**Exploitation and Optimization of Reservoir Performance in
Hunton Formation, Oklahoma**

QUARTERLY TECHNICAL PROGRESS REPORT

Submitted by

Dr. Mohan Kelkar
Department of Petroleum Engineering
The University of Tulsa
600 S. College Avenue
Tulsa, Oklahoma 74104-3189

Contract Date: March 7, 2000

Completion Date: June 30, 2006

Reporting Period: January 1 – March 31, 2006

Date Issued: April 2006

DOE Contract No. DE-FC26-00NT15125

Prepared for

U.S. Department of Energy
Assistant Secretary for Fossil Energy

Contracting Officer's Representative:

Mr. Paul West
U.S. Department of Energy
National Petroleum Technology Office/DOE
Post Office Box 3628
Tulsa, Oklahoma 74103

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Abstract

West Carney field – one of the newest fields discovered in Oklahoma – exhibits many unique production characteristics. These characteristics include:

- 1) decreasing water-oil ratio;
- 2) decreasing gas-oil ratio followed by an increase;
- 3) poor prediction capability of the reserves based on the log data; and
- 4) low geological connectivity but high hydrodynamic connectivity.

The purpose of this investigation is to understand the principal mechanisms affecting the production, and propose methods by which we can extend the phenomenon to other fields with similar characteristics.

In our experimental investigation section, we continue to describe the use of surfactant to alter the wettability of the rock. By altering the wettability, we may be able to recover additional oil through imbibition and gravity drainage process.

In our Engineering and Geological Analysis section, we present a new technique for generate alternate permeability distributions at unsampled wells.

Table of Contents

Disclaimer	ii
Abstract	iii
Table of Contents	iv
Executive Summary	1
Experimental	2
Results and Discussion	4
Engineering and Geological Analysis.....	11
Technology Transfer	11
Conclusions	12

Executive Summary

Significant amount of oil will still remain in the ground after the primary recovery is complete. In this report we present one possible technique of recovering additional oil by injecting surfactant in the reservoir. By altering the wettability of the rock and through gravity assisted drainage process, it is possible to recover additional oil from the reservoir. We validate our hypothesis using both experimental and simulation methods.

Experimental

Kishore Mohanty, University of Houston

Introduction

The objective of the third phase of this project is to test the feasibility of improved recovery in the Hunton reservoir. Because the reservoir is fractured and parts of the matrix may be oil-wet, a large amount of oil may be trapped in the matrix. Surfactant solutions can be introduced into the fractures which can diffuse into the matrix and change the wettability to moderately water-wet.¹ Then surfactant water can then displace the oil by gravity drainage. We have conducted this surfactant-aided gravity drainage process in low permeability limestone cores with permeability typical of the Hunton reservoir. We have developed a simulator to model this process mechanistically and investigated the effect of permeability heterogeneity. These results are described in this report.

Simulation Method

A single fracture block is simulated for surfactant brine imbibition process. In this simulation, surfactant brine surrounds the fracture block and the surfactant diffuses into the matrix. The surfactant then alters the IFT between oil and brine and also changes the wettability of the rock. This leads to further imbibition of the surfactant brine solution and oil recovery.

To study the effect of heterogeneity, a single layer of $1/20^{\text{th}}$ thickness compared to the fracture block height is assumed to be of low permeability, as shown in Figure 1. This layer position with respect to fracture block is varied from middle of the rock to $3/4^{\text{th}}$ the distance from bottom and $1/4^{\text{th}}$ the distance from bottom of the fracture block. The permeability of this layer is assumed to be 50 %, 10% and 1 % of original permeability. The other features of the matrix block are given in Table. 1.

Table 1	
Properties of the core used for imbibition	
Porosity	22.0 %
Permeability(mD)	150
S_{or}	25.0 %
S_{wr}	27.5 %
$k_{r,wet}^0$	0.1
n_{wet}	4.5
$k_{r,nw}^0$	0.9
n_{nw}	2.25
IFT reduction	30 to 0.01 mN/m
Surfactant Conc.	0.05 wt %
Wettability alteration	160° to 75°

The surfactant surrounding the core as shown in Figure 1 is taken to be at 0.05 wt % and it lowers the IFT to a final value of 0.01 mN/m and changes wettability to a final value of 75° . The IFT and wettability are altered inside the porous media as function of surfactant concentration. The changes in IFT and wettability lead to changes in capillary pressure and relative permeability.²

Figure 1: Schematic of Experimental Process

Figure 2: Oil recovery rate for heterogeneous layer in the middle of the fracture block of dimension 0.1 m Dia X 0.1 m in height.

Results and Discussion

Figure 2 shows the plot of recovery of oil for case of heterogeneous layer in the middle of the fracture block. The fracture block dimensions are taken to be 0.1m in diameter X 0.1m in height. Figure 2 shows that when the layer permeability is 50% of native permeability (150 mD) then there is no appreciable change in the rate of recovery. Even with layer permeability of 15 mD and 1.5 mD, the rate of recovery is not altered drastically. With layer permeability at 1.5 mD, the rate of oil recovery is higher in the beginning and gets lowered at later times. This is because oil velocity is higher in the beginning because of less distance to travel to recover, as shown in Figure 3. The bottom part of the medium produces from the side below the low permeability layer. The streamlines of oil recovery at initial and later times are shown in Figure 3. At later times, the block behaves like one layer. The oil velocity is slower than the case of uniform permeability because the streamlines go through the low permeability region. Even though the distance traveled is same in both cases (equal to height of the block) the net resistance to flow is

higher with a layer of low permeability in between. This reduces the rate of oil recovery at later times.

Figure 3: Oil velocity profile for heterogeneous layer in the middle of the fracture block of dimensions 0.1 m diameter X 0.1 m height at time $t = 5.4$ days and $t = 189$ days.

Figure 4: Oil recovery rate for heterogeneous block with low permeability layer at a) 25 % height from bottom and b) 75 % height from bottom. Fracture block dimension is 0.1 m diameter X 0.1 m height.

Figure 4 shows recovery rates from a heterogeneous block with the low permeability layer at 25% of the height from the bottom of the block or 75 % from bottom of block. Figure 4 also shows that layered heterogeneity does not affect the rate of recovery drastically for this dimension fracture blocks.

Figure 5: Oil recovery rate for heterogeneous block with low perm layer in the middle of the fracture block of dimension 0.1 m diameter X 1.0 m height.

Figure 5 shows the oil recovery from a heterogeneous fracture block of dimension of 0.1 m diameter X 1 m height. The low permeability layer is located in the middle of the block. The heterogeneous layer in this case aids in oil recovery as the oil velocity is enhanced by shortened distance to travel as explained earlier. Due to high aspect ratio (h/d) and because of low permeability barrier, the oil travels less distance as compared to half the height of the block as shown in Figure 6. This leads to enhanced rates of recovery with a low permeability barrier.

Figure 6: Oil velocity profile for heterogeneous layer in the middle of the fracture block of dimensions 0.1 m diameter X 1.0 m height at time $t = 53$ days and $t = 1058$ days.

Figure 7 shows the recovery rates for a heterogeneous layer for a fracture dimension of 10 m diameter X 10 m height. Here, since the ratio of diameter to height is 1, we can expect from earlier discussion that a low permeability barrier would decrease the rate of production as seen in Figure 7. Similar simulations were performed for different matrix dimensions and it was observed that for higher diameter to height ratio blocks, a low permeability barrier decreases the rate of oil recovery, and for lower diameter to height ratio blocks, it increases the rate of oil recovery. For an aspect ratio of near 1, the rate of recovery is lowered by having a permeability barrier because the driving force is in the direction of gravity and the resistance in the flow in that direction has increased by virtue of low permeability barrier.

Figure 7: Oil recovery rate for heterogeneous layer in the middle of the fracture block of dimension 10 m diameter X 10 m height.

Conclusions

Up to 50% of the initial oil in place can be recovered from fractured limestones in 50 days at the laboratory scale by surfactant-aided gravity drainage. Vertical layered heterogeneity affects oil recovery rate, but not drastically. For fracture blocks of higher diameter to height ratio, a low permeability barrier decreases the rate of oil recovery, but for blocks of lower diameter to height ratio, it increases the rate of oil recovery. This project will be completed in the next quarter.

References

1. Seethepalli, A., Adibhatla, B., and Mohanty, K. K., "Physicochemical Interactions during Surfactant Flooding of Fractured Reservoirs," *SPE J.*, **9** (4), 411-418 (December, 2004).
2. Adibhatla, B., Sun, X., and Mohanty, K. K., "Numerical Studies of Oil Production from Initially Oil-Wet Fracture Blocks by Surfactant Brine Imbibition," SPE 97687, SPE International Improved Oil Recovery Conference, Kuala Lumpur, Malaysia, 4-6 December, 2005.

Engineering and Geological Analysis

Mohan Kelkar, The University of Tulsa

One the biggest difficulties we found in examining the recoveries from reservoirs which are de-watered is the fact that the recoveries of oil and gas are extremely low during the early depletion phases. However, as the pressure is reduced, the recoveries increase significantly. This is in contrast to typical oil reservoirs where the recovery during the early depletion is lot higher and as the pressure declines, the incremental recovery becomes very small. Intuitively this is not surprising since in de-watering project the expansion energy is largely consumed in producing water in early stages and only after we recover significant quantities of water, the expansion energy is used to recover additional gas and oil. We need to develop a better procedure to explain this behavior. Currently, we are developing a better material balance procedure to explain this behavior. We will have the details of the method as well as validation of this method using field data in the next report.

Technology Transfer

On February 16th, as part of the technology transfer workshop, a presentation was made at the Oklahoma City SPE Section. Over 100 people attended the meeting and lot of interest was shown in the development of technology. In addition, following two papers were presented and/or published as part of this project:

1. Seethepalli, A., Adibhatla, B., and Mohanty, K. K., "Physicochemical Interactions during Surfactant Flooding of Fractured Reservoirs," *SPE J.*, **9** (4), 411-418 (December, 2004).
2. Adibhatla, B., Sun, X., and Mohanty, K. K., "Numerical Studies of Oil Production from Initially Oil-Wet Fracture Blocks by Surfactant Brine Imbibition," SPE 97687, SPE International Improved Oil Recovery Conference, Kuala Lumpur, Malaysia, 4-6 December, 2005.
3. Adibhatla, B., Mohanty, K.K.: "Oil Recovery from Fractured Carbonates by Surfactant-Aided Gravity Drainage: Laboratory Experiments and Mechanistic Simulations," SPE 99773, paper presented at the SPE/DOE IOR Symposium, Tulsa, OK, April 22-26, 2006.

Conclusions

Based on the material presented in this report, the following conclusions may be drawn:

- Use of surfactants can help us to change the wettability of the rock. If we can change the wettability of the rock from moderately oil wet to water wet, additional oil can be recovered using imbibition process
- The feasibility of surfactant displacement as a potential recovery process is validated using both simulation and lab studies.