PROCEEDINGS, Twenty-Fourth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 25-27, 1999
SGP-TR-162

Shallow level sub surface characters of Tatapani Geothermal field, India.

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ABSTRACT

Tatapani is the most promising geothermal field located on Son-Narmada lineament in Central India. Two types of litho units comprising Proterozoic basement rocks viz. granite gneiss, biotite gneiss, phyllite, and Lower Gondwana group consisting of sandstone , shale are exposed in this area. Fractures in Proterozoic rocks control the permeability of the reservoir.

Reservoir temperature of 180-190 °C is indicated by Na/K and 160°C by quartz geo thermometer, respectively. GSI has completed 5 production wells, upto depth of 350m, to exploit thermal water @ 1800 lpm of 100°C on the surface. Down hole well testing was completed by GSI-ONGC to decipher the sub -surface characters of shallow reservoir . The data from the well testing are discussed here.

The well testing observations suggest maximum temperature of 112.5 °C in the borewell. The temperature profile shows gradual increase in temperature with depth but slight inversion in temperature is reported below the depth of 300m, indicating cold water incursion . The pressure ranges from 4-5 kg/cm^2 at well head to 34 kg / cm^2 at the depth of 350m. The pressure gradient is uniform and slightly more than the hydro static pressure. Permeable zones are interpreted around the depth of 110-150m, 175 to 275m and > 300m. Major thermal water feed zone is at 200m while the cold water incursion occurs at >300m and at shallow level. The interference tests show interconnection of borewell Tat/23 with Tat/6 and 24, though perceptible effect is not noticed on the discharge of these borewells on each other. The thermal profiles indicate convective flow at the depth of 175m and below. The P and T data indicate single phase liquid dominated reservoir. The well testing results are encouraging for further exploration work.

1. INTRODUCTION

Geothermal studies of hot spring area were initiated in Central and Northern India, by GSI, as a part of National Non-Conventional Energy Program. Five production wells GW/Tat/6, and 23 to 26 were drilled at Tatapani field (fig. 1). Feasibility studies to establish the thermal potential of upper 350m part of geothermal reservoir capable of sustaining power generation of 300 Kwe, were taken up in 1989-90, at Tatapani, by GSI in association with ONGC. GSI-ONGC completed the well testing of the borewells in February ’93 and March’95. This paper enumerates the data generated during the studies.

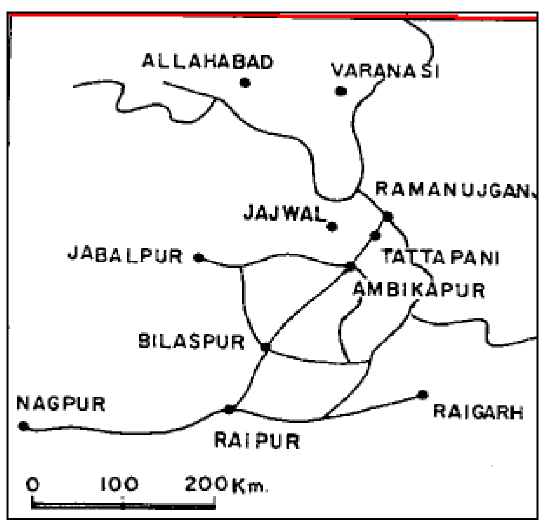

Fig.1, Location Map.

The shape of temperature -depth curve provides valuable information on the ground water flow regime around the drill holes and therefore, on the physical model best suited to describe the local thermal regime and the process that has generated it (Pfister & Rybach, 1995).

2. GEOLOGY -

Two different litho types , Proterozoic and Gondwana Super group of rocks are exposed in the area. Gondwana rocks exposed NW of Tatapani are known as Tatapani -Ramkola coalfield. Proterozoic rocks are exposed south of the Tatapani fault which marks contact with the Gondwana rocks. The proterozoic basement rocks comprise granitic gneiss, grey biotite gneiss, bands of phyllite and quartzite. All the rocks show effects of shearing near the main Tatapani fault. The borehole cores show profuse fracturing at 30°,40°, 60° and 70° (Pitale et al 1995) to the horizontal.

3. BOREWELL TESTING -

Down hole testing of the borewells was conducted in collaboration with the ONGC, in Feb’93 and March’95. The well testing was conducted by the Kuster guage. The T and P profiles represent the nearest approximation as the base line of the chart gave faint impression. The observations of the well testing are comparable to the results obtained during the well testing of Tat/6 and 23, in Jan’93. The borewells are drilled vertically. The drilling started with 168 mm at well head, reduced to NX size at the depth of around 70m. The NX casing is put in borewells Tat/6,23 and 24 upto 110m depth . The borewells Tat/25 and 26, have casing upto 237 and 190 m, respectively. The production zone is without any casing with borehole diameter of 86 mm. Caving is the major problem in these borewells, causing blockage of the wells. Scaling is not observed in the discharge pipes /valves except the deposition of $CaCO_3$ in the reducer pipe of Tat/6.

Following parameters were measured in the well testing -

a. Static and flowing well Temperature (T) and Pressure (P) profile.
b. Cold water injection T and P profile
c. Interference test.

3.1 **Borewell GW/Tat/6 -**

GW/Tat/6 borewell is the oldest well drilled in this field upto the depth of 506 m, but presently it is clear upto 320m . The thermal logging of

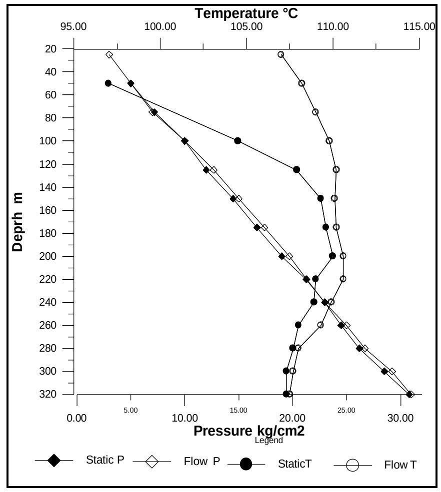

Fig.2, P and T profile of borewell Tat/ 6

the static borewell records T of 97°C at 50m, 100°C at 70m, and peak of 110°C at 170-200m depth (fig. 2). The zone 170-320m represents zone of convective flow. The temperature decreases slowly to 107°C at the bottom as observed in static and flowing well conditions, indicating incursion of cold water in the borewell. The static and flowing pressure profiles are almost similar measuring 4 kg/cm2 at well head to 32 kg/cm2 at the bottom. The flowing pressure profile shows marginally less pressure than the static pressure profile indicating interconnected fractures. The borewell is consistent in discharge and attains full discharge within 10 minutes from the opening of the valve. The borewell attains normal discharge 3.5 hours after the cold water injection test. Fracture zones are observed at 100-120m, 200-220m and 300-320m depth. Discharge is 270-300 lpm.

3.2 **Borewell GW/Tat/23-**

This borewell is drilled upto 353m,and is clear till bottom. The well has free flow of 270-300 lpm, of 100°C on the surface. Static pressure in the borewell is 4 kg/Cm2 at well head , to 34 kg/ cm^2 at 350m depth (Fig. 3). Flowing well P also shows similar trend. Static well T profile recorded 97°C at well head rising to 100°C at 50m, and 110°C at 110m depth. Maximum T of 112,5°C was recorded at 275m depth below which temperature inversion is noticed. The flowing well T fluctuates within narrow range of 110°C at well head to 112.5°C at 275m further declining to 110°C at the bottom . The T profile is recorded 0.5 °C less during the interference

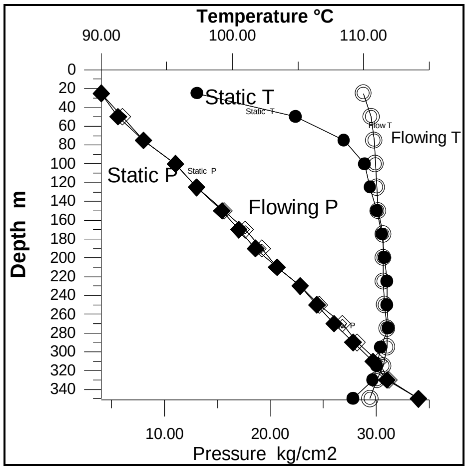

Fig.3, P and T profile of borewell Tat/ 23

test, suggesting interconnection of the borewells and possible heat loss due to the conductive cooling. Cold water injection test reveals that the thermal profile has gentle slope upto 175m depth and has conductive profile . The temperature shoots up to 97 ° C at 200m and 110°C at 320m depth due to convective circulation (fig.7). The main thermal water feeder zone is at 300-320m, 275m and 175-200 m depth. The permeable zone below 325m causes cold water inflow . The interference test with Tat/24 does not show any effect on discharge parameters.

3.3 GW/Tat/24

The borewell was drilled up to 244.6m depth below which caving curtailed the drilling activity. The well testing could be completed up to 175m only due to obstruction below this depth. Casing is put up to 110m depth (fig. 4). The static borewell P rises from 4 kg/cm^2 at well head to 18 kg/cm^2 at 175m depth, which is slightly more than the hydrostatic gradient. The static T profile rises from 104 °C at 50 m to 110.5 °C at 175m, corresponding to convective cycle. The main feeder zone could not be encountered due to shallow depth of testing. Discharge of this borewell varies from 435 to 470 lpm. Caving zone is noticed around 115m, 151m and 180m depth.

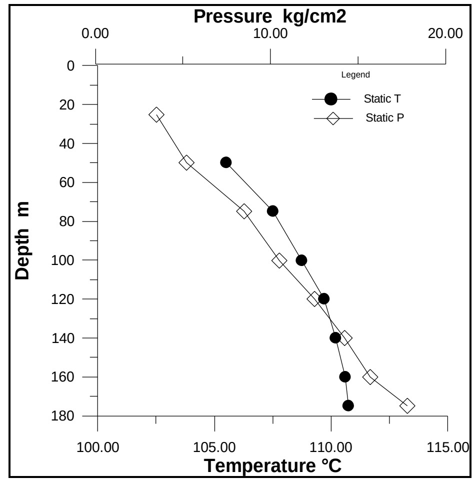

Fig.4, P and T profile of borewell Tat/24.

3.4. GW/Tat/25 -

The borewell is drilled up to 350m depth. The discharge of this borewell is recorded around 300 lpm. A major caving zone is encountered at235-240m,restricting the accessibility for the well testing. The P profile indicates 4 kg/cm^2

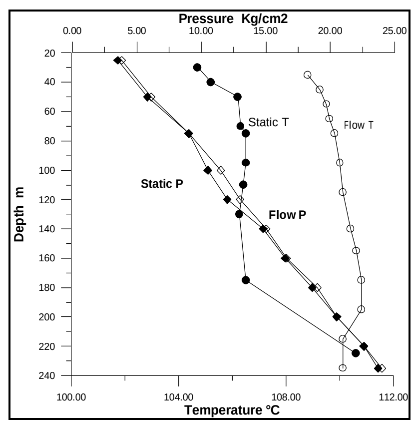

Fig.5, P and T profile of borewell Tat/25.

at the well head and 24 kg/cm ^{2} the depth of 235m, respectively (Fig. 5). The static and flowing well profiles are almost similar. The static T shows 104°C at 25m which rises to 106° C at 70 m . The temperature spurts to 110.5°C at 210m. The flowing well T profile show rise in T from 108.5° C at well head to 110.5°C at 170-190m. The flowing T profile indicates feeder zone at 175-200m , depth. Minor cold water influx is noticed at <60m, 130 and 235m depth. The 235m zone is also a major fracture zone. The Injection testing of the borewell reveals steady rise in T from 55°C at surface to 92°C around 200m depth, suggesting a major thermal water recharge zone at this depth (fig. 8).

3.5 Borewell GW/Tat/26

This borewell was drilled up to 239m depth . A major caving /fracture zone was encountered around 165m depth hence the borehole was diverted at 164m. It again encountered a major cavity / breccia zone at 209 and 219m depth. The well testing was completed up to 210 m depth only. The static borehole P of 4 kg/cm^2 was recorded at well head and 21 kg/cm^2 at the210 m (fig.6). The flowing well P is slightly less than static well P. The static T profile recorded T of 99 °C at 55m, and 102 ° C at 110m depth. Maximum T of 110.5°C was recorded at 210 m depth. The main recharge

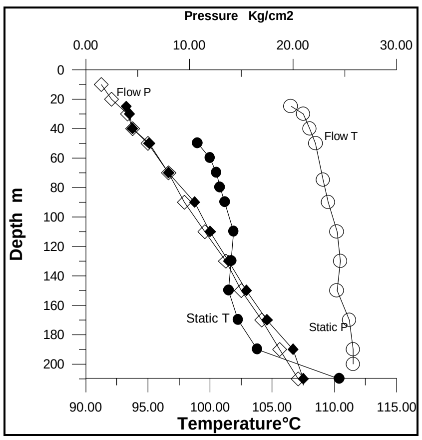

Fig.6.P and T profile of borewell Tat/26

zone is inferred at 190-210m and 110-150m depth. The zone 70-190m may be a zone of convective cooling. The T profile indicates conductive cooling and inflow of ground water above 90m depth. The fracture zone 170-210m depth may be a zone of convection acting as a feeder zone. The borewell has discharge of 455 to 510 lpm.

4. COLD WATER INJECTION TEST-

Cold water injection test was conducted to study the T profile during injection and recovery of the wells. The resultant P and T profile was studied to decipher the zones of hot water recharge.

4.1 **GW/Tat/23-**

The thermal profile is conductive cooling profile. The permeability in upper part of the borewell is less . Major permeable zones are encountered at 200m, 250m, and 280-300m and below. The injection and buildup profiles are almost similar (fig. 7).

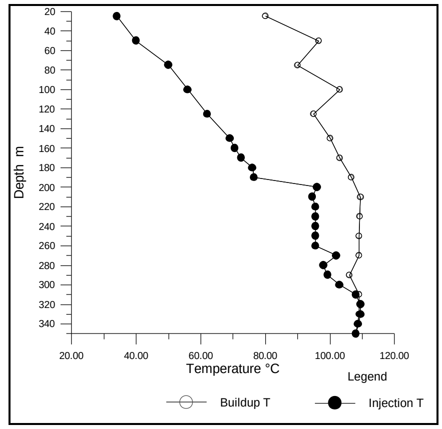

Fig.7, Injection profile of borewell Tat/23.

4.2 **GW/Tat/25**

The T profile indicates convection zone from 90-170m depth. The good permeable zone is encountered at 60-160 m depth and below 200 m, indicating a fracture zone here. Zone of good permeability is also encountered at 200m and below. This may be zone of convection (fig. 8).

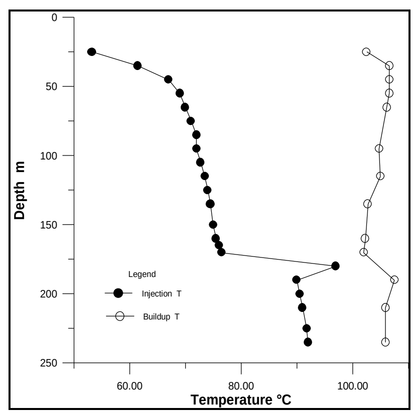

Fig.8, Injection profile of borewell Tat/25.

4.3 GW/Tat/26-

The borewell has permeable zones from 30-50m, with zone of convection from 90-170m. A zone of good permeability (caused due to solution cavity) was recorded at >200 m, also. The T profile during build up is almost vertical suggesting convective flow (Fig.9) and recharge zone.

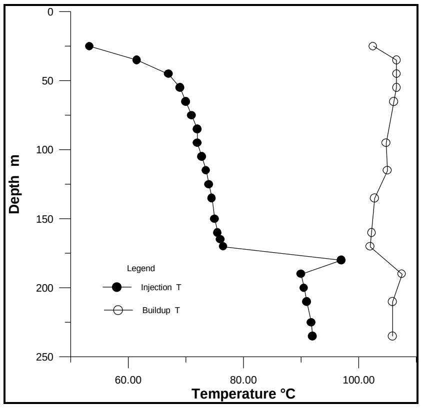

Fig.9, Injection profile of borewell Tat/26.

When heat transfer is controlled by conduction , a slope of constant profile is observed. When it is controlled by convection , vertical or inverted profile is observed. Convection occurs when a permeable zone with fluid is intersected. (Drury1982).

As inferred from the shape of temperature - depth curve , the inter zonal flow and mixing of fluids (caused by drilling) in the borehole , have made it impossible to determine sub-surface temperatures(Combs & Govanson 1995).

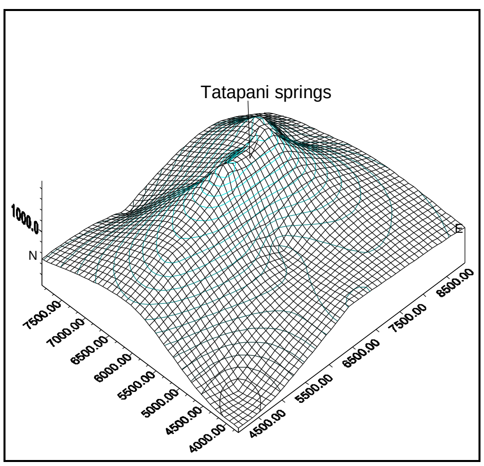

Fig.10,SubsurfaceThermal reservoir at Tatapani.

5. THERMAL GRADIENT

The other borewells in this field have measured thermal gradient more than twice the normal. The heat flow from this field is reported to be 219$\pm$ 85 mW/m^2 (Ravishankar 1988). Based on the simple extrapolation of the thermal gradient measured in the borewells, the subsurface configuration of the hot rock reservoir upto the depth of 1.5 km, covering 100°C isotherm is shown in fig. 10 . The sub surface configuration shows dome shaped reservoir with gentle slope away from the Tatapani area. The reservoir is noticed at shallow depth near the borewells. The volume of the reservoir upto the depth of 1.5 km. is calculated to be 6.92E9 m$^{3.}$ Assuming the effluent temperature of 86°C (112-86°C) for the binary cycle plant, the thermal energy in liquid may sustain production of 10.9 Mwe electricity for 20 years, at the efficiency of 10%.

Dither bitmap of the Tatapani area, based on isotherms is presented in fig. 11. The high temperature zones are aligned in NNE to NE trend in this map, suggesting linear extent of the Tatapani geothermal field towards east.

6. PERMEABILITY

The permeability in sandstone is controlled by porosity**.** The Talchir shale is an impermeable horizon acting as a cap rock. As the reservoir rocks are Proterozoic granites and gneisses , the permeability is mainly controlled by fracture pattern. The borehole cores show profuse fracturing at 30°,40°, 60° and 70° (Pitale et al 1995) to the horizontal.

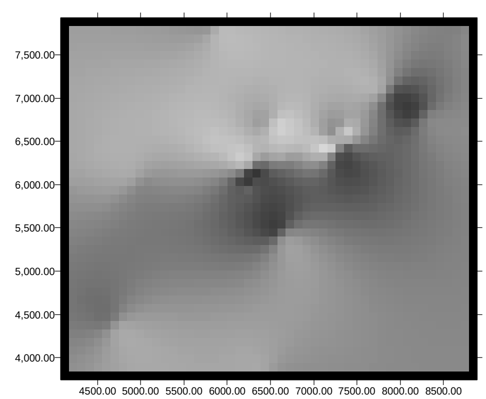

Fig.11, Thermal activity zone at Tatapani.

Besides fractures there is profuse development of solution cavities e.g. GW/Tat/25 and 26, which helps in improving the permeability. The reservoir is explored to the maximum depth of 350m, which produces 1800 lpm of thermal water. The fractures are mostly thin and are occasionally filled in with secondary silica or platy calcite. The fracture zones are <10 m wide, but mostly inter connected, facilitating free flow of hot water within the borewells.

Veins are produced by filling up open fractures with hydrothermal minerals and the consequent blockage of the fracture (Tateno et al 1995). This causes reduction in permeability and subsequent increase in T of the rock. Considering the cold water incursion at the depth of 320 m level, there is possibility that the deep reservoir is located below , as reported in the Kakkonda geothermal field by Tateno (1995). This observation is supported Joga Rao (1987)who postulated low resistivity zones at the depths of about 300m to 600m, based on the Schlumberger soundings.

7. CONCLUSION -

The well testing data indicate that the reservoir is located at the depth of 70m and below in Proterozoic rocks. The geothermal area has depth persistence and extends in NNE to NE direction.

The maximum temperature recorded in the borehole is 112.°C at the depth of 200m. The temperature profile indicates conductive cooling near surface while at the depth of 175 to 275 m , it represents zone of convection. The fracture zones are interpreted at 120-150,175-200m, 250-300m and below 300m. The T profiles suggest zone of hot water influx at 150m and 250-275m, while cold water incursion is inferred at the depth of >300m. Thus the bore wells represent multi zone low permeability reservoir. The permeability is fracture controlled. The P profile shows progressive increase in the P with depth, corresponding to hydrostatic pressure. In spite of the high pressure the temperature in the borewells is less than the temperature of saturated steam indicating that the reservoir is single phase liquid dominated, possibly with considerable dilution by cold ground water.

The potential of 10.9 Mwe Binary cycle electricity generation is estimated upto the depth of 1.5 km., for a period of 20 years, at the effluent temperature of 87°C. The well testing results are encouraging for undertaking further exploration program.

Acknowledgements -

The authors are thankful to Dr. S. K. Acharyya, Director general, GSI, for granting permission to publish this paper. The facilities provided by Dr. R.N. Mishra, Deputy Director General and Mr. V.V. Mulay, Director, GSI, Nagpur for writing the paper are gratefully acknowledged. The authors are thankful to the officers and staff of GSI and ONGC for the support extended during the course of the work.

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