REASSESSMENT OF GEOTHERMAL ENERGY POTENTIAL IN TATTAPANI GEOTHERMAL FIELD IN BALRAMPUR DISTRICT, CHHATTISGARH STATE, INDIA

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Abstract

Tatapani geothermal field is one of the most important geothermal manifestations in Peninsular India, along Son-Narmada-Tapi (SONATA) rift zone. Earlier workers established feasibility of electric power generation of 300 kWe over the period of 20 years and inferred reservoir potential of 17 MWe.

The reassessment work involving collection of geological; and collation of these data with previous work were undertaken. The Magneto-Telluric survey (MT) indicated four conductor bodies right from 0.5km depth to 20km depth. The aqueous geothermometers indicated a temperature range of 160°C to 210°C. The maximum temperature is recorded 112.5°C in a borehole located at 23°41'16.4" N: 83°38'57.8" E.

The assessment is carried out on a shallow depth conductor body exist at 0.5km to 2km depth for which thermal log data of exploratory boreholes and hand pumps are available. The main geothermal zone extends over a length of 1380m from ENE to WSW with width varying from 270m in ENE to 345m in WSW at the depth of 250m. The average temperature surfaces at 500m interval has been used for constructing a 3D model to decipher vertical disposition of temperatures in the thermal reservoir. The geothermal reservoir shows elliptical shape with longer axis parallel to ENE-WSW trending Tatapani fault. The shape is also corroborated by the MT survey.

The available heat for power generation is calculated 42 MWe for 20 years from the volume of 4.4 x 10^9 m^3 having depth of 1000m to 2000m. It is also attempted for 500m productive zone from 1500 m to 2000 m depth which is worked out 31 MWe for 20 years from the volume of 2.95 x 10^9 m^3 having depth of 1500m to 2000m. The reassessment indicates that the Tatapani geothermal resource has high potential to generate electricity from shallow depth by binary cycle method.

1 Introduction

The Tattapani geothermal field, which falls in Son River basin is one of the most important geothermal manifestations on Son-Narmada-Tapi (SONATA) lineament. The geothermal manifestation is in the form of hot springs and marshy ground. The area has been extensively studied and mapped by GSI to assess the resource potential for development of geothermal energy. During the geothermal investigation carried out from 1980-1995, 26 exploratory boreholes have been drilled to know the subsurface geology, extension and subsurface reservoir condition of geothermal resources, evaluation of resources up to 350m depth for pilot power generation. GSI established feasibility of electric power generation of 300 KWe (Sharma, 2015) and inferred the reservoir potential of 18 MWe over the period of 20 years (Pitale et al 1995). Magne-Totelluric (MT) studies in the area have delineated a deep, anomalous conductive zone possibly indicating the subsurface extent of the reservoir (Harinarayana et al., 2004).

Chhattisgarh Renewable Energy Development Agency CREDA and National Thermal Power Corporation Limited (NTPC Ltd) had signed the Memorandum of Understanding (MoU) on 16th February 2013 to explore the potential of geothermal resources and subsequently implement geothermal based power project at Tattapani in the State of Chhattisgarh on Build, Own and Operate (BOO) basis. GSI has come forward to provide the geological input for preparation of Detailed Geological Project Report (DGPR) for geothermal power project at Tattapani, Chhattisgarh. Therefore, the Memorandum of Understanding (MoU) is signed between GSI and NTPC Ltd on 7th January 2014. Therefore, the review work on assessment of geothermal energy potential had been taken up during the period from March 2013 to March 2015.

2 Geology

The rocks exposed around Tattapani area belong to Archaean Complex and Gondwana Supergroup. The rocks of Archaean are widespread and occupy north, south and southwestern part of the Tattapani area, while the Gondwana rocks are exposed in the north western part which forms the part of Tattapani-Ramkola Coalfield (Fig 1). The Archaean Complex is represented by grey pink gneisses, which grade into augen gneiss, hornblende gneiss, biotite gneiss, amphibolites etc. Granulite bands of 1m to 4m thickness are observed which form as good marker horizons for picking up cross faults. Two generations of pegmatite and quartz veins are reported in granite phase. Gondwana Supergroup is represented by splintery shale, conglomerates, sandstone and shale bands with coal streaks and plant fossils; reddish to reddish brown sandstone and grit bands.The geothermal activity is controlled by ENE – WSW trending Tattapani Fault and NE – SW trending cross faults (Sharma, 2015).

3 Data collection

The authors have collected field data on geology, geochemical and isotope study of Tattapani geothermal manifestations during 2013-2015 as well as collect and collated thermal logging data of exploratory boreholes drilled during the period from 1980 to 1995 by observing geothermal activity in the study area. Magneto-Telluric Survey was carried out by the NGRI. The field data collected during ongoing study and thermal logging data collected from previous reports have been immensely helped in reviewing the geothermal energy resources. In this paper, the thermal log data is exclusively used for building model and assessing the geothermal energy resources by taking into consideration of output of geochemistry, geophysical and isotope studies.

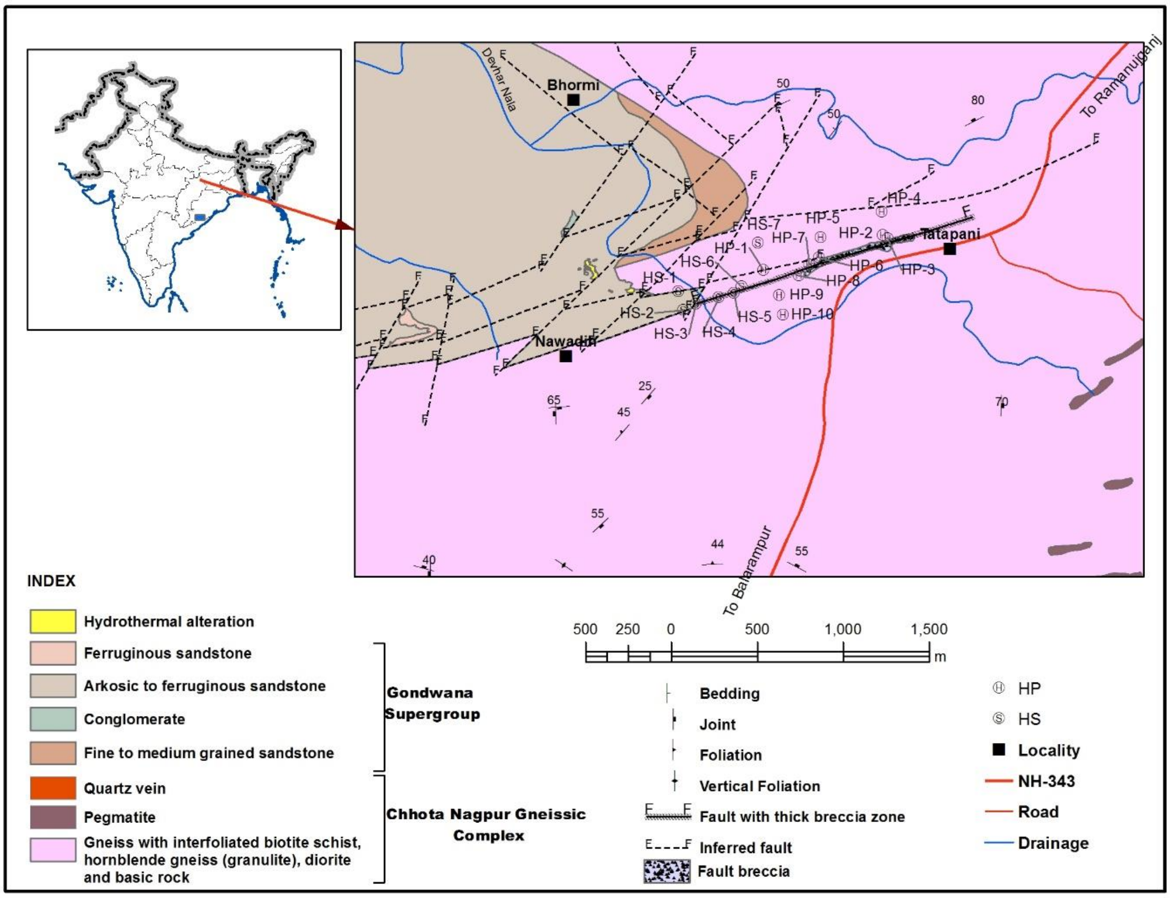

Fig.1: Geological map of area

4 Data Interpretation

4.1 Isometric diagram and evaluation

The isometric zoning of temperature from 27°C (average surface temperature) to >100°C has been done for every 10°C interval say <30°C-40°C, 40°C-50°C (Fig. 2). Thermal log data of boreholes and hand pumps are plotted up to 250m to 350m depth, along spatially plotted borehole and hand pumps. In case of hand pump, the extrapolated temperature data beyond 50m depth of hand pumps were used for plotting on the isometric diagram. The thermal logging of hand pumps could be carried out for the depth ranging from 20m to 65m, depending on the clear depth of the borehole. After preparing the isometric diagram for the whole area of previously drilled 26 exploratory boreholes and hand pumps, the major zoning of temperature has been attempted for <50°C, 50°C-100°C and >100°C to focus on the viable area of geothermal field.

The temperature more than 100°C is expected at 70m depth in the WSW (around TAT/6, 23, 24, 25 & 26) to 100 to 200m depth in the ENE (around HP/2, 3, 4) and this high temperature zone coincides with ENE-WSW trending Tattapani fault. There is slight inversion of temperature in the borehole no. TAT/7 as observed from thermal log and the thermal log of HP/3 carried out during May 2015 has given low thermal gradient of 0.29°C/m and low bottom hole temperature (BHT) of 53°C at the depth 55m as compared to HP/2 & 4. The exploratory borehole TAT/7 and HP/3 might be located on subsurface non-thermal water channel. Otherwise, the hand pumps nos. HP/2 and TAT/4 located nearer to TAT/7 and HP/3 have measured BHT of 68.7°C and 73.6°C at 48m and 55m depth, respectively. By considering above facts and area of influence based on isometric diagram at an average depth of 250m, the surface dimension of viable geothermal zone has the length of 1380m ENE-WSW direction and width of

270m in ENE part to 345m in WSW part covering total area of 0.433 sq km.

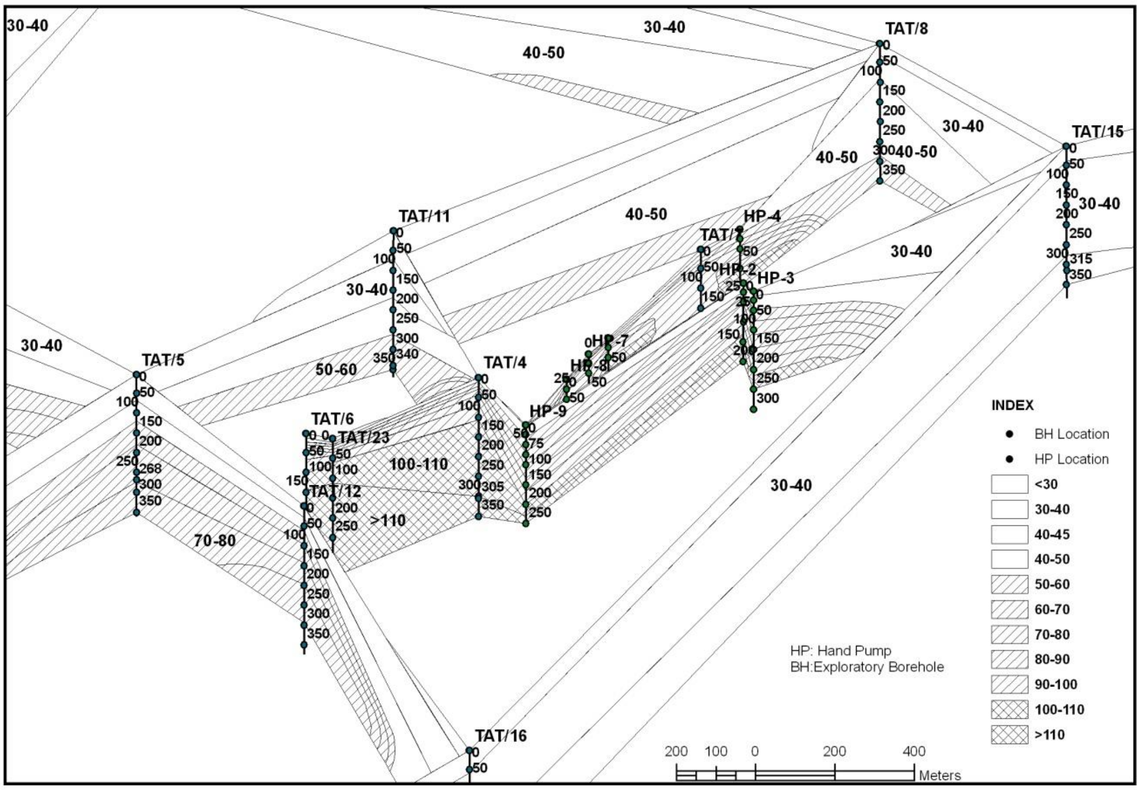

Fig. 2: Isometric diagram for thermal log of previously drilled boreholes and hand pumps

4.2 Heat flow

The heat flow values are calculated in the range 300 ±18 mW/m^2, which is higher than the average continental heat flow value of 65 mW/m^2. The average heat flow for Tattapani area is of the order of 290 + 50 mW/m^2, however, these values are only tentative and will have to be refined when more precise data on thermal conductivity are available for Tattapani core samples (Ravi Shanker, 1987). The average heat flow for viable geothermal zone of 0.433 sq km area is worked out 1290 mW/m^2. It suggests a strong geothermal field where high temperature around 190°C may be expected as suggested by aqueous geothermometry, fluid inclusion, geothermal mineral alteration studies etc.

4.3 Temperature at various depths

The maximum temperature of 112.5°C and pressure of 42 kg/cm^2 at 280-300m depth has already been recorded during shallow depth exploration (Pitale et al, 1996). Reservoir temperatures are expected to be 112°C ± 30°C at 1 km depth and 230°C ± 40°C at 3 km (Vaidya et al, 2015). The well testing of TAT/6, 23 to 26 recorded maximum temperature of 112.5 °C and static pressure in the ranges from 4-5 kg/cm2 at well head to 34 kg/cm^2 at the depth of 350m (Sarolkar et al, 2002). The authors have calculated average temperature for 1000m depth of the study area based on interpreted temperature for boreholes and hand pumps. The contours of more than 100°C temperature are taken for calculating the area and its configuration is almost comparable with surface temperature. It is observed that the viable area of more than 100°C temperature is about 2.587 sq km. However, the area for more than 130°C temperature is about 0.569 sq km.

The average temperature for 1500m depth of the study area is prepared based on interpreted temperature for boreholes and hand pumps. The contours of more than 130°C temperature are taken for calculating the area and its configuration is almost comparable with surface temperature. It is observed that the viable area for more than 130°C temperature is about 2.321 sq km. However, the area for more than 160°C temperature is about 0.672 sq km.

The average temperature for 2000m depth of the study area is prepared based on interpreted temperature for boreholes and hand pumps. The contours of more than 130°C temperature are taken for calculating the area and its configuration is almost comparable with surface temperature map. It is observed that the viable area for more than 130°C temperature is about 7.567 sq km. However, the area for more than 160°C temperature is about 2.145 sq km.

4.4 Configuration of geothermal reservoir

The depth configuration of geothermal reservoir is prepared by using the surface area of viable geotherms at various depths decided during the preparation of average temperature layers. The viable temperature zones at 250m, 1000m, 1500m and 2000m have been used for constructing the scene for vertical appearance of thermal reservoir (Fig. 3). It is observed to be elliptic conical in shape with elongated axis parallel to ENE-WSW trending Tattapani fault. The temperature > 125°C is expected to get from 1km depth with an aerial extent of 0.745 sq km and the same temperature is expected to spread over the area of 9.75 Sq km at 2 km depth. There is continuity of temperature >125°C from 1km depth. Hence, the ultimate 3D shape of geothermal reservoir is considered as an elliptic conical frustum from depth of 1000m to 2000m. The lengths of elongated axis of elliptic conical frustum at the depth of 1000m and 2000m are 2.5Km and 4.3Km km respectively.

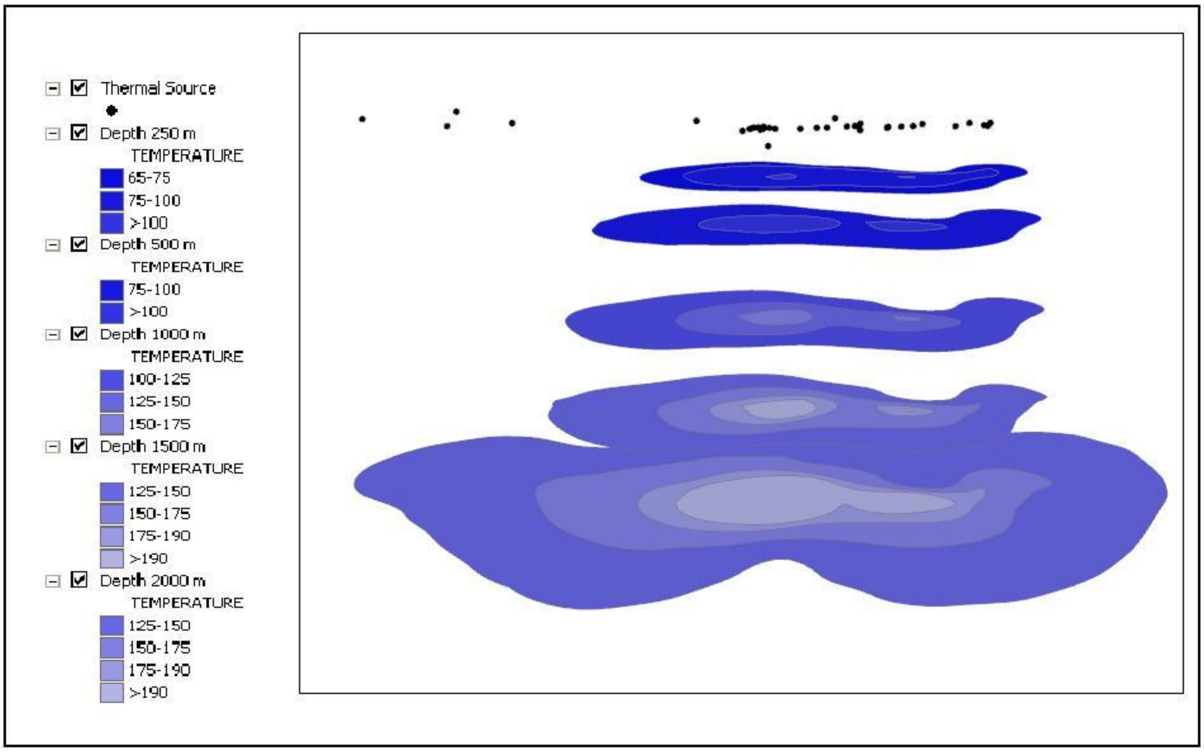

Fig. 3 : Configuration of Reservoir at various depth

4.5 *Geophysical Survey*

Earlier, MT survey was carried over 150 sq km area indicated the presence of an anomalous zone extending in an east west direction near the hot springs (Sarolkar, 1994). MT results delineated anomalous deep conductive structure at a depth of about 2.0 km extending towards west of Tattapani related to the geothermal manifestation of the region (Harinarayana et al, 2004). NGRI has carried out the MT survey, the regional traverse trending in an approximate NE-SW direction cutting across the Tattapani fault is brings out four major conductors. First conductor at 10-20 km depth about 2-3 km south of the Tattapani fault zone. The two conductors at about 4-5 km north of the fault of which the northern conductor is relatively shallower and southern lies at deeper 8-10 km level. The shallowest conductor located just north of Tatpani fault which lies at 1-2 km depth.

3D MT model brought out a high conductivity anomaly close to the north of Tattapani fault which shows an elliptical shape conductive zone oriented in a near N-S direction at the depth of 2km. The upper crustal conductor, particularly at shallower depths (0.5km), with a high resistive rim around it, appears as a "bay" or an elliptical shaped conductive body.

5 Evaluation of Geothermal Resources

India is yet to be come forward for exploiting the geothermal energy resources for power generation and other ancillary uses. Tattapani is the only geothermal field in India, which is attempted several times for exercising the resource potential assessment and exploitation for power generation. We have to depend partially or fully on overseas for establishing the power plant on geothermal energy resources as the required equipment and technology are lacking in India for exploring and exploiting the renewable energy from geothermal system. Once, the power project at Tattapani geothermal field become successful and run for several years, and then it will open the avenue for exploring and exploiting the geothermal resources available at other places in India. The assessment of geothermal resources is restricted to 2000m depth by seeing constraints for exploitation of geothermal energy.

The geological and geophysical studies confirmed the elliptic conical shape of geothermal reservoir at Tattapani with elongated axis is parallel to the ENE-WSW trending Tattapani fault. There is a continuity of temperature >125°C after 1000m depth. Therefore, the 3D shape of geothermal reservoir is considered as an elliptic conical frustum from 1000m to 2000m depth. The bottom depth for resource calculation is restricted to 2000m due to reason enumerated in the previous paragraph. The lengths of elongated axis at the depths of 1000m and

2000m are 1.49 km and 4.3 km respectively. The temperature > 125°C is calculated over an aerial extent of 0.745 sq km at 1000m depth and it is expected to spread over an area of 9.74 sq km at 2000m depth. The volume of the geothermal reservoir is calculated by applying formula of elliptic conical frustum.

The thermal potential of the Tattapani area has been calculated with an assumption of elliptic conical frustum of geothermal reservoir with basal areal extent of 9.75 sq km at depth of 2000m, 5% assumed fracture porosity in rock and Temperature ΔT (185°C-100°C). The highest temperature of 185°C is taken in to consideration of calculating the resource potential at 2000m depth as several geoscientific studies like aqueous geothermometers, fluid inclusion, geothermal mineral alteration studies etc. suggested temperature around 150°C to 190°C in the Tattapani geothermal field. The maximum temperature was recorded 112.5°C at 350m depth in borehole No. TAT/23.

The following equations after Mendrinos et al 2008 have been used for geothermal energy resource calculation:

$$E_{st} = [(1-\phi) \times \rho_r \times C_r + (\phi \times \rho_w \times C_w)] \times V \times (T-T_b) \quad \text{..........1}$$

$$E_r = E_{st} \times R \quad \text{...........2}$$

$$N_e = \frac{E_r \times \eta}{F \times t} \quad \text{..........3}$$

Where: E_{st} – Stored heat in kJ or mJ, E_r – Recoverable heat in kJ, ϕ – Porosity in %, ρ_r –Rock density in kg/m^3, ρ_w – Water density in kg/m^3, C_r – Rock heat capacity in kJ/kg°C, C_w – Water heat capacity in kJ/kg°C, V – Rock Volume in m^3, T – Rock natural state temperature in °C, T_b –Base temperature in °C, R – Recovery factor, N_e –Installed power plant in MWe, η – Conversion efficiency, f –Load factor, t –Commercial life span of the plant in years

6 Result

There may be a continuity of temperature >125°C after 1000m depth. The bottom depth for resource calculation is restricted to 2000m due to reason enumerated in the previous paragraph. The lengths of elongated axis at the depths of 1000m and 2000m are 1.49 km and 4.3 km respectively. The temperature > 125°C is calculated over an aerial extent of 0.745 sq km at 1000m depth and it is expected to spread over an area of 9.75 sq km at 2000m depth.

In general, most geothermal power plants, either flash or binary, operate with conversion efficiency is around 10-15%. (Mendrinos et al 2008). Recovery factors vary between 10-50% depending on the geological prevailing conditions, with an average value of 25% for hydrothermal resources (Mendrinos, 1988). In order to express the geothermal resources in terms of MWe of power plant installed, we need to define the life of the plant (usually taken as 20-25 years) and the load factor (usually taken as 90-95% for base load plants) (Mendrinos et al, 2008). The geothermal geothermometers and thermal logging data indicated that there may be a continuity of temperature >125°C below 1000 m depth. The heat available for power generation is attempted for 1000m to 2000m depth and followed by 1500m to 2000m depth of productive zone to see in which zone, the maximum heat is available for power generation.

6.1 Heat for power generation in 1000m to 2000m productive zone

The average temperature 175°C as extrapolated from measured temperature is taken in to consideration for calculating the resource potential from 1000m to 2000m depth. The volume for the productive zone of 1000m to 2000m is calculated in the order of 4400929078 m^3.

The heat for power generation is assessed as:

Volume of anomalous area (V) : 4400929078 m^3

Porosity of rock (ϕ) : 5 %

Density of rock (ρ_r) : 2700 kg/m^3

Specific heat of rock (C_r) : 0.79 kJ/kg °C

Expected base temperature (T_b) : 175 °C

Temperature limit for electricity generation by ORC system (T) : 85 °C

Density of water at 175°C (ρ_w) : 893 kg/m^3

Heat capacity of water at 175°C (C_w) : 4.39 *kJ/(kg °C)*

A) Energy liquid = $(\phi \times \rho_w \times C_w)] \times V \times (T-T_b)$

= 0.05 x 893 x 4.39 x 4400929078 x 90

= 7759.82 x 10^{10} kJ

= 7759.82 x 10^7 MJ_{Th}

= 7759.82 x 10^7 MJ_{Th} / 63 x 10^7 Seconds

= 123.02 Mwe for 20 years

=36.90 Mwe ∴ The recovery factor consider as 30%

=3.69 Mwe ∴ The conversion efficiency taken as 10%

B) Energy rock = $[(1-\phi) \times \rho_r \times C_r \times V \times (T-T_b)$

= 0.95 x 2700 x 0.79 x 4400929078 x 90

= 80818.4 x 10^{10} kJ

= 80818.4 x 10^7 MJ_{Th}

= 80818.4 x 10^7 MJ/63 x 10^{7}seconds

= 1281.36 MWe for 20 years

=384.41 MWe ∴ The recovery factor consider as 30%

=38.44 MWe ∴ The conversion efficiency taken as 10%

Total Energy (A+B) = 3.69 + 38.44 MWe

= 42.13 MWe for 20 years

The geothermal energy for power generation from 1000m productive zone at the depth of 1000 m to 2000 m over an area of 4.4 x 10^9 m^3 is calculated by assuming 0.05% porosity. It is worked out to be in the order of 42 MWe for 20 years.

6.2 Heat for power generation in 1500m to 2000m productive zone

The average temperature of 185°C as extrapolated from measured temperature is taken in to consideration for calculating the resource potential for 500m productive zone at 1500m to 2000m depth. The calculation of volume for 500m productive zone is is calculated in the order of 2956745543 m^3.

The parameters for heat calculation:

Volume of anomalous area (V) : 2956745543 m^3

Porosity of rock (ϕ) : 5 %

Density of rock (ρ_r) : 2700 Kg/m^3

Specific heat of rock (C_r) : 0.79 kJ/Kg °C

Expected base temperature (T_b) : 185 °C

Temperature limit for electricity generation by ORC system (T) : 85 °C

Density of water at 185°C (ρ_w) : 882 Kg/m^3

Heat capacity of water at 185°C (C_w) : 4.45 *kJ/(kg °C)*

i. Energy liquid = (ϕ x ρ_w x C_w)] x V x (T-T_b)

= 0.05 x 882 x 4.45 x 2956745543 x 100

= 5802.47 x 10^{10} kJ

=5802.47 x 10^7 MJ_{Th}

= 5802 x 10^7 MJ/ 63 x 10^7 Seconds

= 91.99 MWe for 20 years

=27.6 MWe ∴ The recovery factor consider as 30%

=2.76 MWe ∴ The conversion efficiency taken as 10%

ii. Energy rock = [(1-ϕ) x ρ_r x C_r x V x (T-T_b)

= 0.95 x 2700 x 0.79 x 2956745543 x 100

= 60330.5 x 10^{10} KJ

= 60330.5 x 10^7 MJ_{Th}

=60330.5 x 10^7 MJ/63 x 10^7seconds

=956.3 MWe for 20 years

=286.96 MWe ∴ The recovery factor consider as 30%

=28.69 MWe ∴ The conversion efficiency taken as 10%

Total Energy (i + ii) = 2.76 +28.69MWe

= 31.45 MWe for 20 years

The geothermal energy for power generation from 500 m productive zone at the depth of 1500 m to 2000 m over an area of 2.95 x 10^9 m^3 is calculated by assuming 5% porosity. It is worked out to be in the order of 31 MWe for 20 years.

Recoverable heat from liquid, assuming no recharge, is of the order of 3.1 MWe at proven temperature of 112°C (Pitale et al, 1995). In fact, higher temperature > 190°C as envisaged from aqueous geothermometry, fluid inclusion, geothermal mineral alteration studies etc. It is likely to be encountered at 2000 m depth. Once these temperatures are actually recorded in deep wells, the potential of geothermal field at Tattapani is like to increase manifold and sustain full-scale commercial utilization in the field of electricity generation and direct heat utilization. If the proper recharging considers of geothermal system, then the existing resources may sustain the power generation of 40 MWe for 20 years span or we can comfortably establish 10 MWe power generation by binary cycle Rankine system after exploring deep resources by drilling at least three deep boreholes up to 2000m depth. An Organic fluid binary–cycle power plant is suitable for electricity generation for low to medium enthalpy of the thermal water (Muffler et al, 1978) and the binary-cycle pilot power plant may be planned in a cascading method to utilize the effluent water of 87°C from the primary binary unit for generation of additional electricity; Sarolkar, 2000). The Magnento-Telluric Survey indicated four conductors at various depth up 20km and the resources evaluation is attempted for shallower depths (0.5km) conductor only.

Based on the above calculation, it appears to be interesting for examining the Tattapani geothermal area through power generation angle. At least, three deep wells to the depth of 2000 m are to be drilled to arrive at the exact nature of the reservoir and its behaviour at 2000 m depth level and calculation proved geothermal energy resources.

7 Conclusion

The study carried out to review energy resources in Tattapani geothermal field, Balrampur District, Chhattisgarh State, India in view of initiation of Government of Chhattisgarh and National Thermal Power Corporation Limited (NTPC) for establishing geothermal power plant. The field data collected during ongoing study and thermal logging data collected from previous reports have been immensely helped in reviewing the geothermal energy resources. The isometric diagram was helpful in deciding the surface dimension of viable geothermal zone having length of 1380m and width of 270m in ENE to 345m in WSW covering total area of 0.433 sq km at an average depth of 250m. From the existence of faults and temperature data, It is observed that the recharging of geothermal system is taking place in western part through the sedimentary horizons of Gondwana Supergroup ranging in thickness from 200 to 500m and the geothermal fluid is reaching the surface in the form of hot springs by convective heat transmission process through secondary porosity (fault system) in the eastern part.

The extrapolated temperatures have been calculated for various depths up to 2000m from thermal log data and established the 3D scene. The 3D scene indicated the elliptic conical shape of geothermal reservoir. It is also confirmed that the temperature > 125°C is expected to get from 1000m depth with an aerial extent of 0.745 sq km and the same temperature is expected to spread over the area of 9.75 Sq km at 2000m depth. Ultimately, the inferred nature of assessment geothermal energy resources has been for Tattapani geothermal area. The total available heat in the geothermal system is assessed as 163588 x 10^7 MJ_{Th} over an area of 4.95 Km^3 with depth from 70m to 2000m. The available heat for power generation is assessed as 42 MWe for 20 years over an area of 4.4 Km^3 with depth from 1000m to 2000m. The calculation of available heat for power generation is also attempted for 500m productive zone from 1500m to 2000 m depth. It worked out 31 MWe for 20 years over an area of 2.95 Km^3. Though, the assumed temperature for assessment of geothermal resources is exclusively based on the various geoscientific investigations and shallow depth exploration carried out by GSI, the confidence level has been increased from the configuration of geothermal reservoir as well as confirmation of conduit zone (Tattapani fault) and existence of four major conductors investigated by MT survey carried out by NGRI. There is need to explore the deeper reservoir to establish actual potential of the geothermal reservoir (Sarolkar et al 2015).

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References

Harinarayana, T., Someswara Rao, M., Sarma, M.V.C., Veeraswamy, K., Lingaiah, A., Rao, S.P.E., Virupakshi, G., Murthy, D.N. and Sarma, S.V.S., 2004: Delineation of a deep geothermal zone in Tattapani region, Surguja district, M.P. EM-INDIA Seminar, Hyderabad, India, Abstracts.

Mendrinos, D. (1988) : "Modelling of Milos Geothermal Field in Greece", Master in Engineering Thesis,

Proceedings, Twenty-First Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 22-24, 1996

Ravi Shanker; Thussu, J. L. and Prasad, J. M. (1987): Geothermal Studies at Tattapani Hot Spring Area, Sarguja District, Central India. Geothermics, Vol. 16, No. 1, pp. 61-76, 1987, Printed in Great Britain.

Sarolkar P.B. (1994): Subsurface geological studies in Tatapani geothermal field, district surguja (M.P)., Records GSI Vol.127, pt. 6, pp. 147-151.

Sarolkar, P.B.; and Sharma, S.K. (2002): Geothermal Well Testing at Tattapani Geothermal Field, District Surguja, India. Proceedings, Twenty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 28-30, 2002

Sarolkar, P. B. (2000): Suggestions for the proposed Binary-Cycle Geothermal Power Plant, Tattapani, District Surguja, India. *Geothermal Resources Council Transactions*, Vol. 24, September 24-27, 2000

Sarolkar, P. B., and Das, A K (2015): Assessment of Tattapani Geothermal Field, Balarampur District, Chhattisgarh State, India. Proceedings World Geothermal Congress 2015 Melbourne, Australia, 19-25 April 2015

Sharma S. K. (2015): Low Enthalpy Geothermal Resource Development At The Tattapani, India. Proceedings World Geothermal Congress 2015, Melbourne, Australia, 19-25 April 2015

Vaidya, D.; Shah, M., Sircar, A.; Sahajpal, S. and Dhale, S. (2015): Geothermal Energy: Exploration Efforts in India. International Journal of Latest Research in Science and Technology, Volume 4, Issue 4: Page No.61-69, July-August 2015

Department of Theoretical and Applied Mechanics, School of Engineering, University of Auckland, New Zealand, 1988.

Mendrinos, D.; Karytsas, C. and Georgilakis, P. S. (2008): Assessment of geothermal resources for power generation. Journal of Optoelectronics and Advanced Materials Vol. 10, No. 5, May 2008, p. 1262 – 1267

Muffler, P and Cataldi, R (1978) : Methods for Regional Assessment of Geothermal Resources, Geothermics, Vol. 7, (1978), pp 53-89.

Pitale, U. L.; Padhi, R. N. and Sarolkar P. B. (1995): Pilot geothermal power plant and scope of commercial utilisation of Tattapani geothermal field, Surguja District, Madhya Pradesh, India. (World Geothermal Congress 1995)

Pitale, U. L.; Sarolkar, P. B.; Rawat, H.S. and S. N. Shukla (1996): Geothermal reservoir at Tattapani geothermal field, Surguja district, Madhya Pradesh, India.