Extending CO\textsubscript{2} EOR and Associated Storage to Low-Pressure Oil Reservoirs by Adding Rich Gas Components to the Injection Stream

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Abstract

Based on the International Energy Agency Global Energy Review, around 33 Gt (billion tonnes) of CO\textsubscript{2} will be emitted globally by the end of 2021. In addition, climate change caused by this greenhouse gas has become a critical issue to be solved. A variety of dedicated and associated CO\textsubscript{2} storage projects have been successfully implemented to demonstrate the feasibility of high-volume CO\textsubscript{2} sequestration in different geologic environments, including saline aquifers and oil reservoirs. With readily available infrastructures and well-characterized reservoir properties, depleted oil reservoirs with deep formation depths are considered good candidates for CO\textsubscript{2} enhanced oil recovery (EOR) and storage operations since miscible EOR could be conducted under high pressure. However, there are also many shallow oil reservoirs with lower allowable injection pressures, which makes miscible EOR challenging to perform because of the risk of fracturing the formations. A significant quantity of CO\textsubscript{2} could be stored in these low-pressure reservoirs if CO\textsubscript{2} EOR can yield economical oil production. A systematic study covering different aspects of the CO\textsubscript{2} EOR and storage process was performed to investigate the potential of extending CO\textsubscript{2} EOR to low-pressure oil reservoirs by adding rich gas components to the injection stream.

The literature survey showed that shallow reservoirs are widely distributed in the United States. For instance, around 68% of the reported conventional reservoirs in the Appalachian Basin have formation depths less than 2000 ft. These reservoirs cover over 774,000 proven acres with more than 12.35 billion barrels (bbl) of original oil in place. The majority of these reservoirs have a low oil recovery factor (<25%) after primary depletion and waterflooding operations, which leaves billions of barrels in the reservoirs. The reservoir pressure was reduced to a very low level: less than 500 psi in most of the reservoirs after waterflooding. These low-pressure reservoirs could have great potential for economic CO\textsubscript{2} storage associated with lower-carbon-intensity oil production if CO\textsubscript{2} EOR can be utilized.

The production of hydrocarbon gas increased dramatically in the United States with the development of unconventional resources in the last decade. For instance, the gas production rate in the Bakken Formation reached 3 billion cubic feet per day (Bcf/d) in October 2021. Based on the PVT (pressure, volume, temperature) analysis data across the main oil-producing areas in the Bakken, the produced gas contains 15–22 mol\% of ethane (C\textsubscript{2}), 10–18 mol\% of propane (C\textsubscript{3}), and 4–8 mol\% of butane (C\textsubscript{4}); these components make the gas quite rich. According to the data released by the U.S. Energy Information Administration, the hydrocarbon gas liquids production in U.S. gas plants reached around 1.9 billion bbl in 2020. Field practices showed that rich gas (or natural gas liquids) with a high
percentage of C2–C4 could effectively recover oil from reservoirs with relatively low pressure. Experimental work was performed to study the interactions between oil and different gases. Results showed that rich gas components can make oil flow easier under low-pressure reservoir conditions by effectively reducing the gas/oil interfacial tension and minimum miscibility pressure compared to CO2 flooding. Gas extraction experiments also showed that ethane and propane could recover more than 90% of oil hydrocarbons from rock samples at a pressure of around 1500 psi, while CO2 could only recover 30% at the same pressure. Both experimental and field data indicate that adding rich gas components to the CO2 injection stream may improve the EOR performance in reservoirs where miscible flooding is difficult to achieve using CO2 alone.

A series of simulation activities were performed to investigate the potential CO2 EOR and storage improvement by adding rich gas components to the CO2-flooding process. To ensure the CO2-rich gas–oil interactions can be captured in the simulation, reservoir and fluid data were collected from the Wasson Field, where CO2 EOR has been implemented since 1983. An 11-component equation-of-state, with all gas composition separated, was employed in the study so that a variety of rich gas–CO2 mixtures can be considered in the simulation process. A wide range of reservoir pressure and temperature was considered in the simulation process to cover different reservoir conditions in the EOR processes. Simulation output was analyzed to reveal the effects of different rich gas components on oil recovery and CO2 storage performance. Results showed that adding rich gas components (C2, C3, C4, or their combinations) to the CO2 injection stream could increase the miscible level between oil and gas and, thus, improve EOR performance when reservoir pressure is low. For instance, adding 30 mol% of butane to the injection gas stream could improve oil recovery by 37% compared to pure CO2 flooding alone and store 2 million tonnes of CO2 in a 280-acre spacing over 40 years of operations with a maximum injection pressure of 1000 psi.

**Keywords:** CO2 EOR; CO2 storage; miscible CO2 flooding; low-pressure oil reservoirs; rich gas EOR