22. Occurrences of Geothermal Resources and Geochemical Characteristics of Thermal Water of Sothern Indus Basin, Pakistan.

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Abstract

"Most of the high grade geothermal resources of the world are found within seismic belts of weak crustal plate margins and centres or volcanic activity. Similarly, geotectonic framework of Pakistan directs towards a region which poses a commercially exploitable sources of geothermal prospects of energy.
Presence of alteration zones and fumaroles, hot springs as well as Quaternary volcanism are all indication of good prospects.
The Southern most Indus basin of Pakistan are lie in the Geo-Pressurized Thermal zone system. Geothermal activities are thermal spring, geysers such as in Karachi and Dadu area, as well as abnormal high temperature in drilling oil/gas wells, is due to the great thickness and geo-pressured water of sedimentary basins. The presence of two thermal springs at Mangho Pir and Karsaz, Karachi specify a Cl - HCO^3 and Cl-SO4 types of water chemistry. Reservoir temperature also reported comparatively low by the Silica geothermometers due to mixing of sea water and rock water interaction in subsurface. However, geochemistry of thermal water indicates further to conduct a detailed survey of the area for exploring future prospects of geothermal resources."

Keywords: *"Geothermal water;Reservoir temperature; Geothermometers;Lower Indus basin."*

1. Introduction

Geothermal energy is considered as the energy which is derived from the heat of earth internal core. It is clean abundant and reliable source of energy as compared to other source of conventional and unconventional means. If geothermal source is properly developed, it can offer a renewable and sustainable energy source.

People have used geothermal energy resources in many ways including healing and physical therapies, cooking, space heating and other applications. It is also used for electricity generation, direct use of heat and geothermal heating pumps
Geothermal systems commonly can be classified as:

- Volcanic systems with the heat source being hot intrusions or magma chambers in the crust,
- Convective systems with deep water circulation in tectonically active areas of high geothermal gradient,
- Conductive sedimentary systems with permeable layers at great depth (2-5 km),
- Geopressured systems often in conjunction with oil resources,
- Hot dry rock or EGS systems where abnormally hot masses of low permeability rocks are found at drillable depths, and
- Shallow resources in normal geothermal gradient areas utilized with ground-source heat pump applications.

A classification for geothermal systems was proposed in Iceland which is divided into low and high-temperature geothermal systems where temperature is below 150°C in the uppermost layers (km) and a temperature of 200°C is

reached at 1 km depth respectively. The high-temperature geothermal fields are all related to volcanism whereas the low-temperature geothermal fields draw heat from the general heat flow of the crust. Low-temperature geothermal system is directly related to the sedimentary basin which has thin conductive permeable sedimentary layers.

A global seismic belt passes through Pakistan and the country has a long geological history of geotectonic events. Permo-carboniferous volcanism (Panjal traps in Kashmir) as a result of rifting of Iran-Afghanistan microplates, Late Jurassic to Early Cretaceous rifting of the Indo-Pakistan Plate, widespread volcanism during Late Cretaceous (Deccan traps) attributed to the appearance of a "hot spot" in the region, emergence of a chain of volcanic islands along the margins of the Indo-Pakistan Plate, collision of India and Asia (Cretaceous-Paleocene) and the consequent Himalayan upheaval, and Neogene-Quaternary volcanism in the Chagai District (Kazmi & Jan, 1999; Raza & Bander, 1995).

2. Location & Method

The study area comprise of Southern Indus basin marginal zone where the existence of a large number of thermal springs indicates the presence of widespread geothermal systems. The clusters of thermal springs in the Dadu district, Mangho Pir and Karsaz area at Karachi represent interesting areas for geothermal exploration. Correlation between the hot springs and tectonics is not easy in the flat basin, prior to geological and geophysical investigation. (Mughal, 1998). However, a large number of thermal spring along the Indus basin marginal zone and its marginal extension at Karachi can be a good prospect for further study. Apart from this, numerous exploration wells has been drilled in Indus basin and offshore trough region for oil and gas exploration, many of which showed higher than normal subsurface temperature. This paper also encountered all those factor to give a precise review of geothermal prospects.

3. Tectonic Framework

Tectonically, Pakistan is situated on the western-rifted margin of the Indo-Pakistan sub continental plate. In the existing plate tectonic setting, Pakistan lies partly on (i) the northwestern corner of the Indian lithospheric plate, (ii) the southern part of the Afghan craton, and (iii) the northern part of the Arabian oceanic subducting plate. The eastern part of Pakistan represents (a) the Tertiary convergence with intense collision between the Indian and Eurasian plates in the north creating Karakorum Thrust Zone and (b) the translation between Indian continental plate and the Afghan craton in the north-west developing Chaman Transcurrent Fault System that connects the Makran convergence zone (where oceanic lithosphere is being subducted beneath the Lut and Afghan micro-plates) with the Himalayan convergence zone (where the Indo-Pakistan lithosphere is under thrusting the Eurasian continental plate).

4. Potential Geothermal Sources In Pakistan

Most of the high ranking geothermal resources of the world are found within seismic belts associated with zones of crustal weakness such as plate margins and centres or volcanic activity.

The geotectonic framework of Pakistan suggested that the region poses a commercially exploitable sources of geothermal prospects of energy. It is further reinforced by the equitably extensive development of alteration zones and fumaroles in many regions of Pakistan, presence of a fairly large number of hot springs in different parts of the country, and indications of Quaternary volcanism.

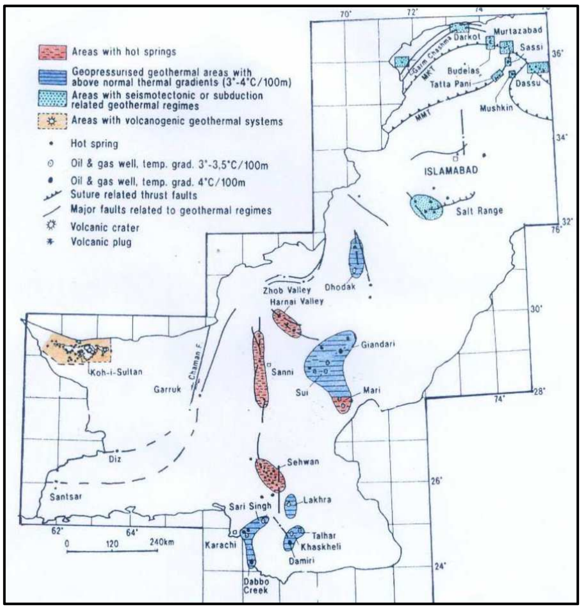

Fig. 1. Geothermal resources of Pakistan

In general, the geothermal exploration addresses at least nine phases of integrated study, i.e., i) identification of geothermal phenomena, ii) classification of the geothermal field production field exists, iii) location of productive zones, iv) ascertaining that a useful geothermal, v)estimation of the size of the resource, vi) determination of heat content of fluids that will be discharged by wells in the geothermal field, vii) compilation of a body of data against which the results of future monitoring can be viewed, viii) assessment of pre-exploitation values of environmentally sensitive parameters, ix) determination of any characteristics that might cause problems during field development. First three phases have so far been undertaken in Pakistan on limited scale to study the geological characteristics of the geothermal energy sources.

Thus in our country Pakistan, these manifestations of geothermal energy are found within three geotectonic or geothermal environments.

- Geo-pressurized systems related to basin subsidence which is mainly encountered in the Indus river basin in Southern part of Pakistan.
- Seismo-tectonic or suture-related systems: is found in northern part of Pakistan, manifested by many thermal spring. This regime is comprised of Karakorum, Hindu Kush and Himalayan thrust mountainous belts, exhibits strong seismicity activities.
- Neogene-Quaternary volcanism. Lies in the western belt of Pakistan and associated with Chaghi magmatic arc and Koh-e-Sultan volcanoes manifested by mineralized thermal spring. This regime apparently exhibits the highest potential of geothermal source in Pakistan (Zaigham, 2005).

5. Geothermal System Of Southern Indus Basin And Trough

This paper aims to provide a general characteristic of Thermal system of Southern lower part of Indus basin. Pakistan. This zone along with the western margin of the Indus Plain are lie in the Geo Pressurized Thermal zone system. The Lower Indus Basin is filled with 5,000 to 10,000 m thick sedimentary rocks of Mesozoic to Recent Ages. It is generally considered that geothermal systems in sedimentary grabens usually derive their origin from the difference in thermal conduction, i.e. the "isolating effect" due to low thermal conductivity of sediments. The hot sedimentary aquifers are associated with hydrocarbons and also developed as a result of development of secondary faults in the Indus Basin where dozens of geothermal springs have been identified.

The geothermal activities which is found in the Indus basin are thermal spring, geysers such as in Karachi and Dadu area, as well as abnormal high temperature(>110 °C) due to geo-pressured hot water associated with hydrocarbon, are encountered in drilling different oil/gas wells.

5.1. Lower Indus Trough

The lower Indus trough and offshore are aslo characterized by more than normal geothermal gradient for instance a well Damiri-1 had a geothermal gradient of 4ºC/100m (Khan and Raza, 1986), whereas the wells at Talhar and Khaskheli have encountered geothermal gradients in the range of 30 to 3.5°C/100m. The offshore well at Dabbo Creek revealed a geothermal gradient of 3.7ºC/100m.
Generally, in this system the normal heat flow is trapped by insulating impermeable beds in a rapidly subsiding sedimentary basin. It is due to its great depth (as much as 6,000 m) that temperatures ranging from less than 93ºC to more than l50ºC encountered. They commonly contain pressurized hot connate water at pressures ranging from 40 % to 90 % in excess of the hydrostatic pressure corresponding to the depth. Gradual subsidence has led to the ultimate isolation of trapped pockets of water contained in alternating pervious and impervious sequences.

5.2. Karachi Area

Karachi area geologically fall in Kirthar province of Indus basin. It may broadly divide into two parts, the hilly terrain on the North and West part and underlying plain and coastal area, are in South-East. The hilly part in Karachi are the southward extension of the Kirthar ranges which merges into alluvial plain of Karachi. The rocks exposed in Karachi are of sedimentary origin and range from Paleocene to Recent in age.

There has been two hot spring are found in Karachi shown in Fig 2.

i. Mangho Pir thermal spring (K1) is located in Karachi West (Lat. 24°59'N; Long 67°03'E). It is situated on the eastern flank of the anticline, at an altitude of about 20m above sea level whereas,
ii. Karsaz hot spring (K2) is located in Karachi East (Lat. 24°53'N; Long 67°06'E) approximately 11 km North of Arabian sea.

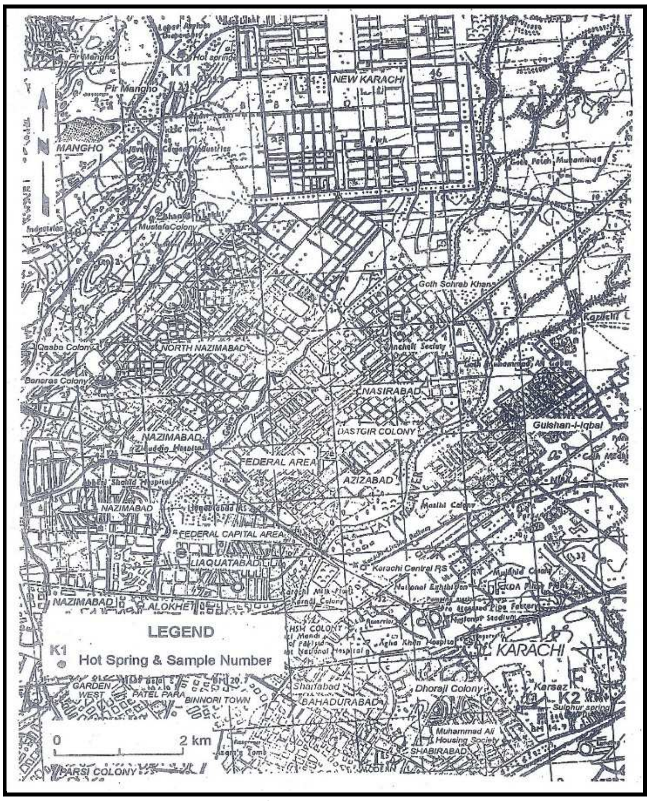

Fig. 2. Location map of Mangho Pir & Karsaz hot springs.

The exposed rock of these area consist of shale, sandstone and limestone of Nari and Gaj formation of Oligocene and Miocene age (Fig.3). There is no volcanic activity found in this area. The system of fracture and fissure developed in shale formation of Mangho Pir area are commonly closed and the permeability is also very less. However aquifer of the mineral water found in the Orangi Town nearby area of Mangho Pir, are primarily exist in sandstone of Nari formation (Muslim & Das 1988). In this way, shales of Nari and Gaj formation play a role of cap rock. Fractured Limestone and sandstone is considered to act as a shallow geothermal reservoir in Mangho Pir area (Todaka, Shuja)

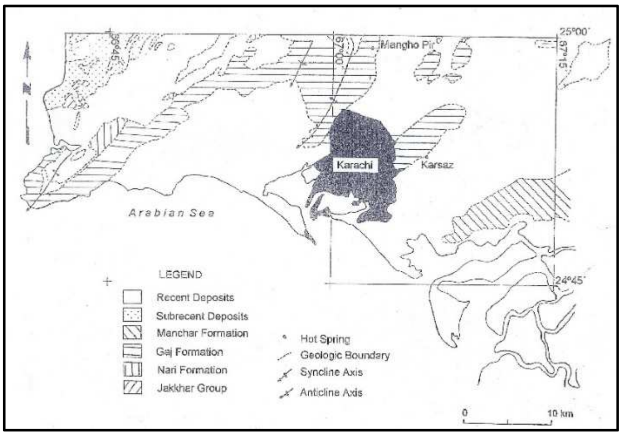

Fig. 3. Generalized geological map of Karachi

5.2.1. Characteristic of Thermal Waters and Its Classification

Geochemistry of thermal water mainly used to provide estimates of the surface reservoir temperature and the general chemical characteristics. This information helps further in the selection of geothermal areas for more detailed surface explorations and exploratory drilling. Various chemical geothermometers have been proposed for this purpose, based on different relationships and reactions between the fluid and the host rock.

According to Todaka, hot spring thermal water at Mangho Pir and Karsaz zone are classified as Cl - HCO^3 and Cl-SO4 type (Fig 4).The physical features of these hot spring in Karachi are shown in table 1. It is believed that the presence of high contents of HCO^3, Hg and H_2S or SO4 in near-surface waters are indicators of high temperatures at depth. Similarly, high Cl/F ratio and Cl/SO4 ratio may indicate the existence of a high temperature system as well. Generally, geothermal water contains a variety of elements with different solubility resulting from the water rock interaction when the water flows through the rocks at the ambient temperature. The source of the hot waters in both areas area assumed to be the fracture and fissures in subsurface host rock. It also contain high value of Na and Cl which is due to the precipitation and mixing with sea water, especially in Karsaz hot spring, because of its close proximity to Arabian Sea coast. Classification of thermal water has shown in Fig 5. (Todaka)

Table 1. Chemical composition of water from Mangho Pir & Karsaz (Todaka 1998)

Parameters	Sample (K1) Mangho Pir	Sample (K2) Karsaz
Ph	7.45	7.87
EC (us/cm)	2380	7910
TSM (mg/l)	1560	5780
Na (mg/l)	355	1400
K (mg/l)	14	81
Ca (mg/l)	56	176
Mg (mg/l)	34	124
Cl (mg/l)	432	1971
SO4 (mg/l)	221	1388
HCO3 (mg/l)	308	243
CO 3 (mg/l)	16	0
SiO2 (mg/l)	24	46
Water Temp at field	50.3	39.0

To a large extent, chemical content of the water controls, its properties with regard to utilization and therefore it is very important to have a good database of it at an early stage.
Low-temperature geothermal waters in crystalline rocks are usually dilute, i.e. have low values of total dissolved solids (<500 mg/I), and no harmful trace elements. Such waters can often be used directly, e.g. for heating of houses or swimming pools and even for direct agricultural use or drinking. However, if the

chemical content is high, such as with low-temperature fields in sedimentary rocks, high temperature fields and brine fields in general, indirect usage may be necessary in order to utilize the energy and avoid scaling or corrosion in pipes and systems.

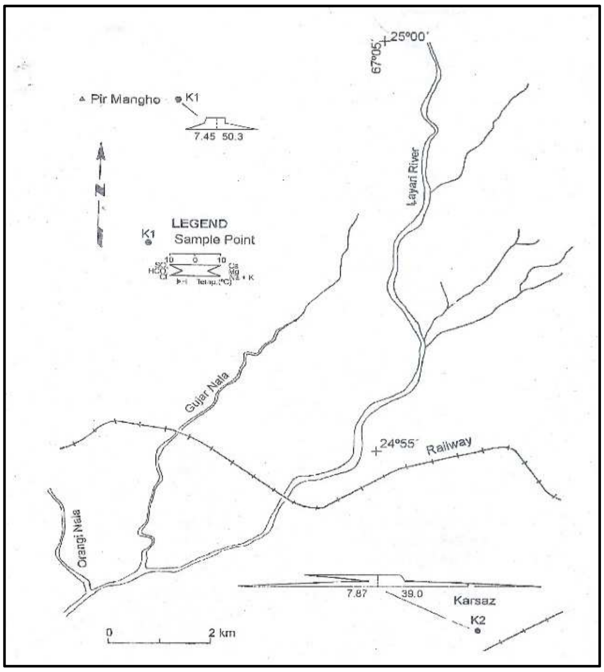

Fig. 4. Hexadiagram showing chemical composition of water from Karachi hot springs (K1, K2)

Often, heat-exchangers of various types can be used so that hot geothermal water heats up dilute cold water which is then used for the heating systems or agricultural purposes. Sometimes mixing chemicals can solve these problems. Of special importance is keeping the systems closed, so the water does not absorb oxygen, as this increases the corrosive properties of the hot water. For electrical production, geothermal steam can usually be used directly, though in some cases mixing chemicals may be necessary to avoid scaling or corrosion.

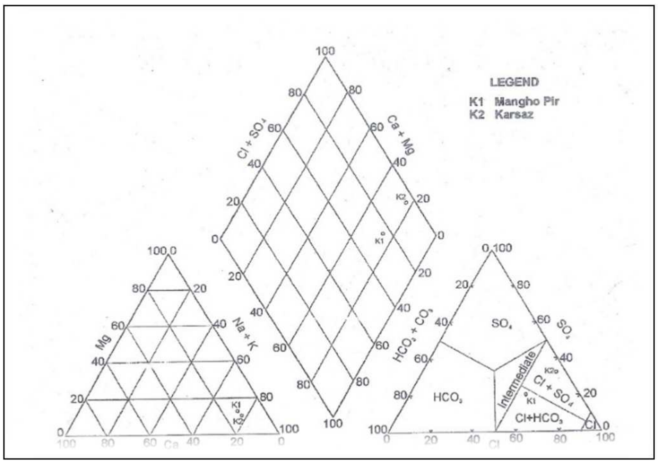

Fig. 5. Classification of water from Karachi thermal spring (Mangho Pir, Karsaz)

5.2.2. Reservoir Temperature

Reservoir temperature are usually estimated by chemical geothermometers, which can be used in both high- and low-temperature geothermal systems. Many chemical geothermometers have been developed during the past two decades, the most commonly used ones being the silica geothermometers (e.g. Foumier and Potter, 1982; Arn6rsson et. aI. 1983) and Na-K *I* Na-K-Ca (Mughal 242 *Report 9)*
These geothermometers often give different reservoir temperatures for the same fluid. This may be due to

lack of equilibrium between minerals and thermal fluids or mixing of cold water during the up flow. It is also suggested that the thermometers are not suitable for some area due to specific geological conditions. (Fig. 6) Different rates of response may show temperatures from different depths and/or ages. The most commonly used geothermometers is the silica geothermometers. The quartz geothermometers is used for prediction of high temperatures (> 180°C), while the chalcedony geothermometers is used for low reservoir temperatures. The solubility of silica is affected by the pH values of the fluid, thus, pH has to be accounted for when it is greater than 9.5. In order to deal with high pH and hard waters that do not yield reliable temperatures when using the silica geothermometers, the Na-K and the Na-K-Ca geothermometers were proposed and have been used successfully in such systems.

According to Todaka and Shuja the reservoir temperature of Mangho Pir and Karsaz is estimated in range from 71° to 89° by the Silica geothermometers and from 138° to 170° C by the Na-K-Ca geothermometers showing in table 2.

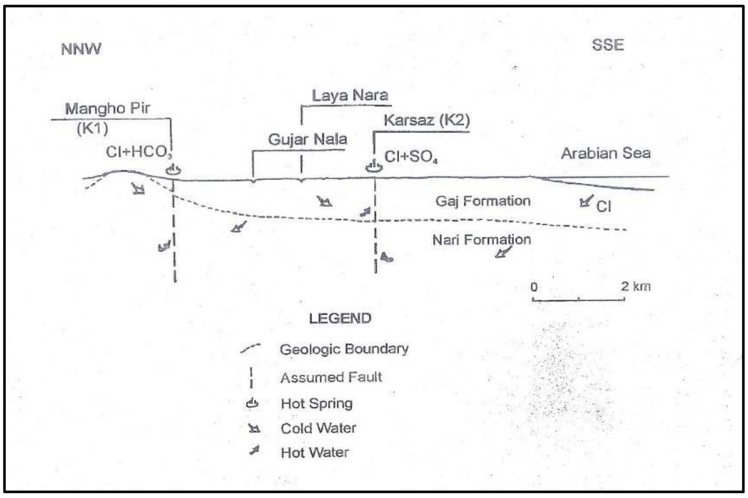

Fig. 6. Conceptual model of a geothermal system at Mangho Pir (K1) and Karsaz (K2) area, Karachi, showing the probable transfer of heat from the subsurface (Source: GSP / JICA, 1988)

Usually, geothermometers (Fournier and Trusedell, 1973; Am6rsson et al., 1983) and it's relatively show high temperature than Silica Geothermometers. However, in this case it is apparent that the reservoir temperature is comparatively not much higher. This may be due to chemical composition of the hot water, which is subjected to the influence of mixing of sea water and the quantity of silica content is also very low. Hence, silica geothermometers may indicate low reservoir temperature less than 100° C. (Todaka, Shuja)

Table 2. Reservoir temperature of water from Mangho Pir & Karsaz (Todaka 1998)

PARAMETERS	Sample K1		Sample K2	
Temperature C°	50.3		39.0	
Thermometer				
Silica (SiO_2)	Adia.	Conc.	Adia.	Conc.
	76	71	100	98
Na-K-Ca	138		170	
Mg	170		18	

6. Discussion

Nearly half of the developing countries have rich geothermal resources, which could prove to be an important source of power and revenue. Geothermal projects can reduce the economic pressure of developing country fuel imports and can offer local infrastructure development and employment. The advantage of geothermal power in a country like Pakistan, where coal and oil resources are limited, is evident. The geothermal resources can provide a clean source of energy. Direct utilization for bathing and heating and possibly electrical production may satisfy local needs in villages and small towns.
The area belongs to the sedimentary basin and along the whole margin zone, the presence of thermal springs and abnormal high temperature in oil/gas well contribute a positive indication of geothermal

energy potential in Indus basin marginal zone. Besides geochemistry, deep reaching methods can be preferred, such as resistivity sounding and gravity. However, high salinity of the sedimentary rocks may, in some places, pose a difficulty for the usefulness of the resistivity method. Gradient wells could be used with advantage to map local near-vertical structures.

Due to the subtropical climate in the southern part of the area, such as near Karachi and Dadu district, and with a resource of relatively low temperatures, a study of utilization prospects needs to be done before any expensive exploration programme. Hot water or steam springs, geysers or fumaroles are type of hydrothermal energy resources which are continuously flowing in many areas of Pakistan.

Many of abandoned deep dry oil & gas wells with high temperature having more than 105°C show deep geothermal energy resources could produce geothermal energy for power generation in Pakistan, However detailed investigations are required to evaluate the potential of each well for power generation.

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