34

Unlock EOR Potential of Carbonat Reservoir by CO2 Injection in Sukowati

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Unlock EOR Potential of Carbonat Reservoir by CO2 Injection in Sukowati

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PT Pertamina EP

Abstract

Pertamina EP has mature oil fields that still produce in primary and secondary stages. These problems can be solve by applying tertiary or enhanced oil recovery (EOR) methods. EOR screening processes was conducted using the combination of Al-Adasani (2011) and Taber (1983 & 1997) to determine the most suited EOR methods for each reservoir. From preliminary EOR screening results showed 10 oilfields with CO2 miscible method, 4 oilfields with CO2 immiscible, and 10 oilfields with WAG method. Sukowati oil field has very good pressure maintenance due its reservoir strong water drive mechanism. From 10 years oil production only made 200 psi differ from original pressure. From its original reservoir water drive mechanism, it's expected to achieve 50% recovery factor. Tertiary program is a next stage to gain more oil production 16,8% recovery factor with CO2 EOR injection.

Sukowati is onshore field located at Tuban, Bojonegoro, East Java. The field was discovered in 2001 and start producing in Juli 2004, reached peak primary production at 44923 BOPD at September 2011, and recently at 30.04.2018 oil production has reached 6160 BOPD. Since 20 Mei 2018, Sukowati field is being operated by Pertamina EP that previously by JOB Pertamina Petrochina East Java.

Sukowati Field is top kujung tuban formation that described as tall carbonat reef build up. OOIP Sukowati is 297 MMSTB with cumulative oil production is 114 MMSTB as of 30.04.2018. It has API 39, Viscosity 0.43 cP, avg permeability 156 mD, temp 275 F, main composition C5-C12, and depth 6300 ft. With these reservoir property, regarding to the EOR Screening criteria shows the CO2 EOR was suited to be applied in Sukowati. At appropriate pressure oil hidrocarbon will make mass-transfer process CO2 dissolution and condensation that can lighter oil and moves the residual oil. This also supported by potensial CO2 Source from Jambaran Tiung Biru that located 44 km away from Sukowati with 100 MMscfd CO2 gas that will on stream at 2021.

Slim tube test has been done, full scale application will be miscible without causing fracture pressure. However, some challenges to implement CO2 EOR in Sukowati; one thick layer with gross thickness 780 ft (no gascap), uncertainty faults, and water channeling behind casing.

This paper will describe the CO2 injection program in Sukowati field. Variation scenarios already applied as reservoir simulation that CO2 injection with specific rate will show best oil production performance at incremental 50 MMstb.

Keywords: EOR, Sukowati, CO2 Injection, Carbonat

1. Introduction

CO2 injection is one of the EOR methods that is good enough to be applied at various types of oil and reservoir, especially there are several CO2 sources that can be utilize. To reduce the effect of the greenhouse (Global warming), it is seemed necessary to carry out CO2 injection strategy into a reservoir in the framework of CCUS EOR (Carbon Capture Utilization Storage) by re-injecting the CO2 production and build up energy to maximize oil production.

Sukowati Field with OOIP 297 MMSTB is located in the Bojonegoro region, East Java and operated by PEP Asset 4 (Figure 1). Status of April 2018, there are 36 wells were drilled in Sukowati field, 27 production wells, 8 suspend wells and 2 water injection wells with cumulative production of 115 MMbbl, 8,193 BOPD oil production rate, and water production rate of 21,082 BWPD gas production rate of 14.74 MMSCFD with levels of around 40% CO2. It is necessary to concern for HSE, remembering Sukowati Field has high H2S level of 2% (20,000 ppm). The field put on production on 2 July 2004 through SKW-01 and SKW-02. This field previously operated by JOB PPEJ then since May 20, 2018 has operated by Pertamina EP.

EOR screening has been studied, with API 39, Visc 0.429, Saturation Oil> 55%, Avg perm 156 mD, Temp 260 F and 33% porosity showed that CO2 flood implementation was chosen as the proper tertiary recovery activity to increase production, accordance with SPE ref paper 130726. The formation target of Sukowati Field is the Tuban Formation (Carbonate).

In this paper, field test scenario is evaluated whether is huff & puff or pilot 5 spot inverted to seek which is the possible, fastest time track and the most reliable to scale up full scale CO2 injection. The selected scenario will state on candidates for injector and producer wells, along with their production predictions. This paper also examines if field Sukowati potential for CCUS – EOR.

2. Methodology

In this paper using compositional reservoir simulator is used predict oil gain by CO2 injection. The injection CO2 segregation scheme with continuous. Fluid data, cores, logs, well tests, and production are integrated to model reservoir characterization. Then this reservoir model is validated by doing a history of matching production (oil, water and gas) and reservoir pressure. Flow Methodology has shown in Figure 3.

Fluid modeling is done by fine tuning EOS with SKW-29 (taken 2013). This EOS was chosen because it representative as the recent fluid and slim tube simulation gives 2800 psi (Figure 4).

After tuned the EOS, then we use it in Geo - simulation model. After doing history matching, then we make cases to see the most feasible and economical way as follow:

1. Huff & Puff Scenario
2. Pilot Scenario
3. Full field Cases Oil production prediction due to CO2 flooding is simulated using several rate scenarios such as the following; CO2 injection Gravity Stable with 55, 70 and 100 MMSCFD.

2.1 Slimtube Experiment

By injecting CO2, we will get additional energy to make oil recovery, that can be obtain with the miscible or immiscible injection scheme. Reliable miscible condition if CO2 Inject in reservoir that has reservoir pressure above MMP (Minimum Miscible Pressure) and below fracture reservoir pressure. With the CO2 injection, there are 3 mechanisms that will occur; viscosity reduction, Oil Swelling /Oil expansion and surface tension reduction. With these three conditions will get optimum RF if the pressure reservoir above MMP, production oil rate below critical rate and CO2 injection rate carry out with mobility ratio <1 that will give the piston like effect.

The Minimum Miscible Pressure (MMP) Sukowati field has defined by SKW-29 Slimtube test that gives value of 2800 psia. If you need a miscible condition, 2 options can be done: first, repressurise the reservoir condition by injecting a large amount of fluid or injecting a quantity of solvent to reach the MMP point. From the geometry data SKW-17, reservoir fracture pressure show value of 4700 psia is still above the MMP value, so it is possible to do Miscible without fracking the reservoir.

As for the option to reduce MMP, the sensitivity of MMP correlation has been done. The analysis focuses on the sensitivity of the composition solvent (Mixing CO_2 with light components). Using the correlation of shokir et al, we can see changes in MMP with the addition of C1, C2-C4, N_2 & H_2S shown in figure 5.

From the picture above it can be seen that with the addition of 0.23% H_2S, 7% C2-C4 and 92.7% MMP will be obtain at 2600 psi. To do miscible on a pilot scale, the addition scheme can be done intermittent by injecting C2-C4% first, and continued with CO_2 injection. For select injection method, it will be discuss in a further study, but in this paper we will only discuss the possibility pilot test with existing condition.

2.2 Compartemen Identification

PVT analysis can also to look for possible compartments. From table 1, only PVT from SKW-06 and SKW-29 give the same saturation pressure value, SKW-14 and SKW-18 has high value of Pb is assumed when taking bottom hole sampling, there was a captured gas. There are various methods to quantify the existence of a compartment, from the 4 PVTs that Sukowati has, show that there is no compartment and only 1 fluid is valid based on justification below (Figure 6 & 7):

1. PVT of four composition have the same almost value (except SKW-06).
2. On the ternary table, all four fluids are in the same area.
3. In the graph of Bo vs GOR and Bo vs Pb, shows the same trend and no separation
4. All Oil Viscosity data in undersaturated state show the same slope.

2.3 Cap Rock Identification

The most important public concern about CO_2 geological storage is the long term isolation performance. To prevent the stored CO_2 leakage into groundwater sources or the atmosphere, the possible leakage paths, must be examined and identified. Cap rock integrity is the most important factor to evaluate the long-term CO_2 isolation performance. For start identification can be shown from cores, and logs. Then the cap rock integrity must validated by doing test and further geomechanic study. Sukowati formation is carbonat that lays in top formation kujung as seen at figure 9 with depth 5830 TVDss. From Figure 8 we can capture that there are 10 meter shale between top kujung formation and ngrayon formation.

3. CO_2 Source from Oil & Gas Plant at East Java

There are several source CO_2 gas from the field /structure around Sukowati field that described in the Figure 2 and Table 3.

To conduct CO_2 EOR injection at Sukowati Field consist of 2 stages, pilot stage and the full field scale. To carry out the pilot stage will utilize CO_2 gas which produced by Sukowati Field itself around 5 MMScfd. This is selected due to existing produced gas, paterned well pilot selection (will discuss in Pilot part). Existing condition, there are CO_2 and H_2S separation only for boiler purpose that has capacity around 5 MMSFD produced gas, thus there is no separation facility to separate the production gas. To do fullfield scale requires a large amount of CO_2 gas that will occupied from the Jambaran-Tiung Biru (JTB) Field. The Jambaran Tiung Biru field is expected to be On-stream in mid-2021, with CO_2 gas production plateau of 110 MMSCFD for 15 years until the end of the contract, September 2035. PEP should build a tie line at the AGRU stripped out that has composition 92% CO_2 and 8% H20. To prevent corrosion in the pipeline JTB to sukowati, the CO_2 gas necessary to go through dehydration system before being sent to sukowati.

From pilot stage to fullscale, CO_2 gas will breakthrough like figure. At the start conditions the composition of CO_2 gas has reached 45%, and when starting Injection the CO_2 content becomes 53%, and becomes 90% when fullscale (Figure 12 and table 4)

4. Simulation Study

The Static Model of Sukowati Field was built using Petrel software while the dynamic model was run by compositional software CMG-GEM. The total number of blocks after upscaling is 1247142 and the number of active blocks is 424068. The model has grid number 271x177x26.

In Sukowati simulation model, liquid production was used as the constraint. Result of history matching can be seen at figure 10. . History matching of the water rate has problems because the produced water source cannot be ascertained considering the problem of cement bonding which results in channeling of water to the tubing. History of matching Sukowati Field can be seen in figure 10.

4.1 Huff & Puff Scenario

To do field test, PEP also considers Huff & Puff Scenario besides 5 spot inverted pilot. With water injector that has rate 7000 bwpd, this respond to the well block pressure at SKW-14, SKW-16, and SKW-12. This wells selected based on close to injector well SKW-I01 (Figure 11). The scenario for CO_2 Huff & Puff is CO_2 injection for 10 days then soaking for 5 days, and then put it on production. The cumulative oil and incremental oil found in the table 2. Sensitivity CO_2 rate will cary out at 0.5 and 2 MMscfd. Eventhough the huff & puff results give a negative value to the baseline, the SKW-12 with 0.5 MMscfd injection can give jump incremental oil rate of 153 bopd.

4.2 Pilot 5 Spot Inverted

The pilot scenario selected based on injection well location, and well observation is the smallest pattern based on existing wells. The well locations should be in high structure since the fullscale flooding will be from top of the structure. For CO_2 pilot implementation will be immiscible process since current reservoir (2600 psia) below MMP and pilot is not confined. Adding water injection fences surrounding the pilot may not be technically and economically justified. For pilot scenarios, the pilot will use 5 spots inverted, CO_2 response can be obtained from the surrounding wells SKW-02, SKW-07, SKW-08 and SKW-21. For CO_2 implementation, the plan will be open perforation 100 ft below the top structure, convert SKW-27 into injector gas and inject injection CO_2 at rate 5 MMSSCFD (Figure 15).

Sensitivity varying at rate of 0.5, 3 and 5 MMSCFD can provide RF 1, 2 and 5% within a year (Figure 14). The breakthrough time each scenario is given Figure 16.

For pilot implementation, scenario that will selected of injection rate of 5 MMSCFD can provide maximum CO_2 storage at 97,267 tons in 1 year with the fastest days breakthrough 200 days.

5.3. Full Scale Scenario

Based on literature, the best strategy is to inject CO_2 from the top using a gravity stable mechanism or segregation. Sukowati has thick gross thickness 830 ft carbonat build up . If CO_2 flooding inject at this type geological, gas CO_2 will move upward and make gravity override due to density difference with oil.

For full field scenario, 9 new wells injector gas plus SKW-27i injector are required. The completion of this these injector gas is open only 100 ft below the top structure. The sensitivity has been made with vary rate CO_2

injection rate for 53, 77, and 100 MMSCFD. The completion will be open from top to bottom above to WOC, and the completion will close when reach 10.000 cuft/BO.

5. Result and Discussion

For field test, pilot 5 spot inverted is selected because is more respresentative the fullscale implementation. Regarding from H&P show only less incremental, that will make inconclusive decision (Table 2).

For fullscale implementation, The three scenarios are carried out with the same schedule only differentiating the gas flow rate. It can be seen that the gas flow rate scenario of 100 MMSCFD results in the greatest increase in production rates in the beginning. The incremental oil rate is around 15,000 bopd. While the scenario with a flow rate of 77 MMCFD and 53 MMCFD gives incremental oil rate 11000 bopd and 7000 bopd. It can be seen increasing rate after CO2 injection, the reservoir pressure is build up into 2900 psi, where the value is above MMP that make miscible process. Oil cumulative of gas injection rate 100 MMSCFD is greater than the two other cases seen in Figure 17 and Table 5.

In the 15 year period, CO2 injection of 100 MMSCFD has filled 62% of HCPV which can provide incremental 50 MMSTB or around 17% incremental Oil. With the best scenario with injection rate 100 MMCFD, we will get storage of 16 million tons of CO2. This can be seen in Figure 18.

In the process of CO2 EOR injection will thickened oil colom Sukowati with the following process:

1. 2004, Put on production
   WOC 6680 ft ss, Gross Thickness 830 ft
2. 2018, Current condition,
   WOC 6050 ft ss, Gross Thickness 200 ft
3. 2020, Start CO2 inject time
   WOC 5900 ft ss, Thickness 50 ft
4. 2025, after 5 years CO2 injected, GOC 5950, WOC 6050 ft ss, Gross thickness 100 ft
5. 2035, after 15 years CO2 injected, GOC 6000 WOC 6200 ft ss, thickness 150 ft

At start point of CO2 injection at 2020, the gross thickness has shrinked 830 ft to 50 ft Because of primary condition the WOC get higher, and if the pressure reach Pb then will make secondary gascap. After 15 years of CO2 injected, the CO2 will fill the most top part the reservoir then it will fill downward as volume increase and make the oil colomn thickened from 50 to 150 ft as seen in Figure 19.

6. Conclusion

From the discussion above, it can be concluded that:

1. CO2 EOR injection is suitable tertiary Recovery activity for Sukowati Field to boost an energy to enhance oil recovery. Even if it not achieve miscible condition its still can swell volume of oil, lowering surface tension that can mobile oil in porous media. However since MMP is feasible to achieve, it’s recommended to do it in miscible way for full scale.
2. For pilot, by inject 5 MMSCFD from Sukowati field can get incremental oil 5% that may store 97000 ton CO2.
3. It’s founded that Sukowati has cap rock with 10 m thickness which is shale above top tuban kujung formation that make Sukowati good candidat for Carbon Capture Storage.
4. Beside of maximize oil Recovery, CO2 stored at Sukowati during the CO2-EOR can be count of CCS-CCUS. For the best scenario for Full scale with injection rate 100 MMSCFD, Sukowati can stored 16 MM ton CO2 that will displace 50

MMstb (17%) with 0.62 HCPV injected within 15 years.

7. Recommendation

For future study, we plan to do pilot study coreflooding test, and geomechanic study.

The future Pilot CO2 EOR Study may be conducted to evaluate the EOR process recovery efficiency in the field, asses the sweep efficiency of the CO2 injection, obtain data to calibrate reservoir simulation models for fullfield predictions, prove efectiveness gravity stable or vertical conformance, Identify operational issues and concerns for fullfield development and to find unexpected issues, define Monitoring & Surveillance program with specific tools, and define matrix of success criteria

For laboratorium scale, coreflooding will describe understanding displacement mechanism by CO2 injection. With using the native core and recombination fluids will mimic segregation scenario as full-scale simulation. For a lab scale this is best way to get result CO2 EOR performance flooding. We expect core flood will describe how CO2 can mobilize residual oil saturation, does CO2 injection alter core permeability, and does CO2 injection make asphaltene deposition.

In order to assess the risk of CO2 Leakage, there are several study should be taken, geomechanic study to test if the injection pressure to reservoar should induce any fracture at reservoir, and if the CO2 and rock interactions might alter the cap rock and affect sealing integrity.

8. Acknowledgement

I would like to express my deepest gratitude to EOR Management team for guidance and advice are the key element for the completion of this paper. Secondly, I would like to thank Upstream Technology Center Pertamina, JOB PPEJ and Pertamina EP Aset 4 very much for allowing me to publish data from previous study Pre-FS CO2 EOR Sukowati 2016

9. References

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List of Figures

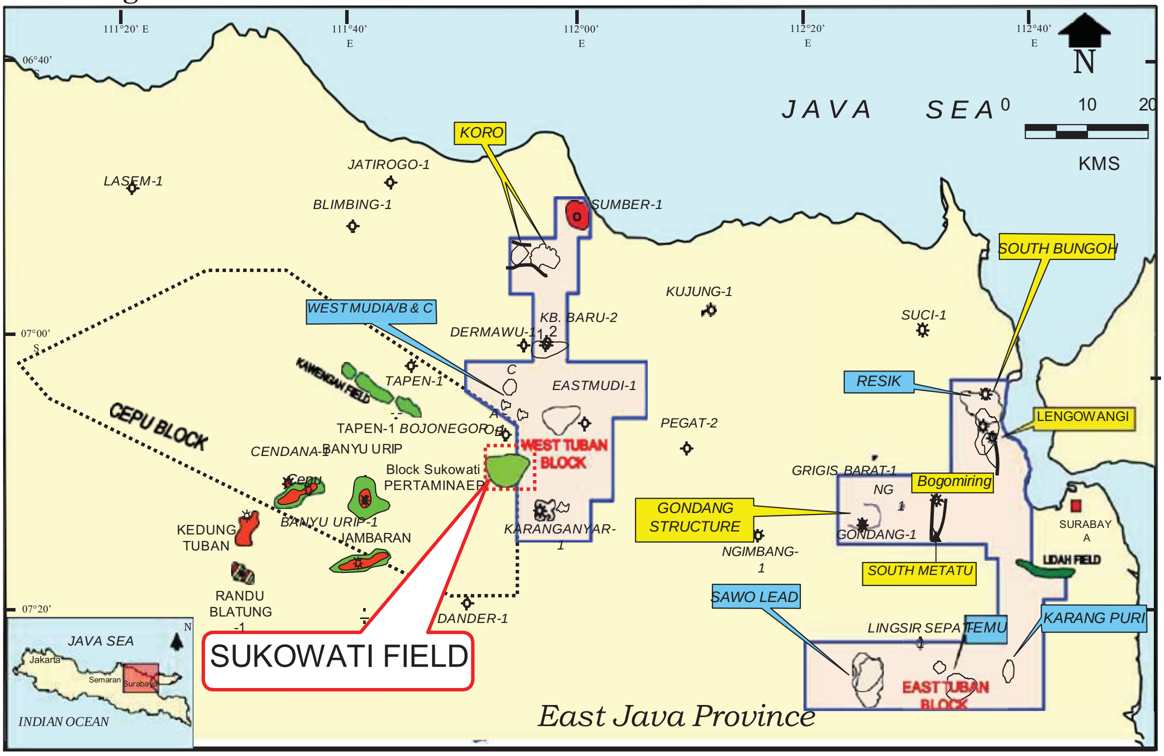


Figure 1 Location Map of Sukowati Field at East Java

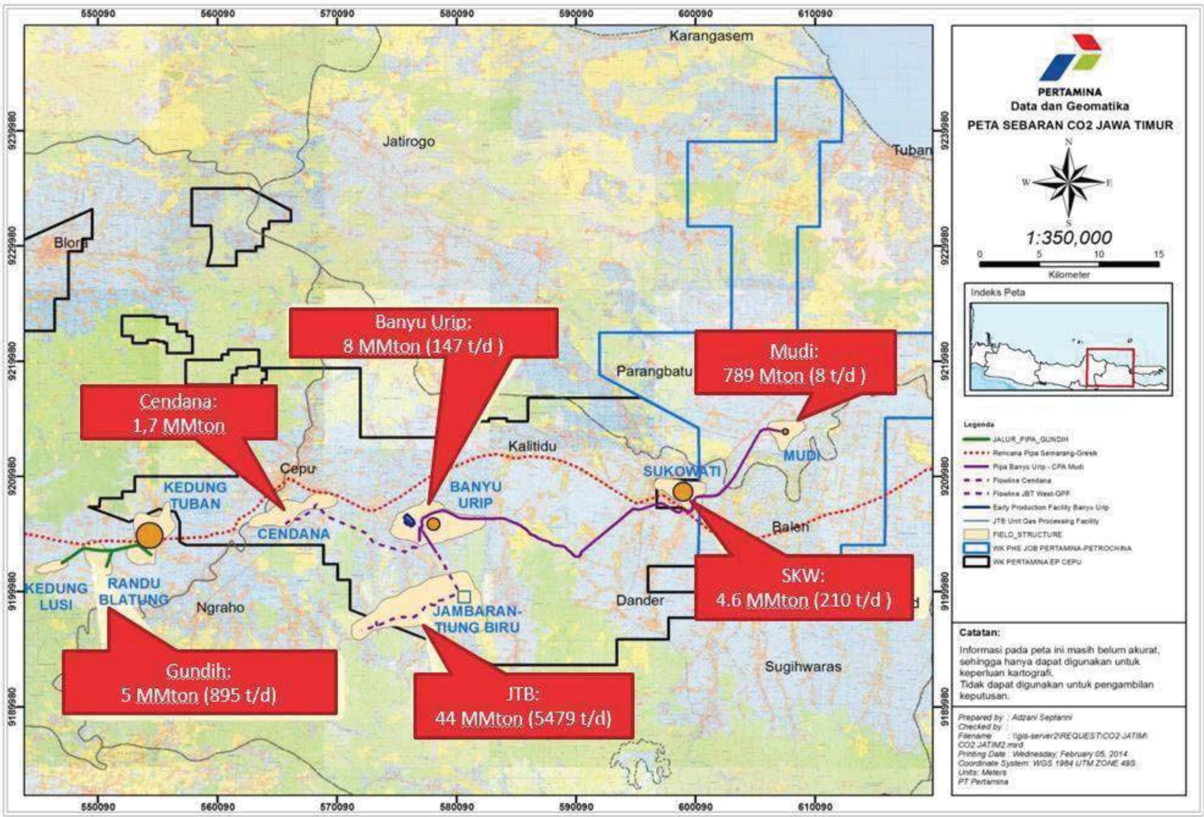


Figure 2. Picture Potential CO2 Source around Sukowati Field

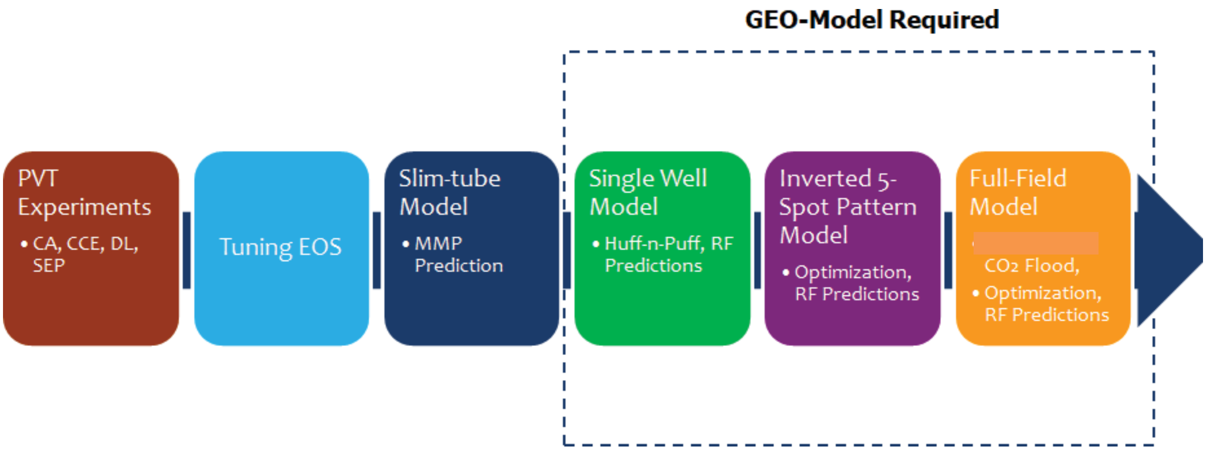
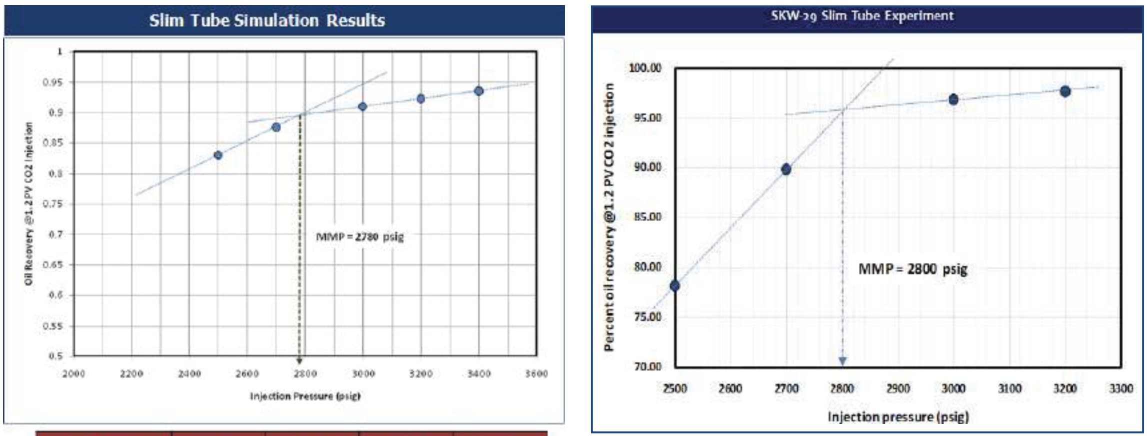


Figure 3 .Workflow CO2 EOR study



Correlation	SKW-6	SKW-14	SKW-18	SKW-29
Cronquist (1978)	3,735	3,901	4,643	2,781

Figure 4 .Slim tube simulation vs Slim tube Experiment SKW-29

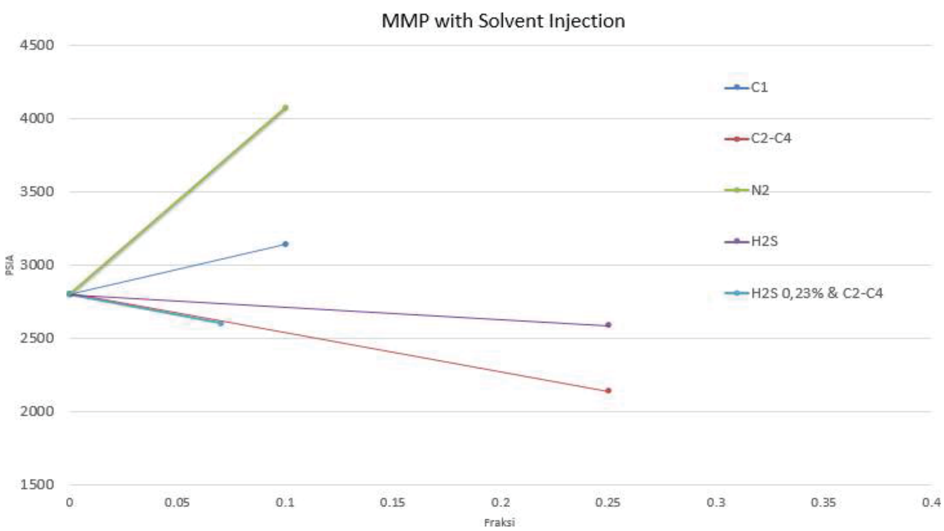


Figure 5. MMP prediction PVT SKW-29 with solvent injection by correlation Shokir et all

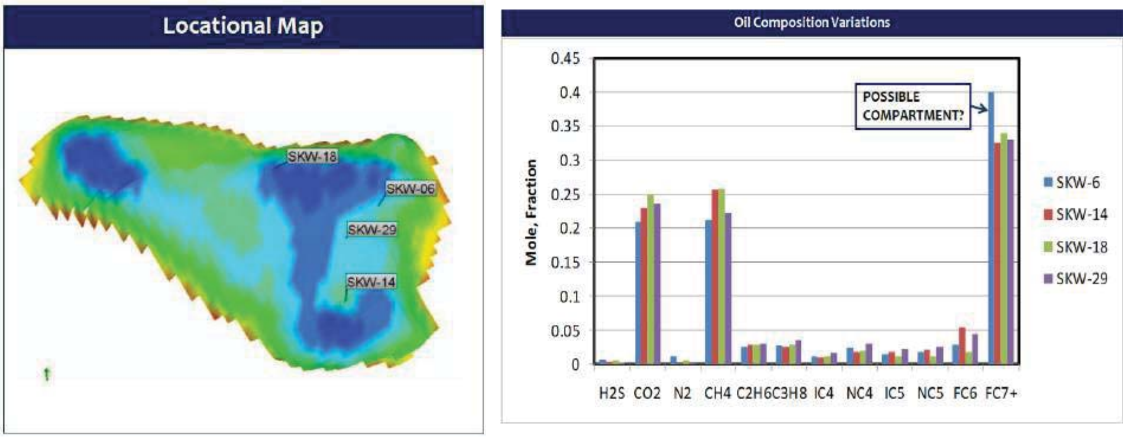


Figure 6 .PVT Sukowati Location Map (left) and Oil Composition (Right)

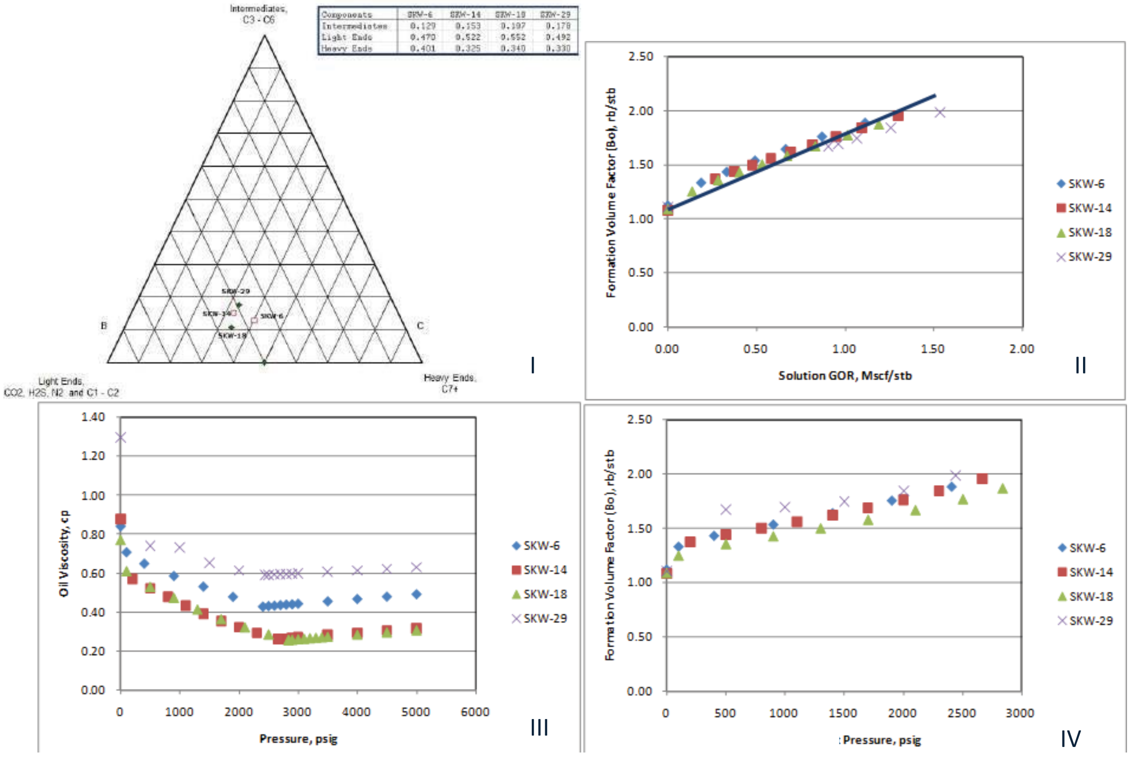


Figure 7 . Characteristic all PVT Sukowati: Pseudo Ternary Sukowati (I), Bo vs Rs PVT Sukowati (II), Oil Viscosity vs Pressure (III), and Bo vs Pressure (IV)

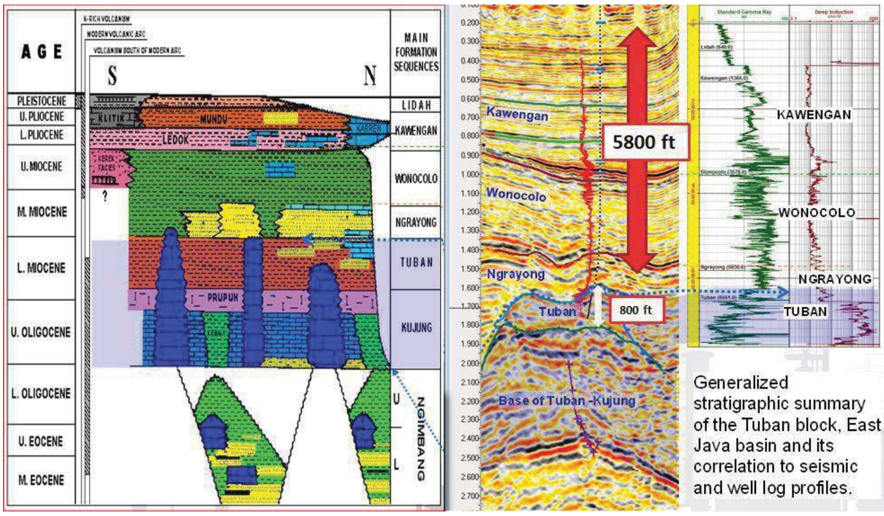


Figure 8 . Formation Tuban Sukowati Field

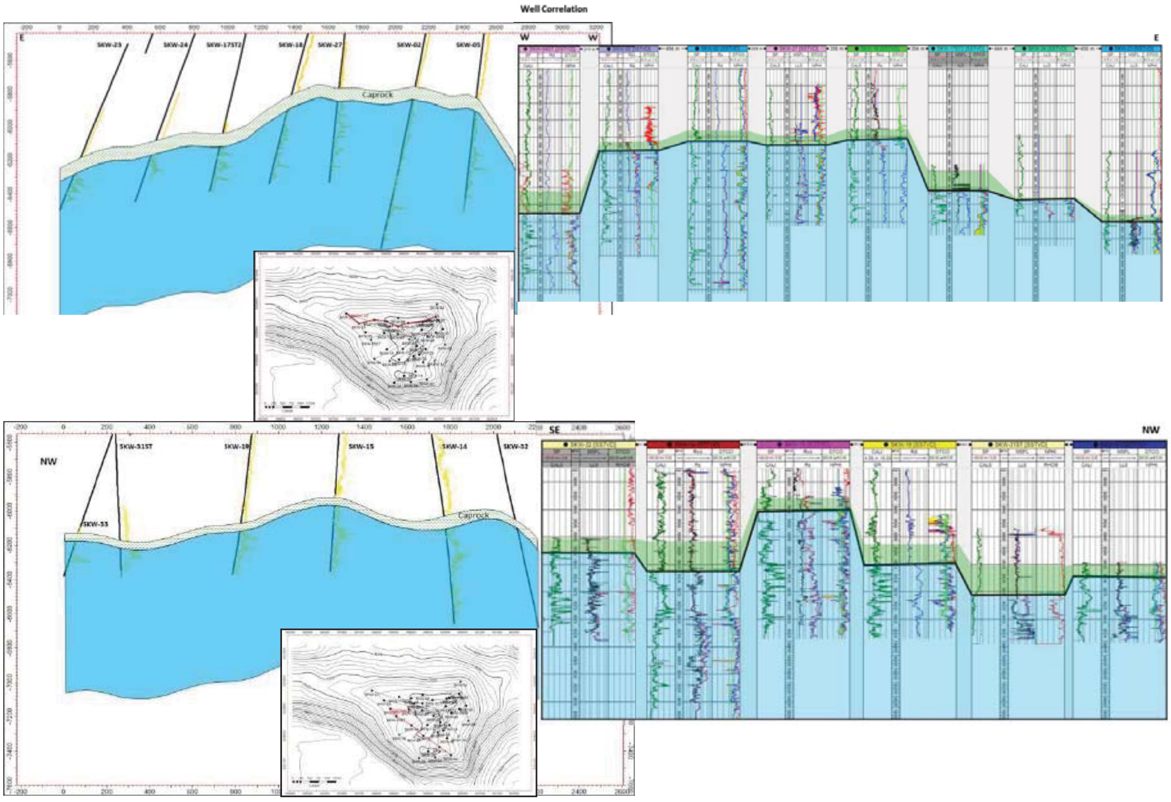


Figure 9 . Stratigraphic sucession & Well Corelation

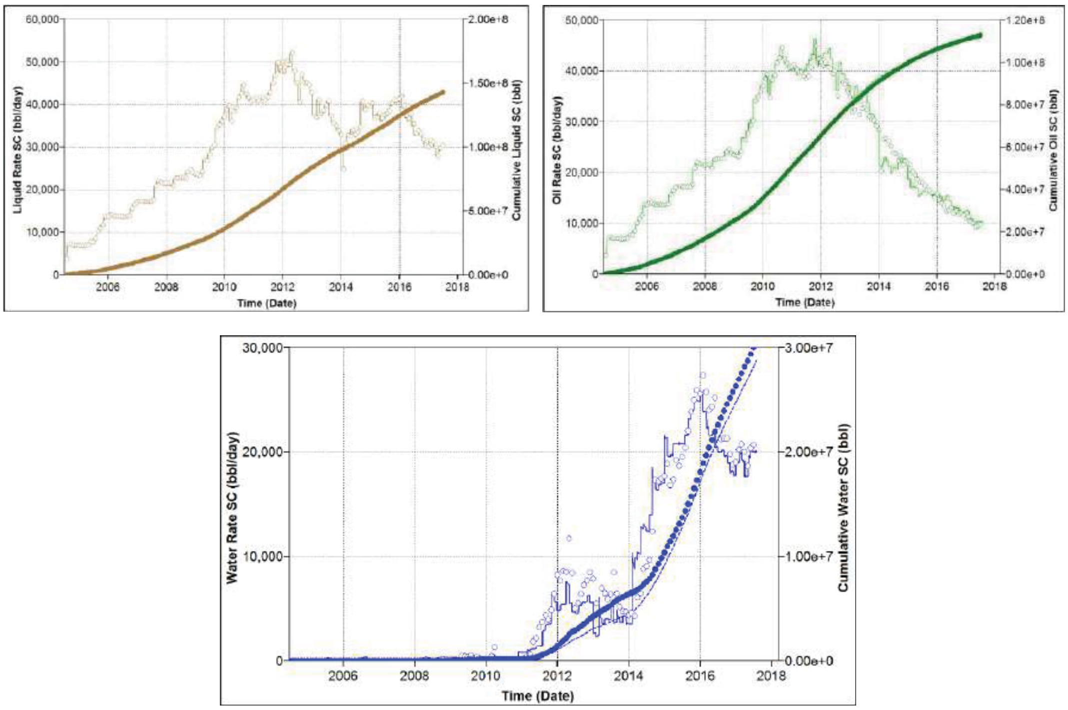


Figure 10. History matching Liquid rate, Oil Rate and Water rate

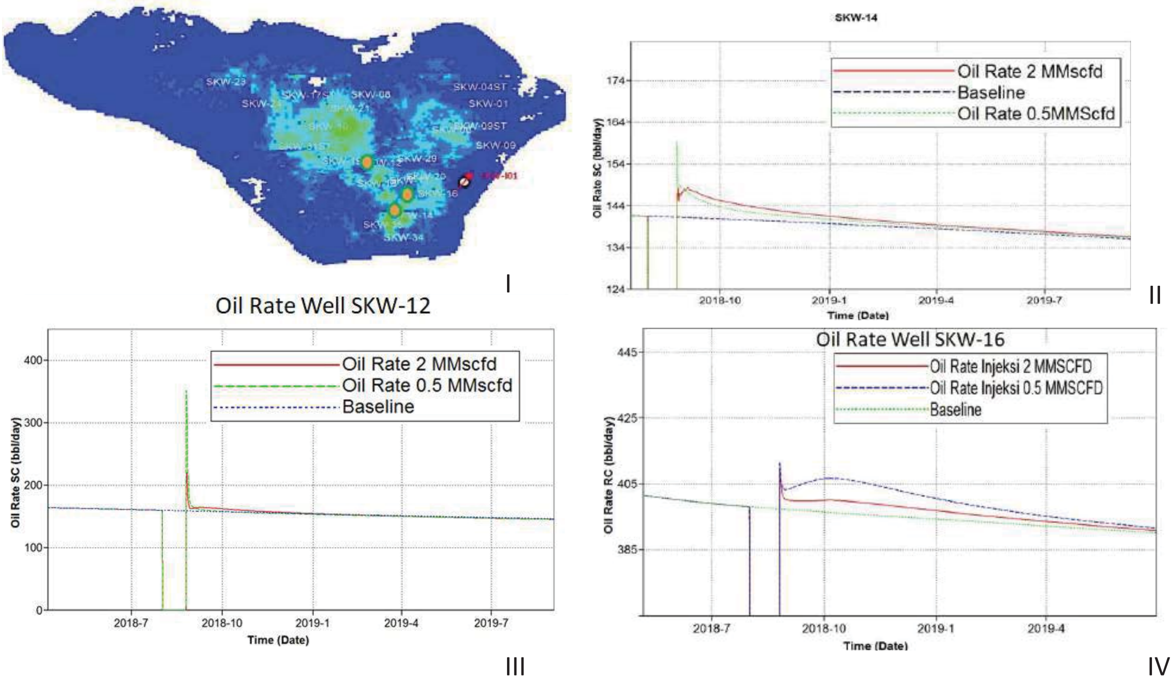


Figure 11 .Location Map candidat well H&P (I), Oil rate Prediction H&P SKW-14 (II), SKW-12 (III) & SKW-16 (IV)

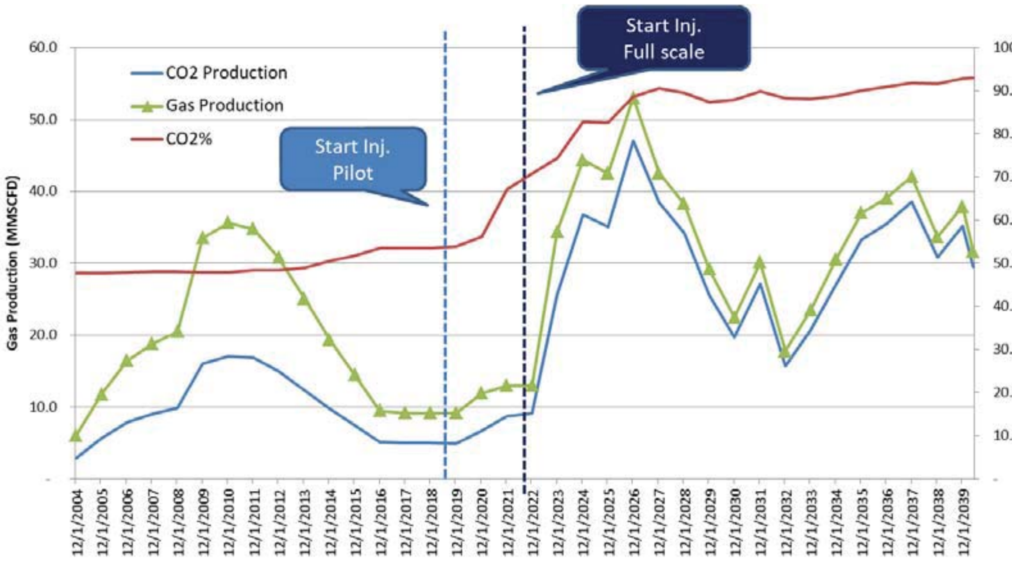


Figure 12. Evaluation CO2 breakthrough from Pilot to Full Field

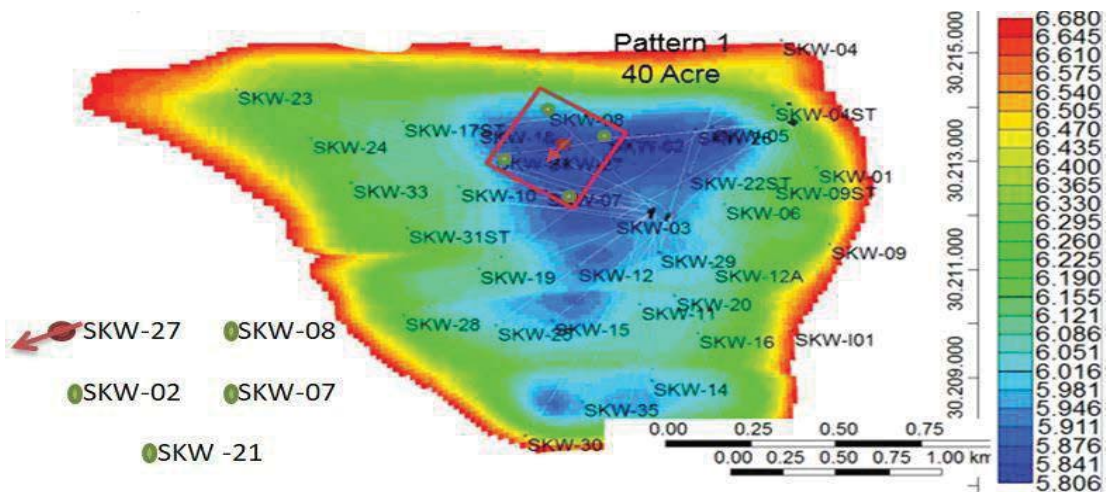


Figure 13 . Location Map candidat Pilot

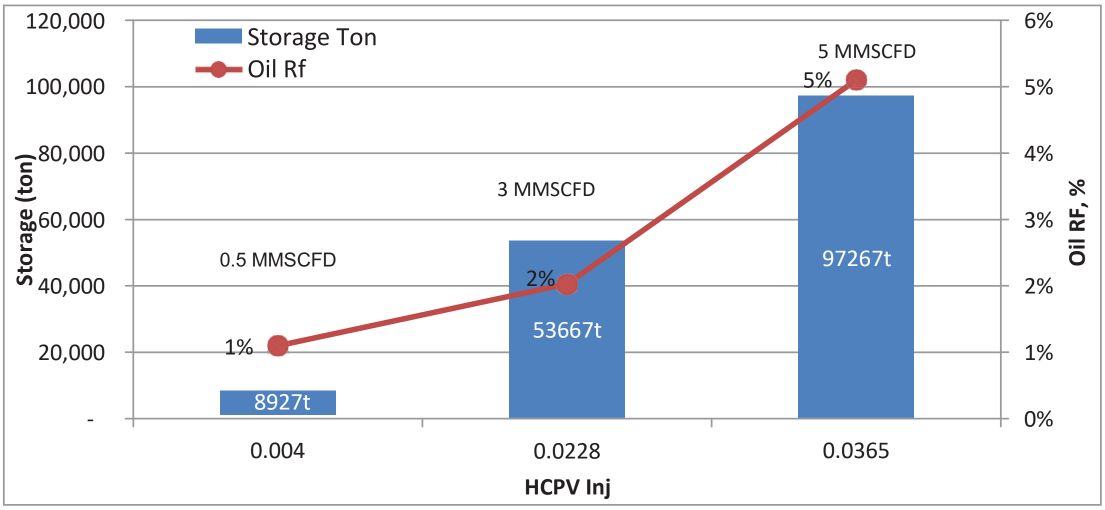


Figure 14. Storage Ton & RF, vs HCPV CO2 injected for 1 year

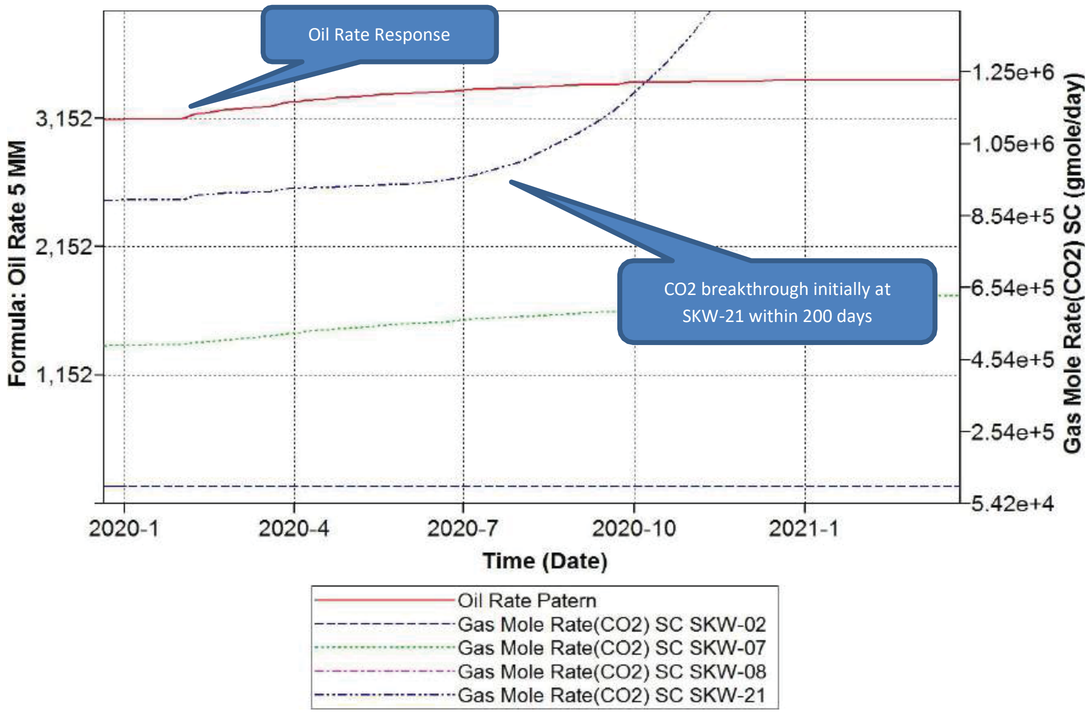


Figure 15. Oil Rate & Mol Gas for Patterned Well Pilot

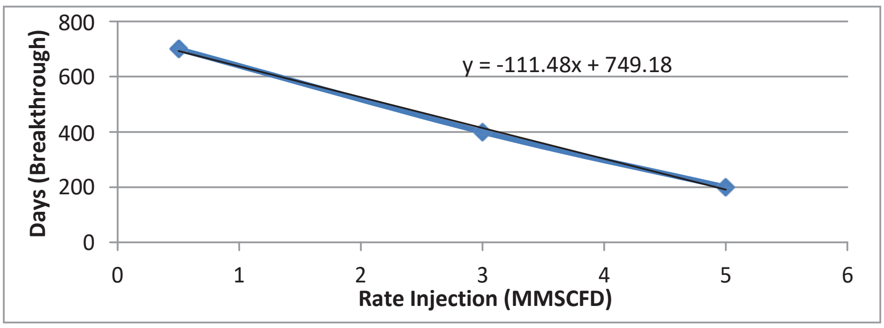


Figure 16. Time days breakthrough for variation injection rate for Pilot

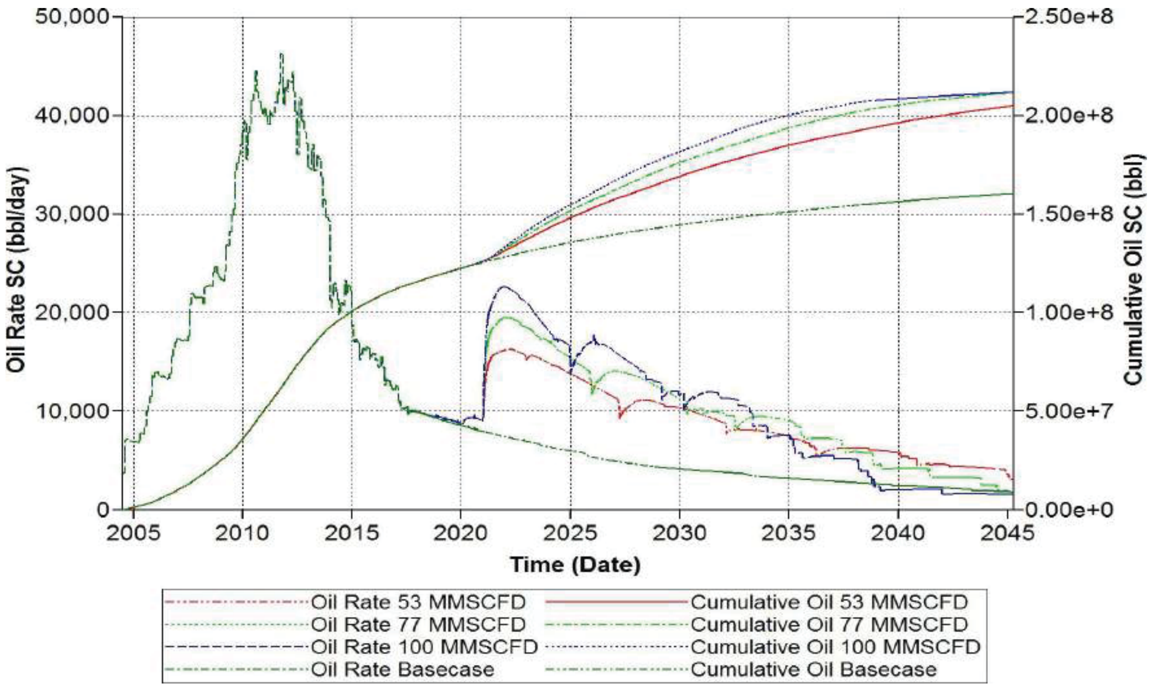


Figure 17. Oil Rate Prediction for Injection CO2 53,77, & 100 MMscfd Fullscale

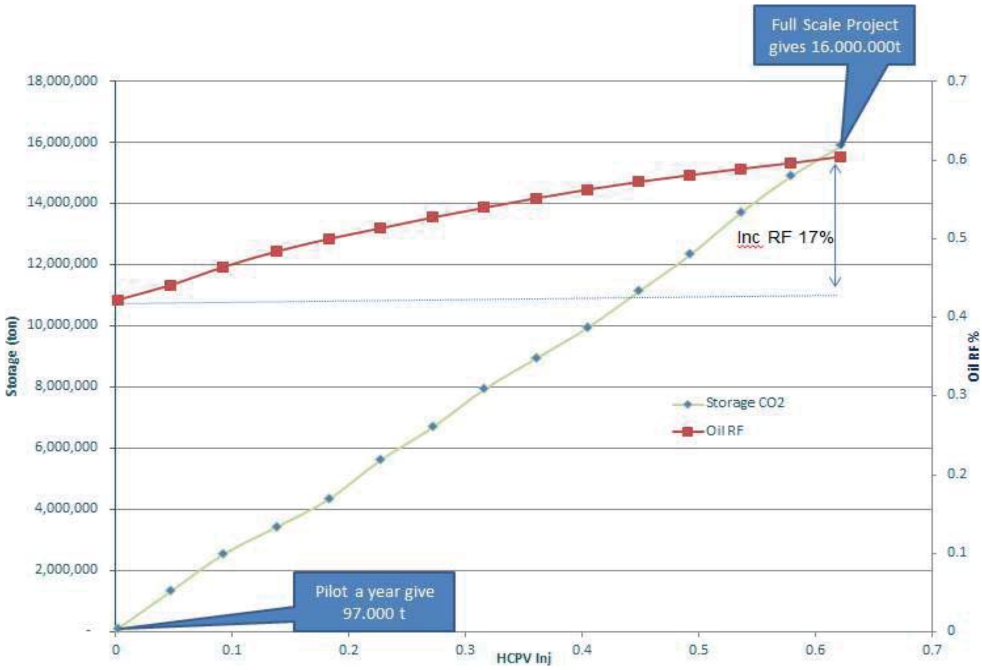


Figure 18. Prediction Storage ton vs HCPV Injected with RF

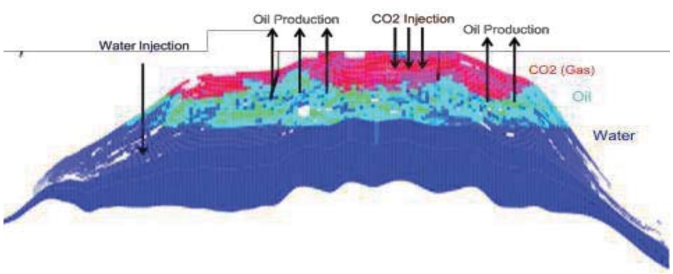


Figure 19. CO2 injection displace 62%HCPV within 15 years (Ternary Plot)

Table 1. PVT at Sukowati Field

date	Well	Interval (ftMD)	Depth (ftTVD)	Pb (psig)	Rsi (scf/bbl)	Boi (bbl/stb)	Visc ,cp	Pi (psig)	T (F)	API
28/7/07	SKW-06	6620-6660	6339.84	2405	1112	1.885	0.429	2814	275	40.3
30/12/09	SKW-14	7180-7202	6366	2667	1297	1.955	0.26	2721	269	36
8/2/2012	SKW-18	8260-8310	6101	2835	1192	1.869	0.255	2840	284	39.5
30/12/13	SKW-29	6300-6330	6300	2440	1535	1.986	0.588	2696	260	39.3

Table 2. Prediction Oil Cumulative & Oil rate candidat H&P; SKW-16, SKW-14 and SKW-12

Gas Rate Injeksi H&P		**Cum Oil SKW-16,stb per 2022/11**		**Oil rate inc**	**Cum Oil SKW-14, stb per 2022/11**		**Oil rate inc**	**Cum Oil SKW-12, stb per 2022/11**		**Oil rate inc**
MMscfd	Ton/d			bopd			bopd			bopd
Basecase		2.136.202			2.637.161			4.963.201		
0.5	27	2.129.973	-6.229	7	2.634.673	-2.488	8	4.932.020	-4.181	193
2	108	2.129.993	-6.209	5	2.634.309	-2.852	4	2.932.059	-4.142	20

Table 3.List CO2 Source around Sukowati Field

Field Structure	CO2 (%)	Reserves Initial	Cadangan CO2 (bscf)	Rate CO2 mmscfd	Rate CO2 ton/d	Remark	Jarak (km)
Sukowati	40	297 mmstb	181	5	242	Asso	0
Mudi	15	163 mmstb	15	0.15	8	Asso	10
Kedung Tuban RanduBlatung Kedung Lusi	22	435 bscf	95.7	17	895	Non Asso	52.48
JTB	30-33	3,02 tcf	907	100	5479	Non Asso	45.83
Cendana	32-36	90 bscf	32	-	-	Non Asso	44.15
Banyu Urip	35	1,5 Bstb	241	24	1263	Asso	31.65
Sumber-1 (well)	50	177 bscf	88.5	10	526	Non Asso	50

Table 4. Prediction Gas Composition & Rate for Pilot & Fullscale

		Fullscale		Pilot	
Parameter		**Injection**	**Breakthrough**	**Injection**	**Breakthrough**
Time	days	-	41	-	200
Flow Gas	MMSCFD	-	40-58	-	9-12
Flow CO2	MMSCFD	100	37-47	5	7-9
Pressure	psig	2000	120	2150	120
Temperature	°F	95	120	95	150
Gas Composition (% volume)					
CO2	%-mol	95	>74	95	>56
N2	%-mol	0.5	<1	0.5	<1
CH4	%-mol	4.5	<23	4.5	<45
H2S	%-mol	0	<1	0	2

Table 5. CO2 Performance Parameter with vation Injection rate Fullscale

CO2 Performance Parameters	CO2 Injection Rate , MMCFPD		
	53	**77**	**100**
Incremental Recovery Factor, % OOIP	11.4	14.38	16.8 ~ 17
Cum Oil, MMSTB	33.91	42.72	50.62
Cum CO2 Inj, BCF	390	565	692
Cum CO2 Prod, BCF	210	292	316
Gross CO2 Utilization, MCF/STB	11.5	13.22	13.6
Net CO2 Utilization, MCF/STB	5.3	6.39	7.43