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Research article

Risk of temperature differences in geothermal wells and generation strategies of geothermal power

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Supplementary

Appendix A

Since we do not have references or data to directly link $T_{dw}(t)$ and $MC(t)$, a parameter of γ was put in place to relate $T_{dw}(t)$ to $MC(t)$ in the following way. As shown in Table 3, the SPATECH Shinshu (http://spatec-shinshu.jp/c3b.html) estimates the cost of removing scale from a single 147.6 mm [1] diameter well at a cost of 625,000 JPY per year. This cost represents the maintenance cost $MC(0)$, as shown in Equation (2).

[1]Based on the photos of the buried pipe replacement project posted on the SPATECH website, the length of a 170 cm adult male hand in the shape shown in the photo is 147.6 mm. This value is estimated to be the same for the hand and pipe diameter in the photo, so the pipe diameter is assumed to be 147.6 mm.

Table 3 Descaling Cost Items per Pipe in an Assumed Plant: The maintenance cost for descaling is 625,000 JPY, which is sum of 410,000 and 215,000 JPY, from the above items. In general, there are three types of chemical treatment of silica scale deposited in wells: dredging method, chemical injection method and pH adjustment method. In this study, we assume that the chemical injection method using the SPA-KS series is applied. Since the geothermal plant does not replace the pumps in a short span of two years, the cost of pump replacement is not required.

Cost Item	Descaling Cost[2] [in 10,000 JPY] /year
Pump Lifting Cost	41.0
Pump Cleaning Cost	21.5
Pump Replacement Cost	0

Subsequently, according to Japan's Ministry of Environment (2010), the diameter of a 2000 m-class well used in a 30,000 kW-class geothermal power plant is approximately 215.9 mm as an example. It was estimated as a cost 91,420 JPY per year to descale on a single well of this diameter. This amount is the cost of cleaning the scale from a single well. Therefore, in the case of the Sumikawa geothermal power plant which is classified in the 30,000 kW, with 14 wells in operation, it was estimated that one geothermal plant with 14 wells would require 12.8 million JPY at $t = 0$ as shown in Equation (7).

$$625{,}000 \text{ JPY} \times \frac{215.9}{147.6} mm \times 14 \text{ wells} = 12{,}798{,}949 \text{ JPY} \approx 12.8 \text{ million JPY} \quad (7)$$

The temperature difference between the production and injection wells, as in the data of Snyder et al. (2017), is 75.6°C, calculated from the difference in the mean, we assume $T_{dw}(0)$ is substituted into the $e^{\alpha T_{dw}(0)+\beta}$ in right-hand side of Equation (2) at $t = 0$ and is 7.30 mg in Equation (8).

$$e^{\alpha T_{dw}(0)+\beta} = e^{0.1244 \times 75.6°\text{C} - 2.1923} = 7.30 \text{ mg} \quad (8)$$

[2]It is assumed that the descaling process is the same for SPATECH and the geothermal plant, but the location of scaling in the pipes is different because of the different temperature zones; however, at SPATECH, the maintenance cost of the descaling for two pumps, in and out pipes, are removed twice every two years, so the pump lifting cost of 1.64 million yen and the pump cleaning cost of 860,000 JPY were calculated for the maintenance cost of the two pipes per two years. However, the pump in the assumed plant is designed to have a pair of in and out pipes, which have a high temperature variation and are likely to generate scale. Since the cost covers the maintenance of a single pump of this type, it was assumed to be half the cost of maintenance performed by SPATECH. Therefore, 1.64 million JPY and 860,000 JPY were divided by 4, and 410,000 JPY and 215,000 JPY were set as the annual maintenance costs per single pump for descaling.

Descaling the scale size of 7.30 mg is assumed to cost 12.8 million JPY from the SPATECH Shinshu cost calculation above. Thus, the conversion factor γ is the cost per plant to remove 1 mg unit size of scale, and the value is 175.3420 [in 10,000 JPY] as substituting these parameters into Equation (2).