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The Hijiori Hot Dry Rock test site, Japan Evaluation and optimization of heat extraction from a two-layered reservoir

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Abstract

The Hijiori hot dry rock (HDR) system, Japan, consists of a shallow and a deep reservoir, both in fractured granitic rocks. During a long-term circulation test (LTCT) lasting approximately 18 months and which tested different fluid production scenarios, large changes were observed in output fluid temperatures, pressures, and flow rates. A multi-reservoir, numerical model of the Hijiori HDR system was developed using the finite element heat and mass (FEHM) transfer code and applied to simulations of the LTCT. The model reproduced the pressure, temperature, and flow data observed during the test. Based on the modeling study, it was concluded that most of the produced fluid came from the shallow reservoir, that the permeability of the deep reservoir changed during the initial part of the LTCT, and that the redistribution of injected water between the two reservoirs had little impact on the relative amounts of deep and shallow fluid production. After validating the model on the LTCT, it was used to optimize injection rates in both reservoirs. The model was also used in simulations of reservoir performance where an additional heat transfer surface area has been created in the subsurface through hydraulic fracturing.

Keywords: HDR; EGS; Long-term circulation test; FEHM code; Two-layered reservoir; Hijiori; Japan

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Nomenclature

a	representative asperity height (m)
A	total area of the fracture (m^2)
A_r	total cross-section of the nails (m^2)
b	ratio of the nail cross-section to length
C	constant (Eq. (11)) $(\mathrm{Pa\,s})^{-1}$
E	Young's modulus of a nail (Pa)
Ent_v	steam enthalpy (kJ/kg)
Ent_w	hot water enthalpy (kJ/kg)
f	Lomize's friction factor for fracture flow (Eq. (10))
I_0	total number of nails
k	intrinsic permeability (m^2)
ΔL	length in the flow direction (m)
n	parameter affecting the distribution of nail heights
N	number of nails
NTE	net thermal output (MWt)
P	effective stress (Pa)
P_α	effective modulus of the asperities (Pa)
P_w	fluid pressure within the fracture (Pa)
ΔP	change of water pressure along the flow direction's length ΔL (Pa)
q	volumetric fluid flow rate (m^3/s)
q_v	steam production rate (kg/s)
q_w	hot water production rate (kg/s)
Q	total mass of water injected (tonnes)
t_{inj}	temperature of injected water (°C)
t_{pro}	temperature of produced fluid (°C)
W	fracture aperture (m)
W_0	maximum fracture aperture (m)
x	change in fracture aperture (Eq. (3)) (m)

Greek letters

α, β	constants (Eq. (14); tonnes)
μ	fluid viscosity (Pa s)
σ	stress normal to the fracture (Pa)

1. Introduction

The thermal energy attainable from geothermal sources has historically had a major role in electric power generation and space-heating if the reservoirs containing the hot fluids are at reasonable depth and exhibit both high temperatures and sufficient rock permeability. It is likely that the power derived from geothermal sources will increase in future as the cost of reducing CO_2 emissions is gradually factored into the total cost of electricity generation. Geothermal energy production from hot dry rock (HDR) systems, in which a heat transfer surface area is created by hydraulic fracturing, seems likely to extend the emissions-related benefits of geothermal energy to many parts of the world that currently have high thermal gradients but insufficient