Reasearch

Simulation Study for Potential Identification of Light Oil Air Injection in Malaysian Reservoirs

Zeeshan Mohiuddin[1§], Ismail Mohd. Saaid[1], D.M Anwar Raja[1] and Nor Aidil B Anua[2]

Address: [1]Petroleum Engineering Programme, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia. http://pumpjack.tamu.edu/Faculty&Staff/faculty/schechter/baervan/homepage.html, [2]PETRONAS Research Center, Lot 3288 & 3289, Off Jalan Ayer Itam, Kaw. Inst. Bangi, 43000 Kajang, Selangor, Malaysia

Email: Zeeshan Mohiuddin – zeeshan_mohiuddin@utp.edu.my, zeeextra@yahoo.com; Ismail Mohd Saaid – ismailsaaid@petronas.com.my; D.M Anwar Raja – anwarra@petronas.com.my; Nor Aidil B Anua – noraidil@petronas.com.my

[§]Corresponding author

Published: 20 December 2006 Received: 17 November 2006

E-Journal of Reservoir Engineering 2006, *ISSN: 1715-4677.* Accepted: 17 December 2006

This article is available from: http://www.petroleumjournalsonline.com/

Abstract

Malaysian forecast of oil production is expected to decline from 2007 and projections of domestic consumption indicate that the country might become a net oil importer by the end of this decade. Nevertheless, some of the existing reservoirs still contain large volumes of oil, which has not been effectively recovered. Therefore, Enhanced Oil Recovery (EOR) techniques are inevitably required to recover the remaining oil from these matured reservoirs. This paper highlights the simulation work carried out to identify the potential of Light Oil Air Injection (LOAI) to recover the remaining oil from Malaysian depleting oil reservoirs. The research work involves simulations of suitable oil reservoir(s) to evaluate the future performance of LOAI. The project starts with the screening of 22 Malaysian oil reservoirs using a set of criteria, which had been developed after evaluating successful LOAI projects around the world and consulting industry experts. In principle, the screening criteria entailed major reservoir properties such as the reservoir temperature, reservoir pressure, oil viscosity, formation depth and reservoir permeability. E12/13 and 14 reservoirs of Dulang field were selected based on the screening criteria for the LOAI simulation project. The simulation work used black oil simulations to eliminate complex thermal reaction scheme. Furthermore, the simulation work evaluates nitrogen effects in place of air to simplify the complex reaction mechanisms of the combustion process in the reservoir. The present simulation studies used history matched model of year 2003 which was upgraded for nitrogen injection from year 2006. Incremental recovery obtained from nitrogen injection was then compared with water injection (WI) and water alternating gas (WAG) base cases. The simulation results indicated that the LOAI significantly increased the oil recovery factor from the Dulang E12/13 and 14 light-oil reservoirs.

Background

Malaysian E&P offshore acreage extends to approximately 500,000 sq. km containing 52 offshore blocks. However, a number of existing producing fields in the country are already entering the maturing stage with declining oil rates and pressure [1]. Oil production is expected to decline starting from year 2007 and the country could become a net oil importer by the end of this decade [2]. The need for Enhanced Oil Recovery (EOR) techniques to increase the recovery factor has become significant. Light Oil Air Injection (LOAI) is one of the EOR techniques which offer unique advantages as compared with other conventional EOR techniques [3]. The techniques of air injection is extending its realm to lighter oils where it contributes not only to viscosity reduction but also providing additional driving mechanisms to oil production [4]. The method starts with the injection of air into deep, hot and high pressure reservoir. Oxygen in the injected air will then react with approximately 5-10% of original oil in place (OOIP) and produces carbon oxides [5]. Nitrogen, the principal component of air, pushes the remaining oil to the production well.

Method adopted in research work: To identify suitable Malaysian reservoirs for the LOAI project, a screening criteria was developed [6]. **Table 1** summarizes the basic requirement of the candidate reservoir for the process of LOAI. Based on the availability of the data of 22 Malaysian light oil reservoirs, E12-14 reservoirs of Dulang field were selected for the detail study. Since nitrogen content in air is high and the physical properties of air is quite close to that of nitrogen, we have used nitrogen in place of air for the simulation studies. In the selected reservoirs of Dulang field, miscibility is difficult to achieve for carbon dioxide gas injection [7]. Since nitrogen miscibility in oil is higher than carbon dioxide [8,9], an immiscible effect is used in simulation studies. In addition, the combustion in the reservoir was considered to occur in the low temperature oxidation (LTO) range because in light oil reservoirs, oxygen can easily be consumed in this range [10]. Since the amount of temperature increment after LTO reaction is reasonably low and the thermal effects were not significant [10,11]. Therefore, black oil simulations were used to model the reservoir and the process.

Production history of Dulang E12-14: The Dulang S3 fault block was developed with a total of 6 wells, including two down-dip water injectors i.e. A29L and A31L. The first production from the block started in year 1991. The initial depletion strategy for Dulang S3 block was by natural depletion. Subsequently, falling reservoir pressures coupled with decreasing production rates had led to the implementation of a peripheral water injection scheme through down-dip wells in year 1996. Feasibility studies in year 2002 identified re-injection of the produced gas as an EOR option [12]. Pilot project of Water Alternating Gas (WAG) was initiated in year 2002 with an attempt to improve recovery from the E12/13 and E14 reservoirs in S3 fault block and also, to evaluate its suitability as future EOR process for the rest of Dulang field.

Table 1: Screening Criteria of LOAI to Select Candidate Reservoir

Required Parameter	Criteria developed
Current Reservoir Pressure (P)	Moderate (1200-2500 psi)
Current reservoir Temperature (T)	Higher than 100 °C
Current Oil Saturation (S_o)	Minimum 30%
Pay thickness (t)	Not less than 8m
Formation Depth (d)	Minimum 200 m
Porosity (ø)	Minimum 20%
Vertical Permeability /Horizontal Permeability (k_v/k_h)	Maximum 0.4
Oil Gravity	Minimum 30° API
Current Water Saturation (S_o)	Maximum 60%
Homogeneity	Preferred

Simulation studies

Simulation model: A detailed reservoir simulation study was conducted in year 1999 and later in year 2001 to re-assess the various WAG injection options in E12/13/14 reservoirs in South-3 block[12]. These studies were the starting points for the design and development of field (pilot) testing of IWAG in South-3 block in Dulang field. In August 2003, a revised geological model was constructed. The model was built on a regular 25m by 25m grid oriented in a North South direction. There were a total of 24 layers used to model the E12/13/14 leading to a model with a total of 433680 cells. **Figure 1** shows the top and side view of the model. The layering within the model is shown in **Table 2**. In the present research study, history matched model for year 2003 was used for the validity of simulation.

Table 2: Formation Distribution in Simulation Model

Formation	Layers
E12/13A	1 to 3
E12/13B	4 to 8
E12/13C	9 to 13
E12/13 Shale	14
E14	15 to 24

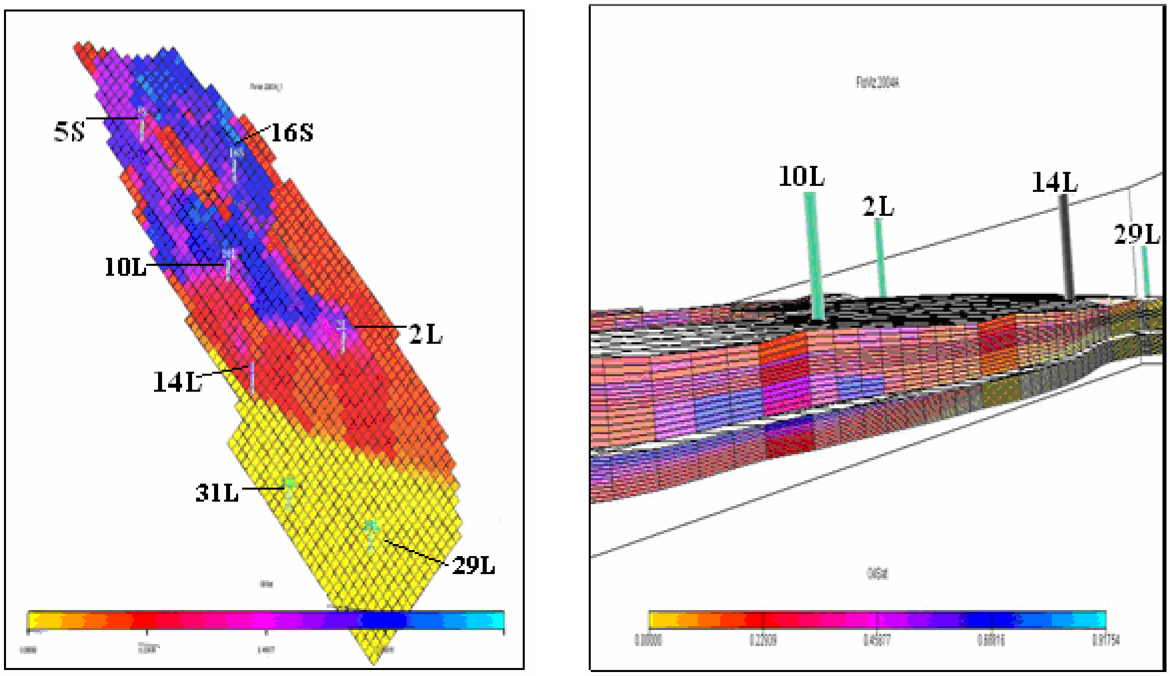


Fig. 1: Top and side view of the simulation model of Dulang E12-14 reservoirs

Setting the base cases: In order to compare the results obtained after injection of air into the reservoir, two different scenarios were considered:

- Water injection from year 1996 to year 2020
- WAG application from year 2002 to year 2020

In the first base case, the secondary recovery through water injection was continued from year 1996 to 2020. This water injection was initiated after the primary depletion from year 1991 to 1996. The upper target limit for overall water injection was set as 10000 stb/day. The second base case describes the actual scenario adopted in the reservoir, which is implementation of WAG in year 2002 after secondary recovery. Therefore, restarting of history matched model was carried out from year 2003 and production of oil was predicted till year 2020. Upper target set for the gas injection rate at surface was 4000Mscf/day with voidage replacement fraction of 0.7. The target set for the water injection at surface was 10000 stb/day, with no immediate control. WAG time period was set 90 days to allow alternate cycling of water and gas.

Results and discussion of optimization studies: In optimization studies, different configurations were simulated. The parameters which were studied are based on changing injecting time of the nitrogen and changing production well status by shutting it and conversion into injection well. Brief details of these studies are mentioned below:

Effect of injecting time: Effects of nitrogen injection time for the E12/13 and 14 reservoirs were checked on the performance of the LOAI. Two different cases were simulated; restarting nitrogen gas injection in April 2006 with base case 1 and restarting nitrogen gas injection in April 2006 with base case 2. The first case represented the injection of nitrogen in year 2006 after water injection from year 1996 to 2006. It is an imaginary case since actual WAG was implemented in year 2002 and continued till date. However, second case represents the injection of nitrogen in year 2006 after WAG implementation from year 2002 to 2006. In both cases, nitrogen was injected into the reservoirs from wells 14L and 10G. Wells 31L and 29L were used as water injector for the pressure support. The upper target limit for the overall water injection was set as 10000 stb/day. However, the upper target limit for over all nitrogen gas injection was set as 4000 Mscf/day. Water was used as complete voidage replacement fluid or as a top up phase. **Figure 2** shows comparison of the 2 cases with 2 base cases.

Figure 2 indicates that at the end of year 2019, highest oil recovery of 10.8 MMstb (Recovery Factor = 36.9%) could be achieved when nitrogen injection has been implemented in year 2006 after water flooding in year 1996 to 2006. However, this case could not be implemented in actual. The total oil production after WAG from year 2002 to 2006 could produce second highest oil production profile (Recovery factor =35.6%). **Figure 2** also shows that field water cut will be minimum if nitrogen is injected in year 2006 after implementation of WAG from year 2002 to 2006. However **Figure 3** shows that implementation of nitrogen injection in year 2006 after WAG or water injection may cause an unfavorable increment in gas oil ratio (GOR).

Effect of Well Configurations: This study was made to check the effect of production by changing preferences of the down dip production well 2L. Two different cases were simulated using restart of the second basecase from year 2006 to 2020. In the first case, production well 2L was isolated and considered shut. This configuration operates with two producer wells, 5S and 16S, and two nitrogen gas injectors, 10G and 14L, with injection rate of 2000 and 1000 Mscf/day respectively. In the second case, well 2L was converted from oil producer into nitrogen gas injector. This configuration also operates with two producer wells, 5S and 16S, but three nitrogen gas injector wells, 10G, 14L and 2L, with injection rate of 2000, 1000 and 1500 Mscf/day. **Figure 4** shows the comparison between the 2 cases and the 2 base cases.

Figure 4 indicates that at the end of year 2019, highest oil recovery of 10.4 MMstb(Recovery factor 35.1%) can be achieved when the producing well 2L was converted into a nitrogen gas injector well. Water cut could also be reduced. Shutting well 2L may produce production of 9.6 MMstb (Recovery factor =33.38%) which is a close value in comparison with WAG scheme adopted in reservoir (Recovery factor 32.69%). However **figure 5** shows that implementation of both of these schemes might cause unfavorable increment of gas oil ratio(GOR) which might be due to the reservoir heterogeneities and unfavorable mobility ratio between the oil and the injected gas .

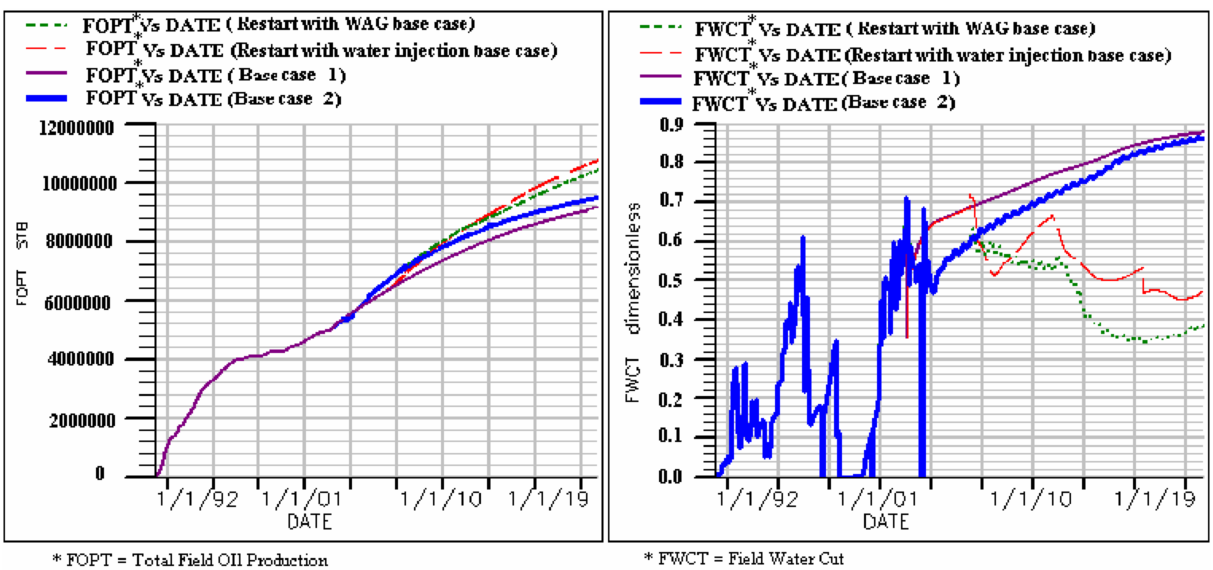
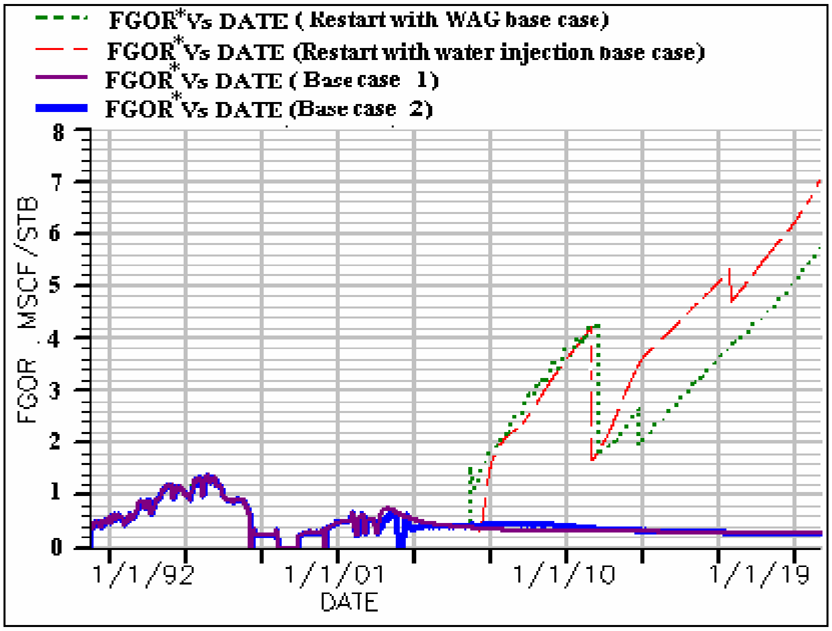
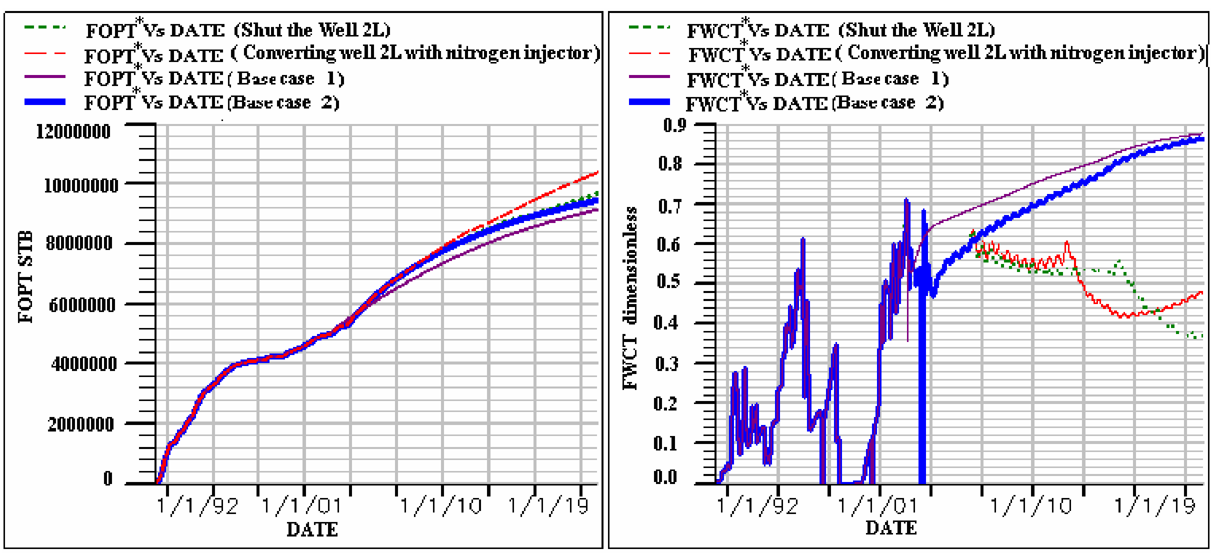


Fig. 2: Comparison of total field oil production and field water cut among 4 cases



*FGOR= Field Gas Oil Ratio

Fig. 3: Comparison of GOR among 4 cases



* FOPT= Total Field Oil Production

*FWCT= Field Water Cut

Fig. 4: Comparison of total field oil production and field water cut among 4 cases.

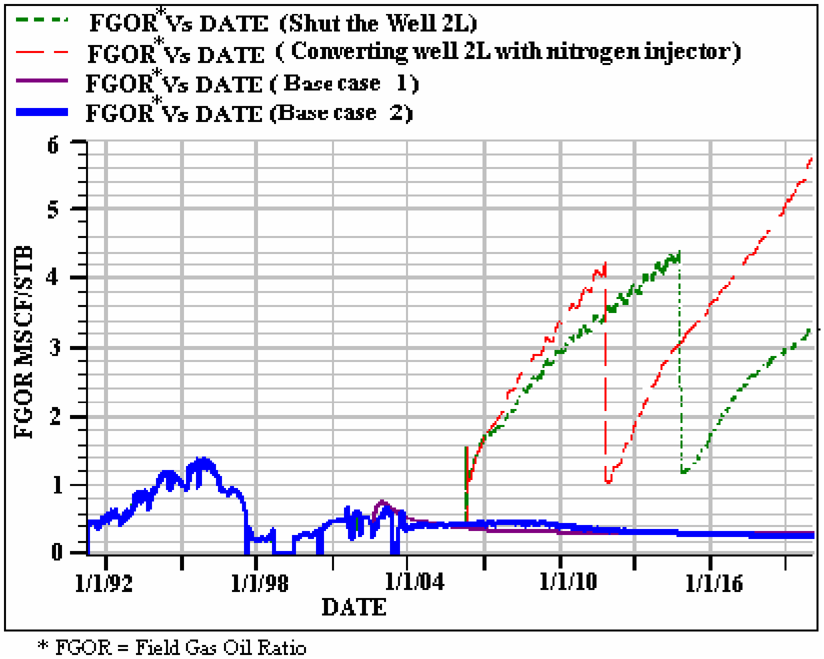


Fig. 5: Comparison of GOR among 4 cases

Conclusions

Incremental oil recovery using LOAI might be obtained if the method is implemented in E12-14 reservoirs of Dulang field. Air injection in Dulang field might produce 11MMstb at the end of year 2020. The current WAG EOR in Dulang E12-14 reservoirs may produce 9.2 MMstb at the end of year 2020. However, the significant rise in GOR suggests that if LOAI is implemented in year 2006 then measures should be taken to remove the amount of gas in the produced oil. In addition, the 100% utilization of oxygen in the injected air must take place into the reservoir. If the breakthrough of un-burnt air takes place at the producing wells, it might create safety problems. Therefore, laboratory experiments should be carried out to determine the reactivity of the reservoir oil with oxygen in the injected air at reservoir conditions of temperature and pressure

References

1. M.K Hamdan, N. Darman, D. Hussain, Z. Ibrahim : **EOR in Malaysia : Making it reality**. SPE 93329, 2005.
2. Jon Chadwick: **Improved oil recovery – meeting the challenge.** Presentation on 20 October 2003
3. M.R Fassihi, D.V Yannimaras, V.K. Kumar: **Estimation of recovery factor in light-oil air - injection projects**. SPE 28733, 1997
4. M Greaves, A.Wilson, M. Al-Honi, A.D. Lockett: **Improved recovery of light /medium heavy oils in heterogeneous reservoirs using air injection/ insitu combustion (ISC)**. SPE 35693, 1996.
5. G Moore, S.A Mehta, M.G. Ursenbach: **A guide to high pressure air injection (HPAI) based oil recovery**. SPE 75207, 2002
6. Zeeshan Mohiuddin, Ismail M Saaid, D.M Anwar Raja: **Potential application of light oil air injection to enhance oil recovery from Malaysian reservoirs**. International Conference on Environment (ICENV), 2006.
7. Zahidah Md Zain, Nor Idah Kechut, Ganesan Nadeson, Noraini Ahmad, D.M Anwar Raja: **Evaluation of CO_2 gas injection for major oil production fields in Malaysia – experimental approach case study: Dulang Field**. SPE 72106, 2001.
8. A.T. Turta, A.K Singhal: **Reservoir engineering aspects of light oil recovery by air injection**. SPE 72503, 2001.
9. W.F.Yellig, R.S Metcalfe: **Determination and prediction of CO_2 minimum miscibility pressures (MMP)**. SPE 7477, 1980.
10. S.R. Ren , M.Greaves, R.R Rathbone: **Air injection LTO process: An IOR technique for light-oil reservoirs**. SPE 57005, 2002.

11. S. Sakthikumar, K.Madaoui, J Chastang. **An investigation of the feasibility of air injection into a waterflooded light oil reservoir**. SPE 29806, 1995.
12. P Neve: **Fault block S3 WAG scheme – Reservoir Simulation Modelling**. PRSS report, 2004.