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Accurate thermal conductivity measurement of Java and Sumatra rock samples using time varying heat flow measurement

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Abstract. Thermal conductivity is an important parameter for many applications, including having an essential role in the thermal history reconstruction of a petroleum system. This paper will present an accurate methodology of rock's thermal conductivity measurement by time-varying heat flow. The thermal conductivity measurements were done to various lithologies of rock samples from Java and Sumatra, including mud from Purwodadi Bledug Kuwu mudflow. The collected sample cover many lithologies, such as Limestone, Volcanic, Shale, Coal, and Sand.Particular measurement of time-varying heat flow has been designed and applied to various samples. The equipment consists temperature sensors, heat source, heat measurement and data recorder. The measurement results show that the thermal conductivity of shale rocks ranges from 0.414-2.749 J / s.m.°C, sandstone 0.931-2.748 J / s.m.°C, coal 0.353 J / s.m.°C whereas limestone carbonate is 0.92-6.86 J / s.m.°C. The thermal conductivity of each type of rock is unique, even for the same rock's lithology may have different values. The thermal conductivity parameter is influenced by the particle size distribution, pore parameter including pore shape or pore structure, fracture parameter of rock, and even the fluid or water content in the rock pores.

1. Introduction

Thermal conductivity has many essential roles in many applications, such as the reconstruction of thermal history, geothermal heat flow study, and also heat absorbant feasibility study. In earth resources study, thermal conductivity plays essential roles such as shale gas characterization [1] geothermal heat flow measurement [2,3], fault heating mechanism [4,5] and hydrocarbon source rock study.

The thermal heat induces the change of organic matter and other thermalification. This thermal heat affects numerous rock properties, such as indurations, porosity, and clay mineralogy. Therefore, thermal heat information has a close association with the maturity of source rock in sedimentary basin analysis which is one of the critical factors in petroleum system. The thermal history can describe the temperature distribution over time and depth. The geothermal heat flow is more widely used by practitioners in the industry because it involves the characteristics of each rock in each formation that is thermal conductivity of rock.

We present the thermal conductivity of the collected rocks from Indonesia, especially Java and Sumatra. It is since, Java and Sumatera has huge earth resources [6,7], and also some unique phenomena [7,8]. The laboratory measurements data are obtained by taking direct measurements of several rock samples in the laboratory. The measured rock contains several types of rock samples: shale, carbonate, sand, coal, granite and conglomerate.

The thermal conductivity of a rock is the value of the rock's ability to conduct heat (thermal). If there is a temperature gradient in a system, or if there are several systems of different temperatures in contact, there will be a heat transfer (Figure-1).

The type of observed heat transfer in this experiment is conduction. The heat transfer in propagation or conduction is the transfer of heat from a solid body part to another part of the same solid, or from one solid to another solid because there is physical contact or attachment without the transfer of molecules from the solid itself. The heat transfer of conduction is the process of heat transfer when heat flows from where the temperature is high to where the temperature is low, but the medium for heat transfer remains (Figure 1).

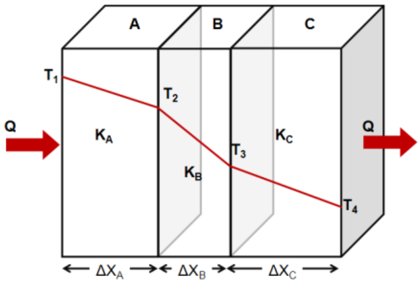

Figure 1. Illustration of heat transfer and temperatures in various thermal conductivities.

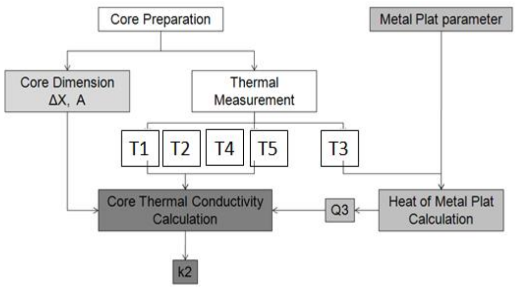

Figure 2. Workflow of thermal conductivity measurement**.**

2. Methodology

Three measurements were conducted through two stages of procedures: preparation of rock samples and thermal conductivity measurement (Figure 2). The rock samples were collected from some regions in Indonesia, especially Java and Sumatra. Number and code of samples are presented in table 1.

Table 1. Origin of sample, lithology and code of samples in the measurement.

No	Lithology	Origin	Number of Sample	Sample Name
1	Shale	Sumatra	5	SMTR#1, SMTR#2, SMTR#3, SMTR#4, SMTR#361
2	Sandstone	Sumatra	3	TMR#7, SAND#1, BTR#6
		East Java	1	RND#2B
3	Limestone	Sumatra	1	ILRN#5,
		West Java	3	CKM#1, CKM#2, CKM#3
4	Coal	Sumatra	1	COAL#1

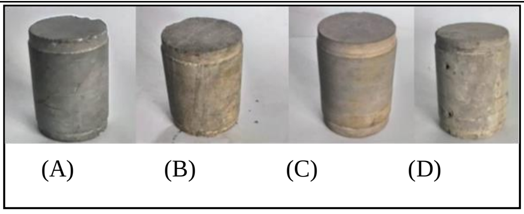

Figure 3. Photographs of samples and their dimensions in these measurements

Table 2. Origin of sample, lithology and code of samples in the measurement.

No	Core name	Length (mm)	Diameter (mm)	Density (Kg/m3)
1	SMTR#1	58.3	39.2	2615.09
2	SMTR#2	58	39.2	2357.19
3	SMTR#3	51.3	39.2	2413.08
4	SMTR#4	54.5	39.2	2139.12
5	SMTR#361	55.8	39	2381.55
6	TMR#7	59	38.6	2200.82
7	SAND#1	59.5	39.2	2496.20
8	BTR#6	59.5	38.2	1747.27
9	LPRK#2	57.8	39	2540.29
10	CKM#1	51.1	26.5	2650.44
11	CKM#2	49.2	26.5	2634.87
12	CKM#3	62.2	40	2686.70
13	ILRN#5	29.8	39	2581.55
14	JMB#1	60.9	37.5	2798.76
15	COAL#1	60	37	1472.58

The samples were prepared as presented in Figure (3), with detailed informations: density, length, and diameter which shown by Table 2.

Figure 2 shows a diagram of the measuring instruments used to measure the heat conductivity of sample. There are 5 temperature sensors in this measurement (T1, T2, T3, T4, T5). Each the two sensors are placed in both ends of the both samples (T1, T2, T4, T5) which are useful for measuring the temperature difference. Furthermore, the temperature differences are used to calculate the gradient of the temperatur throughout the sample. The third sensor is placed on copper which is useful for measuring copper temperatures over time.

The thermal conductivities of samples were measured using equipment with scheme of measurement as shown by Fig 2. To measure the conductivity of rock, samples of rock were cored as cylinder, and smoothed properly in certain size, 3-4 cm in length, and 3 cm in diameter (see Figure 3). In a thermal conductivity measurement needs at least 2 samples.

Figure 4 shows measurement's scheme of thermal conductivities of samples. There are many temperature sensors should be attached to a sample of rocks to measure the heat flow. There are also at least five temperature sensors for measuring heat flow accurately. The equipment has the hot and the cold reservoir. Then, the temperature of water in the hot reservoir should be kept to be a constant or steady state temperature using a digital controller (PC software).

The data, i.e.: time of measurements, and temperature data of sensors are collected simultaneously using logging temperature data system in real time condition (using PC and ADC). The samples of rock have 3 - 4 cm in length and 3 cm in diameter in smoothed cylinder. In a thermal conductivity measurement needs at least two samples of rock which have same lithology and size.

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The direct measurement outputs of the equipment are shown by figure 5 are temperature and heat flow. Therefore, once we provide heat flow and gradient of temperature, the thermal conductivity of rock sample could be estimated by equation (1):

$$Q=k\ dT/dz \qquad (1)$$

Where, Q indicates thermal heat flow, k denotes thermal conductivity of rock, and dT/dz represent the gradient of temperature.

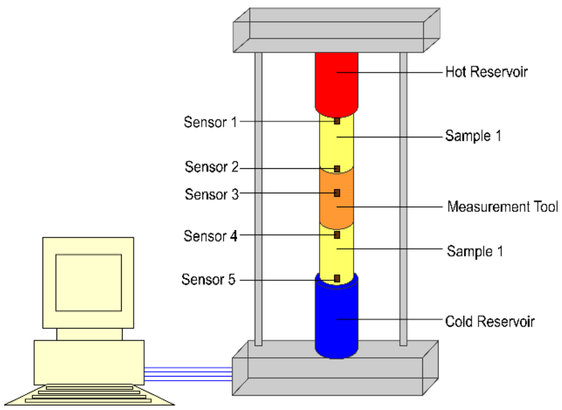

Figure 4. Thermal conductivity measurement.

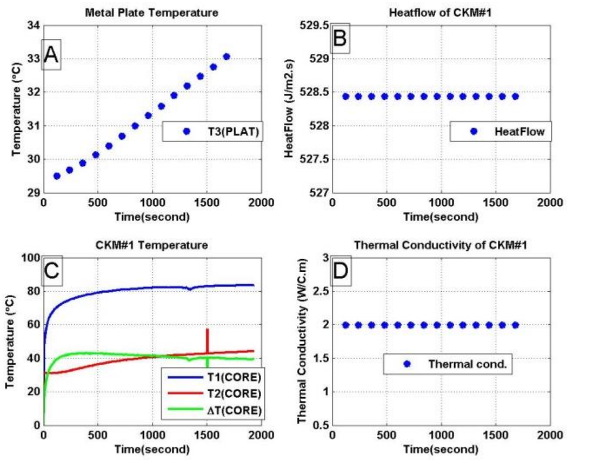

Figure 5. Information of temperatures and heat flows from sensors and calculations

3. Result and Discussion

The thermal conductivities parameter can be estimated by dividing the heat flow (Q) parameter with gradient of temperature, see equation 1. We measured some lithologies collected from Sumatra and Java. Figure 6, Figure 7, Figure 8, Figure 9, Figure 10 show respectively the data of thermal conductivity in various time of some lithologies in East Java Basin (clay, vulcanic tuff, carbonate, and even clay from Bledug Kuwu Mud).

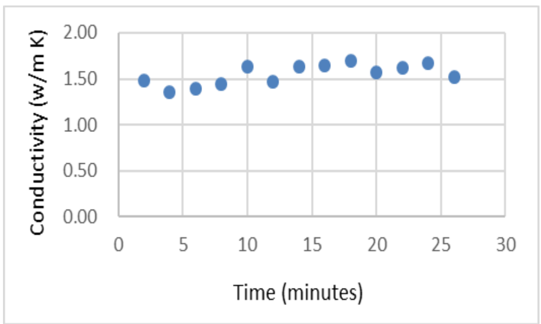

Figure 6. Thermal Conductivity of Tegalrejo Carbonate

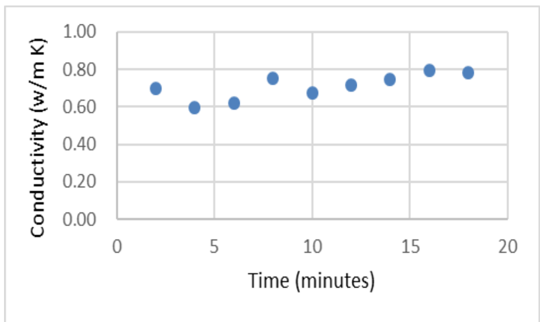

Figure 7. Thermal Conductivity of Bago Shale.

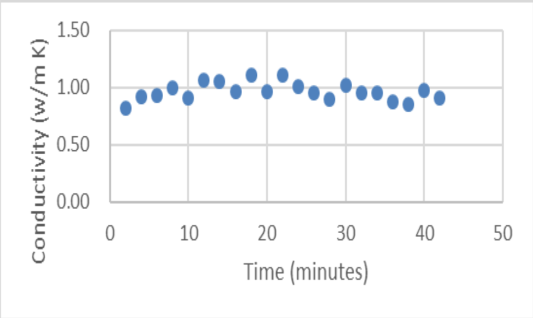

Figure 8. Thermal Conductivity of Muktiharjo Tuff.

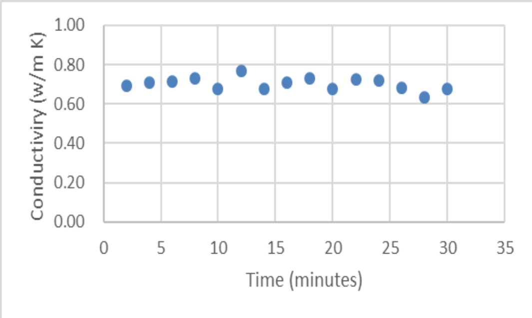

Figure 9. Thermal Conductivity of Alluvial.

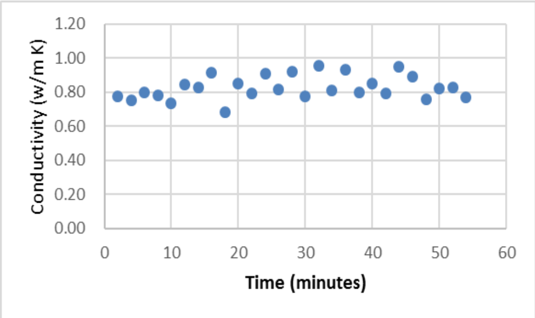

Figure 10. Thermal Conductivity of Bledug Kuwu Clay.

The heat flow is actually time varying value (or units). Therefore, to produce accurate measurement of heat flow, we measure the time varying measurement of heat flow as well as thermal conductivity of collected samples. The average of the thermal conductivity value of collected samples from Java and Sumatra are shown in Table 3.

Table 3. Measurement results of thermal conductivity from various regions of Indonesia

No	Lithology	Core name	Thermal Conductivity (J/s.m.ºC)
1	Shale	SMTR#1	2.749
2		SMTR#2	1.725
3		SMTR#3	2.115
4		SMTR#4	1.731
5		SMTR#361	1.638
6	Sandstone	TMR#7	2.662
7		SAND#1	2.748
8		BTR#6	1.313
9		LPRK#2	0.931
10		RND#2B	2.639
11	Carbonate	CKM#1	1.99
12		CKM#2	0.92
13		CKM#3	1.21
15		ILRN#5	6.856
16		JMB#1	2.867
17	Coal	COAL#1	0.353

The thermal conductivity of Java and Sumatra shale rocks ranges from 0.414-2.749 J / s.m.^{o}C, this variation may be caused by the water content, porosity, and the hardness of rock. The sandstone has range 0.931 to 2.748 J / s.m.^{o}C, it is depend also on porosity, water content and mineralogy. The coal has low thermal conductivity value, 0.353 J / s.m.^{o}C whereas limestone carbonate is 0.92-6.86 J / s.m.^{o}C.

Thermal conductivity of each type of rock is unique, even for the same type of rock's lithology may have different values. The very hard carbonate rock from Iliran has high thermal conductivity value, therefore the hardness and porosity of rock influence the value of thermal conductivity.

Results of this measurement present that the thermal conductivity parameter are influenced by the particle size distribution, pore parameter including pore shape or pore structure, fracture parameter of rock, and even the fluid or water content in the rock pores.

4. Conclusions

We have designed and succesfully developed an accurate equipment for measuring accurately the thermal conductivity of rock using time varying heat flow measurement. The thermal conductivity of rock can be measured accurately since the measurement consider the time varying of heatflow, then the average value of thermal conductivity can be estimated more accurate.

We have measured some samples collected from Sumatera and Java, the lithology of samples are: carbonate, clay, sandstone, and also clay. The sandstone the thermal conductivity of shale rocks ranges from 0.414-2.749 J / s.m.^{o}C, sandstone 0.931-2.748 J / s.m.^{o}C, coal 0.353 J / s.m.^{o}C whereas limestone carbonate is 0.92-6.86 J / s.m.^{o}C. Thermal conductivity of each type of rock is unique, even for the same type of rock's lithology may have different values. The carbonate sample has wide range, the high thermal conductivity of carbonate is very hard carbonate rock. The thermal conductivity parameter are influenced by the particle size distribution, pore parameter including pore shape or pore structure, fracture parameter of rock, and even the fluid or water content in the rock pores.

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