Heat flow study results and geothermal energy distribution in the Vietnam offshore sedimentary basins

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Abstract

The study of the heat flow in Vietnam's offshore oil basins has been carried out at the Vietnam Petroleum Institute by using data from 80 exploratory wells, distributed from the Song Hong basin in the North to the Nam Con Son basin in Southern part of the Vietnam East sea. The thermal conductivities of 427 cores were measured using equipment from CCOP, brought to Vietnam by Dr. O.Matsubayashi and simultaneously using the Thercon 2 - 1992, high quality new Vietnamese-made equipment designed and manufactured by Prof. Dam Trung Don of Hanoi University. The temperature gradients of wells were calculated from well log data and from well tests data. The average heat flow values of sedimentary basins in offshore Vietnam are as follows: Song Hong basin (119mW/m²), Da Nang basin (89mW/m²), Cuu Long basin (64mW/m²), Nam Con Son basin (80mW/m²).

The distribution pattern of heat flow in a sedimentary basin is believed to be related to its tectonic history. The heat flow and temperature history are the consequence of the geological history of a basin, therefore the main phases of rifting and phase of recent volcanic activity will be the primary sources of thermal energy in Vietnam's sedimentary basins (Fig.2).

The Red River Fault (RRF) in the Song Hong basin, the North - South trending fault in the Bac Bo gulf, and others faults are important thermal channels in offshore Vietnam. The coal beds in the Song Hong basin, the Rotalit shale in the Cuu Long basin and the local shale layers in all basins are good thermal sealing layers. Due to the differences in geological characteristics and heat flow regime, Vietnam's sedimentary basins have different geothermal energy distributions. Their thermal regimes are generally conducive for providing the conditions necessary for the maturation of hydrocarbon source rocks and facilitating the migration of oil to the traps. Also, with high heat potential, the geothermal energy of some regions is favourable for power generation and for other industrial and human needs.

1. Introduction

Geothermal energy is thermal energy generated and stored in the earth. At the core of the earth, temperatures may reach over 5,000°C. Heat is conducted from the core to surrounding cooler rocks. High temperatures and pressures cause some rock to melt, creating magma which migrates upwards since it is lighter than the solid rock. The magma heats rock and water in the crust, sometimes up to 370°C. The earth's internal energy flows to the surface by conduction at the rate of 44.2 terawatts (TW) and is replenished by radioactive decay of minerals at a rate of 30TW. These power rates are more than double humanity's current energy consumption from all primary sources, but most of this energy flow is not recoverable. In addition to the internal heat flows, the top layer of the earth's, surface to a depth of 10m, is heated by solar energy during the summer and releases that energy and cools during the winter. In most of the world, excepting these seasonal variations, the geothermal gradient of temperatures through the crust is 25 - 30°C per kilometer of depth. The conductivity heat flux averages 0.1MW/km². These values are much higher near tectonic plate boundaries where the crust is thinner. They may be further augmented by fluid circulation, either through magma conduits, hot springs and hydrothermal circulation or a combination of these. Geothermometry is a branch of geophysics which has the objective to study and elucidate these problems.

Discovering the origin and distribution of regional heat flows is of great practical importance because they can help us to understanding the geological development history, especially the geodynamic regime of the studied areas. In the petroleum domain, geothermal research contributes to determination of the source rock maturation (e.g. the cooking process

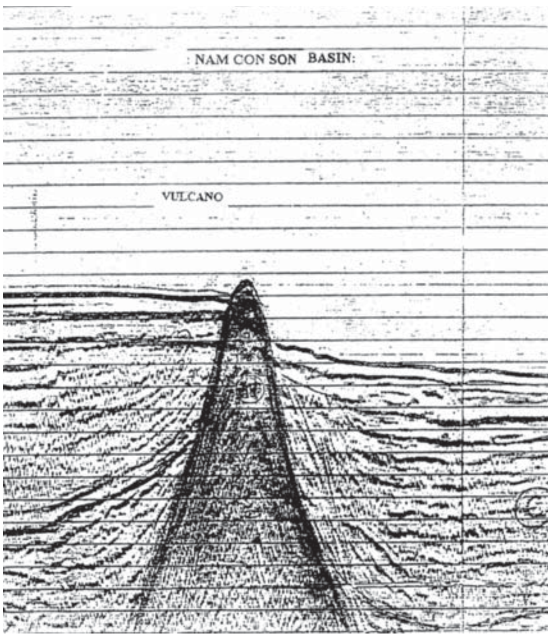

Fig.1. *The recent volcanic activity of Nam Con Son basin is from seismic data. In offshore Vietnam, the main phases of rifting and the phase of recent volcanic activity are the primary sources of thermal energy in its sedimentary*

whereby organic matter in a rock is converted into gaseous and liquid hydrocarbon), the migration of oil from source rock into a more permeable medium and movement through the permeable conduit into the reservoir as well as the remobilization of reservoired petroleum. Defining thermally anomalous zones in a prospect is a very important task in the selecting the drilling technology in order to avoid technical risks in the drilling process [1 - 4].

2. Study results

2.1. Thermal conductivity

Thermal conductivity is dependent on the composition and geometry of the rock matrix, on porosity and on pore medium. Additional influences in the situation of a deeply buried rock are pressure and temperature. Measurements of thermal conductivity cover a wide spectrum of techniques that can be subdivided into direct (laboratory) and indirect (well-logging) approaches. The indirect approach can potentially circumnavigate the problem of based single-point rock sampling for laboratory measurements and also provide thermal conductivity values along the entire borehole profile, but its use depends on the quality and the number of logs available.

In our study, thermal conductivity was measured in more than 427 conventional core samples covering representative stratigraphic intervals of 80 exploratory wells in four oil basin areas of Vietnam. Core samples having a flat surface with an approximate area of 12 x 8cm and a thickness of 6cm were smoothed and soaked in water for 48 hours before being measured at a constant room temperature of about 26^{o}C. The thermal conductivity values obtained by the two instruments mentioned above were corrected by calibrating them with a fused quartz standard sample, which has a thermal conductivity of 1.16kcal/mhK^o (Fig. 3).

By knowing the thermal conductivity and thickness of each rock type the unit-averaged thermal conductivity Kf and the average for a well Kw can be calculated using the following equations:

$$Kf = (t1/k1 + t2/k2 + \ldots + tn/kn)/(t1 + t2 + \ldots. + tn)$$

$$Kw = (ta/kfa + tb/kfb + \ldots + tn/kfn)/(ta + tb + \ldots. + tn)$$

Where k1, k2…, kn are the averaged thermal conductivity of each rock type after correction for the effect of in-situ temperature; Kf and Kw are respectively the thermal conductivities of the stratigraphic unit and the whole section of a well, and t1, ta are respectively the thickness of individual rock types and stratigraphic units. The thermal conductivities in some other wells were also calculated based on the well-log data. The following formula was used in the calculation:

$$K = Rs/[Ks^{(1-phi)} \times Kw_a^{(phi)}] + Rm/[Km^{(1-phi)} \times Kw_a^{(phi)}]$$

Where K, Ks, Km, Kw_a are the thermal conductivity of bulk formation, of sandstone, of mudstone and of formation water; "phi" is average porosity, Rs and Rm stand for fractions of sand and mudstone (shale) content, where Rs + Rm = 1.0.

The average thermal conductivity of 80 wells was calculated, and Table 1 shows the average conductivity of each of the sedimentary basins studied in this work. The following generalizations can be noted:

- In the Cuu Long basin the average conductivity value is the lowest of the basins studied;

- In the Song Hong basin the thermal conductivity value onshore (3.37W/mK^o) is higher than offshore (2.98W/mK^o) due to coarse grained sediments onshore and more fine- grained sediments offshore. The highest thermal conductivity is observed in the North-Western part. Conductivity decreases gradually towards the South-East (where K^o - Kelvin degree);

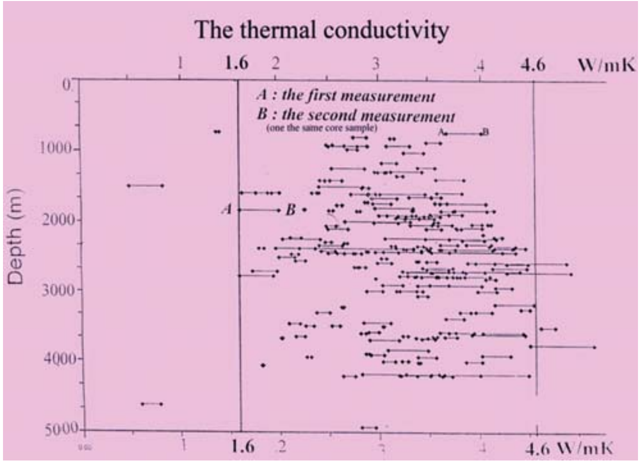

***Fig.2.** The thermal conductivity results from core samples in the Vietnam offshore sedimentary basin in Vietnam offshore oil basin by QTM Thercon 2-1992 - Made in Vietnam and QTM N0911 - Made in Japan*

- For the Nam Con Son basin, thermal conductivity is higher in the Western part (4.14W/mK°), where coarser-grained deposits predominate. However, in the Southeastern, Northeastern and central parts it tends to be lower (2.47W/mK°) because of finer grained deposits in these areas;

- In the Da Nang area, thermal conductivity is higher in the Northeastern part (3.00W/mK°) than in the Southeastern part (2.16W/mK°). This rapid decrease towards the South may be due to carbonate deposition in the South.

2.2. Geothermal gradient

Geothermal gradient is the rate of change of temperature with depth in the earth. Here, the temperature gradient was computed by extrapolation of the successive bottom hole temperatures (BHT) of wells and assuming a surface temperature of 80°F (26.67°C). The temperature derived from well-logs is corrected to obtain the true formation temperature by using Dowdle and Cobb's (1975) method as expressed by the following formula:

$$TF = TL + C\log[(t1+t2)/t2]$$

Where:

TF: True formation temperature;

TL: Measured temperature (BHT) at time t2 during geophysical logging;

t1: Circulation times after drilling stopped and before the bit pulled;

t2: Times between cessation of circulation and measuring TL;

C: A constant.

In order to obtain true formation temperature values for all the wells studied (in the Nam Con Son, Da Nang, Cuu Long and offshore Song Hong basins) the authors used a nomogram based on the above formula. For all the wells in onshore Song Hong basin, true formation temperatures were obtained by temperature logging under taken from four days to two years after the circulation of drilling fluids stopped. The temperature gradient (G) was computed by using the following formula:

$$G = dT/dz = (BHT\ corr - 26.67)/z$$

The average temperature gradient of each basin aresummarized in Table 1. Individual basins have the following characteristics:

- In general, in the basinal areas of Vietnam, temperature gradients decrease with depth;

- The temperature gradient of the Cuu Long basin is the lowest of the offshore basins studied;

- In the Song Hong basin, the temperature gradient increases rapidly towards the central part and decreases to the Northeast;

- In the Nam Con Son basin, the temperature gradient decreases rapidly to the West, with a value of 26K°/km in the Northwest, and increases to the East to about 40K°/km;

- In the Da Nang area, the temperature gradient increases rapidly to the North and Northeast, and decreases gradually to the South;

- In the Cuu Long basin, the temperature gradient is highest in its central part.

2.3. Heat flow

Terrestrial heat flow (Q) is obtained as the product of thermal conductivity (K) and temperature gradient (G):

$$Q = K \times G = K \times dT/dz$$

The average heat flow of 80 exploration wells in Vietnam was calculated by using the above formula and the results for each basin are shown in Table 1. The average heat flow value of Vietnam's sedimentary basins is 82.95mW/m^2. This is higher than the world average (63mW/m^2), but is similar to those in adjacent zones

__Table 1__. Average thermal conductivity, temperature gradient and heat flow of basinal areas in Vietnam

Basin	Thermal conductivity (W/mK°)			Temperature gradient (K°/km)			Heat flow (mW/m²)		
	Min	Max	Aver.	Min	Max	Aver.	Min	Max	Aver.
Song Hong	2.64	4.15	3.37	29.3	42.4	35.9	100	140	119
Da Nang	2.15	3.25	2.77	26.2	42.5	34.6	55	125	89
Cuu Long	1.77	2.61	2.28	22.6	33.5	27.8	45	85	64
Nam Con Son	2.28	4.13	2.67	26.0	41.5	35.9	50	110	80

and other sedimentary basins of South East Asia such as the Southern Malay basin (92.37mW/m²); Balingian (92.13mW/m²); Malaysia (81.7513mW/m²); Sarawak (78.8mW/m²).

In Vietnam, most characteristically the heat flow in the Northern part (119mW/m²) is much higher than in the Southern part (73.67mW/m²). Due to the difference in the geological structure, tectonic regime, geological development history and deposition processes, these sedimentary basins have individual geothermal regimes. The Song Hong basin has the highest regime, followed by the Nam Con Son, Ma Lai - Tho Chu and Cuu Long basins; respective values are 119, 80, 74 and 64mW/m². Lower heat flow zones (less than 50mW/m²) as in the Phu Khanh basin, the Southern part of Song Hong basin and Southeast of offshore Vietnam (Blocks of 06, 07, 08) may be caused by carbonate deposits being present here. In each sedimentary basin, the heat flow distribution displays individual local contours and their distribution pattern is believed to be related to the deep structure, tectonic activities and geological history of the area. From observations mentioned above, some conclusions can be drawn as follows:

- In offshore Vietnam, heat flow in the Song Hong basin is the highest, and in the Cuu Long basin the lowest;

- In the Song Hong basin, heat flow increases rapidly towards the West and North-West, and decreases gradually towards the Southeast;

- In the Da Nang area, the heat flow decreases gradually towards the South;

- In the Nam Con Son basin, the heat flow increases to the West and Northeast, and decreases towards the Southeast.

2.4. Geothermal energy distribution in the Vietnam offshore sedimentary basins

According to preliminary calculation, for the objective of power generation, the prognostic geothermal energy in the reservoir of the whole shelf is 21,558.4 x 10^{18}J (joules), electric equivalent to 6,030 billion MWh. Of this total quantity, in the Song Hong basin Qr = 8,871.8 x 10^{18}J, or 41% (2,450 billion MWh); Nam Con Son basin Qr = 7,542.2 x 10^{18}J (35%); Ma Lai - Tho Chu basin Qr = 3,700 x 10^{18}J (17%); and Cuu Long basin Qr = 1,544.4 x 10^{18}J (7%) (Fig.5).

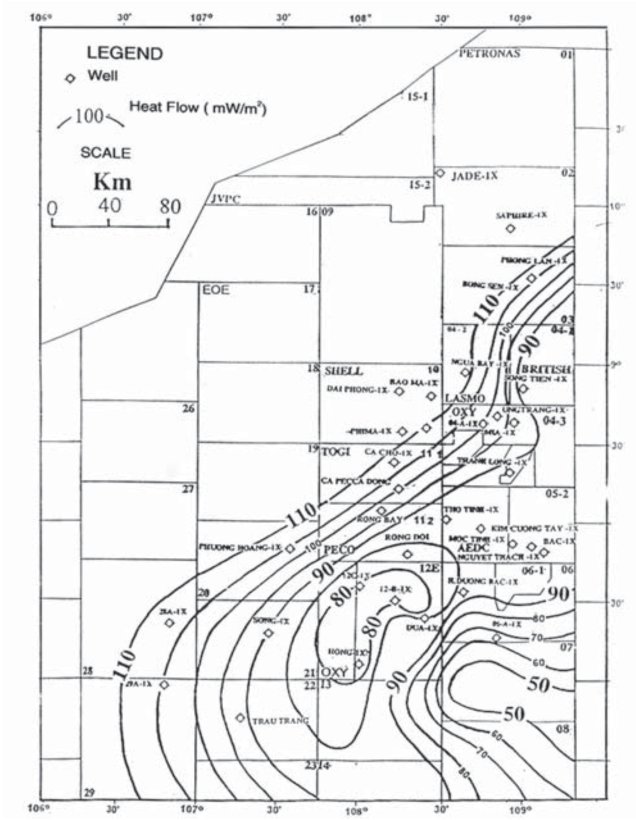

Fig.3. *Heat flow map of Nam Con Son basin*

Geothermal energy distribution in each sedimentary basin:

The results of the investigationshows that the geothermal regimes are different in different basins. The geothermal energy distribution module in the Song Hong basin is 0.08 x 10^{18}J/km²; in Nam Con Son is 0.05 x 10^{18}J/km² and in Cuu Long basin is the same value approximatively.

Geothermal energy distribution in each sedimentary formation:

Neogene sediments in Vietnam consist of a large thickness of alternating sandstone, siltstone and claystone distributed all over the continental shelf. They overlie the eroded Paleogene sediments and are overlain in turn by 30 - 500m thick quaternary sediments. Due to the difference in tectonic characteristics and sediment supply sources, the depth of occurrence and thickness of Neogene formations differ in different basins. The water-bearing formations consist of medium to fine grained sandstone, fractured and weathered shelf limestone and coral limestone. In almost all sedimentary basins, the clay/sand content of the Neogene sediments reaches about 40 - 50%. The thickness of sandstone and of shelf and coral carbonate layers varies from a few meters to some tens meters. The temperature of the water varies from 30 - 100°C, the total dissolved solids (TDS) is relative low and tends to increase with depth from 1 - 3g/l. The chemical composition of the thermal water is mainly HCO_3ClNa. According to the result of C^{14} radiometric dating, the age of the thermal water in Neogene strata is 5 - 25Ma.

The geothermal energy distribution in Neogene sediments is as follows: Prognostic geothermal energy in the reservoir of Song Hong Neogene is Qr = 3,923.31 x 10^{18}J; of Nam Con Son Neogene is Qr = 3,227.55 x 10^{18}J, and of Cuu Long Neogene is Qr = 1,353 x 10^{18}J.

Paleogene sediments in Vietnamese basins comprise alternations of claystone and sandstone sequences, of which the clay component is predominant, varying from 60 - 70%.The distribution of the sediments is very complicated due to the uplift and erosion causing them to completely or partially disappear in some places . In the depressions, a complete sequence is most likely to be present. However, so far in those locations, no wells have been drilled.

In the Song Hong basin, due to the very complicated geological conditions and low density of wells drilled, the Paleogene sediments have not been thoroughly investigated. Some wells have encountered these sediments in the continental shelf such as 103TH-1X, 103TG-1X, 107PA-1X, 112BT-1X, 114KT-1X, 119CH-1X and on the mainland such as GK204, 104, 110, 81, 203, 200, D14-STL. The thickness of these sediments varies considerably over large range.

On the contrary, in the South of the Vietnam continental shelf, the Paleogene sediments cover nearly all over the sedimentary basins and their thickness varies from 100 - 1,400m. In the Cuu Long basin, the Paleogene sediments occur at depths from 1,580 - 4,300m. In the Nam Con Son basin they are encountered at depths from 1,850 - 4,300m and in the Ma Lai - Tho Chu basin from 1,850 - 4,300m.

The water-bearing formation of the Paleogene consists of sandstone, volcanic rocks, and pyroclastic sediments with thickness varying from a few tens to hundreds of meters. The temperature of the ground-water varies in the range 80 - 115°C and, in the main, its chemical composition is HCO_3ClNa. The DTS varies from area to area depending on the paleoclimatic and paleohydrochemical conditions of the area. The DTS of the groundwater in the Cuu Long basin varies from a few g/l to some tens of g/l; in the Nam Con Son basin from 1.5 - 3.5g/l and in the Malay - Thochu basin from 1.2 - 3.5g/l. The age of the Paleogene thermal groundwater varies from 27 - 35Ma, according to the C^{14} radiometric dating result.

Prognostic geothermal energy in the reservoir is as follows: $Qr_{\text{Song Hong}} = 4,848.49 \times 10^{18}$J;

$Qr_{\text{Nam Con Son}} = 4,314.65 \times 10^{18}$J; $Qr_{\text{Cuu Long}} = 190.66 \times 10^{18}$J.

The weathered and fractured basement has good water bearing capacity. In the Song Hong basin the Pre-Cenozoic basement was encountered in some wells such as 112BT-1X, 112HO-1X, 112AV-1X, 115A-1X, 104QV-1X. The basement rocks consist mainly of dolomite, dolomite-carbonate, siliceous rocks, limestone and terrigenous sediments with moderate porosity. The total thickness of the weathered zone reaches as much as thousands of meters.

In the Cuu Long basin, the basement is met in numerous wells in the Bach Ho, Rong, Rang Dong, Hong Ngoc, Ba Vi… fields and is mainly composed of granite and granodiorite. The fractured zones are usually oriented in a vertical direction, therefore the liquids with high temperature, rising up from the great depths, are likely to form local thermal water reservoirs in the old uplifted basement. To the present day, geothermal energy in the basement is not yet studied as there are still insufficient data for determining the in-situ geothermal energy reserves of the weathered - fractured basement.

3. Geothermal classification by temperature

In the sedimentary basins of Vietnam, the temperature distribution is as follows:

Therefore, in the sedimentary basins of offshore Vietnam at the depth from 500 - 4,000m, minimum temperature varies from 44.1 - 115°C; maximum temperature from 54.1 - 185.0°C and average temperature from 49 - 151°C (Table 2). The thermal water sources in terms of temperature can be divided as follows:

- Low temperature: < 90°C;
- Medium temperature: 90 - 150°C;
- High temperature: > 150°C.

Table 2. *Distribution of the temperature versus depth*

Depth (m)	Min (°C)	Max (°C)	Average (°C)
500	44.1	54.1	49
1,000	56.2	77.8	67
1,500	67.3	107.8	87
2,000	78.0	118.0	98
2,500	87.3	136.0	112
3,000	98.1	155.0	127
3,500	106.0	170.0	138
4,000	115.0	185.0	151

Normally, high and medium temperature geothermal sources are used for electricity generation, whereas the medium and low temperature geothermal source may be used directly for heat pumps. With the above classification, the geothermal sources in the Tertiary sedimentary basins of Vietnam can be evaluated and classified as the low and medium temperature class (to the depth of 3,000m). In particular, the geothermal sources in the South of the Bac Bo plain (block 112, 113, 114, 115) down to the depth of 4,000m can be classified a high temperature resource.

The Song Hong basin has more favorable conditions for thermal energy exploitation due to the higher geothermal gradient and smaller depth. Here, at the depth of 2,000m, the mean temperature may reach 110°C, whereas in the Nam Con Son basin the temperature is lower.

Examining all conditions as a whole, the Hanoi depression and Southern Deo Ngang areas can be seen as the regions of greatest geothermal energy potential in Vietnam's sedimentary basins [6,7].

4. Conclusion

1. The sedimentary basins in the Vietnam continental shelf contain large and valuable energy resources - oil and gas, coal and geothermal energy but up to now the geothermal regime is poor studied. Therefore, it is very important to have a comprehensive policy for investment and for further investigation to evaluate the geothermal energy potential in more detail through application of advanced technologies for these activities.

2. Geothermal energy of offshore Vietnam can be exploited in Neogene and Paleogene formations at depths from 500 - 3,000m. The geothermal temperature of sedimentary basins is from moderate to high, favorable for the use of geothermal energy for power generation and directly for industrial and human needs.

According to the preliminary calculation, for the objective of power generation, the prognostic geothermal energy reserves of the whole shelf are 21,393.4 x 10^{18}J, equivalent to 6,030MWh. The onshore reserves are also fairly large. Therefore, we propose that the Ministry of Sciences and Technology, Petrovietnam should develope an adequate research program for exploration and exploitation of geothermal potential in our country, especially in the Hanoi trough and South Deo Ngang areas, to serve for the state sustainable energy development program to the year of 2020 and beyond.

Reference

1. *Abstracts of 30th International Geological Congress*. China. 4 - 14 August 1996.

2. Asian Council on Petroleum (ASCOPE). *Terrestial heat flow mapof Southeast Asia*. Technical paper TP/6. Indonesia. 1986.

3. Cao Dinh Trieu, Nguyen Xuan Binh. *Earthquake activities in Vietnam*. Geology and Petroleum. 1999.

4. M.Dickson and M.Fanelli. *Status of geothermal research in the world and in Asia*. First conference of Indochina. Vietnam. 1986; 2.

5. O.Matsubayashi and S.Uyeda. *Estimation of heat flow in certain exploration wells in offshore areas of Malaysia*. Bull. Earthquake Res.Ins. 1979; 54: p. 31 - 44.

6. Do Van Dao, Tran Huyen. *CCOP Technical bulletin*. 1980; 25: p.55 - 62.

7. Tran Huyen. *The heat flow and geothermal energy distribution of sedimentary basins offshore Vietnam.* Asian Geothermal Symposium 2000.