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Tracing Reinjected Condensate Using Microearthquake Monitoring at the Kamojang Geothermal Field

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ABSTRACT

The Kamojang geothermal field in Indonesia has been in operation for nearly 30 years. One effort carried out to maintain the sustainability of the geothermal resource at Kamojang has been to reinject the production condensate through reinjection wells. A key for the success of this is knowing the pattern of the reinjected fluid. Several attempts have been made to determine the flow pattern or connectivity between reinjection wells and production wells, one of which is using microearthquake monitoring. A station network of three-component digital seismometers has been deployed at the Kamojang geothermal field since 2010, with six installed stations at the beginning and the addition of five more in 2013. By observing the microseismic activities, it was hoped that orientation of reinjected condensate path could be identified. In addition, a tracer test was also conducted to get further information on the path of the reinjected condensate, and the connectivity between the reinjection and production wells.

1. INTRODUCTION

The Kamojang geothermal field was the first geothermal field developed in Indonesia. It lies in Java Island which is located at about 40 km distance to the southeast of Bandung, the capital of West Java (Figure 1). Moreover, the Kamojang geothermal field is a vapor-dominated system with a total installed capacity of 200 MWe. Reinjection is very important to the fulfillment of two requirements: the need for regulatory compliance with environmental laws (there should be no condensate or geothermal brine contamination in the environment) and the maintenance of reservoir sustainability, especially in terms of the reservoir pressure. Re-injection can give a positive effect in maintaining the productivity of production wells but it can also have a negative impact through cooling which leads to a decrease in production. Hence, it is important that the management of reinjected fluids is carried out properly. Here, the location of wells is important and the usage of a proper injection rate is crucial. In the Kamojang geothermal field, there are 45 production wells and four active reinjection wells used for condensate reinjection.

The microearthquake (MEQ) method has been applied in the Kamojang geothermal field since 2003, using a one-component geophone sensor and analog recording of data using a paper drum. In 2010, the system was updated through the installation of three-component geophones and digital recording of data at six stations. Five additional stations were added in 2013, bringing the total number of microearthquake observation stations to 11 stations (Figure 2). The microearthquake method is used to reveal the permeability structure of the Kamojang geothermal field and to determine the reinjection fluid movement pattern in the production field. Furthermore, this method is also used to determine the boundary of the reservoir.

KMJ-21 is one of the reinjection wells at the Kamojang geothermal field. It is Kamojang's most effective reinjection well, with an injection rate of 2000 lpm (litre/minutes). The KMJ-21 reinjection well is located in the middle of the Kamojang geothermal field, which is also in the middle of the Pangkalan caldera. Its contribution is important in maintaining the pressure and mass balance in the surrounding production wells.

Figure 1: Location map of Kamojang geothermal field in West Java.

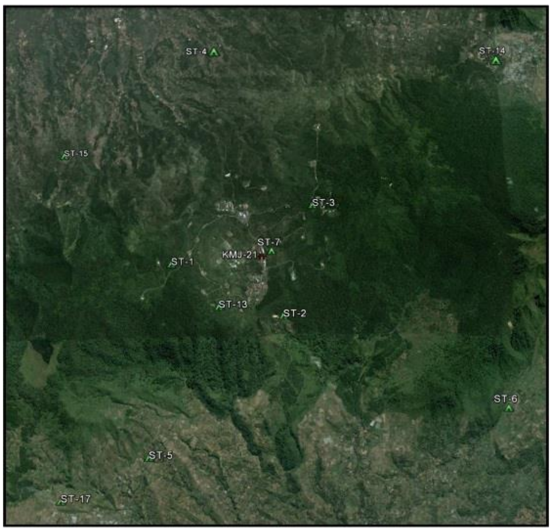

Figure 2: Location of microearthquake station and reinjection well KMJ-21

To further understand the fluid flow pattern from the reinjection well (KMJ-21) and to determine its connectivity to the surrounding production wells, tracer tests using HFC R134a were carried out. The tracer test and the monitoring of the microearthquakes were expected to help in revealing the pattern of connectivity between the reinjection wells and production wells.

2. MICROEARTHQUAKE DATA ACQUISITION AND PROCESSING

Microearthquake data used in this study were collected from 2011 to 2013. The seismograph network comprised 11 stations (Figure 2). The microearthquake monitoring network, which was put in operation, used Geotech Smart-24R digital three-component geophone instruments which recorded P-waves through the vertical component (Z) and S-waves with horizontal components oriented in the N-S and W-E directions. The recording was continuous with a sample rate of 200 samples per second. Each microearthquake station included a hard disk of six Gb internal memory and 60 Gb external memory, a solar panel, a GPS receiver, and a 12 V battery power source. The microearthquake monitoring stations were deployment in two phases. The first phase consisted of six stations deployed since 2010 and the second phase increased the number of stations to 11 by adding five new stations to the network in 2013. Geophones were buried to a depth between two and five meters. Microearthquake stations were placed far away from home residences, main roads, and factories; in order to avoid noisy conditions and achieve the highest possible signal-to-noise ratio.

In this study, the P-wave and S-wave arrival times were manually picked on seismic waveforms that were recorded by a minimum of three stations. To improve the picking quality of unclear P-and S-wave arrival times, filtering techniques were applied (e.g. band-pass filtering). At the beginning, all events were located using a 1D velocity model. These relocations were performed with a standard Geiger method inversion using the Seisplus software program from Geotech.

3. THE TRACER TEST

The HFC R134a tracer was injected into the reinjection well KMJ-21 in February 2013. Tracer returns were monitored at eight production wells surrounding KMJ-21. The production wells monitored in this study were: KMJ-33, 34, 45, 18, 49, 71, 69 and 76. HFC R134a is a vapor-phase tracer, which has been used in fields with a water-dominated system, two-phase system, or vapor-dominated system. A total of 201.4 kg of HFC R134a was injected into the reinjection well KMJ-21 with tracer concentrations of 512.99 ppmv. Sampling was done every two days at the eight selected production wells from February to July 2013.

4. RESULTS AND DISCUSSION

From the map of the epicenter of the microearthquake distribution (Figure 3), a cloud of microearthquake events surrounding the reinjection well KMJ-21 can clearly be seen. This activity is expected to be associated with the injection of the condensate into KMJ-21. There are clusters of events that spread from KMJ-21 to several directions. The spread of the microearthquake epicenters can also be seen in the partially forming patterns which follow existing structures. From these clusters of events, it could be concluded that the seismicity was due to contraction cracking associated with the cooling and circulation of the reinjected condensate. The distribution of microearthquake epicenters can be interpreted in terms of the flow path pattern of the injected condensate fluid in KMJ-21. The distribution of microearthquake events surrounding the well KMJ-21 is clearly visible and visible microearthquakes also spread towards the north. Moreover, the spread of the microearthquake epicenters to the south through existing structures can likewise be seen. Finally, some microseismic events can be seen towards east, although the pattern is not very clear (Figure 3).

From a vertical cross-section in the NE-SW direction (Figure 4), the distribution of microseismic events around KMJ-21 at depths ranging from 500 to -1500 m a.s.l. is evident. In Figure 4, the blue dots are the microearthquake events, the black dots indicate the top position of the total lost circulation (TLC), and the triangle is the top position of the perforated casing. The distribution of the microearthquake events clearly shows the spread of microseismic events towards the south, as well as towards wells 38 and 45. Furthermore, to the east of well KMJ-21, the microseismicity shows a spread of events towards wells 71, 69, 75 and 76 at depths between 200 and -1000 m a.s.l. (Figure 4).

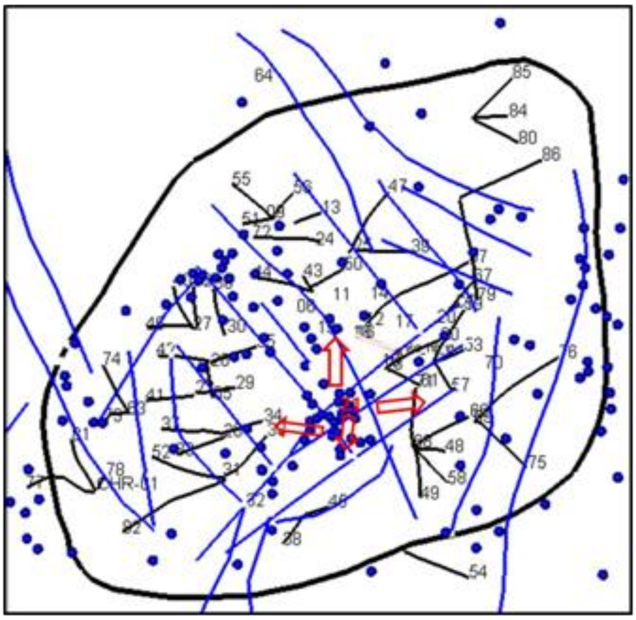

Figure 3: Map showing the distribution of microearthquake events in the vicinity of reinjection well KMJ-21

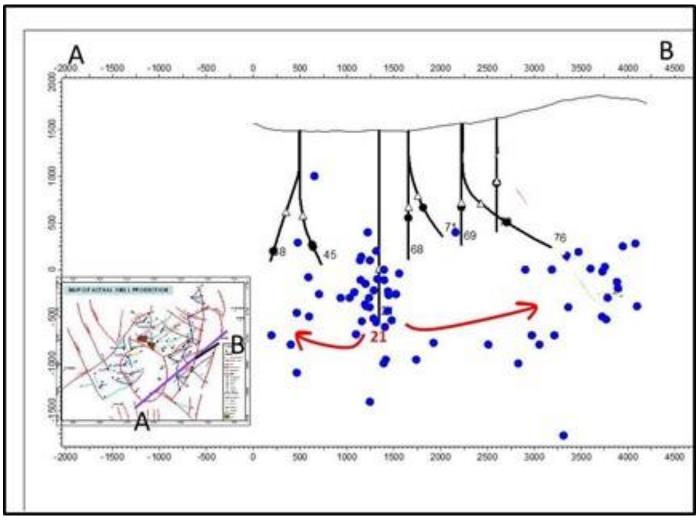

Figure 4: Vertical intersection show fluid flow path pattern of reinjected condensate from well 21 toward surrounding production well

The analysis of tracer tests using HFC R134a on eight production wells surrounding well KMJ-21 (KM- 33, 34, 45, 18, 49, 71, 69 and 76) showed that the tracer appeared in all of these production wells but with the different arrival times (Figure 5). The tracer data, based on the returns in the production wells, showed the flow path pattern from the reinjection well KMJ-21 (Figure 5). The analyses showed that the peak concentrations of tracer returns at production wells were observed in relatively short times, i.e. in 5 to 22 days (Figure 6). The highest concentrations were obtained in the production wells located in the eastern part of the field. From this result, it was estimated that most of the mass of the condensate reinjected into KMJ-21 flowed to the east.

Based on the results of the microearthquake data analysis and the tracer test, similar interpretations of the fluid flow path pattern can be derived. The distribution of microearthquake showed the spread of events towards the southern and northern directions. Similarly, the tracer test results indicated the same flow path direction with the appearance of the tracer (HFC 134a) at wells 18 and 45. Furthermore, the microearthquake distribution was also seen on the east and west sides of the KMJ-21 reinjection well, which was consistent with the results of the tracer tests. The tracer, HFC 134a, was found at wells KMJ-33, 34, 69, 71 and 76.

5. CONCLUSION

Based on the study of the distribution of microearthquakes and tracer injection, the flow path pattern of condensate from the reinjection well KMJ-21 in the Kamojang geothermal field has been suggested. The distribution of microearthquake events is clearly seen towards the south and north. It can also be seen, to some extent, towards the west and east, although the pattern of distribution is not very clear here. This interpretation is supported by the results of the tracer test, using HFC R134a tracer, which shows the same pattern of connectivity between the reinjection and production wells.

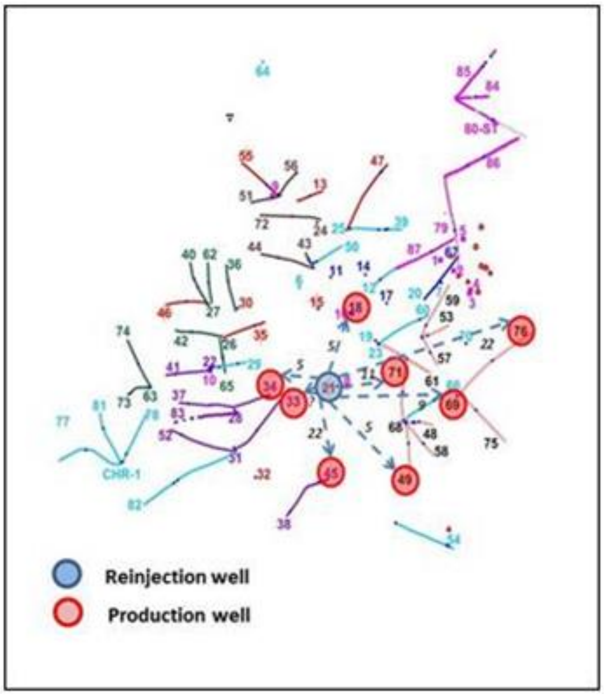

Figure 5: Condensate flow path pattern from reinjection well KMJ-21 toward surrounding production well, obtained from tracer test result

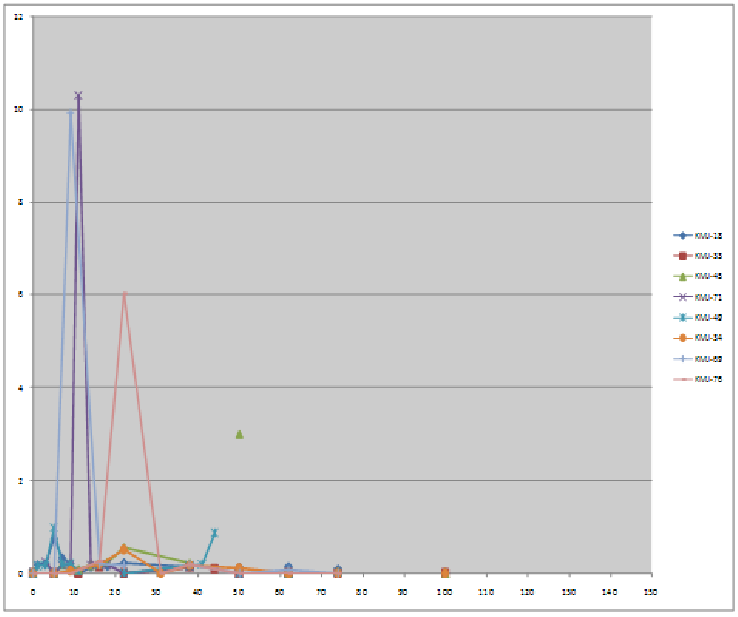

Figure 6: Graph showing the relationship between the concentration of HFC R134a at monitoring wells and the sampling time.

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