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A NUMERICAL SIMULATION STUDY TO EVALUATE THE USE OF WATER ALTERNATING GAS (WAG) AS A PILOT EOR METHOD IN DULANG UNIT, MALAYSIA

By

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DECLARATION OF OWN WORK

I declare that this thesis

A Numerical Simulation Study to Evaluate the Use of Water Alternating Gas (WAG) as a Pilot EOR Method in Dulang Unit, Malaysia

is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

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ABSTRACT

Water alternating gas (WAG) injection schemes have become an important strategy to enhanced oil recovery (EOR) around the world and has been the focus of interest in recent years in Malaysia. S3 block E12/14 reservoirs of Dulang Unit were selected as a pilot project to evaluate the feasibility of EOR using immiscible WAG injection. This block had been producing for the last 11 years and has had water injection for the last 6 years. The study commenced with the analysis of all pertinent data on the reservoir that were used as an input into the model. The production data were updated from February 2000 until December 2002 by incorporating additional pressure, production and injection data. The input data were fine-tuned by history matching studies before proceeding with the prediction runs. Based on current well performance, maintaining current operating strategy gave a total ultimate recovery of 10.9 MMstb at the end of 2020 which represents an average oil recovery factor of 33.7%. Two candidates for WAG injector, DULA010L and DULA002L in this block were accessed on its performance to sweep the oil. Studies conducted indicate that converting well DULA002L into WAG injector was the best scenario which gave additional 1.2 MMstb of oil. Total oil recovery under this scenario was predicted at 37.4% after 29 years of production. In order to obtain an optimum WAG injection cycle length, five different sensitivity cases were studied and showed that injection of gas for 90 days and followed by water for another 90 days was the best case for piloting this block. This gave a gas to water ratio of 1:1.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In recent years there has been an increasing interest in miscible and immiscible water-alternating-gas (WAG) injection. The WAG process was initially proposed as a method to increase the sweep efficiency during gas injection. In practice the WAG process consist of the injection of water and gas as alternate slugs by cycles or simultaneously. In some recent applications, the produced hydrocarbon gas was re-injected alternately with water for improving oil recovery and for pressure maintenance. Its ability to contact unswept zones by exploiting the segregation of gas to the top and accumulating of water towards the bottom can increase the oil recovery.

Immiscible WAG displacement is a well established technique for increasing oil recovery. This has been applied to reservoirs throughout the world[1]. Dulang Unit that is part of Dulang Field is the first oil field in Malaysia to be considered for this mode of recovery process. This field has a low water flood recovery and potentially vast reserves of oil which necessitates the consideration of advanced oil recovery technology. Location of Dulang Unit is approximately 130 kilometres from offshore Terengganu, Eastern Peninsular Malaysia in water depth of 76 meters in South China Sea. Water had been injected for pressure maintenance but continuous depletion of recoverable reserves and pressure necessitates the development of enhanced oil recovery (EOR) that will increase these recoverable reserves. Figure 1.1 shows the location of this field in respect to Peninsular Malaysia.

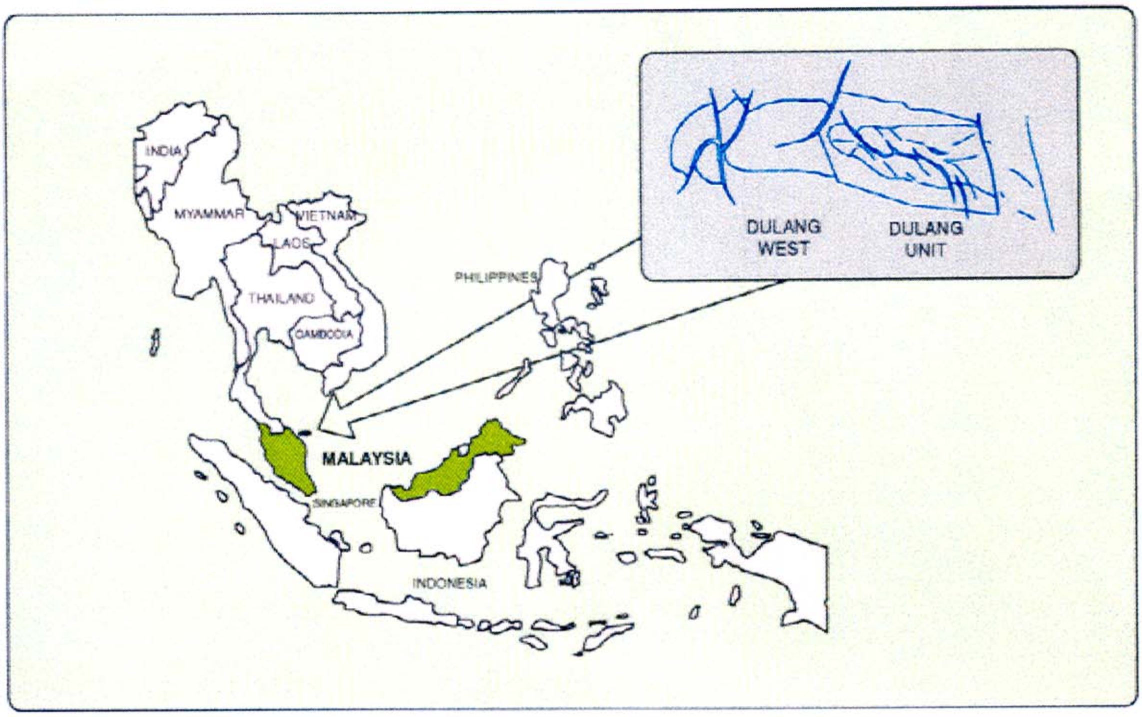

Figure 1.1: Location of Dulang Unit in respect to Peninsular Malaysia

Pilot projects are usually conducted to reduce major uncertainty and risks. With several successful and very few unsuccessful projects in the literature, risks and uncertainties of exploiting WAG project in Dulang Unit can be reduced and manageable by conducting a pilot operation in S3 block E12/14 reservoirs for a short period (a year or two) and proceed to a field wide implementation if the performance is acceptable. Therefore, this study was designed to reach two main objectives as below:

1) To determine the suitability of well DULA002L and well DULA010L as WAG injectors.
2) To obtain the optimum injection cycle length for gas and water.

CHAPTER 2

LITERATURE REVIEW

2.1 General Description Related to WAG

WAG injection is known as a method to control gas fingering and to improve vertical sweep efficiency. It has been recognised as an effective improved oil recovery (IOR) procedure and is widely applied to enhance trapped oil production in reservoirs. This recovery process has been applied successfully on several oil fields, especially in USA, Canada and more recently in Norway. Generally, field's projects are based mainly on carbon dioxide (CO_2) or hydrocarbon gases injected at miscible conditions. However, Manrique et. al[1] found in their study that some field experiences have shown WAG could be an efficient method for improving oil recovery at immiscible conditions with CO_2 and other hydrocarbon gases. Reinjection of produced gas is favourable due to environmental concerns and the enforced restrictions on flaring activity.

The WAG process was patented by Parrish[2] in 1966. It was proposed as a method to improve sweep of gas injection, mainly by using the water to control the mobility of the displacement and to stabilise the front. In addition, WAG injection was found to improve the displacement efficiency in heavy oil reservoirs by swelling of oil phase and viscosity reduction. Sharma and Lucille[3] performed a study on WAG application in a West Texas. They concluded that CO_2 gas has proven to be very effective miscible injectant leading to the nearly complete mobilisation of residual oil.

The main factors affecting the WAG injection process are the reservoir heterogeneity (stratification and anisotropy), rock wettability, fluid properties, miscibility conditions, gas entrapment, injection technique and WAG parameters like cycling frequency, slug size, WAG ratio and injection rate as describe by Sanchez[4]. Although mobility control is an important issue, other advantages of the WAG injection should be noted as well. Compositional exchanges may give some additional recovery and may influence the fluid densities and viscosities.

Changes in incremental of oil recovery by WAG floods are predominantly due to changes in sweep efficiency. A simplified model to predict effects on WAG flooding performance conducted by Genrich[5] in 1986 concluded that discontinuous shales near the bottom or at the middle of the reservoir can enhance vertical sweep efficiency, while such shales near the top have much less effect on oil recovery.

Gorell[6] had studied the effects of trapping and WAG injection on tertiary miscible displacements. He found that if enough water is injected with the solvent, a low mobility solvent-water bank is created which moves with the same velocity as the back of the oil bank. Stable water-oil-gas fronts occur only for a limited number of the injection gas-water ratio. Injection below this WAG ratio is predicted to give good displacement efficiency and poor sweep. The injection above this ratio will increase sweep efficiency at the expense of reduced displacement efficiency.

The WAG injection results in a complex saturation pattern since two saturations (gas and water) will increase and decrease alternately. This gives special demands for the relative permeability description for the three phases (oil, gas and water). There are several correlations for calculating three phases relative permeability in the literature but only recently an approach designed for WAG injection using cycle dependent relative permeability has been developed. This was discussed by Virnovsky et. al[7] in their study of stability of displacement fronts in WAG operations performed in 1994.

Some simple relations are helpful in understanding the advantages of the WAG injection. The oil recovery can be describe by three contributions:

$$REC = E_v \times E_h \times E_m \quad \text{........... Equation 2.1}$$

Where;

REC = Oil recovery

E_v = Vertical sweep efficiency

E_h = Horizontal sweep efficiency

E_m = Microscopic displacement efficiency

Maximising any or all of these three factors can optimise the recovery. The contribution of E_v and E_h is called macroscopic displacement efficiency.

The residual oil saturation will go towards zero in the flooded areas when performing a miscible displacement. However, even with an immiscible displacement the remaining oil saturation after gas flooding is normally lower than after water flooding, meaning that gas has better microscopic displacement efficiency than water. Recent simulation studies have shown that the inclusion of gas trapping, reduced phase mobility and lower residual oil saturation in three phases zone may influence the extent of the WAG zone in the reservoir and leads to higher oil recovery as found and explained by Christensen et. al [8]. The following sub-chapters are quoted from review of WAG field experience written by these authors except when it is clearly mentioned by others.

2.2 Horizontal Displacement Efficiency

The horizontal displacement efficiency will be strongly influenced by the stability of the front defined by the mobility of the fluids. The mobility ratio can be described as:

$$M = \frac{K_{rg}/\mu_g}{K_{ro}/\mu_o} \qquad \text{........... Equation 2.2}$$

Where;

M = Mobility ratio

K_{rg} = Gas relative permeability

K_{ro} = Oil relative permeability

μ_g = Gas viscosity

μ_o = Oil viscosity

The WAG displacement will be optimised if the mobility ratio is favourable (less than 1). Increasing the viscosity of the gas or reducing the relative permeability of the fluids can reduce the mobility ratio. Injecting water and gas alternately can reduce mobility of the gas phase. It is important to adjust the amount of water and gas so that the best possible displacement efficiency can be achieved. Too much water will result in poor microscopic displacement and too much gas will result in poor vertical and may also be horizontal sweep.

2.3 Vertical Displacement Efficiency

The reservoir properties affecting the vertical sweep efficiency mostly are reservoir dip angle, variation in permeability and porosity. Normally porosity and permeability increasing downwards will be advantageous for the WAG injection and this combination will increase the stability of the flood front. The ratio between viscosity and gravity force influence vertical sweep efficiency. Guzman et. al[9] found large three phase on flow regions in a field study exist for a large range of viscous to gravity force ratios and it could be expressed by the following correlation:

$$R_{v/g} = \left(\frac{v\mu_o}{K_o g \Delta\rho}\right)\left(\frac{L}{h}\right) \qquad \text{........... Equation 2.3}$$

Where;

v = Darcy velocity

L = Distance between the wells

K_o = Oil permeability

g = Gravity force

$\Delta\rho$ = Density difference between the fluids

h = Height of the displacement zone

2.4 Classification of the WAG Process

WAG processes can be grouped in many ways. The most common is to distinguish between miscible and immiscible WAG displacements. For the miscible displacement, reservoirs are repressurised in order to bring the pressure above the minimum miscibility pressure (MMP) of the fluids. In reality, the field cases may oscillate between miscible and immiscible gas during the life of the oil production due to failure to maintain sufficient MMP pressure. Most miscible WAG project had been performed onshore within a close well spacing.

Immiscible displacement process can be achieved by maintaining reservoir pressure below the MMP of the fluids. It is applied with the aim of improving frontal stability or contacting unswept zones. In addition, the microscopic displacement efficiency may be improved as well. Sometimes the first gas slug dissolves to some degree into the oil. This can cause oil swelling and favourable change in the fluid viscosity and density relations at the displacement front. The displacement then becomes near miscible.

2.5 Design of the WAG Project

The WAG injection is applied as an EOR method meaning that the oil field had been in production for some time and had experienced both primary depletion and normally water flooding as well. The main objective is to achieve additional recovery compared to other possible injection operations.

The injection gases used in the WAG projects today can roughly be classified into three groups which are CO_2, hydrocarbons and non-hydrocarbons (CO_2 excluded). It is worth noticing that corrosion problems is often mentioned and seems not to be totally avoided when using CO_2 as a solvent. Hydrocarbon gas is available directly from the production and for this reason, all offshore WAG injection today uses hydrocarbon gases. However, possibility of injecting CO_2 is currently investigated because of environmental concerns.

The five spot injection pattern seems to be the most popular with a fairly close well spacing. A regular pattern is normally applied on-shore and seldom used offshore. This is due to expensive price of drilling operation and data collection. The other factor to consider in applying WAG injection is tapering. Tapering can be defined as injecting water and gas at different ratio throughout the life of the field. Generally, it had been used in the first field trials in the early 1960s. In many cases, tapering was not planned but had been a consequence of increasing recycling. The injection volume of water relative to gas had been increased at a later stage of the WAG injection to control channelling and breakthrough of gas. Tapering is extremely important when an expensive gas sourced is used.

2.6 Operational Problems

Operational problems cannot be avoided in the production life of an oil field. The WAG injection is more demanding than a pure gas or water injection since the injection needs to be changed frequently. Although only a small number of operational problems are reported in the literature, it is basically the same issues from the different fields.

Poor understanding of the reservoir or inadequate reservoir description can lead to unexpected events such as early gas breakthrough. Several field experienced early gas breakthrough due to channelling. This problem is difficult to solve especially at the offshore fields. Override or channelling can be very critical since the number of wells in the projects generally is very limited. Loss of pressure in miscible projects is a serious problem since loss of miscibility will result in significantly lower recovery.

Corrosion is a problem that needs to be solved in almost all WAG injection projects. This is mainly due to the fact that the WAG injection is normally applied as a secondary or tertiary recovery method. The WAG projects have to use old injection and production facilities that originally were not designed for this kind of injection. Furthermore, injection of CO_2 could accelerate the corrosion problems especially in the piping and other surface facilities. Using high quality of steel, coating of pipes and treatment of equipments can solve these problems in most cases.

2.7 Review of CO_2 Gas Injection in Dulang Field (Experimental Approach)

Zain et. al[10] performed a study to evaluate CO_2 gas injection in Dulang Field. Study conducted indicates that at the reservoir temperature of 215°F, CO_2 gas injection would not be able to achieve miscibility with the crude oil at the current reservoir pressure or even if the pressure increased to the initial reservoir pressure. Equation-of-State (EOS) showed that the multiple contact miscibility pressure for CO_2 and produced hydrocarbon gas was 3230 psig and 3340 psig respectively. These pressures are significantly higher than the initial reservoir pressure of 1800 psig.

Vaporisation of Dulang crude by pure CO_2 and the CO_2-riched produced gas was studied. Laboratory experiment suggested that significant vaporisation of 15% of the stock tank oil with pure CO_2. Based on EOS, the vaporisation ranges from 2% to 5% with produced gas at operating reservoir pressure of 1400 psig to 1800 psig.

2.8 Review of Dulang Composite Core Displacement Study

Composite core laboratory displacement studies were conducted by Nadeson et. al[11] in 2001 to obtain key laboratory data to evaluate the applicability of WAG injection in Dulang Field. Composite core technology was chosen over conventional single core flood test as the former provides larger pore volume for fluid contact and movement. It reduces saturation end effects and allows assembly of cores from different sands.