Evaluation study on the effect of production and fluid reinjection towards reservoir using micro gravity in Kamojang geothermal field

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Abstract. Geothermal fluid exploitation is expected to cause physical as well as chemical changes to the reservoir of a geothermal field. This is what happened to Kamojang Geothermal Field which has been producing for four periods, starting from the initial production capacity of 30 MW (1983) which became 140 MW (1987), then 200 MW (2008) and 235 MW since 2015 up to now. To observe changes of subsurface condition, Microgravity, is called time-lapse gravity as well, as one of geophysical survey activity is carried out in order to obtain the reservoir changes in a wider view based on the changes of gravity value as a reflection of rock density changes due to the extracted fluid mass. Generally, the microgravity study result from 1984 until 2018 shows the existence of microgravity value changes which correlates to the amount of fluid mass produced and the water mass which was reinjected back into the reservoir. This can be observed from the Time-lapse Anomaly Map in accordance to each of the production period of Geothermal Power Plant (GPP) Unit 1, 2, 3, 4 and 5.

Keywords: Microgravity, time-lapse gravity, rock density, GPP

1. Introduction
This study is conducted in Kamojang Geothermal Field, which is located in the southeast of Bandung or in the northwest of Garut, with 25 km distance (figure 1). Kamojang Geothermal Field is the first geothermal field which was explored and developed in Indonesia. This field is one of the Geothermal WKP owned by PT Pertamina Geothermal Energy. Since the utilization of the geothermal energy into electricity from 1983, Kamojang Geothermal Field has reached the operating age of 37 years. The current installed capacity is 235 MW, from 5 Geothermal Power Plants (GPP), comprised of Unit 1 (30 MW), Unit 2 (55 MW), Unit 3 (55 MW), Unit 4 (60 MW) and Unit 5 (35 MW). For the production of 235 MW, steam of about 1645 ton per hour is supplied from 58 production wells, which are distributed in an area of approximately 14 km². To balance the mass that is taken out, water with total capacity of 500 tons per hour is injected through 9 reinjected wells.

To monitor reservoir condition during the field management, observations are conducted in the form of well temperature and subsurface pressure measurement, as well as well fluid extraction for chemical analysis purposes. Geophysical method is implemented to observe the reinjection water pattern by
installing a stationary micro earthquake tool. Such microgravity measurement has been performed in 1984, 1986, 1988, 1992, 1997, 1999, 2005, 2008, 2011, 2012, 2014, 2016 and 2018. A number of researchers have previously conducted microgravity study during the time interval of 2–24 years, among which Timbul Silitonga (1984–1988 and 1989–1992); Satrio Jati (1984–2008); Yayan Sofyan (1999–2005) and Lendriadi Agung (2014–2016) [1-4]. Silitonga stated that during the initial production (1984–1988) no significant change occurred (3 mega ton). After the installed capacity is increased from 30 MWe to 140 MWe, the mass balance in the reservoir during the period of 1989–1992 significantly reduced to -15 mega tons, with estimated natural recovery flow relatively stayed the same level, which is 4–5 megatons per year [1]. The study result by Jati stated that there has been a mass change in the northern area of about +22.76 million tons, as well as in the eastern area of about -2.94 million tons [2]. Sofyan stated that there has been fluid mass increase towards the northeastern direction and a fluid mass decrease in the southwestern direction [3]. Agung stated that there is a difference of 1.4 million tons more of fluid mass that was extracted from the well, compared to the result of microgravity monitoring which produced 18.6 million tons of fluid mass. This is caused by the addition of fluid mass from natural recharge [4].

In this paper, author conducted microgravity study within the period of 1984–2018 with re-evaluation of the gravity data of 1984 until 2018. The limitation in the data processing and analysis is due to the limitation of distribution and the amount of Bench Mark (BM) points as the measurement point in the period of 1984 where placement of Bench Mark (BM) points did not cover all prospect areas, resulting in a limited microgravity anomaly map.

2. Methodology

2.1. Data acquisition and processing
The first gravity measurement was conducted by using Lacoste & Romberg Type G gravimeter in 1984–2005, Scintrex CG-3 gravimeter in 2008, and Scintrex CG-5 gravimeter for measurements done since 2011.

![Kamojang Geothermal Area](image-url)
Data acquisition is started by collected the microgravity field data from difference time measurement. Then tide and drift correction was done for getting gravity value measurement from each measurement. By subtracted of the two corrected measurement will get the value of the time-lapse anomaly. Analysis and interpretation that based on the time-lapse value will be easier made in the map (figure 2).

Gravity data acquisition was carried out with closed polygon method by knotting Bench Mark (BM) points considered as permanent and located outside of the production area. Tools used in the Bench Mark (BM) points coordinate and elevation measurement were Theodolit and GPS. Steam production data is acquired from 1982 to 2018, whereas the water reinjection data is from 1983 to 2018. Steam production data measurement was carried out by using orifice method, whereas the reinjection data measurement by using flowmeter tool.

2.2. Production and reinjection history
Up to this point, 91 wells have been drilled in the Kamojang field, including 5 wells from the Dutch occupation era. Out of the 91 drilled wells, 58 wells provide the supply for electricity production of 235 MW, which are distributed through Pipe Line/PL-401, 402, 403, 404, 405 and PL-406, whereas the separated water is injected though 9 reinjection wells.

During the period between 1982 to 1987, the produced steam amounted to 10.8 billion ton (figure 3) through pile network of PL-401, in order to supply the production of GPP Unit 1, where the separated water was reinjected back into the wells amounted to approximately 2.2 million ton to well KMJ-15, KMJ-21 and KMJ-32 (figure 4).

During the period between 1987 to 2007, the steam was produced not only for the supply of the above GPP Unit 1, but also for GPP Unit 2 and 3 with 159 billion ton, resulting in total produced steam for the 3 units of 169.8 billion ton. Separated water reinjected in this period was approximately 32.7 million ton and was channeled to reinjection wells of KMJ-15, 21, 32, 35, 46, 55 and KMJ-13, resulting in the reinjected water to reach accumulation of 34.8 million ton.

In the period between 2008 to 2015, other than for supply of the abovementioned Unit 1, 2 and 3, there was also steam production of 93.3 billion ton to supply Unit 4 so that the total steam produced for the 4 units reached 251.4 billion ton. The additional separated water during this period is about 19.7 million ton so that the cumulative up to 2015 reached up to 54.5 million ton through wells KMJ-15, 21, 32, 35, 30, 55 and KMJ-20.

Figure 2. Data acquisition flow diagram
In the period of 2015 up to now, other than for supply of the above mentioned Unit 1, 2, 3, and 4, there was also steam production of 35.2 billion ton to supply Unit 5 only, so that the total steam produced until 2018 for the 5 units of GPP reached 298.2 billion ton. As for the additional separated water injected during the period of 2015–2018 is about 6.4 million ton through wells KMJ-15, 21, 32, 35, 55 and KMJ-20 so that the total water reinjected to reservoir reached up to 60.9 million ton.
3. Results and discussion

Analysis of the microgravity data processing result is done to evaluate the impact of production and reinjection during the supply of GPP Unit 1 (1983–1987), Unit 2 and 3 (1987–2008), Unit 4 (2008–2015) and lastly by the addition of Unit 5 (2015–2018), as seen in table 1.

3.1. Period of GPP unit 1

Initially, the extraction of geothermal fluid from wells in PL-401 for the supply of GPP Unit 1 of 30 MW did not put a discernable impact on most of the reservoir. Time-lapse anomaly map during the period of 1986–1984 (figure 5) showed a change of gravity values around -0.02 to -0.04 mGal towards the eastern area of the research area, from well KMJ-18 towards KMJ-7. This gravity changes due to mass extraction around PL-401 area. In the areas where absence of production wells, there is no significant change of gravity values. Meanwhile in the middle part, surrounding well KMJ-15 a gravity value around 0.02 to 0.04 mGal was observed. This means that there is an addition of fluid mass into the reservoir from reinjection water coming from well KMJ-15.

| Install capacity of power plant | Period of microgravity survey       |
|---------------------------------|-------------------------------------|
| Unit 1, 30 MW                   | 1984 - 1986                        |
| Unit 2 & 3, 110 MW              | 1986 - 2008                        |
| Unit 4, 60 MW                   | 2008 - 2014                        |
| Unit 5, 35 MW                   | 2014 - 2018                        |

*Table 1. History of microgravity KMJ*

*Figure 5. Time-lapse anomaly map, period of 1984–1986.*
3.2. Period of GPP unit 2 and 3

Additional GPP Unit 2 and 3, with 2 x 55 MW install capacity that supplied from the wells of PL-402, 403 dan PL-404 caused the changing of microgravity anomaly pattern. On the microgravity anomaly map during period of 1986–1988 (figure 6a), which the GPP is commence on 1987, showed a decrease of gravity value up to -0.02 mGal from the wells within northern and western area.

This is caused by starting of mass extraction from PL-402 to PL-404 area for Unit 2 and Unit 3 in this period, while in the area surrounding well KMJ-15, 55 and 21 shows a positive gravity value due to reinjection water around these areas. The decreased of gravity value increase become around -0.06 to -0.09 mGal in 5 years after GPP operated (figure 6b).

![Time-lapse anomaly map, period of 1986–1988](a)

![Time-lapse anomaly map, period of 1986–1992](b)

**Figure 6.** (a) Time-lapse anomaly map, period of 1986–1988, and (b) Time-lapse anomaly map, period of 1986–1992.
3.3. Period of GPP unit 4
Additional GPP Unit 4 that commence on 2008, with 35 MW install capacity which supplied from the wells of PL-405 caused the appearance of microgravity anomaly pattern in south-eastern area. The initial of microgravity anomaly pattern of this period (figure 7a) showed a negative gravity value -0.08 to 0.1 mGal approximately in PL-405, which means that there has been a decline of fluid mass which resulted in the decline of rock density. However there is an addition of water mass by reinjection well KMJ-55 which resulted in a positive gravity value of 0.03 mGal surrounding the well at northwestern side. Otherwise the reinjection well KMJ-21 that close to PL-405 area is not influence clearly to the addition gravity value in this area. May be this is due to the initial production of the wells of PL-405.

![Figure 7](image.png)

**Figure 7.** (a) Time-lapse anomaly map, period of 1988–2008, and (b) Time-lapse anomaly map, period of 2012–2014.
Figure 7b shows the microgravity anomaly pattern after this GPP running in six years approximately. The negative anomaly pattern become wider tent move to east side but the positive anomaly pattern at northern side tend wider surround PL-402 area that influence of the reinjection well KMJ-55 and also due to stop production of several wells due to shutdown of GPP Unit 1.

3.4. Period of GPP unit 5

GPP Unit 5 with 35 MW install capacity was commencing on 2015 which the steam supply from wells of PL-406 at north-eastern. Figure 8a showed that production area at north-eastern has increase of decline of gravity value up to -0.06 to -0.09 mGal, due to start of mass extraction at this PL-405 area,
which means that there has been fluid mass decline in the reservoir. Positive gravity value and small gravity value changes occurred in the area surrounding reinjection well KMJ-55 & KMJ-21 due to the addition of water mass into the reservoir through the reinjection well. While in period 2016–2018 (figure 8b), after 3 years Unit 5 operation, in PL-406 area gravity value change tend to stable, around -0.06 to -0.08 mGal due to stabilize of reservoir decline at this area.

4. Conclusion

4.1. Conclusion
The change of microgravity anomaly pattern which reflects increase or decrease of geothermal fluid mass relatively matches the production and reinjection period. Rejection water capacity has an indiscernible impact in controlling the production rate decline due to the fluid mass which was reinjected in a much less capacity compared to the capacity of produced fluid mass.

4.2. Suggestion
There needs to be additional reinjection wells in each well area representing each PL (pipe line). To obtain the baseline of gravity value of a field, it is necessary to place gravity measurement BM points which covers areas of all prospect region as well as a few BM points outside of the prospect areas as measurement knotting point. To acquire data with better quality, it is suggested to utilize the kind and type of the same tool to carry out microgravity measurement.

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