Proc. 10th New Zealand Geothermal Workshop 1988

THE USE OF A CONCEPTUAL MODEL TO PREDICT THE POTENTIAL OF KAMOJANG GEOTHERMAL FIELD UNDER WATER INJECTION

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ABSTRACT

The ultimate potential of Kamojang Geothermal field is estimated by means of the conceptual model (Gomaa, 1985). To use the model, it is assumed that the brine is injected into the reservoir to extract the remaining heat from the rock. It is further assumed that the reservoir is a naturally fractured system. The fluid flow mechanism in the reservoir is strongly controlled by fractures, meanwhile matrix rock, acts as a source, transmits the heat to the reinjected brine by conduction.

If the Kamojang Geothermal field is fully developed, it is estimated that the ultimate potential of electricity producible from the reservoir is 15,500 Megawatt-year or 517 MW for 30 years.

INTRODUCTION

Kamojang Geothermal Field is located in the western part of Java Island, Indonesia. It is about 40 km. south of Bandung City. Currently, the 150 MWe power plant has been running utilize the steam energy produced from the reservoir. The reservoir boundary and well location is presented in Figure - 1.

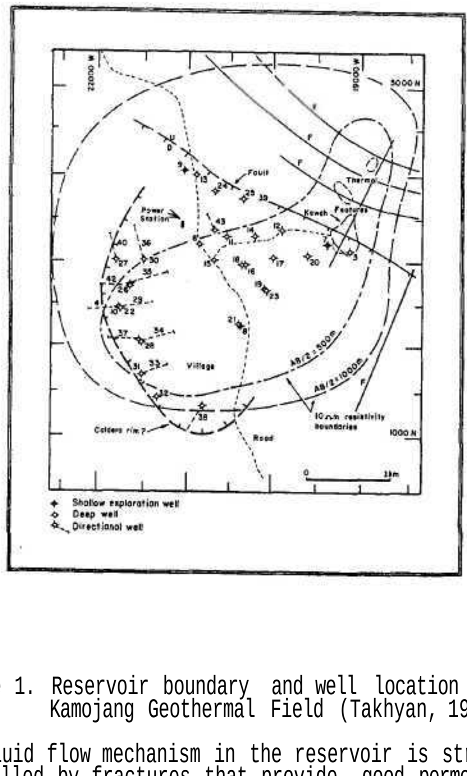

Figure 1. Reservoir boundary and well location in Kamojang Geothermal Field (Takhyan, 1985)

The fluid flow mechanism in the reservoir is strongly controlled by fractures that provide good permeability for fluid flowing towards well bores.

The reservoir performance prediction was done by means of the reservoir simulator (Takhyan, 1985). It was indicated that the potential of electricity producible from this field is between 180 MW - 410 MW for 30 years, assuming that if hot recharge from the brine and cold recharge from the surface occurs.

the aim of this paper is to predict the potential of Kamojang reservoir by use of the simple method (the conceptual model, Gomaa, 1985). In this model, it is assumed that the system does not exhibit heat recharge, so the brine is injected through injection wells to extract the remaining heat from the rock. The conceptual model is essentially a combination of geologic representation and energy balance of the reservoir.

POTENTIAL PREDICTION

The potential of Kamojang Geothermal Field is predicted under the assumption that the reservoir is a naturally fractured system (Figure - 2). The reservoir is represented by two parts; fractures (100 % porosity, where the fluid flow is mainly through) and matrix rock (non permeable part, acts as a heat source, where heat can only be transmitted to the reinjected brine by conduction).

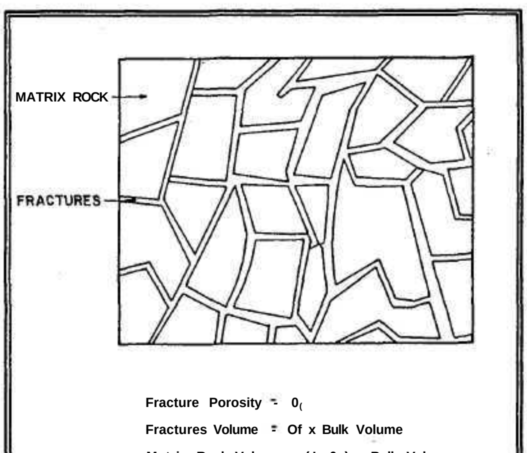

Figure 2. Schematic illustration of conceptual model for fractured system (Gomaa,1985)

The overall heat capacity of the reservoir can be expressed as follows :

$$C_f = 4.356 \times 10^{-11} A\ h\ \phi_f\ f_w\ c_w \quad (1)$$

$$C_m = 4.356 \times 10^{-11} A\ h\ (1 - \phi_f)\ c_m \quad (2)$$

where C_f is heat content in fractures and C_m is heat content in the matrix rock.

The reservoir heat production can then be calculated by the following equation :

$$Q = (f_f c_f + f_a f_m) V \Delta T \quad (3)$$

where ff is a contact mixing efficiency of fractures and f_m is a matrix rock contribution factor, ff and f_m represent the volume fractions contributing to heat production from the fractures and the matrix rock respectively. f_a is an areal sweep efficiency, defined as the fraction of the field area which is contacted by the reinjected brine. This value is a function of the development plant. For full-field development, f_a is close to 1.00.

The specific temperature drop per unit heat production from the reservoir can be expressed as follows :

$$\Delta T^* = \frac{1}{f_f c_f + f_a f_m c_m} \quad (4)$$

ΔT^* as a function of ff and f_m can be plotted by using the above equation.

Characteristic Production Temperature Decline Curves (relating production temperature to net heat produced for various locations of producing wells) can be calculated for prior and after breakthrough of reinjected brine.

a. <u>Prior to Breakthrough of Reinjected brine</u> :

Before the reinjected brine reaches the producing wells, the production temperature drop, ΔT_p, can be estimated by the following equations :

for uniform initial reservoir temperature :

$$\Delta T_p = 0 \quad (5)$$

for non-uniform initial reservoir temperature distribution :

$$\Delta T_p = \frac{Q \Delta T^*}{V} \quad (6)$$

where V is the fraction of the reservoir volume enclosed between injection and producing wells boundaries.

The total net heat prior to breakthrough can then be calculated as follows :

$$Q_{bt} = 4.356 \times 10^{-11} A h V \beta_f f_{sb} (H_o - H_j) \quad (7)$$

b. <u>After Breakthrough of Reinjected brine</u>

After the reinjected brine reaches the producing wells, the production temperature drop, ΔT_p, can be estimated by the following equation :

$$\Delta T_p = 0.5[(2\Delta T_a - \Delta T_1) + \left\{\Delta T_i - (\Delta T_i - \Delta T_a)\frac{R_i - R_p}{R_i - R_{al}}\right\}] \quad (8)$$

$$\Delta T_1 = \ ^* \quad (9)$$

$$R_{al} = \frac{R_i - R_p}{\ln \frac{R_i}{R_p}} \quad (10)$$

KAMOJANG GEOTHERMAL FIELD POTENTIAL ESTIMATION

By applying Equations 1 through 10 that have been previously described, the potential of Kamojang Geothermal Field is estimated under the relevant assumptions. The pertinent data used for the calculation is as follows (Takhyan, 1985 and Ghozali, 1987) :

Resource area, A	3,212 Acres
Total reservoir thickness, h	3,000 feet
Average initial reservoir temperature, T_o	378 °F
Interconnected fracture porosity, ϕ_f	0.084
Density of reservoir fluid at 378 °F, ρ_f	19.06 lb/cu-ft
Specific heat of matrix rock, c_m	41 BTU/cu-ft- °F
Specific heat of fractures, c_f	1.01 BTU/cu-ft- °F
Turbine temperature, T_j	266.4 °F
Enthalpy of reservoir fluid at average initial temperature, H_o	901.22 BTU/lb
Enthalpy of reinjected brine, H_j	840.95 BTU/lb
Average reservoir temperature, P_j	338 psia
Radius of producing wells boundary, R_p	2000 ft
Radius of injection wells boundary, R_i	4716 ft
Areal sweep efficiency, f_a	0.7
Volumetric sweep efficiency at breakthrough, f_{sb}	0.6

Figure - 3 shows the specific temperature drop for Kamojang Geothermal field. In general, this figure describes the reservoir temperature drop per unit heat production as a function of matrix rock contribution factor and contact mixing efficiency.

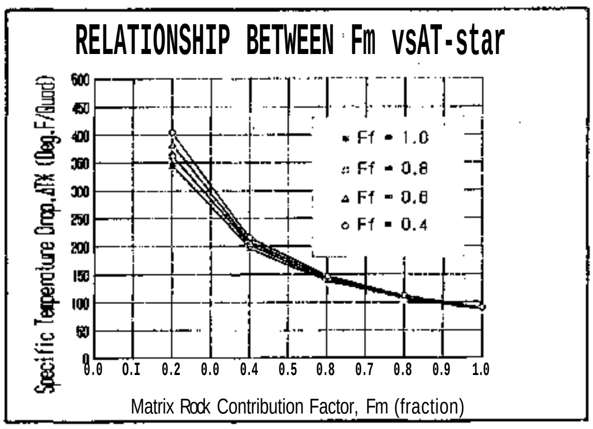

Figure 3. Specific temperature drop for Kamojang Geothermal Field as a function of ff and f_m

The Characteristic Production Temperature Decline Curves are constructed in Figures.-4 through 7 for various values of ff and f_m. Based on this relationship, the total net heat produced from the reservoir can be calculated where the result is shown in Figure 8.

The geothermal potential in term of electrical energy is commonly expressed in megawatt - year. For Kamojang field, this potential can be estimated from its Characteristic Production Temperature Decline Curve as follows :

$$E = 3.344 \times 10^4 Q_{ult} F_p \quad (11)$$

where, Q_{ult} is the ultimate net heat produced read from the Characteristic Production Decline Curve at a temperature equal to the minimum acceptable feed-temperature for the power plant. Fp, is the conversion efficiency of power plant. This value is in the range of 15 - 30 % (Gomaa, 1985). Assuming Fp = 0.2, The Kamojang Geothermal potential (in terms of electrical energy) as a function of fm and ff is calculated and the result is presented in Figure - 9.

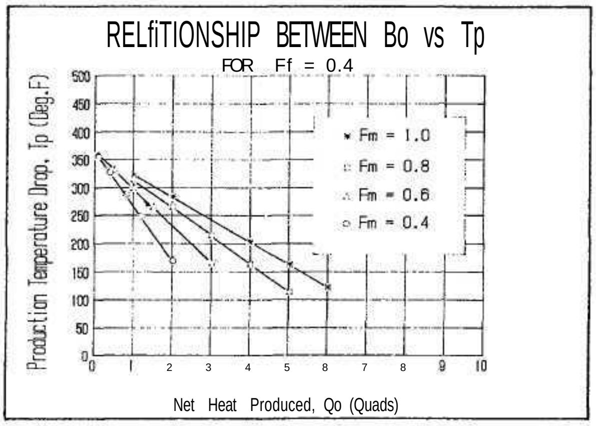

Figure 4. Production temperature drop for Kamojang Geo-thermal Field as a function of f_m, and f_f = 0.4

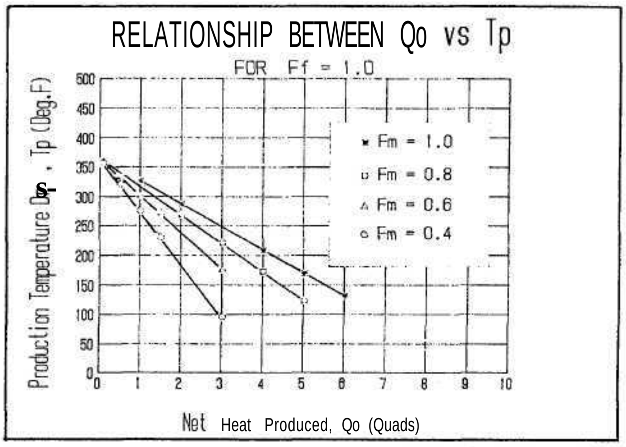

Figure 7. Production temperature drop for Kamojang Geo-thermal Field as a function of f_m, and f_f = 1.0

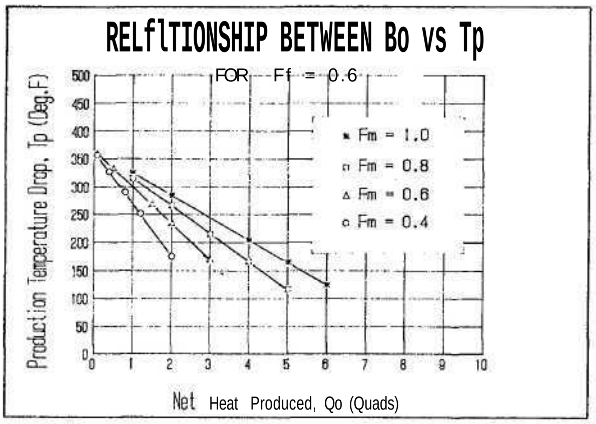

Figure 5. Production temperature drop for Kamojang Geo-thermal Field as a function of f_m, and f_f = 0.6

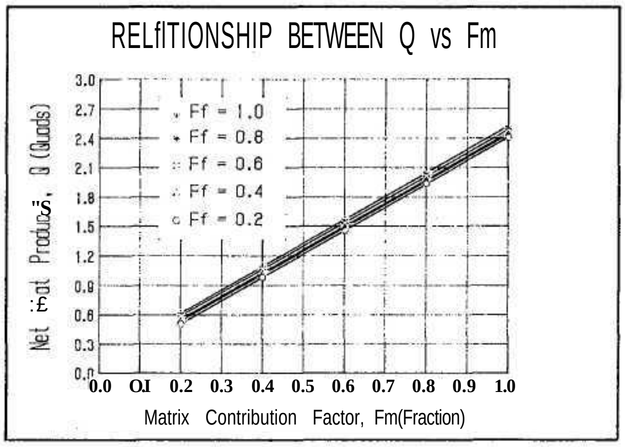

Figure 8. Net heat Produced for Kamojang Geothermal Field as a function of f_f and f_m

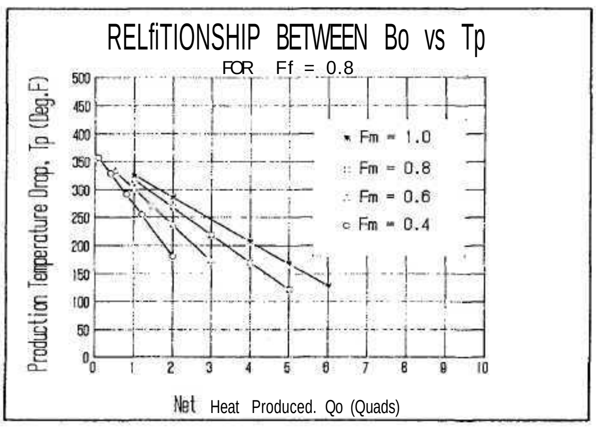

Figure 6. Production temperature drop for Kamojang Geo-thermal Field as a function of f_m, and f_f = 0.8

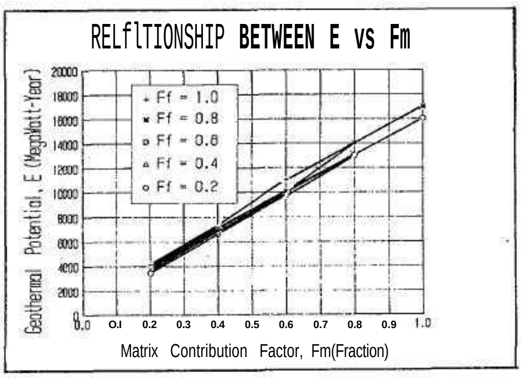

Figure 9. Ultimate geothermal potential of Kamojang Geo-thermal Field as a function of f_f and f_m

As an example, if Kamojang field is fully developed, ff = 1 and f_m = 0.9 (this value is estimated from Figure-10, Gomaa - 1985, under the assumption that the average fluid production rate is equal to 0.05 reservoir pore volume/year), the potential will be 15,500 Megawatt-year or 517 MW for 30 years.

CONCLUSION

The conceptual model can be used to predict the Kamojang Geothermal potential. Assuming that heat recharge is from reinjected brine and the field is fully developed, the ultimate potential of electricity producible from this field is 15,500 Megawatt-year or 517 MW for 30 years.

NOMENCLATURE

A = Resource area, acres
cm = Volumetric heat capacity of matrix rock, Btu/cuft - OF
c_w = Specific heat of reservoir fluid, Btu/lb- °F
Cf = Heat content of fractures, Quads/°F
Cm = Heat content of matrix rock, Quads/°F
E = Geothermal Potential, Megawatt-Year
fa = Areal sweep efficiency, fraction
ff = Contact mixing efficiency for fractures, fraction
fm = Matrix contribution factor, fraction
fsb = Volumetric efficiency at breakthrough, fraction
Fp = Conversion efficiency of power plant, fraction
h = Total reservoir thickness, ft
Hj = Enthalpy of reinjected brine, Btu/lb
H_o = Enthalpy of reservoir fluid at average initial temperature, Btu/lb
Q = Net heat produced, Quads
Qbt = Net heat produced at breakthrough, Quads
Qult = Ultimate net heat produced, Quads
Ri = Radius of injection wells boundary, ft
Rp = Radius of producing wells boundary, ft
Ral = Logarithmic average of Rj and Rp, ft
V = Fraction of reservoir volume enclosed between injection and producing wells boundaries
0f = Interconnected fracture porosity, fraction
f_w = Density of reservoir fluid at average initial temperature, lb/cuft
AT = Specific temperature drop, °F/Quad
AT_a = Average temperature drop in reservoir, °F/Quad
AT-j = Temperature drop at injection wells boundary, °F
ATp = Production temperature drop, °F

ACKNOWLEDGEMENT

The author thanks the management of PERTAMINA for their permission to prepare and publish this paper.

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