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To cite this article: F D Haq *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **318** 012023

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Production and ReInjection Evaluation on The Basis of 3D Time-lapse Microgravity Inversion

F D Haq, T Sastranegara, L Agung, A D Kusuma, T Hendriansyah, A F Fanani and I B Raharjo

Pertamina Geothermal Energy, Skyline Building, Jakarta, Indonesia

fadhilaz@pertamina.com

Abstract. An equilibrium in the geothermal is important especially in terms of reservoir sustainability. Fluid in the reservoir will continue to decrease if the reinjection activity unable to compensate the steam production. Field "US" is one of the geothermal field that has more than 5 Megaton production rate. The fluid depletion should be controlled so the reservoir is able to continue to supply the steam. Re-injection strategy plays an important role to keep up with the amount of fluid that comes out. Preparation of this strategy requires 4D microgravity or time lapse microgravity method to know which area has the most fluid depletion. The use of microgravity for monitoring has become the ultimate method in geothermal. In this paper, we will discussed on how advanced microgravity processing able to be a consideration in the production and re-injection strategy. The data used in this paper is microgravity survey which conducted every year from 2015 - 2017. Further processing such as inverse modelling is also used in this paper to estimate the mass changes inside the area of interest. In the modelling, we used staggered grids as an initial model to produce more suitable final model. Initial models are made based on geophysical research data such as Magnetotelluric resistivity data and hypocenter from Micro-earthquake so the position of the top reservoir can be determined. The Gauss's Flux method also used in this paper to be compared with the result from inversion. The result of this research is to maintain the sustainability of reservoir in geothermal energy by make re-injection plans more effective and precise.

1. Introduction

The Geothermal energy (geothermal) becomes one of the alternative energy that can be maintained for a long time. In order to maintain the sustainability of the geothermal, the gravity method is been used. This method is used to measure the variation of the gravitational field at the surface caused by density contrasts within the rocks. Advanced processing in the gravity method such as inversion could generates results that should be a consideration in the geothermal field development.

2. Methods

2.1. Data Processing

Data acquisition was conducted every year since 2015 until 2017 at "US" geothermal field which has 100 local measurement points. The measurement area is 10 x 10 km². There are also regional measurement points which approximately 30 km away from the proven area. A regional measurement point is required to obtain a gravity measurement value that is not affected by any changes that might be inside reservoir area. This paper will focus on the proven area and around the re-injection wells (figure 1).



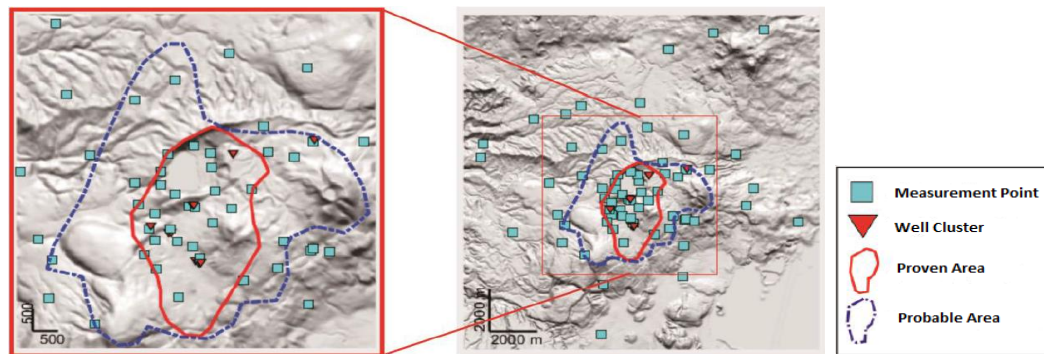


Figure 1. The measurement point distribution and the boundary of US geothermal field.

We used two Scintrex Gravimeter CG-5 for a better efficiency and also we could use one of them for tidal observation in the base. Field measurements are performed by closed looping by starting the measurement at the base and then measuring several points and then back to the base. This way could avoid or minimize the drift effect (tool's fatigue).

Processing of 4D microgravity is different from microgravity processing for exploration. The differences between these two processes lies in the correction. The microgravity for exploration processing is done by applying some corrections such as Free Air Correction, Bouguer Correction, and Terrain Correction. In the other hand, the 4D microgravity has no correction because each measurement point will be reduced with the previous measurement, in this case the measurement that been conducted in year before. This reduction causes any correction will be mutually subtracted. Figure 2 shows the difference between microgravity measurement results in 2017 and 2016.

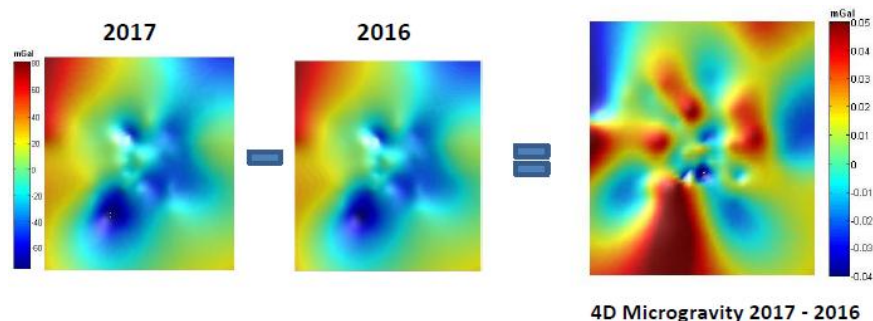


Figure 2. Example of 4D Microgravity Map.

2.2. Inverse Modelling

The result of 4D microgravity measurement can be used to estimate mass changes that occurs beneath the surface. The mass changes estimation can be calculate by inversion method. The inversion method is a backward modelling method by providing inputs of the initial model and certain parameters (Grandis 2009). The equation below consists of d which is microgravity data, m is initial models, and A is kernel matrix (forward operator).

$$m = (ATA)^{-1} ATd \quad (1)$$

Kernel Matrix of the forward operator A could be counted in the accordance with Plouff (1976) formula:

$$g = -G\rho \sum_{i=1}^2 \sum_{j=1}^2 \sum_{k=1}^2 \mu_{ijk} \left[x_i \log(y_j + r_{ijk}) + y_j \log(x_i + r_{ijk}) - z_k \arctan \frac{(x_i y_j)}{z_k r_{ijk}} \right] \quad (2)$$

$$r_{ijk} = \sqrt{x_i^2 + y_j^2 + z_k^2} \quad (3)$$

$$\mu_{ijk} = (-1)^i (-1)^j (-1)^k \quad (4)$$

The initial model is made according to subsurface condition based on resistivity model and P90 boundary based on Micro-earthquake hypocenter from another research. Figure 3 is the initial model which has staggered grid type (Sastranegara and Raharjo 2013) and the input parameters, minimum error <0.0001 with initial density values between -3 to 3.

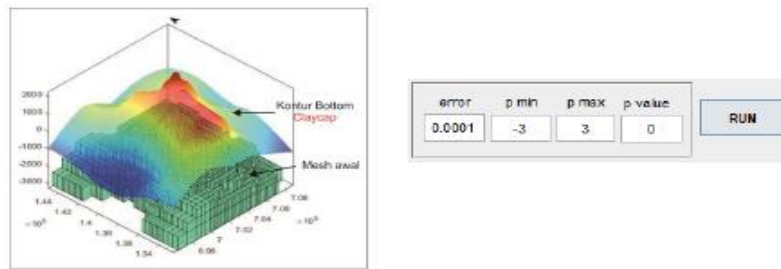


Figure 3. Initial model and input parameter for inverse modelling.

Another method to estimate mass changes is based on Gauss's flux theorem. The basis of the use of Gauss's flux theorem is to calculate the total flux or vector perpendicular to a surface plane, then the amount of mass changes can be calculated within the plane of the surface (Lafehr 1965). Equation (5) can be used to determine the amount of mass changes that occur beneath the surface.

$$\Delta m = 2.39 \times 10^{10} \sum_{j=1}^n n(\Delta g_n \cdot \Delta A_n) \quad (5)$$

3. Results

3.1. Reinjection Evaluation

During the 2015 period (January 1st 2015 until December 31th 2015) there are 8.61 MTon of steam produced and the amount of re-injection are 2.55 MTon. The difference between the amount of the extracted and re-injected fluid are 6.06 MTon that we will called it mass deficit. From January 1st 2016 until December 31th 2016, there are 5.78 MTon steam extracted and 1.65 MTon fluid re-injected. Total mass deficit in the 2016 period are 4.13 MTon.

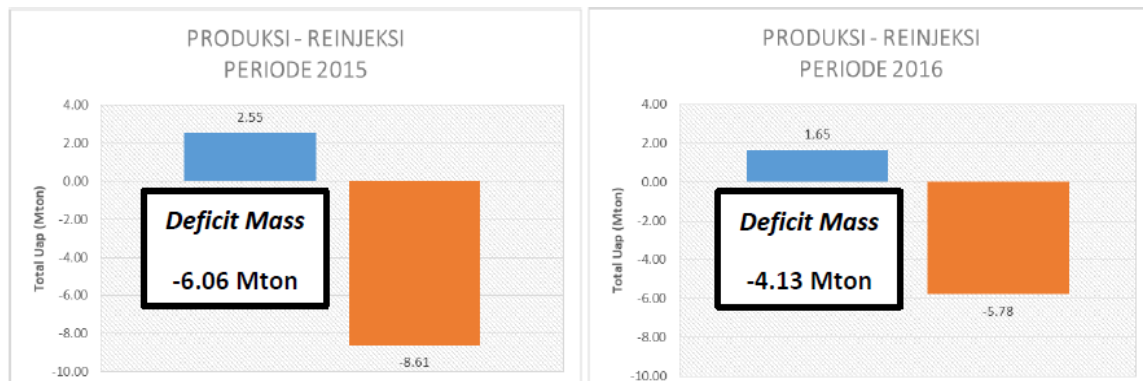


Figure 4. Production and Re-injection recapitulation in the period 2016 and 2015.

Both 4D microgravity maps show differences in several area. Then we choose three areas that show prominent changes and highlight these with different colour of boxes. The main change is inside the proven area where all the wells are located. The proven area then will be processed further

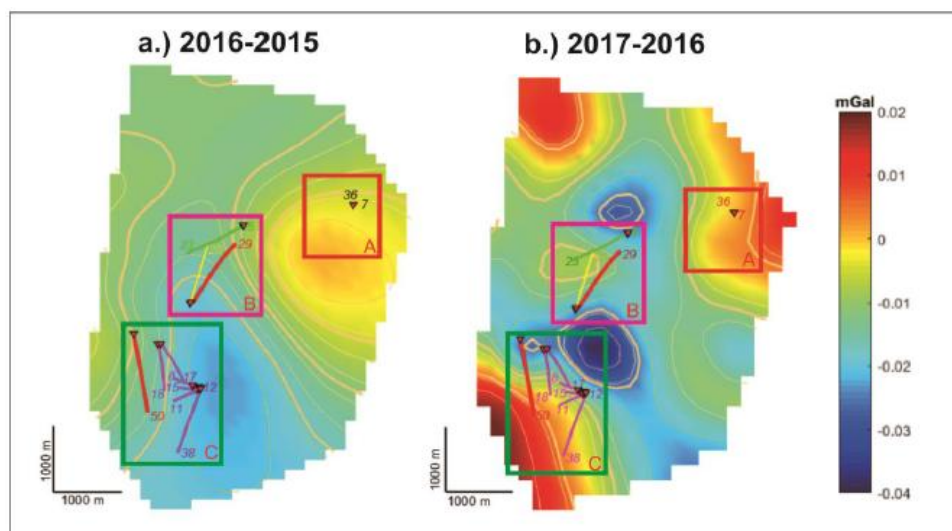


Figure 5. (a) 4D Microgravity Map 2016-2015 and (b) 4D Microgravity Map 2017-2016.

In the picture of zone A below (figure 6), there is a significant difference on the East of the re-injection wells US-7 and US-36. This indicates a sub-surface mass reduction associated with a reduction in the amount of re-injection fluid from July 2015 to around December 2016.

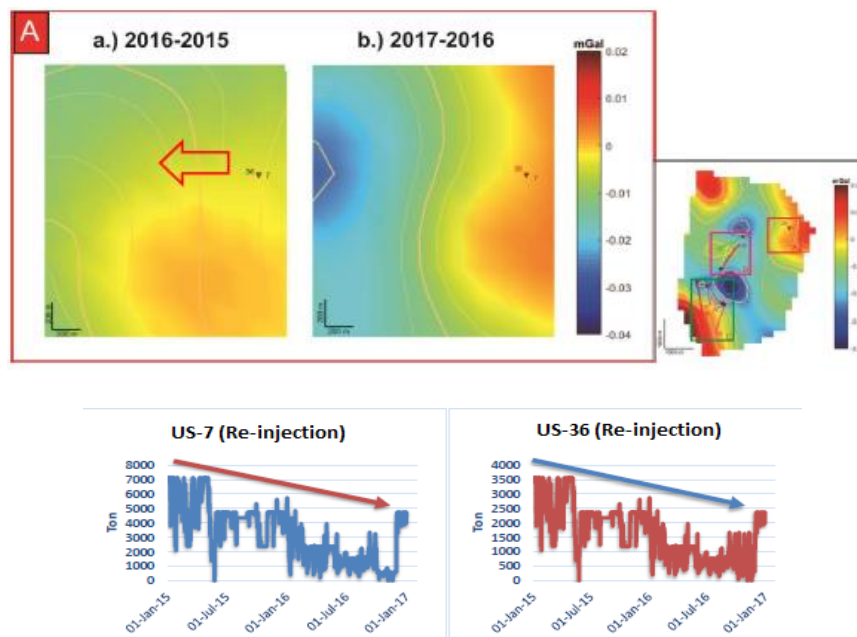


Figure 6. Inside box A (a) Microgravity 4D Response 2016-2015 and (b) Microgravity 4D Response 2017-2016, the graph b shows the amount of re-injection fluid is decreasing overtime

Next box is zone B, which shows around the well US-23 there is a changes in microgravity response previously negative (figure 7) then becomes positive. The steam production data confirms the change occurs because the well US-23 is stop producing. While the influence of the LHD-29 re-injection well is also seen on the North of the map

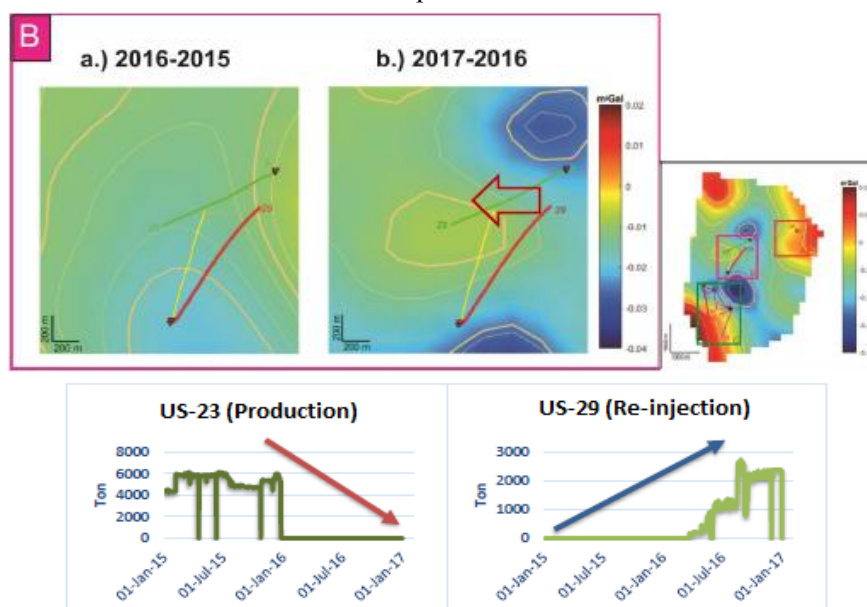


Figure 7. Inside box B (a) Microgravity 4D Response 2016-2015 and (b) Microgravity 4D Response 2017-2016, the graph b shows the amount of production and re-injection.

The box C (figure 8) shows the re-injection well US-50 gives some prominent effect in one year period. Re-injection data confirms that re-injection activity at US-50 wells was began in July 2016 until January 2017 with a total fluid re-injection around 200,000 Ton. The huge colour differences also occurs because production rate also drop-off inside box C.

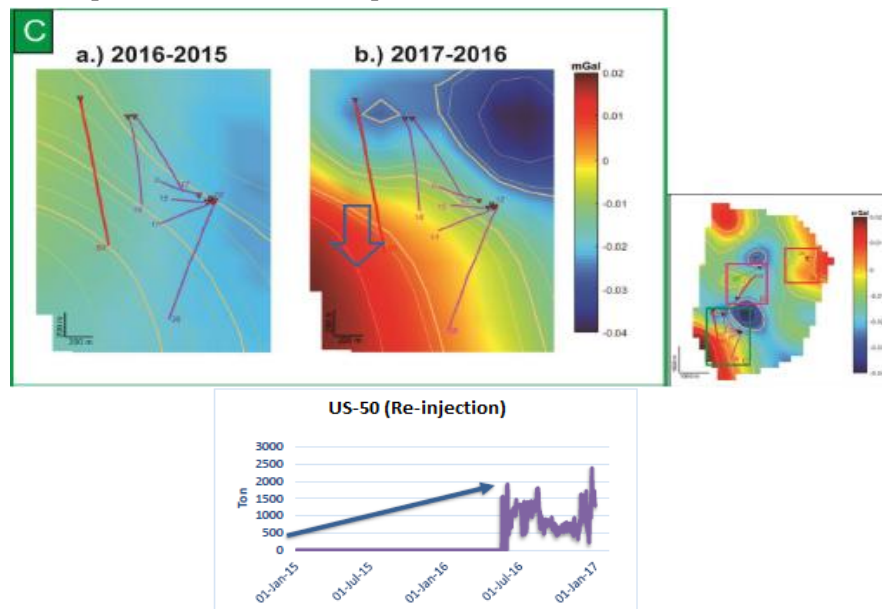


Figure 8. Inside box C (a) Microgravity 4D Response 2016-2015 and (b) Microgravity 4D Response 2017-2016, the graph shows the amount of re-injection is rising.

3.2. Mass Changes Estimation

The mass changes estimation in 2017-2016 using The Gauss's Flux method need the amount of squares that cover the area of interest. The amount of the squares are (n). Focusing inside the proven area, we get the result -3.2067 MTon fluid. We can simply conclude that the production rates is higher than the reinjection rates so the fluid beneath the surface decreased as much as 3.2067 MTon.

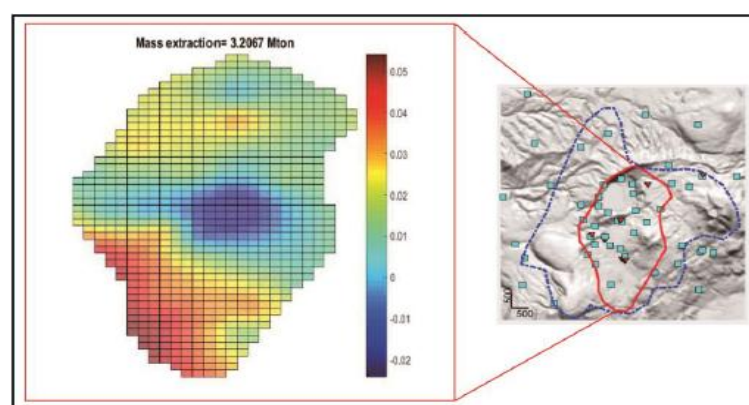


Figure 9. The calculation results of the mass changes estimation of the Gauss's Flux method.

In comparison with The Gauss's Flux method, the result from inverse modelling is different. This could happen because the inverse modelling will take the geometry beneath the surface as a consideration in the mass changes calculation. After several iterations, the result is almost similar with the initial model.

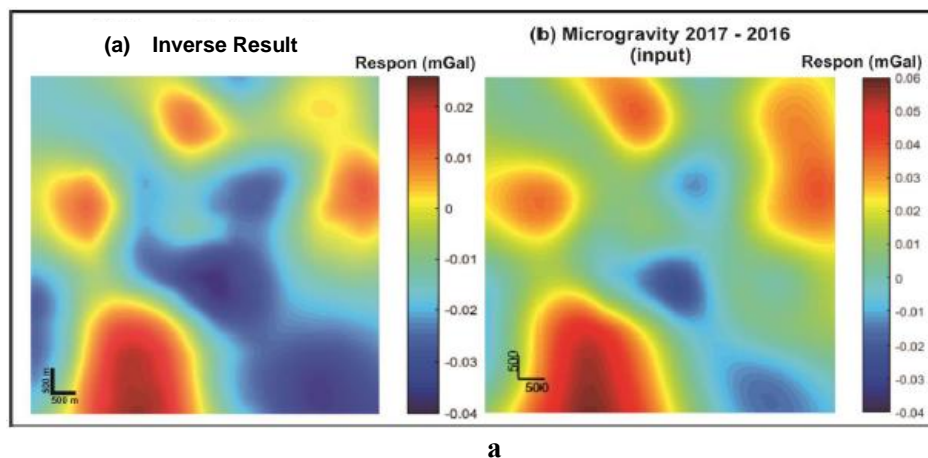
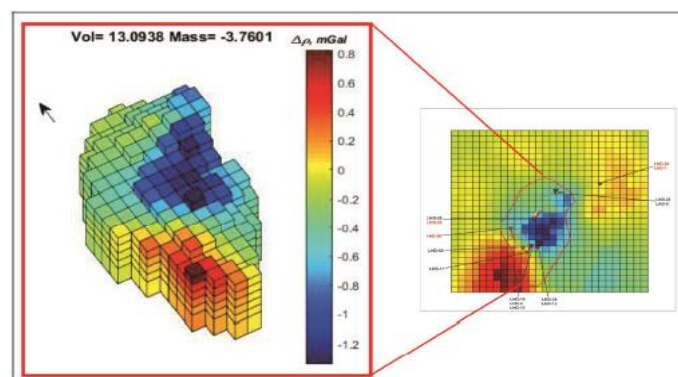


Figure 10. (a) Inverse modelling result, (b) Initial model input.

Calculating the mass changes after inversion is not difficult. By dividing the result into a mesh, then the density value will be spread to every cube of the mesh. The volume of the cube then could be calculated so then we get the mass of each cube. The result is pretty similar with Gauss's Flux



Method, which the inverse modelling get -3.7601 Mton mass change inside the proven area.

Figure 11. Mass change calculation using Inverse Modelling Method shows that the result is close to Gauss's Flux Method.

4. Conclusion

The microgravity measurement which is done every year could produce a 4D microgravity map. The map can tell the density has been changes in some periods that could occurs because of the production and re-injection activity on the surface. Both maps in this study confirms that there are density changes beneath the surface that associates with the amount of the fluid inside the reservoir. The re-injection strategy on wells (US-7, US-36, US-29 and US-50) succeeded in injecting fluid into areas that lack of fluids. Further processing for 2017-2016 data using Gauss's Flux method and Inverse modeling method yields mass changes calculation value from -3.20 Mton to 3.76 Mton. Meanwhile, observation data shows the amount of mass deficit is 4.13 Mton. The difference between the calculation and the observation data is pretty close so we could conclude that there are some unknown source of fluid which we assume it as a potential recharge as much as 0.37 - 0.93 Mton or 9% - 23% of the deficit mass of observation data. These result could be a proof that the further processing of gravity method could be used for many useful things, in terms of geothermal field, the result could be a consideration for production and re-injection strategy.

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