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CO_2 Geological Storage Coupled with Water Alternating Gas for Enhanced Oil Recovery

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Due to the climate change and global warming, the concern about CO_2 emission into the atmosphere has been raised in many industries such as oil and gas business. The sources of CO_2 include natural gas processing and other processes. The current technology to mitigate CO_2 is carbon capture, storage and utilisation. At the same time, oil production is expected to increase due to the higher consumption. CO_2 geological storage in depleting oilfield coupled with enhanced oil recovery can be a better technology to meet both requirements. The excellent example of this technology is the Weyburn Project in Canada that can store CO_2 and produce more oil as well as prolong the reservoir life. From this successful project, the technology is studied by applying it with the depleting oilfield for both oil production and CO_2 storage in the North of Thailand by using simulation model. It becomes the objective of this research, which is to evaluate CO_2 geological storage coupled with water alternating gas (WAG) for enhanced oil recovery as well as to study the effects the parameters, such as total hydrocarbon pore volume (HCPV) injection and WAG ratio, on oil production and CO_2 consumption and sequestration for enhanced oil recovery, with the added benefit of carbon sequestration. CMG software from Computer Modeling Group Ltd. is used to create the 3D simulation model to predict the CO_2 storage in the geological formation. From the simulation, the results reported that oil can be produced up to 125,976 m^3 of oil or 57 % recovery, CO_2 consumption is 66,261 m^3 of gas and CO_2 utilisation is approximately 0.53 m^3 of gas per m^3 of oil. The main parameters for WAG process is WAG ratio in that oil production increases as WAG ratio increases. CO_2 consumption increases with total HCPV injection. The results of this study can be applied to develop the CO_2 enhanced oil recovery (EOR) in the depleting oilfield in the North of Thailand for both oil production and CO_2 storage.

1. Introduction

In recent years, many industries have been highly concerned about the reduction in Greenhouse Gases emission, especially carbon dioxide (CO_2) due to the threat of climate change (Gallo et al., 2002). One of the most effective method to reduce CO_2 emission is Carbon Capture and Storage (CCS), which is the capturing and injecting of CO_2 to underground storage in depleted oil reservoirs (Metz et al., 2005). CO_2 has the capability to enhance oil recovery with a recovery potential of an additional 15 - 20 % of the original oil in place after primary and secondary recovery due to its miscibility mechanism (Global Energy Institute, 2012). The additional extraction of oil will provide more space available for CO_2 storage in long term. The use of CO_2 for enhanced oil recovery (EOR) resulted in exceeding benefits to improve oil production with the extending of project's life. It helps to minimise the environmental impact by reducing CO_2 emission in atmosphere and storing it in an underground depleted reservoir (Mathias et al., 2009).
Water alternating gas (WAG) processes is one of the various techniques to enhance oil recovery by injecting CO_2 alternated with water. This technique is related to the injection of a CO_2 slug into oil reservoir, followed by a slug of water that serves as the chasing fluid that help maintain reservoir pressure, displace the injected CO_2 and crude oil, adjust flood front to be more stable, reduce mobility of CO_2, and increase injectivity (Donaldson et al., 1989). This cycle is repeated as operational design. The WAG process fundamentally consists two mechanisms, including the injected CO_2 reacts with crude oil thereby reducing the oil viscosity consequently making the oil can flow easily due to miscible and immiscible effects. The second mechanism is where the

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alternating water injection can maintain reservoir pressure and help to reduce the amount of CO_2 consumption (Ghahfarokhi et al., 2016). The objective of this research is to evaluate CO_2 geological storage coupled with WAG for EOR and to study the effects the parameters, such as total hydrocarbon pore volume (HCPV) injection and WAG ratio, on oil production and CO_2 consumption and storage.

2. Simulation

In this study, GEM (2011) software by Computer Modelling Group Ltd. is used as a tool to construct the 3D reservoir model and to evaluate the performance of WAG technique in various scenarios. The homogeneous reservoir model is created based on a reservoir segment in Fang oil field, Thailand. This model consists of two layers of shale formation above and below reservoir to ensure that the injected CO_2 will not leak from the sandstone formation while injecting CO_2 at high pressure. Total area of this model is 145,161 m^2 with total thickness of 27.4 m which include 9.1 m of above and below shale formation, and 9.1 m of sandstone formation. The pattern of production well and injection well in this model is quarter five-spot pattern that comprises one injection well and one production well at the opposite corner of model and the well spacing is 538.9 m. The dimensions of model together with location of two wells are displayed in Figure 1. The reservoir properties of this models are summarised in Table 1. There are 29 components in this reservoir and the API gravity of the reservoir fluid is about 31° API.

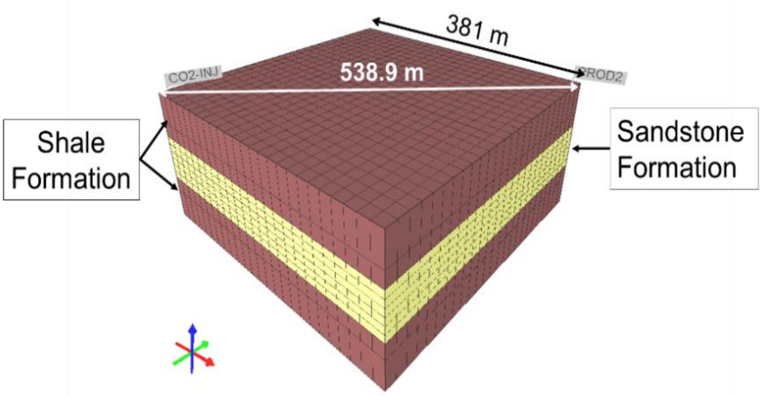

Figure 1: Dimensions of reservoir model with location of two wells

Table 1: Reservoir properties using for created reservoir model

Parameter	Values	Unit
Grid Dimension	25 x 25 x 6	block
Reservoir Size	381 x 381 x 9.14	m
Top of Reservoir	1,347.2	m
Reservoir Thickness	9.14	m
Porosity	0.25	fraction
Horizontal Permeability	150	mD
Vertical Permeability	15	mD
Reservoir Pressure	4.69	MPa
Reservoir Temperature	62.2	°C

3. Results

3.1 Effect of WAG HCPV injection

The effect of HCPV injection on the performance of CO_2 WAG is investigated by performing five runs of 0.10, 0.15, 0.20, 0.25, and 0.30 HCPV within ten years of production. The relationship between oil recovery factor and producing time for all cases is shown in Figure 2. The results indicated that higher oil recovery factor can be obtained by injecting with higher HCPV injection due to CO_2 EOR mechanisms. However, the injection of higher HCPV required more amount of CO_2. Higher HCPV injection provide more oil recovery factor with additional amount of CO_2 storage into the reservoir.

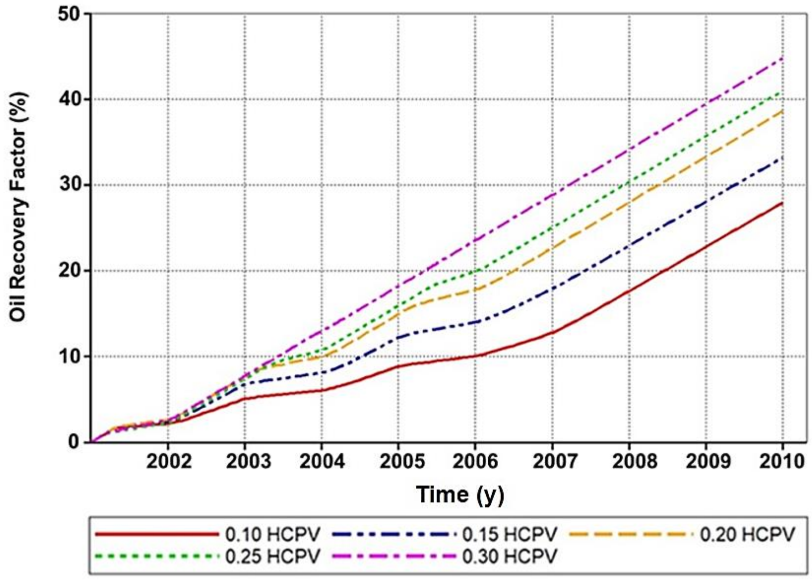

Figure 2: The effect of WAG HCPV injection on oil recover factor

3.2 Effect of WAG ratio

The effect of WAG ratio on oil recovery factor is also investigated by conducted 5 runs as following; WAG 1 : 1, 1 : 2, 2 : 1, 3 : 1, and continuous CO_2 flooding. Results of these runs is presented in Figure 3 that the highest oil recovery factor of 45 % is obtained by using WAG 2 : 1 or 3 : 1. Continuous CO_2 flooding shows poor performance (18 % oil recovery factor) which in line with the conclusion of previously research (Zekri et al., 2011). The poor performance of continuous CO_2 flooding could be described to the low volumetric sweep efficiency as a result of unfavorable mobility ratio that cause of early breakthrough and viscous fingering. Theoretically, increasing of WAG ratio is able to improve the performance of WAG method due to the volumetric sweep efficiency improvement (Attanucci et al., 1993). However, increasing of WAG ratio to be higher than 3 : 1 would not rise the oil recovery factor because of the limitation of formation fracture pressure.

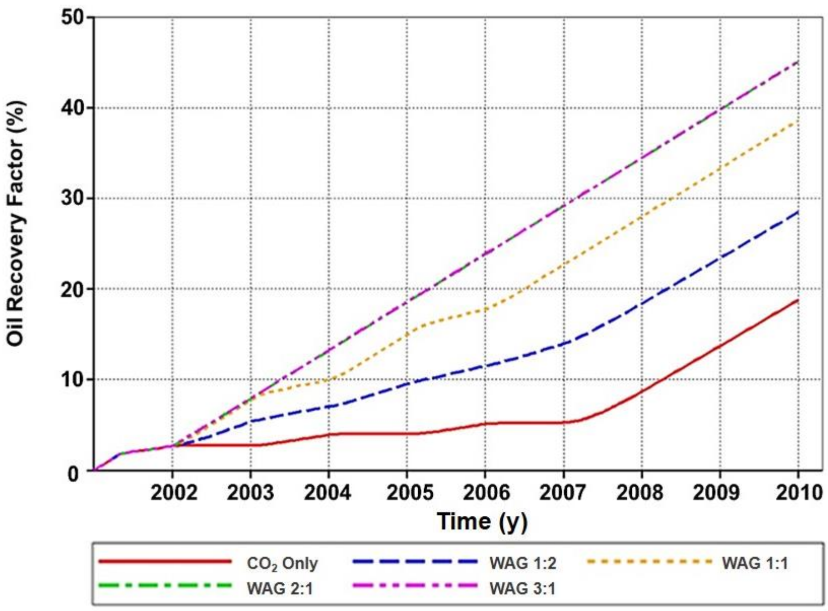

Figure 3: The effect of WAG ratio on oil recover factor

3.3 Effect of number of cycle and WAG cycle time

Number of WAG cycle can affect the oil recovery factor in CO_2 WAG process. The most favourable WAG cycle is one cycle, that is shown in Figure 4. The highest oil recovery factor occurs in the minimum WAG cycle case because the largest amount of CO_2 and water are injected into the reservoir in only one cycle, allowing the pressure in the reservoir to be above the minimum miscibility pressure (MMP) and miscibility effects would occur. The addition of more WAG cycle provides lower oil recovery factor due to the same amount of CO_2 and water are separately injected into the reservoir, which is insufficient to maintain the reservoir pressure to be higher than MMP. The shorter WAG cycle time provides the highest oil recovery factor due to the effect of the number of cycle that is already mentioned. The effect of WAG cycle time on oil recovery factor is presented in Figure 5. The highest oil recovery is obtained when slugs of CO_2 and water are injected in the shortest time with the lowest number of cycle due to the greatest reservoir pressure as compared to other scenarios.

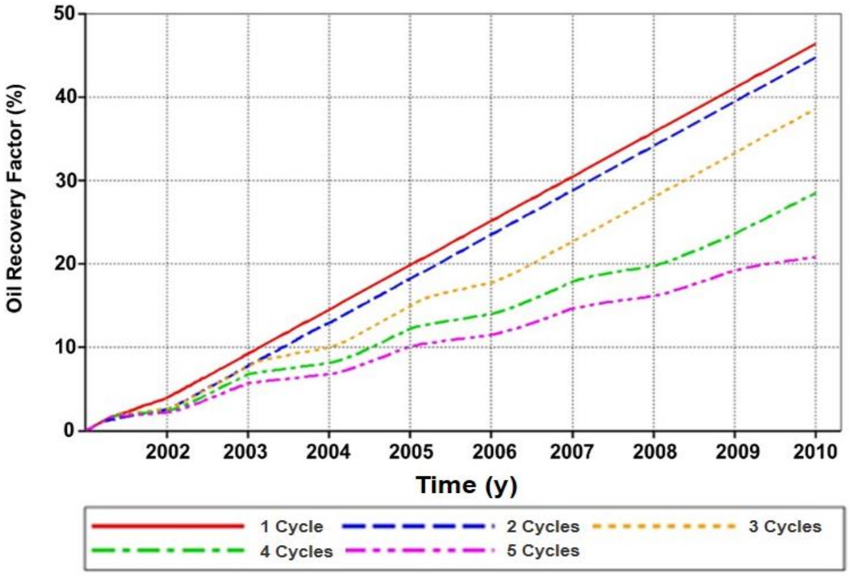

Figure 4: The effect of number of cycle on oil recover factor

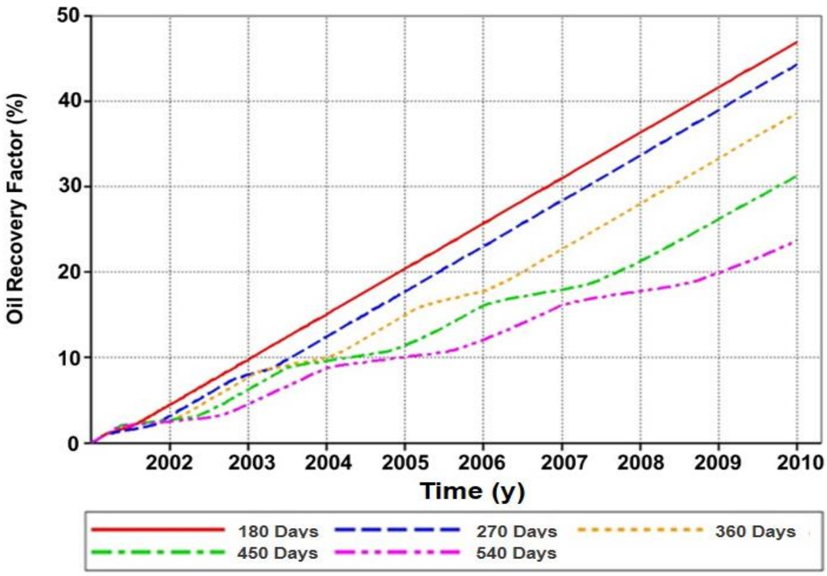

Figure 5: The effect of WAG cycle time on oil recover factor

3.4 Sensitivity Analysis

The sensitivity study is performed as a series of simulation to investigate the impacts of these operating parameters on CO_2 WAG method in ten years. The comparison of these parameters is presented in Figure 6, based on the incremental oil recovery factor. As shown, the most important parameter is WAG ratio, followed by number of cycle, WAG cycle time, and total HCPV injection. The range for the incremental oil recovery factor at ten years of production is 28.5 % to 45 % of original oil in place (OOIP)

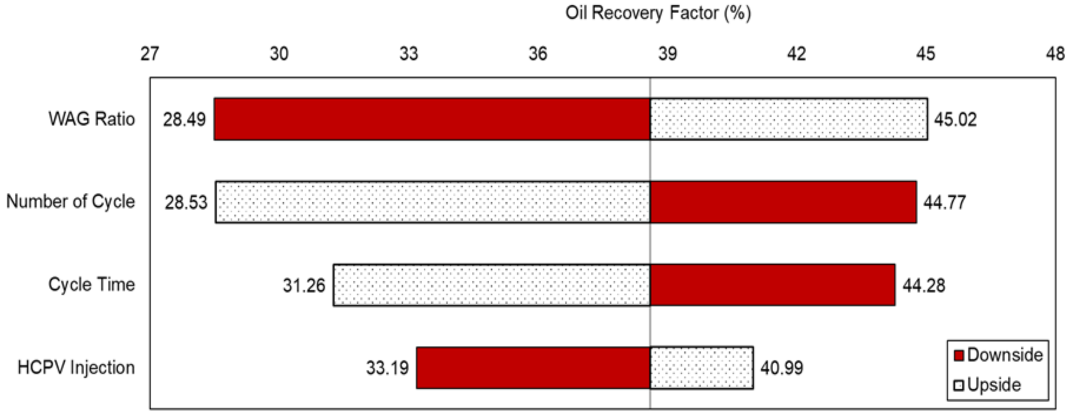

Figure 6: Sensitivity analysis of oil recovery factor in WAG process

3.5 Comparison to Primary Recovery

From the simulation, the results reported that the oil can be produced was 125,976 m^3 of oil or 57 % recovery with CO_2 WAG technique, comparing to the primary production with merely 2.92 % of OOIP. CO_2 WAG technique would obviously be the effective process to achieve the incremental oil production up to 54.08 % of OOIP above primary production. CO_2 consumption of CO_2 WAG technique is 66,261 m^3 of gas that entire injected CO_2 is stored in reservoir by replacing of residual oil. The CO_2 utilisation of this method is 0.53 m^3 of gas per m^3 of oil. Finally, the comparing results of CO_2 WAG process and primary production is presented in Figure 7 and Table 2.

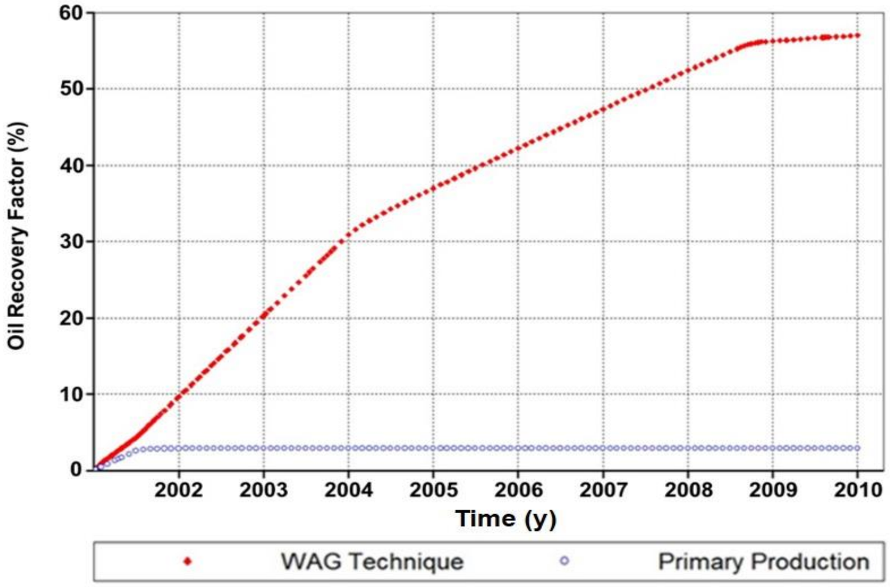

Figure 7: Comparison of oil recovery factor between CO_2 WAG and primary production

Table 2: The comparison between CO_2 WAG method and primary production

Method	Recovery Factor (%)	Cumulative Oil Production (m^3 of oil)	Cumulative CO_2 Injection (m^3 of gas)	CO_2 Storage (m^3 of gas)	CO_2 Utilisation (m^3 of gas per m^3 of oil)
CO_2 WAG	57.00	125,976	66,261	66,261	0.53
Primary Production	2.92	6,458	0	0	0

4. Conclusions

Alternating slugs of CO_2 and water contain the capability to enhance oil recovery due to oil viscosity reduction, reservoir pressure maintenance, sweep efficiency improvement, trapped-gas effect, and crude displacement by CO_2 and water. The increasing of WAG ratio is able to develop the WAG performance by the injected slugs of water, which can improve the volumetric sweep efficiency. However, the injection of CO_2 without alternating of water provides poor EOR performance due to low volumetric sweep efficiency that can be caused by the early breakthrough, viscous fingering, and gravity overriding effect.

In term of sensitivity analysis, WAG ratio and HCPV injection should be highly concerned in WAG design because these parameters can have direct effect to the oil recovery factor and CO_2 consumption. The smallest number of WAG cycle together with the shortest WAG cycle time should be selected for effective design because they will provide the highest reservoir pressure that can maintain miscible mechanism. The CO_2 WAG process should be stopped at the time when the first CO_2 is produced because the CO_2 flood front is initially reaching the production well and almost the whole CO_2 is stored into the reservoir.

Acknowledgments

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