Introducing An Advanced Method To Model A Single Well Closed Loop Geothermal System

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Summary

The phenomenon of temperature change in a wellbore, which occurs during the production process due to heat transfer with surrounding formations, is crucial for the effectiveness of geothermal wells. Simulating these temperature changes is complex, requiring advanced numerical models and computational tools. The simulation demands a high number of grids to accurately represent the well's conditions, leading to high computational costs. To address this, a novel approach reducing run time while maintaining accuracy was proposed. This approach was validated against experimental data from a closed loop system, showing excellent agreement. The study further investigated various well parameters to optimize temperature management, including energy extraction comparisons for tubing and annulus injection, depth impact, and the effect of tubing to annulus area ratio. It was found that low injection rates with a smaller area ratio in annulus injection are more effective for energy extraction. Conversely, high injection rates favor tubing injection, yielding up to five times more energy. The results underline the complex interaction between injection rate, heat transfer, and heat loss, emphasizing the need for precise control of these factors to optimize geothermal well performance.

Methodology

The pore-scale description of the non-isothermal flow of a Newtonian fluid can be obtained by solving the equations of continuity, Navier-Stokes, heat advection-conduction in the fluid phase, and heat conduction in the solid phase. By applying the volume averaging method, the macroscopic heat transport equations for fluid and solid phases will be derived [2]. By applying the dimensionless form of this equation and converting the length, temperature gradient, heat flux, gravity force, inlet mass flow rate to the dimensionless form, total number of meshes decrease drastically.

Results, Observations, Conclusions

A closed loop single well system is simulated to determine the temperature profile of the well. The fluid is injected into the tubing and produced from the annulus. The well is set at 2000 meters (m) long. To study the effect of injection rate on the temperature variation, different mass rates were studied. As it is illustrated in Figure 1, with increasing injection rate, the slope of the heat transfer in both tubing and annulus decreases which causes a reduction in the outlet temperature. When the injection rate is low, in the tubing, the fluid has more time to get heat and the temperature increases. When the fluid goes up to the annulus, the casing is warmer than the fluid and the fluid gets extra heat from the boundary. It can be seen that the fluid is still heating up until -1400 m. Then it loses heat to the wall and temperature decreases. When the injection rate increases, the fluid has less time to get heat from the wall and the temperature decreases at the bottom of the well and outlet one.

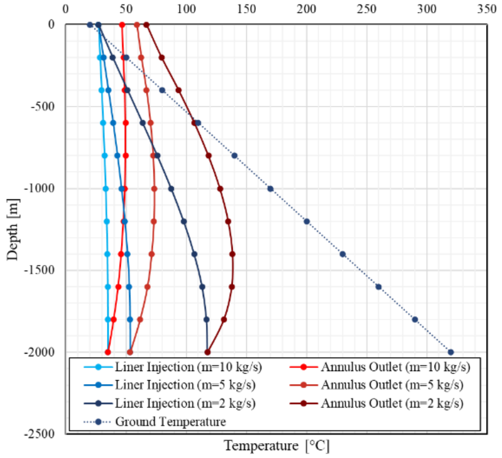

Figure 1: Variation of temperature according to injection mass rate

In previous studies [2 - 4], researchers decided to inject from tubing or the annulus without any specific reason. Each case they mentioned that they had better efficiency in their cases. This difference in each study made an idea to compare the efficiency of injection point. Two models were generated with injected temperature of $T_{injection}$ = 27 °C, and depth of H_{well} = 2000 meters (m) long. For the first case water is injected into the tubing with different mass rate. For the first case water is injected into the tubing with different mass rate of m = 0.1 kg/s to m = 10 kg/s. The second case has the same injection rate, but water is injected into the annulus. The comparison of outlet temperature of each case is illustrated in Figure 2. It is seen that when the injection rate is low, the outlet temperature is significantly higher in the annulus injection condition. For instance, at injection rate of m = 0.1 kg/s, the outlet temperature is more than 2.5 times. When the fluid is injected into the annulus, the water is directly in touch with the wall. At the low injection rate, the water has more time get heat and becomes warmer. However, the trend of graph shows decreasing on the temperature by increasing the injection rate. The dominancy of the annulus injection ends in the intermediate injection rates.

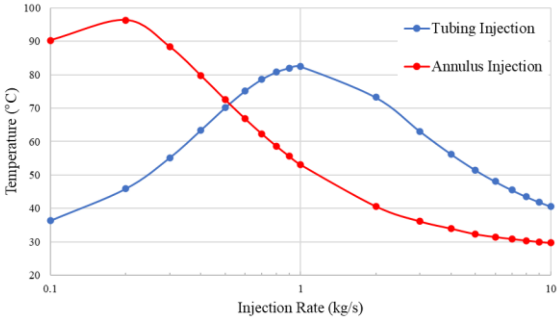

Figure 2: Variation of temperature according to injection mass rate for tubing injection and annulus injection.

As is clear, the depth of the well influences the outer temperature due to the increased contact surface of fluid and the wall. The effect of well depth on the outlet temperature is illustrated in Figure 3 for two additional depths of H_{well} = 3000 m and H_{well} = 4000 m. For the tubing injection case of well with H_{well} = 3000 m, the rate of temperature increase appears to be relatively consistent throughout the data. The temperature fluctuations of mass rates more than 1 kg/s are relatively small compared to the initial temperature rise. For annulus injection case, at lower mass rates, the temperature generally decreases as the mass rate increases. At higher mass rates, the temperature starts to decrease significantly. When the fluid is injected into the tubing of a well with H_{well} = 3000 m, the rate of temperature increase appears to be relatively consistent throughout the data. For lower mass rates, the temperature increases gradually. However, when the fluid is injected into the annulus, the temperature values in this data set continue to show a varied trend compared to the H_{well} = 3000 m. There are fluctuations and changes in temperature at different mass rates.

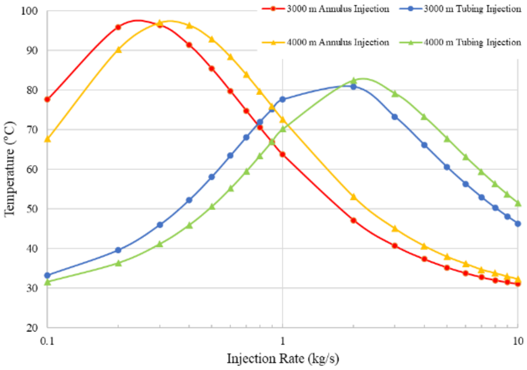

Figure 3: Temperature variation according to injection mass rate for tubing injection and annulus injection at depth 3000 and 4000 meter.

As it was discussed, to reach the optimum heat extraction in the geothermal system, different scenarios have to be considered. It was shown that when the injection rate is low, an annulus injection condition with lower area ratio makes a higher extracted energy. Under conditions of high injection rates, it is observed that the tubing injection scenario yields a substantial increase in energy, approximately fivefold.

Acknowledgements

Financial support from the Energi Simulation Centre for Geothermal Systems Research, The Energy Harvesitng Processes Program (ConocoPhillips, Ashaw Energy, Kalina Distributed Power, Telsec, Remedy Services, The Alberta Geological Survey and The Geological Survey of Canada) and the Fundamentals of Unconventional Resources program (NSERC, Alberta Innovates, Chevron, CNRL, ConocoPhillips and Enerplus) is gratefully acknowledged.

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