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Experimental Investigation of Oil Recovery From Siliceous Shale by CO_2 Injection

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Abstract

Enhanced oil recovery from fractured low permeability reservoir rock is challenging and while studied previously, significant challenges remain in improving the recovery factor. In many cases the reservoir has been pressure depleted and gas released from solution. In such cases, continuous gas pathways from fracture to the matrix may have been created aiding our ability to deliver gas to the matrix. Gas injection (i.e., CO_2) then proceeds from immiscible to perhaps miscible conditions. The efficiency of gas transport to the low permeability matrix is limited by the presence of a gas phase in the matrix, injection pressure, and cocurrent or countercurrent flow conditions, among others.

This work presents the results of a series of experiments using low permeability (0.02 – 1.3 mD), medium porosity (30 – 40 %) siliceous shale reservoir core samples initially saturated with either: live oil, depleted to a pressure of 200-300 psi; or dead oil brought to near miscible conditions; followed by CO_2 injection at pressures proceeding from immiscible to CO_2 near miscible conditions. Two gas injection modes were used: CO_2 flow across one face of the core (countercurrent flow) which intends to account for the diffusive transfer mechanism; and CO_2 flow along the length of the core (cocurrent injection). The experimental setup was monitored using X-ray computed tomography that helped to visualize phase flow and distribution during the processes.

The incremental oil recovery caused by the immiscible CO_2 injection ranged from 0-10% for countercurrent flow mode and from 18-25% for cocurrent flow mode, whereas for near miscible conditions the recovery was found to be 25% for the countercurrent flow mode and 10% for the cocurrent flow mode. Countercurrent recovery appears to be critically sensitive to the distribution of the gas phase near the fracture face. Oil recovery potential by CO_2 injection into siliceous shale rock is challenged by low permeability, rock heterogeneities, distribution of oil within the rock matrix, but it is aided by the presence of continuous gas pathways that allow CO_2 penetration into the matrix. Near miscible injection displays clear multiple contact miscibility; also countercurrent flow seems to exhibit a greater recovery under near miscible as compared to immiscible conditions.

Introduction

Improving oil production from low permeability resources is strategically important. For instance, it is estimated that about one half of the worldwide petroleum resource is found in fractured siliceous and carbonaceous formations, yet fractured resources make up only roughly 20% of reserves (Saidi, 1983). As a greater number of reservoirs have matured and are reaching abandonment, recovery options are needed for more difficult to produce hydrocarbon settings. Examples of sizeable low permeability hydrocarbon resources include the Monterey Shale (CA, USA), West Texas Carbonates, the North Sea Chalks, and the Asmari Limestone (Iran). This paper is mainly concerned with enhancing recovery from the various units of the Monterey Formation that are biosiliceous and marine in origin, but we believe our work to be relevant to gas injection in the other rock types.

In the San Joaquin Valley (CA), the uppermost productive member of the Monterey is the so-called Diatomite and includes fields such as South Belridge and Lost Hills. As depth increases, the rock has undergone diagenesis and transitions from amorphous to semi-crystalline opal. Beneath the Diatomite lie various siliceous shales such as the Brown and Antelope. Generally, metamorphism due to burial of diatomaceous oozes has led to first to opaline cristobalitic chert and porcelanite and with greater depth and time to quartzitic chert and porcelanite (Bramlette, 1946; Murata and Nakata, 1974). Burial diagenesis leads to loss of porosity and permeability, but to rock phases with greater thermodynamic stability.