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PROPOSED EMPIRICAL GAS GEOTHERMOMETER USING MULTIDIMENSIONAL APPROACH

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ABSTRACT

Several formulas of surface gas geothermometer have been developed to utilize in geothermal exploration, i.e. by D'Amore and Panichi (1980) and by Darling and Talbot (1992). This paper presents an empirical gas geothermometer formula using multidimensional approach. The formula was derived from 37 selected chemical data of the 5 production wells from the Awibengkok Geothermal Volcanic Field in West Java. Seven components, i.e., gas volume percentage, CO_2, H_2S, CH_4; H_2; N_2 and NH_3 from these data are utilize to developed three model equations which represent relationship between temperature and gas compositions. These formulas are then tested by several fumarolic chemical data from Sibual-buali Area (North Sumatera) and from Ringgit Area (South Sumatera). Preliminary result indicated that gas volume percentage, H_2S and CO_2 concentrations have a significant role in term of gas geothermometer. Further verification is currently in progress.

INTRODUCTION

One of some methods used in geothermal exploration is surface gas geothermometer. Several formulas have been developed, and one of them is the empirical gas geothermometer proposed by D'Amore and Panichi (1980). It is developed on the bases of four theoretical assumption i.e.: free carbon and pyrite reactions, oxygen and CO_2 partial pressure.

A gas geothermometer that is based on the ratio of methane to ethane, has also been developed by Darling and Talbot (1992). This corresponds to a temperature range of 150 - 350 °C.

By using multidimensional approach, this paper presents an other method that can be used to developed an empirical gas geothermometer. In general, aspect of this formula are:

a. relatively simple equation
b. relatively accurate to estimate the geothermal reservoir temperature.
c. utilize principal emission gases commonly found in a geothermal field.

MULTIDIMENSIONAL APPROACH.

Chemical reactions in geothermal reservoir are controlled by subsurface temperature and consequently it could be estimates the reservoir temperature using cation or anion ratio in geothermal fluid or geothermal gases.

An empirical relation between cation and anion compositions in geothermal fluid can be expressed simply by:

T = function of

$$\left[\frac{(K^+)}{(Na^+)};\frac{(Ca^{++})}{(Na^+)^2};\frac{(Mg^{++})}{(Na^+)^2};\frac{(Ca^+)}{(Na^+)};\ldots etc\right]$$

From this understanding, a non-dimensional equation can be made:

$$T = Ko\left[\frac{(K^+)}{(Na^+)}\right]^{C1}\left[\frac{(Ca^{++})}{(Na^+)^2}\right]^{C2}\cdots\left[\frac{(Cl^+)}{(Na^+)}\right]^{Cn}$$

A multidimensional approach could be used to calculate the constant: Ko, C1, C2, ... Cn. Selected used data in this method must involve the well temperatures and chemical compositions of either the well water chemistry or gas chemistry. At the beginning this approach in has been tested by worldwide geothermal well data of Wahl (1977). The results indicated that the error of formula influences by the quality and numbers of data.

For practical purpose, this method is applied to four components with input data are concentration ratio of (K/Na), (Ca/Na^2) and (Mg/Na^2) and then it is tried by 3 given data:

$$T\,(^{o}K) = 2752{,}631 \times (K/Na)^{0{,}26119} \times (Ca/Na^2)^{0{,}06199} \times (Mg/Na^2)^{0{,}02798}$$

with deviation 1,4343%

FORMULA DERIVED FROM AWIBENGKOK GEOCHEMICAL DATA

Eleven geochemical data from exploration and production wells from Awibengkok Geothermal Field (West Java) have been utilize to develop a formula. These data are supplied by Geothermal Division PERTAMINA.

The Awibengkok field is located on the flanks of Gunung Salak volcanic complex, 70 kilometers south of Jakarta. Awibengkok field at present is operated under joint contract between PERTAMINA and Unocal Geothermal of Indonesia. This field underlies the western Gagak-Perbakti-Endut complex.. Gunung Gagak and Gunung Endut are younger andesitic cones built on the northwestern and southwestern slopes of Perbakti. The regional stratigraphy shows that the Salak-Perbakti product overlies folded Miocene rocks that consist of andesitic and dacitic in the upper unit and sedimentary rocks (predominantly calcareous argillite) as a lower unit. The sediment are unaltered and posses low porosity and permeability, suggesting that they act as a floor of geothermal reservoir (Noor et.al, 1992)

After calculation, it is found that the formula can be written as:

$$T\,(^{o}K) = 1087{,}5328 \times (K/Na)^{0{,}18335} \times (Ca/Na^2)^{0{,}1022} \times (Mg/Na^2)^{-0{,}04101}$$

using elements K, Ca, Na and Mg.

The general disadvantage of cation geothermometer is that this method dependent on the hydrogeologic of the geothermal field. Surface water mixing to geothermal brain will dilute the fluid concentration. This case is still unproved, e.g. percentages of mixing

Development for gas geothermometer

In order to reduce the disadvantage of surface water mixing to geothermal brain, the evaluation then proceeded by gas content evaluation.

In developing a formula of gas geothermometer 37 gas chemistry data from 5 production wells from Awibengkok Field have been selected. Seven components, i.e., gas volume percentage, CO_2, H_2S, CH_4, H_2, N_2, and NH_3 from these data are utilized to develop an equation which represents the relationship between temperature and gas components. From multidimensional approach three models are proposed as follows:

Model-1 :

$$T(^{O}K) = 190{,}5954\,(\%\mathrm{Vol\ Gas})^{(-0{,}1567)}\,(CO_2)^{(0{,}2166)}\,(H_2S)^{0{,}0174}\,(CH_4)^{(-0{,}0134)}\,(H_2)^{(0{,}0178)}\,(N_2)^{(0{,}0239)}\,(NH_3)^{(-0{,}1535)}$$

Model-2 :

$$T(^{O}K) = 1138{,}9501(\%\mathrm{Vol\ Gas})^{(0{,}0037)}\,(CO_2)^{(-0{,}2019)}\,(H_2S)^{0{,}1076}\,(CH_4)^{(-0{,}0056)}$$

Model-3:

$$T(^{O}K)= 738{,}3091(\%\mathrm{Vol.Gas})^{(-0{,}0008)}\,(CO_2/H_2S)^{(-0{,}1037)}$$

Deviations of those formulas are 0,68%, 1,73 %, and 1,73 % for the first, the second and the third respectively. Chemical data for the first formula are not always available. Therefore the second and the third models are more realistic for practical purpose.

MODEL VERIFICATION.

Nowadays the models are verified by production well chemical data of well LHD-4 from Lahendong Field which located at North Sulawesi (see table 1). The result gives an estimated reservoir temperature range from 309.48 °C to 365.80 °C or has average value of 337 °C. This is relatively as the same as the interpretation subsurface highest temperature of 322 °C, estimated by Priyanto (1984) using other gas geothermometer. On the other hand, Surachman et al (1987) pointed out that in Lahendong Field there is a deep reservoir of 350 °C at the depth of 1300 meters as is recorded from the exploration wells.

The proposed formula then tested by several surface data of fumarole chemistry from Sibual-buali area (North Sumatra) and from Ringgit area (South Sumatra). The result clearly shows some remarks (see table 2 and 3):

a. Estimated temperature for each fumarole data by model-2 and model-3 gives identical results.
b. Estimated temperatures for each fumarole data by model-1 indicate significant difference in comparation to those from model-2 and model-3.

At present the results for proposed formula from Sibual-buali and Ringgit data could not be really verified because there are no exploration wells in those area.

Modification of model-1 using zero powered of unused components in the model-2 and model-3 revealed two models i.e. , model-1A and model-1B. The utilization of the later models shows relative good results. The result from model-1A and model-1B are identical in comparation to those of model-2 and model-3. Therefore these models are more realistic for geothermometer. In general it is concluded that gas volume percentage; CO_2; H_2S and CH_4 are the principal components that gives significance role in subsurface temperature estimation.

High difference estimated temperature for each fumarole data might be due to local geological condition or geographical distribution. It is suggested that in geothermal interpretation the local geological condition and other supported should be considered.

CONCLUSION

A simple and practical usage of empirical gas geothermometer can be developed from multidimensional approach. Preliminary results indicate that gas volume percentage, H_2S and CO_2 play a significant role in term of gas geothermometer. These proposed formulas need more clarification.

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TABLE 1.

CO_2/H_2S ratio from the production weel LHD-4 (Lahendong Area, North Sulawesi) for testing the model-3 .

Date	WHP (kscg)	Enthalpy (Kj/Kg)	% wt. gas	CO_2/H_2S	T(°K) estimated	T(°C) estimated
9/7/86	19.7	1800	0,61	7,11	602,68	329.53
11/7/86	30.2	1805	0,94	9,82	582,63	309.48
14/7/86	41.8	1820	0,35	4,47	632,67	359.52
16/7/86	52.4	1820	0,32	5,12	623,87	350.72
18/7/86	62.2	1790	0,42	5,54	618,66	345.51
29/7/86	69.6	1750	0,54	4,05	638,95	365.80
1/8/86	83.7	1685	0,40	5,12	623,76	350.61
19/8/86	25.7	2000	0,45	6,58	607,69	334.54
26/8/86	25.7	2040	0,81	7,87	596,23	323.08
2/9/86	25.3	2025	0,77	7,89	596,09	322.94
9/9/86	25.3	2035	0,80	8,9	588,68	315.53
13/9/86	7.4	2060	0,54	4,47	632,45	359.30
17/9/86	20.4	2040	0,72	6,99	603,66	330.51
20/9/86	42.2	1985	0,45	6,0	613,53	340.38
23/9/86	61.9	1850	0,36	5,43	620,02	346.87

WHP = Well Head Pressure

TABLE 2.

Selected data of fumarole from Sibualbuali Area (North Sumatra) and Ringgit Area (South Sumatera) for testing the formula (FUM= fumarole, F, HS= fumarole and hot spring, MP = mud pool).

Sample Id.	Type	T°C	% Gas	CO_2	H_2S	CH_4	H_2	N_2	NH_3	CO
SBB92-01	FUM	105	0,9	95,4	3,22	0,36	0,814	0,0704	0,165	0,00057
SBB92-02	FUM	101	0,7	94,1	4,78	0,3371	0,638	0,0272	0,0963	0,00028
SBB92-03	FUM	96	8,2	95,8	2,87	0,264	0,499	0,482	0,0182	0,00025
SBB92-04	FUM	97	0,5	91,8	6,05	0,308	0,507	0,926	0,394	0,00068
SBB92-05	FUM	96	5	97,8	1,47	0,0867	0,422	0,148	0,0405	0,00058
SBB92-10	FUM	94	10,4	97,8	1,51	0,173	0,305	0,154	0,005	0,00051
SBB92-11	FUM	120	2,9	97,8	1,5	0,039	0,209	0,438	0,0179	0,00015
SBB92-20	FUM	131	0,2	91,7	7,08	0,234	0,438	0,0439	0,528	0,00126
SBB92-14A	FUM	93	-	98,9	0,848	0,0577	0,0448	0,0448	0,123	-
SBB92-14B	FUM	93	3,4	97,1	1,61	0,307	0,248	0,248	0,316	0,00065
SBB92-18	FUM	96	1	97,5	1,83	0,0289	0,331	0,331	0,0951	0,005
SBB92-19	FUM	97	0,7	96,0	1,26	0,0303	2,08	2,08	0,551	0,00078
RF-02	FUM	97	0,19	91,6	4,18	0,997	1,61	0,57	1,0	0,00282
RF-03	FUM	97	0,13	88,3	7,16	0,265	1,95	1,17	1,12	0,00049
RF-04	F,HS	97	0,67	91	5,86	0,504	1,68	0,65	0,309	0,00036
RF-05	FUM	97	0,51	95	2,9	0,371	1,42	0,00864	0,335	0,00013
RF-07	FUM	130	0,78	94,4	3,34	0,734	0,677	0,566	0,293	0,00089
RF-08	MP	94	6,89	97,8	0,0497	0,13	0,13	1,33	0,00414	-
RF-09	FUM	98	0,13	92,7	0,0638	0,129	0,129	1,28	0,739	-

Notes: SBB = Sibualbuali Area
RF= Ringgit Area

TABLE 3.

Estimated reservoir temperature (in degree Celcius) for Sibualbuali and Ringgit Area

Sample Id.	Model -1 (°C)	Model-2(°C)	Model-3(°C)	Model-1A (°C)	Model-1B (°C)
SBB92-01	208,80	244,62	246,44	264,92	257.6
SBB92-02	210,22	269,01	269,05	288,49	281.08
SBB92-03	63,57	234,53	239,15	108,62	101.87
SBB92-04	298,56	287,00	284,04	319,63	310.35
SBB92-05	89,14	201,11	203,97	142,6	129.2
SBB92-10	29,95	199,37	205,02	94,28	85.74
SBB92-11	123,38	205,24	205,18	184,68	165.21
SBB92-20	347,96	299,49	293,67	415.4	402.13
SBB92-14A	div/0	div/0	div/0		
SBB92-14B	129,53	203,77	209,00	161,09	154.28
SBB92-18	212,26	218,64	215,72	271,5	246.24
SBB92-19	275,70	201,27	198,05	296,81	270.72
RF-02	397,89	263,77	263,61	401.23	401.2
RF-03	469,91	305,10	296,76	456.4	443.53
RF-04	271,85	283,92	282,57	287.95	282.83
RF-05	239,91	240,24	241,29	313.16	305.42
RF-07	144,51	245,97	249,04	270.99	268.74
RF-08	61,86	166,70	169,63	120.24	104.73
RF-09	446,09	282,75	273,73	473.78	446.74