

Forward Modeling Time-Lapse Seismic based on Reservoir Simulation Result on The CCS Project at Gundih Field, Indonesia

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Abstract

This paper contains reservoir simulation study of carbon storage at Gundih field in Central Java Island, Indonesia. Two different cases of injection simulation were performed and analyzed in this paper. The cases represent the conditions when the smallest and largest volumes of CO₂ are injected into the subsurface to see the changes of reservoir that happen after the injection processes. The simulation result shows that when a larger amount of CO₂ is injected into the targeted reservoir, it will migrate to the peak of anticline structure located in the southeast of CO₂ injection well. The displacement of CO₂ in the simulation progress shows that it will not reach the fault location. The geological model for synthetic seismogram calculation is then built based on the simulation reservoir result. The furthest displacement of CO₂ is calculated on each case and described as the saturated CO₂ layers. Forward modeling is performed to create synthetic seismic gather which will be processed to construct seismic section. The difference between the initial seismic section before the injection process and seismic section including saturated CO₂ layer after the injection process will be evaluated by the potential of injected CO₂ monitoring using time-lapse seismic survey in the Gundih field.

Keywords: CCS, Gundih, reservoir simulation, time-lapse seismic

1. Introduction

Gundih field is a gas-producing field located in Central Java. It is assigned to be the first pilot project for Carbon Storage in Indonesia. In every CCS (Carbon Capture Storage) project, CO₂ leakage through available fault needs to be avoided; therefore, the migration of injected CO₂ should be observed. After the reservoir characterization phase has been completed in the Gundih project (Asikin, et al., 2017), the next step to be done is the reservoir simulation phase. The reservoir simulation is very important to the procedures of CO₂ geological storage project, because we can evaluate the movement of the injected CO₂ within the reservoir. If this study is scaled up from a pilot project into a demonstration or even a commercial project, the maximum amount of CO₂ that can be injected will also increase with longer injection time. Therefore, several scenarios have been created which have different rates and length of injection to represent different stages of the Carbon Storage project in Gundih area. This study will focus on the area around Jepon-1 well, covered by 2 x 1.5 km² pseudo 3D seismic data which is acquired in 2016. The information of CO₂ distribution in reservoir is also important to realize the effective (low-cost) CO₂ storage, because we can use the information in the design of CO₂ injection wells.

Central Processing Plant (CPP) is available on the production field area to separate the produced gas from the unwanted gas, including CO₂. The CO₂ gas will be transported to the Jepon-1 Well, located about 22 km on the northern side of Gundih field. The CPP of Gundih field emits about 800 ton/day of CO₂ (15.2 MMSCFD) which is flared into the atmosphere. In this pilot project, about 30 ton/day of CO₂ (0.57 MMSCFD) will be transported from the CPP (Suprpto, et al. 2015). Production gas in Gundih field comes from Kujung limestone formation, and the purified CO₂ will be injected in the Jepon-1 Well into Ngrayong sandstone formation. Based on the study of fault seal analysis, the fault in the studied area is sealing type, but we need to consider the additional pressure

caused by CO₂ injection which can be withheld by the fault (Sapiie et al., 2015).

There are 4 trapping mechanisms in CO₂ storage: structural trapping, residual trapping, solubility trapping and mineral trapping (IPCC, 2005). In this study the CO₂ trapping only takes the structural trapping into account to see how much CO₂ can be stored in a short injection, involving free gas or supercritical fluid (Nghiem et al., 2009).

2. Methods

2.1 Reservoir Simulation for Prediction of CO₂ Distribution

Injection simulation is mainly influenced by the physical properties of the reservoir such as porosity, permeability, Net to Gross, water saturation, as well as pressure and temperature condition of the reservoir. Previous study by Onishi et al. (2015) has already been done to try several physical parameter values, in which single value of each property is applied to every simulation process. Meanwhile, in this study, the input grid data is derived from geological modeling that has been built previously by Asikin, et al. (2017). The simulation is done using commercial software Eclipse E300. The results of the injection simulation are then analyzed to determine the spread of injected CO₂ beneath the surface.

Since there is only one well in the vicinity of the studied area, the physical properties are distributed using acoustic impedance inversion data. CO₂ injection will be performed on Sand B layer which has the depth of 854 m and the thickness of 8 m. The average porosity range in this layer is 15-18% and the permeability value ranges from 500 md to 800 md with the average of 600 md (CCS Gundih Team, 2017). Water saturation is considered 1 for all parts of the aquifer to be injected.

Injection pressure constrain of 200 Bar at the bottom hole is used in this study based on the fractured gradient reservoir as the maximum acceptable pressure increase without re-activating an existing fault (Schembre-McCabe, et al, 2007). Reservoir has an initial pressure of 100 Bar and a temperature of 75°C in the initial datum depth of 1,000 m. The injection will be carried out when CO₂ is already in supercritical state, which is in the pressure condition of 100 Bar with the temperature of 40°C (Supratpto, et al., 2016) to reduce pressure compressor for injection (Leits, 2016). With those conditions, the density of supercritical CO₂ is assumed to be 628 kg/m³ in the surface.

Two different cases, which are made from the combination of rate and length of injection, are performed by using the same physical properties and simulation parameters mentioned above. Those cases represent the smallest and largest amount of CO₂ that will be injected into the reservoir which will be analyzed then. The first case will perform 30 ton/day of CO₂ injection within 2 years period with the total injection of 21,600 ton. This case represents the planned Pilot Project Carbon Storage in Gundih field. The total volume of the injected CO₂ in the second case is maximized following the injection rate used by already known commercial project in the world, to know the maximum capacity of aquifer layer in Gundih area. With the rate of injection increased by 100x from the pilot project, 3,000 tons per day of CO₂, which equals to the total of 10.95Mton of CO₂, will be injected into the targeted layer for 10 years.

2.2 Time-Lapse Seismic Modeling

Ngrayong Formation was selected to be the targeted reservoir for CO₂ injection because the monitoring techniques and methods would be more applicable in shallow reservoir (Srigutomo et al., 2015). In the case of a large amount of CO₂ that has been injected into the reservoir, like in Sleipner Project (Eiken et al., 2000), the effect of the injection usually can be seen. However, with only a small amount of CO₂ planned to be injected to the Pilot Project Carbon Storage in Gundih area, this forward seismic modeling study needs to ensure whether the seismic signal can capture the injection effect while the targeted layer is located in shallow reservoir.

Pseudo 3D seismic data is obtained using 8 tons of vibroseis due to our circumstances in the field, such as permissions, easy repeatability, and lower cost compared to using dynamite as a source (Bahar et al., 2017). Forward seismic modeling is performed in this study based on the interpretation of the Pseudo 3D seismic model. Physical properties used in this model are obtained from average velocity and density throughout each formation, shown in Table 1. The saturated velocity and density from the injected layer are calculated using Biot Gasmman equations (Mavko, 1998), derived from the known value of properties in the targeted layer filled with different fluids; that is CO₂. The saturation value of CO₂ follows the simulation result of each case which is 0.08 for the first case and 0.38 for the second case.

Table 1. Physical properties from each formation (modified from Asikin, 2015)

Formation	Velocity (Vp) m/s	Velocity (Vs) m/s	Density Kg/m ³
Ledok	2147.76	1240.01	2.009
Wonocolo	2742.52	1583.394	2.2739
Ngrayong	3008.65	1737.048	2.4174
Ngrayong (Saturated by 0.08 CO ₂)	2292.91	1738.55	2,413
Ngrayong (Saturated by 0.38 CO ₂)	2194.32	1744.25	2.397
Tuban	3295.075	1902.412	2.4954

3. Results

The simulation is done without adding water injection after CO₂ injection although adding water can lower the depth of CO₂ plume to prevent a leaking event on the top of the seal, as it is recommended by Putra (2014). The reason is when the fault is located quite close to the injection wells, the water injection can create more CO₂ leaking at the fault due to the pressure caused by water injection (Leits, 2016). In the targeted formation, the distance between the targeted anticline structure and the fault is quite near, which is around 400 m (Tsuji et al., 2014).

The simulation result of the first case is shown in Figure 1. The distribution of gas saturation is analyzed before the injection begins on the first year of injection and on the second year of injection which is the end of injection. The CO₂ distribution is also analyzed after the injection is finished to see the movement of the CO₂ on the following years. On the second case, the gas distribution on the fifth year of injection and tenth year of injection are analyzed, as shown in Figure 2. Similar to the first case, the distribution of CO₂ is also analyzed after the injection ends in one year, ten years and a hundred years.

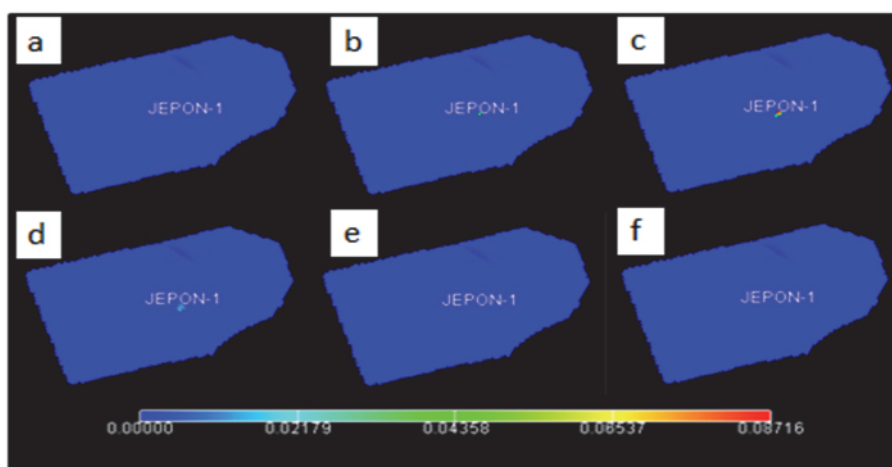


Figure 1. The distribution of gas saturation from simulation result of the first case; (a) condition before the injection begins (b) first year of the injection (c) second year of the injection/the end of the injection (d) one year after the end of the injection (e) ten years after the end of the injection (f) a hundred year after the end of the injection

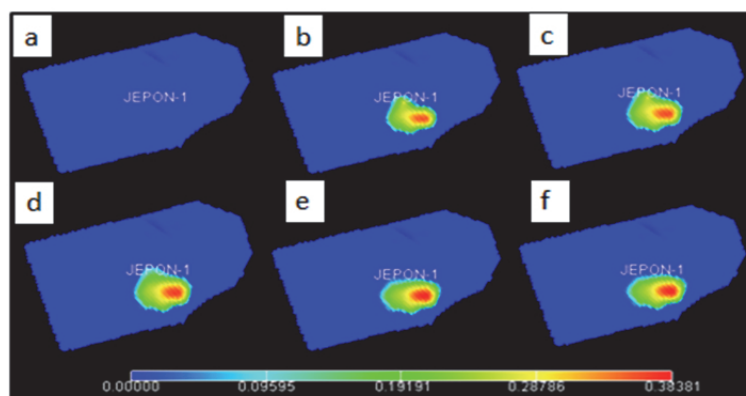


Figure 2. The distribution of gas saturation from simulation result of the second case; (a) condition before the injection begins (b) the fifth year of the injection/the end of the injection (c) the tenth year of the injection/the end of the injection (d) one year after the end of the injection (e) ten years after the end of the injection (f) a hundred years after the end of the injection

Synthetic geological model is built from the interpretation of the inline and crossline data of Pseudo 3D seismic data that past Jepon-1 well, as shown in Figure 3. Four different layers which represent Ledok Formation, Wonocolo Formation, Ngrayong Formation and Tuban Formation are made by using the physical properties described in Table 1. This model represents the condition before the injection begins. Meanwhile, the synthetic geological model in Figure 4 shows the condition of reservoir after ten years of the injection process in the second case.

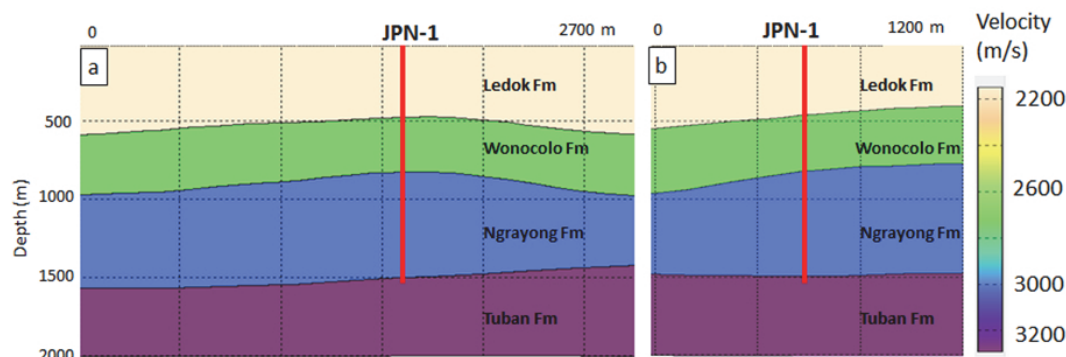


Figure 3. Initial geological model used in forward seismic modeling; (a) the inline section and (b) the crossline section. The first layer (cream color) is the Ledok Formation, the second layer (green) is the Wonocolo Formation, the third layer (blue) is the Ngrayong Formation, and the last layer (purple) is the Tuban Formation. The Jepon-1 well is indicated by a red line

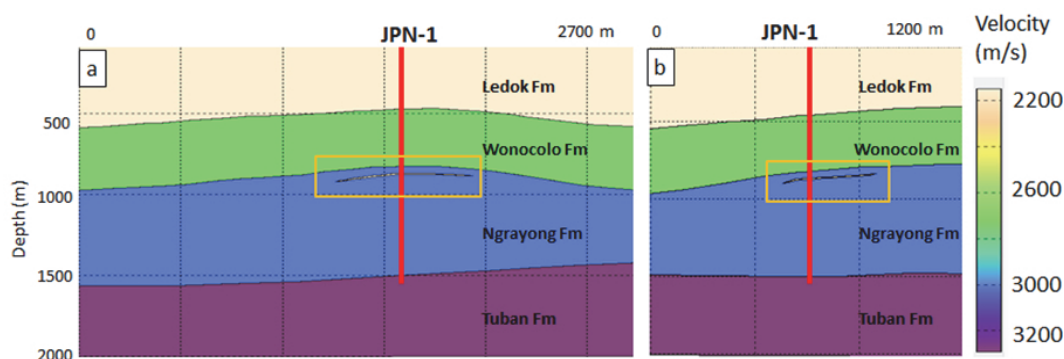


Figure 4. Synthetic geological model similar to Figure 3, with the difference shown in the yellow box representing CO₂ saturation from the reservoir simulation result of the second case when the largest amount of CO₂ being injected into the reservoir

The source and receiver intervals are 10 m of each and the time sample is every 2ms, following from the previous Pseudo 3D seismic acquisition. This time-lapse seismic modeling is performed by using Tesseral software. Because the dispersion of CO₂ on the second case is larger than that on the first case, it is decided to test the seismic responses by using the model in Figure 4 to see the modeling ability in mapping the thin layers. Vertical incidental modeling process is applied in the data to produce the seismic section on the following figure. On the second case where the amount of injected CO₂ which is performed is very large, the amplitude change can be detected. It is shown in Figure 6.

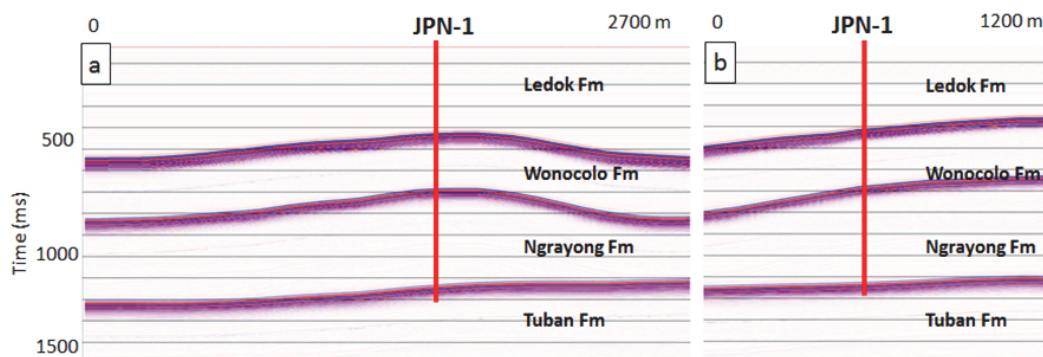


Figure 5. The inline and crossline sections of the initial model in Figure 3

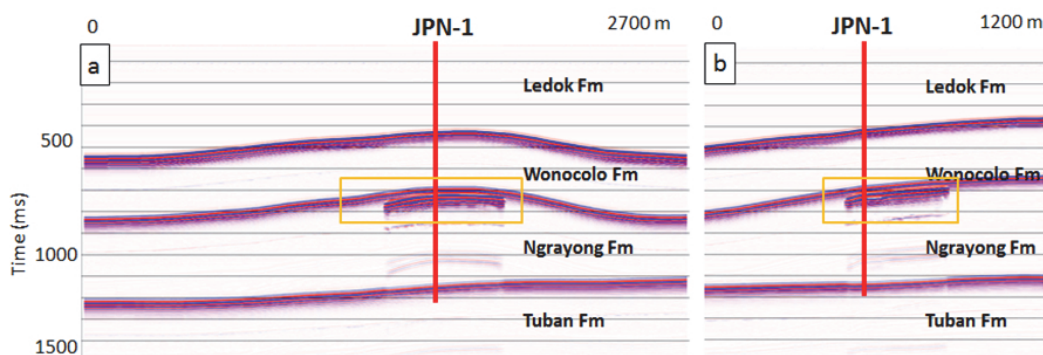


Figure 6. The inline and crossline sections of the synthetic model in Figure 4 that serve as the condition after the injection. The yellow box indicates CO₂ effect in the seismic section

One more modeling is performed using the simulation model from the first case where the total injection is only 21,600 tons with a very small CO₂ movement. The synthetic geological model that represents the condition of reservoir after two years of injection can be seen in Figure 7. The same acquisition of parameters and processes on the second case are also applied to the synthetic model to generate seismic section in Figure 8.

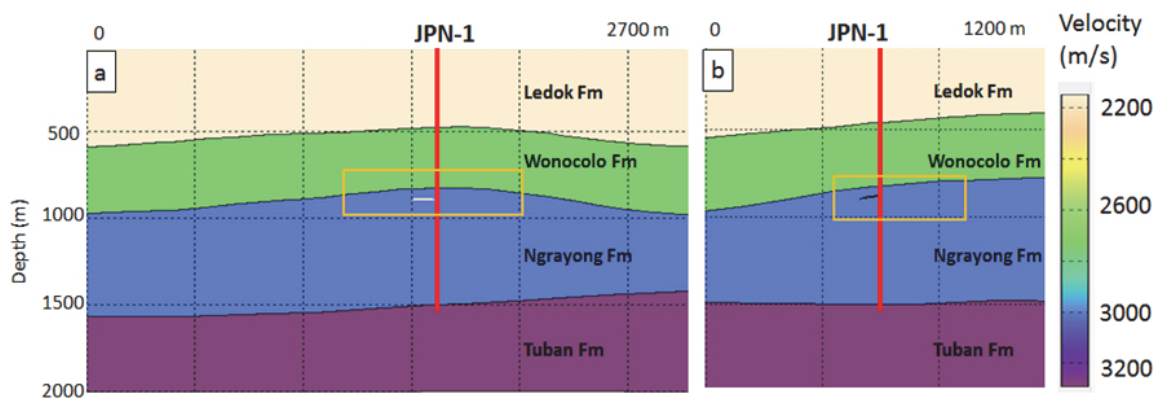


Figure 7. Synthetic geological model of the first case when a smaller amount of CO₂ is injected to the reservoir

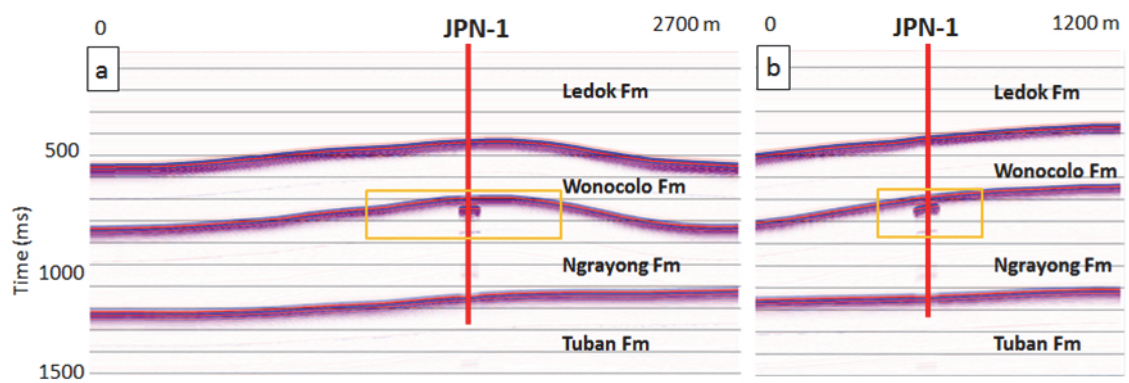


Figure 8. Synthetic seismic section generated from the synthetic model in Figure 7

Ricker wave is used in this study with two different dominant frequencies: 70 Hz and 30 Hz. The high frequency is used in this modeling to detect Sand B layer as the targeted injected layer which has the thickness of only 8 m. Figure 6 and 8 are modeled using 70 Hz dominant frequency. However, due to the long required modeling time for high frequency acquisitions, another acquisition is made using 30 Hz frequency, adjusting the dominant frequency extracted from Pseudo 3D seismic data. The modeling is performed on both cases, as it is shown in Figure 9 and 10. The results of the modeling using the 30 Hz frequency seem still able to map CO₂-saturated layers well. Although it is very small, the amplitude changes can still be detected.

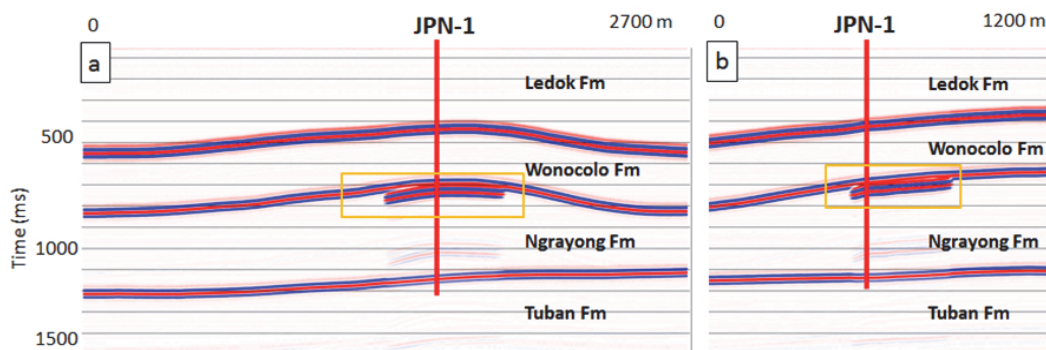


Figure 9. Seismic section from the second case using 30 Hz of dominant frequency

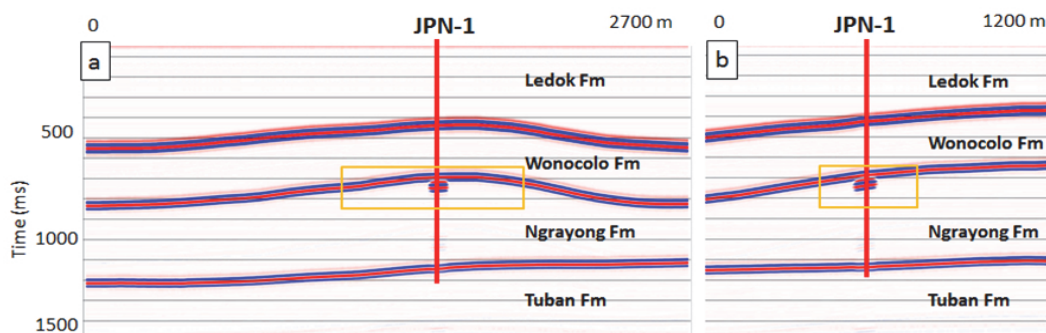


Figure 10. Seismic section from the first case using 30 Hz of dominant frequency

4. Discussion

On the first case where the rate of injection is low (30 ton/day), there is no noticeable change from before, during and after injection. In the properties of gas saturation, the change only occurs around the Jepon-1 well, as shown in Figure 11. The difference on value indicating the CO₂ movement is only ~75 m from the site of Jepon-1 well

at the end of the second year of injection. The CO₂ even does not reach the top of the anticline structure, as shown in saturation gas graph in Figure 12(a). Ten years after the injection is done, the gas saturation is not visible or detected. It happens most likely because the CO₂ is dissolved with water. The change of value occurred on water saturation is the opposite process of gas saturation. Ten years after the injection, the value of water saturation is back to 100% as the period of pre-injection. The pressure value is 72.4 Barsa and has increased simply to 72.6 Barsa at the time of the injection (Figure 12(b)). When injection has ended, the pressure is reduced slightly and is in a constant condition of 72.5 Barsa.

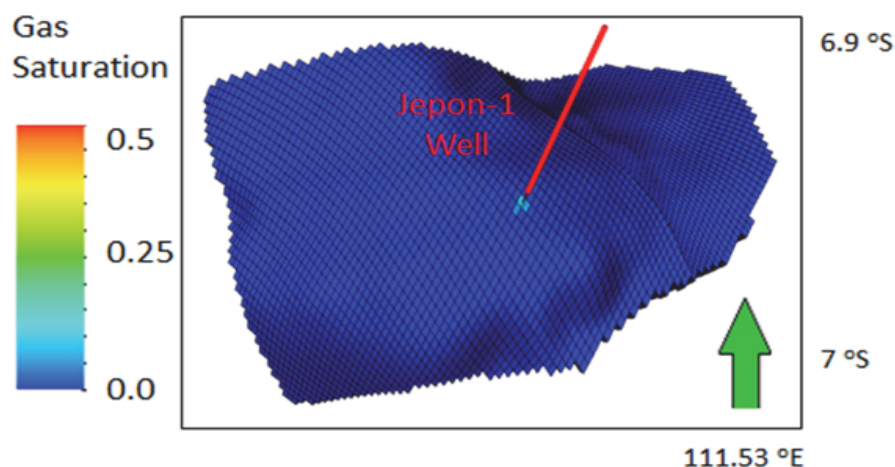


Figure 11. Distribution of CO₂ saturation after two years of injection from the first case. The CO₂ only spreads in the area around the Jepon-1 well due to the small total number of injections, within a range of <100 m from the injection well

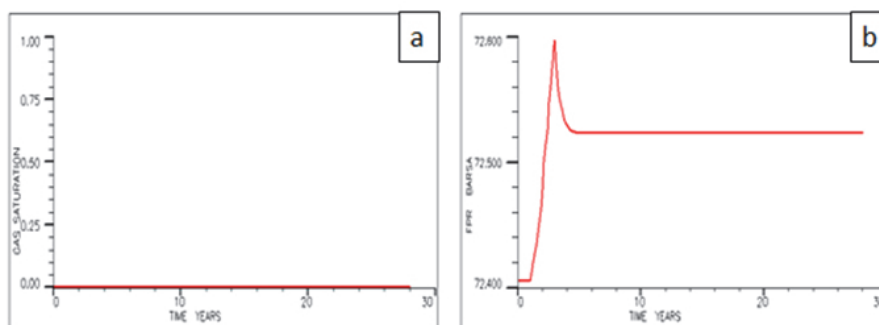


Figure 12. (a) Gas saturation graph that represents CO₂ saturation at the peak of the anticline structure; (b) Field pressure distribution graph of the studied area. Both (a) and (b) are produced from the first case simulation

The latter case is completed to know the direction of CO₂ movement when the amount of injected CO₂ approaches the maximum anticline capacity, ie the injection rate of 3,000 tons per day. In the fifth year of injection, CO₂ is detected to move as far as 420 m on the south west direction from Jepon-1 Well. When injected, CO₂ moves to fill the anticline structure located on the southwest of the injection well. CO₂ occupies an area along 520 m on the direction of east-west and along 430 m on the direction of north-south. The closest distance from the CO₂-filled area to the nearest fault is ~260m. In the tenth year of the injection, the movement has risen to 627 m on the east-west direction and 500 m on the north-south direction, in which the distance to the fault is ~238m.

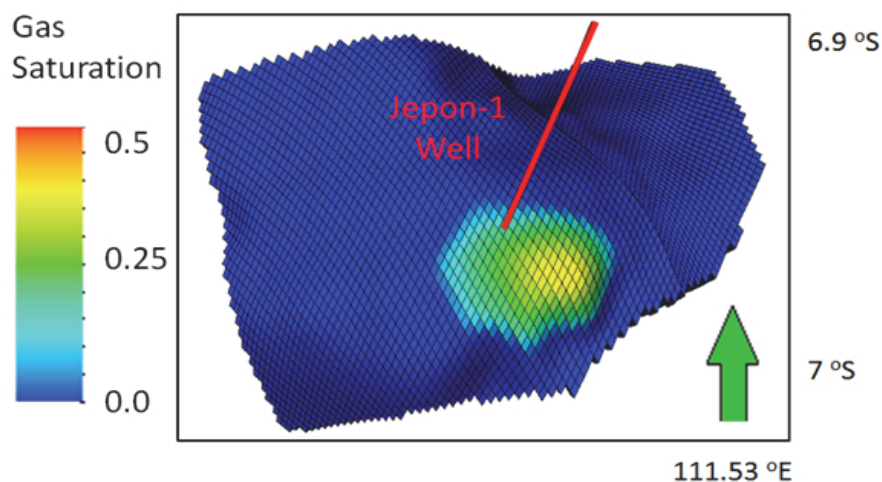


Figure 13. Distribution of CO₂ saturation after ten years of injection. The injected CO₂ will migrate to the peak of anticline structure even after the injection process ends

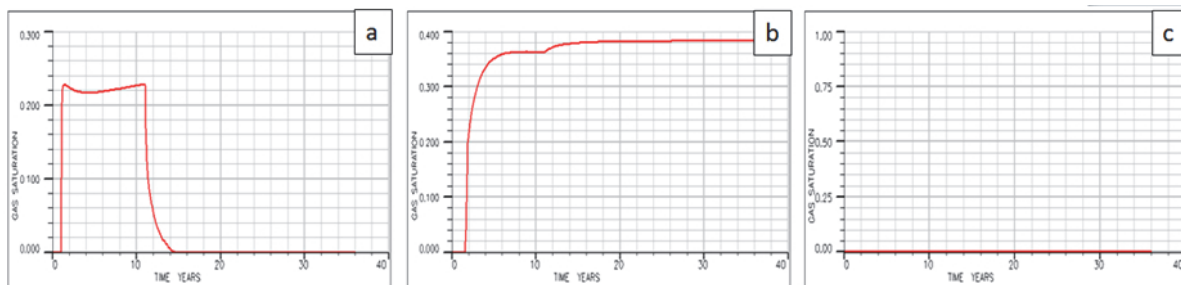


Figure 14. Gas saturation graph from different grid location: (a) at the Jepon-1 well; (b) at the peak of anticline structure; (c) at the nearest fault from the injection well

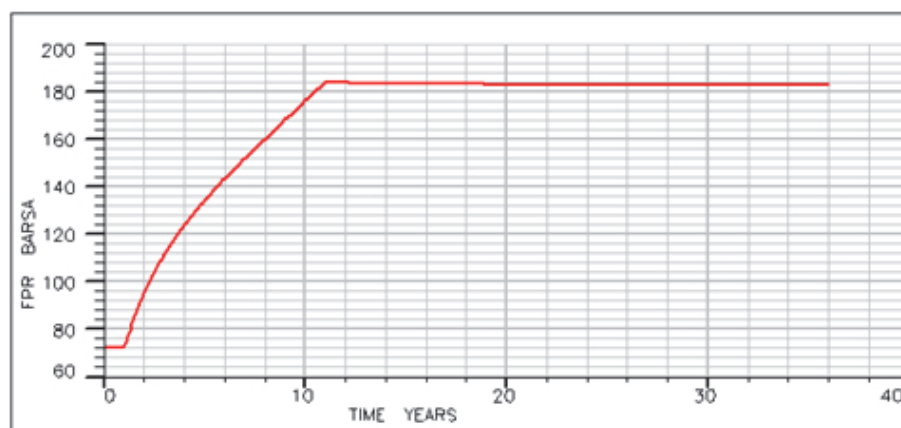


Figure 15. Field pressure distribution graph. The injection process causes an increase in pressure and will remain stable after the injection ends

The maximum gas saturation appears to fill the peak area of the anticline structure as shown in Figure 13. The graph of Figure 14 is made to show the saturation changes occurring on a particular grid. The first graph signifies CO₂ saturation at the Jepon-1 Well location and the second graph is the located peak of the anticline. The third graph indicates the changes on the fault area. From the first graph, it can be seen that CO₂ in the well increases drastically when the injection begins in the first year, with 0.22 of maximum saturation. The value is relatively constant during the injection that lasts up to 10 years. After the injection stops, the saturation goes back

to the value before the injection is begun. The second graph shows that in the fifth year of injection, the CO_2 saturation at the peak of anticline increases from zero to 0.36. It also shows that CO_2 continues to fill the pore with maximum saturation of 0.38 after tenth year of injection. The saturated area becomes wider in the tenth year of injection, centered at the top of the anticline. After ten years of injection is complete, there is no significant change in the area and in the maximum saturation value as it happens when the injection ends. However, the distribution of pressure at Jepon Area shown in Figure 15 changes significantly from 70 Barsa to 140 Barsa after five years of injection, and later to 180 Barsa after ten years of injection. The pressure distribution remains almost the same after the injection has finished.

Besides of reservoir simulation result, CO_2 distribution can also be detected in seismic section. After the reduction on each inline and crossline section between pre and post injection states, amplitude changes to become more apparent. From the higher frequency of 70 Hz dominant frequency result, the targeted thin layer can be distinguished, as it is shown in Figure 16 and Figure 17. As predicted by the extensive dispersion shown in reservoir simulation result, amplitude changes which are resulted from the second case are well shown on Figure 16. On Figure 17, although the injected amount CO_2 is very small, which is 30 ton per day after two years of injection, the changes can be detected around the Jepon-1 well.

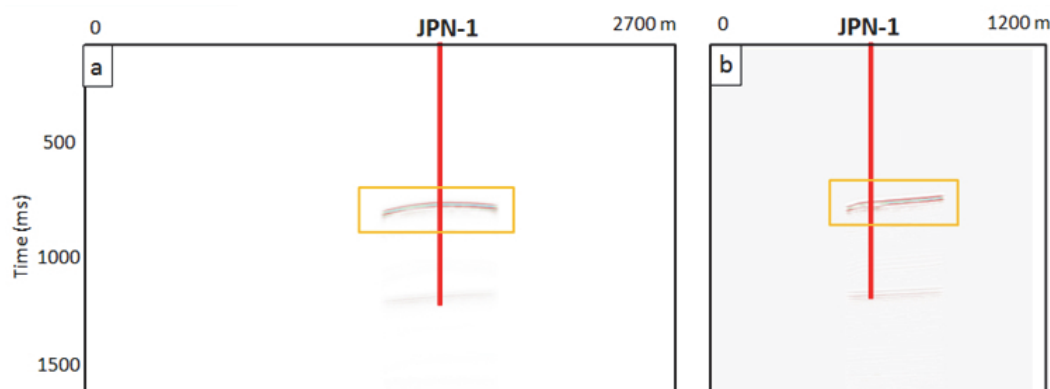


Figure 16. Differences in the inline and crossline sections resulted from CO_2 injections on the targeted layer for the second case by using 70 Hz of dominant frequency

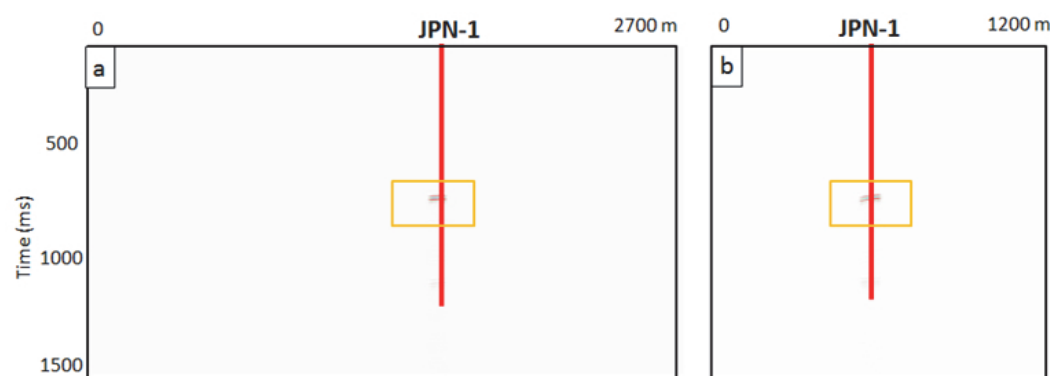


Figure 17. Differences in the inline and crossline sections resulted from CO_2 injections on the targeted layer for the first case by using 70 Hz of dominant frequency

From the result of time-lapse modeling using lower dominant frequency which is 30 Hz, the top of saturated CO_2 layer can also be identified as it is shown in Figure 18 and Figure 19. Considering the computation time to create each model and also to synchronize with the actual seismic frequency in real acquisition, the 30 Hz modeling is good enough to be used to monitor the CO_2 distribution.

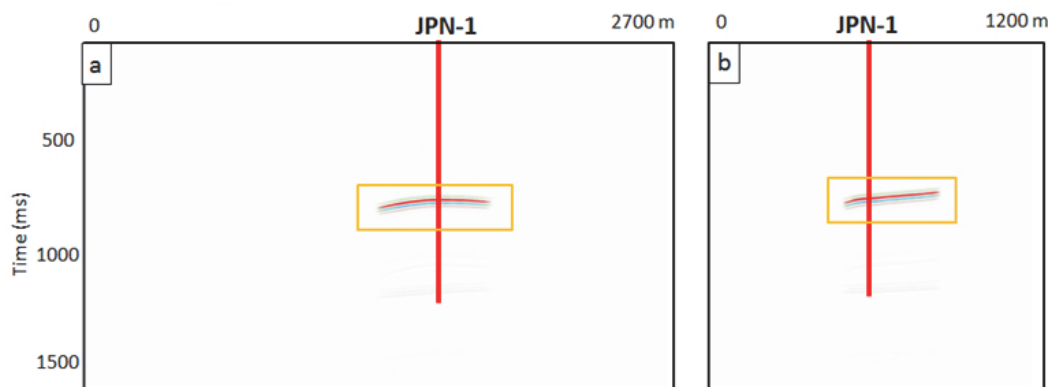


Figure 18. The amplitude change recorded due to CO₂ injection on the second case using 30 Hz of dominant frequency

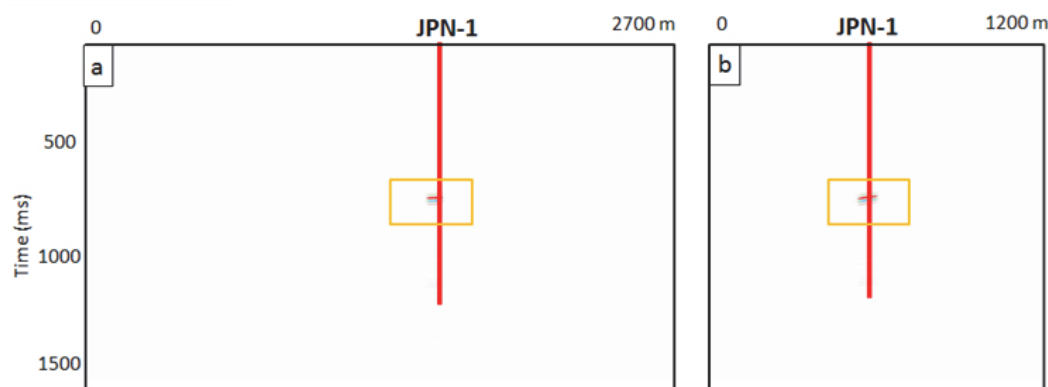


Figure 19. The amplitude change recorded due to CO₂ injection on the first case using a frequency of 30 Hz

5. Conclusion

The reservoir injection simulation which is performed shows the direction of CO₂ migration which tends to flow toward the top of the structure. The direction is to the southeast of the Jepon-1 well. From different injection scenarios, it can be seen that with a long duration and large injection rate of 100x from the initial target of the study, the anticline structure found in the Jepon-1 well area can accommodate the CO₂ injection. This time-lapse seismic modeling method is able to show the different anomalous response resulted from reservoir injection. Both 30 Hz and 70 Hz frequencies can identify the top of saturated CO₂ layer. With the initial injection target of CCS Gundih Project, which is 30 ton per day after two years of injection, the amplitude changes can be detected around the Jepon-1 Well.

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