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Status of Investigation at Tatapani Geothermal Field, District Surguja and Future Perspective

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ABSTRACT

Tatapani geothermal field is the most promising geothermal resource in Central India. Investigations for assessment of geothermal resource at Tatapani, Surguja district, were carried out over two decades. Geochemical survey at Tatapani has revealed 60 to 110 ppm each of Na, Cl, SO_4 content, 123 to 161 ppm SiO_2, low K, B, Mg and 15 to 20 ppm F content. The thermal water is immature water, which shows mixing with ground water. The source water is meteoric in origin and indicated reservoir temperature is 150°-160°C by quartz geothermometer and 180°-190° C by Na/K method. The above observations are supported by fluid inclusion studies, which measured Th median of 180° to 200° C. Hydrothermal alteration studies, have reported stilbite, smectite, illite, calcite and epidote in thin sections, indicating that the geothermal system operated in the temperature range of 180°C to 250°C.

Five shallow production wells have been drilled in Tatapani upto maximum depth of 350m. Maximum temperature of 112.5°C was reported in the boreholes during well testing. The five production wells recorded discharge of 1800 lpm initially. Present discharge is 1125 lpm from four bore wells. A 300 kWe binary pilot plant was proposed for utilizing present discharge.

Geophysical investigations have suggested aquifer zones at the depth of 300m and around 600m. MT survey indicated that the geothermal reservoir might continue at deeper level. Geothermal resource potential of 11 to 18 MWe was estimated based on the available data. Drilling to the depth of >1500 m is essential for assessing geothermal potential of the deep reservoir. Deep exploration may yield two-phase reservoir conditions suitable for power production.

1. INTRODUCTION

Tatapani Geothermal field, Surguja district, Chhattisgarh State, is a promising hot water reservoir in Central India, located along the Son-Narmada lineament. The index map in Fig. 1b shows location of Tatapani geothermal field in India.

Thermal manifestations in Tatapani consists of hot springs (52°C-97°C) in marshy ground, and hydro thermally altered clay zones covering an area of about 0.1 sq km (Ravishanker, 1987). Geological Survey of India has carried out prospecting at Tatapani Geothermal Field (TGF) for proving potential of geothermal resource by geochemical and geophysical methods and exploration by drilling (Thussu and Prasad, 1987; Thussu and Gyanprakash, 1987; Joga Rao et al, 1987). Tatapani Geothermal field is located 95 km NNE of Ambikapur (Fig.1b) and is connected by all weather tar road from Bilaspur. Accessibility to Tatapni geothermal field is shown in Fig.1b below.

Fig. 1a, Index map of Tatapani field.

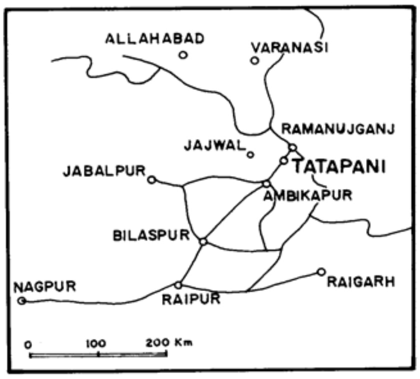


Fig.1b, Location map of Tatapani

Total 22 boreholes were drilled for exploration out of which borehole Tat/6 proved to be a successful borewell producing hot water of 100°C @ 270 lpm. Four more borewells Tat/23, 24, 25 and 26 were drilled as production wells with cumulative discharge from four bore wells of 1500 lpm. The feasibility of geothermal binary cycle power plant by utilizing this discharge was established in association with Oil and Natural Gas Commission (Pitale et al 1995).

2. GEOLOGY

Archaean rocks comprising massive light grey gneisses, biotite-chlorite schist, biotite gneiss and few calc-granulite bands cover the area. Precambrian pink porphyrytic granite consisting of feldspar phenocrysts and stringers of biotite is exposed south of Tatapani. The pink granite is affected by shearing inducing gneissosity and crude alignment of biotite in the rock. The area north west of Tatapani is covered by rocks of Gondwana Supergroup, comprising green shale and laminated siltstone of Talchir Formation; thin bands of conglomerate comprising pebbles of biotite gneiss, chlorite schist, sandstone and quartz veins; and coarse, feldspathic, coal bearing Barakar sandstone. The rocks of Gondwana Supergroup show trend of N-S to

N25°E- S25°W with low to moderate dips towards northwest. The contact between granite and Gondwana rcoks is marked by a fault. The fault zone is marked by injections of quartz vein.

3. STRUCTURE:

The area of study is affected by intense tectonic activity. A fault trending ENE -WSW with sub-vertical dips is exposed south of village Tatapani, demarcating contact between Lower Gondwana Group and Archaean /Precambrian rocks. The fault is marked by a thick shear zone and hard fractured, brecciated pink granite gneiss. The shear zone material shows wedge like patches of sandstone along with granite gneiss. Sympathetic faults are observed north of the Tatapani fault trending in NE-SW to ENE-WSW directions. NE -SW trending cross faults near village Newadih and Tatapani cut across the main fault system. Fractured pink granite is exposed along the trend of cross faults. The hot springs of 52° C to 97°C temperature and a zone of marshy ground; are confined to this system of ENE-WSW Tatapani fault and NE-SW trending cross faults. The intensity of geothermal manifestations decreases away from this fault system.

4. DISCHARGE:

Total five boreholes (GW/Tat/6,23 to 26) have free flow discharge of 100°C water on surface. Discharge of individual borewell varied from 270 lpm in Tat/6 to 460 lpm in Tat/24. The initial discharge of five bore wells was 1800 lpm, which has been reduced to 1125 lpm at present due to caving. The borehole GW/Tat/24 is not operational and needs repairs. The maximum wellhead temperature varies from 104°C in Tat/25, 26 to 109°C in Tat/23. NHPC has reported wellhead temperature of 138°C in discharge of a bore well (Personal communication).

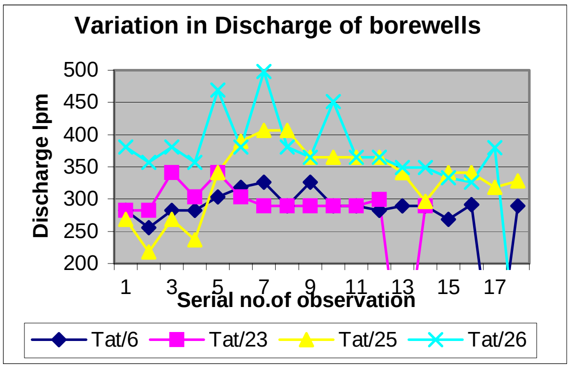


Fig.2, Graph showing discharge pattern.

5. CHEMICAL CHARACTERS:

The chemical composition of thermal water is summarized in Table 1.

The thermal water from Tatapani hot springs as well as bore wells was analyzed in Chemical Laboratory, GSI Central Region, to decipher the chemical composition. The thermal water is mostly bicarbonate sodium type. The thermal water is mildly alkaline with pH ranging from 7.7 to 9.0. Chloride content varies from 68 to 140 ppm, TDS varies from 491 to 545 ppm, SO_4 ranges from 52 to 76 ppm, sodium varies from 100 to 146 ppm, calcium and potassium content is low, SiO_2 varies from 130 to 161 ppm and fluorine content varies from 10 to 20 ppm. (Sarolkar & Mukhopadyay, 1998). The thermal water contains low arsenic and high fluorine. The SO_4 content is rather high and could have been generated due to oxidation of pyrite in the host rock. Calcium has reverse solubility; hence, the low calcium content in thermal water may depict high reservoir temperature.

The ternary Cl- SO_4 -HCO_3 diagram (Fig.3) shows that Tatapani thermal water is mixed chloride-bicarbonate type. The thermal water plots in HCO_3 dominant field with subordinate sulphate content. The above observation is supported by Na-K-Mg ternary diagram, which shows that the thermal water samples from Tatapani plot in Mg field (Fig.4) suggesting that the thermal water is immature, and may not represent the geothermal water from deep reservoir (Giggenbach, 1997).

Table 1: Chemical composition of thermal water.

Radical	Median	Average	Min	Max
pH	8.5	8.5	7.7	9.0
Cond at 25°C	593	580	435.0	707.0
CO_3 ppm	22	23	5.0	47.0
HCO_3 ppm	114	112	28.0	169.0
Cl ppm	72	73	68.0	140.0
SO_4 ppm	67	66	52.0	76.0
Ca ppm	3	3	1	6
Mg	1	2	1	5
$CaCO_3$ ppm	12	12	4	20
Na ppm	112	113	100	146.0
K ppm	7	8	5	11
TDS ppm	514	514	491	545
SiO_2 ppm	133	130	43	161
B ppm	1	1	0.5	0.7
F ppm	15	16	10	20
As ppb	10	24	10	100

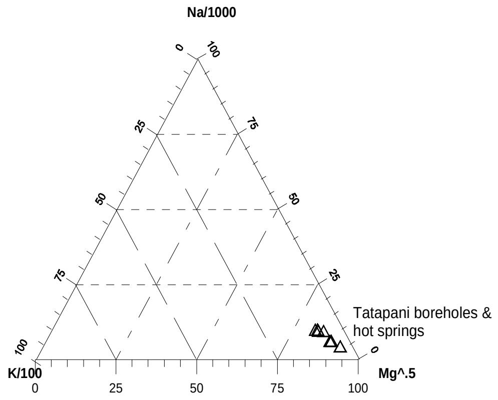


Fig.3, Cl-HCO_3-SO_4 ternary diagram, Tatapani

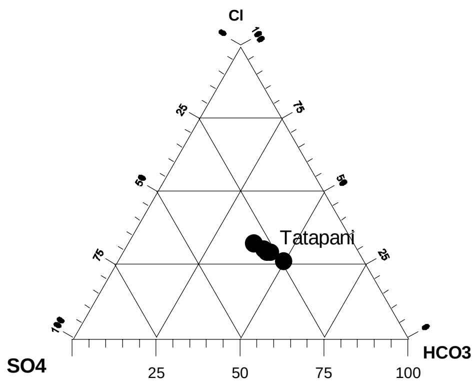
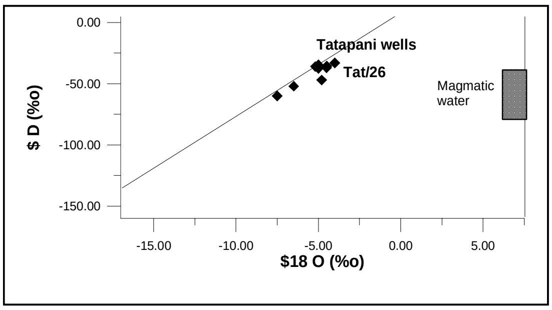


Fig.4, Na-K-Mg ternary diagram, Tatapani

The above observation suggests that the Tatapani thermal water is mostly a product of meteoric water heated during percolation to shallow reservoir and mixing with ground water during ascend to surface. The deep reservoir geothermal water is yet to be tapped in the bore wells. Uniform boron content (in thermal water) points to the common source of water (Wright 1991).

5a. Isotope Study

The oxygen and deuterium isotope study of Tatapani is depicted in Fig.5. The oxygen isotope study of Tatapani thermal water indicates that the thermal water is mostly meteoric in origin. (Misissale *et al*, 2000). The thermal water from the bore well Tat/26 shows enrichment in ^{18}O content as compared to the water samples from the other bore wells and is slightly displaced from the meteoric water line.



Fig, 5, Plot of isotope content of thermal water.

The bore well Tat/26 has maximum ^{18}O shift, which may be due to some water rock interaction (Sharma 1996). The isotope data indicate dilution trend with the meteoric water contributing the greater proportion. Thus, isotope analysis has confirmed the meteoric origin of thermal water at Tatapani. Tritium content in Tatapani water indicates residency period of 30-40 years (Thussu et al 1987).

5b. Reservoir Temperatures

The indicated reservoir temperatures by aqueous geothermometers vary as shown in table 2.

The indicated reservoir temperature by K-Mg method is very low ranging from 69°C to 94°C, hence, is unrealistic. The quartz (Fourmier, 1985) and K –Mg geothermometer tend to respond more quickly to sharp cooling gradients and subsequent re-equilibrium (Simmons et al 1994), which may explain the discrepancy in reservoir temperatures indicated by quartz solubility and K-Mg method. Most appropriate mineral water equilibrium for hot springs of Tattapani have been observed at 150°C, hence, it is indicated that the quartz-chalcedony geothermometer may successfully evaluate the reservoir temperature of Tatapani hot springs (Saxena, 1996). Thus, the indicated reservoir temperature at Tatapani is probably 150°C to 180°C.

Table2: Reservoir temperatures indicated by aqueous geothermometers.

Sl no.	Method	Min. Temp	Max Temp	Temp Median
1	Silica, max steam loss	137°C	152°C	147°C
2	Silica, no steam loss	128°C	166°C	154°C
3	Na/ K(F)	168°C	217°C	180-190°C
4	Na / K (G)	177°C	232°C	190-200°C
5	NA-K- Mg	213°C	258°C	230-240°C

5c. Geophysical Survey

Resistivity survey carried over in Tatapani indicated that low resistivity channel is confined between the high gravity in north and Tatapani fault in south. Deep resistivity surveys have confirmed presence of low resistivity zone at the depths of 300 m and 600 m, respectively. The AMT surveys have indicated zone in the sub surface, close to the hot springs, which may correspond to the hot water formation (Joga Rao *et al* 1987). AMT survey at Tatapani has depicted an elongated E-W trending telluric low, suggesting presence of conductive zone in this direction. (Harynarayan, 1998). The conductive zone may extend more towards west of the hot spring area than to the east. A model with aquifer at 200-400 m depth, together with fracture zone having resistivity of 100 *Ohm m* is found to fit the data closely. The Tatapani MT anomaly is associated with a narrow conductive fault /fracture zone extending to deeper levels in addition to shallow aquifer with a width of about 3 km (Harinarayan, 1998).

6. FLUID INCLUSION STUDY:

Fluid inclusion studies on primary and secondary biphase inclusions in few samples collected from quartz vein in granite and calcite / zeolite, in cavity fillings, has measured Th of 139° to 258°C, during the heating cycle (Fig.6).

Majority of the fluid inclusions measure Th of >200°C and some of them measure Th of 150°C to 200°C. Few inclusions measure Th of <150°C. Fig.5 shows frequency distribution of Th measured in fluid inclusions. The wide variation in Th may indicate different conditions of formation with change in time. Temperature of melting (Tm) of fluid inclusions ranges from -0.3°C to –21.5°C, corresponding to salinities ranging from 0.5%o to 23.3%o with an average of 8.9%o, NaCl equivalent.

The low salinity of most of the fluid inclusions suggests a meteoric origin for the geothermal waters. Some of high Th inclusions show low salinity where as few inclusions with low Th indicate high salinity. The high salinity inclusions may not be related to current thermal activity. The high salinity fluid inclusions (≈23.3%o) may be attributed to non- geothermal geological processes. Thus, fluid inclusions formed during geothermal as well as non-geothermal activity are observed in this area. Further studies are necessary to establish the chronological order of these fluid inclusions.

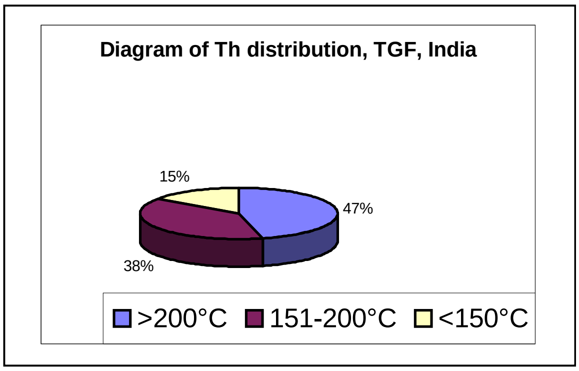


Fig.6, Frequency distribution of fluid inclusions

7. HYDROTHERMAL ALTERATION:

The hydrothermal minerals comprise smectite, illite, stilbite, quartz, albite, laumontite, chlorite, calcite and pyrite. Hydrothermal alteration is controlled by temperature, permeability and pressure conditions in geothermal reservoir. Hydrothermal alteration is mostly observed near Tatapani fault zone. Widespread silica sinter observed in the area suggests that the geothermal fluid was alkali chloride type. The smectite– illite and calcite hydrothermal assemblage above 200 m depth indicate that the temperature of geothermal field was in the range of 160°C -180°C. Similarly, the laumontite and chlorite indicate different thermal regime mostly around 230°C. The laumontite suggests maximum temperature of 240°C to 250°C (Liou, 1971).

The bladed calcite crystals indicate boiling zone at this depth (Browne, 1992). At Tatapani, platy calcite is reported at two levels 60 m and >120 m, indicating that the zone of boiling shifted to greater depths with times. Calcite seems to have deposited by loss of gas phase (CO_2) from liquid phase at TGF. The decrease in gas pressure resulted into boiling at lower temperature.

Montmorillonite –illite minerals are stable over wide range of temperature and are formed by low temperature hydrothermal processes (Steiner, 1953). The hydrothermal mineral assemblage quartz – smectite- illite, interlayered illite – smectite, are probably product of alteration of feldspar. Hydrothermal epidote provides unequivocal evidence of temperature in excess of 250°C during hydrothermal activity (Absar, 1991). Epidote tends to be deposited by high pH fluids at temperature of > 250°C, formation of illite requires relatively low pH fluids of lesser temperature. Two separate events of different phases of the same event may only make epidote and illite – kaolinite occurs in the same hydrothermal mineral assemblage. (Absar, 1991). Microscopic studies revealed formation of epidote at the expense of feldspar, suggesting that the TGF had attained temperature of 250°C, in the past. In Wairakei, the minerals indicating high temperature such as epidote, clinozoisite and prehnite are more common in the depth range of 1000m (Cox & Browne, 1998). Thus, indicating possibility of getting high temperatures at greater depths.

8. BOREWELL TESTING:

Pressure and temperature profile survey of the bore wells was carried out in collaboration with the ONGC (Fig.7). The well testing was conducted by Kuster gauge to record shut-in and flowing P & T profiles. The maximum temperature recorded in a bore well is 112.5°C (borehole GW/Tat/23) at the depth of >200 m. The bottom borehole pressure ranges from 21 bars in bore well Tat/26 at 210m to 34 bars at 350m depth in Tat/ 23. The borehole pressure is slightly more than the normal hydrostatic gradient and may be responsible for the free flow discharge of the bore wells. Since all wells are giving different flow rates, there is difference in lateral fracture permeability. Static pressure in all the wells is higher than the hydrostatic head, and as result all wells are going to flow (Sharma & Tikku, 1998).

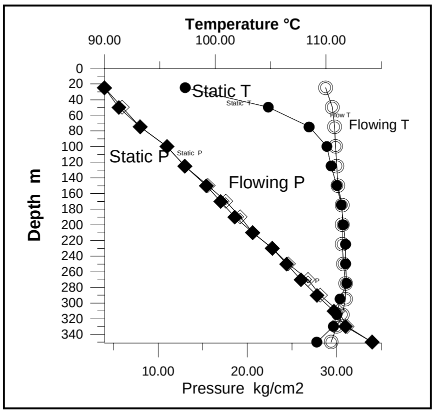


Fig.7, P & T profile of bore well Tat/23.

The temperature in the bore well shows steady increase up to a depth of 250 m below which slight temperature inversion is recorded in boreholes Tat/6, 23 & 25. Maximum shut in temperature varies from 110°C in Tat/6, to 112.5°C in Tat/23. Flowing temperature profile indicates conductive cooling curves upto the depth of 200m below which zone of convection is inferred based on the temperature inversion in the boreholes Tat/6, 23 & 25. The well testing data indicate that fracture zones are located at the depths of around 120 m, 150 m, 200 m, 250 m to 275 m and below 300 m. The zone below 300 m is a zone of cold water incursion, while the fracture zone around 250-275 m may be thermal water recharge zone (Sarolkar *et al* 1999). The boreholes represent a multi zone low permeability aquifer. The permeability is mostly fracture controlled.

Tatapani is an active geothermal system, and encouraging results may be obtained if exploration is carried to deeper level. The estimated area of the reservoir based on gradient of 50°C/km at the depth of 1500 m is calculated to be 7.2 sq km (Pitale *et al*, 1999). Assuming the discharge temperature of 112°C and effluent water temperature of 87°C for binary cycle plant, the reservoir may have capacity to sustain production of 3.5 MWe for a period of 20 years, from energy in liquids.

9. ENVIRONMENT

The thermal water is mostly potable with low TDS and low toxicity. The main possible pollutants are silica, arsenic (2 ppb) and fluorine (10-20 ppm). Monitoring of SiO_2 and F is essential during production stage to assess possible pollution. Fluorine content in water needs to be controlled to permissible limits before cascade uses for direct heat utilization. Reinjection is one option, which would postpone the need for fluorine treatment at present but might aggravate the fluorine pollution in future due to increasing concentration in the reservoir fluid. Dilution by cold surface water with low fluorine content is low cost, feasible method for control of fluorine toxicity. Among the gases, H_2S (0.01 mole %) and CO_2 (12.9 mole %) may also contribute to the air pollution.

10. ECONOMICS:

The economic feasibility of binary cycle power plant needs to be examined carefully in the changing global scenario and advancement in technology. Preliminary estimates with 95% production capacity factor and 8% interest rate without tax liability indicated that the production cost might be $ 0.14/kwh for 300 kWe and $ 0.1/kwh for 5 MWe capacity. The economics of production improves with the increasing installed capacity of the power plant. Hence, it would be advisable to continue simultaneously, the installation of power plant and the deeper drilling for capacity augmentation.

11. DISCUSSION:

The TGF is poised for development. The present data suggests that a binary cycle power plant of 300 kWe or more is feasible at Tatapani. The borewells need cleaning for attaining continuous production. Monitoring over the past few years has indicated that the discharge is rather consistent. The geophysical, geochemical, AMT survey has corroborated the observation that the reservoir at deep level may have higher temperature. The indicated reservoir temperatures inferred by various methods are summarized in the table below.

Table3: Inferred reservoir temperatures

Sl no.	Method of survey	Indicated temperature
1	Geochemical aqueous Geothermometers	160 °C to 190°C
2	Hydrothermal alteration	180°C to 250°C
3	Fluid inclusion study	140°C to 250°C
4	Discharge monitoring	102°C-138°C

The above studies have postulated possibility of high temperature (160° to 190°C) reservoir at deeper level. AMT survey has suggested low resistivity zone at a depth of >300m to 600m, which might correspond to deep aquifer.

The present discharge is capable to sustain binary cycle power plant of 300 kWe. At Tatapani, the fact that the flow rate is high, that they emerge at near boiling point of water at atmospheric pressure but in association with a gas phase of clear meteoric signature, suggests the presence of a very well developed convective circuit (Mississale and others, 2000). The effluent water from binary plant could be utilized for direct uses viz. spa and tourism.

The estimated reservoir potential at Tatapani is 11 MWe (Sharma & Sud, 2000) to 18 MWe (Pitale et al, 1996). Exploration may be initiated for assessing deep reservoir potential (1500m), simultaneously with the pilot plant installation. The additional hot water production may be utilized for augmenting the production from binary cycle plant. New deep production wells may be planned near present bore wells. A reinjection well would be useful for maintaining the recharge. Cascade direct heat uses, spa and tourism may follow the power plant production.

12. CONCLUSION:

Tatapani Geothermal field is an active geothermal system. Discharge temperature upto 138°C has been recorded during monitoring. Reservoir temperature of 160°C to 190°C is postulated by different geothermometers. Geophysical survey has inferred extension of low resistivity recharge zone (aquifer) at depths below 300m and 600m. As Tatapani is an active geothermal system, encouraging results may be obtained if exploration is carried to deeper level. Present discharge may sustain a 300 kWe binary cycle plant. Exploration to deep level reservoir may prove full potential and commercial viability of power plant.

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REFERENCES

Absar A (1991): Hydrothermal epidote- an indicator of temperature and fluid composition, Journal of Geological Society of India, vol. 38, pp-623-628.

Cox Malcom E and Browne P.R.L (1998) : Hydrothermal alteration mineralogy as an indicator of hydrology at Ngawha geothermal field, New Zealand, Geothermics Vol.27,no. 3,pp-257-270

Fournier R.O. (1981): Geothermal systems , principle and case histories, John Wiley, pp109-140

Giggenbach W.F. (1997) The origin and evolution of thermal fluids in magmatic -hydrothermal systems in Geochemistry of hydrothermal ore deposits, editor Barnis H.S,Wiley interscie. pp 737-789

Harinarayan T & Sarma S.V.S. (1998): Deep electrical conductivity investigations in some geothermal areas of India, Deep electromagnetic exploration, editor Roy K.K., Narosa Publishing House, New Delhi, pp 16.0-175.

Joga Rao M.V, rao A.P., Midha R.K., Padmanabhan K, Kesavmani (1987) Results of geophysical Surveys in the Tatapani Hot Spring area, Distt. Surguja,M.P., Records GSI, vol.115 pt 6, pp 66-83.

Liou J.G.(1971) : P-T stabilities of laumontite, wairakite, lawsonite and related in the system CaAl2Si2O8-SiO2-H2O, Jour.Petrol. vol.12, pp 379-411

Misissale A, Vaselli O, Chandrasekharam D, Magro G, Tassi F and Casiglia A, (2000): Origin and evolution of "intracratonic" thermal fluids from Central –Western peninsular India, Earth and Planetary Science letters, 181, pp 377-314.

Pitale U.L., Sarolkar P.B., Rawat H.S Shukla S.N,.(1996) Geothermal reservoir at Tatapani Geothermal Field, Surguja district, Madhya Pradesh , India, 21rst Stan.geoth workshop, 1996 pp-565-572.

Sarolkar P.B and Mukhopadhyay D.K. (1998): Geochemistry of thermal water from production wells, Tatapani geothermal field, India, GRC transcactions, vol.22, pp-129-135.

Sharma S.K. and Sud V.K. (2000): Technological developments and applications for harnessing geothermal energy, Bulletin of ONGC, Vol.34, No. 2 pp-81-92.

Sharma Suman et al (1996): Isotope and geochemical studies in Tattapani area, GSI sp pub 45, pp- 233-242.

Sharma Suman, Nair A. R, Kulkarni U.P, Navada S.V., Pitale U.L. (1996): Isotope and geochemical studies in Tattapani Geothermal area, Surguja district, Madhya Pradesh, Geothermal energy in India, GSI Sp .Pub no.45, pp223-232.

Steiner A (1953): Hydrothermal rock alteration at Wairakei, New Zealand. Economic Geology, vol no. 48, no.1, pp- 1-13.

Simmons S.F, Stewart M.K, Robinson B.W, Glover R.B.(1994): The chemical and isotopic composition of thermal waters at Waimangu, New Zealand, Geothermics, vol. 23, no.5/6, pp-239-553.

Thussu J.L, Prasad J.M., Saxena R.K., Gyan Prakash, Muthuraman K. 1987: Geothermal energy resources potential of Tatapani hot spring belt , district Surguja, M.P., Geo, Surv. Ind, rec. Vol.115,pt 6,pp 29-55.

Thussu J.L. and Gyanprakash (1987): Assessment of geothermal potential of hot springs of Narmada valley, Madhya Pradesh, GSI, records no. 115, pt 6, pp-84-96

Saxena V. K. (1996): Mineral fluid interaction and chemical equilibrium of prominent geothermal systems of India, GSI Sp pub no.45, pp-233-242 .

Wright Phillip M 1991: Geochemistry, GHC bulletin, Jan ’91, pp8-12.