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Modeling of geothermal energy production from stratigraphic reservoirs in the Great Basin

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ABSTRACT

Large, potentially commercial geothermal resources exist in sedimentary rocks beneath high heat-flow basins of the United States. Geothermal reservoir modeling was performed to explore the available power density (MWe/km^2) attributable to two general classes of reservoir: a multi-layered "sandwich" and single high permeability layer. Variations in reservoir temperature (i.e. conductive heat flow), permeability, and layer thickness were evaluated. The high permeability layers were assumed to be horizontal and laterally extensive. Production wells were assumed to be pumped at a constant rate, and all produced water was injected at 75 °C after being cooled in a power plant. Modeling was undertaken using the STARS Advanced Process and Thermal Reservoir Simulator, Version 2010, by Computer Modeling Group. Five reservoir models were simulated: (1) Sandwich (base) reservoir model to test heat sweep for a reservoir-seal configuration with an average reservoir temperature of 200 °C at 3 km depth; the reservoir comprised four 25 m thick layers with a permeability of 100 mD. (2) Single layer reservoir with the same initial temperature and transmissivity of the sandwich reservoir. (3) Low temperature (150 °C) sandwich reservoir model. (4) Low permeability sandwich reservoir model, involving lower permeability layers than the sandwich base model. (5) Short-circuit sandwich reservoir model where a high permeability layer results in a higher transmissivity than the base sandwich model. All models assumed isotropic permeability, uniform porosity (10%), and an initial thermally conductive vertical temperature gradient and hydrostatic pressure gradient. All models utilized a five spot pattern with a 500 m well spacing, with the flow rate in producer and injector wells being 1000 gallons per minute. The base sandwich model, which may be representative of stratigraphic bedrock reservoirs beneath some basins of the Great Basin, has a power density 3–10 MWe/km^2 over a 30 year period. During 30 years of production and injection, production wells in the low permeability model each generated 140 MWe-years of power compared to 65–90 MWe-years per production well in the single layer and short circuit models. A consistent result from all the models was that vertically distributed reservoir layers allow a much greater fraction of heat to be swept from lower permeability seal units. In all models, the lateral pressure gradient induced between injectors ranged between 30 and 60 bars, which is not unusual for geothermal developments.

1. Introduction

Most geothermal power developments in the U.S. tap into hydrothermal up-flow zones, where water (and sometimes steam) is at a temperature high enough, and it is sufficiently shallow, to be economically accessed by production wells for power generation. However the most obvious and attractive of these resources have been developed and it is becoming increasingly difficult to find hidden (blind) up-flow zones. Deep basins within the high heat flow parts of the western U.S. may have stratigraphic reservoirs between about 3 and 4 km depth with temperatures of 150–250 °C (Allis et al., 2011, 2012) and may be attractive for geothermal power production as well. These reservoirs are sub-horizontal and are much larger in area (>102 km^2) than the traditional fault-hosted hydrothermal reservoirs that have been developed in the past within the Great Basin (typically <10 km^2). Blackwell et al. (2012) have suggested that the sub-vertical up-flow zones of many of these hydrothermal systems that have been the target of production wells may be less than 1 km^2 in plan-view Although the sub-horizontal bedrock layers considered by Allis et al. (2012) are at slightly greater depths than traditional geothermal production wells, if these layers have sufficiently high transmissivity they may

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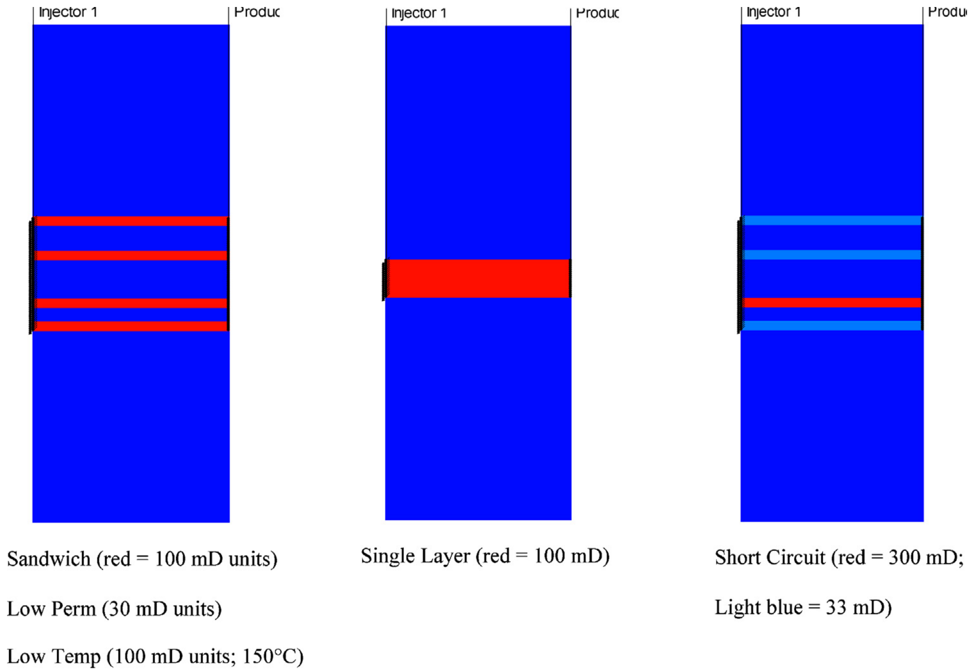

Fig. 1. Permeability layering for the five models.

Table 1
STARS Input for sandwich and single layer reservoir models.

Properties	Sandwich	Single
Dimension	500 m × 500 m × 1300 m	
No. of layers	9	
Grid (*i,j,k*)	100 @ 5 m × 100 @ 5 m × 100 @ variable m *k*: 1–20 = 25 m, 500 m total (layer 1) 21–25 = 5 m, 25 m total (layer 2) 26–32 = 5 m, 35 m total (layer 3) 33–37 = 5 m, 25 m total (layer 4) 38–57 = 5 m, 100 m total (layer 5) 58–62 = 5 m, 25 m total (layer 6) 63–75 = 5 m, 65 m total (layer 7) 76–81 = 5 m, 25 m total (layer 8) 81–100 = 25 m, 500 m total (layer 9)	
Permeability	100 mD-layers 2,4,6,8 1 mD-layers 1,3,5,7,9	100 mD-layer 5 1 mD-layers 1,3,4,6,7,8,9
Transmissivity	10 D-m	
Porosity	0.1	
Rock therm. cond.	2.5 W/m °C	
Water saturation	0.99	
Initial temperature	200 °C at 3 km depth Gradient 35 °C/km	
Initial pressure	300 bar at 3 km depth Gradient100 bar/km	
Well pattern	2× ¼ injector located at 0,0 m and 1000,1000 m 2× ¼ producer located at 0,1000 m and 1000,0 m	
Water inj. (total)	1000 g/min, (US) 4700 psi BHP, 100 °C (Each of 2 injectors has ¼ of 1000 GPM)	

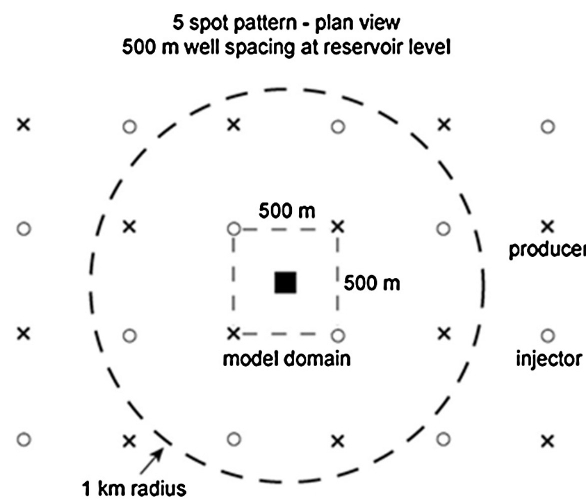

Fig. 2. Five spot well spacing used in the modeling.

present a much easier drilling target. The large reservoir areas of these basins implies a power potential of hundreds of megawatts (MWe).

The purpose of this study is to investigate the rate of heat extraction from sub-horizontal reservoirs consisting of a realistic range of permeabilities, layer thicknesses, and thermal regimes.

Table 2
Variation in STARS input for the sandwich, low temperature, low permeability, and short circuit models.

Properties	Sandwich	Low temp.	Low perm.	Short-circuit
Permeability	100 mD-layers 2,4,6,8 1 mD-layers 1,3,5,7,9	100 mD-layers 2,4,6,8 1 mD-layers 1,3,5,7,9	30 mD-layers 2,4,6,8 1 mD-layers 1,3,5,7,9	300 mD-layer 4 33 mD-layers 2,6,8 1 mD-layers 1,3,5,7,9
Transmissivity	10 D-m	10 D-m	3 D-m	10 D-m
Initial temp.	200 °C	150 °C	200 °C	200 °C