Evaluating Geothermal Reserves with Application of Well Interference and Pressure Buildup Tests

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ABSTRACT
In order to evaluate geothermal reserves, it is necessary to estimate the porosity-thickness product of the reservoir. This paper deals with the method for estimating the porosity-thickness product of geothermal reservoirs by means of combining well interference and pressure buildup tests. A field study from the Chingshui geothermal area in Taiwan is given to illustrate the application of the method.

INTRODUCTION AND THEORIES
It is necessary to estimate the porosity-thickness (\( \phi h \)) product of the reservoir for evaluating geothermal reserves. This paper proposes a method to evaluate the \( \phi h \) value for that purpose. The authors derived equations, which demonstrate the relation between the pressure drop and the \( \phi h \) value of the observation well, from combining the theories of pressure buildup and interference tests. By using the equations and plotting the field surveying data on semilog paper, the \( \phi h \) value can be obtained.

Suppose well No.1 is a production well and well No.2 an observation well. By an interference test for the infinite reservoirs, the pressure drop in the close-in observation well due to continued production in well No.1 is given by

\[
P_e - P_{abs} = \frac{q_1 B_o \mu}{6.15 \ k} \log \left( \frac{14.22 \ k}{\mu c \phi r^2} \right)
\]

In Eq.(1), the \( k \) value can be estimated by the pressure buildup test on well No.2. The pressure buildup test is better done prior to the interference test which, however, should not be conducted until the pressure in well No.2 becomes quite stable. By the pressure buildup test, the pressure of well No.2 which has been shut-in for a time \( t \) will be

\[
P_f = P_e - \frac{q_2 B_o \mu}{6.15 \ k} \log \left( \frac{s}{t + \delta} \right)
\]

Now if we write

\[
m = \frac{q_2 B_o \mu}{6.15 \ k}
\]

then

\[
P_f = P_e - m \log \left( \frac{s}{t + \delta} \right)
\]

Eq.(4) indicates that the buildup pressure \( P_f \) plotted versus \( \frac{s}{t + \delta} \)
on semilog paper will be a straight line of slope \( m \), expressed in psi per cycle, and from the value of \( m \) obtained graphically, the \( k_h \) value may be found as

\[
k_h = \frac{q_2 B_w H}{6.15 m}
\]

--------- (5)

Substituting Eq. (5) in Eq. (1)

\[
P_e - P_{abs} = \frac{q_1 m}{q_2} \log \left( \frac{2.312 q_2 B_w t}{C \phi h m r^2} \right)
\]

or

\[
P_e - P_{abs} = \frac{q_1 m}{q_2} \log \left( \frac{2.312 q_2 B_w}{C \phi h m r^2} \right) + \frac{q_1 m}{q_2} \log t
\]

--------- (6)

If we write

\[
b = (P_e - P_{abs})_{t=1}
\]

then

\[
b = \frac{q_1 m}{q_2} \log \left( \frac{2.312 q_2 B_w}{C \phi h m r^2} \right)
\]

--------- (7)

and

\[
P_e - P_{abs} = b + \frac{q_1 m}{q_2} \log t
\]

--------- (8)

Eq. (8) indicates that the pressure drop \((P_e - P_{abs})\) plotted versus \( t \) on semilog paper will be a straight line (Fig. 1), and from the value of \( b \) obtained graphically, the \( \phi h \) value may be found as

\[
\phi h = \frac{2.312 q_2 B_w}{C m r^2 \log^{-1} \left( \frac{b q_2}{m q_1} \right)}
\]

--------- (9)

Figure 1. \((P_e - P_{abs})\) plotted versus \( t \) on semilog paper

Then the producible fluid content in reservoir per square kilometer can be calculated by

\[
W = \frac{\phi h P \times 10^6}{3.281 B_w}
\]

--------- (10)

FIELD TEST RESULTS

The reservoir of the Chingshui geothermal field, a liquid-dominated system, was estimated by combining pressure buildup and interference tests. The stable flowing rate of well 4T was

\[
q_2 = 132.6 \text{ ton/hr} = 138.1 \text{ kl/hr} = 20848 \text{ bbl/day}
\]

Table 1 presents the pressure buildup data. Figure 3 is the Horner pressure-time semilog plot. From the straight line on the graph \( m = 37 \text{ psi/cycle} \).
Table 1. Pressure Buildup Data
\((t = 60.56 \text{ hr})\)

<table>
<thead>
<tr>
<th>(\Delta t (\text{hr}))</th>
<th>(\frac{\Delta t}{\Delta t})</th>
<th>(P(\text{psig}))</th>
<th>(\Delta P)</th>
<th>(\frac{\Delta t}{\Delta t})</th>
<th>(P)</th>
<th>(\Delta P)</th>
</tr>
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When the pressure in well 4T is quite stable, after the well was shut-in, the interference test was started. During the interference test period, well 16T was producing, and pressure responses were observed in well 4T.

In Table 2, the flow rates of the production well were taken from the output of the well as given in Figure 3.

The pressure drop \((P_e - P_{abs})\) plotted versus \(t\) on semilog paper is a straight line (Fig.4). From the straight line on the graph,

\[
b = (P_e - P_{abs})_{t=1} = 2
\]
Table 2. Interference data

<table>
<thead>
<tr>
<th>Flowing time (hr)</th>
<th>Pressure in Observation well (psi)</th>
<th>Pe-P abs (psi)</th>
<th>Pressure in production well (kg/cm² G.)</th>
<th>Flow rate of production well (ton/hr)</th>
<th>Cumulative liquid production (ton)</th>
<th>Average flow rate (ton/hr)</th>
<th>Cumulative liquid production (bbl/day)</th>
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</table>

*113.7 ton/hr = 118.4 kl/hr = 17,872 bbl/day

Besides, other data were given:

\[ T = 405^\circ F \]
\[ p = 0.857 \text{ g/cm}^3 \]
\[ P = 1625 \text{ psia} \]
\[ B_w = 1.0 + 1.2 \times 10^{-4}(T-60) + 1.0 \times 10^{-6} \]
\[ (T-20)^2 - 3.33 \times 10^{-6} P \]
\[ = 1.0 + 1.2 \times 10^{-4}(405-60) + 1.0 \times 10^{-6} \]
\[ (405-60)^2 - 3.33 \times 10^{-6} \times 1625 \]
\[ = 1.155 \]
\[ C = 1 \times 10^{-5} \text{ psi}^{-1} \]
\[ r = 1,000 \text{ ft} \]

and from Table 2
\[ q_1 = 17,872 \text{ STB/day} \]

Substituting above information in Eq.(9)

\[ \phi h = \frac{2.312 q_1 B_w}{\text{cm}^2 \log^{-1} \frac{1 \text{ bd}_2}{\text{md}_1}} \]
\[ = \frac{2.312 \times 20848 \times 1.155}{37 \times 10^{-5} \times (1000)^2 \log^{-1} \frac{(2 \times 20848)}{37 \times 17872}} \]
\[ = 130 \text{ ft} = 40 \text{ m} \]

and then,

\[ W = \frac{\phi h P \times 10^6}{3.281 B_w \text{psi}^{-1}} = \frac{130 \times 0.857 \times 10^6}{3.281 \times 1.155} \]
\[ = 29.4 \times 10^6 \text{ ton/km}^2 \]
CONCLUSION

1. Geothermal reserves can be evaluated by means of combining pressure buildup and interference tests. The evaluating method proposed by this paper demands that the pressure buildup and interference tests be performed respectively and successively. Generally, interference test requires more time than pressure buildup test. For saving time, it is advisable to conduct pressure buildup test prior to interference test.

2. The evaluation method given in this paper is suitable for a liquid-dominated geothermal system, since the pressure of such a system very easily becomes stable.

NOMENCLATURE

$B_w$ = fluid formation volume factor, bbl/STB
$C$ = fluid compressibility, psi$^{-1}$
$h$ = net pay thickness, ft
$k$ = permeability, darcy
$m$ = slope of Honor pressure buildup line, psi/cycle
$P_e$ = static pressure of the reservoir, psia
$P_r$ = pressure measured in well No.2 when the well has been shut-in for a time $\tau$ during pressure buildup test, psia
$q_1$ = the rate of production of well No.1 during interference test, STB/day
$q_2$ = the rate of production of well No.2 prior to shut-in of the well during the pressure buildup test, STB/day
$r$ = the distance between well No.1 and well No.2, ft
$T$ = producing time of well No.2 prior to shut-in of the well, day
$t$ = producing time of well No.1, day
$W$ = producible fluid content in reservoir, ton/km$^2$
$\tau$ = shut-in time of well No.2 after flowing for a time during the pressure buildup test, day
$\mu$ = fluid viscosity, CP
$\rho$ = density of fluid in reservoir, g/cm$^2$
$\phi$ = porosity

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REFERENCE

