PROCEEDINGS, 41st Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 22-24, 2016
SGP-TR-209

Utilisation of Geothermal Resources of West Coast, India

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Keywords: Ganeshpuri, Tural, west coast, hot springs, India

ABSTRACT

West Coast of India hosts a series of hot springs along a nearly 300 km long stretch parallel to the coast, Koknere in north and Rajapur in south delimit this hot spring belt. Hot water of 42°C at surface is discharged at Rajapur and 71°C at Unhavre (Khed). The discharge of these hot springs varies from 30 lpm at Sativli to 800 lpm at Unhavre (Khed) / Aravali. The hot water from these springs show sodium bicarbonate- sulphate type water. Chloride content of hot water varies from 25 ppm at Rajapur, 340 ppm at Tural to 1060 ppm in Unhavre (Khed); SO_4 content varies from 100 ppm at Tural to 192 ppm at Sativli; HCO_3 from 47ppm at Tural to 213 ppm at Rajapur; sodium 87 ppm at Rajapur to 500 ppm at Unhavre (Khed). SiO_2 varies from 20 ppm to 88 ppm at Unhavre (Khed). Na/K geothermometer indicates reservoir temperature of these springs from 113°C at Rajawadi to 170°C at Tural. (Khed). Fluorine content varies from 1.3 to 1.9 ppm in these springs. Chemical composition of these springs suggests that the thermal water from Tural, Ganeshpuri and Unhavre (Khed) show more affinity to geothermal water. The demand for electricity in Maharashtra State is continuously increasing. Similarly, the increasing industrial activity requires additional cold storage facility, green house cultivation and easy energy substitute. The availability of geothermal resource at West Coast can be utilized for site specific energy production and substitution. The water quality, indicated reservoir temperatures and local conditions suggest that the hot springs at Unhavre (Khed), Tural and Ganeshpuri may be utilized for power generation as well as direct heat uses.

1. INTRODUCTION

Numerous hot springs are located along West Coast of India, spread over a 300 km long NNW-SSE trending stretch with a width of 20-30 km (Ravi Shanker 1987, Pitale and Padhi 1995). The West Coast geothermal belt consists of 18 hot springs viz. Koknere in north and Rajapur to south along the coast. The geothermal belt has been divided into 3 sectors. The northern sector comprising Koknere, Heloli, Sativli, Ganeshpuri, Akloli: central sector comprises Pali, Sov, Vadavli, Unhavre (Tamhane) and southern sectors consist of Khed, Unhavre (Khed), Aravali, Tural, Rajawadi, Math, Sangmeshwar and Rajapur hot springs, respectively. Surface temperatures of these hot springs vary from 34°C at Koknere to 71°C at Unhavre (Khed), whereas discharge varies from < 1 to about 14 lps.

2. STRUCTURE

The terrain is mostly covered by basaltic flows, traversed by lineaments in NNE-SSW and NNW-SSE directions and cross lineaments in E-W direction. Columnar joints are very prominent, trending in NE-SW and NW-SE directions. All these planar features are likely to act as conduits for thermal fluid. Permeability is fracture controlled. Fracture zones are recorded at 15 to 70 m and 175 m depths in the boreholes at Unhavre (Khed). These fractures are mostly at 45° or higher.

3. GEOCHEMISTRY

The water from these hot springs is mostly Na-Cl type with high SO_4 content (Table - 1). High Cl values of > 1000 mg/l, Na concentration of 200 to >600 mg/l and SO_4 values of >100 mg/l, all point to the possibility that thermal waters along the west coast are mixture of meteoric and sea water in different proportions (Muthuraman 1987). Based on parameters, such as, surface temperature, silica content and indicated reservoir temperature, Unhavre (Khed) and Tural host springs have been selected here for a further study.

These thermal waters composition are characterized by high Cl and SO_4 contents (Table–1). The Na/K geothermometer suggests reservoir temperature of 170°C at Tural and 145°C at Unhavre (Khed). Applicability of this thermometer to west coast hot springs is, however, doubtful due to possible seawater incursion.

Table 1: Chemical composition of hot springs, West Coast

	Tural 1	**Rajwadi**	**Unhavre (Khed)**	**Rajapur**	**Ganeshpuri**	**Sativali**
pH	7.5	7.6	7.5	8.6	8.4	8.5
Cond at 25°C	1359	15.3	3480	458	2340	2760
CO3	0	0	0	13	12	12
HCO3	49	22	18	213	0	0
Cl	340	380	1060	25	700	950
SO4	100	110	141	3	132	130
Ca	52	52	180	8	152	186
Mg	0	5	0	15	0	0
Hard Ness as CaCO3	130	150	440	80	380	410
Na	244	270	604	87	350	432
K	10	10	26	17	14	23
TDS	858	917	2331	302	1723	1932
SiO2	83	88	54	20	56	55
B	5	0.5	0.5	0.5	0.5	0.5
F	1.84	1.9	1.3	0.75	1.94	1.63

Temperature estimated by silica method may also be on the lower side due to mixing of local groundwater / sea water at shallow levels (Table-2).

Table 2: Indicated reservoir temperatures

Area	Na/K	SiO_2 No St loss	SiO_2 Max St loss
Unhavre	145°C	130°C	127°C
Tural –1	170°C	127°C	124°C
Rajwadi 1	282°C	64°C	67°C
Rajwadi 2	113°C	74°C	78°C

After Fournier (1979 & 1985)

4. HYDROTHERMAL MINERALS

The hydrothermal alteration study at Unhavre (Khed) boreholes indicates a zone of low temperature minerals at shallow depth to 52 m, comprising kaolinite, clinoptilite, calcite, magnetite and hematite. The assemblage calcite, stilbite, montmorillonite, heulandite, clinoptilite, apophyllite, hematite and magnetite are reported at depth of 106 m to 169 m (Pitale et al 1996). Platy calcite is reported at the depth of 130 m.

This hydrothermal mineral assemblage indicates a temperature of > 100° C to 130° C, with the possibility of boiling, as suggested by the presence of platy calcite. Platy calcite is absent at shallow levels due to higher solubility of calcite at low temperature. The reservoir temperatures of about 130°C indicated by the hydrothermal minerals are similar to those inferred by silica thermometry but far too high as compared to temperatures recorded in the boreholes in Unhavre (Khed). This implies that either the true temperature conditions are masked by inflow of shallow cold water or the area has cooled down substantially with time. Another possibility that can not be ruled out is that boreholes at Unharve are peripheral to the upflow zone.

5. BOREHOLE DATA

Total 8 exploratory boreholes were drilled in Unhavre (Khed) -Tural area. Data from some of these are summarized in Table-2.

Thermal profiles at Unhavre (Khed) and Tural shows temperature inversions at shallow depth. Bottom hole temperature of 58°C is reported in UNGW-5 at 230 m and 54°C at 500 m in UNGW-1 (Pitale et al 1987) . The bottom hole temperature is less than the hot spring temperature of 71°C. These temperature reversals are related to inflows of meteoric/ ground water and have resulted in masking higher temperature that may occur at the deeper level. Alternatively, the boreholes are located away from the upflow zone.

Table 3: Summary of boreholes at Unhavre (Khed) and Tural

Borehole no.	Depth	Bottom hole temp °C	Max Temp °C	Depth of Max temp	Mixing zone
UNGW-1	500m	49	54	70m	90-190m
UNGW-2	90m	52.3	58	70m	70-90m
UNGW-3	75m	42.2	--	-	--
UNGW-4	168m	38.8	--	--	--
UNGW-5	230m	56.5	58	20m	20-50m
UNGW-6	300m	48.1	--	--	--
Tural –1	49.85m	45.5	50	50m	50-70m
Tural -2	100m	41	--	--	--

The study of thermal profiles of these boreholes shows temperature reversal at shallow depth. The boreholes UNGW-3 & 4 show conductive thermal gradient. Boreholes UNGW-1, 2, 5, and Tural 1 & 2 show thermal reversal below the depth of 100m, indicating mixing zone. The temperature reversal is recorded in the borehole UNGW-1 at the depth of 90-190m, at 80-90 m depth in UNGW-2 borehole, 20m at UNGW-5, and at 50-60m depth in Tural-2. Steep gradient thermal profile is recorded in borehole Tural –1.

The silica content at Unhavre might be diluted due to mixing at shallow level. Even though this possibility is indicated by well logging at Unhavre (Khed), it needs to be confirmed. Hence, it may be surmised that the silica content in the thermal water at Unhavre, (64 ppm at surface) may be within the silica saturation in effluent water (Temperature 149°C to 65°C) from binary cycle power plant. The sulphate also shows similar trend in hot water at Unhavre (Khed). The major hazardous radical fluoride is within permissible limits and may not cause problem in production. Most of the boreholes show increase in temperature up to the depth of 60-70m, below which mixing zone is encountered. High Na and Cl content in the hot spring in Unhavre (Khed) certainly points to the possible mixing with sea water, which is also supported by temperature reversal observed in the thermal log of boreholes in this area. At Tural hot springs, the silica content is reported to be 122 ppm. The thermal logging of boreholes at Tural indicated temperature inversion around 50 m depth. The Na and Cl content in the Tural hot spring water is lesser as compared to Unhavre (Khed) hot spring, indicating lack of incursion of seawater.

As the thermal water at shallow level is affected by mixing, deeper drilling is necessary to prove the parameters of deep geothermal reservoir.

6.1 ELECTRICITY GENERATION

Huang (2015) indicated that binary cycle can run on temperature of 95°C and outlet of 65°C to produce electricity using R245fa organic fluid. Taggdosi et al (2015) have estimated that in Indonesia a 6 MW binary cycle power plant can be established with 175°C hot water of 1200 KJ/kg and discharge of 60 kg/s. Similarly, Heberle et al (2015), indicated that geothermal power generation for 5.5 MW double stage power plant was possible with R245fa as working fluid. Geothermal water of 135°C @ 122 lps discharge, with outlet temperature of around 68°C is used in this binary cycle power plant. Similarly, the low temperature, high discharge resources at Unhavre (Khed) and Tural may be utilized for binary cycle power generation.

Unhavre (Khed) hot springs have indicated reservoir temperature of 130° to 145°C and indicated reservoir temperature of 170°C is at Tural. The above indicated temperatures suggest that the reservoir may be mostly liquid dominate, with less steam content. The electricity production from these hot springs may be through binary cycle power plants, using secondary fluid operated through an Organic Rankine Cycle. The ambient temperature in this area is around 35°C to 40°C in summer; hence the binary cycle power plant can be designed to operate at the temperatures in the range of 170°C to 65°C. The upper temperature limit is restricted by the thermal stability of the organic binary fluids. Isopentane with boiling point of 28°C is suitable for Organic Rankin Cycle power plant. Table 4 shows the possible power potential per kg of fluid.

Table 4: Power potential of binary cycle plant at different temperatures

Tempe ratu Re	Inlet Enthal py kj/kg	Outlet (65°C) Enthalpy kj/kg	ΔH kj/k G	Power output Kwe/kg
170°C	712.3	272.4	440	44
150°C	628	272.4	356	35.6
145°C	607.5	272.4	335	33.5
130°C	544.7	272.4	272	27.2
120°C	502.8	272.4	230.	23

The discharge rate at Unhavre (Khed) is 14.5 lps and at Tural 6 lps. The Tural boreholes do not show artesian flow; hence may require use of pumps for production. In these hot spring there is possibility of getting higher temperature in the reservoir, below the zone of mixing. Studies on the potential of geothermal energy generation show a significant potential for low-temperature resources (Bertani, 2003; Stefansson, 2000). Therefore binary power plants, like the Organic Rankine Cycle (ORC) are suitable as power generation units. In general, the geothermal power generation by ORC is limited by the minimal temperature difference, so called pinch point, between the heat source or sink. Innovative concepts to increase the cycle efficiency are the transcritical cycle, the pinch point smoothing, use of zeotropic mixtures or the double-stage ORC concepts (Heberle et al 2015).

6.2 Direct Heat Uses

Besides power generation, the hot springs at West Coast may be utilized for following direct uses-

i. Refrigeration for preservation of fruits and vegetables (Temperature required, 70°-100°C).

ii. Greenhouse (Temperature required, 60-80°C).

iii. Food processing- Fruits and see-weed drying, drying of vegetables, onions and fishes, food processing (Temperature required,60-100°C).

iv. Space Heating/ cooling (Temperature required, 60°C-100°C).

v. Industrial uses, paper and pulp, cement block curing, metal parts washing, timber washing, wool drying (Temperature required, 80-100°C).

vi. Aquaculture and agriculture, crocodile farming etc. (Temperature required, 30-60°C).

vii. Spa, Swimming pool etc. (Temperature required, >40°C).

viii. Tourism (Temperature required, >30°C).

ix. Industrial uses, washing of metal parts, furniture industry etc.(Temperature required, >60°C).

x. Extraction of rare metals, Extraction of helium, Mineral water industry (Temperature > 40°C).

7. CONCLUSION

The hot springs of West Coast geothermal area form part of active geothermal systems having low to medium enthalpy. The indicated reservoir temperatures by aqueous geothermometers vary from 170°C in Tural to 145°C in Unhavre (Khed). Deep drilling is required for knowing character of geothermal reservoir. Based on the present quality and indicated reservoir temperature of the hot springs, binary cycle method may be used for geothermal power generation at Unhavre (Khed) and Tural for electricity generation. The quality of hot water at Unhavre (Khed) and Tural is suitable for industrial uses like spa, food processing, green house cultivation and refrigeration.

Acknowledgements

The author is grateful to Dr. U. L. Pitale for valuable suggestions and the officers of Geological Survey of India, CR, for the cooperation extended during the work.

References

Fournier R.O & Potter R.W.II (1985): A revised expanded silica (quartz) geo thermometer, GRC, Bulletin Nov, pp-3-12.

Fournier R. O. (1979): A revised equation for the Na/K geothermometer, Geothermal Resources Council, transactions vol.3, pp-37-69.

Geological Survey of India (1991): Geothermal atlas of India, pp-68-74

Heberle Florian, Jahrfeld Thomas, Briiggerman Dieter (2015) Thermodynamic analysis of double stage ORC for low enthalpy source based on a case study for 5.5 MW power plant Kirchstockach, (Germany), proceeding WGC 2015.

Lichang Huang (2015): Case study of mid-low temperature geothermal power plant in China, proceedings WGC 2015.

Muthuraman K (1987): Geochemistry of thermal water of west Coast, Maharashtra, based on sea water-basalt experimental interaction studies, GSI records, vol.115 pt 6 pp-137-149

Padhi R.N. and U.L.Pitale (1995): Potential geothermal fields in the context of national scenario on non-conventional energy resources development programme in India. Procee. WGC 1995, pp 525-530

Pitale U. L. (1996): Hydrothermal alteration mineralogy: a clue to thermal history of West Coast geothermal system, Maharashtra, India; Geothermal energy in India, GSI Sp.Pub. 45, pp 41-60.

Pitale U.L., Dubey R., Saxena R.K., Prasad J.M, Muthuraman K, Thussu J.L., Sharma S.C. (1987): Review of geothermal studies of west Coast hot springs belt, Maharashtra. GSI records vol.115, pt 6, pp- 97-136.

Ravi Shanker (1987): Status of geothermal exploration in Maharashtra and Madhya Pradesh, Central Region, GSI records vol.115, pt 6, pp- 9-20.

Sarolkar P.B. (2005): Geochemical Characters of Hot Springs of West Coast, Maharashtra State, India, Procee. WGC 2005, regd no. 836

Taghaddosi Mohsen, Porkhiat Sohail (2015), Technical, economic analysis of well head GPP and 20 MW GPP for Meshkin- Shahr geothermal power plant, proceedings WGC2015.