THERMAL FLUID CHARACTERISTICS OF GEOTHERMAL PROSPECTS IN THE NORTH CENTRAL VIETNAM AND THEIR POTENTIAL FOR POWER GENERATION

Tran Trong THANG[1], Nguyen Thac CUONG[2] and Pham Xuan ANH[3]
[1]Vietnam Institute of Geosciences and Mineral Resources
[2]Ministry of Natural Resources and Environment
[3]Vietnam Oil and Gas Group
email: ttthang@yahoo.com

ABSTRACT

There are 30 geothermal sources in the North Central Vietnam but we have selected nine most potential ones for calculation of reservoir temperature using geochemical methods. The results showed that these geothermal resources have relatively high temperatures at the reservoirs. This means the application of binary cycle technology for electric generation is very suitable. These geothermal reservoir's temperatures are used to calculate the electric generating capacity. However, to calculate the power generation capacity, the parameters such as: the area of the reservoir, the thickness of the reservoir and some others are estimated or referenced from the published literatures. According to the results of calculation, the total capacity of electric generation from these geothermal resources is 115MWe. However, the development of geothermal energy still has a lot of barriers such as the initial investment cost or the lack of geothermal specialist, knowledge and experience. Hopefully these problems are solved by time and the geothermal energy will be developed in Vietnam in the near future.

Keywords: geothermal prospect, geothermometer, power generation capacity, barriers, North Central Vietnam.

1. INTRODUCTION

In recent years, the demand for the development of renewable energy in general and of geothermal energy in particular became popular in Vietnam. The understanding of the geothermal and geothermal energy has also increased for the politicians, managers and geologists.

Although not much experience but the government of Vietnam has invested in research and assess the overall hydro-geothermal potential in almost national territory including the North Central Vietnam. Of the 30 hot springs in the study area, we chose the sources with relatively high temperature on the face, which is also a more complete analysis of the remaining sources to calculate the temperature in the deep reservoirs and then electric generating potential.

There is not any geothermal exploration has been completed in Vietnam until now, so the assessment of geothermal electric generating capacity is just estimated and very relative by using geothermal reservoir temperatures resulted from calculating and interpreting thermal fluid data, the other parameters via the literature reference, handbook. In addition, the reservoir area and the thickness of the reservoir are estimated empirically based on a common understanding of the geological conditions of the geothermal resource area. The results of estimates are in line with the comparison with some geothermal resources in the world having similar condition as well as comparison of geothermal resources in the study area together.

2. GEOLOGICAL SETTING

The tectonic activities generally generate the important tectonic factors e.g. young fault, subsidence, uplift and magmatic activities those are considered as favorable premises to form the geothermal systems. The study area is divided into three structural geological zones between those the borders are large deep faults characterized regionally (Fig. 1):

(1) Binh Tri Thien Paleozoic structural zone: From Bach ma to Rao Nay fault. This zone comprises the Paleozoic formations. The younger formations are considered as covering layers those are controlled by geodynamic mechanism of the adjacent areas in the consecutive stages afterward.

(2) Nghe Tinh Paleozoic – Mesozoic structural zone: From Rao Nay to Song Ma fault. There are diversified geological formations in which the terrigenous deposits are altered with acidic extrusive those are called “reactivation” typed structural formations or some authors supposed that this is acidic extrusive in Mesozoic following geodynamic mechanism of continental rift fractured on the Paleozoic basement.

(3) Thanh Hoa structural zone: From Song Ma to Song Da faults. This zone consists of the formations of ancient rocks aged from late Proterozoic to early Mesozoic, metamorphosed and fractured by Song Da hinterland rift geodynamic mechanism then in-filled by P_2-T_1 mafic extrusive.

At the Cenozoic stage, the tectonic and geologic activities control all the areas of Vietnam, so the North Central Vietnam is just a small area that is impacted generally in the regional tectonic setting forming Eastern sea edge of Vietnam in the West ring of the Pacific (Tapponnier, 1982).

There is not any volcanic activities in the study area as well as the evidences of the young volcanoes. The magmatic rocks of granite and rhyolite are mostly present. There are two systems of faults in the study area:

(1) The deep fault systems oriented in Northwest – Southeast direction: Paleozoic age, play a role in destroying the early Precambrian continental, performing the tectonic processes then generating the Paleozoic continental crust until complete.

(2) The fault systems oriented in Northeast – Southwest direction: Early Mesozoic age, at the end sections of the NE-SW fault systems, there are some sections those change the direction to sub-Meridian relating to Neogene sediment basin lying the emergence of basaltic spread (Nguyen N. M. 1980). The geothermal systems in the study area are present in many places closely associated with young fault systems. In addition to the creation of the basin, the young faults those formed the uplift block-structures in the area of magmatic development also generated geothermal reservoirs.

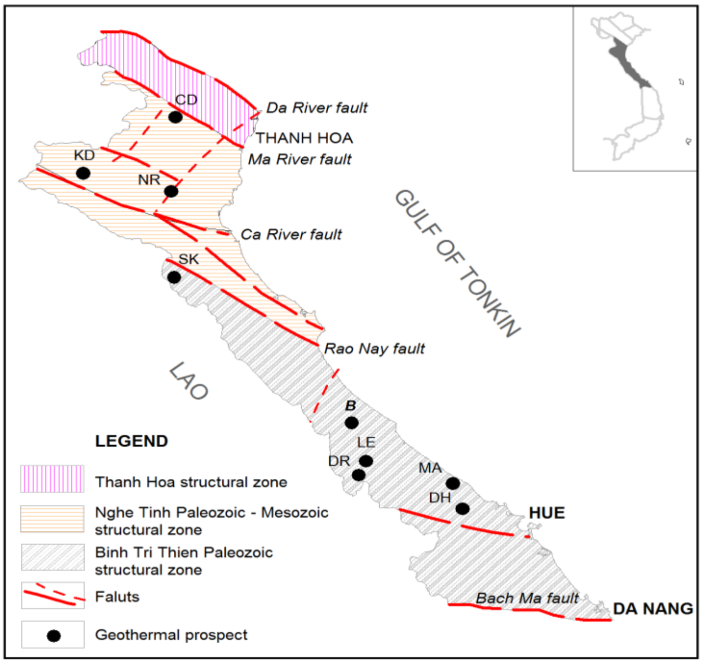

Figure 1: Geothermal prospects and zoning scheme of structural geology in North Central Vietnam.

3. THERMAL FLUIDS CHARACTERSTICS

The water samples were collected in accordance with the geothermal sampling procedures and got analyzed in the laboratories in Vietnam for the compositions: Na, K Ca, Mg, SiO2, B, Cl, F, SO4, HCO3, NH4, As, Rb, Fe, Mn. Particularly, the stable isotopes ($\delta^{18}O$ – δD) were analyzed at the GNS Science, New Zealand (Cao D.G. et al., 1998).

The results of analysis were selected to clarify the characteristics of thermal fluids of these geothermal resources using the formulas and diagrams those are often used in geothermal studies, surveys and exploration.

The diagram of fig. 2 shows that almost of the geothermal fluids are the HCO_3-types. There are only two geothermal resources belonging to Cl-types but the source of Cl may come from seawater, therefore less capable of geothermal water going up from deep geothermal reservoir. The reservoir temperatures of HCO_3-type geothermal resources are usually known as not so high.

The geothermal water here mostly immature while Lang Eo and Duong Hoa (LE and DR) geothermal resources are the partial equilibrium waters. The triangle diagram of Na-K-Mg (Figure 3) also found that the temperatures of the geothermal resources are > 150ºC Giggenbach (1991a). The results of temperature estimation from this chart are also quite equal with calculated Na/K geothermometers. Findings of Barnett et al. (2005), Mariner and Janik (1995) and Maturgo et al. (2000) also showed that the application of this diagram to estimate the temperature of the geothermal resources are consistent with the results calculated by geothermometers as well as the results measured from the actual wells in geothermal reservoir.

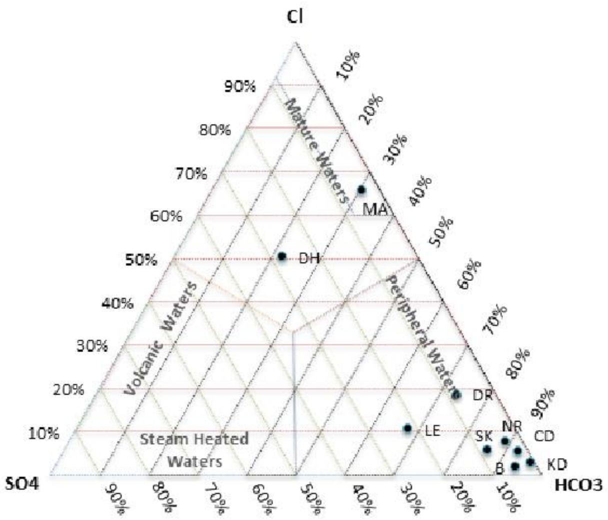

Figure 2: Cl-SO_4-HCO_3 diagram of 18 geothermal prospects.

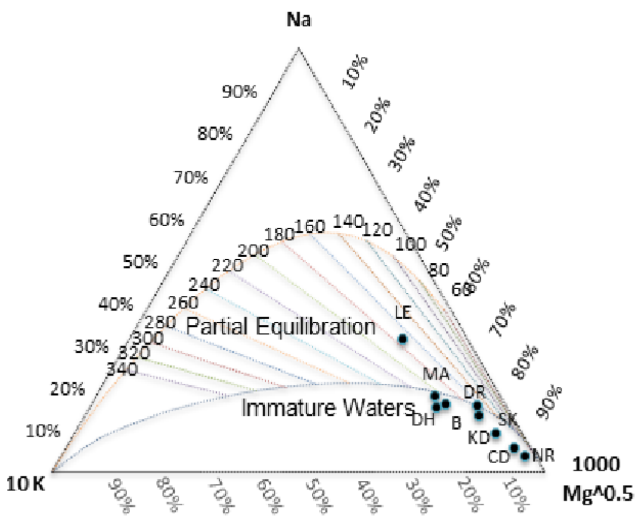

Figure 3: Na-K-Mg diagram of 18 geothermal prospects.

Among nine geothermal fluid samples, four samples were analyzed for stable isotopes of deuterium and oxygen-18 ($\delta^{18}O$ - δD). The results of this analysis are plotted on the $\delta^{18}O$ - δD correlation chart (Figure 4). In this chart, the geothermal waters are located on or closely to the meteoric-trend-line. It means that these geothermal waters are derived from meteoric water and some geothermal sources are a little bit influenced by the seawater.

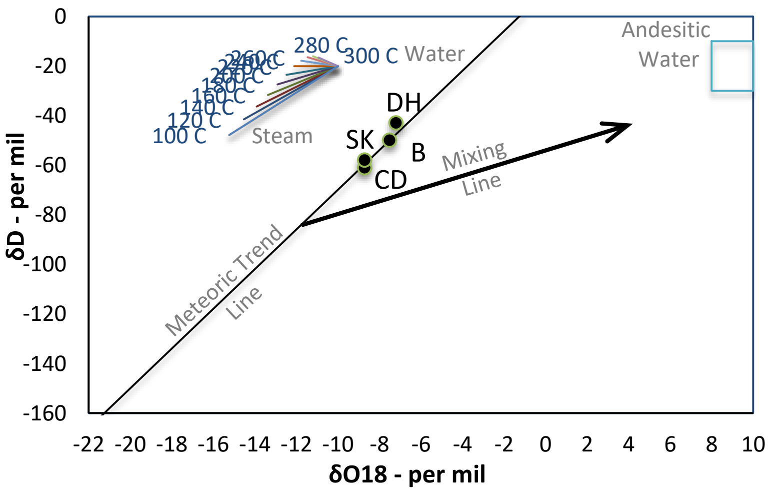

Figure 4: δD vs $\delta^{18}O$ plot for the geothermal fluids.

Figure 5 is a diagram presenting the K-Mg and quartz geothermometers by Giggenbach and Goguel (1989). The diagram uses chalcedony geothermometer that is more appropriate than quartz geothermometer for geothermal resources with a lower temperature. The comparison of these two types of geothermometers is to increase the reliability of the two if they fit together. If inappropriate, it may be dissolved by the balance with amorphous silica, or is affected by acid residues those address the damage of the results of geothermometer calculation, even including when water geothermal has been neutral.

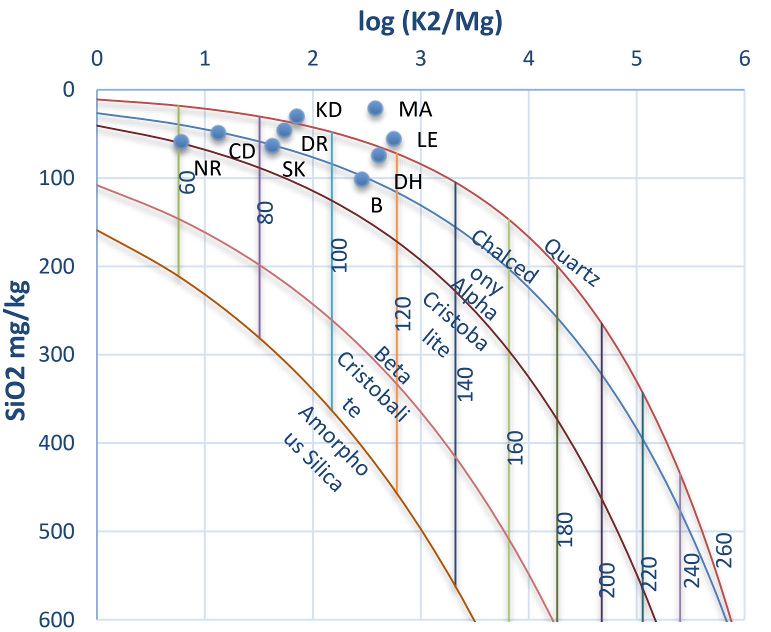

Figure 5: This cross-plot of the K-Mg and the quartz (conductive) geothermometers.

The calculated temperature of the geothermal reservoir using silica geothermometers shows the great different temperatures for every geothermal prospects. Same geothermal source may vary from 20^0C to 200^0C using different silica geothermometer. According to Fournier (1981), the silica geothermometers can be appropriately applied for geothermal resources with a high temperature. According to Barnett et al. (2005), Mariner and Janik (1995) and Maturgo et al. (2000), the geothermal resources in the study area are not appropriated with the application of silica geothermometers.

The cation geothermometers are used, but mostly Na/K geothermometers. The results calculated from 6 pairs of Na/K geothermometers show the difference is not much (10^0C - 50^0C) for one geothermal prospect. The K/Mg geothermometer shows that the temperatures were much lower than the Na/K geothermometers. In order to get temperatures for geothermal reservoirs, we just averaged the Na/K temperatures (Table 1). The geothermal resources with the reservoir temperatures from 123^0C to 189^0C can be developed for electricity by applying binary cycle technology.

Table 1: The reservoir temperatures (°C) of geothermal prospects in North Central Vietnam.

Geothermal prospects	**Label**	**Surface Temp.**	**Na/K[1]**	**Na/K[2]**	**Na/K[3]**	**Na/K[4]**	**Na/K[5]**	**Na/K[6]**	**K/Mg[7]**	**Average**
Cua Dat	CD	50.8	171	132	189	160	159	142	71	146
Nam Ron	NR	57.0	173	134	191	163	161	144	62	147
Kim Da	KD	73.5	164	123	182	151	152	133	91	142
Son Kim	SK	78.0	177	139	195	169	165	149	85	154
Bang	B	100.0	193	158	210	189	180	167	110	172
Lang Eo	LE	70.0	152	109	171	135	140	120	121	135
Dak Rong	DR	70.2	143	99	163	125	132	110	88	123
My An	MA	50.9	192	156	208	188	179	165	115	172
Duong Hoa	DH	68	210	178	226	213	197	186	116	189

Note: 1- Fournier (1979); 2 - Truesdell (1976); 3 - Giggenbach (1988); 4 - Tonani (1980); 5 - Nieva (1987); 6 - Arnorsson (1983); 7 - Giggenbach (1986).

4. POWER GENERATION POTENTIAL

The method of geothermal potential assessment of Muffler, P. and Cataldi, R. (1978) is used to calculate the power generation potential though many important parameters served for the calculations are estimated. The estimates here are based on the geological characteristics through the geological mapping as well as the geochemical and geological surveys in the study area. The temperatures of geothermal reservoir are calculated by the said geothermometers. In addition, the binary cycle technology is the only one assumed to be applied to develop the geothermal resources for electricity in North Central Vietnam.

The assessing process is to calculate the energy contained in geothermal reservoirs then to calculate the power generation capacity from the geothermal resources.

(1) The stored energy in geothermal reservoir are calculated by the following formulas (Muffler, P. and Cataldi, R. (1978):

$$Q= Ah\{\underbrace{[C_r\rho_r(1-\varphi)(T_i- T_f)]}_{\text{heat in rock}} + \underbrace{[\rho_{wi}\,\varphi\, S_w\,(h_{wi} - h_{wf})]}_{\text{heat in water}}\}$$

In which: Q - stored heat (kJ); A - area extent of the reservoir (m^2); h - average reservoir thickness (m); C_r - specific heat of the rock at reservoir conditions (kJ/kgK); T_i - initial average reservoir temperature (°C); T_f - base temperature (°C); φ - porosity of rock; S_w - water saturation; h_{wi} and h_{wf} - water enthalpy at base temperature (kJ/kg); ρ_r and ρ_{wi} - rock and water density at reservoir temperature (kg/m^3).

(2) The power generation capacity is calculated by the following equation (Muffler, P. and Cataldi, R. (1978)**:**

$$E=(Q\, R_f\, n_c)/FL)$$

In which: R_f - A recovery factor to determine the amount of stored heat that can be extracted. The recovery factor is calculated here to be 2.5 times the void space with an upper limit of 50%. This is usually taken to be 20 to 25%; n_c - conversion efficiency for converting the recovered heat to electricity. This is usually taken to be 10% for liquid-dominated geothermal system; L - power plant life (years x 31.5 x 106). It is common to use 20 to 30 years; F - power plant factor. In many geothermal plants, this factor is between 90% and 95%. For binary plant this factor usually taken to be 95%.

The parameters are assumed as:

A = 2,500,000 m^2; h = 2 m; C_r = about 0.8 kJ/kgK; T_i = calculated geothermometers in °C (Table 1); T_f = 90 °C; φ = 8 %; S_w = 100%; R_f – 20%; n_c – 7.5%; F – 95%.

By applying the method of geothermal assessment through the processes of calculation, the results have been presented in table 2. The total power generation capacity from geothermal resources is 115 MWe and the highest potential is Bang geothermal resource (21 MWe).

Table 2: Power generation capacity of geothermal prospects in North Central Vietnam.

Geothermal Prospect	**Label**	**Capacity** (MW)
Cua Dat	CD	9.8
Nam Ron	NR	10.7
Kim Da	KD	10.0
Son Kim	SK	14.2
Bang	B	21.0
Lang Eo	LE	8.7
Dak Rong	DR	9.0
My An	MA	14.5
Duong Hoa	DH	18.5
Total		**116.3**

5. BARRIERS TO POWER GENERATION DEVELOPMENT

Barriers are understood to be a matter of making geothermal power projects hindered without developmental or difficult to develop. From a project perspective, we recognizes there are 2 types of barriers. The first type comes from the investor and the second one came from the government and the external conditions for investors to be able to decide to invest in the development of projects.

The Government of Vietnam, with the aim of developing green economy and achieve environmental commitments as well as to reduce the climate change trend, is ready to create favorable conditions for geothermal power development. However, how to adjust the legal framework and policies to support the geothermal development is still a problem because the government itself does not understand enough about geothermal energy. For example, regarding the PPA (purchase power agreement), how much the reasonable price should be for geothermal power that the government can buy in order to help to geothermal development, because on the other hand the price should also balance with other types of renewable energy as well as the socio-economic conditions in Vietnam, etc.

On the basis of the laws and policies as well as the practical experience in the last many years in geothermal development in Vietnam, we found the barriers and have assigned their contribution in hindering the development of geothermal power in Vietnam as shown in Table 3.

Table 3. Barriers and possible contributions to development of geothermal power generation

No.	**Barriers**	**Possible contribution at attribute (%)**	**Possible contribution at overall (%)**
Subjective elements		**60**	
1	High exploration and evaluation cost	35	21
2	Geothermal project is complicated and takes a long time	15	9
3	Experience on geothermal power generation	20	12
4	Geothermal technician, scientists and experts	30	18
Objective elements		**40**	
1	Legal framework	10	4
2	Policy to support geothermal development	30	12
3	Administrative procedure	25	10
4	PPAs (Power Purchase Agreement – electric price)	35	14
5	Natural conservative areas, national security sensitive areas	0	0
6	Resettlement and compensation	0	0
7	Environment	0	0

6. CONCLUSIONS

Although the North Central Vietnam is not a region of the volcanic activity but it is appeared many hot springs formed by the young tectonic - geological activities. Nine hot springs have been evaluated as the most geothermal potential and are selected to assess their power generation capability. These geothermal prospects have the reservoir's temperatures ranging from 123^0C to 189^0C and they are large enough to produce electricity thanks to the use of binary cycle technology that has been widely applied in many parts of the world so far.

The method for assessing power generation of geothermal resources has been applied for the geothermal resources in the study area. The initial results show that the geothermal prospects in the North Central Vietnam can be developed for electric generation with a capacity of 8.7MWe - 21MWe. The highest estimated capacity is Bang geothermal resource (21MWe).

The most difficult thing for geothermal development is high initial cost then the price of electricity that the government can buy for geothermal power is still not accounted. The long time exploration and the high risk are also more likely to be the major barriers. Besides the difficulties are the experiences and knowledge on geothermal development but these difficulties can be overcome by means of international cooperation or hiring experts. Because of the difficulties as mentioned, the government should have a clear legal framework for geothermal as well as creates the priority policies and simplify the administrative procedures in order to support the development of geothermal energy.

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