Estimated Formation Temperature On Oil Well Using Log and Thermal Method in 'H' Region, Central Sumatra

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Abstract.
Rock temperature is an important parameter in the process of predicting the maturity of hydrocarbons in sedimentary rocks and also can be used as the basis studies related to geothermal reservoir. Direct measurement in well drilling is to determine the temperature at determined depth. This measurement was not done thoroughly on the well, some have only do a measurements on the bottom of wells (BHT). This study estimates the temperature at each depth on well that surface temperature and Bore Hole Temperature (BHT) known using the development of earth heat flow basic concepts, by calculating thermal conductivity of group formation, temperature gradients of group formation and heat flow. These three parameters used as a basic to determine the change in depth on temperature rising at 10^{O}C or 5^{O}C. The temperature in each formation can be used as a parameter to calculate the amount of heat in the reservoir rock and the resulting temperature in each depth can be used as a parameter to estimate the hydrocarbon maturity. The thermal conductivity of rocks in this study obtained by measuring core in the laboratory and calculation based on rock porosity. These two method show a slight different price causing k_F, k_{GF}, gradT, k_W, and heat flow have the same price of the rock thermal conductivity measurement and calculation. The temperature on the A1 well ranges from 27^{O}C (surface) to 127^{O}C (basement), while the B1 well ranges from 30^{O}C (surface) to 100^{O}C (basement).

INTRODUCTION

Temperature affects the organic compounds in sediments. Temperature increasment transform hydrocarbon to crude oil, condensate and become only gas. Petroleum generated from lipid liberation of kerogen is a process that is related to the temperature, which is exponential and starts at temperatures around 93^{O}C. The temperature in a rock is an important parameter in the process of predicting the maturity of hydrocarbons in sedimentary rocks and also can be used as the basis studies related to geothermal reservoir. Heat flows from the bottom spread onto the surface affects the pore space of rock, thus every pore space of rock has a temperature. The temperature in each pore are different because the porosity and thermal conductivity were different, and the difference in the hydrostatic pressure of the rock. Direct measurement in well drilling is to determine the temperature at determined depth. This measurement was not done thoroughly on the well, some have only do a measurements on the basis of wells (BHT). This study estimates the temperature at each depth on the well that the surface temperature and Bore Hole Temperature (BHT) known using the development of earth heat flow basic concepts to determine the temperature at each depth, by: a. calculating the thermal conductivity of group formation; b. calculating the temperature gradients of group formation; c. calculating the heat flow. These three parameters (a, b, c) used as a basic to determine the change in depth on temperature rising at 10^{O}C or 5^{O}C. The contribution of this study are: 1. The temperature in each formation can be used as a parameters to calculate the amount of heat in the reservoir rock; 2. The resulting temperature in each depth can be used as an important parameter to estimate hydrocarbon maturity (oil and gas). The thermal conductivity of rocks in this study obtained by measuring the core in the laboratory and calculation based on rock porosity.

LITERATURE

Thermal Conductivity

According to Eckman (1958), the heat transfer through three different ways, namely conduction, convection, and radiation. Conduction is the process of heat transfer in a substance that is not accompanied by mass transfer (commonly occurs in solids). The thermal conductivity of a substance is the heat conductivity in substances, which means the ability to conduct heat. The SI unit for thermal conductivity (k) is W/m^{O}C. In 1982, Gretener researched the thermal conductivity of rocks (solid), liquid and gas for different lithology below the surface at room temperature. It result that the thermal conductivity for each substances are different, while the thermal conductivity for one substance (same lithology), also different.

Thermal Conductivity of Group Formation

Thermal conductivity of group formation (k_{GF}) is the ability of a group formation in the well to conduct heat. Thermal conductivity for group formation is determined by the calculation based on the formation thermal conductivity and the thickness of the group formation by summing the respective thermal conductivity formations that exist in groups (Dewanto, 2001);

$$k_{GF} = \left[\left(\frac{d_{F1}}{k_{F1}} + \frac{d_{F2}}{k_{F2}} + \ldots\right) \times \frac{1}{d_{F1} + d_{F2} + \ldots}\right]^{-1} \quad 1.$$

where; k_{GF} = thermal conductivity of group formation (10^{-3} cgs), d_{F1} = formation-1 thickness (m), d_{F2} = formation-2 (m), $d_{F1}+d_{F2}$ = group formation thickness (m), k_{F1} = formation-1 thermal conductivity (10^{-3} cgs), k_{F2} = formation-2 thermal conductivity (10^{-3} cgs) and so on.

The thermal conductivity of group formation is for determining the well temperature. The determination of this group of formations adapted to the conditions of the formation at the well.

Thermal Conductivity of Well

The thermal conductivity of well (k_W) is thermal conductivity that calculated from the depth of a well up to the surface. Well thermal conductivity determined by the calculation based on the formation thermal conductivity and the thickness of the formation by summing the respective thermal conductivity formations that exist in the well (Subono and Siswoyo, 1995);

$$k_W = \left[\left(\frac{d_{FA}}{k_{FA}} + \frac{d_{FB}}{k_{FB}} + \ldots + \frac{d_{FN}}{k_{FN}}\right) \times \frac{1}{DA}\right]^{-1} \quad 2.$$

dimana; k_W = thermal conductivity of well (10^{-3} cgs), d_{FA},d_{FB},d_{FN} = formation thickness A, B to N (m or cm), DA = total depth well

Temperature

Heat flows from the bottom spread onto the surface affects the pore space of rock, thus every pore has a temperature. The temperature in each room is different because the porosity and thermal conductivity are different, and the difference in the hydrostatic pressure of the rock (Nakayama and Lerche, 1987). Temperature affect the organic compounds in sediments. Temperature improvement transform hydrocarbon to crude oil, condensate and become only gas. The lipid liberation of kerogen is a process that is related to the temperature that affect the petroleum generate, which is exponential and starts at temperatures around 93^{O}C (Klemme, 1972).

Temperature Gradients

The temperature of oil and gas reservoir is primarily determined by the depth and geological position. Deeper depth has the higher temperature. On the other hand this temperature is determined by the temperature gradients. The temperature gradients (gradT) is stated in the ^{O}F/100 feet or ^{O}C/100 m. Heat that spreads flowing from the bottom to the surface causing the porous of rock which the heat flow through has a temperature. The temperature at each rocks are different. The temperature gradients is defined as follows:

$$\frac{dT}{dZ} = \frac{(Tf - Ts)}{D} \times 100 \qquad 3.$$

where; dT/dZ= temperature gradients (^{o}C/100m), Tf = formation temperature (^{o}C), Ts = surface temperature (^{o}C), D = formation depth (m)

Heat Flow

Subsurface has a heat source located in the center of the earth. Heat flows from the bottom spread onto the surface. Heat flow is the amount of heat flowing from the earth to the surface by conduction. Heat flow (Q) affects the pore space of rocks thus every pore has a temperature. Temperature and thermal conductivity of each rock vary because the porosity that influence the heat coming from the heat flow (Dewanto, 2002). Heat flow rates can be obtained from the product of the thermal conductivity and temperature gradients over an interval and depth. In the form of formulas, geothermal heat flow can be expressed as;

$$Q = k\frac{dT}{dZ} \qquad 4.$$

where; Q = heat flow (HFU or μcal/cm^{2}s or *m*W/m^{2}), *k* = thermal conductivity (10^{-3} cal cm^{-1} dt^{-1} ^{O}C^{-1} or W/m^{O}C), dT/dZ= temperature gradients (^{O}C/100 m), 1 HFU= 10^{-6} kal cm^{-2} dt^{-1}

Implemented Study

Landes (1967) in his research on Eometamorphism, and Oil and Gas in Time and Space, concludes that the change in temperature can cause the onset of metamorphism and very influential in the organic compounds in sediments. According to Klemme (1972) in his research on Heat Influences Size of Oil Giants-Geothermal Gradients, petroleum generated from lipid liberation of kerogen is a process that related to the temperature was exponential. In this case, then the depth and temperature gradients are important factor.

Subono and Siswoyo (1995) in his study of Thermal Studies of Indonesian Oil Basin, provides an overview of the effect of thermal physical properties of the oil basin. The study is a continuation of Tamrin et al (1981) research about the heat flow determining method. Dewanto (2001) in his research on Analysis of the Relationship Between Porosity and Thermal Conductivity of Rock in Measurement and Calculation Results, give some conclusions, first: rocks porosity have variations value due to the rocks temperature and heat differences, second: thermal conductivity of rock influenced by pressure, thus the deeper depth, the thermal conductivity of rocks bigger.

METHODOLOGY

Required Data

1. BHT (*Bore Hole Temperature*)
2. Stratigraphy (lithology)
3. Thermal conductivity of rocks (k_r)
4. Temperature gradients (gradT), heat flow (Q)
5. Well log data

Rock Analysis and Measurement

1. Rock Analysis

Rocks that used to be analyzed is a conventional plug core rock, rock samples from vertical log drilling

2. Rock Measurement

   In this rock measurement, we measured k_r using a tool called needle three needle device or control box.

Data Calculation

1. Determine the thickness formation
2. Determine the group formation and calculate its thickness
3. Calculating the formation thermal conductivity (k_F)

$$k_F = \left[\left(\frac{d_1}{k_1} + \frac{d_2}{k_2} + ... \right) \times \frac{1}{d_1 + d_2 + ...} \right]^{-1} \quad 5.$$

   where, k_F = formation thermal conductivty (10^{-3} cgs), d_1 = lithology-1thickness (m), d_2 = lithology-2 thickness (m), d_1+d_2 = formation thicknes (m), k_1 = lithology-1 thermal conductivity (10^{-3} cgs), k_2 = lithology-2 thermal conductivity (10^{-3} cgs)
4. Calculating the group formation thermal conductivity (k_{GF})
   using equation 1
5. Calculating the well thermal conductivity (k_W)
   using equation 2
6. Calculating the temperature gradients (gradT)
   using equation 3
7. Calculating the heat flow
   Using equation 4 with using the k as k_W
8. Calculating the temperature gradients of group formation ($gradT_{GF}$)
   using equation 4 with using the k as k_{GF}
9. Create a model to determine the change in depth on each temperature rising at 10^OC (dT = 10^OC, dZ = …).
10. Determining the formation temperature at each depth

RESULTS AND DISCUSSION

This study estimated formation temperature of two wells using thermal methods. The first well is A-1 with 6443.4 ft (1963.9 m) depth and the second well is B-1 with 4606 ft (1403.8 m) depth that located in Central Sumatra Basin. Lithology and thermal conductivity of rock data shown in Table 1 and 2 as required data for this study.

Estimated temperature on each formation was done by measuring and calculating k_r, Q and gradT. Heat flow is the flow of heat coming from the earth brought to the surface passes through a rock. Rock properties and density make the heat flow at each well in an area different though sometime it has the same value. The thermal conductivity of rocks can be determined by core direct measuring in the laboratory and also can be determined by calculation based on rock porosity. This study determine k_r price by core measurment and calculation.

Measurement and Calculation Results

Thermal Conductivity of Rocks Calculation for A-1 and B-1 Wells

Based on the calculation of rock thermal conductivity, we will get formation thermal conductivity (k_F), group formation thermal conductivity (k_{GF}), well conductivity (k_W), temperature gradients (gradT), heat flow (Q), and temperature gradients of group formation ($gradT_{GF}$).

First, determining the thermal conductivity of rocks (k_r) in well A-1 with calculation based on rock porosity (ϕ), using the equation $k = k_f^{\phi} \times k_s^{1-\phi}$. Porosity that used in this equation is total porosity for each lithology at the formation in wells A-1. With the value of k_s (thermal conductivity of solid) and k_f (thermal conductivity of fluid) based on Gretener (1982). The result of k_r calculation in well A-1 are shown in Table 1. After obtaining k, determine the thermal conductivity of formations (k_F) value using formation thickness, type and rock thickness data. After obtaining k_F, determine the thermal conductivity of wells (k_W) value. k_W in A-1 is 5.37×10^{-3} cal/cm dt ^OC, shown in Table 3. Heat flow (Q) value obtained by calculating gradT and k_W in each well. k_W, $gradT_W$, and Q are shown in Table 3. After obtaining the heat flow, determine k_{GF} value. Then determine $gradT_{GF}$ value. Next determine the changes in depth (dZ) for temperature rising at 10 ^{O}C (10^{O}C/Z). Calculation result of k_{GF}, $gradT_{GF}$ and dZ are shown in Table 5.

The calculations of well B-1 has the same steps like well A-1. The well B-1 has more shallow depth than well A-1. From the calculations, the price of the k_r in wells B-1 are shown in Table 2. The calculations results of k_W, $gradT_W$, and Q are shown in Table 3. And the calculations results of k_{GF}, $gradT_{GF}$ and dZ are shown in Table 7.

The Thermal Conductivity of Rocks Measurement for A-1 and B-1 Wells

The k_r measurement results in well A-1 shown in Table 1 and well B-1 in Table 2. k_r data processing based on the measurement is the same as data processing based on the calculation. From the data processing based on the measurement, Table 4 shows the results of k_W, gradT, and Q in A-1 and B-1 wells, Table 6 shows k_{GF}, $gradT_{GF}$ and dZ in well A-1, and Table 8 shows k_{GF}, $gradT_{GF}$ and dZ in well B-1.

Discussion

The Thermal Conductivity of Rocks

In wells A-1 and B-1, deeper depth has bigger k_r (for sand and shale). The relationship between k_r and depth (Z) show the exponential (Figure 1-4). These thermal conductivity difference influenced by many factors.

k_r obtained by measuring the core laboratory has almost the same price to k_r calculation by rock porosity (ϕ). $k = k_f^{\phi} \times k_s^{1-\phi}$ equation (Nakayama, 1987) shows that the ϕ greatly affect the k_r. Figure 5-8 shows a relation graph between ϕ and k_r and the graph shows the exponential. Smaller ϕ has bigger k_r. As we can see in the theory that show the increasing depth has the decrease ϕ exponentially (Sclater and Christie, 1980).

Porosity decreases exponentially in every increase of depth caused by the overburden pressure, which affects the pore space of rocks. So that the pore has the different shape and properties. Like the price of ϕ which becoming smaller every increasing depth (Nakayama, 1987, from Rubey and Hubbert, 1959). Because the ϕ getting smaller, then k_r is getting bigger in every increasing depth. ϕ difference is also affected by temperature. We see in A-1 and B-1 wells, the price change of ϕ and k_r are not big in every increased depth. It does not mean the pressure has no effect, beside the over pressure did not happen.

Formation Temperature

Minas Formation well A-1 (0-170 m) has $k_F = 4.14\times10^{-3}$ cgs and well B-1 (0-120 m) has $k_F = 4.52\times10^{-3}$ cgs. In this formation, we see the k_F price differences. Because in this formation, the well B-1 has only one kind of lithology is sand with a thickness of 120 m. While in well A-1, consisting of shale (75 m thick) and sand (95 m thick) lithology. Minas Formation lithology in well A-1 and B-1 have the same age. This fit the theory of thermal conductivity, that in the near surface, k_{SAND} greater than k_{SHALE} (Gretener, 1982). Formation temperature in Minas for well A-1 ranges from 27^{O}C to 37^{O}C, and the Well B-1 ranges from 30^{O}C to 40^{O}C (Figure 9 and 10).

Petani Formation well A-1 (170-284 m) has $k_F = 4.26\times10^{-3}$ cgs and well B-1 (120-240 m) has $k_F = 3.97\times10^{-3}$ cgs. Each wells have shale and have the same age lithology. In this formation, well A-1 has the k_r larger than well B-1 because the formation lithology in well A-1 located in deeper depth that has a bigger pressure and affects the space rocks that affect the price of ϕ. As a result, the k_r change according to a graph ϕ vs k_r and k_r vs Z. Formation temperature in Petani for well A-1 ranges from 37^{O}C to 47^{O}C, and well B-1 ± 40^{O}C (Figure 9 and 10).

Telisa Formation well A-1 (284-698 m) has $k_F = 4.23\times10^{-3}$ cgs and well B-1 (240-605 m), has $k_F = 4.22\times10^{-3}$ cgs. In this formation, well A-1 consists of shale or clay (394 m thick) and sand (20 m thick) lithology while well B-1 has only one lithology that is clay (365 m thick). And each well have the same age lithology. Telisa Formation well A-1 has k_F larger than B-1 wells due to the formation lithology. In this formation, well A-1 is in deeper area and also have sand lithologily. Formation temperature in Telisa for well A-1 ranges from 47^{O}C to 67^{O}C and well B-1 ranges from 50^{O}C to 60^{O}C (Figure 9 and 10).

Upper Sihapas Formation well A-1 (698-778 m) has $k_F = 4.95\times10^{-3}$ cgs and well B-1 (605-685 m) $k_F = 4.47\times10^{-3}$ cgs. In this formation, well A-1 consists of shale (40 m thick) and sand (40 m thick) lithology while well B-1 has only one lithology that is clay (80 m thick). Each well have the same age lithology. In this formation,well A-1 have greater k_F because this well located in deeper depth and the lithology differences. Formation temperature in Upper Sihapas for well A-1 ranges from 67^{O}C to 77^{O}C, and the well B-1 ranges from 60^{O}C to 70^{O}C (Figure 9 and 10).

Lower Sihapas Formation well A-1 (778-969 m) has k_F = 5.25×10^{-3} cgs and well B-1 (685-930 m) has k_F = 5.79×10^{-3} cgs. Each wells have the same age lithology. Lower Sihapas Formation well A-1 has sand (111 m thick) and shale (80 m thick) lithology, while the well B-1 also has sand (185 m thick) and shale (60 m thick) lithology. In this formation, well B-1 has a greater k_F than well A-1 due to the lithology aspect where lithology in well B-1 dominant sand and the two wells located in almost in the same depth, cause the depth factor has a little effect on k_F. Formation temperature at Lower Sihapas for well A-1 ranges from 77^{O}C to 87^{O}C and well B-1 ranges from 70^{O}C to 80^{O}C (Figure 9 and 10).

Pematang Sand Stone (Pematang SS) Formation well A-1 (969-1457 m) has k_F = 6.65×10^{-3} cgs and well B-1 (930-1160 m) has k_F = 6.90×10^{-3} cgs. Pematang SS Formation well A-1 has sand (368 m thick) and shale (120 m thick) lithology. While well B-1 has sand (210 m thick) and shale (20 m thick) lithology. Each well has the same age lithology. If we look at the state of this formation, k_F on well A-1 should have been greater than well B-1. But k_F in well B-1 is greater than k_F in well A-1. This happens because the thermal conductivity is determined by calculations based on ϕ where Pematang Formation SS well A-1 has a greater ϕ than well B-1. Formation temperature in Pematang SS for well A-1 ranges from 87^{O}C to 97^{O}C and well B-1 ranges from 80^{O}C to 90^{O}C (Figure 9 and 10).

Pematang Mud Stone (Pematang MS) Formation in well A-1 (1457-1719 m) has k_F = 6.60×10^{-3} cgs and well B-1 (1160-1318 m) has k_F = 5.55×10^{-3} cgs. Pematang MS Formation lithology for both wells are mudstone or shale where well A-1 lithology has younger age than well B-1. In this formation, well A-1 has bigger k_F although the lithology age younger. This was due to the formation lithology depth where well A-1 located in deeper depth than well B-1. Formation temperature in Pematang MS for well A-1 ranges ±107^{O}C and well B-1 ranges from 90^{O}C to 100^{O}C (Figure 9 and 10).

Pematang Brown Shale (Pematang BRSH) Formation well A-1 (1719-1780 m) has k_F = 6.8×10^{-3} cgs and well B-1 (1318-1342 m) has k_F = 5.08×10^{-3} cgs. Pematang BRSH Formation lithology for both wells are coal where well A-1 lithology has older age than well B-1. In this formation, well A-1 has bigger k_F despite its younger age. This is due to the formation lithology depth where well A-1 located in deeper depth than well B-1. Formation temperature in BRSH for well A-1 ranged from 107^{O}C to 117^{O}C where well B-1 ranges from 90^{O}C to 100^{O}C (Figure 9 and 10).

Pematang LP Formation well A-1 (1780-1880 m) has k_F = 7.01×10^{-3} cgs and well B-1 (1342 1362 m) has k_F = 5.30×10^{-3} cgs. LP Pematang Formation well A-1 has sand (25 m thick) and shale (75 m thick) lithology, while well B-1 has only shale (20m) lithology. In this formation, the well A-1 has bigger k_F than well B-1 dispite the same age lithology. This is due to the formation lithology where well A-1 located in deeper depth than well B-1. Formation temperature in Pematang Formation LP for well A-1 ranges from ± 117^{O}C and well B-1 ranges from 90^{O}C to 100^{O}C (Figure 9 and 10).

CONCLUSIONS

(1) The thermal conductivity of rocks obtained by measuring the core have almost the same price (slight difference) as the thermal conductivity of rocks calculation based on ϕ.

(2) It cause k_F, k_{GF}, GRADT, k_W, and Q have almost the same price for both measurement and calculation.

(3) The temperature based on the thermal conductivity of rocks calculation also have almost the same price to temperature based on the thermal conductivity of rocks measurement for each formations

(4) The temperature of well A-1 with 6443.4 ft (1963.9 m) depth, ranges from 27^{O}C (surface) to 127^{O}C (basement), while well B-1 with 4606 ft (1403.8 m) depth, ranges between 30^{O}C (surface) to 100^{O}C (basement).

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Attachment.

TABLE 1. Lithology data, depth, and thermal conductivity of rocks based on measurement and calculation results in well A-1

Formation	Lithology	Depth (m)	Thermal Conductivity of Rocks Measurement (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)	Thermal Conductivity of Rocks Calculation (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)
Minas	sand	0 - 55	4.25	4.25
Minas	shale	55 - 90	4.00	4.00
Minas	sand	90 - 130	4.25	4.25
Minas	shale	130 - 170	4.00	4.00
Petani	shale	170-284	4.26	4.26
Telisa	shale	284-678	4.41	4.20
Telisa	sand	678-698	4.99	4.90
Sihapas Atas	sand	698-738	5.30	5.32
Sihapas Atas	shale	738 - 778	4.64	4.64
Sihapas Bawah	sand	778 - 803	5.50	5.52
Sihapas Bawah	shale	803 - 828	4.82	4.87
Sihapas Bawah	sand	828 - 853	5.52	5.52
Sihapas Bawah	shale	853 - 883	4.89	4.87
Sihapas Bawah	sand	883 - 908	5.73	5.52
Sihapas Bawah	shale	908 - 933	4.86	4.87
Sihapas Bawah	sand	933 - 969	5.53	5.52
Pematang SS	sand	969 - 1009	6.00	6.36
Pematang SS	shale	1009 - 1029	5.10	5.81
Pematang SS	sand	1029 -1069	6.39	6.38
Pematang SS	shale	1069 - 1089	5.50	5.81
Pematang SS	sand	1089 - 1131	6.47	6.63
Pematang SS	shale	1131 - 1151	5.87	5.81
Pematang SS	sand	1151 - 1211	6.81	6.65
Pematang SS	shale	1211 - 1231	6.02	6.00
Pematang SS	sand	1231 - 1291	7.50	7.55
Pematang SS	shale	1291 - 1311	6.04	6.00
Pematang SS	sand	1311 - 1391	7.55	7.97
Pematang SS	shale	1391 - 1411	6.11	6.00
Pematang SS	sand	1411 - 1457	8.03	8.40
Pematang MS	shale	1457-1719	6.60	6.81
Pematang BRSH	coal	1719-1780	6.80	6.80
Pematang LP	shale	1780 - 1815	6.50	6.81
Pematang LP	sand	1815 - 1840	8.60	8.83
Pematang LP	shale	1840 - 1880	6.70	7.17
Basement	Quarzt	1880-1964	7.59	7.59

TABLE 2. Lithology data, depth, and thermal conductivity of rocks based on measurement and calculation results in well B-1

Formation	Lithology	Depth (m)	Thermal Conductivity of Rocks Measurement (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)	Thermal Conductivity of Rocks Calculation (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)
Minas	Sand	0-120	4.52	4.52
Petani	Shale	120-240	3.97	3.97
Telisa	Clyst	240 - 605	4.26	4.22
Sihapas Atas	Clyst	605 - 685	4.47	4.49
Sihapas Bawah	Sand	685 - 760	6.00	6.10
Sihapas Bawah	Shale	760 - 800	4.75	4.80
Sihapas Bawah	Sand	800 - 860	6.32	6.45
Sihapas Bawah	Shale	860 - 880	4.86	5.00
Sihapas Bawah	Sand	880 - 930	6.40	6.90
Pematang SS	Sand	930 - 1120	7.08	7.25
Pematang SS	Shale	1120 - 1140	5.25	5.56
Pematang SS	Sand	1140 - 1160	7.46	7.58
Pematang MS	Clyst	1160 - 1318	5.55	5.60
Pematang BRSH	Coal	1318 - 1342	5.08	6.00
Pematang LP	Shale	1342-1362	5.30	6.10
Basement	Quarzt	1362-1403.8	7.40	7.35

TABLE 3. k_W, gradT, Q for A-1 and B-1 wells from k_r *calculation*

Well	k_W (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)	gradT (^{O}C/100cm)	Q (HFU)	Q (mW/m^2)
A-1	5.369684x10-3	0.046	2.68	107
B-1	5.022899x10-3	0.051	2.51	100

TABLE 4. k_W, gradT, Q for A-1 and B-1 wells from k_r *measurement*

Well	k_W (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)	gradT (^{O}C/100cm)	Q (HFU)	Q (mW/m^2)
A-1	5.491348´10-3	0.046	2.75	110
B-1	5.104227´10-3	0.051	2.55	102

TABLE 5. k_{GF}, $gradT_{GF}$, and dZ for well A-1 from k_r calculation

Formation	Formation Thickness (cm)	k_{GF} (cal cm^{-1} dt^{-1} $^{O}C^{-1}$)	$gradT_{GF}$ (^{O}C/100cm)	dZ (m)
Minas	96900	4.44	6.05	165
Petani	96900	4.44	6.05	165
Telisa	96900	4.44	6.05	165
Sihapas Atas	91100	6.68	4.02	249
Sihapas Bawah	91100	6.68	4.02	249
Pematang SS	91100	6.68	4.02	249
Pematang MS	91100	6.68	4.02	249
Pematang BRSH	8400	7.59	3.54	283
Pematang LP	8400	7.59	3.54	283
Basement	8400	7.59	3.54	283

TABLE 6. k_{GF}, gradT_{GF}, and dZ for well A-1 from k_r measurement

Formation	**Formation Thickness (cm)**	k_{GF} **(cal cm^{-1} dt^{-1} $^{O}C^{-1}$)**	**gradT_{GF} (^{O}C/100cm)**	**dZ (m)**
Minas	96900	4.53	6.06	165
Petani	96900	4.53	6.06	165
Telisa	96900	4.53	6.06	165
Sihapas Atas	91100	6.87	4.00	250
Sihapas Bawah	91100	6.87	4.00	250
Pematang SS	91100	6.87	4.00	250
Pematang MS	91100	6.87	4.00	250
Pematang BRSH	8400	7.59	3.62	276
Pematang LP	8400	7.59	3.62	276
Basement	8400	7.59	3.62	276

TABLE 7. k_{GF}, gradT_{GF}, and dZ for well B-1 from k_r calculation

Formation	**Formation Thickness (cm)**	k_{GF} **(cal cm^{-1} dt^{-1} $^{O}C^{-1}$)**	**gradT_{GF} (^{O}C/100cm)**	**dZ (m)**
Minas	93000	4.57	5.50	182
Petani	93000	4.57	5.50	182
Telisa	93000	4.57	5.50	182
Sihapas Atas	43200	6.15	4.09	245
Sihapas Bawah	43200	6.15	4.09	245
Pematang SS	43200	6.15	4.09	245
Pematang MS	43200	6.15	4.09	245
Pematang BRSH	4180	7.35	3.42	293
Pematang LP	4180	7.35	3.42	293
Basement	4180	7.35	3.42	293

TABLE 8. k_{GF}, gradT_{GF}, and dZ for well B-1 from k_r measurement

Formation	**Formation Thickness (cm)**	k_{GF} **(cal cm^{-1} dt^{-1} $^{O}C^{-1}$)**	**gradT_{GF} (^{O}C/100cm)**	**dZ (m)**
Minas	93000	4.62	5.53	181
Petani	93000	4.62	5.53	181
Telisa	93000	4.62	5.53	181
Sihapas Atas	43200	6.63	4.01	249
Sihapas Bawah	43200	6.63	4.01	249
Pematang SS	43200	6.63	4.01	249
Pematang MS	43200	6.63	4.01	249
Pematang BRSH	4180	7.40	3.45	290
Pematang LP	4180	7.40	3.45	290
Basement	4180	7.40	3.45	290

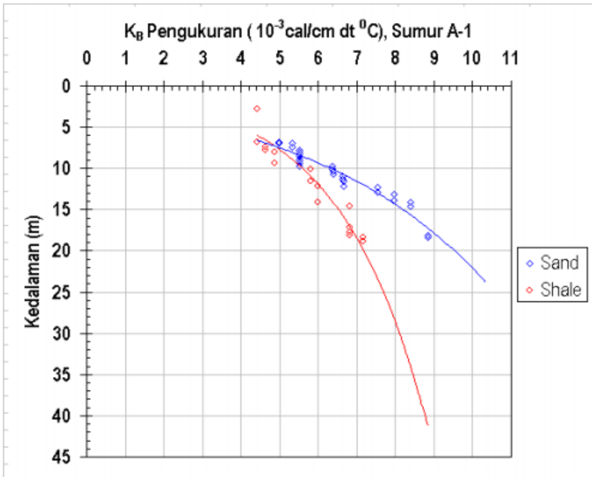

FIGURE 1. Relationship between thermal conductivity of rocks measurement and depth for well A-1

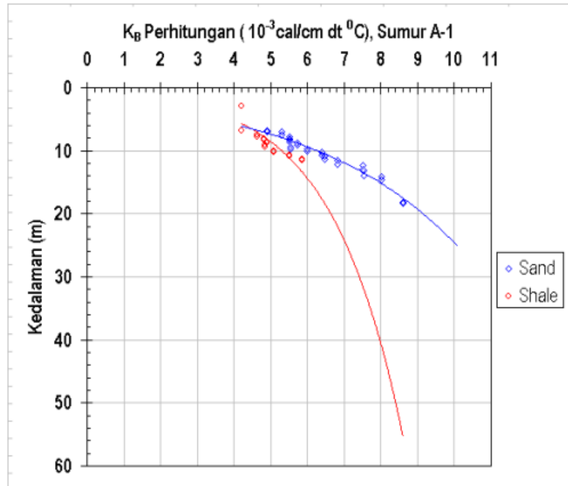

FIGURE 2. Relationship between thermal conductivity of rocks calculation and depth for well A-1

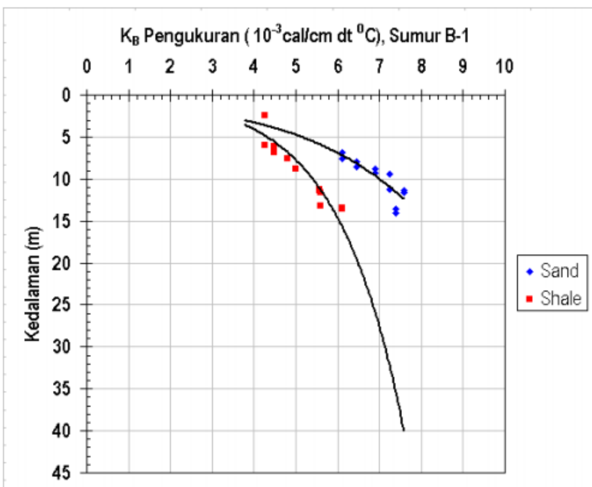

FIGURE 3. Relationship between thermal conductivity of rocks measurement and depth for well B-1

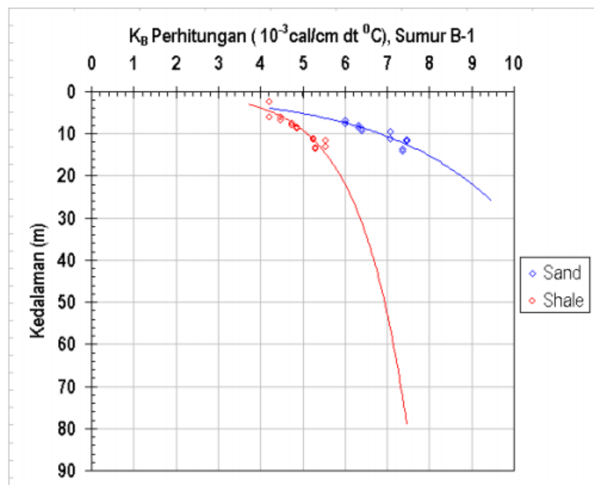

FIGURE 4. Relationship between thermal conductivity of rocks calculation and depth for well B-1

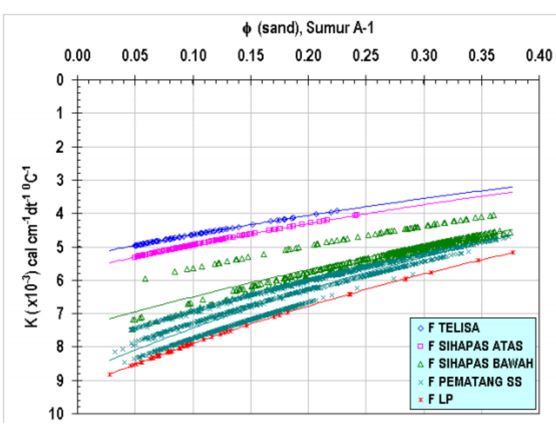

FIGURE 5. Relationship between thermal conductivity of rocks measurement and sand porosity for well A-1

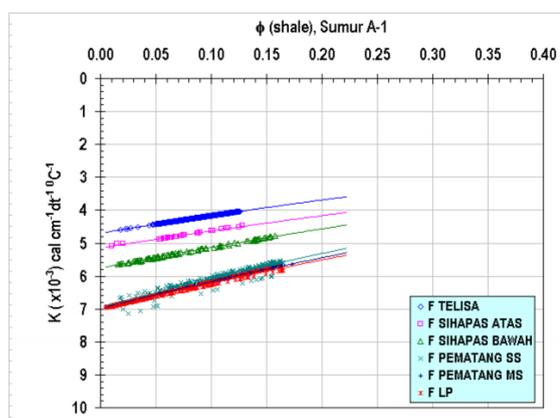

FIGURE 6. Relationship between thermal conductivity of rocks calculation and shale porosity for well A-1

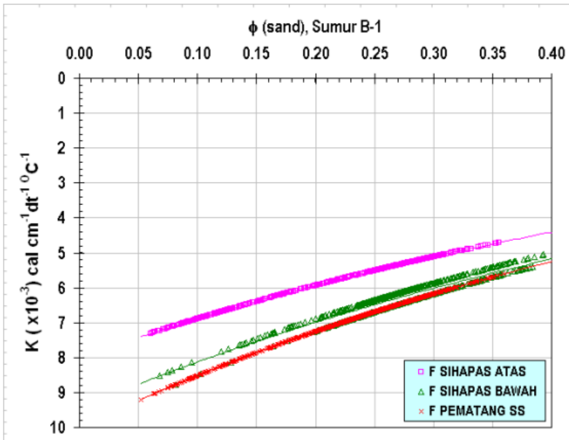

FIGURE 7. Relationship between thermal conductivity of rocks measurement and sand porosity for well B-1

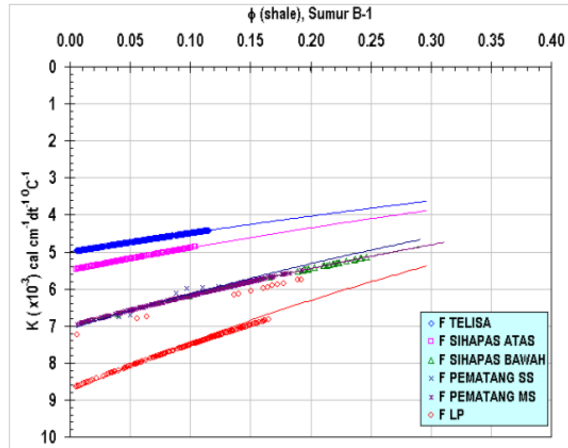

FIGURE 8. Relationship between thermal conductivity of rocks calculation and shale porosity for well B-1

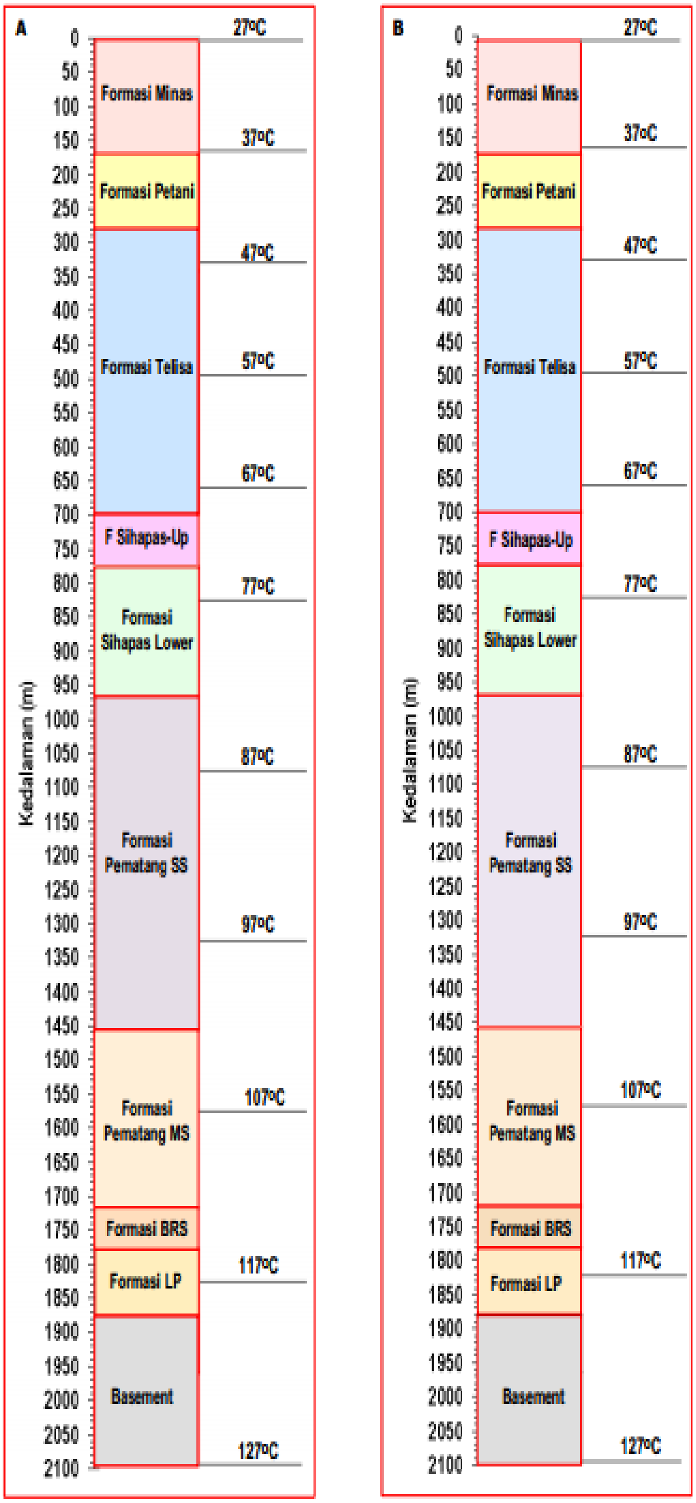

FIGURE 9. Formation temperature for A-1 from thermal conductivity of rocks measurement (A) and calculation (B)

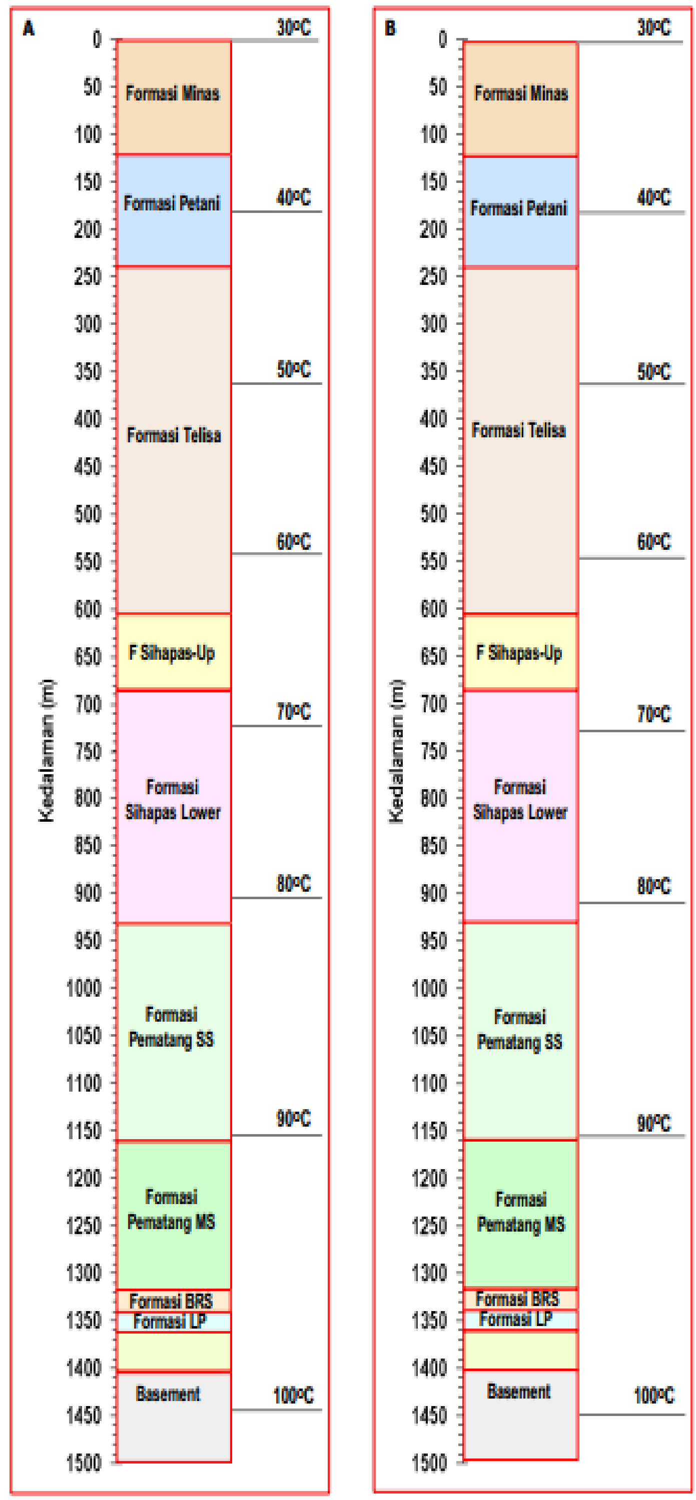

FIGURE 10. Formation temperature for B-1 from thermal conductivity of rocks measurement (A) and calculation (B)