Enhanced Geothermal Systems Creation and Production

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PDH: 2

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Module 5: EGS Creation and Production

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the critical heat transfer time scales (tc1, tc2, tc3) that govern the operational longevity of an Enhanced Geothermal System (EGS).
- **Optimize** water flow strategies to mitigate thermal bypass and maintain high exit temperatures for efficient electricity generation.
- **Assess** the technical and environmental constraints of EGS, including water consumption, corrosion, and induced seismicity.

Executive Summary: The success of EGS depends on managing the coupling of heat transfer between rock and water to ensure sustainable recovery factors and reservoir longevity. Key challenges include preventing "thermal bypass"—where water flows too fast to reach ambient rock temperatures—and optimizing mass flow rates to prevent rapid power decay. Engineering solutions, such as wholly drilled heat exchangers, offer a path to eliminating subsurface uncertainty, provided that environmental impacts like water scarcity and induced seismicity are carefully managed.

Heat Transfer Features of EGS

Two primary determinants for the success of a geothermal system are the **recovery factors** for thermal energy and the **possible lifetime** of a given producing region. Both require understanding the coupling of heat transfer to the water and the change of the thermal energy in the rock.

- **Design Fundamentals**: Effective extraction relies on models of the distribution of cracks and associated fluid flow at depth.
- **Thermal Recovery**: In the absence of significant permeability, rock thermal recovery occurs only by heat conduction, which is relatively slow.
- **Cooling Distances**: Within t = 5 years of contact with cool water, the rock is locally cooled over a distance of approximately 25 meters.
- **Flow Strategy Necessity**: To produce significant usable energy, systems must employ flow strategies tailored to the fracture network.

Thermal Bypass

Thermal bypass occurs when water temperature fails to approach the far-field rock temperature because the flow is too rapid for sufficient heat conduction.

- **Class 1 Bypass**: Results from cracks wider than a critical opening (b0) where water flows too fast for sufficient heat to be conducted through the rock.
- **Class 2 Bypass**: Results from heterogeneous depletion of rock thermal energy (cooling), which can occur even for narrow cracks.

Description of the Heat Transfer Problem

To assess EGS characteristics, we consider coupled one-dimensional models for temperature evolution.

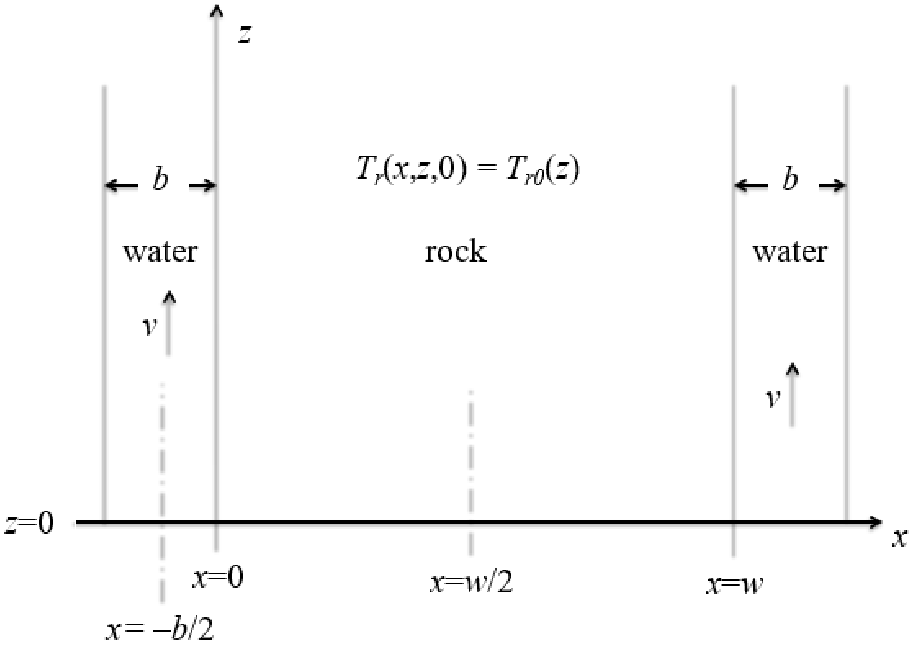

Figure 5-1: A vertical channel of width b and length £ (in z) in underground rock, with water injected at temperature Tw0 flowing upward with speed v. In this section z is vertically upward, consistent with the direction of flow and standard use in heat transfer calculations, but opposite the standard geophysical notation where z is downwards from the Earth’s surface.

Equation 5-1:

$$\frac{\partial T_w}{\partial t} + v\frac{\partial T_w}{\partial z} = k_w\frac{\partial^2 T_w}{\partial z^2} + \frac{2j_r}{bC_w}$$

Where:

- **Tw** = Temperature of the water
- **v** = Fluid velocity
- **kw** = Thermal diffusivity of water
- **jr** = Heat flux transferred from the rock to the water
- **b** = Crack opening/width
- **Cw** = Volumetric specific heat of water

Equation 5-2:

$$\frac{\partial T_r}{\partial t} = k_r \frac{\partial^2 T_r}{\partial x^2}$$

Where:

- **Tr** = Temperature of the rock
- **kr** = Thermal diffusivity of the rock
- **x** = Distance directed into the rock transverse to flow

Critical Time Scales

- **tc1**: Time for water in the channel to equilibrate with the local rock-surface temperature (minutes for b = 1 cm).

- **tc2**: Time when the "cooling wave" in the rock reaches the midpoint between parallel cracks (approx. 2 years for 30m separation).

- **tc3**: Time when the propagating "cooling front" reaches the exit of the heat-transfer zone.

Equation 5-3:

$$t_{c3} = \left(\frac{C_r}{C_w}\right)\left(\frac{vb}{k_r}\right)\left(\frac{L}{vb}\right)$$

Where:

- **tc1** = Time for water in the channel to equilibrate with the local rock-surface temperature (minutes for b = 1 cm)
- **tc2** = Time when the "cooling wave" in the rock reaches the midpoint between parallel cracks (approx. 2 years for 30m separation)
- **tc3** = Time when the propagating "cooling front" reaches the exit of the heat-transfer zone
- **Cr** = Volumetric specific heat of rock
- **Cw** = Volumetric specific heat of water
- **v** = Fluid velocity
- **b** = Crack opening/width
- **kr** = Thermal diffusivity of rock
- **L** = Length of the heat-transfer zone

Illustrative Examples

System performance is highly sensitive to mass flow rates.

- **High Flow (10 m/s)**: Extracts maximum thermal power but does not achieve high water temperatures, providing little useful energy for electricity.
- **Moderate Flow (1 m/s)**: Mines similar energy as high flow but increases electrical power generation by a factor of 8.
- **Optimized Flow (0.1 m/s)**: Maximizes useful energy output by making tc2 and tc3 approximately equal.
- **Slow Flow (0.01 m/s)**: Maximizes water outlet temperature and conversion efficiency but produces a slow rate of extraction.

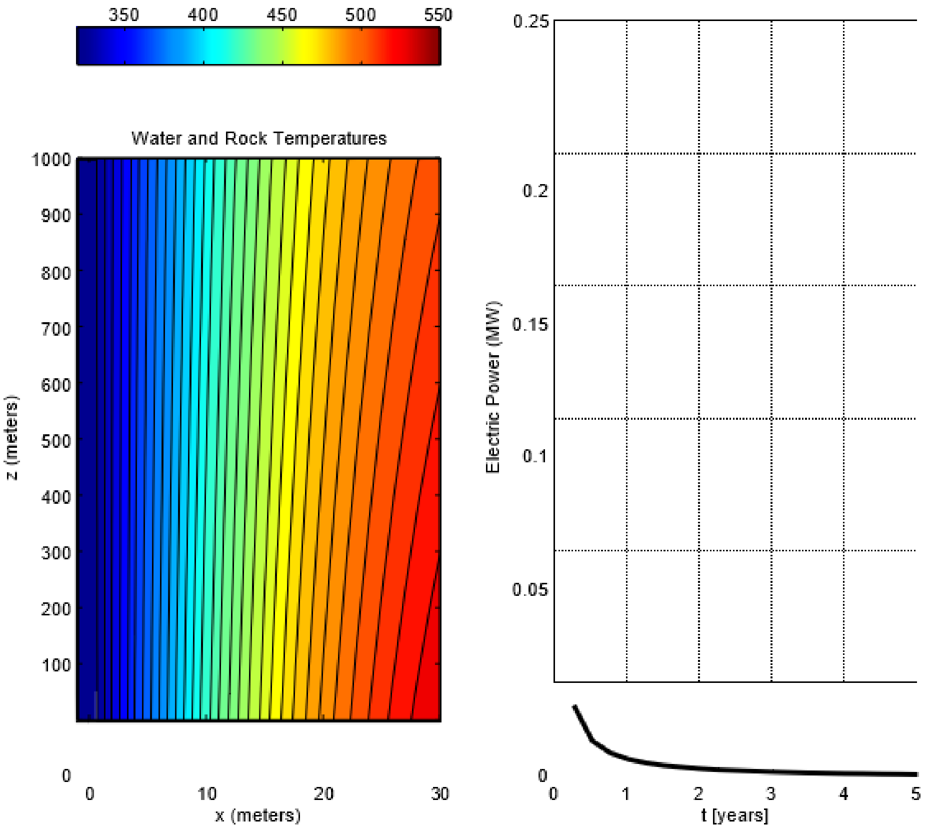

Figure 5-2: Results from example calculation with v = 10 m/s, shown at t = 5 years. On the left is a color contour plot of temperature in the water and rock system, with the water channel on the left made artificially wide for visibility. On the right is electrical power generation as a function of time. Flow speed is much too fast for useful power generation.

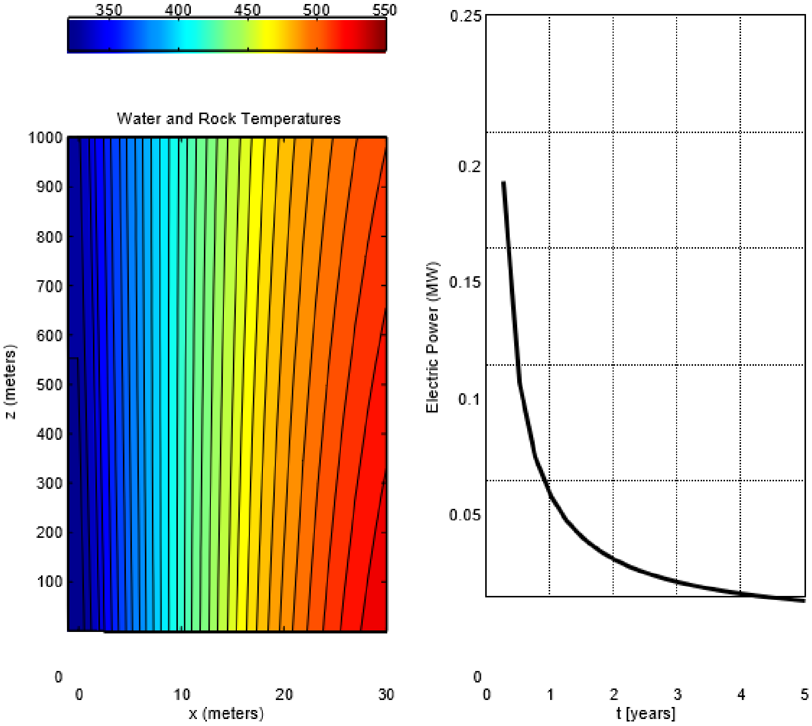

Figure 5-3: Results from example calculation with v = 1 m/s, shown at t = 5 years. Flow speed is still too fast for optimum power generation, although it is much improved over the v=10 m/s case.

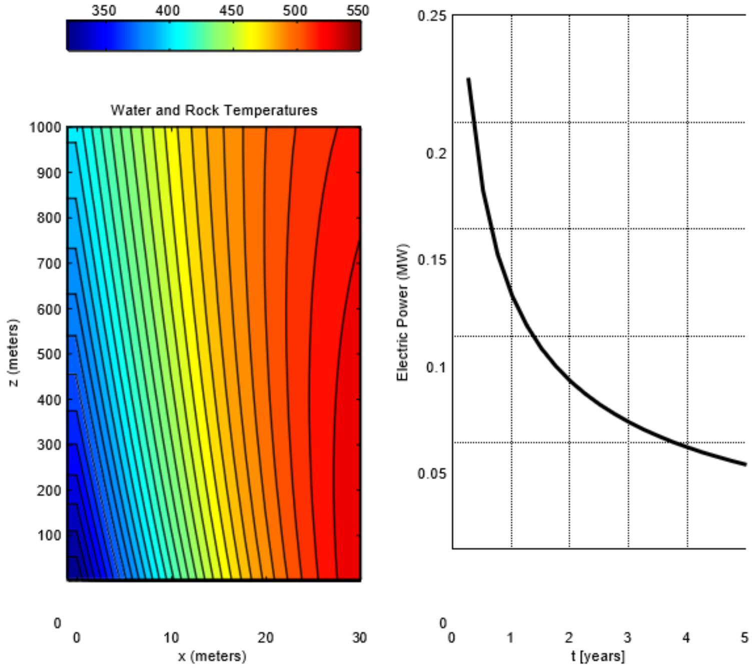

Figure 5-4: Results from example with v = 0.1 m/s, shown at t = 5 years. This system's performance is substantially improved over the faster-flow systems.