Geothermometry of West Coast Geothermal Province, Maharashtra, India

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Keywords
West coast Maharashtra, thermal springs, geothermometer, mineral equilibrium, direct use

ABSTRACT

Around 60 thermal springs emerge at temperatures ranging from 40 to 72°C along the west coast of Maharashtra spanning a linear distance of about 350 km. Silica and cation geothermometers indicate reservoir temperatures of about 120°C, with a few springs showing higher potential. The mineral phase equilibrium plots (Q/K v/s Temperature) yielded higher equilibrium temperatures ranging from 120-170°C. The highest being the Unhavre-Farare and the Tural springs, pointing towards more promising sites with potential for adequate heat generation. Located in an agricultural and coastal area, the province holds great promise for direct heat utilization such as greenhouse, food dehydration and aquaculture.

Introduction

In the last few decades, geothermal energy has developed as an alternative energy source for electrical and direct uses. With technology advancement, low enthalpy resources are also being used for power generation apart from direct applications like space heating, green houses, aquacultures, agricultural drying, bathing and swimming. The worldwide direct use application for geothermal energy in 2014 was 70,329 MWt (Lund and Boyd, 2015). Complexity of a geothermal environment and initial high capital involvement, demands an in-depth analysis of geochemical and geophysical data to understand the characteristics, movement and origin of fluids for exploration. One of the important tasks being the estimation of subsurface reservoir temperatures based on the geochemistry of thermal springs.

Indian geothermal provinces are well defined with around 400 thermal springs are spread across seven provinces (Figure 1a). To date, the only direct-use of geothermal energy in the country is for bathing, swimming and balneology, and in a few cases an energy source for cooking. Since 80% of electricity generation in India is spent for space cooling, a large amount of CO₂ can be saved using geothermal heat pumps (Chandrasekharam and Chandrasekhar, 2015). This use is currently being investigated. The increase in the annual geothermal use for balneology, bathing and swimming has gone from 2,545 TJ in 2010 to 4,152 TJ in 2014, with an installed capacity of 981 MWt. (Chandrasekharam and Chandrasekhar, 2015).

The aim of the paper is to deduce the reservoir temperatures in the west coast geothermal province, in order to assess its potential as an alternative source of energy. Also the geology and the geochemistry of thermal water is discussed to give insight into the processes controlling the evolution of these springs.

Hydrogeological Setting

The Deccan volcanic traps erupted in Late Cretaceous to Early Tertiary era, with maximum eruption volumes occurring between 66-65Ma ago (Duncan and Pyle, 1988; West, 1981). A major tectonic feature, the west coast fault
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was formed prior to the eruption of Deccan traps, which subsequently reactivated several times after Deccan volcanism (Chandrasekharam, 1985, 2005; Kumar et al., 2011). Thermal springs in the western geothermal province are aligned parallel to the west coast fault system, extending from Koknere thermal spring (19° 42’ 42.63”N : 72° 50’ 54.64”E) in the north to Rajapur thermal spring (16° 38’ 44.2”N : 73° 31’ 52.1”E) in the south, a linear distance of around 350 km (Figure 1b). The thermal springs occur through the Thane, Raigad and Ratnagiri districts of Maharashtra and are flanked by Western Ghats to the east and Arabian Sea to the west.

In the study area, the thickness of basaltic flows decreases from around 2000 - 1500 m from the north to approximately 600 m towards the south. The North-South cross-section of Deccan volcanic flows (Figure 1c) shows decreasing thickness towards the southern periphery near Rajapur where these flows are seen abutting against Precambrian basement. These Precambrian granites extend towards the south and south-eastern part of southern India and host U bearing minerals and veins which are being commercially mined near Gugi in Karnataka (Senthil and Srinivasan, 2002). The concentrations of U and Th in these granites vary from 1.1 to 6.4 mg/l and 1.0 to 66.8 mg/l respectively while K concentration varies from 0.2 to 5.9 %. Heat flow values calculated using U, Th and K values for the Gugi granites ranged between 41.0 to 44.9 mW/m2 (Singh et al., 2014).
Although previous studies on these thermal springs emphasized that all the thermal springs circulate through the Deccan basaltic province, recent studies on trace elements have indicated involvement of granites and other meta-sedimentary formations in the evolution of these springs (Trupti et al., 2015; Trupti et al., 2016).

**Hydrogeochemistry**

Temperature of these thermal springs range between 40 - 71 °C with Unhavre- Farare (#16, Table 1) recording the highest and lowest at Anjaneri (# 22, Table 1). Groundwater and surface water temperature is between 29-31 °C. These thermal springs are near neutral to alkaline with pH varying from 7.08 to 8.82 from Koknere to Rajapur. The conductivity of these thermal samples varies from 526 µS/cm to 4870 µS/cm.

The major components of thermal, ground and surface water were plotted in a Piper plot (Figure 2; Piper 1944). Most of these thermal waters along west coast are Na-Ca-Cl or Ca-Na-Cl type except for sample numbers 12, 17 and 22 which are Na-Cl-SO\(_4\) type while Rajapur (# 24) being Na-HCO\(_3\) type. As seen from piper diagram (Figure 2), Rajapur thermal spring has entirely different chemistry compared to its counterparts indicating it belongs to an entirely different reservoir, presumably of granitic composition.

**Geothermometry**

**Silica and Cation Geothermometry**

Over the past three decades or so, many geothermometers have been proposed and applied to calculate reservoir temperature. Reservoir temperatures can be obtained based on the temperature dependent water–rock equilibrium in the reservoir by using the concentration values of chemical constituents in a geothermal water sample. In this paper, several traditional geothermometers, including Quartz (Fournier, 1977), Na–K (Fournier, 1979 and Giggenbach et al, 1988), and Na–K-Ca (Fournier and Trusdell, 1973), were used to estimate the reservoir temperature (Table 2).

The Na-K geothermometers given by Fournier (1979) (Table 2) yielded reservoir temperatures between 91°C to 102°C.
135°C closer to quartz geothermometers except for Rajapur thermal spring. Rajapur thermal springs gave unusually high temperature both with Na-K and Na-K-Ca geothermometer (Table 2). After Ca correction Rajapur springs yielded equilibrium temperatures of 102°C. The highest temperatures of ~135°C was observed at the Unhavre, Aravali and Tural thermal springs. The Unhavre thermal springs emerges at a temperature of 72°C highest amongst all the springs.

**Mineral Phase Equilibrium Geothermometry**

Various geothermometers can yield variable reservoir temperatures for the same field. Reed and Spycher (1984) proposed that calculation of saturation indices for a geothermal water with respect to probable hydrothermal alteration minerals, at varying temperature, can be used as an effective geothermometry tool.

PHREEQC program (Parkhurst and Appelo, 1999) with WATEQ4E thermodynamic database (Ball and Nordstrom, 1991) was used to initially calculate the saturation indices (SI) at outlet temperature and measured pH. Temperature was then changed iteratively between 25°C to 300°C in 10 steps and the SI’s recomputed. Computed SI’s were then plotted against temperature, obtaining plots such as those reported below (Figure 3). If the geothermal water is in equilibrium with considered minerals at a given temperature, the SI curves converge to 0 at that temperature. If the geothermal water mixes with a water of low salinity, all the SI curves are shifted downward into under saturation field, but the intersection cluster remains, indicating approximate temperature of equilibrium. If loss of CO₂ takes place, the SI curves for minerals sensitive to changing pH are shifted to lower values. Except for Rajapur thermal springs which fall in the immature area and also in HCO₃ field in anion ternary plot, data for all other thermal springs have been used to calculate temperature based on mineral solution equilibrium.

From the above plots it is very clear that mixing is prominent in thermal springs in northern sector especially in Koknere.

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**Figure 3.** Mineral saturation geothermometers for selected thermal springs.
where there is no clear mineral solution equilibrium with any hydrothermal mineral. The temperatures range between 100°C – 140°C. The temperature of Unhavre-Farare, Aravali and Tural by log Q/K plot indicates a reservoir temperature of approximately 150 - 170 °C as opposed to quartz and cation geothermometer which ranged from 119°C to 127°C.

Conclusions

The above study indicates existence of medium enthalpy geothermal resources along the west coast of Maharashtra. Studies further indicate Unhavre–Farare and Tural-Rajwadi regions being the most favorable sites due to its supporting temperature. However, lack of comprehensive geophysical data, temperature and exploration wells, makes it challenging to arrive at a possible economic solution for power generation unless a few deep exploration wells are drilled to demarcate the identified geothermal reserve into a bankable reservoir. Nevertheless, from a geothermal direct use perspective, the west coast geothermal province serves as a ready platform for developing green houses, dehydration units for perishable food products, aquaculture centers and health spas, thus promoting the growth of secondary and tertiary industries along with job.

Acknowledgement

This work forms a part of Ph. D thesis of Trupti Chandrasekhar (TC). TC thanks Indian Institute of Technology Bombay for providing facilities during the course of this work.

References


