Investigation of Pore-scale Mechanisms of Microbial Enhanced Oil Recovery (MEOR) using Microfluidics Application

C.L. Gaol*, J. Wegner*, L. Ganzer*, N. Dopffel**, F. Kögler***, A. Borovina***, H. Alkan***
*TU Clausthal, **BASF SE, Ludwigshafen, *** Wintershall Holding GmbH, Kassel

Abstract

Utilization of microorganisms as an enhanced oil recovery (EOR) method has attracted much attention in recent years because it is a low-cost and environmentally friendly technology. However, the pore-scale mechanisms involved in MEOR that contribute to an additional oil recovery are not fully understood so far. The aim of this work is to investigate the MEOR mechanisms using microfluidic technology, among others bio-plugging and changes in fluid mobilities. Further, the contribution of these mechanisms to additional oil recovery was quantified.

A novel experimental setup that enables investigation of MEOR in micromodels under elevated pressure, reservoir temperature and anaerobic and sterile conditions was developed. Initially, single-phase experiments were performed with fluids from a German high-salinity oil field selected for a potential MEOR application: Brine containing bacteria and nutrients was injected into the micromodel. During 10 days of static incubation bacterial cells and in-situ gas production were visualized and quantified by using an image processing algorithm. Thereafter, injection of tracer particles and particle image velocimetry were performed to evaluate flow diversion in the micromodel due to bio-plugging. Differential and absolute pressures were measured throughout the experiments. Further, two-phase flooding experiments were performed in oil wet and water wet micromodels to investigate the effect of microbial in-situ growth on oil recovery.

Bacteria growth was clearly observed in the micromodel. During the injection, cells were partly transported through the micromodel but also remained attached to the model surface. These microscopic observations of bio-plugging were confirmed by the differential pressure increase. In addition, the resulting permeability reduction factor correlated with calculations based on the Kozeny-Carman approach using the total number of bacteria attached. The flow diversion of the tracer particles and the velocity field difference also confirmed that bio-plugging occurred in the micromodel which may lead to an improved conformance control. Oil swelling due to gas dissolution as well as changes in the wettability were also identified to contribute on the incremental oil. Two-phase flow experiments in a newly designed heterogeneous micromodel showed significant effect of bio-plugging and improved the macroscopic conformance of flooding process in the micromodels.

This work gives new insights of the pore-scale mechanisms of MEOR processes in porous media. The developed microfluidic experimental setup enables the investigation of these mechanisms under defined reservoir conditions, i.e. elevated pressure, reservoir temperature and anaerobic conditions.