An Efficient Closed-Loop Geothermal Energy Extraction System

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Introduction

- Common Practice for geothermal power plants: use natural hot water/ steam sources
- Water injection required for producing from dry rock sources
- Our model uses calculations in production and injection tubing to estimate energy output
- Formation contamination avoided
- Measures Fluid Temperature in three conduits

Well Description

- Production and Injection tubing
- Nitrogen Gas blanket
- Long string for production
- Short string for injection
- Water injection rate same as production rate

Theory

We divide the wellbore in two sections
Top Section → GS (Gas Section)
Bottom Section → LS (Liquid section)
Surrounding formation exchanges heat with the annulus:

$$Q_3 = wc_pL_R(T_{ei} - T_a)$$

L_R= relaxation distance. It's a type of overall heat transfer coefficient for the formation/wellbore system

Gas Section:

Q_1= energy entering annulus from the long string

$$Q_1 = 2\pi r_{ls}U_{ls}(T_{ls} - T_a)$$

Q_2=energy entering the short string from annulus

$$Q_2 = 2\pi r_{ss}U_{ss}(T_a - T_{ss})$$

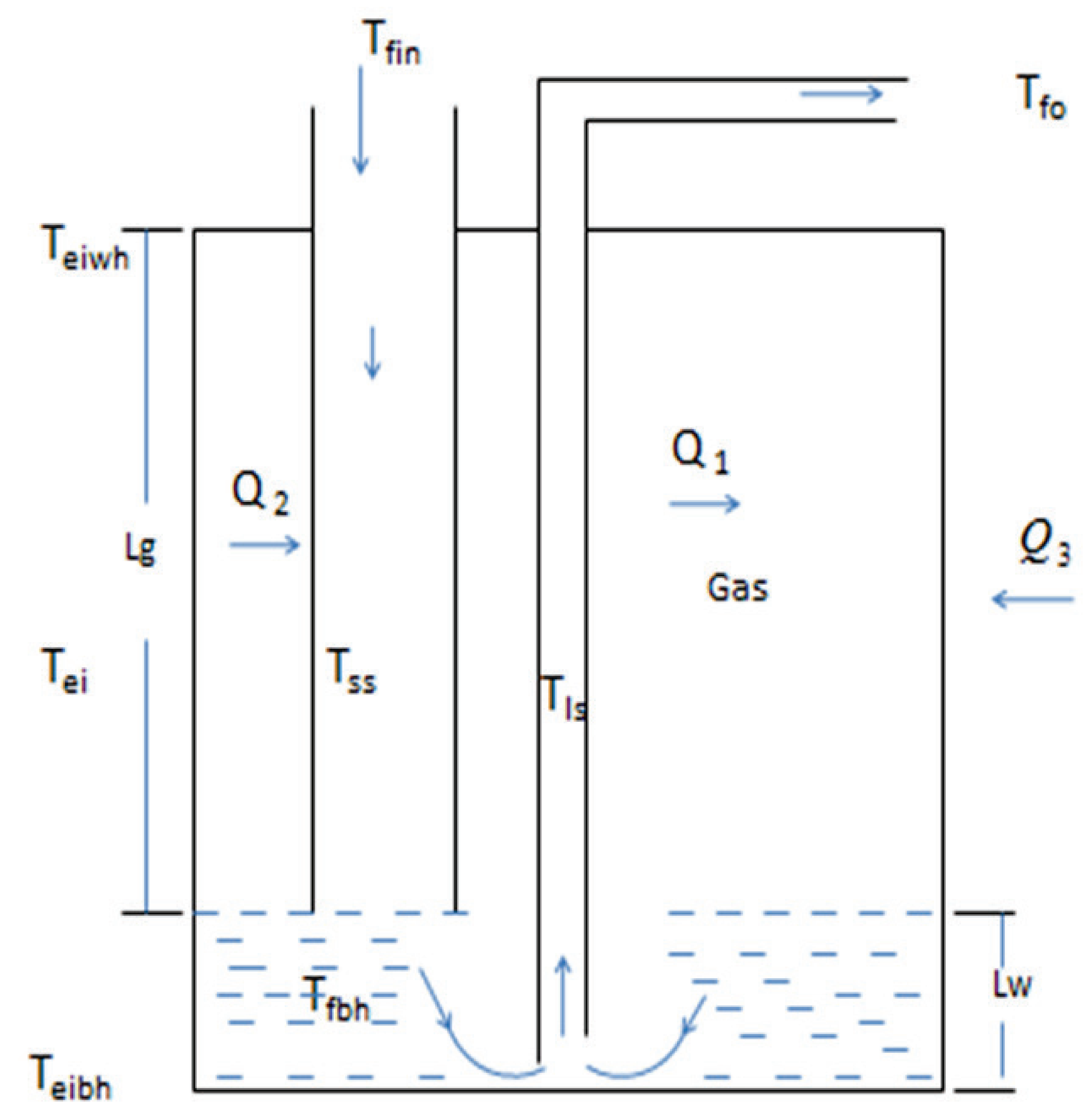
Here, U=overall heat transfer coefficient

$$\frac{1}{U_{ls}} = \frac{r_{ls}\ln(r_{lso}/r_{ls})}{k_{ls}} + \frac{1}{h_{ls}} + \frac{r_{ls}}{r_{casing}h_{ann}} \ \&$$

$$\frac{1}{U_{ss}} = \frac{r_{ss}\ln(r_{sso}/r_{ss})}{k_{ss}} + \frac{1}{h_{ss}} + \frac{r_{ss}}{r_{casing}h_{ann}}$$

The three heat transfer amounts in the gas section are related as follows:

$$Q_2 = Q_1 + Q_3$$



L_g= height of the wellbore above the water level
L_w= height of water
ls = long string
ss =short string

Fig 1: Schematic of the wellbore model

The expressions for fluid temperature in the long and short string are given below:

$$T_{ls} = c_1e^{\lambda_1 z} + c_2e^{\lambda_2 z} + \frac{b_4}{b_3}z + \frac{b_3b_5 - b_2b_4}{b_3^2}, T_{ss} = d_1c_1e^{\lambda_1 z} + d_2c_2e^{\lambda_2 z} + d_3z + d_4$$

$$T_a = d_1c_1e^{\lambda_1 z}\left(1 + \frac{wc_{pss}\lambda_1}{2\pi r_{ss}U_{ss}}\right) + d_2c_2e^{\lambda_2 z}\left(1 + \frac{wc_{pss}\lambda_2}{2\pi r_{ss}U_{ss}}\right) + d_3z + d_4 - \frac{wc_{pss}\lambda_1}{2\pi r_{ss}U_{ss}}\left(\emptyset_{ss} - \frac{gsin\alpha}{c_{pss}} - d_3\right)$$

Liquid Section:

- Annulus fluid moving downward
- Fluid in tubing moving upward

The heat exchange between the water in the annulus and that in the tubing:

$$Q_{ta} = 2\pi r_{ls}U_{ta}(T_a - T_{ls})$$

U_{ta}=overall heat transfer coefficient for annulus-ls heat transfer for liquid section

The solution for fluid temperatures are:

$$T_{ls} = \alpha e^{\lambda_1 z} + \beta e^{\lambda_2 z} + B'' g_G sin\theta + T_{ei}, T_a = (1 - \lambda_1 B')\alpha e^{\lambda_1 z} + (1 - \lambda_2 B')\beta e^{\lambda_2 z} + T_{ei}$$

Table 1. Base case parameter values

Depths, ft	Total Well	15,000	Conductivities Btu/hr-ft-°F	Tubings & Casing	26.0
	N_2	10,000		Cement	1.0
Diameters, in	$Casing_i$	17.0		Formation	1.4
	$Casing_o$	18.5		Insulation	0.02
	$Cement_o$	25.0	Temperature, °F	Formation top	75.0
	Production $tube_i$	3.0		Formation bottom	450.0
	Production $tube_o$	3.5		Injection Fluid, top	200.0
	Injection $tube_i$	8.0		*Produced Fluid, top*	*283.02*
	Injection $tube_o$	9.0			

Results

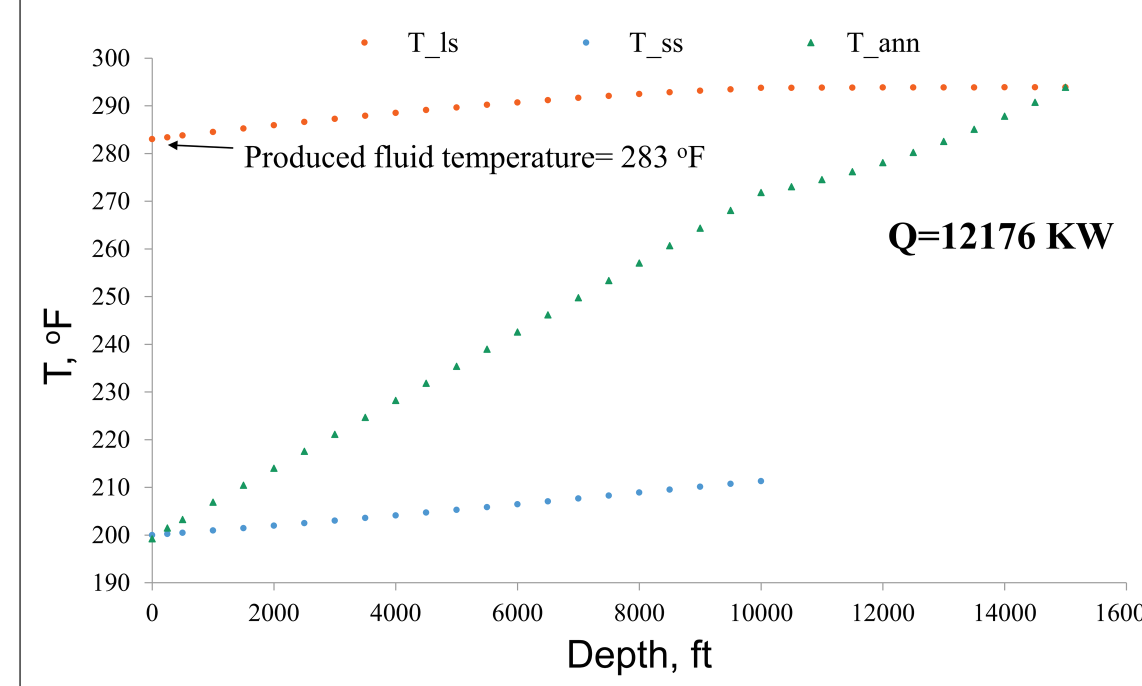


Fig 2. Fluid temperature in three conduits (q=1000 gpm and insulation 0.5 inch)

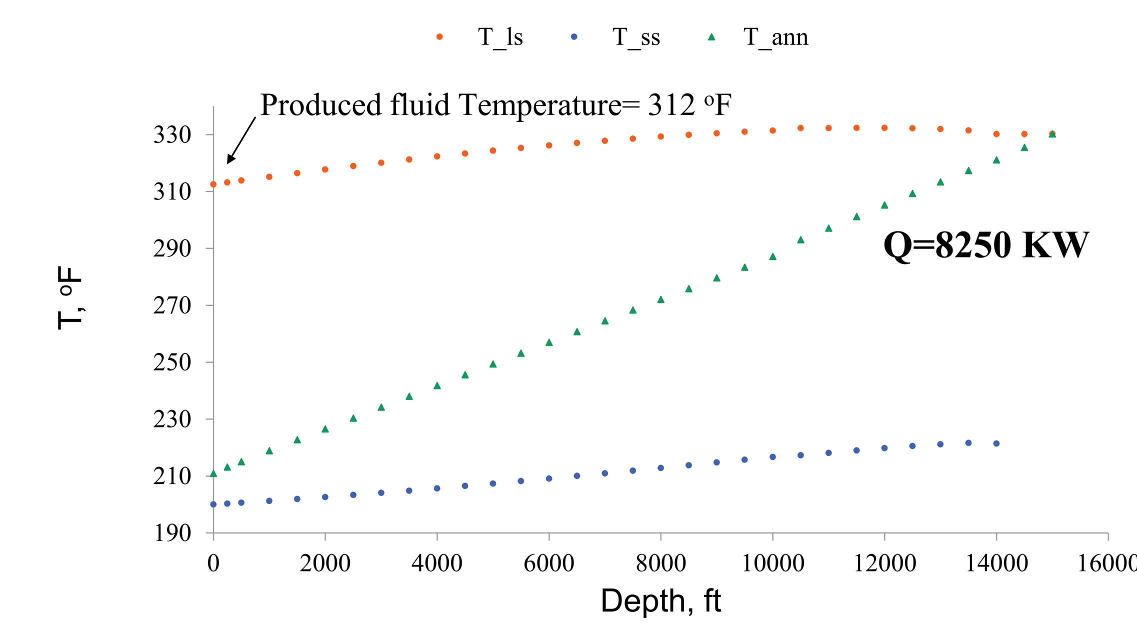


Fig 3. Fluid temperature in three conduits at q=500 gpm and N_2 depth=14000 ft

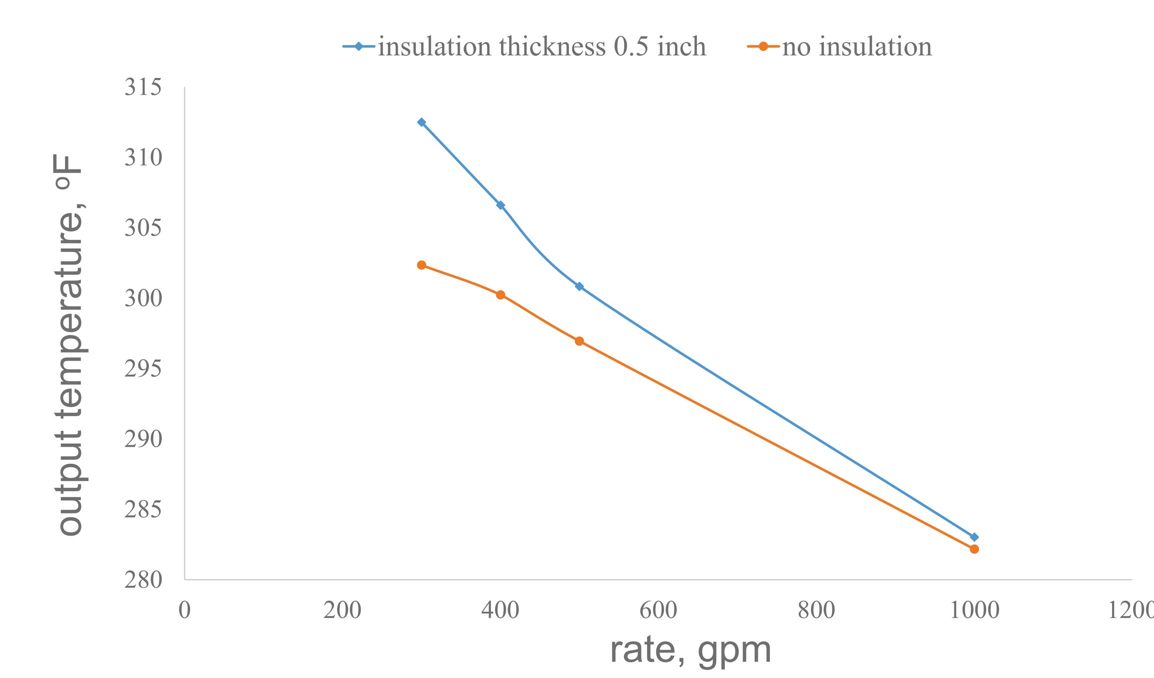


Fig 4: Production temp with and without insulation

Conclusion

- At all flowrates, increasing the Nitrogen coverage increases fluid temperature at the wellhead
- The trend of T_{ann} curve changes as we move from a gas filled annulus to a water filled one
- As production rate increases, Temperature rise decreases for both insulated and uninsulated cases