PHYSICAL MODEL EXPERIMENTS TO EVALUATE THE EFFECT OF WETTABILITY AND FRACTURES ON THE PERFORMANCE OF THE GAS ASSISTED GRAVITY DRAINAGE (GAGD) PROCESS

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This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Calgary, 10-12 September, 2007

ABSTRACT

Previous experimental work on the Gas Assisted Gravity Drainage (GAGD) process demonstrated its effectiveness of improving the oil recovery when applied in water-wet porous media. The current research is an extension and is focused on evaluating the effect of the wettability of the porous medium and the presence of a (vertical) fracture on the GAGD performance. The effect of the injection strategy (secondary/tertiary mode) on the oil recovery was also evaluated. In the physical model experiments a Hele Shaw type model was used with glass beads/silica sand as the porous medium. Silanization with dimethydichlorosilane was used to alter the wettability of the porous medium from water-wet to oil-wet.

The experiments showed a significant improvement of the oil recovery in the oil-wet experiments versus the water-wet runs, both in the secondary as well as the tertiary mode. The experiments in which the presence of a fracture was simulated have also shown the positive effect of a vertical fracture on the GAGD oil recovery.

1. INTRODUCTION

Within the period of 1986 till 2006 the number of miscible CO_2-injection projects has increased from 38 to 80. Although the total number of gas injection projects has declined, the share of production from gas injection enhanced oil recovery (EOR) in the United States has tripled from 18% in 1986 to 54% in 2006 (Moritis, 2006). This demonstrates the growing commercial interest in gas injection projects by the oil industry.

The accepted practice in the oil industry is the Water Alternate Gas (WAG) process. First proposed by Caudle and Dye in 1958, it still remains the default option for mobility control in horizontal gas floods. Mobility control is one of the biggest factors affecting the success of a gas injection project, because the viscosity of the injected gases generally is less than one-tenth of that of the reservoir oil. Christensen et al. (1998) have shown that in the majority of the 59 WAG field projects the incremental oil recovery was in the range of 5 – 10% (with an average of 9.7% for miscible and 6.4% for immiscible WAG

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projects). Kulkarni (2004) reviewed nine commercial gravity stable gas floods in pinnacle reefs and/or dipping reservoirs and showed that all the gravity stable floods were highly successful in recovering residual oil from these reservoirs. These results indicate the benefit of working with nature by making use of the buoyancy rise of the injected gas to displace fluids downwards.

The concept behind the GAGD process is that gas injected in vertical wells accumulates at the top of the payzone due to gravity segregation, thus displacing fluids to the horizontal producer straddling several injection wells near the bottom of the payzone (see Figure 1). The gas chamber grows downwards and sideways resulting in larger portions of the reservoir being swept without any increase in the water saturation in the reservoir, thus maximizing the volumetric sweep efficiency. The gravity segregation of the injected gas also helps in delaying the gas breakthrough to the producer as well as preventing the gas phase from competing for flow with the oil. The process makes use of any existing vertical wells in the field for gas injection and only calls for drilling a long horizontal well for the production of the draining fluids (Rao, et al., 2004).

The use of organosilanes to alter the wettability of porous media is well established in the literature. Takach et al. (1989) used a technique in which they chemically incorporated the vapor of an organosilane onto the surface of the rocks at elevated temperature and reduced pressure. Their findings indicated that strongly oil-wet surfaces could be generated that lasted for up to 24 weeks.

2. EXPERIMENTAL SETUP AND PROCEDURE

2.1 Task Formulation

To investigate the effects of the wettability of the porous medium and the presence of a fracture on the GAGD performance, it was necessary to conduct several experimental runs using both water-wet and oil-wet porous media, with and without a simulated vertical fracture. The mode of gas injection (secondary versus tertiary) and the method of gas injection (constant gas pressure versus constant mass flow rate) were varied to study the effect of these parameters on the GAGD performance.

2.2 Procedure for Conducting the Gas Displacement Experiments

In order to alter the wettability of the glass beads/silica sand to oil-wet, a silanization of their surfaces was carried out using dimethyldichlorosilane (DMDCS) in a methylchloride solution. The glass beads/grains were immersed in the solution at ambient conditions for 10 minutes, after which they were rinsed with methanol and dried in an oven at 150 °C for at least four hours.

The Hele-Shaw type physical model consisted of two transparent plastic plates held between two aluminum frames that were bolted together using eighteen hex bolts. The dimensions of the plastic plates used in the model were 16” by 24” by 1”. The plastic plates bounded a plastic frame with an internal volume of 1445 cc and attached to it were four ports on the top and the bottom, and six ports on one side. The top and bottom ports were used as inlet and production ports respectively. The experimental setup is depicted in Figure 2. Prior to the start of each experiment the physical model was filled with sand grains or glass beads resulting in an average permeability of 5 Darcy.

The secondary mode displacement experiments were conducted according to the following steps:

- Imbibe water into the bead/sand pack.
- Displace the water with n-decane at a constant rate of 3 cc/min in a gravity-stable manner by injecting it from the top. Use a graduated glass cylinder to collect any effluent liquid during the water displacement. The end of the oil flood is reached when no more water is produced. Stop the pump.
- Initiate the gas injection from the top and leave the experiment running for a period of at least 24 hours to ensure thorough displacement and drainage of the fluids. Collect any produced fluids in the glass separator and record the fluid levels using a digital camera and a LabView data acquisition system.
- Constant pressure experiments: Perform the gas injection by using a pressurized gas cylinder and a gas pressure regulator with a pressure gauge in the injection line to ensure that the proper value of the gas pressure is used.
- Constant rate experiments: Conduct the gas displacement by using the gas mass rate controller along with a pressurized gas cylinder.

In addition, gas displacement runs were also conducted in which the presence of a fracture was simulated. This was done by placing a mesh box inside the physical model prior to filling it up with glass beads. The mesh box consisted of strip metal covered with 400-mesh sieve cloth to allow flow through it.

3. RESULTS AND DISCUSSION

The first series of experiments focused on the effect of the wettability on the GAGD performance. The second series of experiments investigated the effect of a fracture in the porous medium on the oil recovery.

3.1 The Secondary Mode Gas Displacement Experiments

Gravity drainage promises to be a very effective enhanced oil recovery method in oil-wet reservoirs because the oil phase is always present as a continuous film on the pore walls thus resulting in potentially very low residual oil saturations. This comes through in the experimental results: the change in wettability from water-wet to oil-wet appears to significantly improve the oil recovery, as can be seen from Figures 3 & 4. The average incremental production can be summarized as follows:

- Constant pressure secondary runs; 0.13 mm sand grains : 9 %IOIP.
- Constant pressure secondary runs; 0.15 mm glass beads : 8.4 %IOIP.
- Constant rate secondary runs; 0.13 mm sand grains : 14.6 %IOIP.

3.2 The Tertiary Mode Experiments

In these experiments the waterflood was conducted using demineralized water at a displacement rate of 3 cc/min.

The positive influence of the alteration of the wettability on the GAGD performance can again be seen in the tertiary mode experiments. From the gas injection recovery results it is evident that the GAGD process was more in the oil-wet glass runs: there was an average increase in oil recovery of 12.5 % of the initial oil in place (IOIP) (see Figures 5 & 6). The difference in the water production for the oil-wet experiments is because the waterflood was more effective in the oil-wet 0.13 mm sand pack as opposed to the oil-wet 0.15 mm bead pack, and thus leaving a higher water saturation at the end of the waterflood. This resulted in more water being produced in the gas injection stage of the experiment for the oil-wet 0.15 mm bead pack.

3.3 The Experiments Simulating a Fracture

These experiments focused on studying the effect of a vertical fracture in the porous medium on the GAGD performance taking into account the effect of the wettability of the porous medium.

The presence of the vertical fracture in the physical model seemed to improve the oil recovery as is evident from Figure 7. The average incremental increase in oil recovery was 6 %IOIP. The increase in oil recovery was possibly caused by the fracture present acting as a low resistance conduit for flow of the oil: the injected gas pushes the oil into the fracture giving the oil an easier way to drain out of the porous medium. On average, the incremental oil recovery was 6.7 %IOIP for the experiments using the 0.13 mm silica sand (Figure 7), and for the 0.15 mm glass bead packs the increase in the oil recovery was 10.8 %IOIP.

The wettability of the porous medium as well as the presence of the fracture had a positive effect on the GAGD performance: all of the oil-wet experiments showed higher oil recovery compared to the water-wet fractured runs. The 0.13 mm fractured oil-wet experiments showed an average incremental oil recovery of 9.6 %IOIP (Figure 8). More details can be found in Paidin (2006).

4. SUMMARY OF FINDINGS AND CONCLUSIONS

In this study, physical model experiments were conducted to study the effects of the wettability of the porous medium and the presence of fractures on the performance of the GAGD process. The physical model used was a Hele-Shaw type model incorporating either soda glass beads or silica sand as the porous medium, and n-decane and deionized water as the fluids. The porous medium was turned oil-wet through treatment with dimethyldichlorosilane. The immiscible gas displacement experiments were conducted using nitrogen and the gas displacement strategy was varied resulting in secondary and tertiary mode experiments. The presence of a vertical fracture was simulated by placing a mesh box in the model and conducting gas displacement experiments under the conditions described above.

The most important conclusions that can be drawn from the experimental results are:

1. The wettability has a positive effect on the GAGD performance: on average, the oil-wet experiments showed an increase of 12 %IOIP in the oil recovery over the water-wet experiments.
2. The presence of a vertical fracture in the porous medium improves the performance of the GAGD process. On average the presence of the fracture improved the oil recovery by 7.8 % (%IOIP) over the non-fractured experiments.

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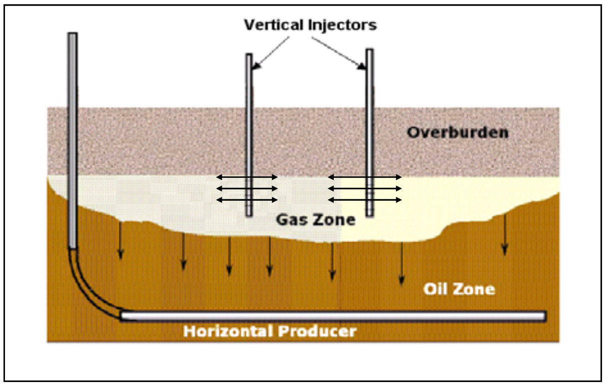

Figure 1: Concept behind the GAGD Process (Rao et al., 2004)

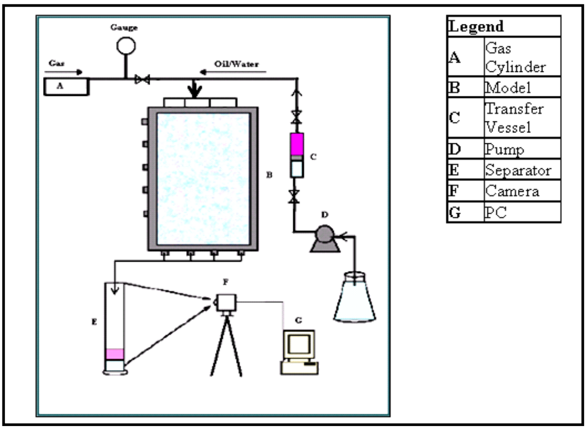

Figure 2: Schematic Depiction of the Physical Model (Sharma, 2005)

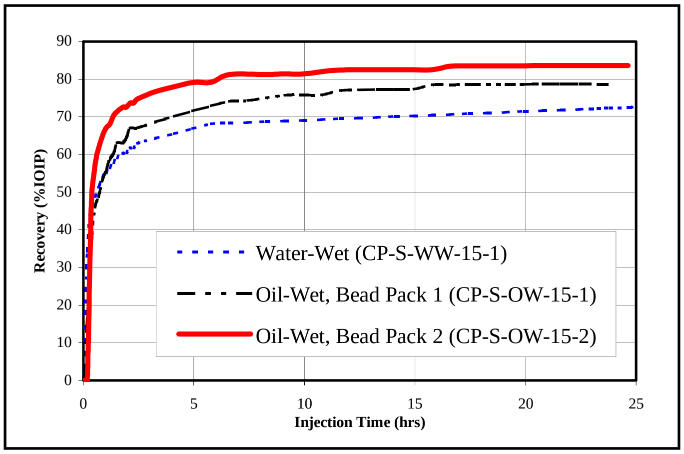

Figure 3: Effect of the Wettability on the Oil Recovery – Secondary Mode, Constant Pressure, 0.15 mm Bead Pack

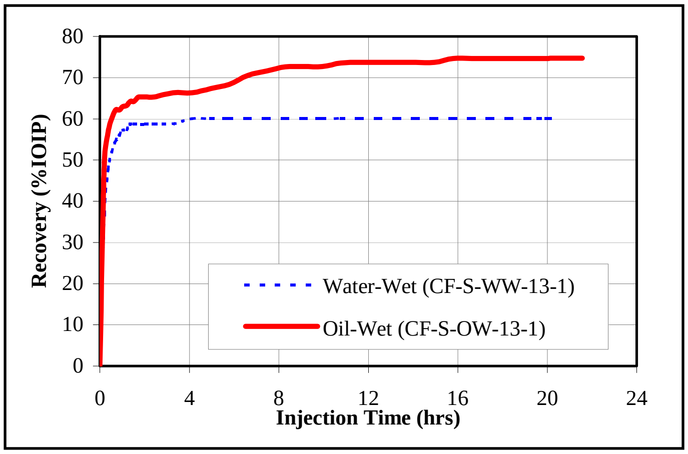

Figure 4: Effect of the Wettability on the Oil Recovery – Secondary Mode, Constant Rate, 0.13 mm Sand Pack

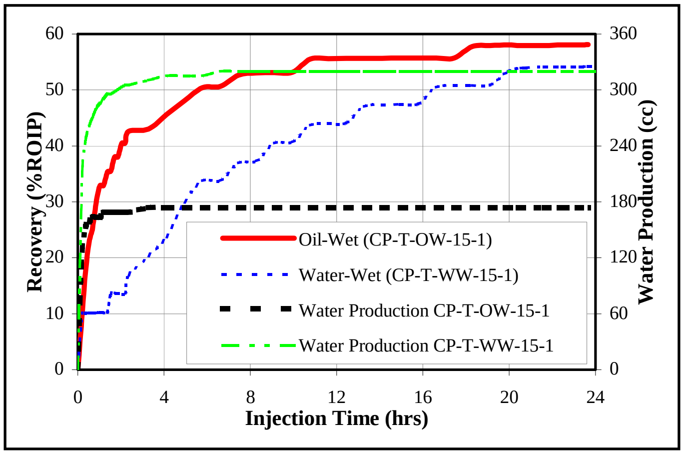

Figure 5: Effect of the Wettability on the Oil Recovery – Tertiary Mode, 0.15 mm Glass Bead Pack

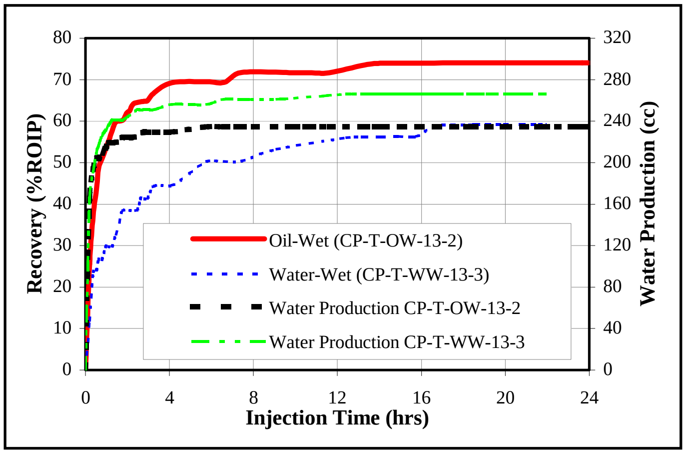

Figure 6: Effect of the Wettability on the Oil Recovery – Tertiary Mode, 0.13 mm Sand Pack

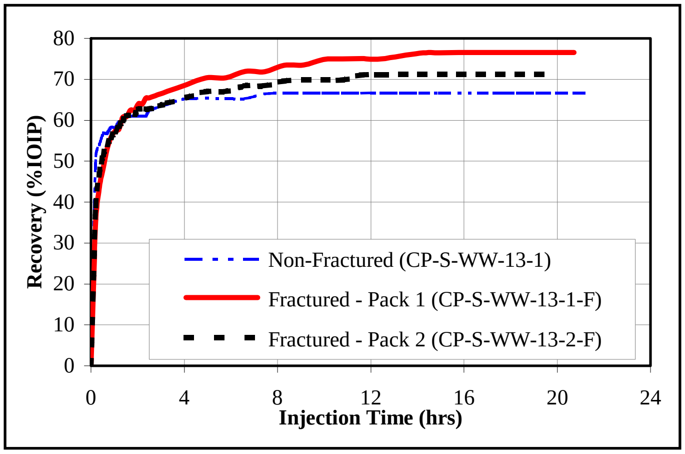

Figure 7: Effect of a Vertical Fracture on the Oil Recovery – Water-Wet Case, 0.13 mm Sand Pack

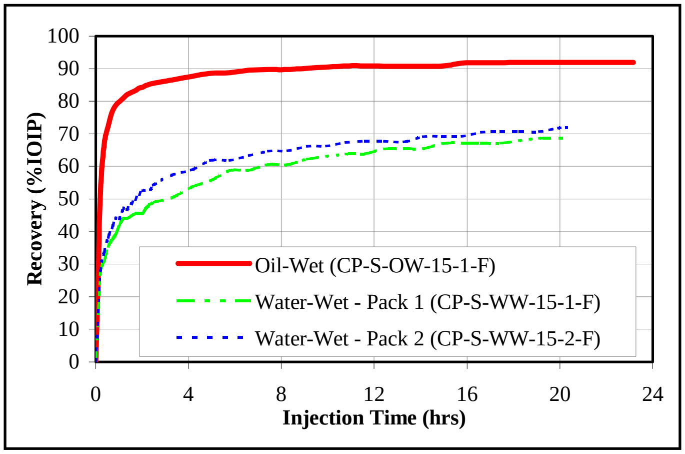

Figure 8: Effect of the Wettability on Fractured Runs – 0.15 mm Glass Bead Pack