An Environmentally Friendly Closed-Loop Geothermal Energy Extraction System

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Introduction

- Most geothermal power plants use hot water/steam sources; producing from dry rock require water injection
- Our closed loop model uses production and injection tubing
- Water doesn’t invade the rock
- Formation isn’t contaminated

Model description

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

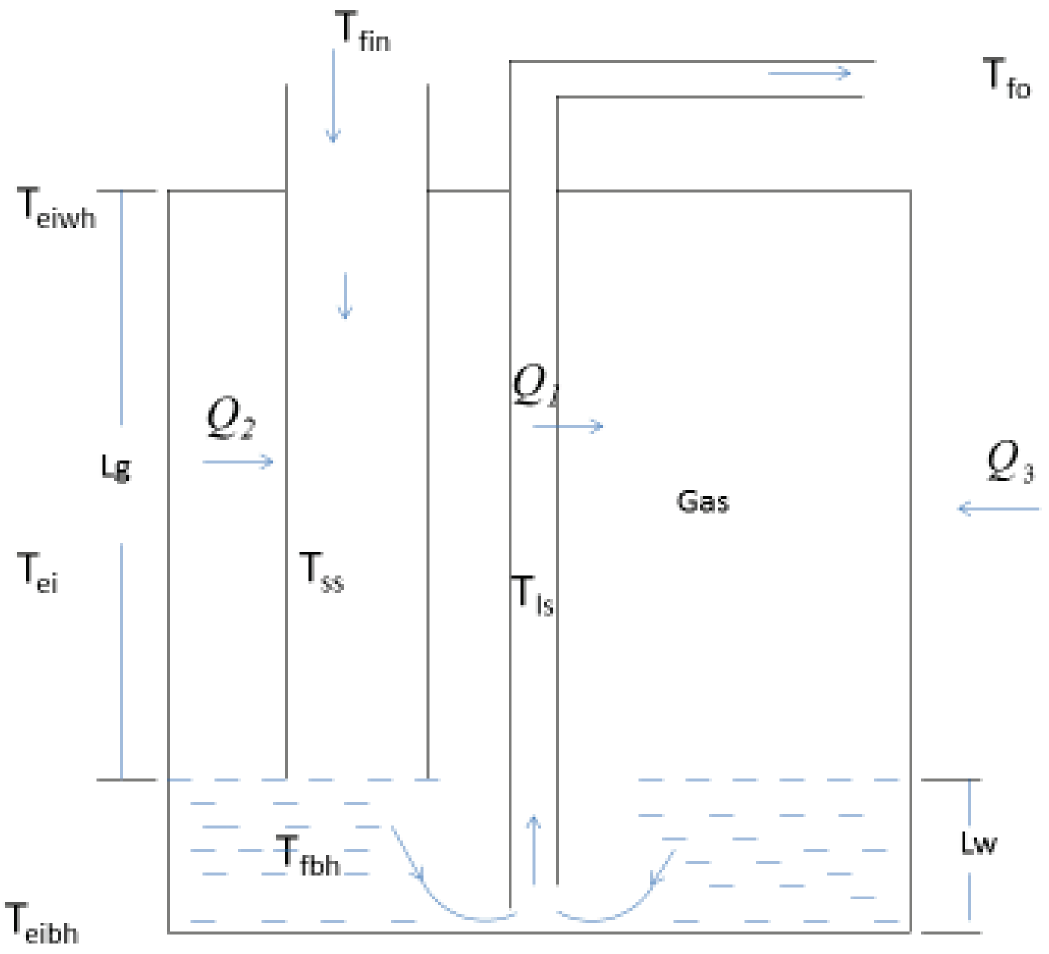


Fig: Schematic of the wellbore

$$Q_2 = Q_1 + Q_3$$

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

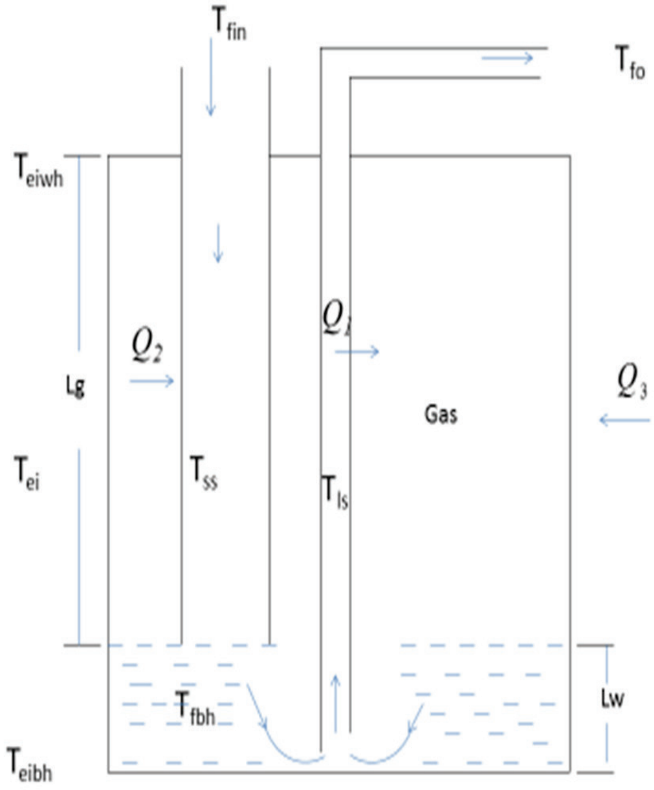
Theory

Wellbore has two sections

Top ← GS (Gas Section)
Bottom →LS (Liquid section)

Surrounding formation exchanges heat with the annulus:

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



Gas Section:

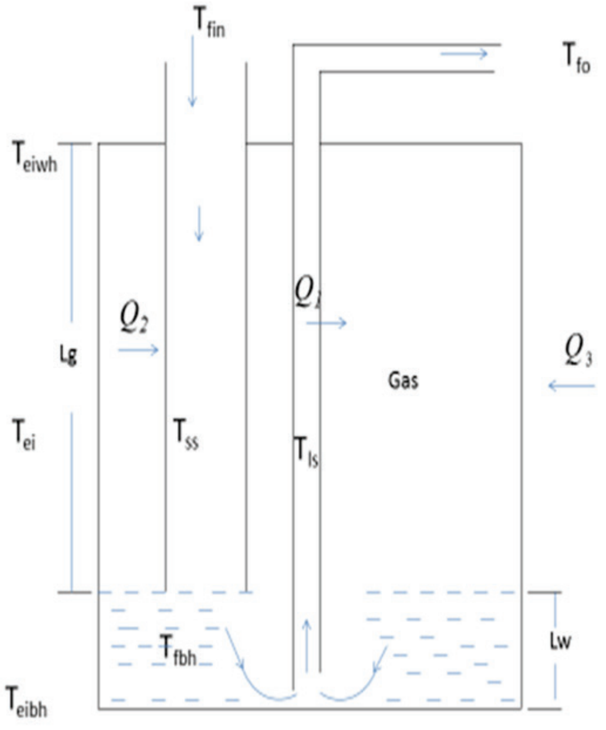
Prod. string exchange heat with annulus:

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

Injection string heat from gas in annulus:

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

U = Overall heat transfer coefficient



Liquid Section:

- Fluid in the tubing moving up
- Annulus fluid moving downward
- Heat exchange between the annulus and the fluid:

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

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Governing Eq.

$$c_{pa}\frac{dT_a}{dz}+D_a \quad = \quad L_{R2}c_{pa}\left(T_{ei}-T_a\right)+\frac{c_{pa}}{B}\left(T_t-T_a\right)$$

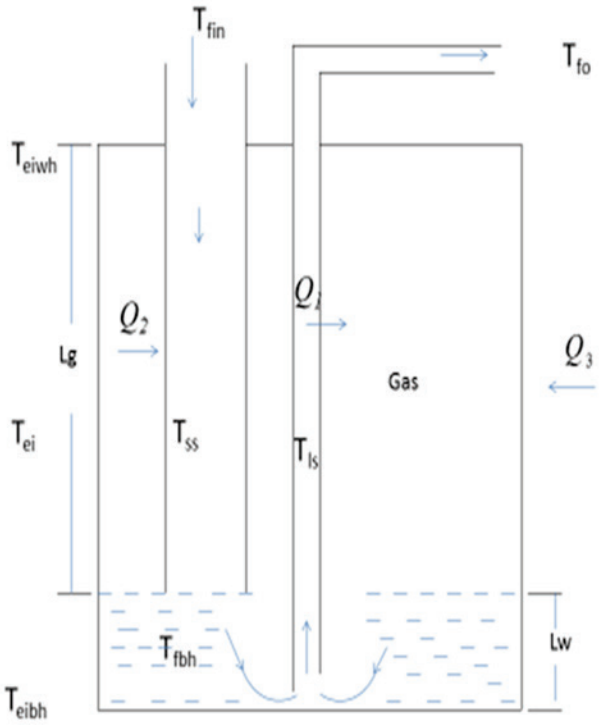
$$\frac{\mathrm{d}T_{ls}}{\mathrm{d}z} \quad = \quad \left(T_{ls}-T_a\right)\frac{2\pi r_{ls}U_{ls}}{c_{pls}w_{ls}}-\frac{g\sin\theta_G}{c_{pls}}+\phi_{ls}$$

$$\frac{\mathrm{d}T_{ss}}{\mathrm{d}z} \quad = \quad \left(T_a-T_{ss}\right)\frac{2\pi r_{ss}U_{ss}}{c_{pss}w_{ss}}-\frac{g\sin\theta_G}{c_{pss}}+\phi_{ss}$$

$$\frac{B'}{L_{R2}}\frac{d^2T_{ls}}{dz^2}+B''\frac{dT_{ls}}{dz}-T_{ls}+T_{ei}+D' \quad = \quad 0$$

Boundary Conditions

- T_{water} @ bottomhole same for annulus and the producing string; $(\frac{dTls}{dz})_{bottomhole} = 0$
- T @ G-L interface same for gas & water



Solution

$$T_{ss} \quad = \quad d_1 c_1 e^{\lambda_1 z} + d_2 c_2 e^{\lambda_2 z} + d_3 z + d_4$$

$$T_a = d_1 c_1 e^{\lambda_1 z}\left(1 + \frac{w c_{pss} \lambda_1}{2\pi r_{ss} U_{ss}}\right) + d_2 c_2 e^{\lambda_2 z}\left(1 + \frac{w c_{pss} \lambda_2}{2\pi r_{ss} U_{ss}}\right) + d_3 z + d_4 - \frac{w c_p}{2\pi r_{ss} U_{ss}}\left(\phi_{ss} - \frac{g \sin\alpha}{c_{pss}} - d_3\right)$$

$$T_{ls} = \alpha\, e^{\lambda_1 z} + \beta\, e^{\lambda_2 z} + g_G \sin\theta\, z + B'' g_G \sin\theta + T_{es} + D'$$

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

Table 1: Base Case parameters

Depths, ft	Total Well	15,000
	N_2	10,000
Diameters, in	Casing (inner)	17.0
	Casing (outer)	18.5
	Cement (Outer)	25.0
	Prod tube (Inner)	3.0
	Prod tube (Outer)	3.5
	Injection tube (Inner)	8.0
	Injection tube (Outer)	9.0
Conductivities Btu/hr-ft-°F	Tubing & Casing	26.0
	Cement	1.0
	Formation	1.4
	Insulation	0.02

Temperatures °F	Formation top	75.0
	Formation bottom	450.0
	Injection Fluid, top	200.0
	Produced Fluid, top	283.02
Production Rate, gpm		1,000
Insulation thickness, inch		0.5

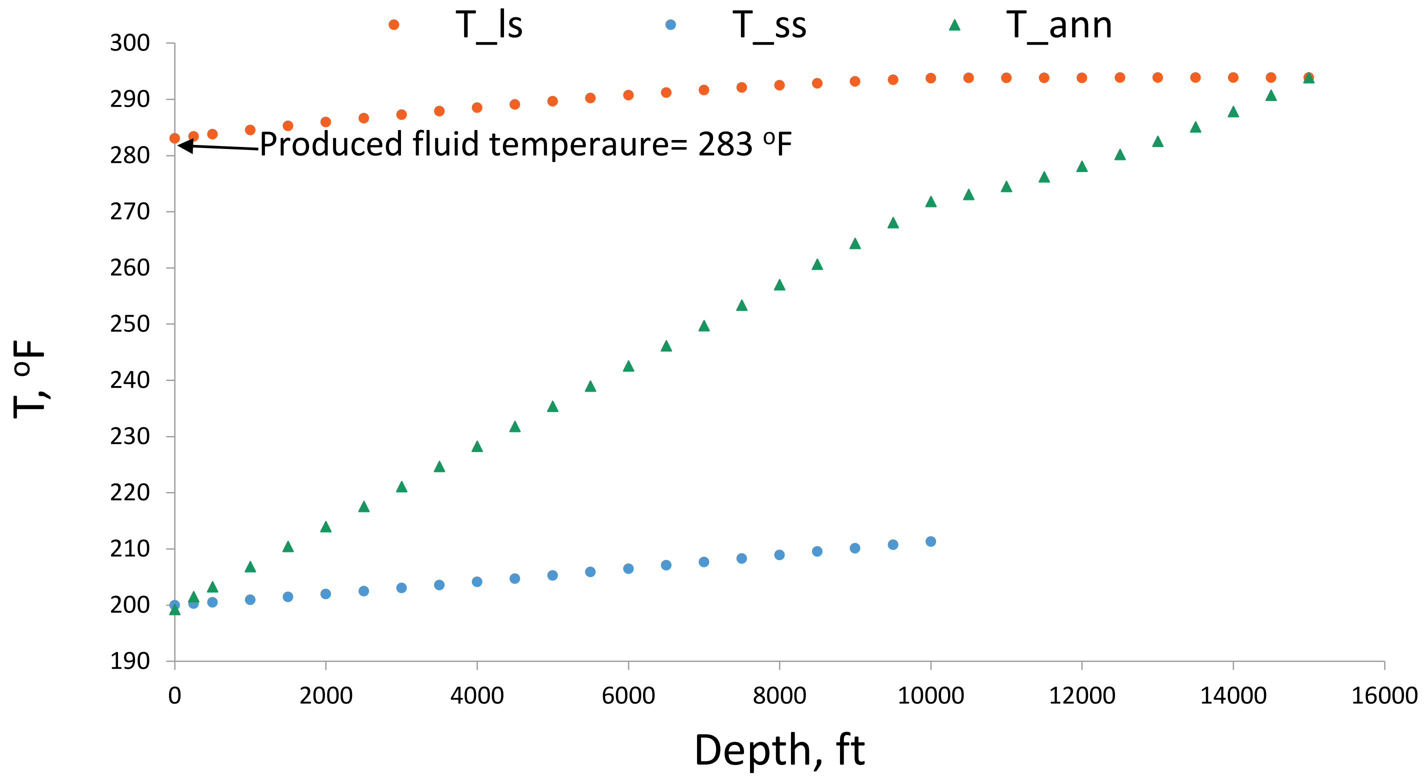


Fig: Fluid temperature in three conduits (q=1000 gpm and insulation 0.5 inch)

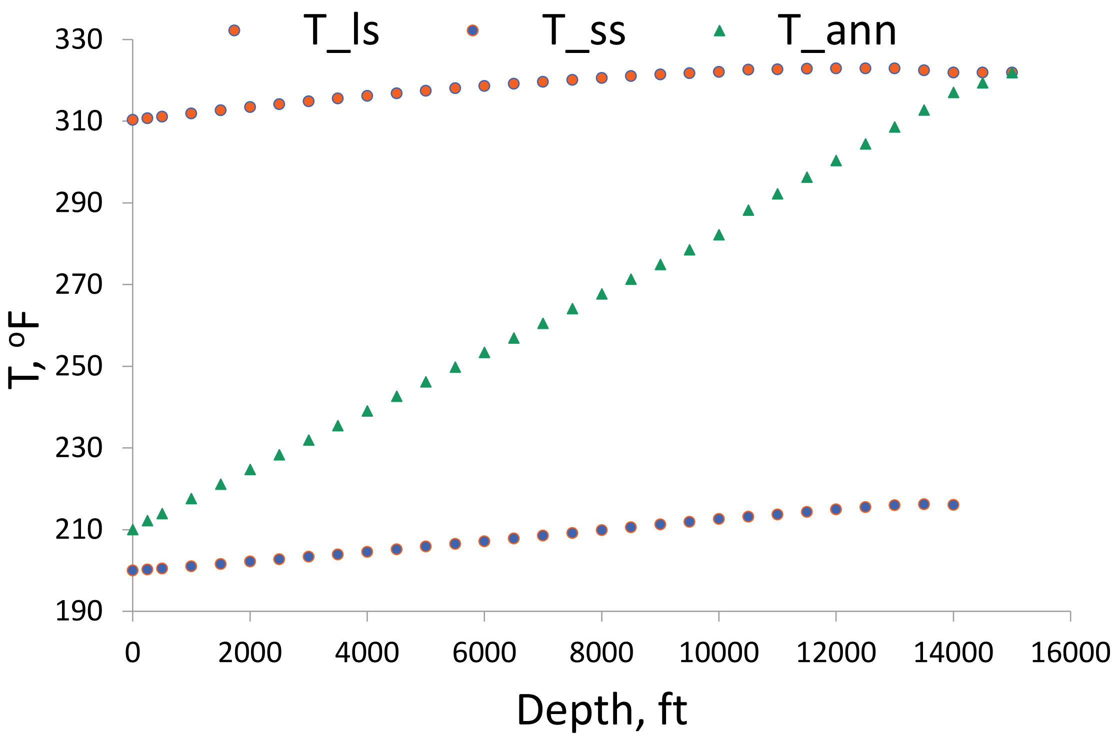


Fig. Fluid temperature in three conduits at q=1000 gpm and N_2 depth=14000 ft

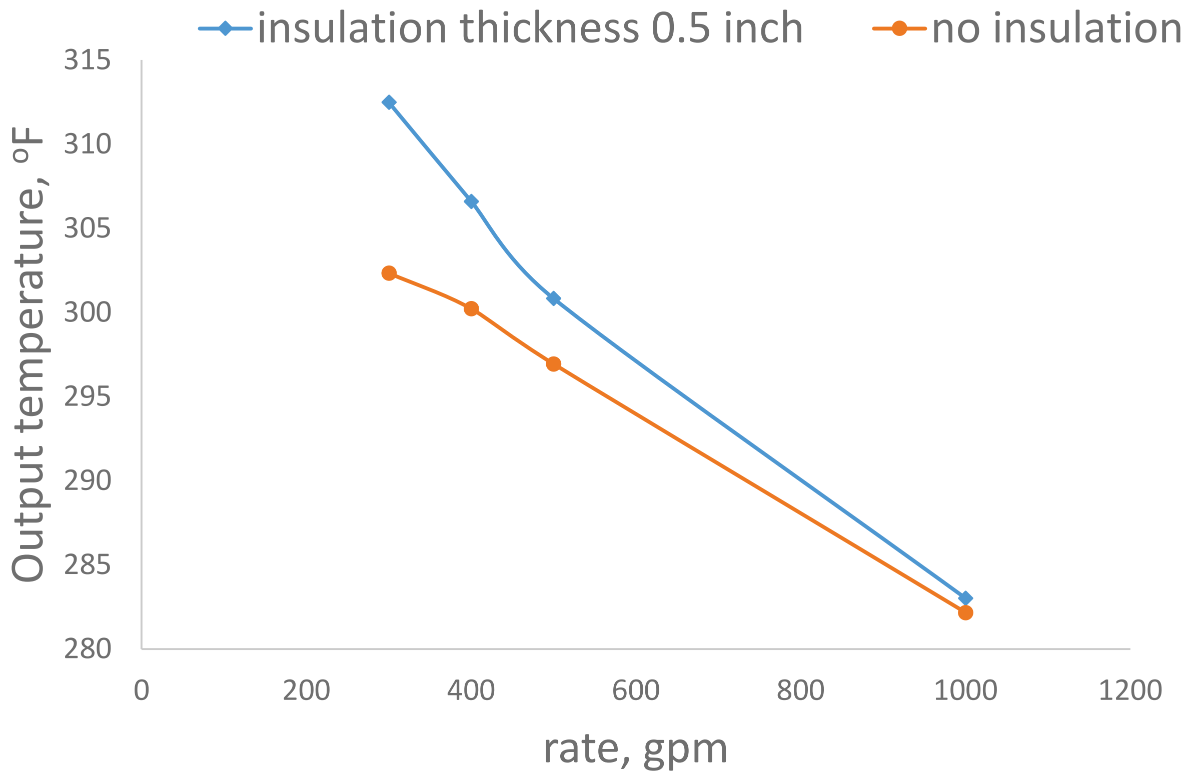


Fig: Production temperature at the surface

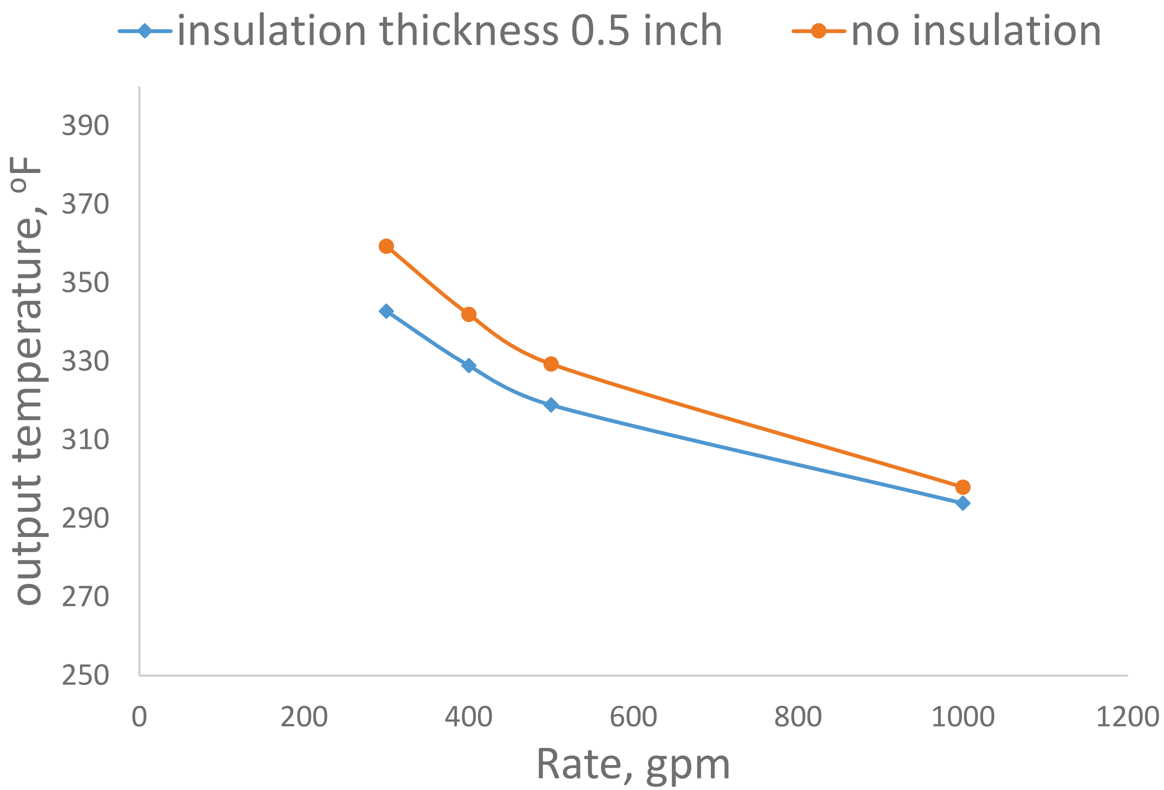


Fig: Bottomhole Temperature with different rates

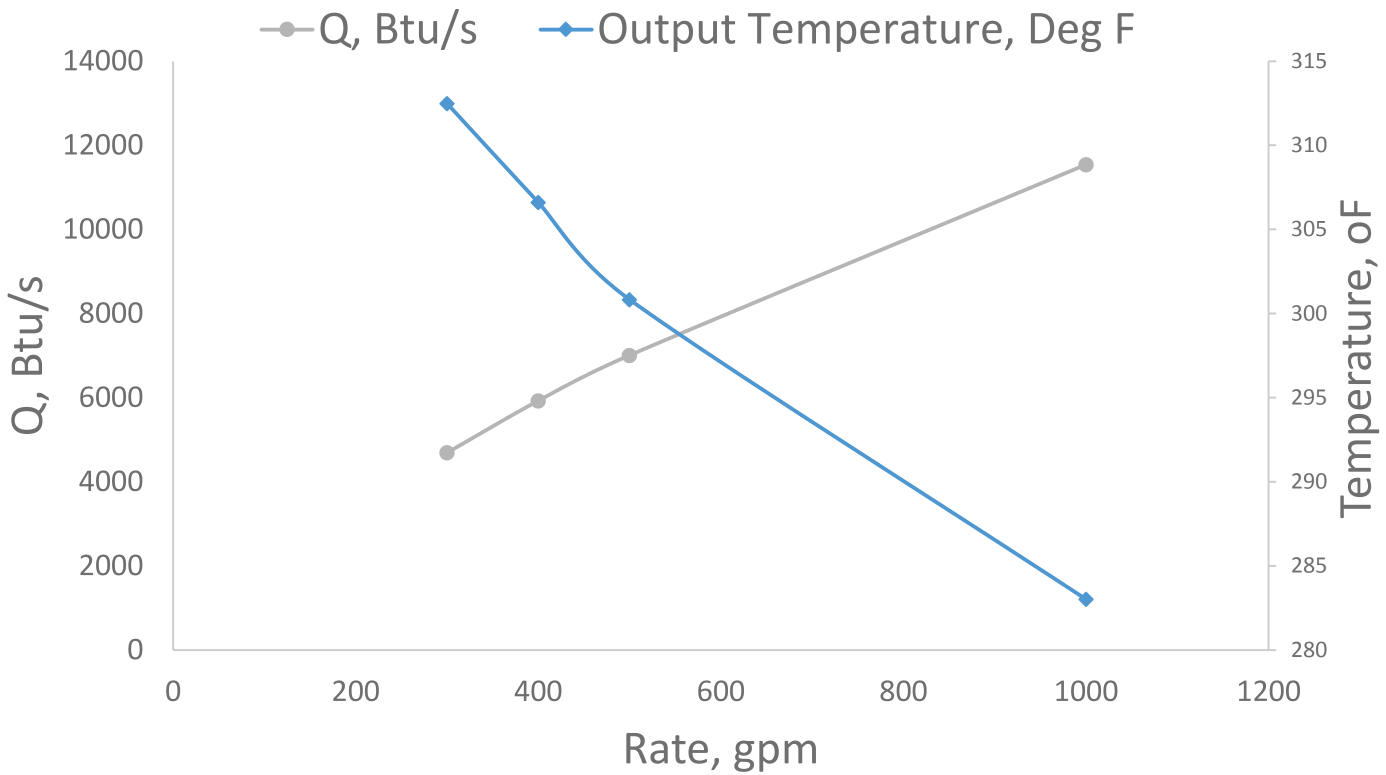


Fig: Power and Output Temperature with different rates

Conclusion

- At all flowrates, increasing the Nitrogen coverage increases fluid temperature at the wellhead
- The inclination of Tann 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