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Geochemical Changes during 12 Year Exploitation of the Southern Reservoir Zone of Lahendong Geothermal Field, Indonesia

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ABSTRACT

Extensive exploitation of the Lahendong geothermal field in Indonesia has had an impact on the reservoir. Since 2001, 37 geothermal wells have been drilled to support 80 MW electricity generation by 4 power plants. This condition leads to several consequences on that reservoir which is reflected by reservoir chemical characterization changes. Geologically, this reservoir is divided into two zones, the southern and northern reservoir. The southern reservoir zone has suffered significant changes in dryness, chemical characterization and temperature based on a chemical geothermometer. Sulphate groundwater influx is known as a cause of the reservoir characterization change and leads to a temperature drop based on the geothermometer.

1. INTRODUCTION

Located at the northern Sulawesi, Lahendong Geothermal Area is the only operating geothermal power plant in northern Sulawesi and supports up to 60% electricity needed in the north and middle Sulawesi region. The reservoir is a hot water dominated system and is divided into two zones – the northern and southern zone – with the southern zone reservoir having a higher reservoir temperature than the northern (Koestono et. al, 2010). This paper will focus on the southern reservoir zone which is developed in an earlier stage in the Lahendong Geothermal Area to support the earlier units (2 x 20 MWe of Unit 1 & 2).

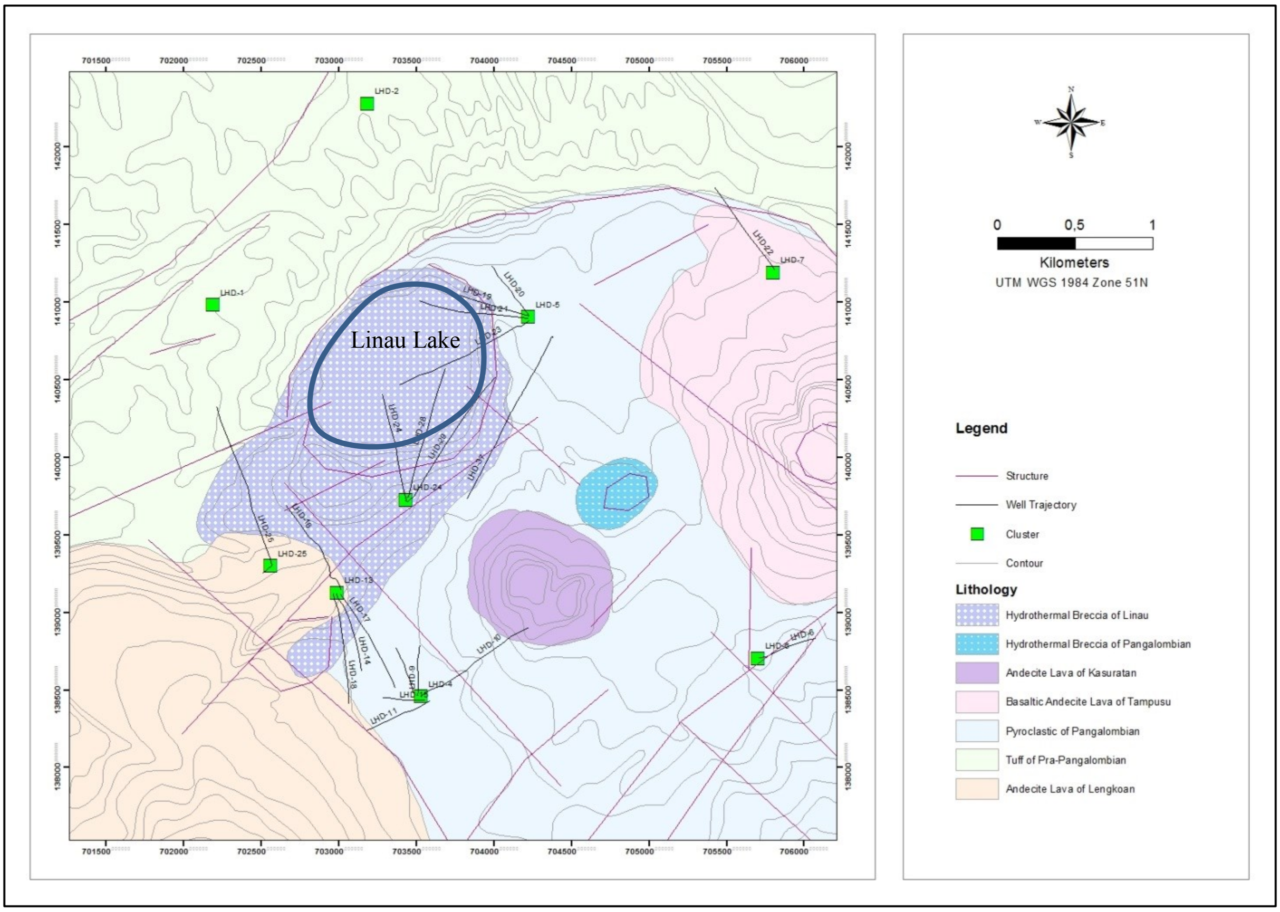

Figure 1: Map of Lahendong Geothermal Area.

2. GEOLOGICAL OUTLINE

Tectonically, Lahendong Geothermal Area is located at Minahasa compartment (NE-SW trend) characterized by active volcanoes (Mt. Soputan, Mt. Lokon, Mt. Mahawu, Mt. Klabat and Mt. Dua Saudara). A K_2O/SiO_2 study has been done which shows that the volcanic products in this area are affected by the subduction zone of Sulawesi oceanic crust in the north and Moluccas oceanic crust in the east (Siahaan et. al, 2005).

The volcanic activity produces a series of volcanic rocks that is characterized as a Post-Tondano Unit, comprising of Pangolombian andesite lava and tuff, Lengkoan lava and tuff, Kasuratan andesite lava and tuff, Tampusu andesite lava, Kasuratan obsidian and tuff, Linau andesite lava and breccia and Masarang andesite lava and breccia (Utami et. al, 2005). Before Post-Tondano were deposited, Tondano tuff (0.871 ± 0.097 Ma) and vulcanic–sedimentary rock of Pre-Tondano unit (2.19 ± 0.03 Ma) took place.

3. RESERVOIR CHARACTERIZATION

Nine wells have been drilled in the northern sector, 12 wells in the southern zone, and 3 injection wells and 5 wells in the proximity boundary of the geothermal system. Wells in the northern zone are mostly targeted at the Linau Crater Lake while the wells in the southern zone are targeted to the southern zone fault system.

Utami et. al. (2004) divided the northern and southern zone in terms of reservoir characteristics. The northern zone (Linau Zone) has acidic fluid from 570 – 370 masl which is confirmed by a VSI (Volcanology Survey of Indonesia) drill hole. The southern zone (Lengkoan Zone) has medium permeability with 2 reservoir layers. The shallow one extends from 450 – 250 masl while the deep reservoir extends from 150 – 1150 mbsl with temperatures more than 300°C. Production wells in the southern zone are characterized by fluid dryness more than 50% with several wells having dryness up to 90%.

The southern zone has different characteristics than the northern one in terms of chemical composition. It has relatively low sodium content (± 200 ppm), low potassium content (± 50 ppm), low chloride content (± 400 ppm), and low sulphate content (± 25 ppm) than the northern zone (± 750 ppm sodium, ± 100 ppm potassium, ± 850 ppm chloride, and ± 600 ppm sulphate).

In early exploitation stage, most of the production wells in the southern zone produced chloride rich fluid. It has been plotted at chloride apex in the Cl-SO_4-HCO_3 diagram. Na/K (giggenbach) liquid geo-thermometer calculation shows that the reservoir temperature in the southern zone reaches ±310°C. This is confirmed by down-hole temperature measurements, which show a reservoir temperature range of about 300 - 350°C. Silica and other cation geothermometer calculations show that the temperature in the reservoir is lower than the actual temperature measured by down-hole measurements.

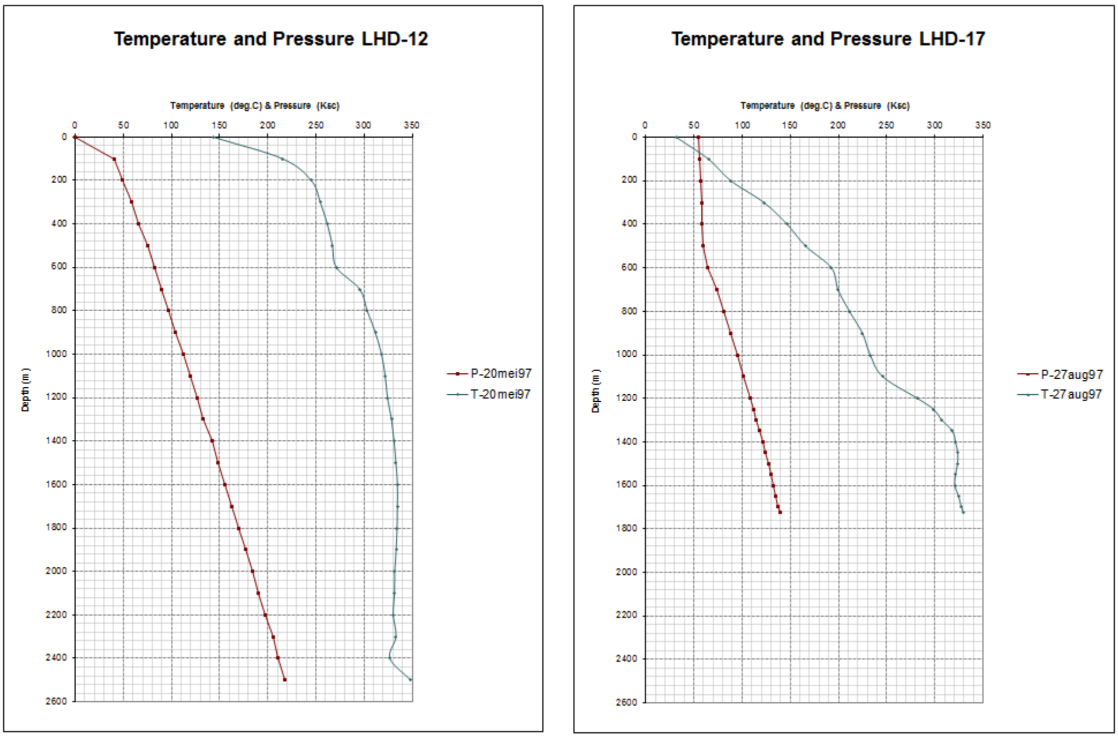

Figure 2: PT downhole measurement in typical southern production well in early exploitation stage.

4. LIQUID MONITORING PROGRAM

The southern zone has been exploited in for almost more than 12 years and the major problem is limited downhole measurement data that can be used in a reservoir monitoring program. Therefore, geochemical monitoring could be a powerful method in a reservoir monitoring program.

During the exploitation stage, several chemical changes occurred in all production wells. The temperature from Na/K geo-thermometer calculations and the chemical characterization have been significantly changed. The water chemical composition also shows a different pattern compared to the initial data. The changes can be seen at two production clusters in the southern area which will be discussed briefly below.

4.1 Cluster 4

There are five production-wells in cluster 4. Those wells mostly have 80% dryness except for LHD-10 and LHD-12. The latest data shows that the dryness of these two wells is less than 50%. There is no significant dryness change in this cluster based on flow measurement data collected from 2010 but if we compare with the initial condition, all of the production wells in this cluster suffer a decrease in enthalpy. LHD-10 is had the deepest decline in enthalpy of about 1,000kJ/kg. Therefore, recently this well has stopped producing geothermal fluid.

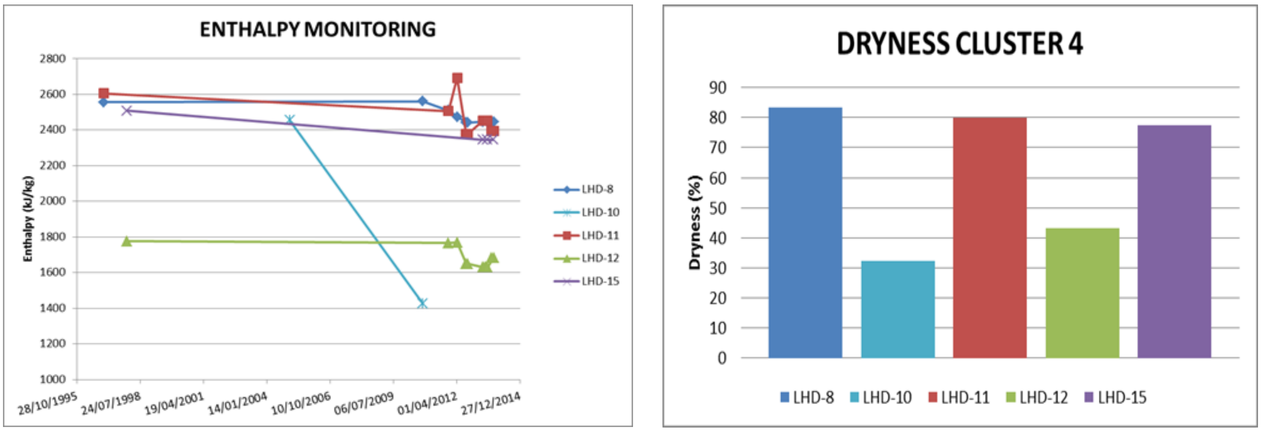

Figure 3: Graph of enthalpy monitoring in cluster 4 (left) and table of dryness in cluster 4 (right).

Chloride composition has decreased significantly in all production wells as shown in figure 3. This condition shows a dilution process in which the reservoir fluid diluted with another fluid that has low chloride concentration. Effect of reinjection breakthrough should not be taken into account since this effect is usually marked by some chemical breakthrough that would have been indicated by increasing chloride composition at production wells.

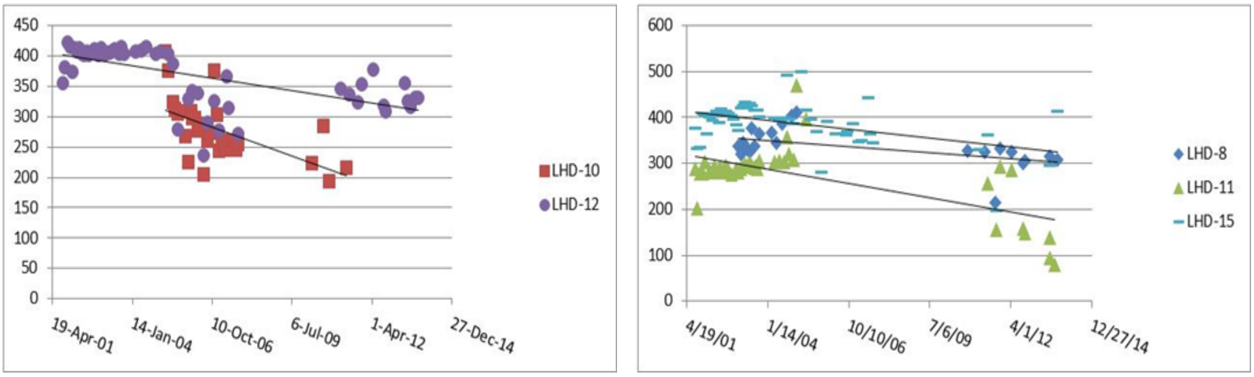

Figure 4: Graph of chloride monitoring in cluster 4.

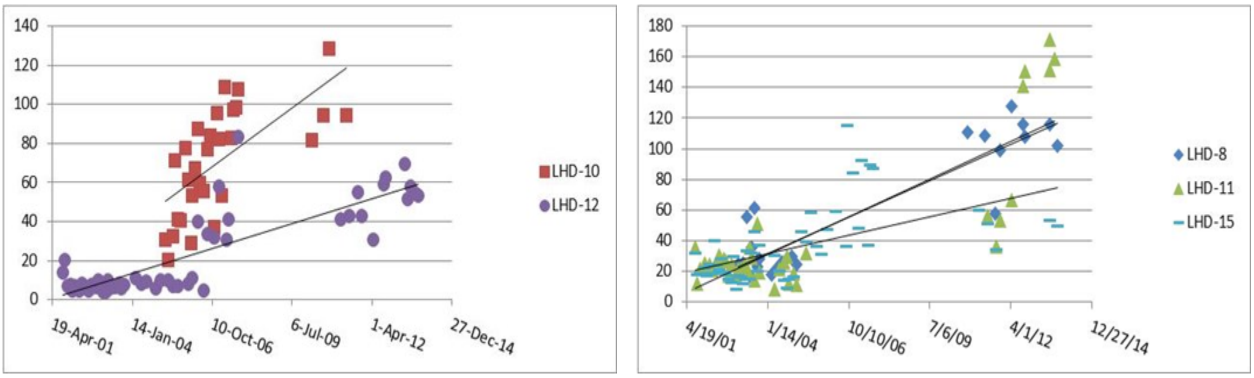

Figure 5: Graph of sulphate monitoring in cluster 4.

Sulphate, bicarbonate and calcium concentration in all production wells have been increased significantly. Silica concentration has depleted causing the temperature measurement with the silica geo-thermometer to drop. Magnesium usually used as an indicator for meteoric influx does not show changes. Lithium, sodium, potassium, boron and fluoride concentration do not give a similar trend among these wells. All of those conditions could be interpreted as a mixing process with a fluid with low chloride composition but high sulphate composition. This is a characteristic of sulphate water that results from steam condensation into near surface water (Nicholson, 1993).

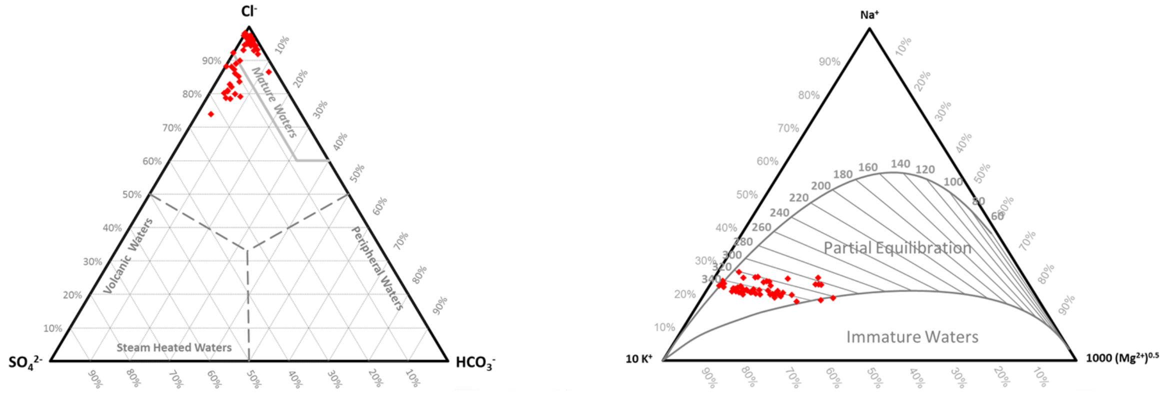

Figure 6: Trilinear diagram of typical southern chemial fluid.

NCG data also becomes useful in the Lahendong reservoir monitoring program. Temperatures from the Fischer-Tropsch-pyrite-pyrrhotite (FT-HSH.3) plot diagram is the best fit for all production wells in cluster 4. It shows the reservoir temperature in cluster 4 is around 300 – 325°C with dryness between 0.01 and 0.3. Reservoir temperatures based on CH_4/CO_2 gas geo-thermometer calculations also reasonably match the down-hole measurement temperatures in early stage.

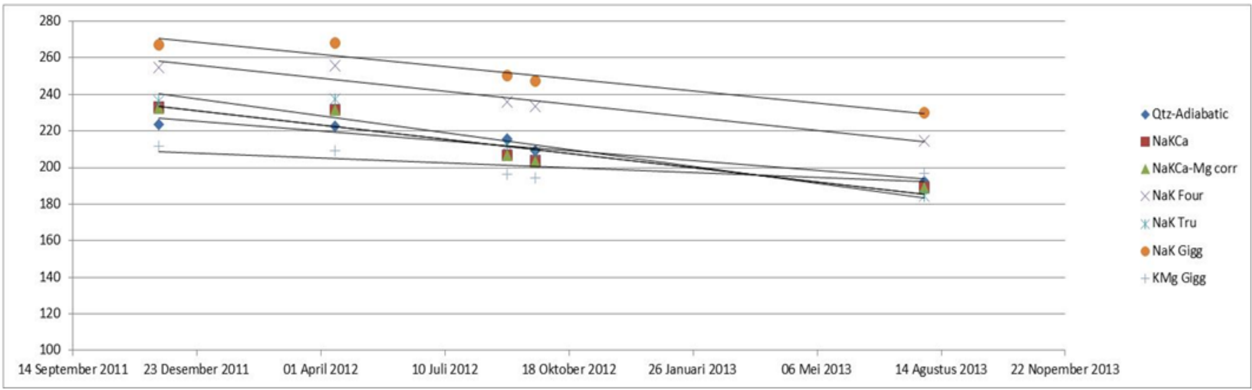

Figure 7: Liquid geothermometry in well LHD-11.

The largest temperature change based on liquid geothermometer measurements has been recorded at well LHD-11 with an annual temperature decline of about 20°C, from year 2010 onwards. However, the gas geothermometer did not show any significant changes in reservoir temperature. The most reasonable reason to explain this condition is that the reservoir was penetrated by production wells in cluster 4 – mainly by LHD-11 – and was flooded by sulphate rich fluid coming from the condensate layer. This condensate layer came from SO_4 rich steam that condenses at shallow depths.

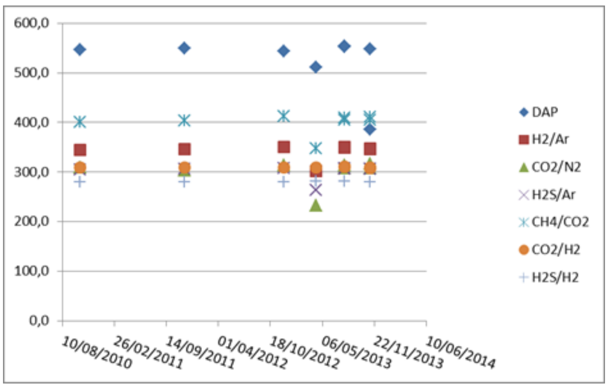

Figure 8: Gas geothermometry in well LHD-11.

4.2 Cluster 13

There are 3 production wells in cluster 13: LHD-13, LHD-17 and LHD-18. LHD-13 started producing in 2011. LHD-13 shows a cyclic pattern either in production behaviour or in enthalpy characteristic. LHD-17 produces a dry well with dryness almost 100% and LHD-18 is a geothermal well with a dryness less than 60%. According to initial data, enthalpy in LHD-18 declined more than 600kJ/kg which had an impact on its dryness.

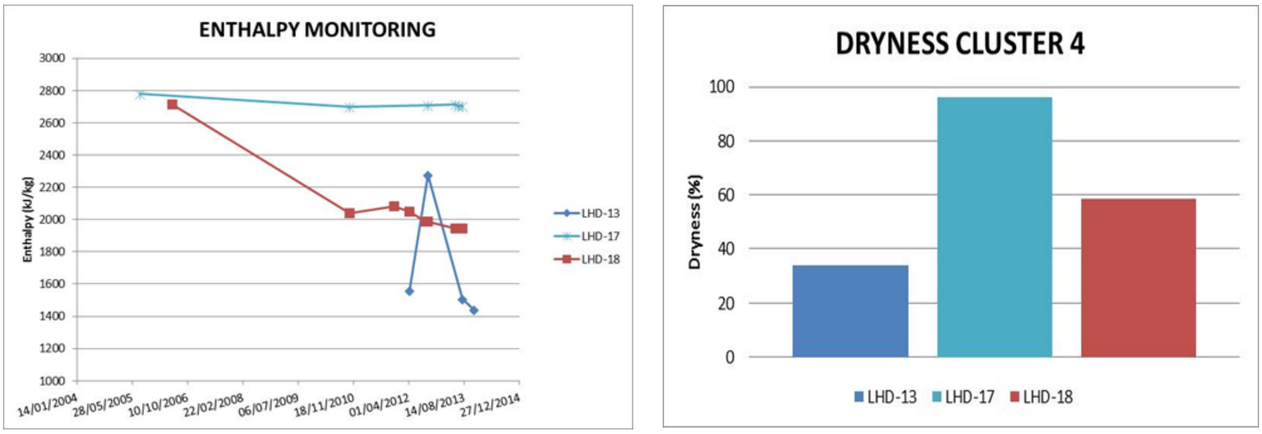

Figure 9: Graph of enthalpy monitoring in cluster 13 (left) and table of dryness in cluster 13 (right).

The results of the chemical analysis for LHD-17 are questionable because they showed a steam carry over characteristic such as low chloride and silica composition (less than 50 ppm). These conditions are probably due to dryness of the well which allows a steam carry over to the liquid sample. As a result, we assume that the liquid sample from LHD-17 mainly comes from a steam sample that was condensing in the sampling process. LHD-18 shows a steady chloride and sulphate concentration. Gas geothermometry FT-HSH.2 and CO_2/N_2 show a correlation with the initial temperature data taken from down-hole measurement survey which shows a reservoir temperature around 315 – 325^{o}C with dryness between 0,01 – 0,05.

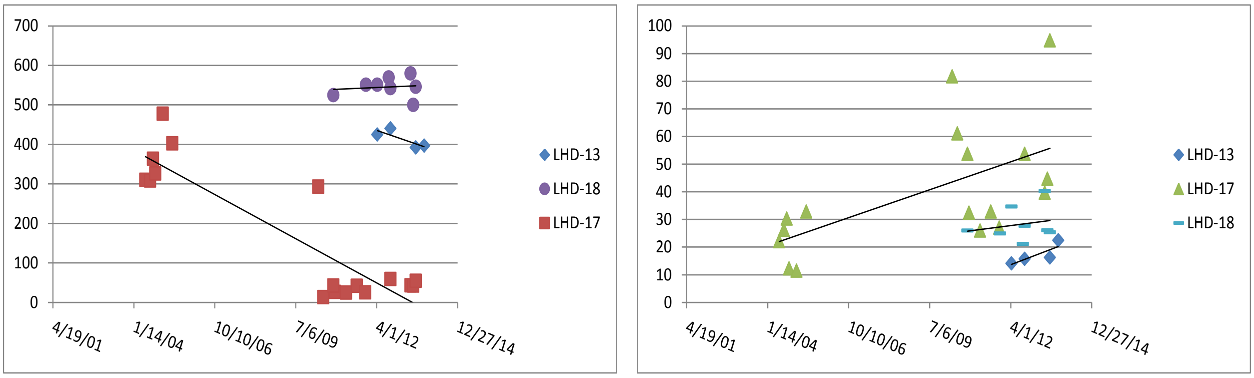

Figure 10: Graph of chloride monitoring in cluster 13 (left) and sulphate monitoring in cluster 13 (right).

An injection tracer test from a reinjection well has been done to establish a reinjection model. 100 kg of 1.6 NDSA (Napthalene Disulfonate Acid) was mixed with water to create a tracer fluid. This fluid was injected to a reinjection well in order to trace a fluid flow from reinjection well into production well. The test has shown that there is a slight connection between the reinjection well and the production well in the southern zone with a good average tracer velocity (± 3 meter/hours) but very little mass percentage recovery (less than 1%).

5. CONCLUTION

The southern zone of the Lahendong Reservoir shows a condition of mixing and dilution with more dilute, low chloride and silica concentrations but high sulphate concentration as shown in almost all southern zone production wells. There are two possibilities to explain this condition, reinjection breakthrough or condensate influx from a shallow aquifer layer. A tracer injection test has been done to confirm the reinjection effect but the result did not show a correlation between the reinjection process and the problem in the southern zone. As a conclusion, the condensate influx is the only possible way to explain this process.

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