PILOT GEOTHERMAL POWER PLANT AND SCOPE OF COMMERCIAL UTILISATION OF TATAPANI GEOTHERMAL FIELD SURGUJA DISTRICT, MADHYA PRADESH, INDIA

Umakant Pitale, Rabindranath Padhi
Prafulla Sarolkar

Geological Survey of India
New office Complex, Seminary Hills,
Nagpur 440006, India

Key Words : Geothermal Power Plant, Commercial Utilisation, Tatapani

ABSTRACT

Tatapani geothermal field is located along faulted Gondwana basin margin within ENE-WSW trending SONATA Lineament zone in Central India. The Tatapani fault and cross faults in Proterozoic gneissic basement and Gondwana rocks control the thermal activity. This field has *400* m x 300 m area of upflow with continuity to depth of 1km., geochemically estimated reservoir temperature of 150°C, thermal gradient of .06 to 0.4°C/m, heat flow of 290± 50 mw/m^2 and boiling zone around 150m depth. Steep fractures as feeder zones have been recorded in explored depth of 500m. Successful completion of five production wells with cumulative discharge of 30 Kg/s of 100°C and maximum temperature of 112°C from shallow thermal zone in 350m depth can sustain up to 300 KWe binary cycle power generation. Heat potential of geofluids from proven shallow thermal zones is of the order of 186 KWe for 20 years. Projection of geothermal parameters to reservoir depth suggests occurrence of conical geothermal body of areal extent of 2 sq.km at 300m and 7.2 sq.km. at 1500 m depth, with capability to sustain commercial development of the order of 3.17 MWe energy from recoverable geofluids and 18 MWe energy in rocks and water combined for temperature drop of 25°C from 112°C to 87°C.

1. INTRODUCTION

As a part of national non-conventional energy resources development programme, Geological Survey of India launched a programme of geothermal studies in northern and central India in 1973-75 and geological, hydrogeological, geochemical, geophysical, thermal-remote sensing studies, mercury dispersal in soils and thermal gradient drilling in selected hot spring areas were carried out. These studies resulted in identification of heat-anomaly zones related with upflow zone vertically linked with deep reservoir of the geothermal system. This significant observation opened an avenue for establishment of pilot geothermal power plants at Puga in Jammu and Kashmir State, Manikaran in Himachal Pradesh and Tatapani in Madhya Pradesh, India, Feasibility studies to establish the thermal potential of upper 350 to 500m part of geothermal system capable of sustaining power generation to the tune of 100 KWe at Tatapani were taken up in 1989-90 by Geological Survey of India (GSI). Testing of production wells was done by the Oil and Natural Gas Corporation Limited (ONGC). Results of these studies under joint GSI-ONGC collaboration programme for installation of 100 KWe binary cycle power plant and scope of full scale commercial utilisation of Tatapani geothermal field are presented in this paper.

2. TATAPANI GEOTHERMAL FIELD

Geothermal activity at Tatapani, a place located 94 km north of Ambikapur, headquarters *of* Surguja district Madhya Pradesh is in the form of 23 hot springs ranging in temperature from 60" to 97' C with cumulative discharge of about 300 litres per minute (Lpm). The hot springs are spread over a 400 m long and 200m wide belt along ENE-WSW trending Tatapani fault (F_1). These hotsprings mostly aligned along fault planes viz. Tatapani fault and cross faults offsetting it, exhibit moderate ebullition of gases. Deposition of silica and calcium carbonate around vents is common. Precipitation *of* native sulphur and fixation of Arsenic sulphide by green algae in the vicinity of hot springs is also recorded in the area. Palaeogeothermal activity is manifested in the form of hydrothermally altered clay around Lakarmanwa village and development of silica sinter near Nawadih village about 500 m west of Tatapani.

2.1 Geological Setting

Two distinct lithotypes, Proterozoic and Gondwana Supergroup, are exposed in the area (Fig.1). Gondwana rocks exposed northwest *of* Tatapani, show faulted contact with the Proterozoics, and extend towards northwest as Tatapani-Ramkola coalfield. Rest of the terrain exposes Proterozoic rocks (Table 1).

Table-1
Geological Sequence at Tatapani Geothermal field, India.

Recent Quaternary		Soil, river alluvium, hydrothermally altered clays
------Unconformity------		
Gondwana Supergroup	Mahadeva formation	Reddish brown coarse sandstone, conglomerate
(Triassic to Lower Permian)	Barakar formation	Sandstone and shale with grit. Plant fossils and coal seams
	Talchir formation	Sandstone, grit and conglomerate, splintery shales
------Unconformity------		
Proterozoic		Phyllite, graphitic schist, quartzite, kyanite-sillimanite schist, augen gneiss granite gneiss, calc-granulite.

Geological mapping of the area reveals a basement of Proterozoic rocks comprising thin bands of phyllite, quartzite, graphitic schist, grey biotite gneiss, hornblende gneiss and pink felspathic porphyritic granite/biotite granite-gneiss. Kyanite and sillimanite schist occur as lensoid bands. Rocks show regional metamorphism upto kyanite-sillimanite grade. Augen gneiss is reported south of the field. The rocks show well developed foliation in the direction N70°E-

S70°W and N80°W- S80°E with steep dip of 75" to 85' towards north as a result of intense folding and cross folding.

A thick pile of Gondwana sediments comprising shale, siltstone and fine grained sandstone of Talchir formation is observed resting unconformably over the basement. The Talchir formation is overlain by grey white sandstone and greyish shale with carbonaceous streaks. Reddish brown sandstone and grit bands are exposed in Tatapani nala. The contact of Talchir with basement is marked by highly sheared granitic rock. Gondwanas in the area have a general strike of N80°W - S80°E with dips towards north at very low angles upto 15". They are gently folded into a westerly plunging synform

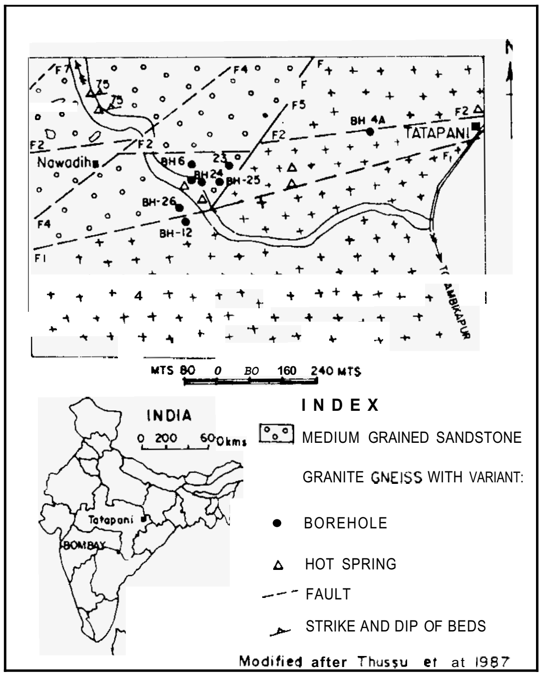

FIG 1- MAP OF TATAPANI GEOTHERMAL FIELD, INDIA

2.2 Structure

Tatapani geothermal field is located in prominent Sone-Narmada-Tapi (SONATA) lineament zone of Central India. Faulted Gondwana basin margin in this SONATA lineament zone exhibits neotectonic acitivity and controls thermal activity at Salbardi, Anhoni and Tatapani hot spring areas from vest to east over a distance of 490 km. (Ravi Shankar 1987). Geothermal activity along Gondwana basin margin is more intense in its eastern sector at Tatapani than in western sector at Salbardi (Pitale et al, 1994).

The area is structurally highly disturbed. The major structural feature, the ENE-WSW trending Tatapani fault (F_1) is characterised by well developed zone of fault breccia of dark grey colour. This fault breccia is seen very prominently in the vicinity of hot springs and also extends over some distance towards east. Here the fault. lies entirely in the Proterozoic. Towards west of the hot springs, there is no prominent expression of the fault. Tatapani fault and the other E-W fault (F_2) are affected by numerous cross faults trending NE-SW causing displacement of out-crops, intense shearing, crushing and development of breccia along these faults. Most of the E-W faults are gravity type. Slicken slides indicating northwesterly movement and plunge of 25' have been noticed along sympathetic shear zones also. The Tatapani geothermal field is bounded by faults on all sides. The southern boundary of geothermal field is marked by ENE-WSW trending Tatapani fault with dip of 78" towards north (Thussu et al 1987). Cross faults F_4, F_5 trending NE-SW demarcate the E-W extent of the thermal manifestation. An E-W fault (F_2) demarcates the northern limit of thermal activity.

2.3 Geofluids and thermal gradients

Hot spring and hot water in shallow dug wells is Na-HCO_3-Cl-SO_4 type. The main constituents of thermal water are sodium 115 to 133 ppm, bicarbonate 87-106 ppm, chloride 70 to 77 ppm, TDS 494 to 570 ppm and silica 45 to 164 ppm. The Na/K ratio is high. The mixing of cold water has marginal effect on quality of the water. The dilution is more in the month of March which gradually subsides by the end of April (Thussu et al 1987). High Na/Ca ratio suggests that the hot spring waters have mixed with similar type of cold water and emerge from same reservoir. Uniform boron concentration indicates that the surface springs are related to single source at depth. Eased on silica geothermometry (Ellis and Mahon 1977) the reservoir temeperature of 150°C to 160°C is inferred for Tatapani geothermal field.

Variation of temperature with depth as observed in exploratory boreholes ranges from 66°C at 30 m to 78°C at 100 m in Tat/2, 62°C to 104°C in Tat/3, 84°C to 109°C in Tat/4, 38°C to 55°C in Tat/5, 90°C to 101°C in Tat/6, 53°C to 88°C in Tat/7 (Ghosh and Das Gupta 1991). Beyond 100 m upto explored depth of 300 to 500m, the temperature of 100°C is near constant or show rise of 4°C to 8°C being in convective zone in these wells. Borehole Tat/7 however shows reversal from 88°C to 77°C beyond 100 m upto 480 m. In the other boreholes though the thermal gradient in upper 100 m is same the temperatures recorded are of lower order. Thermal gradient in upper 100 m thick slice is of the order of 0.06 to 0.6°C/m while that in upper 300 m slice is .09 to 0.4°C/m. Boreholes Tat/2,4A and 6 encountered free flowing geyseric conditions with maximum temperature of 112°C recorded in the explored depth. Subsurface geothermal data of 22 exploratory boreholes revealed that boreholes no. Tat/2, 3, 4A, E and 7 lie in the area of anomalous high thermal gradient. Disposition of isotherms and thermal gradient contours at 100 m (Fig. 2) and 300 m level indicate that upflow zone has an area of 1 sq.km. in upper 100 m slab while in deeper level upto 300m the area of higher thermal gradient extends upto 2 sq.km. Considering surface areal extent of thermal manifestation of the order of .08 sq.km. (400 m x *200* m) the thermal body has an areal extent of about 25 times at 300 m thereby indicating a possible occurrence of high thermal potential reservoir at depth in Tatapani area. Ravishankar (1987) has indicated heat flow value of 290±50 mw/m^2 i.e. *5* times the normal terestrial heat flow, for depth range 100 to 300m at Tatapani which also confirms the possibility of encountering thermal zones capable of sustaining exploitation and geothermal development at Tatapani.

2.4 Geothermal Parameters

Geoscientific studies including geophysical surveys followed by exploratory thermal-gradient drilling resulted in establishing following geothermal parameters of the Tatapani geothermal system.

* Reservoir temperature: 160 ± 10°C. In proven part (upper 100-500 m) 112°C temperature encountered in boreholes.

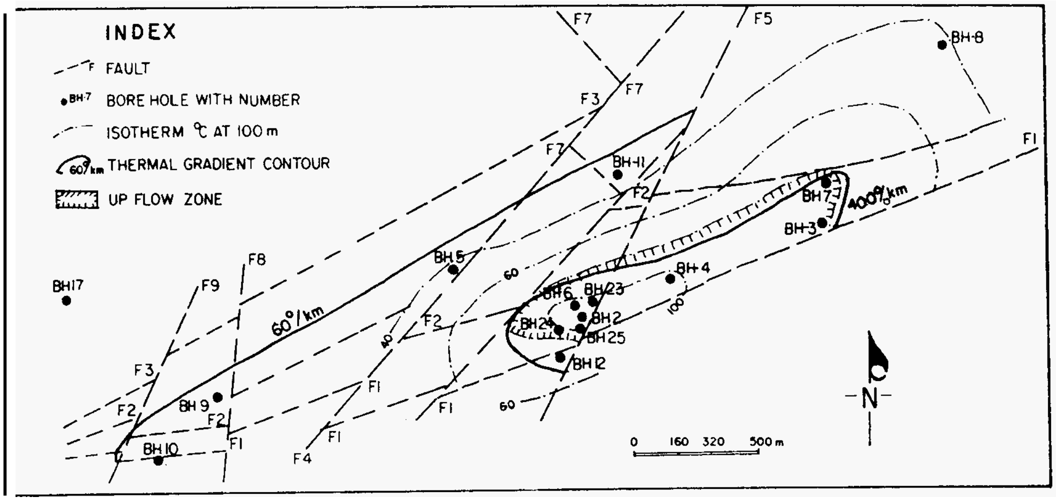

FIG.2 - ISOTHERMS AT 100 m DEPTH; **TATAPANI,**

* Thermal gradient : .06 to .6°C/m in upper 100 m slice; .09 to .4°C/m in upper 300 m slice
* Heat flow : 290 ± 50 mw/m^2
* Upflow zone : Identified around borehole Tat/6
* Depth of boiling : Identified (150-160 m below ground level)
* Free flowing and geyseric condition : In wells Tat/6 (3001pm of 100 °C) and Tat/4A
* Pressure : 37 to 42kg/cm^2 at 350m
* Feature controlling upflow zone : Fractures associated with major faults.
* Thickness of fracture zone in 98 to 506 m depth explored : 45 to 110m.
* Possible deep reservoir rock : Fractured crystallines
* Extent of continuity of saturated thermal zone : About 1 km. as indicated by conductive zone of 10 to 15 ohmm. (Joga Rao et al. 1987).

3 PILOT GEOTHERMAL POWER PLANT

With this background information on geothermal regime in upper 500 m part of geothermal system, chemical geothermometric data on deeper reservoir and possible continuity of conduit zone to a depth of lkm. as assessed from resistivity values of 10-20 ohm m at Tatapani geothermal field, feasibility studies for installation of 100 KWe binary cycle geothermal power plant were taken up. Under this programme four production wells around free-flowing geyseric well Tat/6 were drilled to test the thermal energy potential of shallow thermal zones in upper 350 m part of Tatapani geothermal system.

3.1 Geology of thermal zones

The production wells have encountered sandstone shale sequence of Talchir formation to a depth of 80 to 120 m followed by sheared granite gneiss to well bottom (Fig. 3). The rocks are highly sheared, indurated and fractured at angles of 30°, 40°, 60' and 70' to horizontal. The fractures are filled with secondary silica, zeolites and calcite. Pyrite, chalcopyrite disseminations are common in fractured zones. The borehole cores show thin bands of fault breccia upto 30 cm thick which comprises angular pieces of granite-gneiss, quartz vein, pegmatite, phyllite and chlorite schist. Core samples under thin section reveal rotated felspar with fractured core and pulverisation along margins. The pulverised, rotated felspar crystals suggest that these rocks have been subjected to repeated deformation. Prominent fractures have been recorded in these wells in depth ranges of 120-140 m, 180-190 m, 220-240 m and around 300 m.

3.2 Geothermics of wells

The fractures recorded in depth range of 120-140 m, 180 - 190 m, 220 - 240 m and around 300 m act as feeder zone of thermal water. The thermal water discharge commences below sandstone-gneiss contact with temperature rising to 100°C around 140 - 160 m which constitutes the actual blowout zone. The blow-out zone is shallower near Tatapani fault as seen in wells Tat/25 and 26. High permeability zone is observed from depths of 140 to 250 m suggesting thereby the occurrence of reservoir in fractured Proterozoics. Overlying Gondawana sandstone aquifers which have areal extension regionally in the northern part actually induce some mixing of cold water with uprising thermal waters through fracture conduit systems in the Proterozoics. Surface exposure of Gondwana aquifers in the north actually provide easy access of surface water to underlying Proterozoics. The meteoric water after reaching deeper reservoir and collecting the heat moves upwards through Tatapani fault, cross faults and associated fracture system encountered in the production wells. This also explains the localisation of hot springs to the north of Tatapani fault.

Shut in temperature and pressure in wells Tat/6, Tat/23 and Tat/25 recorded during well testing by ONGC is shown in Fig. 4. The shut-in temperature rises from 98°C at 50 m to 111.89°C at a depth of 175 m indicating a temperature gradient of 0.11°C/m i.e. about 3 times the normal. There exists a zone of convective heat transfer between 175m and 250 m for well 6 and between 175 m and 315 m for well 23 making the temperature constant in this region. Below this depth temperature inversion shows existence of colder zone. Tat/25 shows the rise of convective zone to shallow depth as compared to TAT/6 and 23. Maximum temperature recorded in the wells is 112.5°C (GSI-ONGC 1993). All the wells indicate pressure higher than the hydrostatic pressure. Pressure values at the bottom of the TAT/6, 23 and 25 are 37 kg, 42kg and 32 kg/cm^2 respecti-

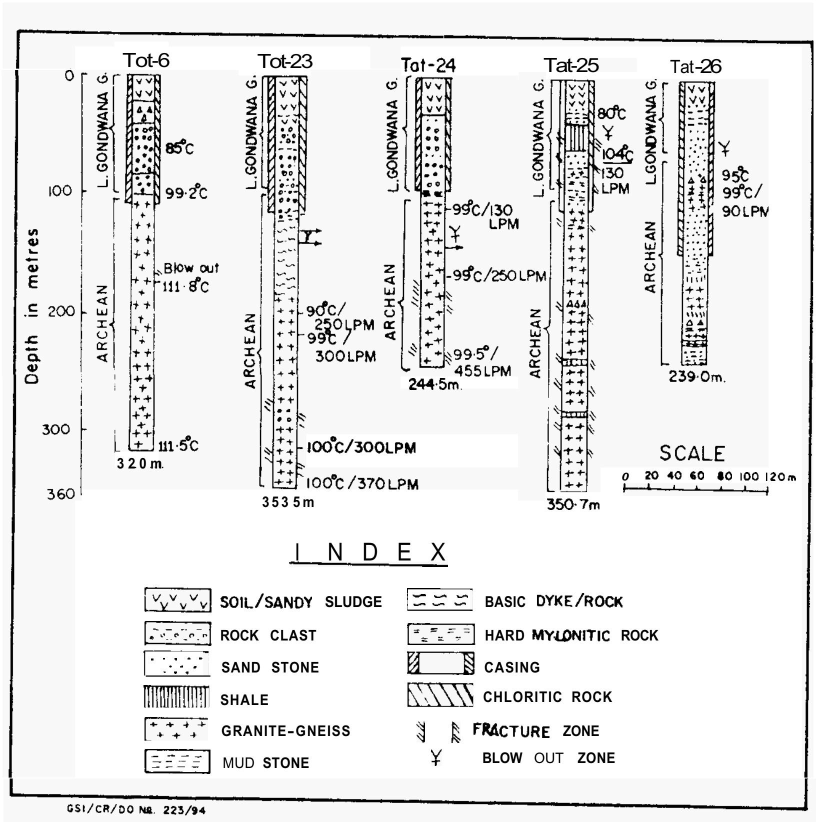

Fig.3 Lithographs of Boreholes, Tatapani

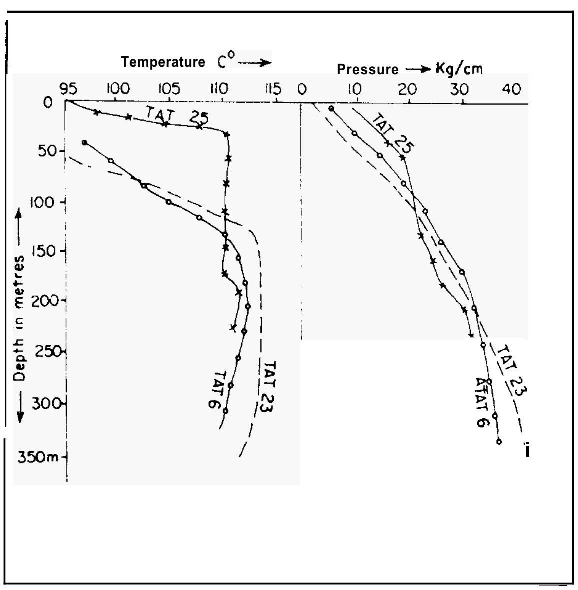

Fig 4 Shut in temperature and pressure profiles

vely. The pressure profile shows a distinct change in its curvature at a depth of about 100 m - 150 m in all the three wells. Corresponding temperature profiles show drop in temperature of the well fluids by 1-2°C in this region. This confirms that due to low pressure encountered in this region flashing is taking place at this depth thereby reducing the fluid temperatures from 112°C at about 150m to 110°C at wellhead.

3.3 Chemistry and Potential of Geofluids

Thermal waters of hot springs and production wells have near similar composition and they are of $Na-HCO_3-Cl-SO_4$ type. Near uniform chemical composition of the waters suggest same source. Flourine (15 ppm) is relatively higher in Tatapani waters. Similar Boron content points to same source of thermal waters. Silica thermometry indicates reservoir temperatures of these thermal water to be of the order of 147°C to 157°C.

The study of precipitation in discharge pipes yield mostly calcite, little silica, thin scales of Cu, As and even silver upto 4 ppm. Thus the discharge water may require elimination of $CaCO_3$ to avoid choking of pipes and that of fluorine for useful surficial consumption.

All the wells are free flowing. The temperature and discharge parameters are summarised in Table-2.

Table-2
Temperature and discharge of Production wells.

Bore hole no.	Depth (m)	Tempe-rature surface °C	Disch-arge lpm	Max temp °C	Pres. at bot-tom kg/cm^2	Energy pote-ntial kj/s
6	320	99-99.5	289-293	111.5	37	510.2
23	353.15	99-100	269-303	112.9	42	501.4
24	244.60	99.5-100	431-451	--	-	773.2
25	350.70	+100	255-269	112	32.1	459.4
26	239	99-100	498-508	--	-	881.9

Total thermal energy potential of all the wells for temperature drop from 112°C to 87°C i.e A T=25°C, the average temeprature range specified for heat exploitation in proposed binary cycle power plant, comes to 3125 KJ/S.

3.4 Thermal requirements of Power Plant

The thermal requirments for 100 KWe organic rankine binary cycle power plant under procurement by ONGC are :

* Hotwater flow : 30 kg/S i.e 1800 lpm
* Hotwater inlet temperature : 100°C
* Outlet temperature : 86.9°C
* Working fluid : Perchloroethylene
* Maximum hotwater pressure : 5 Kg/Cm^2

All the temperature, pressure and discharge conditions are fulfilled by the shallow geothermal zones under exploitation by these five production wells. Plants with improved efficiency cabable of generating 300 Kwe from the same mass flow rate of 30 kg/s are available (Jivcate and Forte, 1990).

3.5 Feasibility of Power Plant

To assess the availability of thermal fluid of plant specifications from shallow thermal zones under exploitation by the five free flowing production wells, the area covered by 100°C isotherm to a depth of 350 m has been taken into consideration. Thermal capacity of the reservoir in the exploitation depth of 350 m calculated on the basis of width of upflow zone on the surface of order of 300 m and cross sectional area (652800 sq.m.) of slice within 100°C isotherm recorded in the production wells is as follows:

*Energy liquid = Cross section area of thermal zone x width of upflow zone x porosity x density x enthalpy (A T=112-87°C)
= 652800sq.m.x300m x 0.1x 948 Kg/m3x105.2KJ/Kg.
= 1.953×10^{12} KJ/S ÷ 6.3×10^{8} seconds
= 3.1 MWe x efficiency 0.06
= 0.186 MWe or 186 KWe for 20 years. (1)

*Energy rock = Volume x(1-Porosity) x density x Sp. heat x temp. diff.
= 652800 x 300 m^3 xO.9 x 2660 Kg/m^3 x 0.19 $x10^3$ Cal/Kg°C x 25°C
= 2.227×10^{15} cal
= 9.37×10^{15} Joules ÷ 6.3×10^{8} seconds
= 14.87 MW for 20 years x efficiency factor .06
= 0.892 MWe = 892 Kwe for 20 years. (2)

*Total energy (1+2) = 186+892 = 1078 KWe for 20 years. (3)

The stored heat in the liquid, assuming no recharge model, is of the order of 186 KWe for 20 years. Geothermal parameters of proved part of the geothermal system at Tatapani therefore clearly confirm the feasibility of this Pilot geothermal power plant project.

4 ENERGY POTENTIAL AND COMMERCIAL UTILISATION OF GEOTHERMAL FIELD

With the establishment of geothermal parameters from surface geoscientific studies followed by thermal gradient drilling and feasibility of Pilot binary cycle geothermal power plant tapping energy from shallow thermal zones in upper 350m part of geothermal system, full scale commercial utilisation of Tatapani geothermal field is on anvil. At this stage of investigation, following geothermal model and scope for commercial utilisation can be conceived.

4.1 Geothermal model

The geothermal system at Tatapani exhibits conical configuration of hotwater body with narrow constriction of 0.08 sq.km at surface with areal extent of shallow reservoir of the order of 1 sq.km at 100m depth, 2 sq.km at 300 m depth and about 7.20 sq.km at 1500 m depth (areal extent where 100°C thermal water is expected at 1500 m depth). Overlying Gondwana sequence with vast areal extent towards north of the field forms a recharge zone for percolating meteoric water. Fracture and fault system in concealed Proterozoic below recharge zone provides downward passage to hot part of the reservoir. Fracture zones associated with Tatapani fault and cross fault form conduit zones for upward passage of thermal water through this conical water body in Tatapani hotspring area. Well no.6 has small amount of Tritium whereas hotspring has very negligible Tritium suggesting thereby residency period of 30 to 40 years (Thussu et al 1987) for the thermal waters. Deep Schlumberger sounding indicate true resistivity of conductive layer to be of the order of 10 to 20 ohm m and one dimensional interpretation indicate large depth of more than 1 km. to resistive basement (Jogarao et al 1987). With this depth persistence of over 1 km. of saturated thermal zone and residency period of 30 to 40 years, the reservoir dimension at 1500 m could be even much more than 7.2 sq.km, as envisaged from extrapolation of thermal gradient for locating zone of 100°C water at 1500 m depth.

4.2 Thermal potential of the Field

Thermal energy potential of the conical hot water body with basal areal extent of 7.20 sq.km. at depth of 1500 m, in rock sequence with 10% assumed fracture porosity for A T (112°C-87°C) is assessed as :

*Area of 100°C isotherm : 7226400 sq.m. at 1500 m depth
*Thickness of zone : 1400 m. (omitting top 100 m sandstone)
* A T = 112°C - 87' : 25°C
*enthalpy E 112°C - E87°C : 105.2 KJ/Kg
*Water density 112°C : 948 gm/ltr.
*Porosity assumed : 0.1
*Rock density : 2.66 gm/cc
*Sp. heat rock : 0.19 cal/cc
*Plant efficiency factor : 0.06
*Life : 20 years
*Volume of cone = 1/3 surface area x height

*Energy liquid □ volume x porosity x density x A enthalpy x efficiency factor

□ 7226400x0.33x1400x0.1x948x105.2 KJx 0.06

6.3×10^{8} = 3.17 MWe for 20 years. (4)

*Energy rock = 7226400 x 0.33 x x1400x.9x0.19x2.66 x105.2x10^{6} x.06

6.3×10^{8} □ 15.16 MWe for 20 years (5)

Total Energy (4+5) □ 15.18 + 3.17 MWe = 18.35 MWe for 20 years (6)

Recoverable heat from liquid, assuming no recharge, is of the order of 3.10 MWe at proven temperature of 112°C. In fact higher temperature of the order of 150°C as envisaged from chemical thermometry is likely to be encountered at 1500 m depth. Once these temperatures are actually recorded in deep wells the potential of geothermal field at Tatapani is likely to increase manifold and sustain full scale commercial utilisation in the field of electricity generation and direct heat utilisation.

4.3 Heat Utilisation Schemes.

Heat in the range above 87°C can be utilised for electricity generation with moderate begining as 100 to 300 KWe binary cycle power plant from shallow thermal zones and large scale generation, once high temperature reservoir is proved by deep drilling.

Keeping in view the raw material resources available in Tatapani area following direct heat utilisation projects can be thought of for thermal fluid below 87°C released from power plant.

*Cocoon boiling for silk thread extraction
*Mineral water
*Mushroom culture
*Cold storage
*Food processing
*Canning and controlled drying of fish
*Boiled rice
*Rice-bran oil
*Spa
*Tourist development

5 CONCLUSION

Feasibility studies for 100 KWe geothermal power plant have proved occurrence of thermal zones in shallow depth of 350 m with thermal potential of 186 KWe for 20 years. Free flowing condition with wellhead temperature of 100°C, maximum temperature of 112°C, pressure of 32 to 42 Kg/Cm^{2} at hole bottom, thermal gradient of 0.11°C/m and cumulative discharge of 30 Kg/s of 100°C from thermal fluid conduit system in fractured Proterozoic rocks have been established in five production wells to be linked to power plant for generation up to 300 KW, of electricity by a temperature drop of 25°C in temperature range of 112°C to 87°C.Geothermal parameters of proven shallow thermal zones suggest thermal zone continuity beyond 1 km depth and deep reservoir of geochemically estimated temperature of +150°C.

Geothermal body has a conical shape with areal extent of 7.2 sq km at 1500 m depth. Total stored heat in liquid (3.17 MWe) and rock (15.18 MWe) in this conical geothermal body is of the order of 18 MWe for 20 years. Recoverable heat from liquid assuming no recharge is of the order of 3.10 MWe at proven temperature of 112°C. With reservoir temperatue of 150°C likely to be encountered in 1500 m deep wells, the potential is likely to increase manifold. Successful completion of feasibility studies of 100 KWe pilot geothermal power plant using shallow thermal zones have opened a scope of full scale development and utilisation of entire potential of geothermal field for generation of electricity to the tune of 3 to 10 MWe and many direct heat applications like cold storage,silk industry, fish drying, rice-bran oil, mineral water, Spa, tourist attractions, health resorts based on effluent thermal fluid of 87°C from power plant.

ACKNOWLEDGEMENTS

Authors express their deep sense of gratitude to the Director General, Geological Survey of India for his kind permission to present this paper at World Geothermal Congress 1995. Authors sincerely thank scientists of Oil and Natural Gas Commission Limited, Dehradun for well testing data and valuable discussions. Shri A. M. Sontakke of Geothermal Division, GSI deserve special mention for his continuous secretarial support to bring the paper to required format. Shri K. Muthuraman, Director, GSI, kindly prepared the camera ready print of this paper using his skill in computer and the software.

REFERENCE

Ellis A.J., Mahon W.A.J (1977). Chemistry and Geothermal systems, *Academy press, New York* PP 144-147.

Ghosh Sibdas and Dasgupta Sujit (1991). (Editors) Geothermal atlas of India, *Geol.Surv. Ind. Misc. Pub. 19* PP 86-99.

GSI and ONGC (1993). Tatapani Geothermal field, a development alternative. *A joint project document prepared by GSI and ONGC, KDM Institute of Petroleum Exploration, Dehradun (Unpublished).*

Jivacate Chaya, Fort N. (1990) Geothermal plants for remote communities : *Proc. 72th New Zealand workshop 1990 P.P. 209-212*

Joga Rao M.V., Rao A.P., Midha R.K, Padmanabhan K., Kasavamani M. (1987). Results of geophysical surveys in Tatapani hot spring area, Surguja district, M.P., *Rec. Geo. Surv. Vol. 715, pt 6.* PP56-83.

Pitale U.L., Karve A.E., Sarolkar P.B (1994). Geothermal Potential along Gondwana margins in Central India, *Proc. IXth International Gondwana Symposium, Hyderabad, India (in press).*

Ravishankar (1987). Status of geothermal exploration in Mahrashtra and Madhya Pradesh (Central Region), *Rec. Geol. Surv. of India Vol. 115 Pt.6* PP. 7-29

Thussu J.L., Prasad J.M., Saxena R.K., Gyanprakash & Muthuraman K. (1987). Geothermal energy resources potential of Tatapani hot spring,district Surguja, MP *Rec. Geol. Surv. of India Vol. 715 Pt.6* PP. 30-55