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THE USE OF SCALED-DOWN METHOD IN GEOTHERMAL RESERVOIR MODELING

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ABTRACT

'his paper is a report of an initial attempt to conduct aboratory-size, in experimental geothermal reservoir nodeling. The method is based on the basic physical nderstanding of a mathematical model of a reservoir. 'he reservoir model used here is a fluid dominated eothermal reservoir. The hydrostatic pressure and ie reference temperature are extracted from the iathematical model, in the form of nondimensional ystem. The Rayleigh number which is the ratio etween the enthalpy of convection to the enthalpy of onduction is kept constant, while the characteristic ime, velocity, and pressure are isolated in order to levelop temperature and flow patterns. In that way, a eal geothermal reservoir can be built in a laboratory-ize geothermal reservoir where the temperature and he flow patterns can be investigated from the eservoir by means of thermocouple and laser)oppler velocymeter.

\ typical example of a laboratory model which can be uilt from a real reservoir is as follow ; when the inear size of the real reservoir is reduced by 10^{-3} and ts permeability is multiplied by 10^3 the resulting 'elocity will be magnified by 10^3. Consequently, the haracteristic time required for the fluid to flow from he bottom to the surface in the real situation will be educed by the factor of 10^{-6}, meaning that the onditions investigated in one-day experiment in the aboratory model is equivalent to almost 3,000 years onditions depicted from the real reservoir.

NTRODUCTION

The problem of convective fluid flow and mass and ieat transport in porous media have become the increasingly fascinating subject of investigations in rcent years due to its application for example in wried electrical cable, geothermal activities, etc. Thermal convection around a uniform flux pipe embedded in a box containing a saturated porous medium was studied experimentally and theoretically (K. Himasekhar et al., *1988)*. The agreement between the theoretical and experimental are reported quite good. In theoretical effort, a simple, two-dimensional, liquid-phase reservoir model was developed and analyzed to gain the basic physical understanding to the fluid flow dynamics and heat transfer mechanism in geothermal system (Sutrisno, *1995)*. In this study we try to bring them together in terms of geothermal reservoir modeling. Thus, it is one of the objective of the present work to study the model in both approach, theoretically and experimentally. In this attempt we also try to overcome the difficulties in any experimental modeling of a geothermal reservoir which is in the time scale means also in the fluid velocity scale (Djoko Wintolo et. al., 1996).

In the present work the previously developed (Djoko Wintolo et al., 1996) is developed further which could transform the conditions used in the mathematical formulation into a physical dimension in the scale of laboratory so the fluid flow dynamics and heat transfer mechanism can be analyzed experimentally and compared it to the numerical results. Another objective of this study is also to establish whether the experimental apparatus may be used to model convection associated with a simple model , as a first step, of a geothermal reservoir.

FORMULATION OF THE MODEL

As mentioned before, the experimental model is based *on* the basic physical understanding of the mathematical model. Thus we first analyzed the model. In this first effort, the geothermal reservoir is simulated as a liquid dominated reservoir with unsteady convective flow development toward a natural state in homogeneous, isotropic porous medium filled with saturated liquid. The law of mass conservation. momentum and energy balance could then be expressed as follow

$$\nabla . \overline{V'} = 0 \qquad \text{------------} \qquad (1)$$

$$\left(\frac{\nabla \rho'}{\rho'_o} - \overline{g'}\right) + \alpha' \left(T' - T'_o\right)\left\{1 + \frac{\beta'}{\alpha'}\left(T' - T'_o\right)\right\}\overline{g'}$$
$$+ \frac{v'_o f'}{k'} \overline{V'} = 0 \qquad \text{------------} \qquad (2)$$

$$\left\{\left(1 - \Phi'\right)\rho'_r C'_r + \Phi' \rho'_o C'_v\right\} \frac{\partial T'}{\partial t'}$$
$$+ \rho'_o C'_v \overline{V'} . \nabla T' = \nabla' . \left(K'_m \nabla T'\right) \qquad \text{..........(3)}$$

with some assumptions that the horst structure matrices (ϕ', K', K'_m) are isotrophical, inhomogeneous and independent of temperature.

The Boussinesq approximation is applied as

$$\rho' = \rho'_0 \left\{1 - \alpha'\left(T' - T'_o\right) - \beta'\left(T' - T'_o\right)^2\right\} \qquad \text{... (4)}$$

The kinematics viscosity which is dependent of temperature is $\gamma' = \gamma_0' f(T)$ and $\rho_o', a', T_o', \beta'$ are all constant. The pressure work and the viscous dissipation are ignored here.

The normalized dimension below can then be applied to form the non-dimensional governing equations

$$\overline{X} = \frac{\overline{X'}}{L'} \quad \overline{V} = \frac{\overline{V'}}{V'_R} \quad t = \frac{t'}{t'_R} = \frac{t'}{(L'/V'_R)} \qquad \text{..... (5)}$$

$$T = \frac{T'}{T'_o} \quad p = \frac{p' - p'_H(\overline{x})}{P'_R} \quad \beta = \frac{\beta' T'_o}{\alpha'} \qquad (6)$$

$$\mu = \frac{\mu'}{\mu_o} \quad k = \frac{k'}{k_o} \quad \overline{g} = \frac{\overline{g}}{g} \quad \tau = \frac{\Delta T'}{T'_o} \qquad (7)$$

where L' is the characteristic length of the reservoir. A T' is the temperature difference, g' is the gravitational acceleration, a' is the coefficient of the thermal expansion, $K_{,}'$ is the absolute permeability, $p_{,,}'$ is the density and v_o' is the dynamics viscosity. In that way, the velocity characteristic is,

$$v'_R = \frac{g' k'_0 \alpha' \Delta T'}{v'_o}$$

and

$$P'_R = \rho'_0 g' \alpha' \Delta T'$$

is the pressure characteristic and $t'_R = L'/V'_R$ is the time characteristic.

The non-dimensional governing equation can then be expressed as

$$\nabla . \overline{V} = 0 \qquad \text{............ (8)}$$

$$\frac{\mu}{K}\overline{V} = -\nabla P - \frac{T - T_H}{\tau}\{1 + \beta(T + T_H - 2)\}\overline{g} \qquad \text{........(9)}$$

$$R\left[C\frac{\partial T}{\partial t} + C_v \overline{V} . \nabla T\right] = \nabla . (K_m \nabla T) \qquad \text{...(10)}$$

where R is the Rayleigh number

$$R = \left(\frac{g' K'_o \alpha' \Delta T' L'}{v'^2_o}\right)\frac{\mu'_o c_{p'_o}}{K'_{m_o}} = \frac{\rho'_o v'_R C_{p'_o} \Delta T'}{K'_{m_o} \frac{\Delta T'}{L'}} \qquad \text{..(11)}$$

and

$$C_m = \frac{\phi Cv' + (1 - \phi)\rho'_r C'_r / \rho'_o}{C\rho'_o} \qquad \beta = \frac{\beta'}{\alpha'} T'_o$$

$$K_m = \frac{Km}{K'_m} \quad , \quad C_v = \frac{C'_v}{C\rho'_o} \qquad \frac{\mu}{K} = \frac{\mu'}{K} \frac{k'_o}{k'}$$

<u>**SCALE** DOWN PROCEDURE</u>

The scale down applied here, is a method to isolate the coefficient in the governing equation, Rayleigh number R equation (11), which is function of variables ; β, C_m, C_v, K_m, and m/K to be a certain value and kept constant by choosing any numerical value of the variables which could suit laboratory size requirement. Mathematically, the solution of the governing equation will be unique.

If the mathematical conditions are comply, a typical example of a laboratory model which can be built from a real reservoir is as follow ; when the linear size of the real reservoir is reduced by 10^{-3} and it's permeability k' is multiplied by 10^3 the resulting velocity, v_R', will be magnified by 10^3. Consequently, the characteristic time required for the fluid to flow from the bottom to the surface in the real situation, t_R', will be reduced by the factor of 10'', meaning that the conditions investigated in one-day experiment in the laboratory model is equivalent to almost 3,000 years conditions depicted from the real reservoir.

THE INITIAL EXPERIMENTAL APPARATUS

A preliminary experimental model based on the method was constructed and basic characteristic investigations for the model is currently in progress. The lay-out of the experimental apparatus and its major dimension are as shown in Figure 1.

The apparatus is built based on the experimental apparatus used by Himasekhar et al. (1988). The apparatus consist of a well-insulated Plexiglas box filled with stone crushed and it is structured into three different region, namely region 111, IV, and V with different porosity as shown in Table 1. The stone *crushed* is used to simulate the porous medium. Region I and II simulate impermeable boundaries.

In fact the structured of the porous medium is one of some differences excist between this apparatus to the one used by Himasekhar et al. *(1988).*

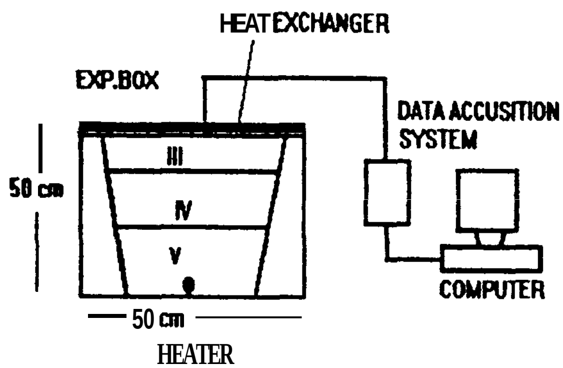

Figure 1. Schematic description of the experiment setup.

Table I. Thermophysic parameters of the crushed stone in the apparatus

Region	Porosity %	Density kg/m3	Specific Heat J/kg C	Conductivity W/mC	Permeability mD
I	3.5	2650	1050	3.01	1.75
II	3.8	2640	1020	3.01	175
III	3.4	2630	1040	3.04	9.45
IV	3.7	2540	1050	2.69	7.35
V	4.5	2550	1030	2.10	8.95

The length of the cylindrical heater spans the box's width. A perforated plate heat exchanger was fitted at the top of the apparatus to pick up the heat from the heater. The perforations are made to accommodate thermal expansion of the fluid inside the apparatus. The permeability of the plate was assumed to be -impermeable and isothermal for the purpose of the theoretical modeling. A water pool of about 10 mm depth is maintained above the plate. At the very top of the apparatus is a sealed cover to prevent evaporation.

Experiment are carried out by inputting the heater with electric power and it is changed in a sequence of small steps. A period of several hours is allowed to achieve steady *sate* condition. When the maximum temperature for the *apparatus* has been monitored, the investigation is repeated by gradually reducing the electric power input to the heater. The flow rate and temperature rise of the cooling water which flows through the heat exchanger plate are continuously monitored and used to calculate the rate of energy outflow from the apparatus. This quantity is then compared to the electrical power input into the heater. The distribution of the temperature was measured by means of a network of thirty-gage copper constantan thermocouples embedded at various locations within the porous matrix. The temperatures were continuously recorded by using data acquisition system. The laser Doppler apparatus to investigate the flow has not been set up yet.

Figs. 2 and 3 are the two example of the temperature distribution in the box for the heater temperature of 72 and 100 ^{o} C. The isothermal distribution was drawn from the reading of the thermocouple matrix which was then manipulate by using a program.

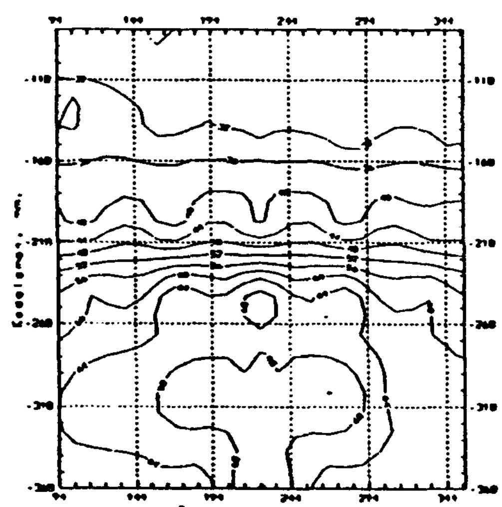

Fig 2. The distribution of the temperatur in experimental box for temperature 72 "C.

The temperature distribution is two dimensional. It can be predicted from the figures that a convection flow has been established. Hot fluid is rising above the heater and descending along the side walls. As the temperature increases, the convective effects are predicted more important.

Numerical solution of the temperature distribution in the box was processed by using TOUGH2 program , a numerical program for geothermal reservoir modeling

Observation of the possibility of transisition into a three-dimensional and time dependent flow is still underway.

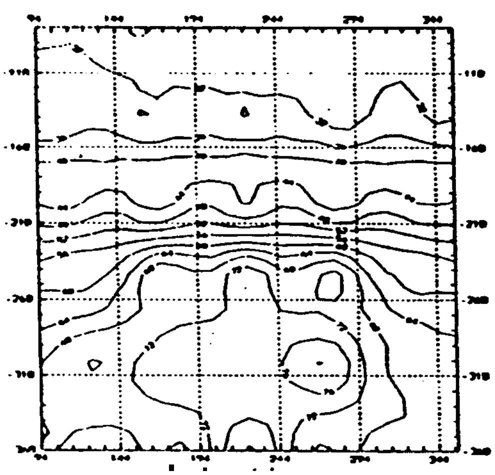

Fig 3. The distribution of the temperatur in experimental box for temperature 100 °C.

NOTES FROM THE STUDY

Preliminary efforts in experimental modeling based on a mathematical approach for a type of geothermal reservoir has been conducted. An apparatus to study the capability of the method in showing the fluid flow dynamics and heat transfer mechanism in the apparatus has also been set up. Investigation of the temperature fields from a heat source embedded and placed in the bottom of the box was carried out.

The approach, which uses simple algebraic operations, shows that experimental modeling for geothermal reservoir in laboratories is theoretically possible. The preliminary experimental evidence shows that there exists temperature fields which tend to follow the numerical results from the TOUGH2.

The adequacy of the experimental apparatus for modeling reservoir with high temperature and pressure conditions is also being examined.

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