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Characterization of Surface Area to Volume Ratio of Fractured Rocks for Temperature Transient: Laboratory and Field Methods

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ABSTRACT

Surface area to volume ratio is an important geometric parameter which influences the temperature transient behavior of fractured rocks. An equivalent radius based on volume and surface area, which treats any shaped body as though it were an equivalent sphere, can be used to predict the temperature transient response of fractured rocks cooled in heat-convective fluids. This paper reviews how to measure surface area to volume ratio in laboratory for naturally fractured rocks. A paraffin coating technique can be used to measure the surface area of naturally fractured rocks in laboratory. Well interference tests can be applied in naturally fractured reservoirs to estimate both permeability-thickness product and porosity–thickness product, which can then be used for estimating in-situ surface area to volume ratio.

1. INTRODUCTION

Heat transfer from fractured rocks to recharge fluid is a two-step process. Heat inside the rock is conducted to the rock surface and then transferred to the surrounding fluid by convection. In fractured geothermal reservoirs, the rock fragments are large and of irregular shape. An analytical solution of the temperature transient performance for irregular-shaped rock fragment is too complex. Kuo, Kruger, and Brigham (1976) studied the heat transfer from single irregular-shaped rocks. They developed a simple shape factor correlation relating the rock fragment geometric parameters to the heat transfer parameters. An equivalent radius based on volume and surface area, which treats any shaped body as though it were an equivalent sphere, can be used to predict the temperature transient response of fractured rocks cooled in heat-convective fluids.

Surface area to volume ratio is an important geometric parameter which influences the temperature transient behavior of fractured rocks. This paper reviews a paraffin coating technique, which can be used to measure the surface area of naturally fractured rocks in laboratory. An interference test can provide field data to estimate in-situ surface area to volume ratio for Chingshui geothermal field, Taiwan.

2. LABORATORY METHOD*: PARAFFIN COATING

*Kuo, Kruger, and Brigham (1976)

Surface area and volume are important geometric parameters which affect the temperature transient behavior. Volume can be more easily determined than surface area. Volumes of irregularly shaped samples were determined by measuring the weight of the samples and dividing by the material density.

Surface area measurement of irregular-shaped rocks on the other hand is difficult. A coating technique was developed which works effectively for surface area measurement. The two primary criteria for a successful coating technique are: (1) a peelable coating so that the weight of coating can be determined accurately, and (2) uniform mean thickness of the coating so that the weight of coating will be proportional to the surface area. The experimental procedure consists of the following steps: (1) Freeze the rock in the dry ice bath, (2) Dip the rock into liquid paraffin at controlled temperature of 75 ℃ to 80 ℃ for 30 seconds, (3) Allow the coated rock to cool at room temperature, (4) Peel the coating from the rock, and (5) Weigh the coating. The paraffin coating starts to crack about one minute after removing the rock from the liquid paraffin. The cracking due to thermal stressing makes the peeling successful and reproducible.

Figure 1 shows a calibration curve which relates the weight of coating to the known surface area for Berea Sandstone samples of regular geometries. The critical steps in obtaining reproducible data were noted to be careful timing of dipping and temperature control of liquid paraffin.

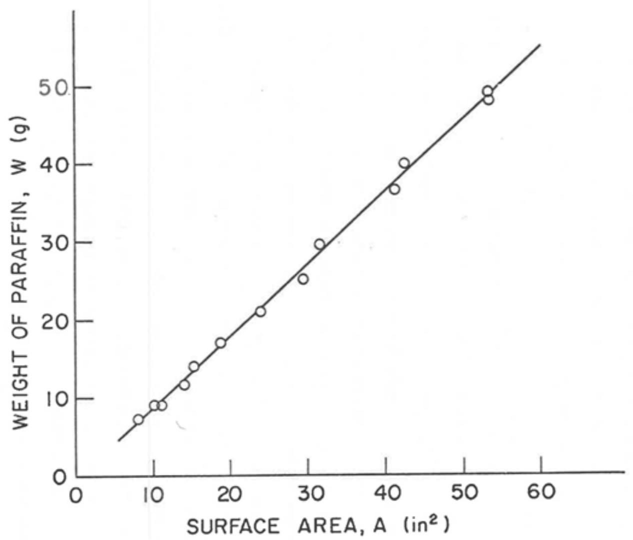

Figure 1: Calibration curve for paraffin weight and surface area (Kuo, Kruger, and Brigham, 1976).

3. FIELD METHOD: WELL INTERFERENCE TEST

Production in the liquid-dominated Chingshui geothermal field, Taiwan is largely from a fractured zone in the Jentse Member of the Miocene Lushan Formation. A multiple-well interference test was performed in 1979. During the 1979 test, well 16T was the production well, and pressure responses were observed in wells 4T, 5T, 9T, 12T, 13T, and 14T 1979 (Chang and Ramey, 1979). Figure 2 shows both surface and bottom-hole locations of these wells. Because in all wells the drilling bit has drifted following geologic structures, it was necessary to estimate the distance between the bottom-hole locations for interpretation of interference test data. The distances between the wells were measured between pairs of feed zones.

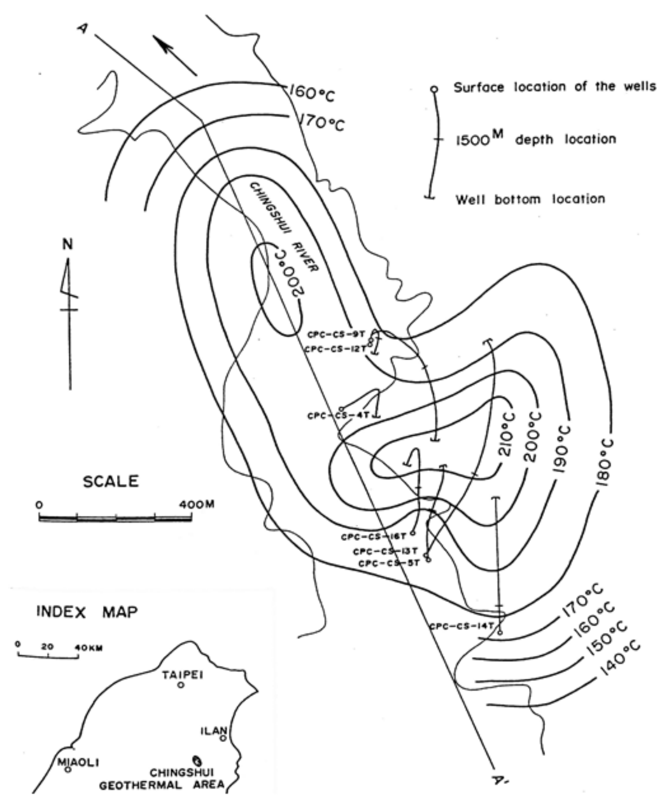

Figure 2: Location of the wells and the isotherms of presumed formation temperature for 1500 m depth in the Chingshui geothermal area (Chang and Ramey, 1979).

The most commonly used analytical solution for interpreting an interference test is Theis solution (Theis, 1935) and the line source solution (van Everdingen and Hurst, 1949) in groundwater and petroleum engineering, respectively. The line source solution assumes a constant production/injection rate case in an infinite-acting, isotropic, reservoir. This is the model used by Chang and Ramey (1979) in their analysis of the 1979 interference test data. As an example, well 4T will be used to illustrate the method to estimate in-situ volume to surface area ratio.

Figure 3 shows the match of the pressure versus time data with van the Everdingen-Hurst solution for well 4T. As shown in Table 1, the estimated permeability-thickness product (*kh*) and porosity–thickness product (ψh) for well 4T are 9.24 Darcy-meter and 3.38 m, respectively. Given a formation thickness (*h*) of 1005 m, the estimated permeability (*k*) and porosity (ψ) for well 4T are 9.19 * 10^{-3} Darcy and 3.36 * 10^{-3}, respectively.

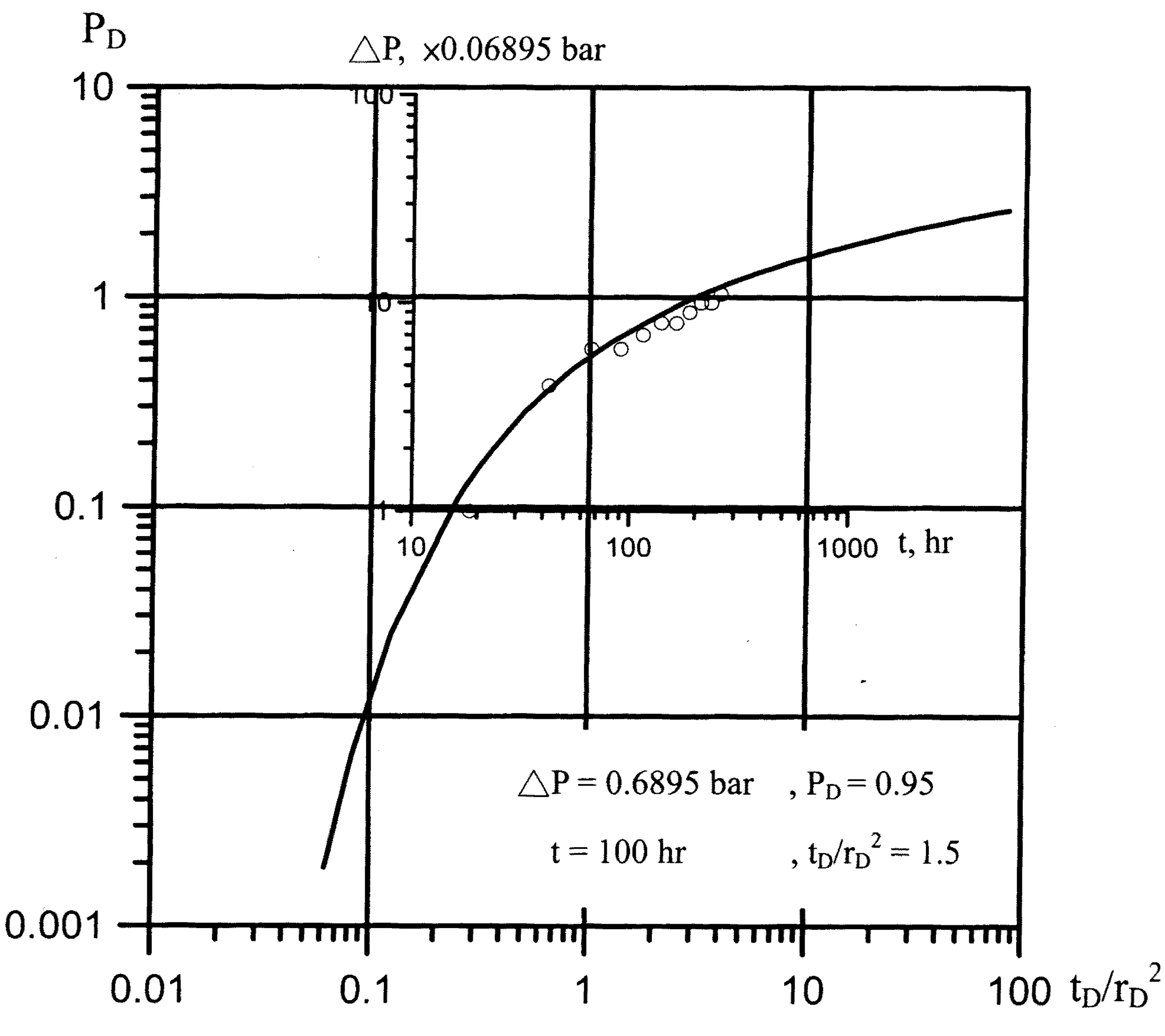

Figure 3: Type-curve match for well 4T using radial flow model.

Table 1: Reservoir parameters obtained from type-curve matching of interference test data for well 4T at Chingshui, Taiwan.

Match point		
$\Delta p = 0.6895\ bar = 0.7031\ kg/cm^2 = 10\ psi$		$p_D = 0.95$
$t = 100\ hrs$		$t_D/{r_D}^2 = 1.5$
Distance, m	175	
kh, Darcy-meter	9.24	
φh, m	3.38	

$q = 105\ tons/hr$; $v_{sc} = 1.08\ cm^3/g$; $\mu = 0.12\ cp$;

$B = 1.1\ reservoir\ volume/surface\ volume$; $c_t = 0.019\ (kg/cm^2)^{-1}$

Assuming that three mutually orthogonal sets of fractures are common in nature, Snow (1968) derived the following equations to correlate the fracture porosity (ψ) and permeability (k) for a cubic arrangement of plane fractures with an average spacing (Δ) and an average aperture ($2B$).

$$\varphi = 5.45 \left(\frac{k}{\Delta^2}\right)^{\frac{1}{3}} \quad (1)$$

and

$$2B = \varphi \frac{\Delta}{3} \quad (2)$$

Given a fracture porosity (ψ) of $3.36 * 10^{-3}$ and a fracture permeability (k) of $9.19 * 10^{-3}$ Darcy, we can calculate fracture aperture ($2B$) and fracture spacing (Δ) using equations (1) and (2). The estimated fracture aperture ($2B$) and fracture spacing (Δ) at well 4T are 697 microns and 0.622 meter, respectively. When fracture spacing (Δ) >> fracture aperture ($2B$), the surface area to volume ratio can be approximated by 6/Δ. For Chingshui geothermal reservoir, the estimated surface area to volume ratio at well 4T is 9.65 $meter^{-1}$. The estimated volume to surface area ratio at well 4T is 0.103 meter.

4. CONCLUSIONS

1. This paper reviews a paraffin coating technique used to measure the surface area of naturally fractured rocks in laboratory.

2. Well interference test data from Chingshui geothermal field,Taiwan are applied to estimate the in-situ surface area to volume ratio.

3. For Chingshui geothermal reservoir at well 4T, the estimated surface area to volume ratio is 9.65 $meter^{-1}$. The estimated volume to surface area ratio at well 4T is 0.103 meter.

4. In-situ fracture aperture and spacing estimated from the well interference test can be compared with outcrop observations in the Chingshui geothermal area.

REFERENCES

Chang, C. R. Y., and Ramey, H. J.: Well interference test in the Chingshui geothermal field, 5th Geothermal Reservoir Engineering Workshop, Stanford University, (1979), 64-76.

Kuo, M. C. T., Kruger, P., and Brigham, W. E.: Shape factor correlations for transient heat conduction from irregular-shaped rock fragments to surrounding fluid, SGP-TR-16, Stanford Geothermal Program, Stanford University, (1976).

Snow, D.T.: Rock fracture spacings, openings, and porosities, J. Soil Mech. & Found. Div., ASCE, 94, (1968), 73-91.

Theis, C. V.: The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage, Trans. American Geophysical Union, 16, (1935), 519-524.

van Everdingen, A. F., and Hurst. W.: The application of the Laplace transformation to flow problems in reservoirs, Trans., AIME 186, (1949), 305-324.