of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>28.47</td>
<td>31.3%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>22.49</td>
<td>24.7%</td>
</tr>
<tr>
<td>Coal</td>
<td>24.75</td>
<td>27.2%</td>
</tr>
<tr>
<td>Nuclear energy</td>
<td>3.92</td>
<td>4.3%</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>6.24</td>
<td>6.9%</td>
</tr>
<tr>
<td>Renewables</td>
<td>5.18</td>
<td>5.7%</td>
</tr>
<tr>
<td>Total</td>
<td>91.04</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

*(1 bbl of crude oil = 5.8 million BTU).*

Table 1.
World primary energy consumption by fuel in 2020 [3].
as unfavorable interfacial fluid/fluid and fluid/rock properties. Therefore, tertiary recovery or enhanced oil recovery (EOR) methods have been thoroughly investigated and implemented to boost the production of the immobile oil left in the reservoirs by improving the microscopic and macroscopic (volumetric) sweep and oil displacement efficiencies.

EOR methods can be broadly classified into four major groups: thermal, chemical, miscible, and other methods. The thermal recovery methods primarily apply thermal energy (sensible heat) to heavy and highly viscous oil reservoirs as well as tar sands to reduce the oil viscosity, thus increasing its mobility. Examples of thermal recovery methods are steam injection, in-situ combustion (fire-flooding), and cyclic steam stimulation (huff-and-puff). Thermal recovery methods are well-established and have proven worldwide as successful EOR techniques. Among all thermal EOR processes, the steam injection has been remarkably successful and more commonly used due to its better control and improved heat transfer efficiency compared with other thermal recovery methods.

2. Classification of EOR Processes

The chemical recovery methods rely on using a wide variety of chemicals, such as surfactants, alkaline solutions, polymers, etc. The objectives of the chemical methods include reducing the oil/water interfacial tension, altering the rock wettability, and increasing the injected water viscosity to prevent viscous fingering and improve the overall oil sweep efficiency.

The miscible methods include the injection of a gas, such as carbon dioxide (CO\textsubscript{2}), light hydrocarbon (CH\textsubscript{4}), and nitrogen (N\textsubscript{2}) into the reservoir. The injected gas completely mixes with the in-situ oil (at the first contact or after multiple contacts) when the reservoir pressure is greater than the minimum miscibility pressure (MMP). The objective of the miscible methods is to reduce the interfacial tensions between crude oil, water, and the rock, which significantly enhances the oil microscopic displacement efficiency. The CO\textsubscript{2} injection method for miscible oil recovery is gaining increasing interest in the oil and gas industry because, in addition to its high oil recovery, some CO\textsubscript{2} could be retained or lost in the reservoir, thus decreasing its devastating impact as a greenhouse gas (GHG) on humans and the environment.

The other EOR methods include microbial (MEOR), nanoparticles, electromagnetic heating, and smart water injection. Despite their growing popularity, however, most of these emerging methods are still in the trial stage. Many of them are attracting research interest, but due to their implementation challenges in oil fields, they are not expected to impact the global oil production in the near future.

 Nonetheless, it is well-known that oil production using EOR methods has been strongly correlated with economics and crude oil prices; however, the general trend of the EOR market has been increasing despite the tumultuous economic environments over the past decades. Thus, we believe that EOR market will continue to grow and play a key role in meeting the growing worldwide energy demand in the years to come despite the current environmental concerns and the ongoing transition to renewables, such as solar energy, biomass, and wind energy. We also believe that in the foreseeable future, renewables and nuclear energy alone will not be enough to replace the other primary energy sources and sustain or meet the growing energy demand of the steadily increasing world population.
Author details

Hseen O. Baled* and Badie I. Morsi
University of Pittsburgh, United States of America

*Address all correspondence to: hob9@pitt.edu

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References


