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Modeling DME-Water Flooding and Feasibility Study of Using this Method for Enhanced Oil Recovery in the Condition of a Heavy Oil Reservoir

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INTRODUCTION

Most of the current world oil production comes from mature reservoirs which faced oil production decline problem. In addition, the rate of replacement of the produced reserves by new discoveries has been declining steadily [1]. Several enhanced oil recovery (EOR) methods including water flooding, solvent injection and chemical injection were applied to compensate oil production decline problem. Generally, large volume of original oil in place (OOIP) is leaving un-swept in the reservoirs after primary recovery period. Conventional water flooding is a common method to produce extra oil which is applied as a secondary recovery method. But because of considerable difference between reservoir oil and injected water mobilities in heavy oil reservoirs, conventional water flooding exhibited an insufficient performance [2]. Moreover, one of the possible solutions for improving the performance of conventional water flooding is to add the Mutual Soluble Solvents (MSS) into the injected brine [3]. During recent years, application of Dimethyl Ether (DME) as a mutual soluble solvent received more attention in the EOR studies [4]. DME is the simplest alkyl ether, and is considered the isomer of ethanol which exists in the vapor phase at ambient condition. However, it is liquefied at room temperature as the pressure increases. DME is colorless and almost non-toxic [5]. DME was chosen as a solvent agent because of its unique preference for miscibility in the oil, and its ability to be dissolved in water [6]. Through a Dimethyl Ether enhanced water flooding (DEW) process, an aqueous phase involving dissolved DME in brine is injected into the formation.

Upon the injected water contacts with the reservoir oil, the DME partitions to the oil and form an oleic phase. Therefore, the reservoir oil swells and its viscosity decreases [3-4]. The combination of these effects mobilizes the residual oil toward the production wells leading to a higher ultimate oil recovery achieved by DEW than that achieved by conventional water flooding, hence the residual oil saturation decreases through DEW [6-8].

MODELING WORKFLOW

During a DME-brine-oil displacement, there are two phases with three components. To understand the effects of DEW technique on the oil production, a one dimensional, linear, two-phase and three components, incompressible fluid flow model was constructed. The mass balance of all components (DME, brine and oil) existing in DEW leads to a system of four partial differential equations as:

$$\phi\frac{\partial(S_a V_{aw})}{\partial t}+\frac{\partial(u_a V_{aw})}{\partial x}-\frac{\partial(\phi S_a D_{ad}\frac{\partial V_{aw}}{\partial x})}{\partial x}=0 \quad (1)$$

$$\phi\frac{\partial(S_o V_{oh})}{\partial t}+\frac{\partial(u_o V_{oh})}{\partial x}-\frac{\partial(\phi S_o D_{od}\frac{\partial V_{oh}}{\partial x})}{\partial x}=0 \quad (2)$$

$$\phi\frac{\partial(S_a V_{ad})}{\partial t}+\frac{\partial(u_a V_{ad})}{\partial x}-\frac{\partial(\phi S_a D_{ad}\frac{\partial V_{ad}}{\partial x})}{\partial x}=0 \quad (3)$$

$$\phi\frac{\partial(S_o V_{od})}{\partial t}+\frac{\partial(u_o V_{od})}{\partial x}-\frac{\partial(\phi S_o D_{od}\frac{\partial V_{od}}{\partial x})}{\partial x}=0 \quad (4)$$

where Sx refers to the saturation of the phase x, aqueous (x=a) and oleic (x=o), Vxz is the volume fraction of component z, brine (z=w), oil (z=h), DME (z=d), in the phase x, Dxs is the molecular-diffusion coefficient of DME in phase x, D_{xz} is the porosity, and ux is the Darcy velocity of phase x. Also, Table 1 gives a summary of input parameters used in the modeling study.

Table 1: Input parameters used in the base case numerical model.

Parameter	Description
Rock type	sandstone
Permeability (μm^2)	0.197
Porosity (%)	20
Initial water saturation (%)	33
Residual oil saturation (%)	20
Oil viscosity (cP)	20
DME partition coefficient (-)	1
Molecular diffusion coefficient of DME in water (m^2/s)	8×10^{-10}
Molecular diffusion coefficient of DME in oil (m^2/s)	3×10^{-11}
DME concentration (vol/vol%)	35

RESULTS AND DISCUSSION

In Figure 1, water saturation profile vs. dimensionless length after 0.25 pore volume (t_D= 0.25) of DEW injection is illustrated. In addition, water saturation profile is somewhat different in comparison with that of conventional water flooding, for instance, in a DEW process two fronts exist in fractional flow curve. Let us consider fractional flow corresponding to t_D= 0.25. At the far right, the saturation profile is similar to that of conventional water flooding, i.e. there is first water front, which is related to the DME-free water. The second front is shown at the left side in the region of high DME concentration, the water saturation is larger than it would have been for a conventional water flooding. The recovered oil from this region flows forward and forms the region of constant water saturation, which can be called oil bank, i.e. the extra oil driven ahead of the second water front. The second shock frontal advancement drives the oil bank toward the production well and causes an additional oil recovery on top of conventional water flooding.

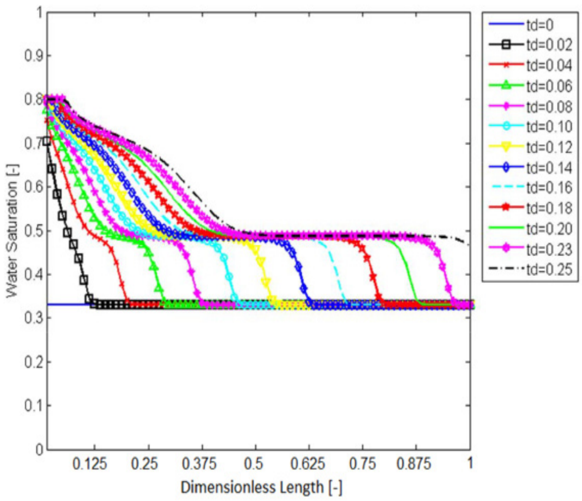

Figure 1: Water saturation profile vs. dimensionless length during DEW displacement after 0.25 PV injection.

Figure 2 illustrates the profile of DME concentration in the oleic phase vs. dimensionless length after 0.25 pore volume of DEW injection. The numerical solution involves a constant concentration state (maximum concentration of 35 v/v%) at upstream, a shock region followed by a zero DME concentration at downstream. Moreover, as time passes, the shock front becomes more diffusive. In addition, this can be attributed to the DME transport from DME-rich oil region to DME-free oil region due to the molecular diffusion. Moreover, an increase in DME concentration in the oleic phase has two effects, e.g. it reduces oil viscosity and increases the volume of the oleic phase.

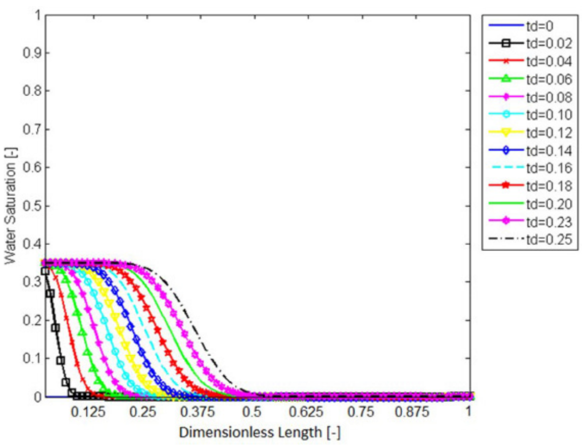

Figure 2: DME concentration profile in the oleic phase vs. dimensionless length during DEW displacement after 0.25 PV injection.

Figure 3 shows oil recovery factor vs. cumulative injected aqueous phase during conventional water flooding (WF) and DEW. Until breakthrough of the first water front, that occurs almost at t_D=0.25, both WF and DEW processes obtained the same oil recovery value (35% of the OIIP was recovered). After that (0.25<t_D<0.80), in DEW process, the presence of DME leads to an oil bank formation and the frontal advancement of the second water front pushes the oil bank toward production well and thus an incremental oil is obtained on top of conventional water flooding (approximately 60% and 43% of oil recovery factor in DEW and WF at t_D=0.8 respectively).

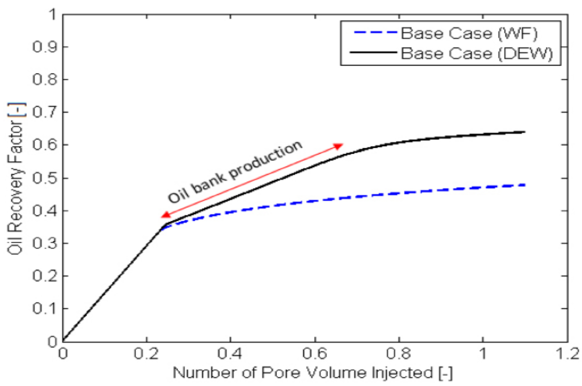

Figure 3: Oil recovery factor vs. cumulative injected aqueous phase during WF and DEW

In this study, we discussed DME/brine-oil displacement in a heavy oil sandstone reservoir to investigate the improvement of oil recovery. Moreover, results showed DME can be transferred from the aqueous into the oleic phase and thus lead to formation of an oil bank. As to oil recovery, it was found that DME- enhanced water (DEW) flooding increases and accelerates oil production as compared to conventional water flooding. Results also showed that the impact of oil viscosity reduction mechanism is more important than the impact of oil swelling in the recovery of heavy oil by the DEW process.

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