

Re-use of E&P-boreholes for geothermal energy production

Geothermal energy applications have gained renewed interest in recent years. One of the interesting applications is the re-use of deep boreholes drilled by oil and gas industry for a Deep Borehole Heat Exchanger (DBHE). A DBHE is based on the principle of a fluid migrating through a coaxial pipe in the subsurface; the fluid is heated gradually as it migrates downwards in the outer pipe, with the inner pipe serving as the return path for the heated fluid. The inner tube is insulated along the total length of the DBHE to prevent the produced water from cooling (Figure 1). The upper section of the injection tube can be insulated from the surrounding rock up to a depth at which the geotherm equals the temperature of the injected fluid.

The energy performance of the DBHE is proportional to the temperature difference between the injected and the produced water, multiplied by the injection rate (m³/h). In this study we present techno-economic models for re-using E&P wells, relying on best practices for asset evaluation from the Oil & Gas industry and taking into account natural uncertainties and the results from decision trees used to evaluate sensitivities and different scenarios (see Floris and Peersmann, 2002). We also show

that in re-using wells that have produced oil or gas, the performance of the wells can be significantly higher because of a temperature rise in the sediments near the well caused by production.

Fast models for DBHE

Fast model calculations for the techno-economic evaluation of dry wells are based on the analytical solutions of Kujawa and Nowak (2000a, 2000b) in calculating the heat fluxes for the inner and outer tubes in the DBHE.

The equations to describe the temperature of the injected fluid flowing downward through the outer tube are defined as follows:

$$1 \quad Q_c dT_1 = K_w (T_2 - T_1) dZ + K_z (T_1 - T_0) dZ$$

$$2 \quad Q_c dT_2 = K_w (T_2 - T_1) dZ$$

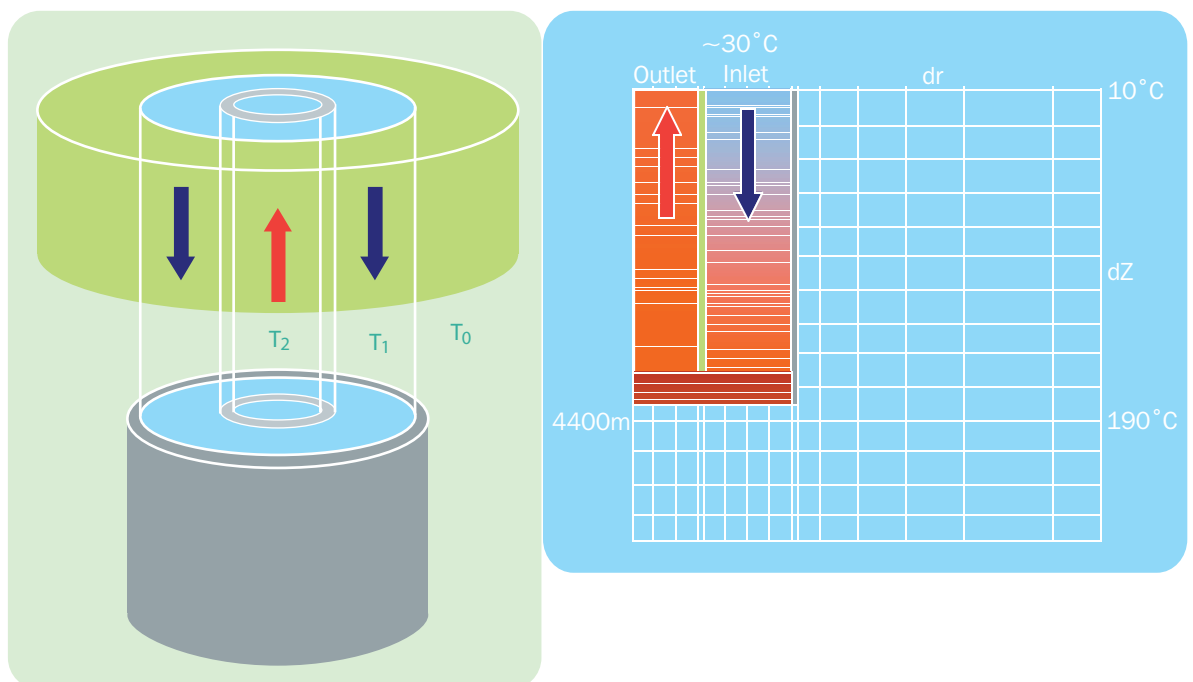
where

$$Q_c = Q C_p$$

$$K_z = k_z 2\pi r_z$$

$$K_w = k_w 2\pi r_w$$

Figure 1.
(left) The tube setup with the isolated outer tube in yellow and the non isolated outer tube in grey.
(right) 2D axi-symmetric numerical finite difference grid.



with Q_c the thermal capacity of heat flow [W/K]; c_p the specific heat at constant pressure [J/(kgK)]; Q the mass flow rate [kg/s]; L the length of borehole [m]; Z the reduced coordinate; r_z, r_w the outer radius of the inner tubing and the inner radius of the outer tubing, respectively; T_1, T_2 the temperatures of the injected and the produced fluids, respectively; T_0 the temperature of the surrounding rock; k_z the substitute overall heat transfer coefficient for the surrounding rock [W/(m²K)]; and k_w the substitute overall heat transfer coefficient for the inside surface [W/(m²K)]. These equations are used in a two-layered system with different values for K_z and K_w for each layer, according to d’Alambert’s method (Kujawa and Nowak, 2000b).

The power E of the system is proportional to the difference between the surface inlet and the surface outlet temperature predicted by the model:

$$E = Q_c * (T_2 - T_1) |_{z=0}$$

The K_w and K_z values play a major role in the outlet temperature of the fluid. These should take into account the effects of thermal insulation of the inner tubing and the thermal boundary layer effects (Kohl et al.,

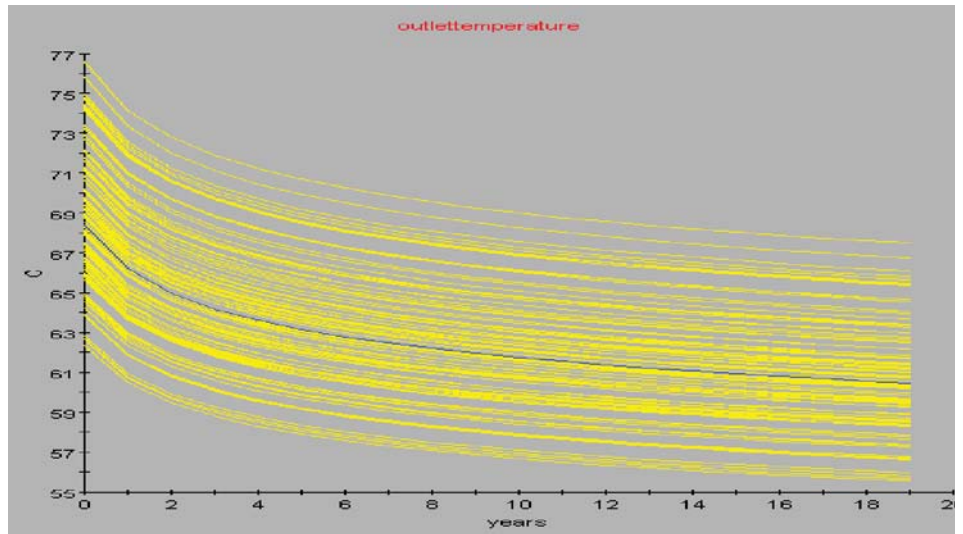


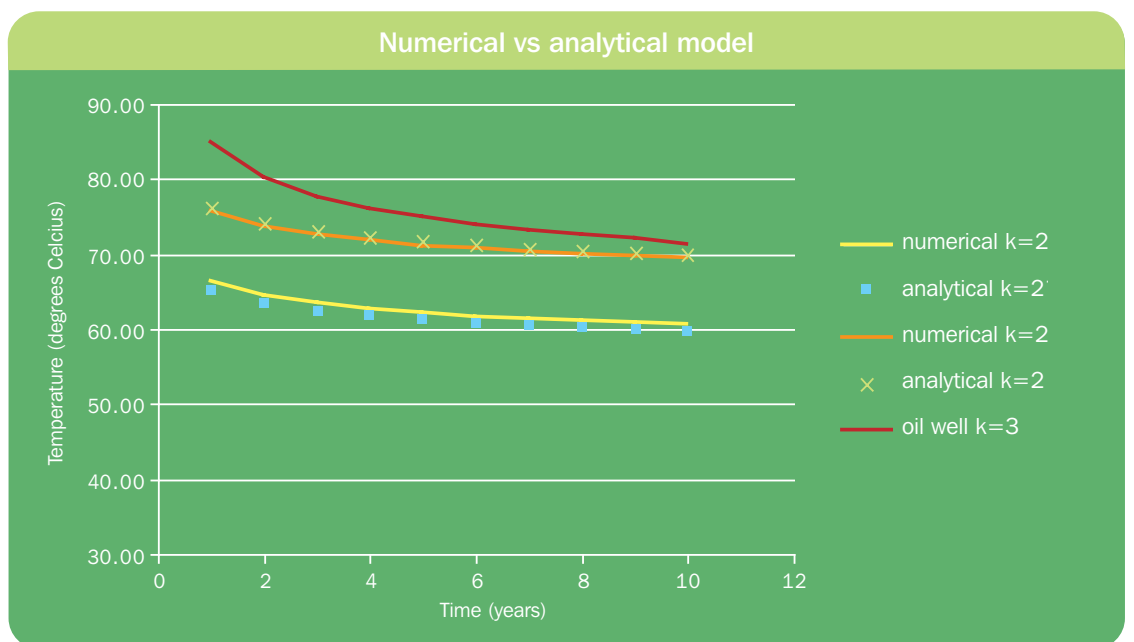
Figure 3. Outlet temperatures per year with basin conductivities between 1.5-2.0 and a geotherm of 40-50 °C/km.

2002), and they should take into account the time-dependent temperature drawdown of the thermal conductivity of the sediments (see Signorelli, 2004). The analytical model results have been compared to numerical finite difference model runs (Figure 1). These results show a good match. Finite difference modelling shows that previous oil production can significantly increase the outlet temperature and power of geothermal re-use, by up to 20%.

Sensitivity

The key to geothermal performance is the difference calculated between the outlet temperature and the inlet temperature (Figure 2, Equation 3). Using probabilistic decision and risk modelling techniques from the E&P industry (see Floris and Peersmann, 2002) linked to the fast analytical geothermal calculations, we were able to study the sensitivities of the model results to natural uncertainties and engineering parameters. This is illustrated through a synthetic

Figure 2. Comparison of outlet temperatures for an analytical and a numerical finite difference model of a 4400 m deep borehole with BHT of 190°C, inlet temperature of 30°C and sediment thermal conductivity values of 2 and 3 (k). Model results for cases with previous oil production show significant increase in performance, up to 20%.



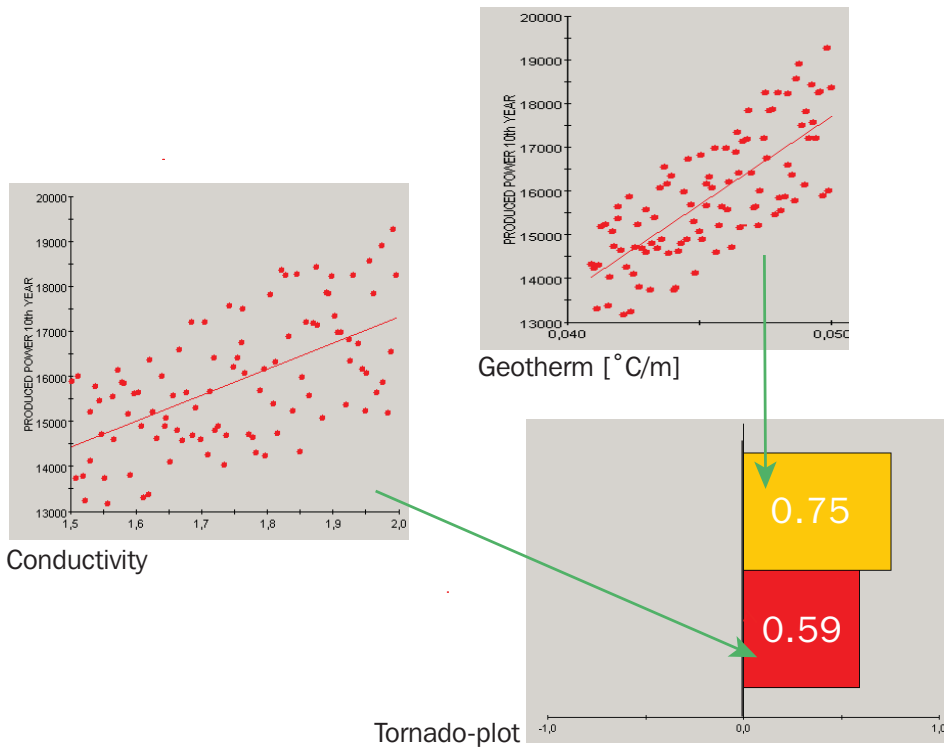


Figure 4. Relative sensitivity of power production to conductivity and geotherm ($^{\circ}\text{C}/\text{m}$).

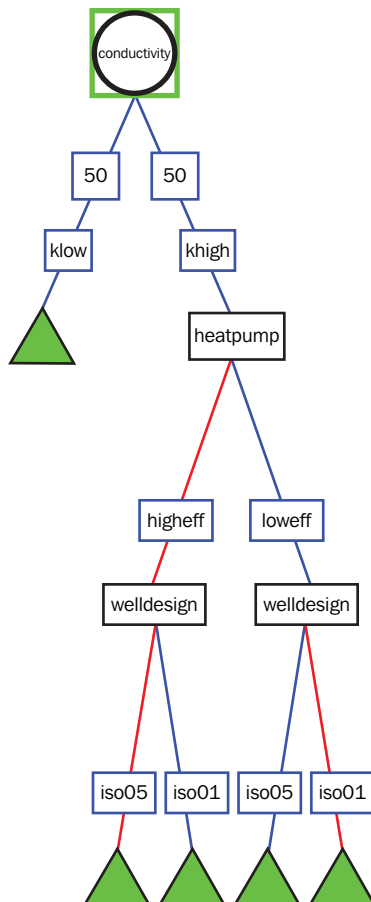
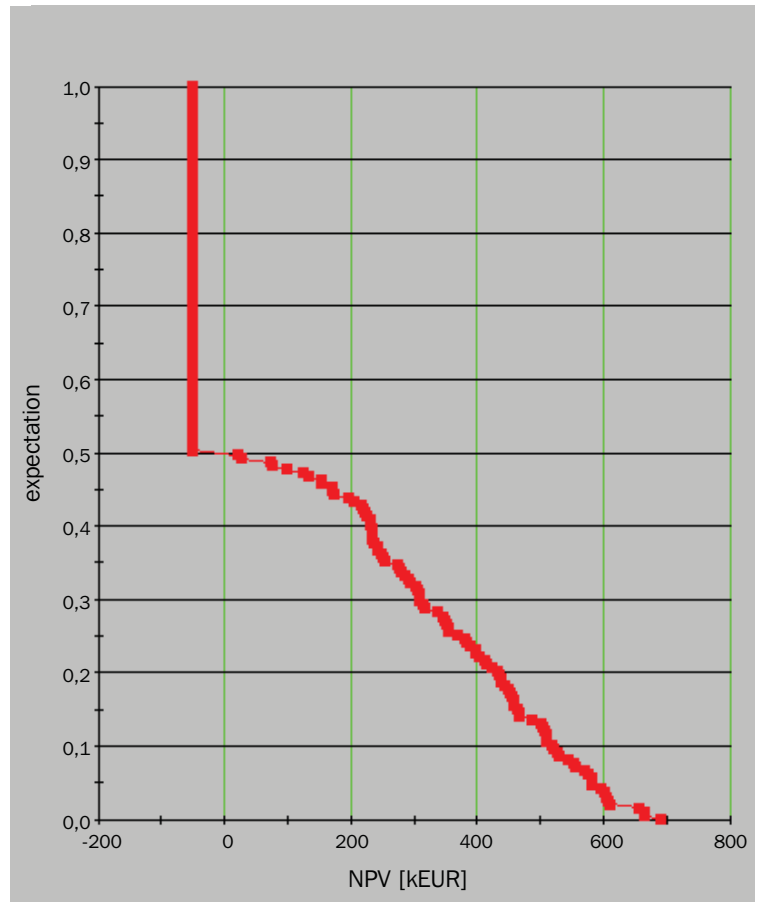


Figure 5. Decision tree.



example, in which uncertainty is assumed in the variables for thermal conductivity of the sediments and geothermal gradient (Figure 3). The Tornado diagram shows that uncertainty in geothermal gradient is more important than conductivity uncertainties.

Decision trees and scenarios

Decision trees (see Floris and Peersmann, 2002) are helpful for selecting optimal engineering scenarios in the face of uncertainty, trading off benefits against costs (Figure 5). The trees allow planners to take 'value of information' into account, in this case represented by the top left scenario, resulting in proving either a negative (k low) or positive conductivity (k high) scenario. Only when information supports the k high scenario should the geothermal asset be developed.

References

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