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INTERFERENCE TEST OF SIBAYAK GEOTHERMAL FIELD NORTH SUMATRA - INDONESIA

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ABSTRACT

Interference test has been recognized as a valuable technique for evaluating reservoir properties such as permeability thickness and storativity over an area where active and observation wells are located. Interference test can also provide qualitative indications of reservoir heterogenities and communication between two or more wells. The availability of sophisticated pressure recorders encourages providing reliable data and improved accuracy. Interference test of Sibayak geothermal field that has been carried out in December 1998 to September 1999 is examined to prove two major fault which are predicted supporting permeability of this area. The presence of linear boundary can be determined by using a new semi-log type curve matching (Sageev et al, 1985). Log-log type curve (Theis Curve) can also be employed to determine the interwell properties i.e. transmisivity and storativity.

The first test that conducted by measuring SBY-8 response to SBY-5 discharge, does not reflect presenting of either fault F4 or F1. The second test of well SBY-7 response to SBY-5 discharge, indicates shifting of the pressure response to the constant pressure linear boundary curve. It is shown in a log-log plot matching (Theis curve) and more clearly in new semi-log. For Sibayak geothermal field the area between SBY-8 and SBY-5, permeability thickness is 40.3 x 10^{-12} m^3 and storativity is 2.64 x 10^{-8} m/Pa. The area between SBY-7 and SBY-5, permeability thickness is 48.3 x 10^{-12} m^3 and storativity is 1.63 x 10^{-8} m/Pa.

INTRODUCTION

Sibayak geothermal field is located about 60 km South West of Medan, the capital city of the North Sumatera, Indonesia. The Sibayak system is classified as a high terrain of a volcanic geothermal type with the liquid dominated reservoir system (Hochstein, 1999).

The Sibayak Geothermal Field is bordered by Sibayak Mountain in the North and Pratektekan Mountain in the Northeast and a rim escarpment along 4 km from East to West in the southern area. The Deep diatrema of Sibayak Volcano is believed as the heat source of geothermal system which the temperature decreases as we go far away from Sibayak Volcano and looks like a mushroom shape.

There are ten wells that have been drilled from 1991 to 1997. Most of them were drilled deviated due to the difficulties of the steep terrain. The reservoir rock comprises of interlayered between altered metasandstone and shale that found relatively at the same elevation. This metasedimentary rock unit is covered by altered andesitic lava. There is no lost circulation while drilling in that boundaries. The permeability of the reservoir is supported by two major faults which cross the field in Northwest – Southeast direction and called by F1 and F4. It is proved by drillling which the wells that intersect to those faults are SBY-6 and SBY-7. The wells that intersect to F1 are SBY-1, 3, 4, 5, 8 but SBY-9 intersect to F4. SBY-10 and SBY-2 as reinjection wells intersect to rim structure.

The reservoir temperature lies between 240°C and 300°C, and the reservoir pressure varies between 45 and 110 barg, and most of the wells have no wellhead pressure at shut in condition. The Enthalpy of the reservoir reaches 1150 kJ/kg and the maximum wellhead pressure achieves 21 barg at the flowing condition.

Analysis of Sibayak interference test measurements is assessed by examining the pressure response of the observation well as the outcome of the pressure response of active production well and active reinjection well. These two active wells influence the response at the same time.

SEMI-INFINITE RESERVOIR

Reservoirs are not really infinite in extent, the geological structure will influence the reservoir especially dealing with the boundary condition. The effect of the reservoir boundary will be felt at the interference test. There are several factors which influence the response of the well :

- the distance to the boundary,
- properties of permeable formation,
- the fluid of the reservoir.

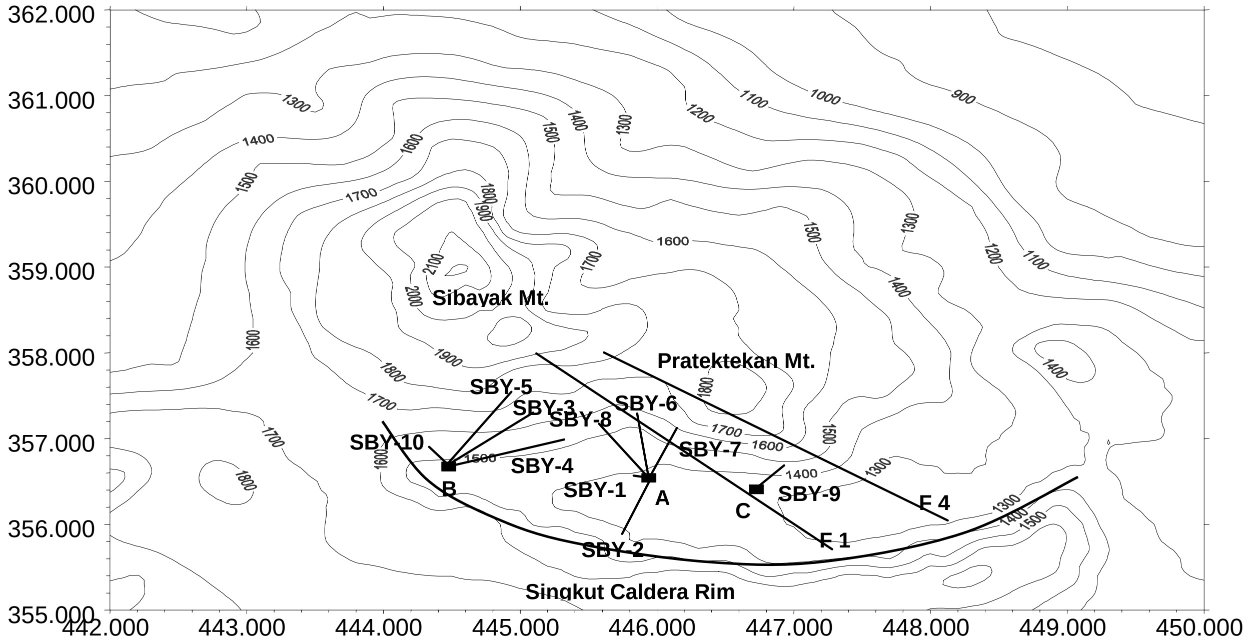

Fig.1. Sibayak geothermal field, well directions and fault structure.

There are two type of reservoir boundaries :

- an impermeable boundary, occurs where the reservoir is sealed and no flow occurs,
- a constant pressure boundary, occurs where the reservoir pressure is controlled by fluid encroachment (either due to natural influx from an aquifer or by fluid injection) (Horne, R.N., 1995).

The reservoir which is influenced by these condition is called semi-infinite reservoir. The test is examined by using new semi log method which is developed by Sageev at al, 1985.

APPLICATION OF SEMI-LOG ANALYSIS

Semi-log analysis is carried out by the following steps :

1. Identify the time when interference is started.
2. Before the test measure a pressure and time where the atmospheric pressure effects thepressure at the observation well. Calculate the difference between highest and lowest pressure (ΔP).
3. Calculate α by using equation :

   $$\Delta P_{well} = \alpha \ \Delta P_{atmospheric} \qquad (1)$$

   and calculate corrected pressure by using equation :

   $$P_{corrected} = P_{well} - \alpha \ P_{atmospheric} \qquad (2)$$

4. Calculate the time difference (Δt) for the interference test :

   $\Delta t = ti - t\ start$

   where ti and t start = time on each point and time when the test is started.
5. Calculate ΔP corrected and plot ΔP against log Δt, then identify the slope of the curve.
6. Calculate the kh by using equation :

   $$kh = \frac{2.303\ W\ \nu}{4\ \pi\ m} \qquad (3)$$

   where m = slope, Pa/log cycle
7. Extend the straight line up to intersect the $\Delta P = 0$ and identify the Δt. Calculate storativity by using equation :

   $$\phi\ c\ h = \frac{2.25\ kh\ \Delta t}{\mu\ r^2} \qquad (4)$$

   where μ = Dynamic viscosity of fluid.
   r = The distance between active and observation wells.

NEW SEMI-LOG TYPE CURVE MATCHING

New semi-log type curve matching has been developed by Sageev et al, 1985 for determining the ratio r_2/r_1 which is the ratio between the distance of image and active wells to the observation well. Sageev et al have developed Stallman's (1952) log-log type curve in semi-log coordinates.

The curves show the lines in branches with the line source solution in the center. The branches below the line source represent the response due to constant pressure linear boundaries and above the line represent the response due to impermeable linear boundaries.

The pressure response of a production well near a constant linear boundary will be reflected by shifting of the curves with certain ratio of r_2/r_1. For the interference wells, where the ratio r_2/r_1 is close to

1, the modified pressure equation can be expressed (Sageev et al, 1985) :

$$P_D^* = P_D + \ln(2 d_D - 1) - \ln(r_2/r_1) \quad (5)$$

and the modified time can be derived :

$$t_D^* = t_D [(2 d_D - 1) / (r_2/r_1)]^2 \quad (6)$$

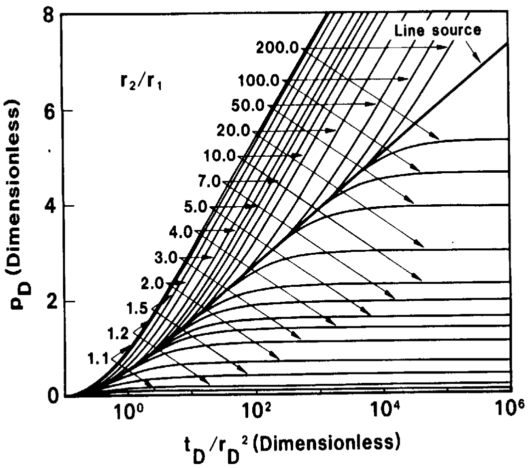

Fig.2. Semi-log curve for a well near a linear boundary (Sageev et al, 1985)

The new semi-log type curve can be described in the following procedure (Sageev et al, 1985) :

1. Make a log-log plot the pressure – time response on the same scale as a log-log line source type curve (Theis curve).
2. Match the early time portion of the data. The late time of the data can probably not fit with the curve but it is not important.
3. Find the ratio of the dimensionless pressure by using the pressure match point.
   $$P_D^* = P\,(P_D \text{ match}) / (P \text{ match}) \quad (7)$$
4. Make a semi-log plot of the dimensionless pressure – time response on the same scale as the new type curve. Dimensionless pressure can be obtained by applying equation :
   $$P_D^* = P\,(P_D \text{ match}) / (P \text{ match}) \quad (8)$$
   and dimensionless time can be expressed :
   $$T_D/r_D^2 = \frac{T\ t}{S\ r^2} \quad (9)$$
   Where T = Hydraulic tranmisivity, kh/μ
   S = Storatiyity, ϕch
   Converting time to dimensionless form is not necessary due to plotting time in logarithmic scale (Sageev et al, 1985).
5. Match the data to one of the two curves on the semi-log type curves and pick a pressure match point.
6. Use the semi-log pressure match point to modify pressure equation (superposition) and evaluate the distance between pressure point and the image well.

CONDUCTING THE INTERFERENCE TEST

The first part of the interference test has been done by producing well SBY-5 at constant rate (52 kg/s) as active well and observe the response at well SBY-8. The pressure response was measured at observation well by using surface reading "Pruet Capillary Tubing (0.125 inch) 7000 R series". The second part has been carried out by observing the response at well SBY-7. All of the separated water during the test at approximately constant rate (43 kg/sec) has been injected to the reinjection well SBY-10

Well SBY-5

Well SBY-5 is a representative well to run the test as an active production well. It is the biggest well in Sibayak and can produce 60 ton/hr of steam at optimum separation pressure (10 barg). The well is deviated in N 15 E direction and the kick off point is at 508 meter. Total depth is 2300 m and the vertical depth is 1994 m. Total loss zone occurs from 1977 to 2300 m depth, and the feed zone is at 2150 and 2175 m. The average feed zone is taken at 2165 m depth as the basis of the interference calculation. The well indicates total loss of circulation in drilling. At the shut in condition the water level stayed at 652 m depth and the maximum heating up temperature reached 300°C at 2025 m.

Well SBY-10

Well SBY-10 was proposed as reinjection well due to environmental consideration of disposal separated water. SBY-10 is an active reinjection well in the test. The well is deviated to the N 34 W direction and the kick off point is at 370 m. Total depth is 2192 m and the vertical depth is 2164 m. Drilling data showed that a partial loss occurred from 1629 m to 1767 m and total loss zone was from 1767 m to the total depth. The water loss survey identified the major feed zone at 1750 and 1775 m. The average feed zone is taken at 1765 m depth as the basis of the interfernce calculation. At the shut in condition the water level stayed at 227 m depth and the maximum heating up temperature is 170°C at 1800 m. The slotted liner was set from 1354 to 2114 m and there was 50 m open hole to the total depth. This provides large area which is suitable for reinjection of separated water.

Well SBY-8

Well SBY-8 is the observation well in the first running of the test, it was drilled for production to supply the first 20 MWe Sibayak in the plan of development. The well taps the reservoir from cluster A and is deviated in the N 6 W direction. The kick off point was set at 400 m. Total measured depth is

2102 m and the vertical depth is 1935 m. The well encounter partial loss zone from 1270 m to 1390 m and total loss zone is identified from 1390 m to 2102 m. The water loss survey showed the major feed zone at 1575 to 1600 m. The average feed zone is taken at 1600 m due to the average reservoir temperature of 260°C at this depth. It is as the basis of the interference calculation. At the shut in condition the water level is static at 553 m depth and the maximum heating up temperature is 270°C at 1800 m.

Well SBY-7

Well SBY-8 is the second observation well in the test. It was drilled from the same cluster as well SBY-8. The well taps the reservoir at 2200 m total depth and 2096 m vertical depth. It is also drilled deviated to the N 16 W direction and the kick off point was 650 m. Drilling records indicated that a partial loss zone occurred from 1343 m to 1410 m and total loss zone was identified from 1410 m to the total depth. The major feed zone was identified at 1625 m to 1650 m. The average feed zone, which is as the basic of the interference calculation, is taken at 1625 m due to the average temperature reservoir of 260°C at this depth. At the shut in condition the water level remains at 542 m depth and the maximum heating up temperature is 266°C at 1600 m.

SBY-8 RESPONSE TO SBY-5 DISCHARGE

The interference test has been done from March 29 to June 9, 1999. While discharging well SBY-5, the pressure response was measured at well SBY-8. The pressure chamber was hung at 1581 m depth. Well data during interference test are listed below :

Table 1. Test Specification Data

	Active Well	Observation Well
Well No	SBY-5	SBY-8
Well Direction	N 15 E	N 36 W
Surface Coordinate	444,543mE ; 356,677mN	446,008mE ; 356,608mN
Subsurface Coordinate	444,937mE ; 357,547mN	445,593mE ; 357,185mN
CHF	1468 m asl	1384 m asl
Feed Zone	2150 – 2175	1575 – 1600
Well to F4	369 m	300 m
Interwell Dist.	980 m	
Discharge	52 kg/s	
T Reservoir	260 °C	
Start Time	11.26 am, March 29, 1999	
Drawdown Period	768 hours	
Total Time	1704 hours	

Log-log Analysis

Log-log pressure – time plots of the data match the line source solution (Theis curve). The plots show a good match at the time above 50 hrs. The matching point (*) was taken at :

$P_D = 0.4$ $\Delta P = 10.8$ k Pa

$t_D/r_D^2 = 10$ $\Delta t = 180$ hours

From the matching point permeability thickness and storativity can be calculated by using equation :

$$kh = \frac{P_D W \nu}{2 \pi \Delta P} \quad (10)$$

and :

$$\phi c h = \frac{kh \quad \Delta t}{(t_D/r_D^2) \; \mu \; r^2} \quad (11)$$

$kh = 40.3 \times 10^{-12}$ m^3 $\phi ch = 2.64 \times 10^{-8}$ m/Pa

New Semi-log Type Curve Matching

Semi-log curve can be obtained by plotting new dimensionless pressure (P_D*) – time, the P_D* is generated by applying equation 8.

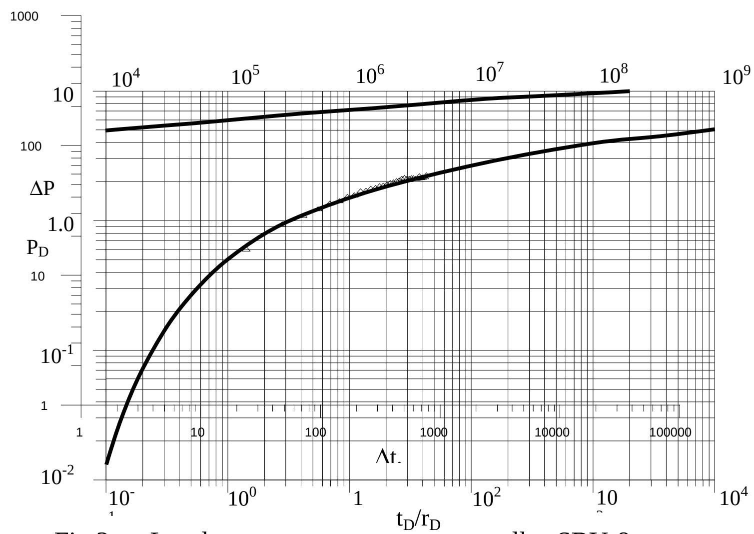

Fig.3. Log-log curve matching well SBY-8 response to well SBY-5 discharge

P_D match equation 10 can be employed. The time can also be converted to dimensionless t_D/r_D^2 by using equation 9.

The matching results of new semi-log to standard new semi-log show an excellent match with line source solution. It reflects no effect of fault on the test response. It will be discussed in the discussion with the results of well SBY-7 response to well SBY-5 discharge.

SBY-7 RESPONSE TO SBY-5 DISCHARGE

The test has been conducted from June 28 to September 1, 1999. It is the second interference test, which was done using the same procedure and equipment as for the first test. Well data during the interference test are listed below :

Table 2. Test Specification Data

	Active Well	Observation Well
Well No	SBY-5	SBY-7
Well Direction	N 15 E	N 36 W
Surface Coordinate	444,543mE ; 356,677mN	446,001mE ; 356,605mN
Subsurface Coordinate	444,937mE ; 357,547mN	446,148mE ; 357,119mN
CHF	1468 m asl	1384 m asl
Feed Zone	2150 – 2175	1625 – 1650
Well to Fault	369 m to F4	213 m to F1
Interwell Dist.	1325 m	
Discharge Rate	52 kg/s	
T Reservoir	260 °C	
Start Time	09.20 am, June 28, 1999	
Drawdown Period	1056 hours	
Total Time	1560 hours	

Log-log Analysis

Plotting log-log pressure – time of the data indicate matching in early time and the curve is shifting down below the line source solution in the middle to late time.

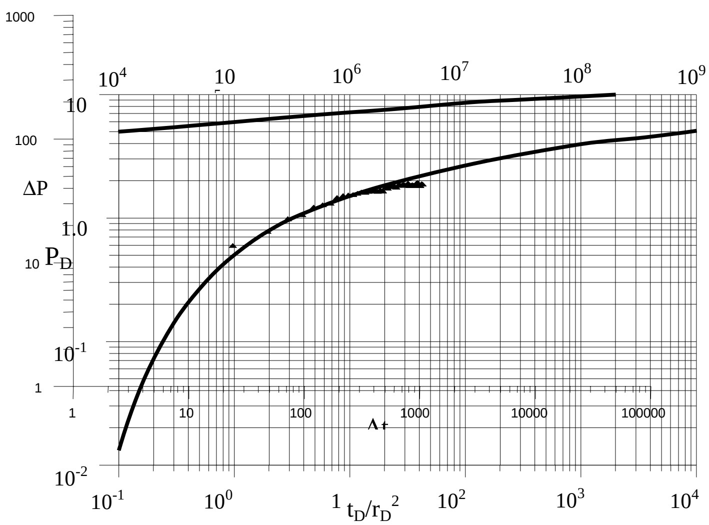

Fig.4. Log-log curve matching well SBY-7 response to well SBY-5 discharge.

The matching point (*) was taken at :

$P_D = 0.2$ $\Delta P = 4.5$ k Pa

$t_D/r_D^2 = 10$ $\Delta t = 170$ hours

From the matching point, permeability thickness and storativity can be calculated by using equation 10 and 11 :

$kh = 48.3 \times 10^{-12}\ m^3$

$\phi ch = 1.63 \times 10^{-8}$ m/Pa

New Semi-log Type Curve Matching

Plotting new dimensionless pressure (P_D*) – time in new semi-log is carried out to identify any shifting and detect the presence of fault. The test was carried out by producing well SBY-5 at constant rate (52 kg/s) and the separated water has been reinjected at constant rate (43 kg/s) at the same time. The distance between production well and observation well is 1325 m. The distances of reinjection well to observation well and fault F4 are 1780 m and 675 m respectively. The P_D is generated by applying equation 4.5. The P_D* is the response of production and reinjection, by applying the principle of superposition, the equation can be derived (Sageev et, al) :

$$P_D^* = P_D + \ln \frac{(2d_{D,P} - 1)}{(2d_{D,R} - 1)} \qquad (5.1)$$

where

$d_{D,P} = r_{P1}/d_{P1}$, $r_{P1} = 1325$ m ; $d_{P1} = 369$ m

$d_{D,R} = r_{R1}/d_{R1}$, $r_{R1} = 1780$ m ; $d_{R1} = 675$ m

Results of the calculation can be plotted as the new semi-log by using same scale as the standard curve. In this test, the time is not converted to dimensionless time due to using logarithmic scale and it does not affect the result.

The new semi-log show excellent match to $r_2/r_1 = 5$ for constant pressure linear boundary curve.

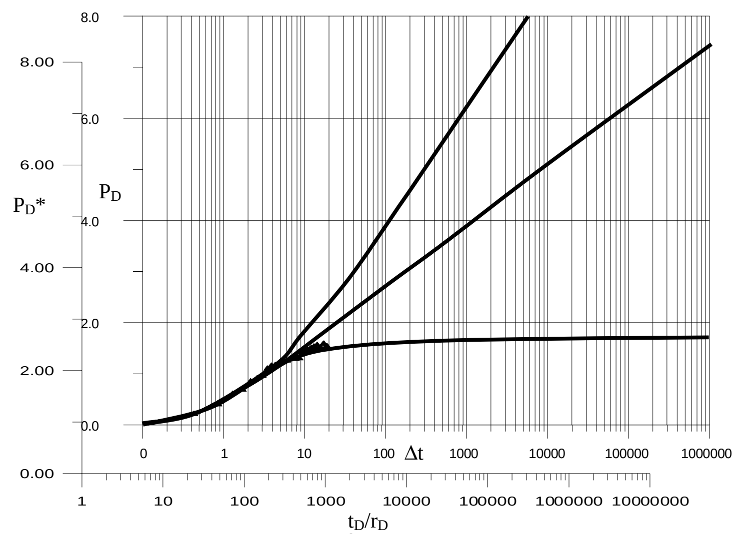

Fig.5. Matching new semi-log on the $r_2/r_1 = 5$ constant pressure linear boundary.

Hence the distance between observation well and production image well is 6625 m, and to the reinjection image well is 8900 m.

DISCUSSION

The first test, which has been conducted by measuring SBY-8 response to SBY-5 discharge, does not show presenting of a fault. It can be explained that

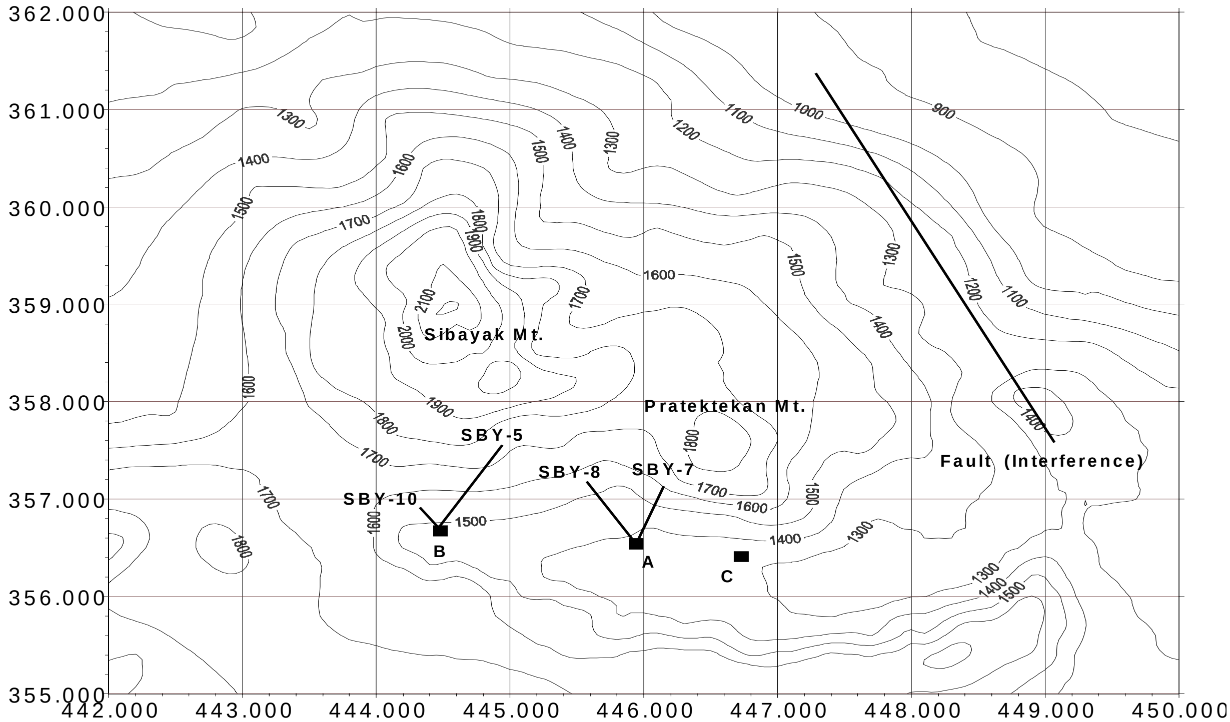

Fig.6. The estimated fault due to the interference test analysis.

the feed-zone of these wells does not encounter the fault. The response follows the line source solution very closely and it is not only shown by a good matching of the log-log plot but also by excellent matching with the new semi-log type curve. It can be deduced that there is no fault between SBY-5 and SBY-8 but those wells encounter the same loss zone of metasedimentary rocks in the difference elevation. It is proved by no return while drilling. It is more likely that the permeability in this area is controlled by secondary permeability. It is formed in one plane of fracture in fault zone's F1.

The second test of well SBY-7 response to SBY-5 discharge indicates a pressure response due to a constant pressure linear boundary. It is shown in a log-log plot matching (Theis curve) and more clearly in the new semi-log. It can be concluded that a fault effects this area. The matching shows the ratio r_2/r_1 = 5 and indicates the image well of the active well distance. The image production well is located at radius 6625 m and the image reinjection well is at radius 8900 m from the observation well (SBY-7). By applying the principle of trigonometry, the position of the active fault in this area can be estimated. The estimated fault affects the area between well SBY-5 and SBY-7, and does not affect the area between SBY-5 and SBY-8. The estimated fault is shown in

The major uncertainty is the difficulty of finding out the exact distances between the wells because all of the wells are deviated. The other error possibilities are :

- incorrect choice of feed zone for the well that has two feed-zones,
- unsuitable choice of average temperature reservoir, due to the different temperature feed zones of the well,
- errors in measuring pressure response eventhough it has been corrected for error in matching the curve.

It would be worthwhile running a simulation program of these interference tests to obtain better matching and develop a representative reservoir model.

The new semi-log curve matching method can determine the presence of a linear boundary from the interference test. In the interference test, the ratio r_2/r_1 may be less than 10 and it can not be developed in semi-log straight line (Sageev et, al, 1985). The other advantages are the dimensionless pressure response characterized by the dimensionless distance between the well and the linear boundary. There is no need to convert to dimensionless time in generating the new semi-log plot.

CONCLUSIONS

1. Interference test can find reservoir characteristics of the area where the active and observation wells are located. For Sibayak geothermal field :
   - the area between SBY-8 and SBY-5, permeability thickness is 40.3 x 10^{-12} m^3 and storativity is 2.64 x 10^{-8} m/Pa,

- the area between SBY-7 and SBY-5, permeability thickness is 48.3 x 10^{-12} m^3 and storativity is 1.63 x 10^{-8} m/Pa.

2. The first result shows that there is no fault in the area between well SBY-5 and Sby-8, and that the permeability in this area is controlled by secondary permeability of fracture. The second result shows that there is an active fault that affects the area between well SBY-5 and SBY-7. This fault could not be located accurately, but is several kilometers to the north-east of the wells.

3. The new semi-log curve matching method is a powerful method for determining the presence of a linear boundary by an interference test.

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