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Radon Measurements in Geothermal Well Testing

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ABSTRACT

Radon concentration was monitored during the flow tests of well IC-09 at the Chingshui geothermal field. The radon concentration was found to increase as a step function of production time, or cumulative production. The observed radon behavior implied that scale deposited near the wellbore in the reservoir. The high skin factors (61.1 and 78.2) determined from pressure buildup tests also supports that scale deposited in the reservoir.

1. GEOLOGY OF CHINGSHUI GEOTHERMAL RESERVOIR

Well CPC-CS-9T is located in the Chingshui Geothermal Field in the north-east of Taiwan. The Chingshui geothermal field is an area of hot springs along the Chingshui River, approximately 13 km southwest of Lotung (Figure 1). The well was repaired and finished on April 24, 2008. Its total depth is 2,086 m. The casing program for the production well CPC-CS-9T was: 50.8 cm (20 in.) conductor, 34 cm (13-3/8 in.) surface casing, 24.4 cm (9-5/8 in.) production casing, and 17.8 cm (7 in.) slotted liner. The production hole is from 539 to 2,086 m.

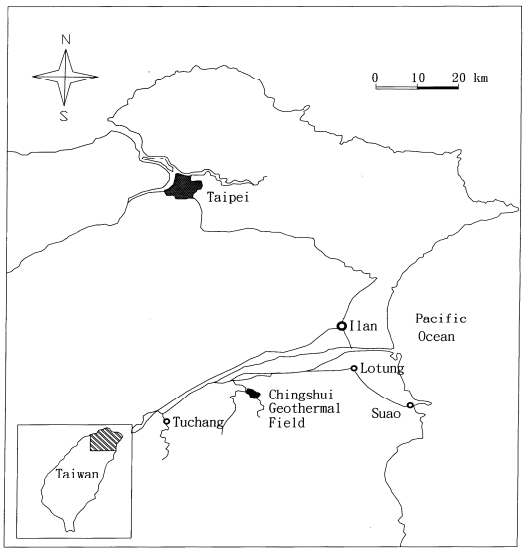

Figure 1: Location map of the Chingshui geothermal area.

The reservoir is within the Lushan Formation, of Miocene age. The Lushan Formation can be divided lithologically into the Jentse, Chingshuihu, and Kulu Members. In general, the Jentse Member is composed mainly of metasandstones intercalated by slates, while the Chingshuihu and Kulu Members consist mostly of slates (Tseng, 1978; Chiang et al., 1979). Geothermal production at Chingshui is largely from a fracture zone in the steeply dipping Jentse Member (Hsiao and Chiang, 1979).

The Chingshui geothermal area is located on a monocline structure, which is cut internally by numerous thrust faults that are lightly curved, and essentially trend NE-SW parallel to the bedding; the most important ones are the Tashi, Hsiaonanao and Hanhsi faults, shown in Figure 2 (Su, 1978; Hsiao and Chiang, 1979). In the field itself, along the Chingshui River, there is the normal, N-S striking Chingshuihsi fault. Active tectonic movements most likely created the numerous faults and well-developed fractures around the Chingshui geothermal area. The best developed fractures in the slates are found near the most convex part of the Hsiaonanao fault along the Chingshui River.

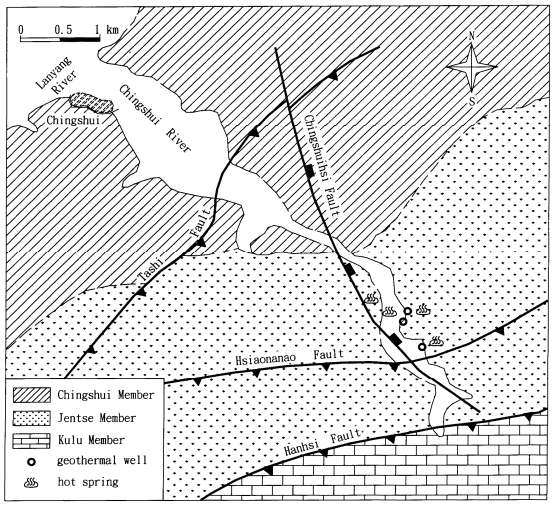

Figure 2: Geological map of the Chingshui geothermal area showing the Chingshuihu, Jentse, and Kulu members of the Miocene Lushan Formation. Triangles and rectangles indicate the up-dipped sides of the reverse faults and the direction of dip of the normal fault, respectively.

2. RADON MEASUREMENTS IN GEOTHERMAL WELL TESTING

After the well workover completed, production test started on April 24, 2008. The production test was conducted in five stages with the total flow rate at 41.3, 32.2, 27.4, 20.2 and 34.2 tons/hr, respectively. Figure 3 shows a multi-rate flow test. The test completed on May 7, 2008. Radon concentration was monitored in the non-condensable gases during the production test. Radon-222 concentration was measured by SARAD-2100.

Figure 4 shows that the radon concentration increases as a step function of production time. Analytical models describing convective transport of radon with hydrodynamic dispersion through a porous media are available in the literatures for incompressible fluids and simple geometries. Stoker and Kruger (1975) presented steady-state solutions of radon transport in liquid phase for linear and radial flow. The observed radon behavior in

Figure 4 implies that scale is present near the wellbore in the reservoir. The reservoir consists of two sections of rocks, one with significant emanating power, the other with scale deposited near the wellbore with essentially zero emanating power. As the liquid in the skin zone near the wellbore is purged out, the radon concentration increases as a step function.

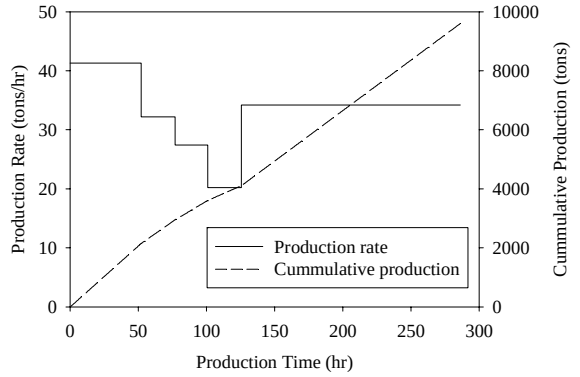

Figure 3: Multi-rate test for well CPC-CS-9T from 16:00 April 24 to 10:00 May 7, 2008.

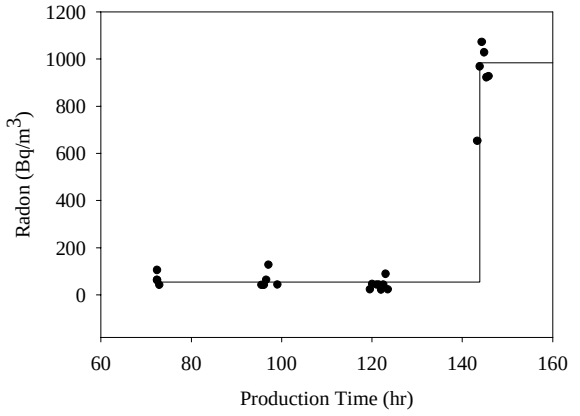

Figure 4: Radon concentration versus production time.

3. PRESSURE BUILDUP TESTS

Two pressure buildup tests were performed on May 14, 2008 and May 17, 2008. Pressure buildup tests analysis were analyzed by Horner plot method (Matthews and Russell, 1967). Table 1 shows the parameter values used in the analyses.

Table 1: Parameter values used in the buildup analyses.

Parameter	Value
Viscosity, μ (cp)	0.12
Formation volume factor, B (reservoir volume/surface volume)	1.1
Fluid compressibility, c_t (Pa^{-1})	1.94×10^{-7}*
Porosity-thickness product, ψh (m)	3.8*
Wellbore diameter, r_w (m)	0.16

3.1 First Pressure Buildup Test

The first pressure buildup test started on 20:15, May 15, 2008 after the well produced from 16:40, May 14, 2008. Average total flow rate was 24.4 tons/hr (3873 BBL/D). The pressure gauge was lowered to 1,300 m, and the wellhead valve was completely closed. Figure 5 is a Horner plot Horner plot for the first pressure buildup test. From the straight line on the graph:

$$kh = \frac{162.6q\mu B}{m}$$

$$= \frac{(162.6)(3873)(0.12)(1.1)}{13.36}$$

$$= 6222\ md-ft$$

$$S = 1.1513\left[\frac{P_{1hr} - P_{wf}\ (\Delta t = 0)}{m} - \log\left(\frac{kh}{\phi\mu h c_t r_w^2}\right) + 3.2275\right]$$

$$S = 1.1513\left[\frac{1664.48-896.64}{13.36} - \log\left(\frac{6222}{12.47\times0.12\times0.00138\times(8.5/21)^2}\right)+3.2275\right]$$

$$= +61.4$$

where k is permeability, md; h is formation thickness, ft; q is flow-rate, BBL/D; μ is viscosity, cp; B is formation volume factor, res.bbl/surface bbl; m is Horner Plot slope, psig/cycle; ϕ is porosity; c_t is compressibility of fluid, (psi)-1; P1hr is pressure when Horner Plot Δt =1hr，psig; Pwf is instant pressure at 1300 m depth when wellhead close, psig; rw is production hole radius，ft.

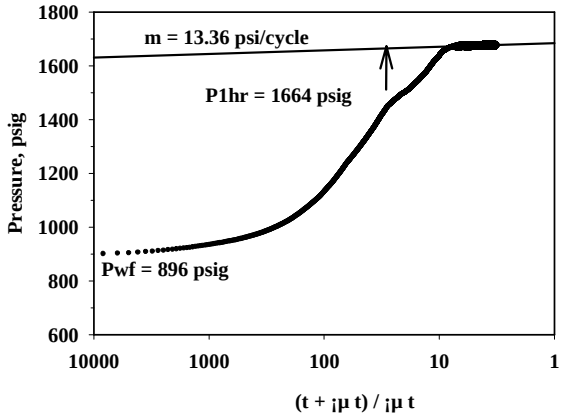

Figure 5: Horner plot for the first pressure buildup test.

3.2 Second Pressure Buildup Test

The second pressure buildup test started on 16:40, May 17, 2008 after the well produced from 19:00, May 29, 2008. Average total flow rate was 26.1 tons/hr (4143 BBL/D). The pressure gauge was lowered to 1,300 m, and the wellhead valve was completely closed. Figure 6 is a Horner plot Horner plot for the second pressure buildup test. From the straight line on the graph:

$$kh = \frac{162.6q\mu B}{m}$$

$$= \frac{(162.6)(4143)(0.12)(1.1)}{13.93}$$

$$= 6383\ md - ft$$

$$S = 1.1513\left[\frac{P_{1hr} - P_{wf}\ (\Delta t = 0)}{m} - \log\left(\frac{kh}{\phi\mu h c_t r_w^2}\right) + 3.2275\right]$$

$$S = 1.1513\left[\frac{1660.33 - 652.39}{13.93} - \log\left(\frac{6383}{12.47\times 0.12\times 0.00138\times (8.5/21)^2}\right) + 3.2275\right]$$

$$= +78.5$$

The high skin factors, 61.1 and 78.2, determined from the first and second pressure buildup tests, respectively, support that scale deposited in the reservoir.

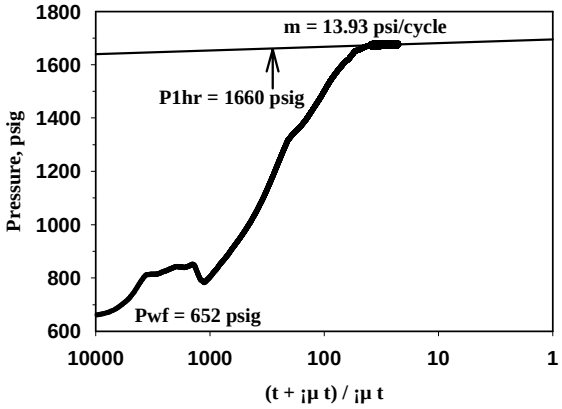

Figure 6: Horner plot for the second pressure buildup test.

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