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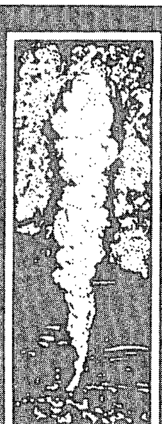

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Evaluating Geothermal Reserves with Application of Well Interference and Pressure Buildup Tests

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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 (Øh) product of the reservoir for evaluating geothermal reserves. This paper proposes a method to evaluate the Øh value for that purpose. The authors derived equations, which demonstrate the relation between the pressure drop and the Øh 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 Øh 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

$$P_e - P_{abs} = \frac{q_1 B_w \mu}{6.15\ kh} \log \left(\frac{14.22\ kt}{\mu c \phi r^2} \right) \qquad \text{---------- (1)}$$

In Eq.(1), the kh 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 δ will be

$$P_\delta = P_e - \frac{q_2 B_w \mu}{6.15\ kh} \log \left(\frac{\delta}{T+\delta} \right) \text{----(2)}$$

Now if we write

$$m = \frac{q_2 B_w \mu}{6.15\ kh} \qquad \text{---------- (3)}$$

then

$$P_\delta = P_e - m \log \left(\frac{\delta}{T+\delta} \right) \qquad \text{-------- (4)}$$

Eq.(4) indicates that the buildup pressure P_δ plotted versus $\frac{\delta}{T+\delta}$

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 kh value may be found as

$$kh = \frac{q_2 B_w \mu}{6.15\ m} \quad \text{---------- (5)}$$

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

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

or

$$P_e - P_{abs} = \frac{q_1 m}{q_2} \log\left(\frac{2.312\ q_2 B_w}{C\emptyset hmr^2}\right) + \frac{q_1 m}{q_2} \log t$$

-------- (6)

If we write

$$b = (P_e - P_{abs})_{t=1}$$

then

$$b = \frac{q_1 m}{q_2} \log\left(\frac{2.312\ q_2 B_w}{C\emptyset hmr^2}\right) \quad \text{------ (7)}$$

and

$$P_e - P_{abs} = b + \frac{q_1 m}{q_2} \log t \quad \text{----- (8)}$$

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 Øh value may be found as

$$\emptyset h = \frac{2.312\ q_2 B_w}{Cmr^2 \log^{-1}\left(\frac{bq_2}{mq_1}\right)} \quad \text{------- (9)}$$

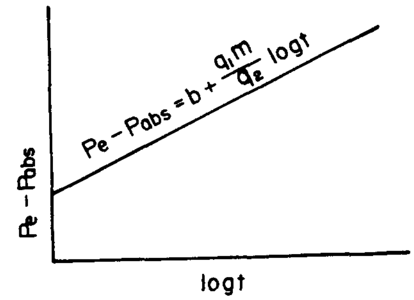

Figure 1. ($P_e - P_{abs}$) plotted versus t on semilog paper

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

$$W = \frac{\emptyset h \rho \times 10^6}{3.281\ B_w} \quad \text{------ (10)}$$

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 psi/cycle.

Table 1. Pressure Buildup Data
(t = 60.56 hr)

Δt(hr)	$\frac{t+\Delta t}{\Delta t}$	P(psig)	ΔP	Δt(hr)	$\frac{t+\Delta t}{\Delta t}$	P (psig)	ΔP
0	-	350	0				
0.083	730.6	444	94	3.00	21.2	928	578
0.167	363.6	580	230	3.50	18.3	932	
0.250	243.2	703	353	4.00	16.1	935	585
0.333	182.9	778	428	5.00	13.1	940	590
0.417	146.2	802	452	6.00	11.1	940	590
0.500	122.1	833	483	7.00	9.65	940	590
0.583	104.9	848	498	8.00	8.57	944	
0.667	91.8	850	500	9.00	7.73	947	
0.750	81.7	855	505	10.00	7.06	949	599
0.833	73.7	862	512	11.00	6.51	949	
1.000	61.6	874	524	12.00	6.05	949	
1.167	52.9	887	537	13.00	5.66	949	
1.333	46.4	896	546	14.00	5.33	949	
1.500	41.4	901	551	15.00	5.04	952	
1.667	37.3	906	556	16.00	4.79	952	
1.833	34.0	911	561	17.00	4.56	954	
2.000	31.3	913	563	18.00	4.36	954	
2.333	27.0	920	570	19.00	4.19	954	
2.667	23.7	923	573	20.00	4.03	954	
				21.00	3.88	957	
				22.00	3.75	957	

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 out-put of the well as given in Figure 3.

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

$$b = (P_e - P_{abs})_{t=1} = 2$$

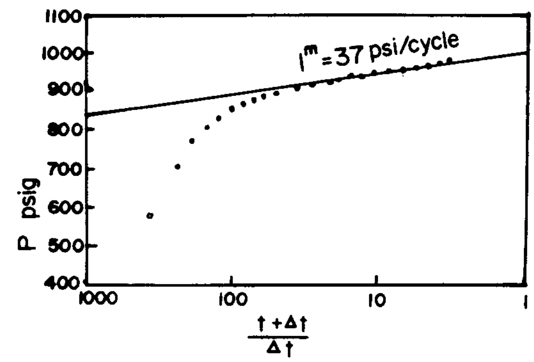

Figure 2. Pressure buildup curve

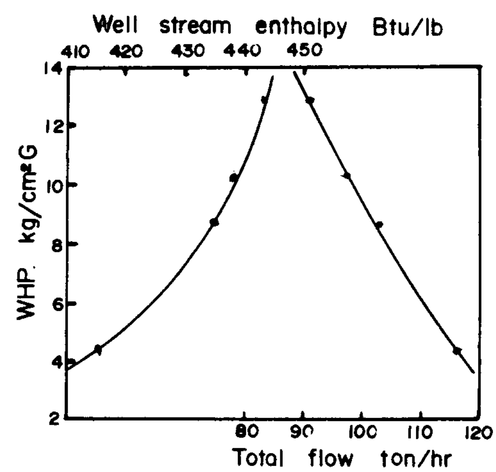

Figure 3. Out-put curve of well 16T

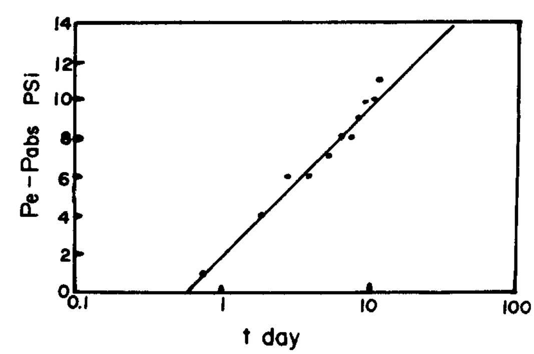

Figure 4. (P_e-P_{abs}) plotted versus t on semilot paper

Table 2. Interference data

Observation well: Well 4T
Flowing well : Well 16T

Flowing time		Pressure in observation well	$P_e - P_{abs}$	Pressure in production well	Flow rate of production well	Cumulative liquid production	Average flow rate	
hr	day	psig	psi	kg/cm2 G.	ton/hr	ton	ton/hr	bbl/day
0	0	172		18.2	0	0		
18.5	0.77	171	1	4.9	114.5	1059		
42.5	1.77	168	4	4.1	117.5	3843		
66.5	2.77	166	6	3.9	118.0	6669		
90.5	3.77	166	6	3.9	118.0	9501		
114.5	4.77	165	7	3.9	118.0	12333		
138.5	5.77	164	8	3.9	118.0	15165		
162.5	6.77	164	8	3.8	118.5	18003		
186.5	8.77	163	9	3.8	118.5	20843		
210.5	9.77	162	10	3.7	118.6	23692		
234.5	10.77	162	10	3.7	118.6	26537		
258.5	11.77	161	11	3.7	118.6	29384	113.7*	17872

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

Besides, other data were given:

$T = 405^{o}F$

$\rho = 0.857\ g/cm^3$

$P = 1625$ psia

$B_w = 1.0+1.2x10^{-4}(T-60)+1.0x10^{-6}$
$(T-20)^2 -3.33x\ 10^{-6}\ P$
$= 1.0+1.2x10^{-4}(405-60) +1.0x10^{-6}$
$(405-60)^2-3.33x10^{-6}x1625$
$= 1.155$

$C \fallingdotseq 1 x 10^{-5}\ psi^{-1}$

$r = 1,000$ ft

and from Table 2

$q_1 = 17,872$ STB/day

Substituting above information in Eq.(9)

$$\phi h = \frac{2.312\ q_2 B_w}{cmr^2\ \log^{-1}(\frac{bq_2}{mq_1})}$$

$$= \frac{2.312x20848x1.155}{37x10^{-5}x(1000)^2\log^{-1}(\frac{2x20848}{37x17872})}$$

$= 130$ ft $= 40$ m

and then,

$$W = \frac{\phi h \rho\ x\ 10^6}{3.281\ B_w} = \frac{130x0.857x10^6}{3.281x1.155}$$

$= 29.4\ x\ 10^6$ 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 build up line, psi/cycle
P_e = static pressure of the reservoir, psia
P_δ = pressure measured in well No.2 when the well has been shut-in for a time δ 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
δ = shut-in time of well No.2 after flowing for a time during the pressure buildup test, day
μ = fluid viscosity, CP
ρ = density of fluid in reservoir, g/cm^2
ϕ = porosity

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