Feasibility Study of CO2 Flooding under Gross-split Mechanism: Simulation Approach

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Abstract: Importance of Carbon Dioxide (CO_2) injection into the subsurface reservoir is essential since the concern of global warming and climate change issues in Indonesia. Selecting the oil reservoir as a candidate for a storage site is an attractive option due to CO_2 gas utilization is effective for Enhanced Oil Recovery (EOR) purpose. Continuous and Water-Alternating-Gas (WAG) CO_2 flooding are the most commonly applied scenarios in the oil and gas industries. Considering the EOR side, choosing an appropriate scenario is mandatory for cost efficiency reason and influences the oil share amount between the Indonesian Government and operator under the gross-split mechanism. Therefore, by using a simulation approach, the feasibility of continuous and WAG CO_2 injection is observed to decide the most financially attractive choice. Simulation results reveal a WAG scenario recovers slightly more oil compare to continuous injection scheme. Application of gross-split under base-share makes both injection strategies unattractive for investors. An adjustment of government-contractor share is required to improve the feasibility of the project.

1 INTRODUCTION

As a part of greenhouse gas (GHG) pollutant, Carbon Dioxide (CO_2) emission issue becomes a major concern of major countries. Through The Kyoto Protocol and Paris Agreement, most countries agreed to reduce CO_2 emission level before 2050 due to avoid the catastrophic effect of global warming and climate change phenomena. Carbon Capture and Storage (CCS) is the only effective scheme to overcome this problem (Agency, 2016). However, storing CO_2 in the aquifer is not financially satisfied since CO_2 is injected into the storage site without gaining any benefit during this activity. This story may sound interesting if CO_2 storage is performed in an oil reservoir.

Besides act as a storage site, injecting CO_2 in oil reservoir may bring another benefit in form oil production enhancement, commonly known as CO_2-Enhanced Oil Recovery (CO_2-EOR). CO_2-EOR has successfully implemented in North America for more than a decade, either using the natural or anthropogenic source (Whittaker et al., 2011; Jishun et al., 2015). Mostly CO_2 Flooding Targets crude oil contains high intermediate component because the miscible condition of CO_2 and crude oil can be achieved under reservoir condition (Abedini and Torabi, 2014). Minimum Miscibility Pressure (MMP) determination is mandatory in designing the injection scenario. MMP can be determined through slim-tube, swelling, vanishing interfacial tension, and rising bubble experiments. Moreover, PVT and slimtube simulation methods are capable to estimate MMP with a reasonable gap with experimental work (Abdurrahman et al., 2015).

Besides MMP, Deciding the injection scheme is also important for CO_2 flooding because it relates to the efficiency of CO_2 utilization in displacing residual oil. In terms of CO_2 utilization factor. Statistically, more than one barrel (bbl) Oil can be produced by injecting 1 million standard cubic feet of CO_2 (Azzolina et al., 2015). CO_2 utilization factor implicitly has an effect to the feasibility of the CO_2 flooding project because it correlates to how

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much CO_2 gas should be provided, i.e., how much fund is required for purchasing CO_2 or constructing CO_2 anthropogenic capture facilities. Deciding to use CO_2 from CCS activity potentially reduce the CCS cost itself (Rubin et al., 2015). Therefore, CO_2-EOR, either from natural or anthropogenic, i.e., from CCS, may bring a financial interest if properly implemented, including the injection scheme selection.

Deciding the most suitable scheme of CO_2 flooding is risky and relates to the oil share between the Indonesian government and operator because Indonesia adopts production share mechanism. Indonesia adopted a relatively new oil share mechanism, known as gross-split. This mechanism is officially introduced and effectively valid since 2017. This new mechanism still has to be improved because indicating an undesirable profit for the operator, feasibility study of CO_2 by considering injection scheme under gross-split mechanism is another interesting topic for the researchers (Irham and Julyus, 2018).

This Paper analyses under simulation method the feasibility of CO_2 flooding scheme by using gross-split mechanism. Two injection strategies, CO_2 Continuous injection and CO_2 Water Alternating Gas (WAG) are compared their capability in recovering residual oil after primary stage and also feasibility during CO_2 flooding stage. Mathematical model represents one of Indonesia oil field condition was generated by using BUILDER generator and simulated under GEM simulator. Both of these modules are licensed under CMG Software. Results from the GEM simulator will be analyzed its feasibility for each injection scenario. Injection scenario is decided by considering the economic parameter such as NPV and IRR.

2 METHODOLOGY

The reservoir grid model from Indonesia oil field is used for demonstrating the field-scale CO_2 flooding in this study. This grid model consists of more than 7,800 cells with 56, 46, and 3 cells along x, y, and z directions (represented as i, j, and k in the software). Figure 1 shows the grid model with its grid-top parameter. The average permeability is quite low, ranged from 30 to 100 millidarcy (md). The range of porosity of 0.13 to 0.19. The pore-volume of this model is 0.83 billion reservoir cubic feet (cuft). Figure 2 and 3 depict the relative permeability (k_r) plot for water-oil and gas-oil systems, respectively. The relative permeability model in this study is obtained directly simulation study (Millah, 2014). In the oil-water system, k_r is plotted over water saturation (s_w) and gas saturation (s_g) for gas- oil system. Subscript o, w, and g in figure 2 and 3 are oil, water, and gas. Twelve injectors are planned to inject CO2 under continuous and WAG scenarios and the performance will be analyzed based on production data on 5 production wells (location of the wells are shown in Figure. 4). Total injection volume is limited on 0.6 PV due to economic reason and the 1:1 WAG ratio is selected because this ratio is common in field-scale operation (Christensen et al., 1998). 2% Half Cycle Slug Size (HCSS) is designed for this study. Configuration of CO2 and water injection rate are tabulated in Table 1.

The model is simulated from 1996 until the end of 2013 for primary recovery stage and continued to 10 years CO_2 flooding under scenario in Table 1 until the injection period is finished (2024). The oil production during this CO_2 flooding simulation is recorded for feasibility calculation.

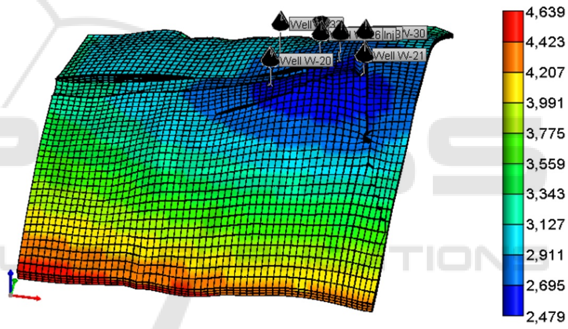

Figure 1: The grid model that is used in this study, the color legend represents the grid top of the cell in feet unit.

Table 1: Gas and water injection rate in CO2 flooding scenarios. "Mscf" means thousand standard cubic feet.

Injection Scenario	Gas Rate (Mscf/day)	Water rate (bbl/day)
Continuous CO_2 injection	1463	-
WAG	1463	1873

Figure 5 draws Schematic share diagram of Gross Split between government and operator (mentioned as "contractor" in this diagram). The difference of this new mechanism with previously cost-recovery mechanisms is the contractor must bear every operating cost, risk, and all taxes. The government and contractor shares are divided from the gross oil production while in the cost recovery mechanism, the oil should be shared to both parties after deducted from cost recovery post. Three variable influences the share of government and contractor, e.g., Base split, variable component, and progressive component

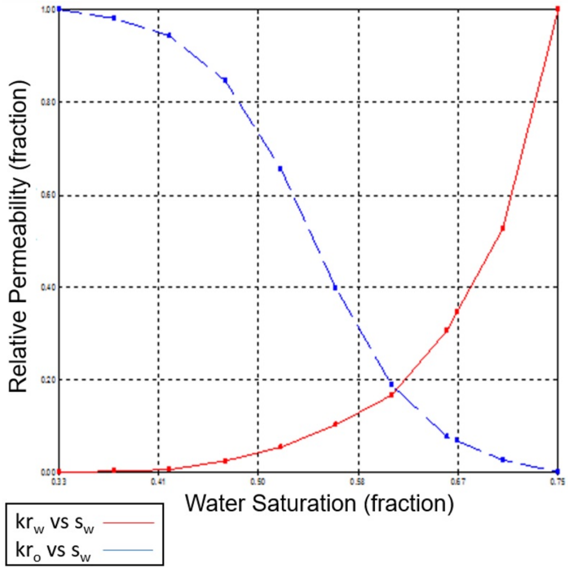

Figure 2: Relative permeability curve for water-oil system.

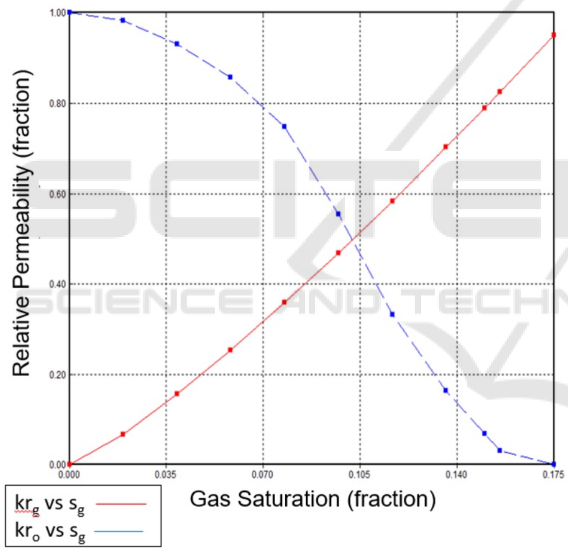

Figure 3: Relative permeability curve for gas-oil system.

(Giranza and Bergman, 2018). These variables are affected by field condition, development status, and oil price (Roach and Dunstan, 2018).

Several assumption will be made for studying the feasibility of CO_2 flooding project in this field. The oil price for this study is assumed 90 US$/bbl and the share for government and contractor is under base split (57% - 43%). Moreover, the Indonesian tax is assumed 45% (Roach and Dunstan, 2018). All cost and revenue components in this study are tabulated in Table 2, based on study of Jarrel et al. (2002). This study also utilized recycled CO_2 and water from the recycling facilities whereby the annual handling

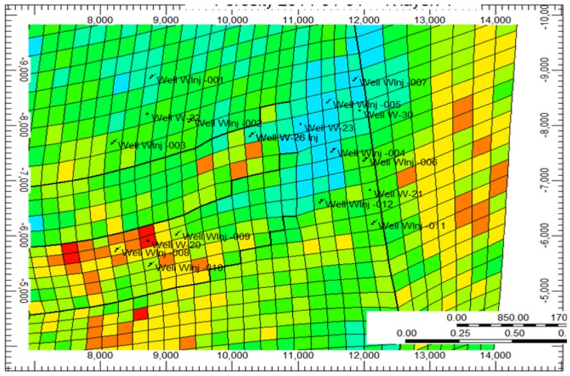

Figure 4: Distribution of injection and production wells in the grid model.

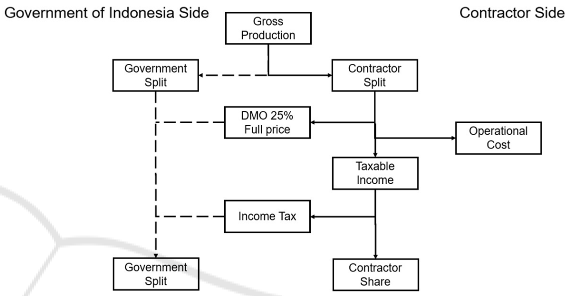

Figure 5: Schematic diagram of Indonesia gross-split mechanism.

capacity of which are 18 MMSCF CO_2 and 730 thousand barrels of water. The Weighing average cost of capital (WACC) for this study is 12%. Net Present Value (NPV) of each scenario is will be compared.

3 RESULT AND DISCUSSION

Figure 6 compares the annual production during 10 years continuous CO_2 Flooding and WAG, while the cumulative production on each scenario are plotted

Table 2: Cost and revenue components assumptions in this study.

Cost or revenue components	Value
Injection well cost	0.600 MMUS$/well
Production well cost	0.450 MMUS$/well
Well completion	0.200 MMUS$
Water injection capital cost	0.011 MMUS$/well
CO2 facility capital cost	0.012 MMUS$/well
Production facility capital cost	0.027 MMUS$/well
Water Injection Cost	1.000 US$/bbl
CO2 Price	2.500 US$/Mscf
Chemical Cost	0.020 MMUS$/well/yr.
CO2 recycle OPEX	0.750 US$/mscf
Water Recycle OPEX	0.300 US$/bbl
Oil Price	90 US$/bbl

in Figure 7. Continuous CO_2 injection shows higher productivity over WAG during two years injection and gradually decrease for the rest period. It is contrast with performance under WAG scenario where the oil recovery is still low in the first year but significantly increase more than 120% in the second year. Productivity on WAG tend to show a stable trend for the next seven years. Results from the figure 7 indicates the WAG application can recover oil slightly more than continuous flooding scenario with 1% recovery gap, i.e. the 10-years oil recovery is same. In terms of CO_2 utilization factor, a ratio of Injected CO_2 to the amount of oil production, simulation results shows low CO_2 utilization factor is revealed for WAG scenario, means requires less CO_2 to produce one barrel of oil. Comparing the data trends on both scenarios clearly indicates a continuous growth of CO_2 utilization factor, indicates the requirement to produce crude oil becomes higher over the time, while WAG shows a decreasing trend. WAG is effective to overcome the gravity segregation issue, compare to continuous CO_2 flooding. Due to lower density. CO_2 tend to move upwards in the reservoir, resulting a poor displacement efficiency (Jaafar et al., 2014),

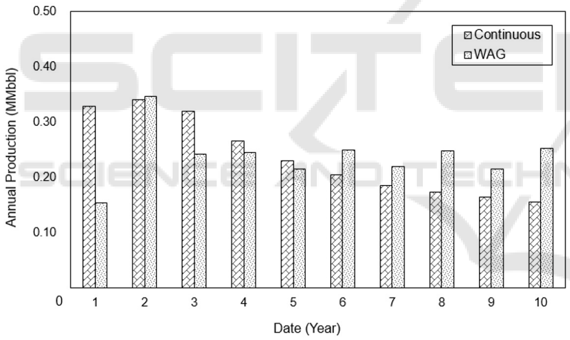

Figure 6: Annual oil production during CO_2 flooding phase for each scenario.

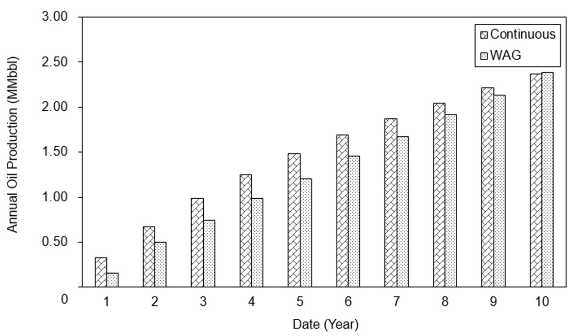

Figure 7: Annual Cumulative oil production during CO2 flooding phase for each scenario.

Despite both injection strategies shows same achievement in term of oil recovery, WAG option

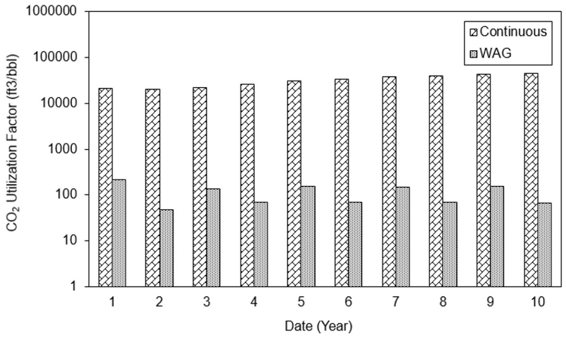

Figure 8: Annual CO2 utilization factor for continuous and WAG CO2 flooding.

is more attractive because consume less CO_2 inducing low CO_2 Purchase cost. Comparing these scenarios under gross-split mechanism reveal unprofitable conclusion, as indicates in negative value of NPV (Figure 9). Therefore, base-share between government and contractor is not feasible from the contractor side, means share adjustment between these shareholders are required. The government-contractor share is then adjusted to 35%-65% because these share is suitable for high operating cost, i.e., both CO_2 flooding scenarios are categorized into high operating cost projects (Roach and Dunstan, 2018). Recalculation of NPV under this new share results negative NPV for continuous injection project (-30.5 MM$) and 6.9 MM$ for WAG, means WAG scenario is more profitable. Moreover, the Internal Rate of Return (IRR) of this project indicate a significant profit can be made during this injection period, i.e., the IRR is higher than Indonesia WACC (32.7% compare to 8%). In short, CO_2 WAG scenario is effective in displacing residual oil and also more profitable than another option. Share adjustment in this study may be an evidence on the urgency CO_2 issue in Indonesia gross-split mechanism. Therefore, it is recommended to include CO_2 issue into the variable and progressive share components.

The information shared to the all of communities. A monitor with all the information related to the water quality installed at the community center or at the point of common assembly of community for easy to delivery of information. Furthermore, all the people and community can have an access to information shows including the status of river water levels. Based on monitoring system then all the information is update for public service and knows the status of the river.

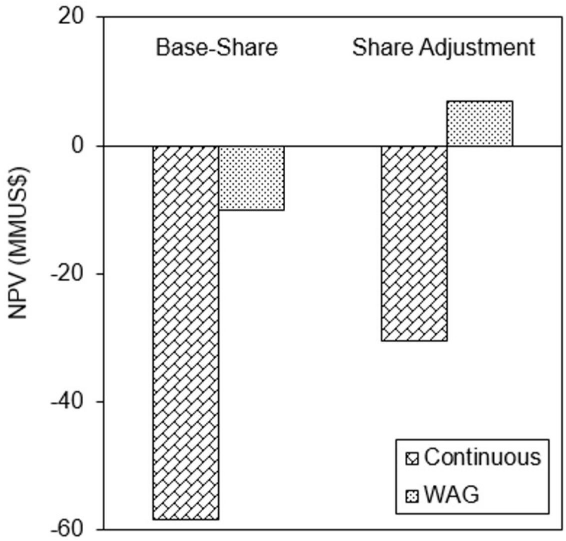

Figure 9: Effect of share adjustment to NPV for continuous and WAG CO_2 flooding.

4 CONCLUSIONS

This paper analyze the feasibility of CO_2 project under Indonesia gross split mechanism by using reservoir simulation method. One of Indonesia oil field reservoir is modelled for this study, where the CO_2 injection schemes is limited to continuous and WAG scenarios. Simulation results reveals a better performance of WAG in recovering remaining oil in the reservoir. Moreover, feasible indication is shown on WAG scheme after adjusting the base share of government and contractor. Including the CO_2 issues into the variable and progressive share, points may increase the tendency of CO_2 flooding application in Indonesia

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