Proc. 6th NZ Geothermal Workshop 1984

ANALYSIS OF INTERFERENCE TESTS FROM THE MALITBOG SECTOR. TONGONAN GEOTHERMAL FIELD, REPUBLIC OF THE PHILIPPINES

Z.F. Sarmiento[1], B.C. Aquino[1] and A.J. Menzies[2]

[1]PNOC-Energy Development Corporation
P.O. Box 1208
Makati, Metro Manila
Republic of the Philippines

[2]KRTA LTD.
P.O. Box 4498
Auckland
New Zealand

ABSTRACT

The major objectives of interference tests are to determine whether two or more wells are in pressure communication (i.e., in the same reservoir) and when communication exists, to provide estimates of the transmissivity (kh) and storativity ($\phi c_t h$) in the vicinity of the wells.

An interference test is conducted by producing or injecting at least one well (the active well) and by monitoring the pressure response in at least one other well (the observation well). The pressure response is then analyzed by comparison with theoritical models to obtain the necessary results.

This paper presents the results of interference tests conducted in the Malitbog sector of the Tongonan geothermal field. The first test results gave a linear pressure response, ihdicative of flow in fractures. The second test results followed. the Theis or radial flow solution.

The results of the tests indicate that very permeable flowpaths exist within the Nalitbog sector, with transmissivities greater than 50 dm and storativity values of 1.5 - 7.5 x 10^{-4} m/kPa.

Figure 1: Location map of Tongonan geothermal field.

INTRODUCTION

Pressure transient tests, both single well and multiple well interference tests, are now routinely used for determining reservoir properties in geothermal systems. The techniques used to analyze the pressure transient data were originally developed for petroleum and groundwater hydrology applications but have now been adapted for geothermal use.

The purposes of pressure transient analysis include:

- determination of the near wellbore condition of the reservoir
- measurement of the transmissivity (kh) of the reservoir
- measurement of the storativity ($\phi c_t h$) of the reservoir

A single well test (pressure drawdown, buildup or fall-off test) can provide all the above information but the calculated transmissivity and storativity values are only applicable to the area of the reservoir affected by the test. In a multiple well interference test the pressure response caused by a step rate change in flow (either production or injection) at one well is recorded in one or more observation wells. Hence, the area of the reservoir affected by the test is increased and areal average transnissivity and storativity values between well pairs can be measured.

The purpose of this paper is to present the results of two multiple well interference tests conducted in the Malitbog sector of the Tongonan geothermal field, Republic of the Philippines. A comparison is also made with die results of single well pressure transient tests. The data has previously been presented in Sarmiento and Aquino (1984).

Atmospheric Pressure and Earth Tidal Effects

The recorded pressure response may not only be due to the effect of the step change in the active well. Atmospheric pressure changes and earth tides can also affect the pressure response, Hanson (1980). It is therefore advisable to record the atmospheric and downhole pressure before the interference test begins to find the correlation between the two. The ratio of the change in downhole pressure to the change in atmospheric pressure is defined as the "barometric efficiency (BE)" and this is used to remove the atmospheric response from the interference data.

Earth tidal effects can also cause changes in the measured downhole pressure. The tidal accelerations can be computed using the formulas of Longman (1959) and the cyclic response can be compared graphically with the measured downhole pressure data. The pressure perturbation induced by the earth tides is expected to be approximately 1 kPa and is therefore unlikely to be signiflcant in the analysis of the interference data.

Instrumentation

The pressure response in an observation well is generally much smaller than that measured during a single well test. It is therefore necessarv to use very sensitive pressure measuring equipment. This equipment has recently become available to the PNOC - Energy Development Corporation through the UNDP.

The equipment, which has been supplied by Pruett Industries. includes:

- capillary tubing for transmitting the downhole pressure signal to the surface

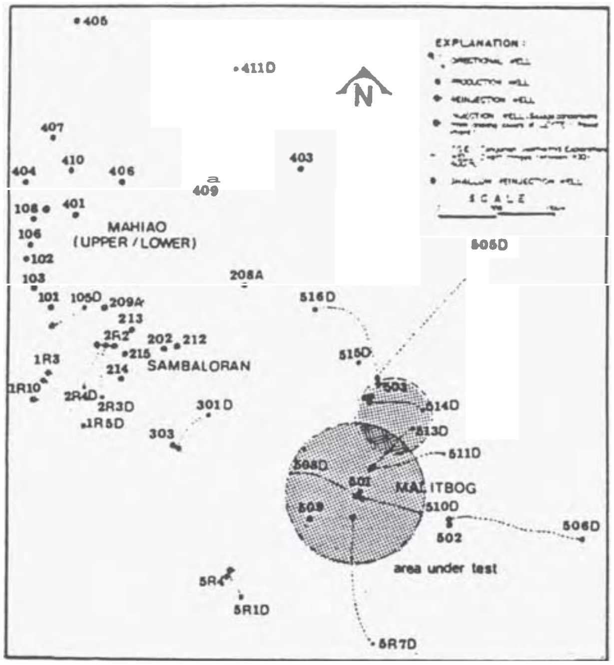

Figure 2: Well locations in the Tongonan geothermal field

"quartz crystal liquid filled pressure transducers which produce an electrical signal proportional to the measured pressure. The accuracy of the transducers is ± 0.07 kPa (0.01 psi).

"surface equipment comprising a programmable computer readout unit coupled to a programmable printer. Up to eight wells can be monitored simultaneously.

With this equipment it is possible to continously monitor the changes in the observation well pressures.

RESERVOIR DESCRIPTION

The Tongonan geothermal field is situated on the island of Leyte in the Republic of the Philippines (Figure 1). Exploration of the field began in 1973 with geophysical resistivity surveying and the drilling of 11 temperature gradient wells. In October 1976 the first deep well (Well 401) was completed in the Mahiao sector to 1940m and encountered a maximum temperature of 314°C.

Since 1976 exploration and development drilling have occurred in the Sambaloran, Malitbog and Mahanagdong sectors in addition to the Mahiao (Figure 2). With more than 50 deep wells now completed, the potential of the Tongonan resource is estimated to be approximately 700 MW. The maximum temperature encountered to date is 329°C in well 410 located in the Mahiao sector.

Large scale development of the resource started with the commissioning of the Tongonan I power station (installed capacity of 112.5 MW) in July 1983. The steam for the power station is supplied from the Sambaloran and lower Mahiao sectors. It is envisaged that three further power plants will be constructed in the Malitbog, Mahanagdong and Upper Mahiao sectors of the resource; bringing the total installed capacity to approximately 440 MW.

The Malitbog sector of the Tongonan resource has been designated as the site for the second stage development of 112.5 MW. Temperatures encountered in this sector are generally lower than in the Mahiao or Sambaloran sectors, possibly due to cool meteoric water percolating down faults or fractures. Geochemical data (Lovelock, Cope and Baltasar, *1982)* also suggests that the fluid is more dilute than in the Mahiao or Sambaloran sectors. The lower temperatures have also meant that the two phase zone encountered in the upper levels of the Mahiao and Sambaloran sectors does not appear to exist in the Malitbog.

Structural Setting and Subsurface Geology
(Leach, Wood and Reyes, 1983)

The geology of the island of Leyte is dominated by the andesitic mountain chain associated with the major northwest trending, strike-slip sinistral Philippine fault. Up to 30 km lateral movement has been estimated to occur along the Philippine fault while offset of intrusives and sediments within the Tongonan region indicate over 1000 m of vertical movement. It is postulated that this vertical movement is due to continuous volcanism, uplift, faulting (both lateral and vertical) and erosion since late Miocene/ Pliocene).

Differential movement along branches of the Philippine Fault has formed a large rhombo-chasm in the Tongonan–Burauen region. The geothermal system at Tongonan appears to be concentrated within the eastern and central, branches where numerous splinter faults have been identified.

The subsurface geology consists basically of 1200-*2600* m of andesitic flows, breccias and tuffs (the Bao volcanics) underlain by a variety of intrusives, grouped together as the Mahiao Instrusive Plutonic Complex. The Plutonic Complex is encountered at 800-1500 m below sea level. Between the two, the contact zone is encountered comprising numerous porphyritic microdiorite apophyces and volcanics (possible roof pendants). This zone occurs within 200-300 m of the Plutonic Complex. The contact zone and the splinter faults appear to be the major sources of permeability within the field.

TEST DESCRIPTION AND RESULTS

Test 1 (501/508D/510D)

Well 501 was the first well drilled in the Malitbog sector and was completed to a depth of 1665 m in April 1978. The well encountered a maximum temperature of 285°C and produces 114 kg/s of steam and water at fullbore discharge.

Wells 508D and 510D are both deviated wellsdrilled from the same pad as well 501. They were completed to 2534 m VD and 2477 m VD respectively, with both having a maximum temperature of 280°C. All three wells encountered permeability in the contact zone.

The objectives of the interference test were to assess the transmissivity and storativity within the Malitbog sector. *As* all three wells had encountered permeability within the contact zone, it was expected that this would be the major permeable connection between the three wells.

The capillary tubing was installed in wells 508D and 510D to an equivalent vertical depth of 1078 m on 23 July 1983 and the static downhole pressures and atmospheric pressure were monitored for about a day before well 501 was discharged. The pressures measured in well 510D were found to show some correlation with the measured atmospheric pressures but this was not the case for well 508D. The data, however, were not sufficient for the calculation of barometric efficiency; hence it is not possible to correct the downhole data collected during the interference test for the effect of atmospheric pressure.

Well 501 was discharged 1100 hrs, 25 July 1983, with the downhole pressures in wells 508D and 510D being monitored at five minute intervals. The wells were monitored for 26½ days (637 hours) and the tubing was then removed. The tubing was reinstalled on 17 September 1983 to monitor the pressure response when well 501 was shut-in on 26 September 1983.

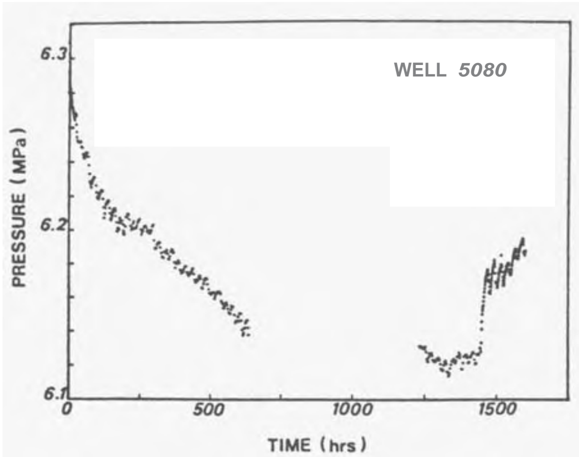

Figure 3: Interference data from well 508D

Results and Discussion

a) Pressure Drawdown

The data from wells 508D and 510D are plotted on Cartesian coordinates in Figures 3 and 4. The pressure response for the first 637 hours are very similar for both wells, with an initial sharp decrease in pressure followed by a linear decrease in pressure'. With time. The linear change in pressure with time is characteristic of pseudo-steady state, indicating that flow is coming from a closed system.

The data were also plotted on log-log coordinates (Figures 5 and 6) for type curve matching with theoritical curves. Both sets of data have an initial slope of approximately one half; a characteristic of linear flow which is normally associated with flow in fractures. Gringarten and Witherspoon (1972) mention that this type of response will only occur when the active and observation wells are completed in the same fracture. The similar pressure response in both wells 508D and 510D further suggest that all three wells are completed in the same fracture.

The data are matched with the uniform-flux fracture solution in Figure 5 and 6. The theoritical curve used is not strictly applicable to interference testing but is very similar to the solution presented in Gringarten and Witherspoon (1972).

In both cases, the experimental data match the theoritical curve up to approximately 370 hours and then appear to deviate above the theoritical curve. The deviation above the curve is characteristic of a closed boundary. As mentioned earlier, the Cartesian plots also appear to indicate the presence of a closed system.

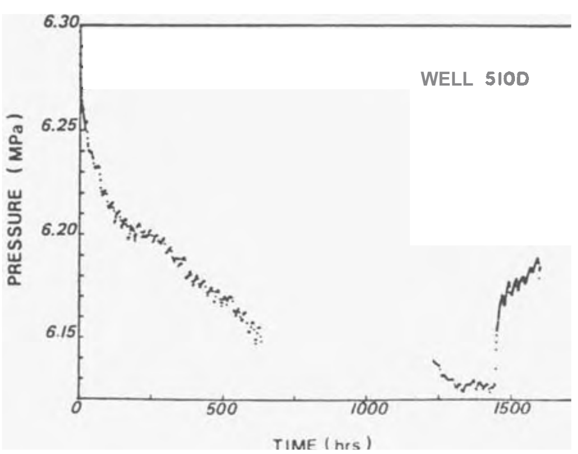

Figure 4: Interference data from well 510D

From the type curve matching it is possible to obtain the transmissivity from the pressure match and the storativity from the time match. The results are compared with the parameters obtained from single well tests and the buildup data in Table 1.

The transmissivity values obtained from the interference test are in good agreement for bothobservation wells, with an average value of 50 dm. This is also in good agreement with the pressure buildup result from well 501. The results from single well tests conducted in wells 508D and 510D range from 4.6-19 dm; in contrast to the interference test results. Grant (1980) found similar permeability contrasts in tests conducted in Broadlands and concluded that the "interference kh" is the permeability of the large scale fracture network while each well may intersect some smaller fracture and its performance would reflect this. The calculated transmissivity value of 50 dm indicates that the fracture network has very good permeability.

The calculated storativity of $4\text{-}8 \times 10^{-4}$ m/kPa gives a porosity-thickness (ϕh) of 200-400 m assuming a compressibility for water at 280°C of 2×10^{-6} kPa^{-1}.

The capillary tubing was reinstalled in wells 508D and 510D on 17 September 1983 and the drawdown in pressure monitored until well 501 was shut-in, 26 September 1983. The measured pressures are included in Figures 3 and 4. The pressures are not consistent with the earlier drawdown data, although the initial slope appears to be similar. The major difference is the indication of a constant pressure boundary near the end of the test. It is possible that this could be due to changes in other nearby wells. The well

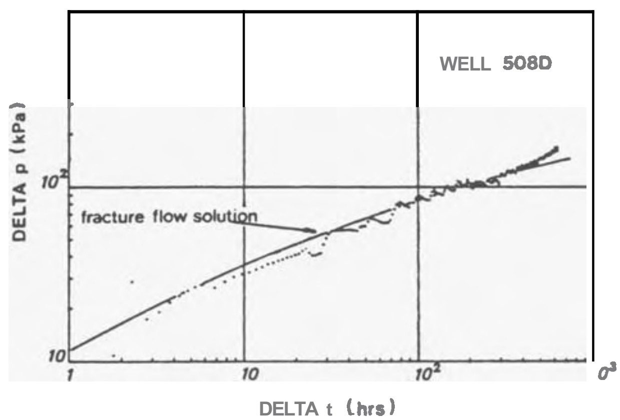

Figure 5: Log-log plot and type curve match for well 508D

which might be expected to affect the response is well 301D, as it may intersect the same linear feature which caused the pressure response in wells 508D and 510D.

b) Pressure buildup

Well 501 was shut-In 26 September 1983 and the subsequent pressure buildup was recorded in both wells 508D and 510D. The data have been plotted on log-log coordinates in Figures 7 and 8. The pressure response does not have the initial slope of one half noted in the drawdown data but apoears to match the Theis or radial flow solution. This may indicate that the flow period had been of sufficient duration to reach the pseudo-radial flow regime and hence the pressure recovery is initially controlled by radial influx.

The transmissivity and storativity are calculated from the pressure and time match respectively and the results are included in Table 1.

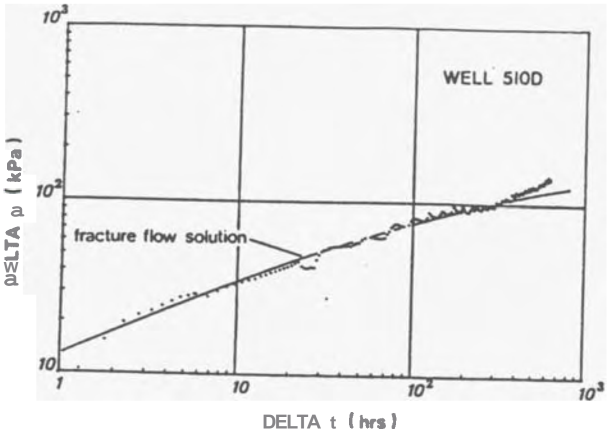

Figure 6: Log–log plot and type curve match for well 510D

Table 1: Interference Test Results (501/508D/510D)

Well	Transmissivity (dm)				Storativity ($\times 10^{4}$ m/kPa)	
	1	2	3	4	1	2
501	-	-	-	50	-	-
508D	46	146	19	14	4.2	2.1
510D	55	146	5.5	4.6	7.5	4.3

1 - interference test (drawdown)
2 - interference test (buildup)
3 - pressure falloff test
4 - pressure buildup test

The calculated transmissivity values are higher than those calculated from the drawdown data. The reasons for this are not clear although the results do confirm the high permeability connection Setween the wells. The calculated storativities are of the same order of magnitudeanthe drawdown results and are similar to the values obtained by Grant (1980) for Broadlands. The calculated porosity thickness of

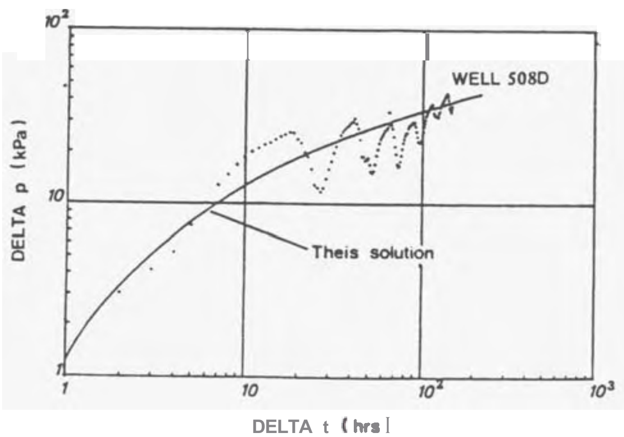

Figure 7: Log–log plot and type curve match for buildup data from well 508D

100–400 m appears to be high but unlike Broadlands it cannot be explained by the presence of two phasefluid. Hence it may indicate a highly fractured formation with good porosity.

Test 2 (513/516D–503/514D)

The second interference test was conducted to assess the transmissivity and storativity in the northern area of the Malitbog sector. During the test. wells 513D and 516D were discharged with average massflow rates of 96 kg/s and 29 kg/s respectively. Enthalpy measurements suggested both wells were producing from a single phase source at 280–290°C.

The observation wells used during the test were wells 503 and 514D. Both wells encountered temperatures greater than 300°C, although measured discharge enthalpies suggested an average resource temperature of 285°C.

The major permeable zones encountered appear to be due to the contact zone in well 503, the East Philippine Fault (EPF) in wells 514D and 516D and both the contact zone and the EPF in well 513D, Leach (1984).

The capillary tubing was installed in well 503 and 514D to 445 m and 396 m respectively on 15 December 1983. The downhole and atmospheric pressures were monitored for about three days before well 513D was discharged on 18 December 1983. There appeared to be a good correlation between the downhole and atmospheric pressure readings but the data collected during the interference test were not corrected as the atmospheric response was found to have little effect on the calculation of transmissivity or storativity.

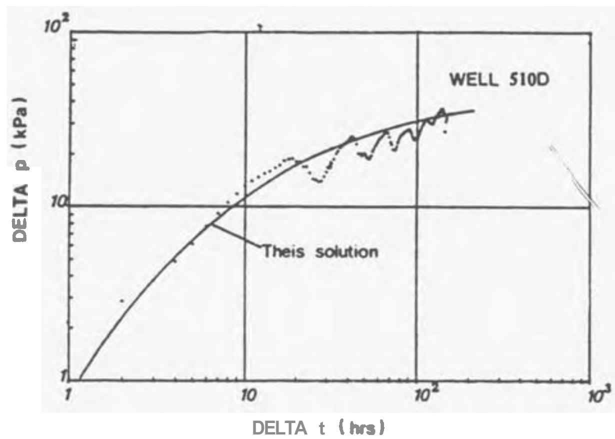

Figure 8: Log–log plot and type curve match for buildup data from well 510D

Well 513D was discharged at 1600 hrs 18 December 1983 with the downhole pressures in wells 503 and 514D monitored at five minute intervals. The test continued with well 513D on discharge until 1448hrs 28 December 1983 when well 516D was discharged. The discharge of well 516D did not appear to affect the pressure response in either observation well (Figure 9), although it is possible that any response may have been masked by the shutting of well 513D at 0920 hrs, 29 December 1983. Due to the possibility that both active wells may have affected the pressure response after 28 December 1983, it was decided to only analyze the data from 18–28 December 1983 at this stage.

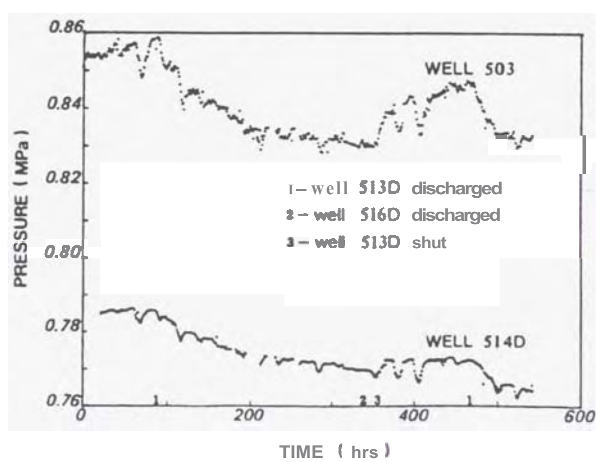

Figure 9: Interference data from wells 503 and 514D

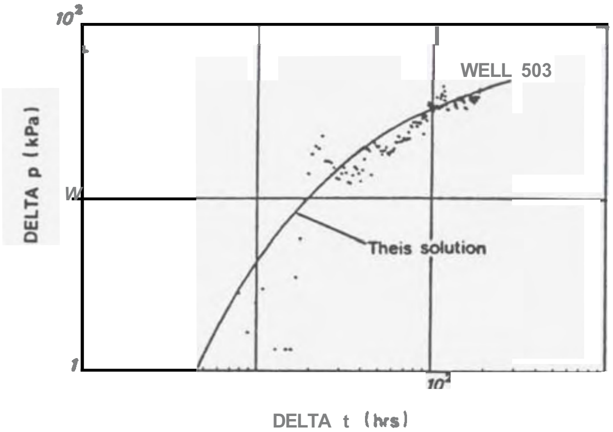

Figure 10: Log-log plot and type curve match for well 503

Results and Discussion

The data from wells 503 and 514D are plotted on log-log coordinates in Figures 10 and 11 for type curve matching. It was found that the data were consistent with the Theis or radial flow solution, in contrast to the fracture solution used to analyze the drawdown data in the 501/508D/510D test.

The calculated results for transmissivity and storativity are compared with the parameters obtained from single well tests in Table 2.

Table 2: Interference Test Results (513D/516D/-503/514D)

Well	Transmissivity (dm) 1	2	3	Storativity (x 10^{4} m/kPa) 1
503	60	4.2	-	3.7
513D	-	VP	VP	-
514D	80	4.8	-	1.5-6.0
516D	-	1.4	0.4	-

1 - interference test (drawdown)
2 - pressure falloff test
3 - pressure buildup test
VP - very permeable

The results give an average interference kh of 70 dm, indicating that the fracture network has very good permeability. This again contrasts strongly with the results from single well tests which suggest a transmissivity of 4-5 dm for the observation wells.

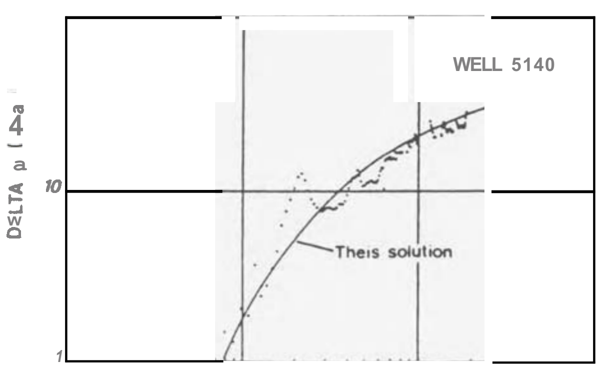

Figure 11: Log-log plot and type curve match for well 514D.

The low transmissivity of 0.4 -1.4 dm for well 516D should also be noted as this may explain the lack of response in the observation wells to its discharge.

The calculated storativity values are similar to the 501/508D/510D test results, suggesting a porosity-thickness of 75-300 m. The range in the results for well 514D reflects the uncertainty in the distance between the permeable zones in wells 513D and 514D. However, the high values for porosity thickness again suggest a highly fractured reservoir.

CONCLUSIONS

The data presented here indicate that with the present capillary tubing and surface equipment it is possible to conduct successful interference tests and to analyze the results with relatively simple theoretical models. The results indicate that the Malitbog sector of the Tongonan geothermal field is highly fractured. This conclusion is based on the calculated transmissivities which indicate that the fracture network is highly permeable and the high values of storativity.

ACKNOWLEDGEMENT

The authors wish to thank the management of the Philippine National Oil Company - Energy Development Corporation (Geothermal Division) for permission to publish this paper.

REFERENCES

Grant, M.A.: Broadlands geothermal field. Interference tests at BR13, 19 and 23. Applied Mathematics Division, DSIR, New Zealand, Report No. 98 (July 1980)

Gringarten, A.C. and Witherspoon, P.A.: A method of analyzing pump test data from fractured aquifers. Proceedings, Symposium on Percolation through Fissured Rock, International Society for Rock Mechanics, Stuttgart (September 18-19, 1972)

Hanson, J.M.: Reservoir response to tidal and barometric effects. Transactions Geothermal Resources Council Annual Meeting, Volume 4 (September 1980)

Leach, T.M. : personal communication (1984)

Leach, T.M., Wood, C.P. and Reyes, A.G.: Geology and hydrothermal alteration of the Tongonan geothermal field, Leyte, Republic of the Philippines. Proceedings, Fourth International Water-Rock Interaction Conference (1983)

Longman, I.M.: Formulas for computing the tidal accelerations due to the moon and the sun. Journal of Geophysical Research, 64(12), (1959)

Lovelock, B.G., Cope, D.M. and Baltasar, A.J.: A hydrogeochemical model of the Tongonan geothermal field. Proceedings, Pacific Geothermal Conference, Auckland, New Zealand (1982)

Sarmiento, Z.F. and Aquino, B.G.: Results of Interference Tests at Tongonan Geothermal Field. Philippine National Oil Company - Energy Development Corporation (Geothermal Division) Internal Report (June 1984)