SIMULATION STUDY ON THE EFFECT OF VISCOUS GRAVITY RATIO ON VISCOUS FINGERING AND GRAVITY SEGREGATION IN WATER ALTERNATE GAS PROCESS

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ABSTRACT

The recovery of residual oil using Carbon Dioxide (CO_2) flooding has received great attention over worldwide to maintain and prolong oil supply. The major problem in applying this process is to control the mobility of CO_2 due to its low viscosity as compared to oil. Therefore, water is suggested to be injected alternately with gas to overcome the mobility problem. The use of Water Alternate Gas (WAG) is simulated using ECLIPSE software to validate the experimental result on the effect of Viscous Gravity Ratio (VGR), which is the ratio of horizontal force to vertical force on gravity segregation and viscous fingering. The study also looks into effect of different perforation injection strategy on ultimate oil recovery. The simulation results agree with experimental result by Nguyen (2000) where the viscous fingering is significant in high VGR value while the gravity segregation is significant at low VGR value. The ultimate oil recovery is found increase with VGR value increase, where at VGR 4.5, 33 and 300, the ultimate recovery is 41.4%, 77.9% and 80.5%. With different perforation injection strategy, ultimate oil recovery is found to be highest when water injection is at top and gas injection is at bottom, and at high VGR, where the ultimate recovery is 83.8% at VGR 300.

Keywords: Water Alternate Gas, WAG, Viscous Gravity Ratio, VGR, Injection Strategy

ABSTRAK

Perolehan minyak menggunakan kaedah banjiran Karbon Dioksida (CO_2) telah mendapat perhatian yang besar oleh seluruh dunia untuk mengekalkan dan memanjangkan bekalan minyak. Masalah utama dalam menggunakan proses ini adalah untuk mengawal pergerakan CO_2 disebabkan nilai kelikatan CO_2 yang rendah berbanding dengan minyak. Oleh itu, air dicadangkan untuk disuntik berselang-seli dengan gas untuk mengatasi masalah mobiliti. Proses Gas Bergantian Air (WAG) disimulasikan menggunakan perisian ECLIPSE untuk mengesahkan keputusan eksperimen kesan Nisbah Graviti kepada Kelikatan (VGR), yang merupakan nisbah daya mendatar kepada daya menegak, terhadap pengasingan graviti dan penjarian likat. Kajian ini juga melihat kepada kesan strategi suntikan yang berbeza terhadap perolehan minyak. Keputusan simulasi bersetuju dengan hasil eksperimen oleh Nguyen (2000) di mana kesan penjarian likat ketara pada nilai yang VGR tinggi manakala kesan pengasingan graviti adalah ketara pada nilai VGR rendah. Perolehan minyak muktamad didapati meningkat dengan peningkatan nilai VGR, di mana pada nilai VGR 4.5, 33 dan 300, perolehan minyak muktamad adalah 41.4%, 77.9% dan 80.5%. Dengan strategi suntikan yang berbeza, perolehan minyak utama didapati tertinggi apabila lokasi suntikan air di bahagian atas model dan suntikan gas di bahagian bawah pada nilai VGR yang tinggi, di mana perolehan minyak adalah 83.8% pada VGR 300..

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LIST OF ABBREVIATIONS

CO2	Carbon Dioxide
EOR	Enhanced Oil Recovery
OIIP	Oil Initial In Place
VGR	Viscous Gravity Ratio
WAG	Water Alternate Gas
WGVR	Water Gas Viscosity Ratio

LIST OF SYMBOLS

k	permeability (mD)
k_v	overall vertical permeability (mD)
k_h	overall horizontal permeability (mD)
k_{rg}	relative permeability of gas
k_{ro}	relative permeability of oil
k_{rw}	relative permeability of water
S_w	water saturation
S_g	gas saturation
μ_g	gas viscosity
μ_o	oil viscosity
μ_w	water viscosity
P	pressure

CHAPTER 1

INTRODUCTION

1.1 Background

Managing oil decline is a crucial issue faced by petroleum industries over worldwide. Enhanced oil recovery (EOR) is a promising method to enhance oil production as well as to prolong oil supply. EOR is a tertiary recovery method implemented after the first and secondary recovery methods have been applied. The two main reasons of the oil is still left behind is due to microscopic factors (low displacement efficiency) such as oil snap-off oil and macroscopic factors (low sweep efficiency) such as gravity segregation (Ahmad Aladasani and Boujan Bai, 2010).

Various EOR methods are available nowadays to overcome the problem of oil being left behind iin the reservoir. Oil flow to the surface in a reservoir occurs under a number of different mechanisms, namely natural flow due to differential pressure between the reservoir and borehole, and artificial flow with the help of gas and water drive mechanisms which are termed as primary recovery. The other form of recovery is secondary recovery which involves water flooding and gas injection whose limit is reached when considerable amounts of both water and gas are produced at the production well and the production is no longer economical. The use of primary and secondary recovery only produces 15% to 40% of the original oil in place (Schlumberger Oilfield Glossary). The other method which recovers the remaining oil is known as Enhanced Oil Recovery (EOR) which Ivan Sandrea (StatoilHydro) and Rafael Sandrea (2007) account for around 3% of the worldwide production. The EOR methods involves a number of methods include thermal processes (steam flooding, in-situ combustion), miscible gas injection (Carbon dioxide (CO_2), hydrocarbon gases, Nitrogen and Flue gases), chemical injection (polymers, surfactants and alkali-surfactant-polymer) as well as Microbial EOR.

When carbon dioxide is used in EOR, it can favourably mix with the oil such that the interfacial surface tension between the oil and the gas effectively disappears. However, the disadvantages of using CO_2 result from its low viscosity and density which in turn are responsible for gravity tonguing and viscous fingering. This low viscosity of the carbon dioxide therefore causes the mobility ratio to be unfavourable in most carbon dioxide floods. According to Stalkup (1983), mobility ratio is defined as the ratio of the mobility of the displacing fluid to the mobility of the displaced fluid. The high mobility brought about by the carbon dioxide in comparison to the low mobility of the oil results into the high mobility ratio. This therefore leads to an early breakthrough in the reservoir. According to Odd Magne (2003), the problem of low sweep efficiency due to high mobility of the Carbon dioxide can be reduced by using 3 methods namely:

i. Use of Water Alternating Gas process
ii. Foaming combined with CO_2 injection
iii. Increasing the gas viscosity by dissolving a polymer into the CO_2

Foaming reduces gas mobility by the creation of bubbles which increase it viscosity and also reduce the effects of reservoir heterogeneities. However foams and polymers are expensive. Water alternate Gas (WAG) is a method which combines the traditional methods of gas injection and water flooding and has been suggested as the most popular way of controlling mobility of the gas. According to Christensen and Stenby (2001), WAG improves sweep efficiency by using water to control the mobility of the displacement and to stabilize the front. The microscopic displacement of the oil by the gas is normally better by than the water and the combination with the improved macroscopic sweep by water injection serves to increase the oil recovery. Blackwell *et al* (1960) suggested that WAG reduces the mobility ratio by about 77 times as compared to the conventional miscible flood. Although mobility control is the main reason for the use of the WAG process, its other advantages should be noted too. Compositional exchange, oil swelling and viscosity reduction, interfacial tension reduction, decrease of oil residual saturation due to three-phase flow and hysteresis are important to note as well. According to Blrarda *et al*, Attanuc *et al (*1994), Virnorvsky *et al (*1993) ,Yamamato *et al (*1997) and Nguyen (2000), WAG appears to be economically attractive option.

Despite these advantageous factors, WAG also results into complex saturation situations in the reservoir that require detailed analysis of three phase relative permeability. The other main factors affecting the WAG efficiency process are reservoir characteristics like heterogeneity, rock wettability, ratio of vertical to horizontal permeability, fluid properties: miscibility conditions, Viscous Gravity Ratio (VGR), Water to Gas Viscosity Ratio (WGVR) and WAG parameters: cycling frequency, slug size, WAG ratio, injection rate, perforation injection strategy. These parameters will influence the level of viscous fingering and gravity segregation which will determine the efficiency of the WAG process. Nguyen (2000) reported numerous studies has been made to investigate the performance of WAG due to gravity segregation and viscous fingering and the parameters that affect it namely by Stone (1982), Jenkins (1984), Christie *et al* (1993), Warner (1977), Winzinger *et al* (1991), Almeida *et al* (1993) and Genrich (1986).

VGR is defined as the ratio of horizontal force to vertical force. For certain reservoirs, when well spacing, different density and permeability are constant, the VGR values are controlled by flowrate (Stone, 1982; Jenkin, 1984). It is found that the higher the VGR values, the higher the oil recovery. However, Blackwell et al (1960) shows that the medium flowrate gives the highest recovery. Flow rates in the range of 0.094 ft/d to 3.1 ft/d (VGR in range of 9.86 to 326) were used in the experiment. It was explained that the higher the flowrate, more oil is trapped by channeling. The contradictions needs further explanation. Nguyen (2000) investigated the effects of VGR in the range of (4.5 to 300) and conclude that for VGR above 14, the ultimate recovery was shown to be logarithmic dependence on VGR and for VGR lower than 14, lower VGR produces higher ultimate recovery.

Perforation injection strategy is the way in which the water and gas are injected into the reservoir. The layers where water and gas are injected are important in determining the ultimate oil recovery during a WAG process. According to Kleppe and Namani (2011), when gas is injected in the lower layers and water in all layers, the highest recovery is achieved. X.Wu and T.Zhu(2004), investigated the interval in relation to the producer and their investigation revealed that producing from the upper part of the perforation produced the highest recovery. The proper selection of layers to inject water and gas according to Kleppe and Namani (2011) in relation to the ratio should be considered. This injection perforation strategy has to be investigated further by considering how it will influence the oil recovery.

Based on the previous studies, it is seen varied VGR and the perforation injection strategies have an effect on the oil recovery. Therefore there is a need to validate the experimental result by Nguyen (2000) and investigate further how oil recovery will be affected under different values of VGR under different perforation injection strategy.

1.2 Problem statement

Experiment conducted by Nguyen (2000) needs validation to prove its result. Therefore, the effect of VGR on gravity segregation, viscous fingering and ultimate oil recovery during Water Alternate Gas will be investigated through simulation in a homogeneous reservoir model that mimic the real experimental condition. The experiment by Nguyen (2000) was conducted with only one injection strategy, hence the effect of different injection strategy on ultimate oil recovery will be investigated through simulation.

1.3 Objectives of study

The objectives of simulation study are:

1. To validate the result of experimental study by Nguyen (2000) on the effect of VGR on gravity segregation and viscous fingering during Water Alternate Gas (WAG) displacement process with unfavourable mobility ratio and unfavourable density difference.

2. To validate the result of experimental study by Nguyen (2000) on the effect of VGR on ultimate oil recovery.

3. To investigate the effect of different injection perforation strategy on ultimate oil recovery.

1.4 Scopes of study

A reservoir simulation study will be conducted to validate the experimental results conducted by Nguyen (2000) on the effect of Viscous Gravity Ratio (VGR) on gravity segregation, viscous fingering and ultimate oil recovery. This simulation will also investigate the effect of Perforation Injection Strategy has on the Ultimate Oil Recovery in a First Contact Miscible Water Alternating Gas (WAG) Displacement.

The manipulated or controlling parameters in this study are VGR and perforation injection strategy. The VGR values investigated 4.5, 33 and 300. The Perforation Injection Strategy will be investigated in 4 different configurations namely:

i. Gas injection between middle and bottom layer and water injection between middle and top layer
ii. Gas injection between middle and top layer and water injection between middle and bottom layer
iii. Gas injection at bottom layer and water injection at top layer
iv. Gas injection at top layer and water injection at bottom layer

The dependant or observed parameters for this study are the viscous fingering, gravity segregation and ultimate oil recovery.

The simulation uses a grid of 100 ×1× 40 which enables the gas and water to have a large area for effects of segregation to take place. The study is based on the following assumptions:

i. The reservoir is homogeneous
ii. The effect of diffusion and dispersion in displacement is negligible
iii. No chemical interaction affects the displacement behaviour
iv. Uniform oil saturation
v. The effect of capillary pressure is ignored
vi. Only one producer and one injector (gas alternate with oil) will be used

The aim of this study is to achieve an understanding on how ultimate oil recovery is affected by reservoir under different ranges of VGR and how injection of the water and gas will affect this recovery. It also aims to answer a number of questions with respect to the study.

- How does VGR affect gravity segregation and viscous fingering in the high water saturation model?
- What effect does VGR have on the ultimate oil recovery?
- Is there an optimum perforation injection strategy and at what VGR does it occur?

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