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THE ESTIMATION OF VERTICAL VELOCITY OF THERMAL WATER BY USE OF TEMPERATURE PROFILE

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SUMMARY - One of the most important parameters which must be studied at a geothermal field is the water delivery potential of the system. Generally, discharge of thermal springs is only a small part of the total water delivery potential. In order to estimate the potential hot water flow, estimation of the vertical water flow by using a temperature profile can be one of the most important steps. In this study, an attempt was made to estimate the vertical velocity of thermal water by using a temperature profile in an homogeneous, isotropic and fully saturated semi-confining layer.

1 INTRODUCTION

An analytical solution was developed by Bredehoeft and Papadopulos (1965) to estimate the rate of vertical groundwater movement by using thermal profile. They considered an isotropic, fully saturated aquifer as shown in figure 1.

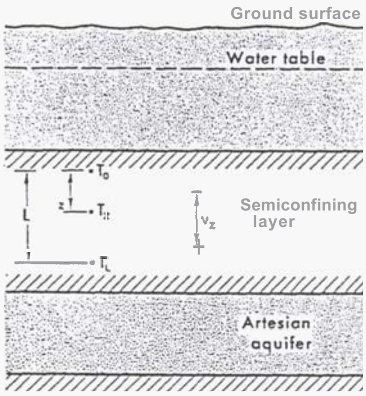

Figure 1: Diagrammatic sketch of typical leaky aquifer (after Bredehoeft and Papadopulos, 1965)

The equation representing vertical thermal conduction and convection is:

$$\frac{\partial^2 T}{\partial z^2} - \frac{c\rho v}{k} \cdot \frac{\partial T}{\partial z} = 0 \qquad (1)$$

The solution of this equation under boundary conditions :

$T_z = T_0$ at $z=0$ and
$T_z = T_L$ at $z=L$

is:

$$f\left(\beta, \frac{z}{L}\right) = \frac{T_z - T_0}{T_L - T_0} = \frac{1 - e^{\frac{-\beta z}{L}}}{1 - e^{-\beta}} \qquad (2)$$

$$\beta = \frac{c\rho v L}{k} \quad \text{(dimensionless)} \qquad (3)$$

This solution can be represented as a type curve (Figure 2) and β and v are estimated by matching the type curve [z/L;f(β,z/L)] and field curve [z/L;$(T_z-T_0)/(T_L-T_0)$].

2 MODIFICATION OF METHOD

If β is greater than 4 then $e^{-\beta}$ becomes 0.0183 which can be accepted as 0 and then the equation can be rewritten as;

$$1 - e^{-\left(\frac{\beta z}{L}\right)} = \frac{T_L - T_0}{T_L - T_0} \qquad \Rightarrow$$

$$1-\frac{T_z-T_0}{T_L-T_0}=\frac{T_L-T_z}{T_L-T_0}=e^{-\left(\frac{\beta z}{L}\right)}\Rightarrow$$

$$\frac{\beta\cdot z}{L}=\ln\frac{T_L-T_0}{T_L-T_z} \quad (4)$$

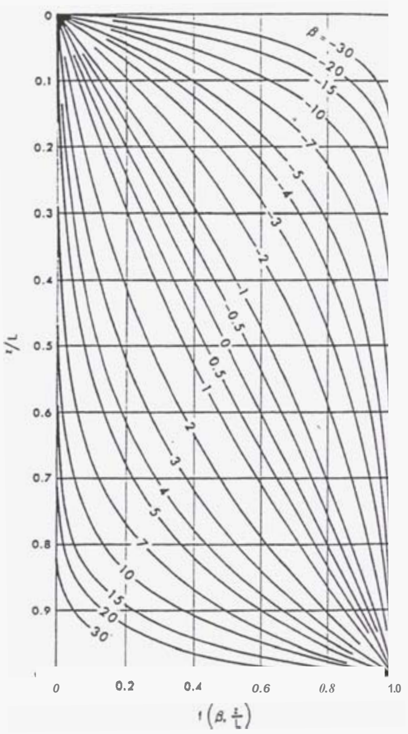

Figure 2: Type curves of the function f(β,z/L) (after Bredehoeft and Papadopulos,1965)

If specific heat of water is equal to 4.2 kJ/kgK and density of water 1000 kg/m^3 then

$$\beta=\frac{4200v\cdot L}{k}\ or\ \frac{\beta}{L}=\frac{4200v}{k}\ .$$

If we multiply both sides by **z**

$$\frac{\beta\cdot z}{L}=\frac{4200v\cdot z}{k} \quad (5)$$

Substituting into equation (4) gives

$$\frac{v\cdot z}{k}=\frac{1}{4200}\ln\frac{T_L-T_0}{T_L-T_z}\ \text{or}$$

$$v=\frac{k}{4200z}\ln\frac{T_L-T_0}{T_L-T_z} \quad (6)$$

So if T_0, T_L and T_z at any z depth are known then the vertical velocity (v) can be estimated. For thermal conductivity (k) an average value 2-2.5.10^{-3} kW/mK can be used if it is not known.

3 APPLICATION OF METHOD

An attempt was made to estimate the velocity of thermal water by using a temperature profile of the Gonen (NW Turkey) G4 thermal water well. The detailed temperature measurements in the well were canied out by the Turkish Mineral Exploration Institute (MTA) after completion of the drilling (Erzenoglu and Ulusahin, 1990). The temperature log of the G4 thermal water well is given in Figure 3. From the temperature measurements of G4 well T_0=29.1 "C, T_L=90 "C, z and T_z are chosen as variables. Velocities were computed for every T_z at **z** depth by using the following equation.

$$v=\frac{2.1\times10^{-3}}{4200z}\ln\frac{90-29.1}{90-T_z}.$$

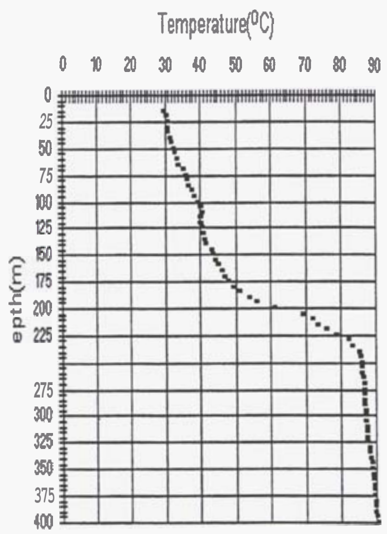

Figure 3: Temperature log of G4 thermal water well drilling

The β value was checked for every computed v value where β≥4 was taken into consideration and the average velocity was found to be $5.42.10^{-9}$ m/s (Table 1) or 0.17 m/year.

Table 1 Results of velocity calculation from temperature T_z at z depth where β≥4

z (m)	T_z (°C)	$v.10^{-9}$ m/s	β=4200vL/K
240	85.0	5.20	4.16
245	85.3	5.22	4.18
250	85.4	5.16	4.13
255	85.5	5.10	4.08
260	85.5	5.00	4.00
265	86.0	5.13	4.11
270	86.1	5.08	4.07
275	86.2	5.04	4.03
280	86.3	5.00	4.00
340	88.0	5.02	4.01
345	88.3	5.18	4.14
350	88.4	5.19	4.15
355	88.6	5.31	4.25
360	88.8	5.40	4.36
365	88.9	5.49	4.39
370	89.0	5.55	4.44
375	89.2	5.77	4.62
380	89.3	5.87	4.70
385	89.4	6.00	4.80
390	89.4	5.92	4.73
395	89.8	7.23	5.79
	average	5.42	

4 RESULTS AND RECOMMENDATIONS

1) It is possible to estimate the vertical velocity of thermal water by using a temperature profile, especially if the lowermost temperature (T_L) in the semi-confining layer is determined,

2) The modified method is valid if β≥4, this value should be controlled for calculation

3) If the discharge region of thermal water can be determined by using water and soil temperature, geophysical methods or aerial photographs, the vertical velocity and the superficial area of discharge region gives the total discharge.

5 NOMENCLATURE

c - specific heat capacity of the fluid (kJ/kgK)

k - thermal conductivity (kW/mK)

L - vertical distance between T_0 and T_L (m)

T_0 - uppermost temperature measurement (“C or K)

T_L - lowermost temperature measurement (°C or K)

T_z - temperature measurement at any z depth (“C or K)

z - depth (m)

ρ - density of fluid (kg/m^3)

6 ACKNOWLEDGMENTS

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7 REFERENCES

BREDEHOEFT, J.D., PAPADOPULOS, I.S., (1965). Rates of Vertical Groundwater Movement Estimated from the Earth‘s Thermal Profile. Water Resources *Research*, Vol. 1 , No.2., American Geophysical Union, Washmgton-USA, 325-328

Z. Erzenoglu - A. Ulusahin (1990). Gonen (Balikesir) Kaplicasi G-4 ve *G4/A nolu Sicaksu* Sondajlari *Kuyu Bitirme* ve *Koruma Alanlari Raporu,* MTA, Ankara (unpubl. report)