Integrated Modeling to Assess Multiphase Flow Behaviour of CO_2 in Wellbore for CCUS Projects

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#FutureOfSimulation

Introduction

- Depleted Gas Reservoirs (DGR) are very good candidates for CCS projects.
- However, they bring challenges as well; including:
    1. Low reservoir pressure that corresponds to gaseous CO2 at bottom hole.
    2. Phase transition of CO2 from liquid (surface) to gas (bottom-hole), as reservoir has low pressure & high temperature.

Outline

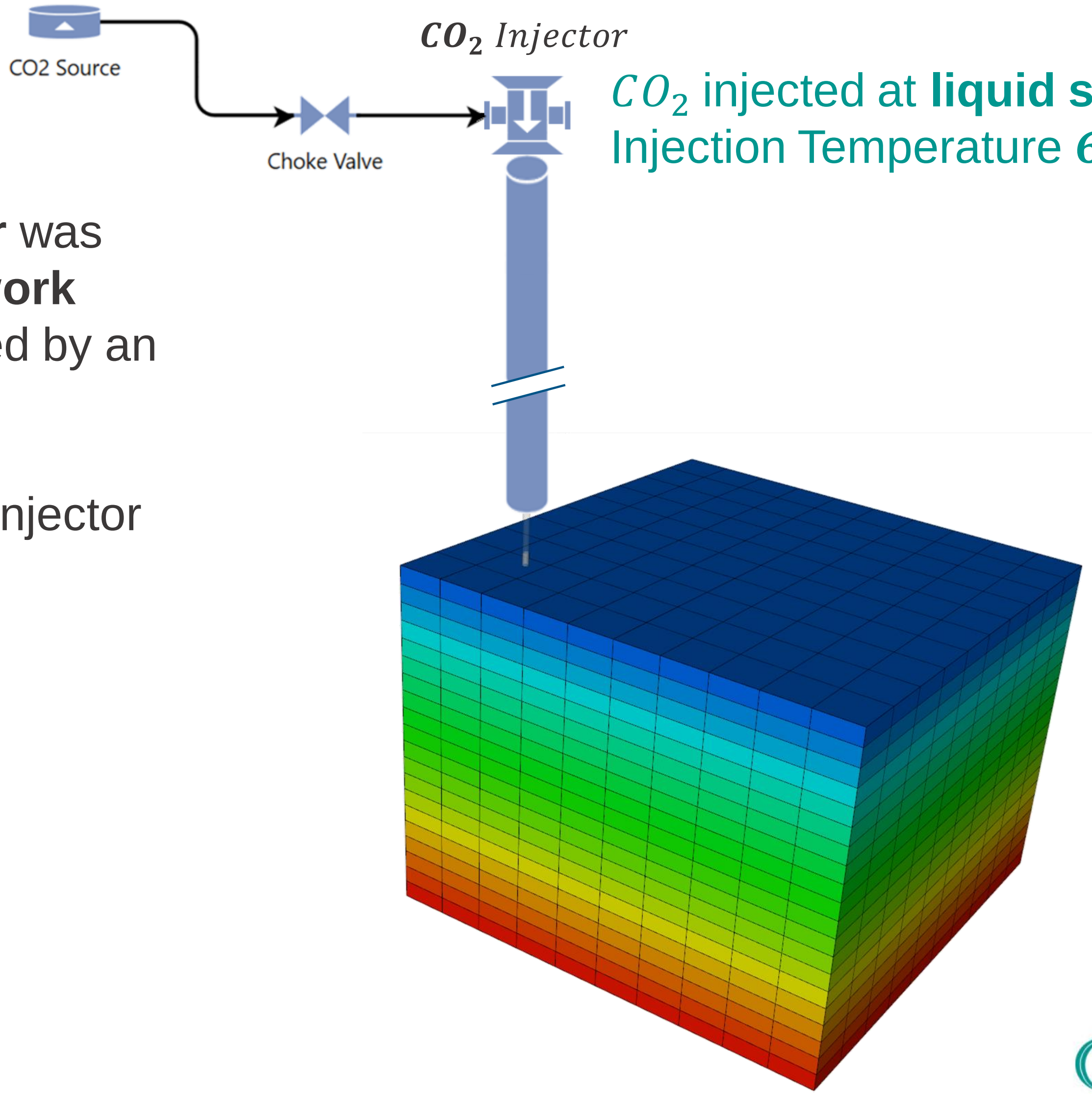
[1]
- Synthetic coupled model of $\boldsymbol{CO_2}$ **Injection in a Depleted Gas Reservoir** → Demonstrates the challenges of CO_2 modelling.

[2]
- Standalone CO_2 injector wellbore analysis to investigate the pressure profile of CO_2 along the wellbore.

[3]
- Solutions to CO_2 injection challenges – modelling and operational

[4]
- Temperature Profile of CO_2 in Gas Phase Injection

Model Schematic

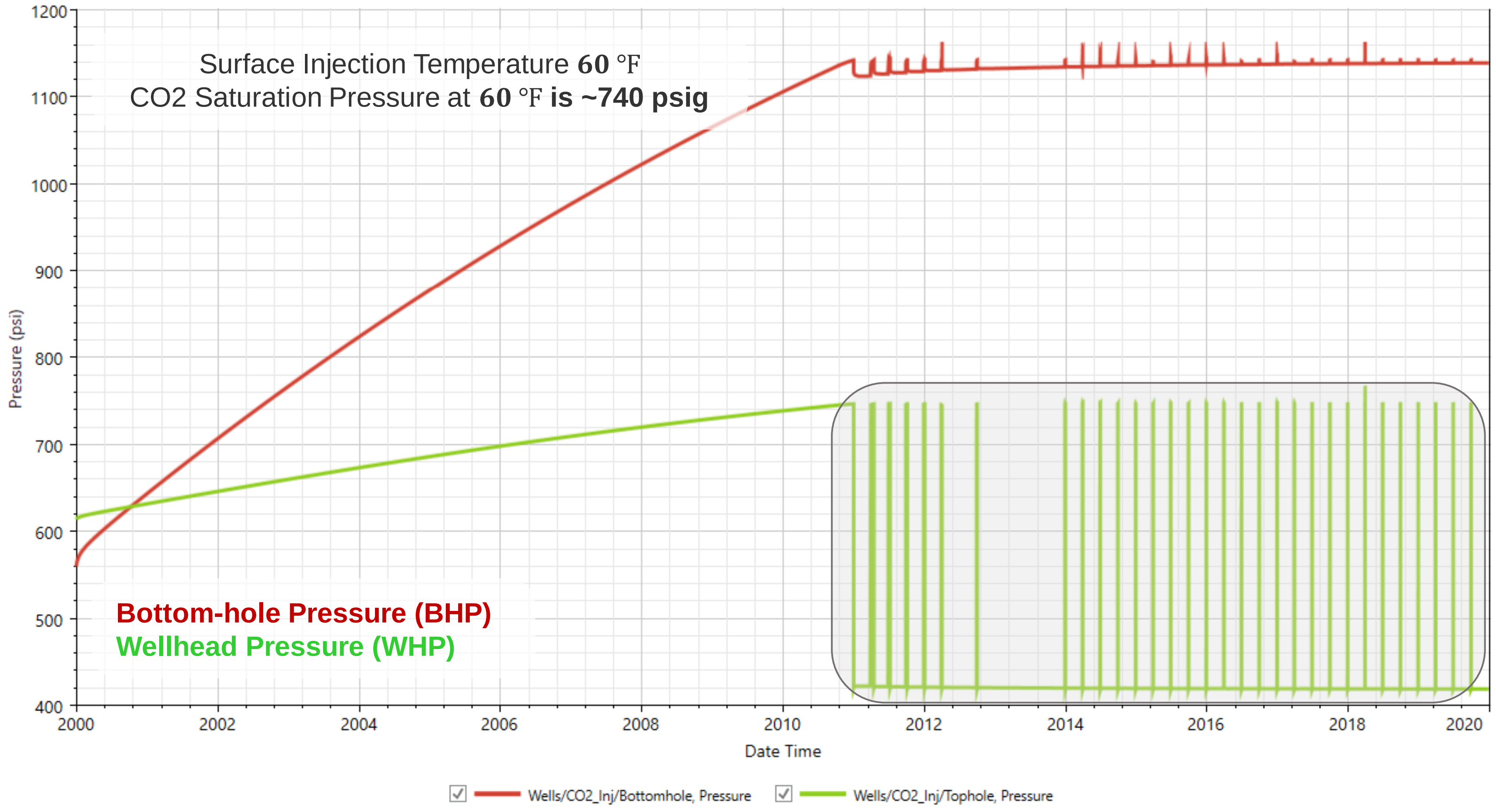


CO_2 injected at **liquid state** (at surface).
Injection Temperature **60** °F

- A **transient thermal reservoir simulator** was coupled to a **steady-state well** and **network model**, with CO_2 **properties** being defined by an **Equation of State model**.

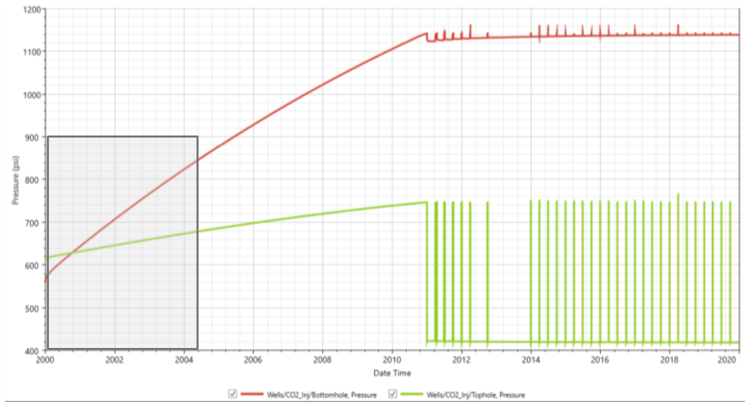
- The model covers the life cycle of a CO_2 injector in a **depleted gas reservoir** (DGR).

Challenges of CO_2 Injection Simulation

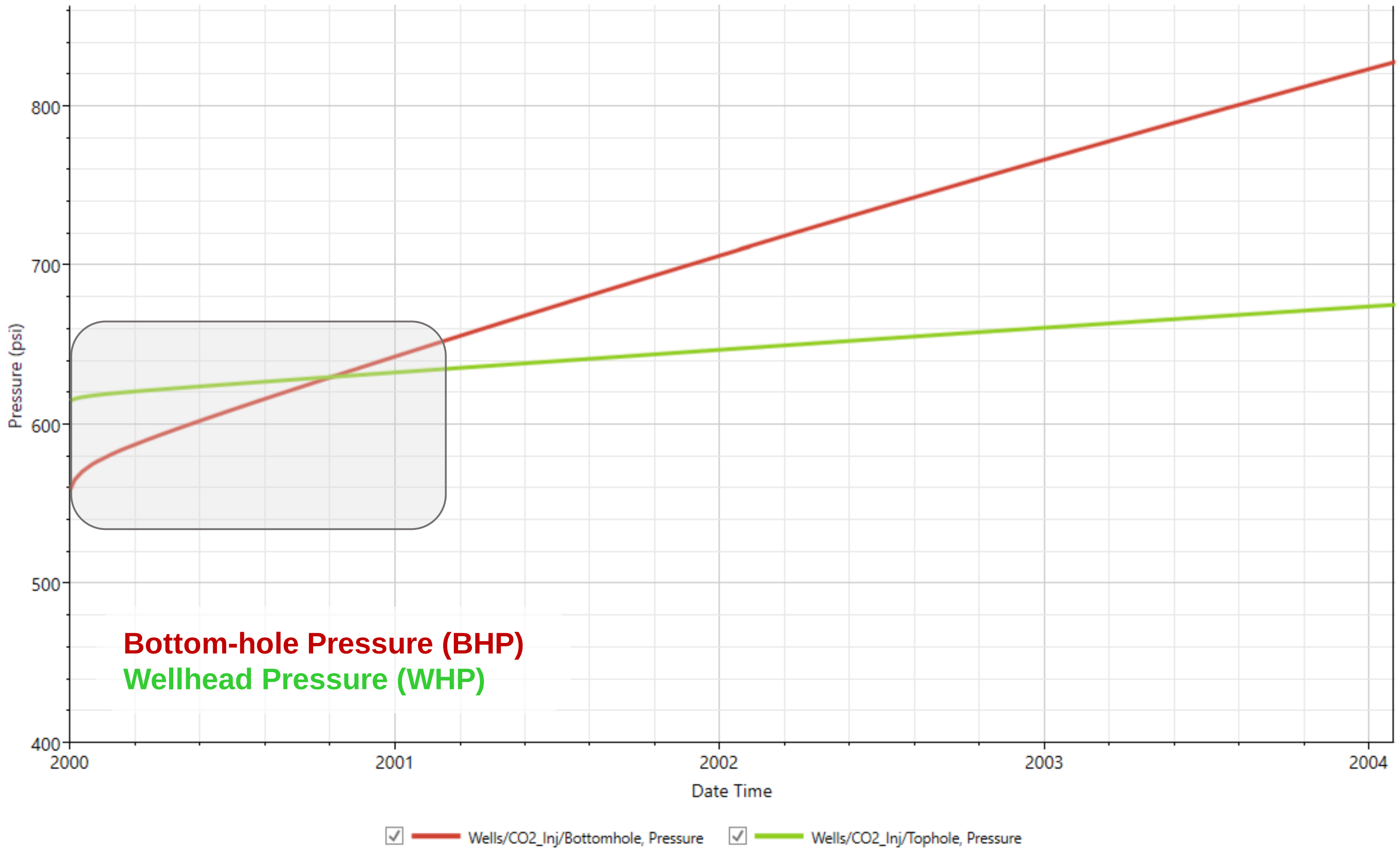


- When the injection pressure reaches to the CO2 saturation pressure at the injection temperature, due to pressure gap, the well is inoperable.
- This results in an oscillatory, behavior.

Challenges of CO_2 Injection Simulation



- At the start of injection when the **back pressure** by the **reservoir** is low.
- The target injection rate can be achieved by lower WHP at which BHP < WHP.



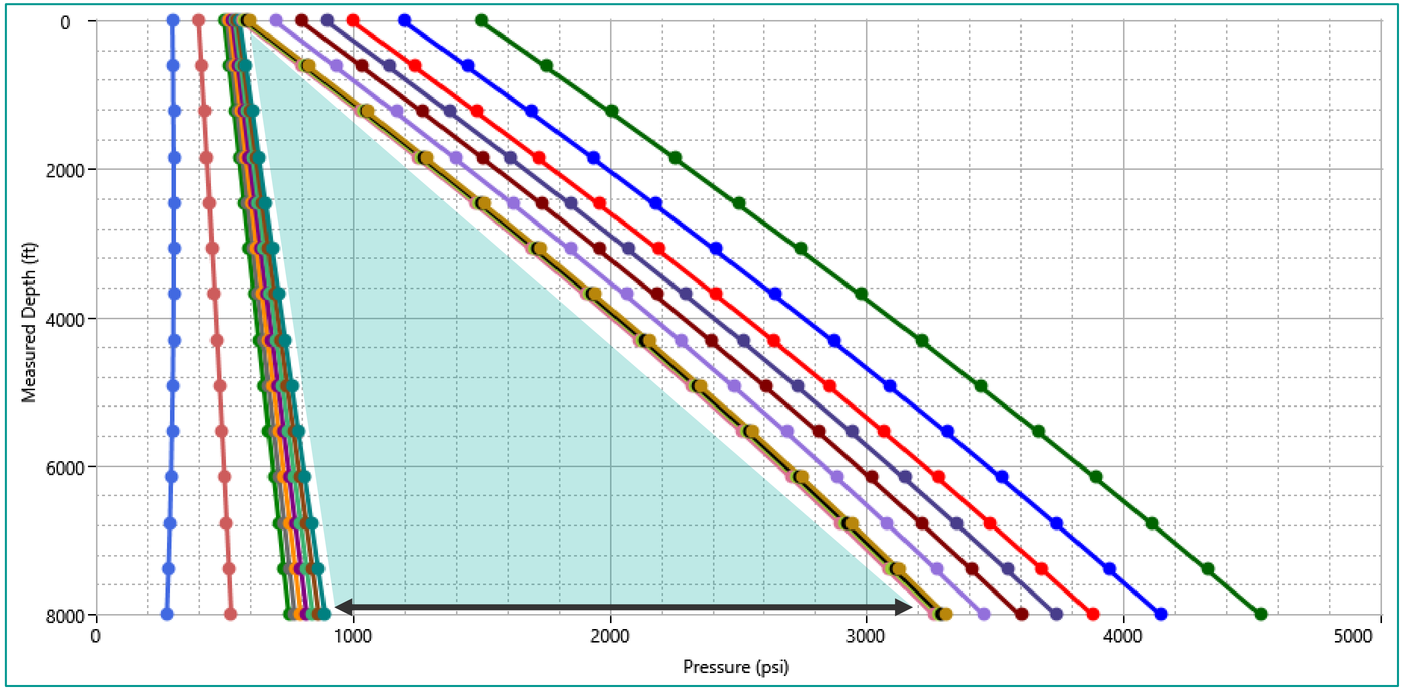
Pressure Profile – Components

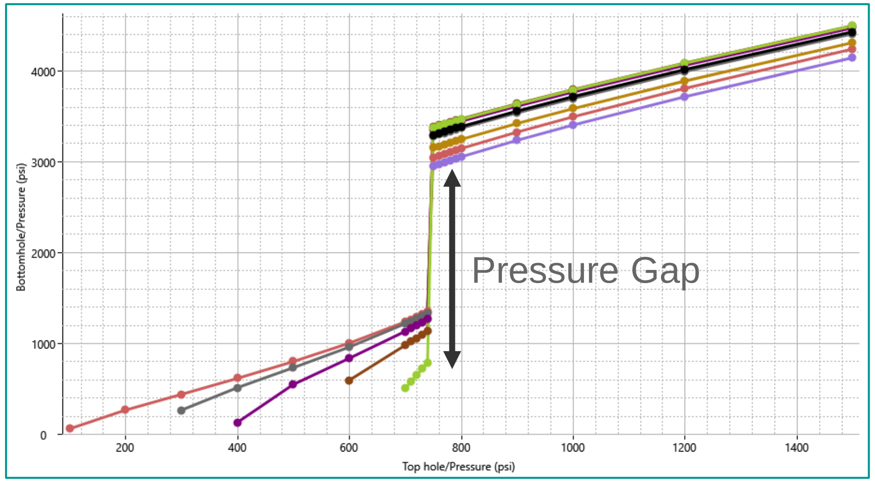
$$\left(\frac{dp}{dl}\right)_{Total} = \left(\frac{dp}{dl}\right)_{Hydrostatic} + \left(\frac{dp}{dl}\right)_{Friction} + \left(\frac{dp}{dl}\right)_{Accelaration}$$

$$\left(\frac{dp}{dl}\right)_{Total} = \frac{g}{g_c}\rho_m \sin\theta + \frac{f_m \rho_m v_m^2}{2 g_c d} + \frac{\rho_m v_m}{g_c}\frac{dv_m}{dZ}$$

Pressure Profile of CO_2 (60ºF Injection Temperature)

Injection pressure (WHP) increases from left to right.

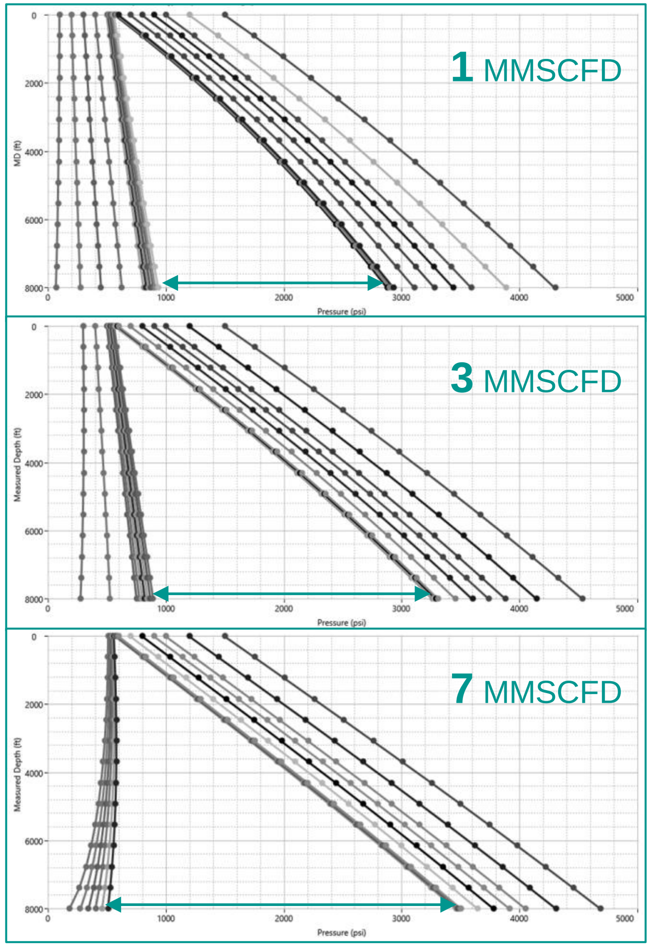


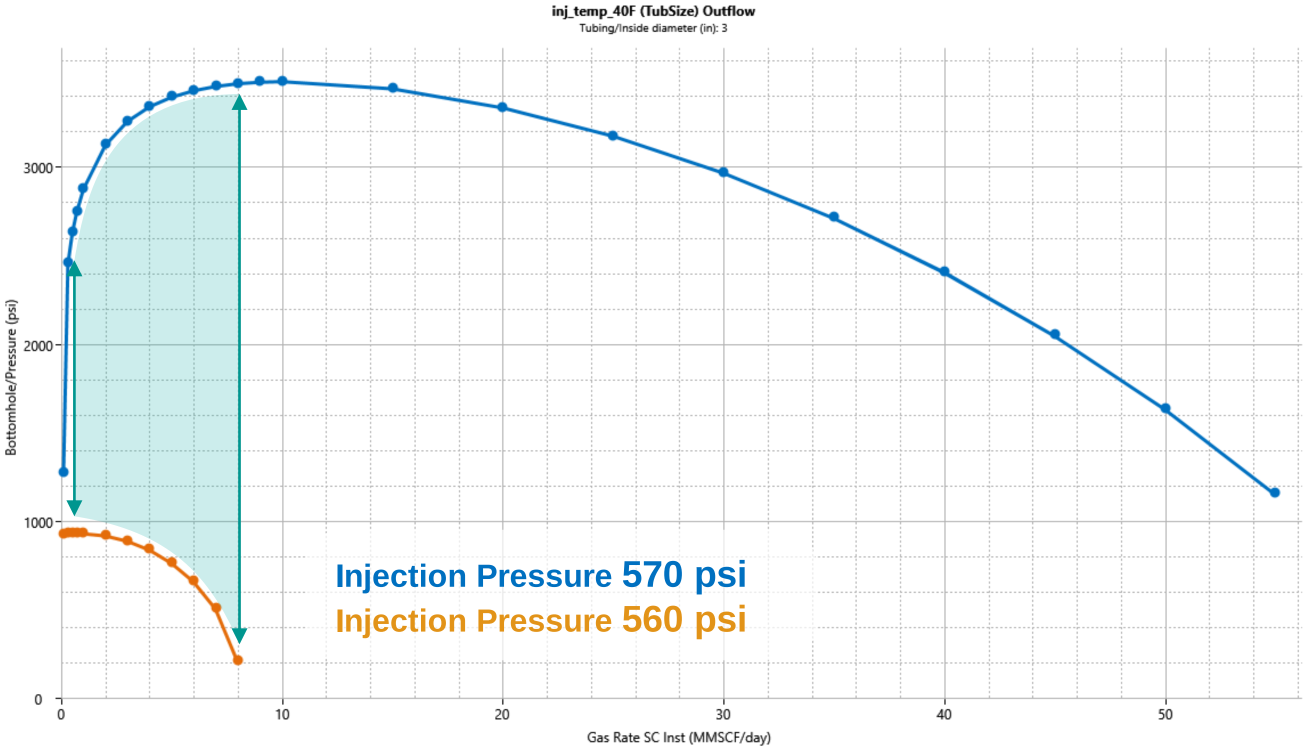


The pressure gap creates a discontinuity in the plot of WHP vs. BHP

When injection pressure is near the saturation pressure of CO2 at the injection Temperature, a small increase in WHP will result in a **significant gap** in **bottom hole pressure**.

Pressure Profile of CO_2 (40ºF Injection Temperature)



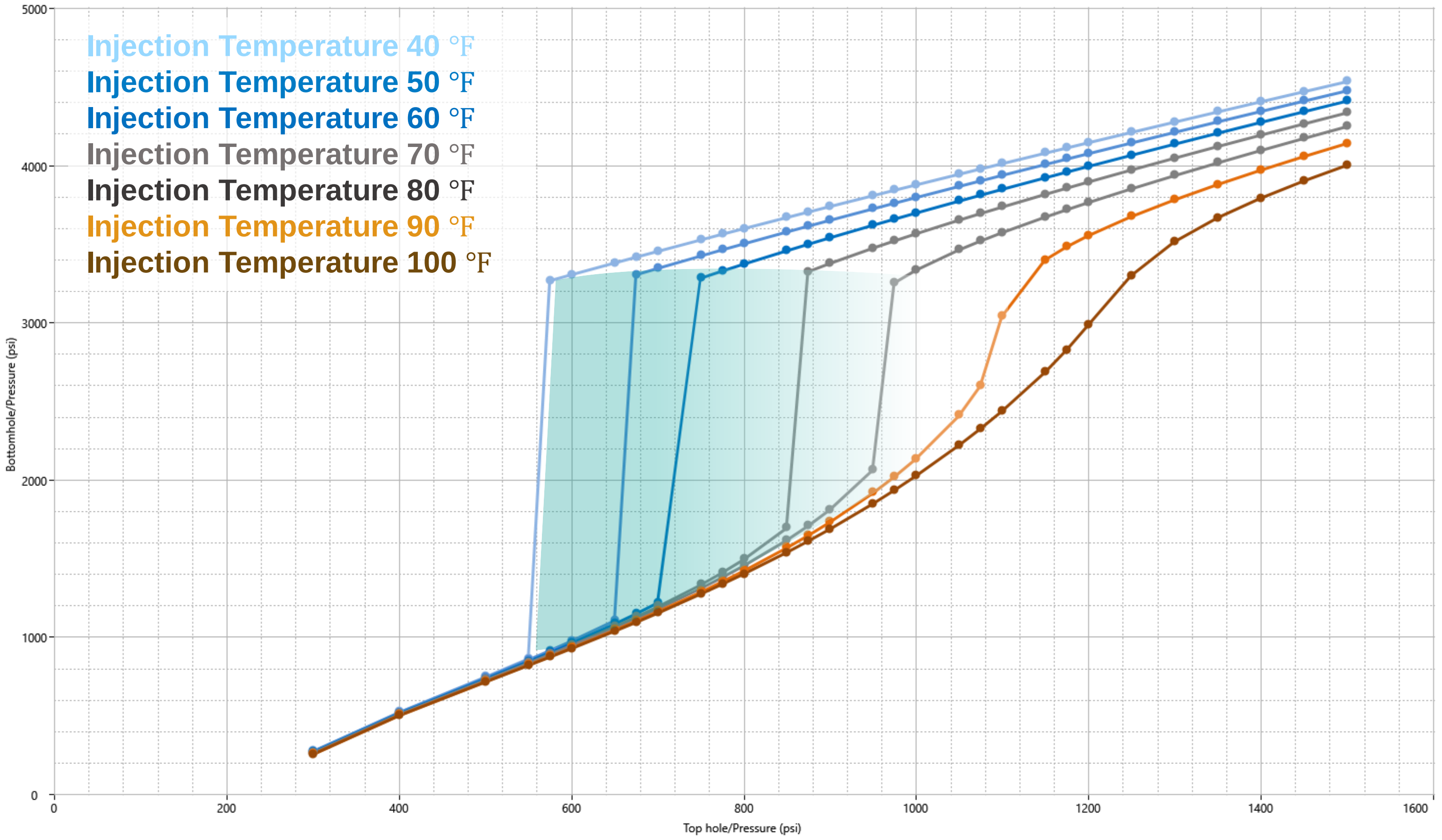


The **pressure gap** becomes **larger** as the **injection rate** increases.

Pressure Profile of CO_2 (Effect of Temperature)

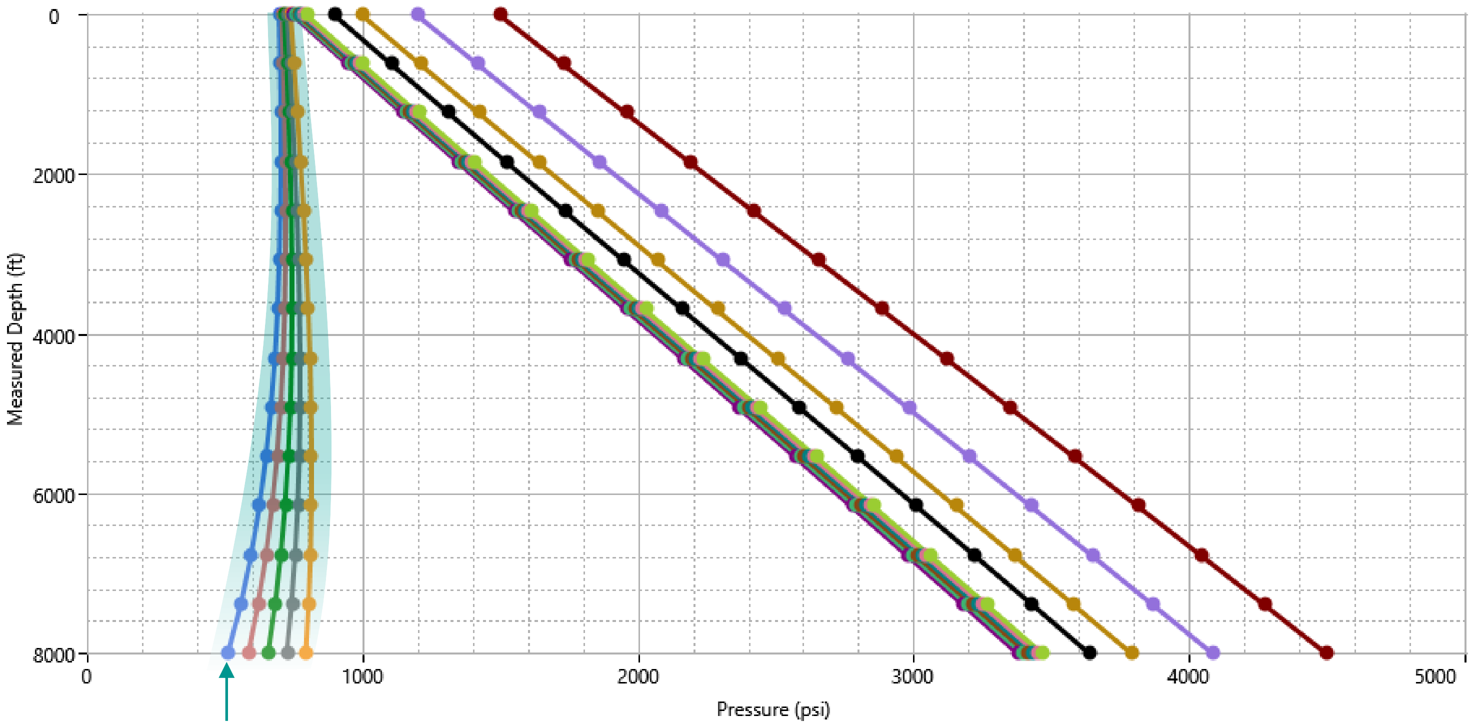
As **injection temperature** ↑↑
Pressure gap ↓↓

Once, the **injection temperature** passed the **critical temperature** then **pressure gap** completely **disappears**.

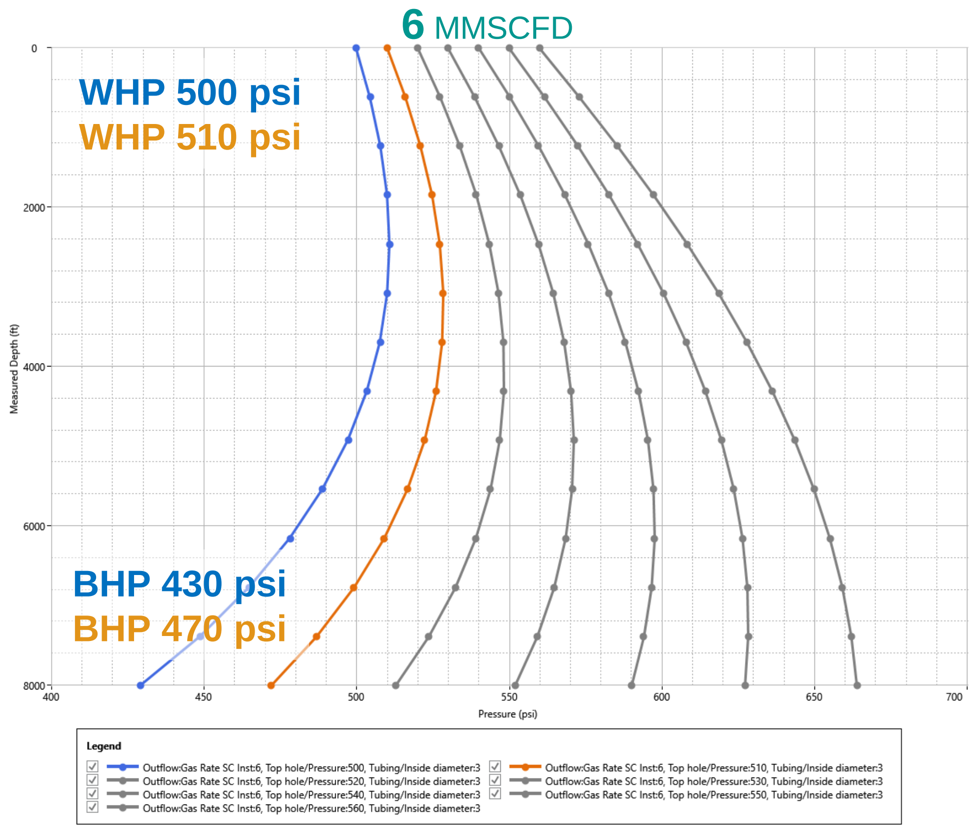


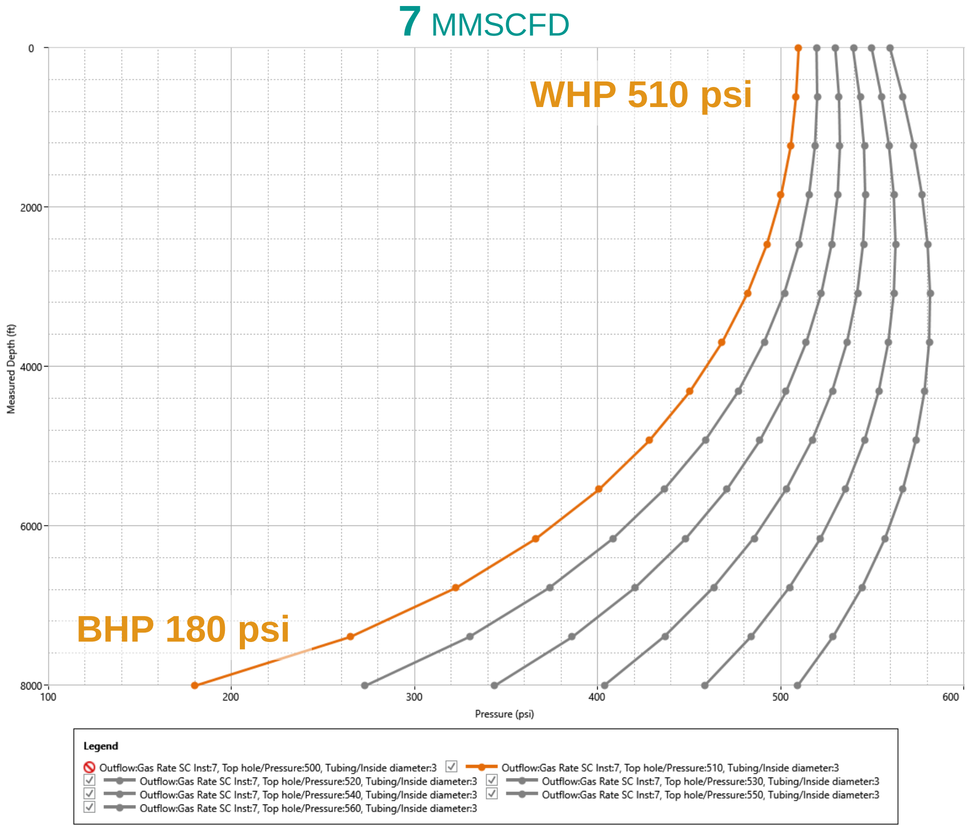
Pressure Profile of CO_2 (BHP vs. WHP)

The pressure profile at lower injection pressures shows a **reversed trend** where the **bottom hole pressure** is **less** than the **wellhead pressure**.



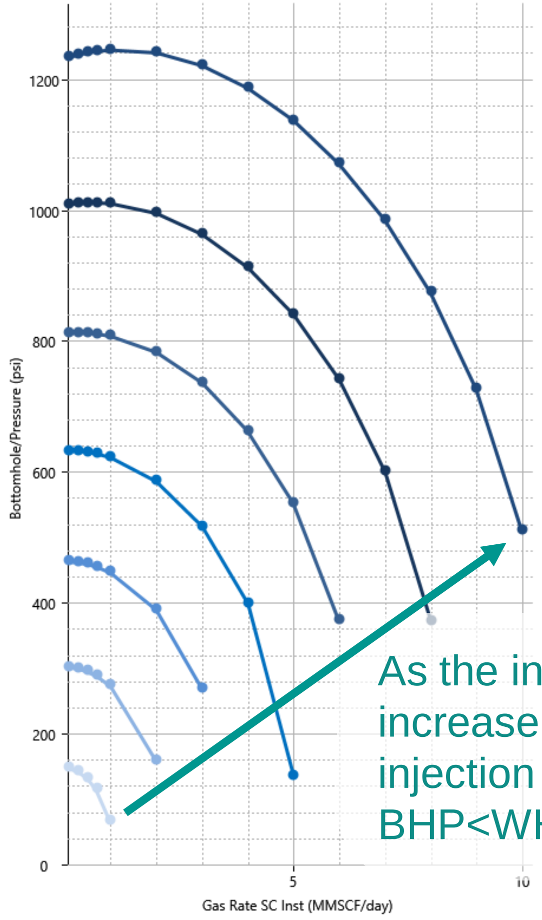
Pressure Profile of CO_2 (BHP vs. WHP – Injection Rate)



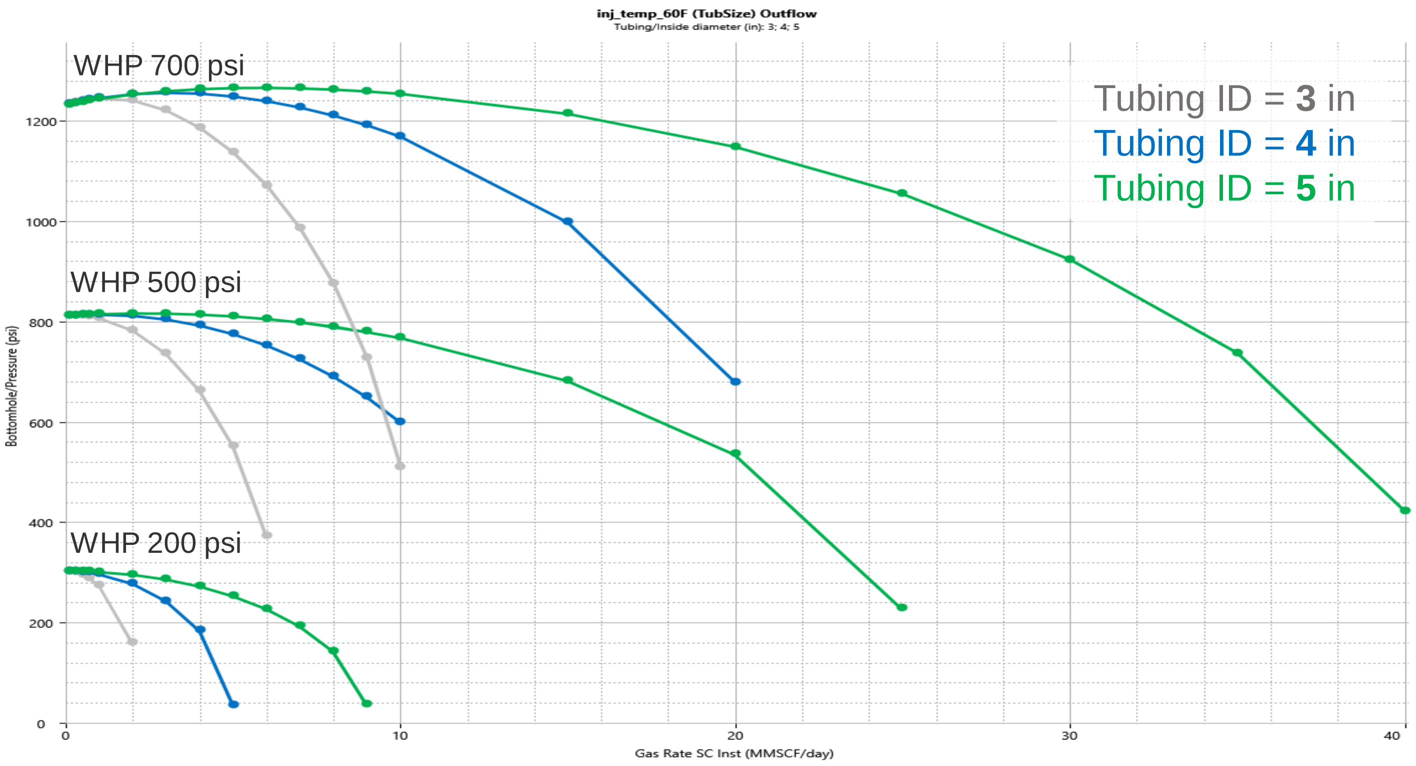


- As the injection rate increases the drop in pressure along the well becomes larger.
- This result in negative (no solution) at low WHPs.
- To achieve higher injection rates, higher WHP is required (Depending on Tubing ID)

Pressure Profile of CO_2 (BHP vs. WHP – Tubing Size)

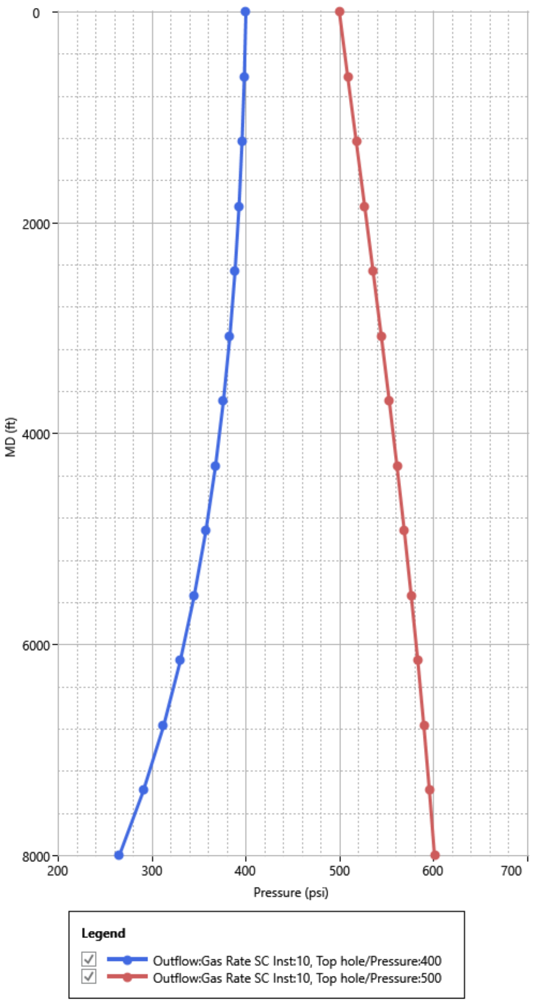


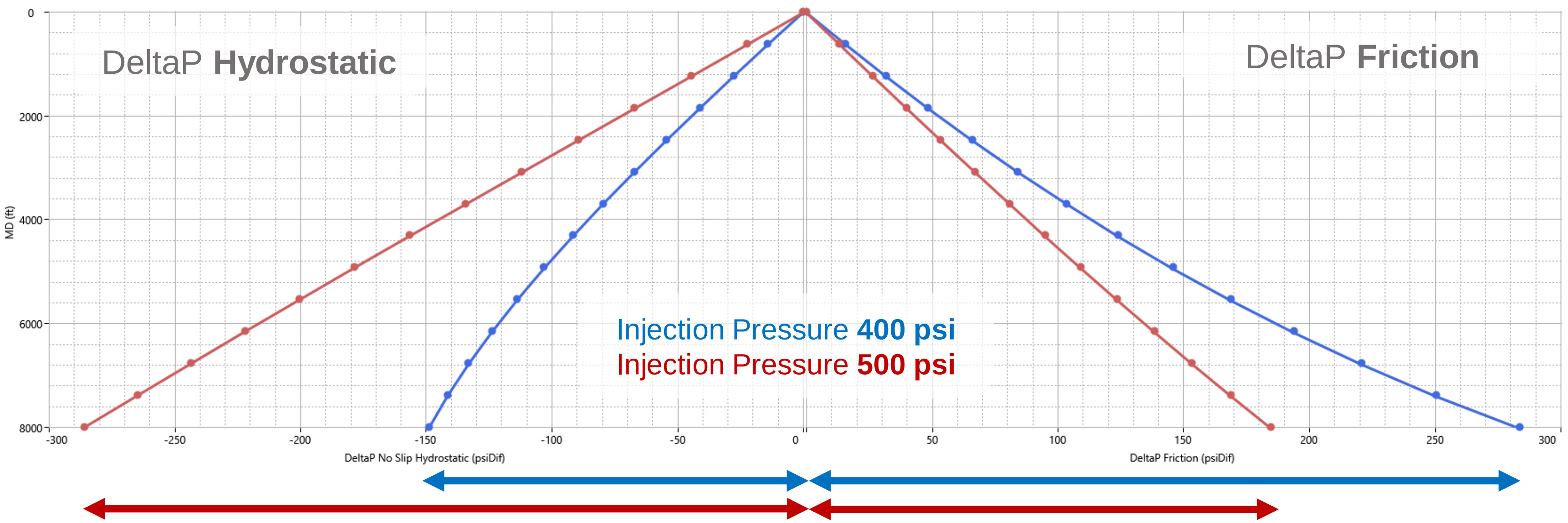
As the injection pressure increase, the minimum injection rate before BHP<WHP also increases.

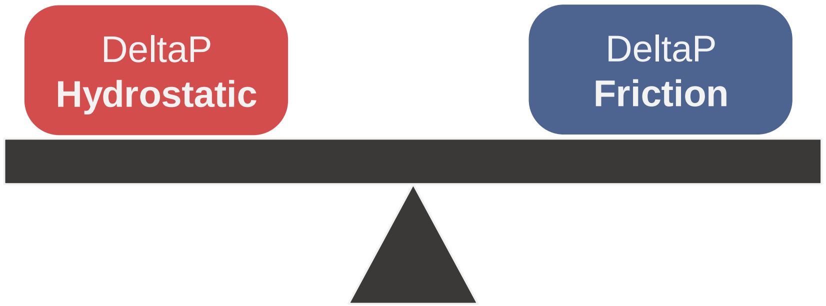


Using bigger tubing ID, higher rates at the same injection pressure is achievable.

Pressure Profile of CO_2 (Contributing Forces)



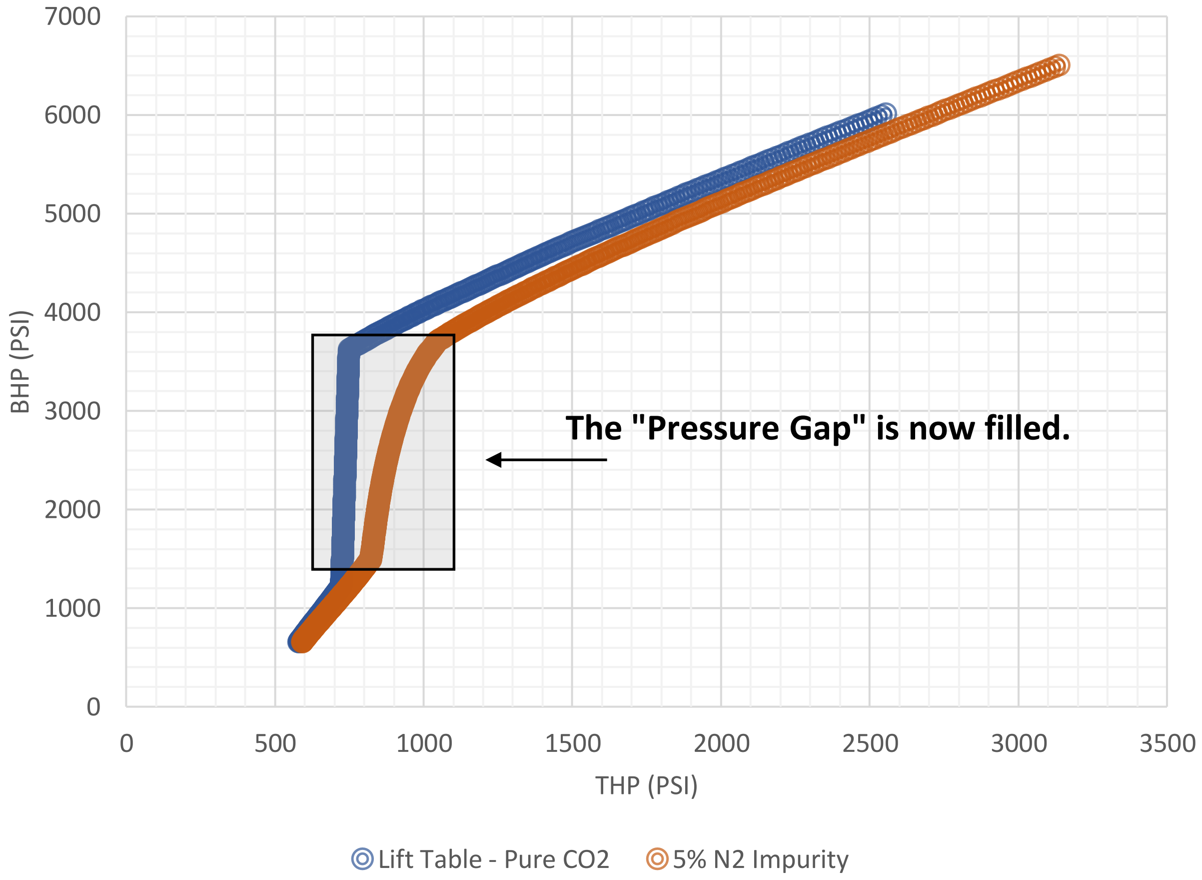




Solutions – Modelling & Operational

- The pressure gap is due to the **discontinuity** between CO2 **liquid** and **gas densities**
  - An artifact of the **steady-state assumption**.

- Possible modelling solution: use a **transient wellbore simulator** to capture the two phase region and therefore fill the pressure gap.
  - Acceptable approach… **BUT**… will be **expensive** for large models.



Other approaches:

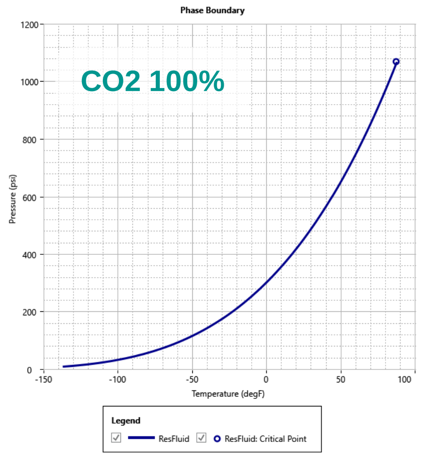
- To use lift tables

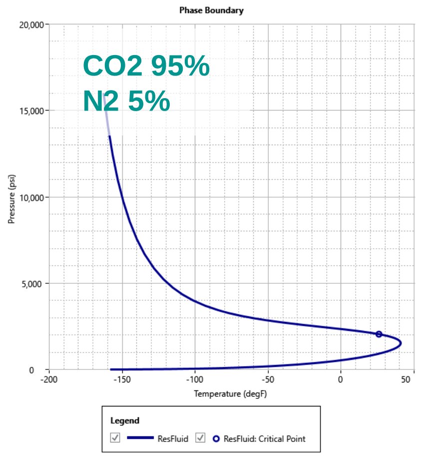
  This will help with modelling of CO2

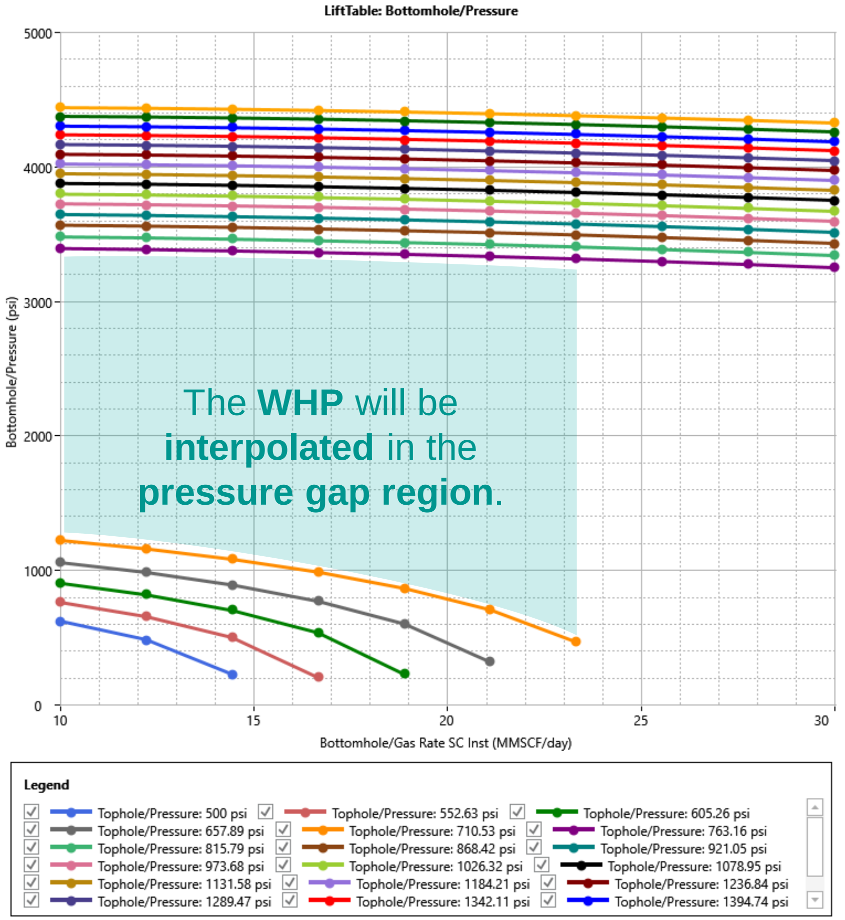
- To add impurity to CO2

  This will help to operate the well smoothly and avoid unstable two phase region of CO2

Solutions



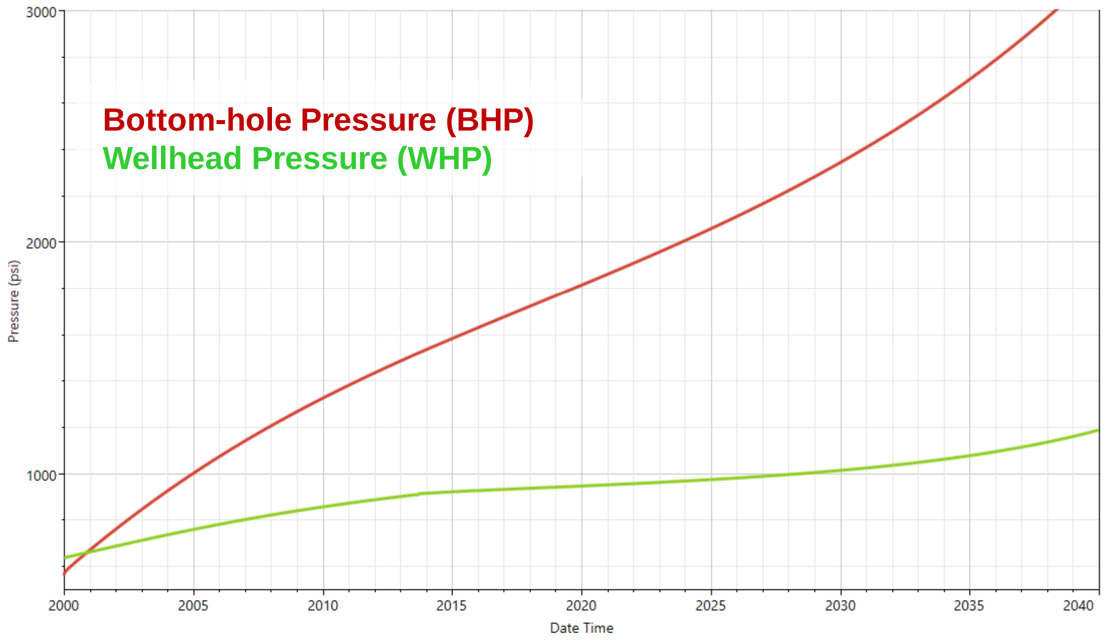




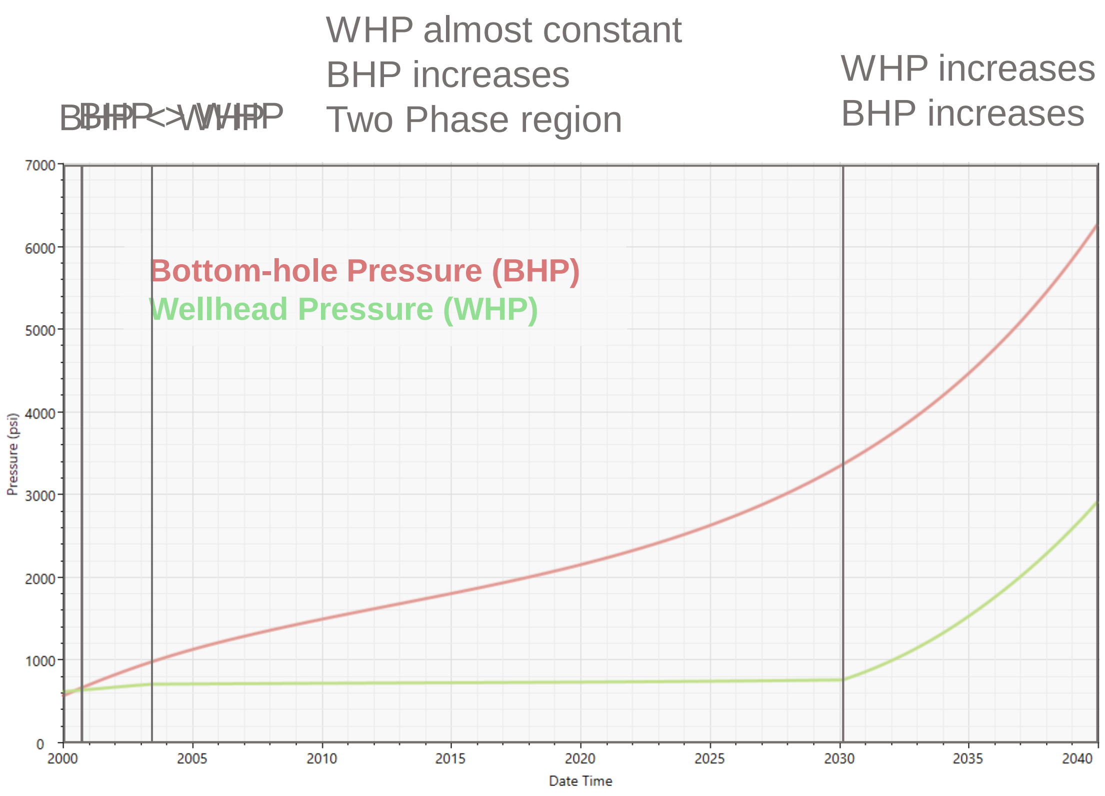
- The WHP inside the pressure gap region will be calculated using a table look up of the lift table.

- The two phase region is passed **sharply** with pure CO_2.
- The presence of the impurity will create a **smooth transition** from liquid to gas state.

Results



Using **N2** as **Impurity**



Using **Lift Tables**

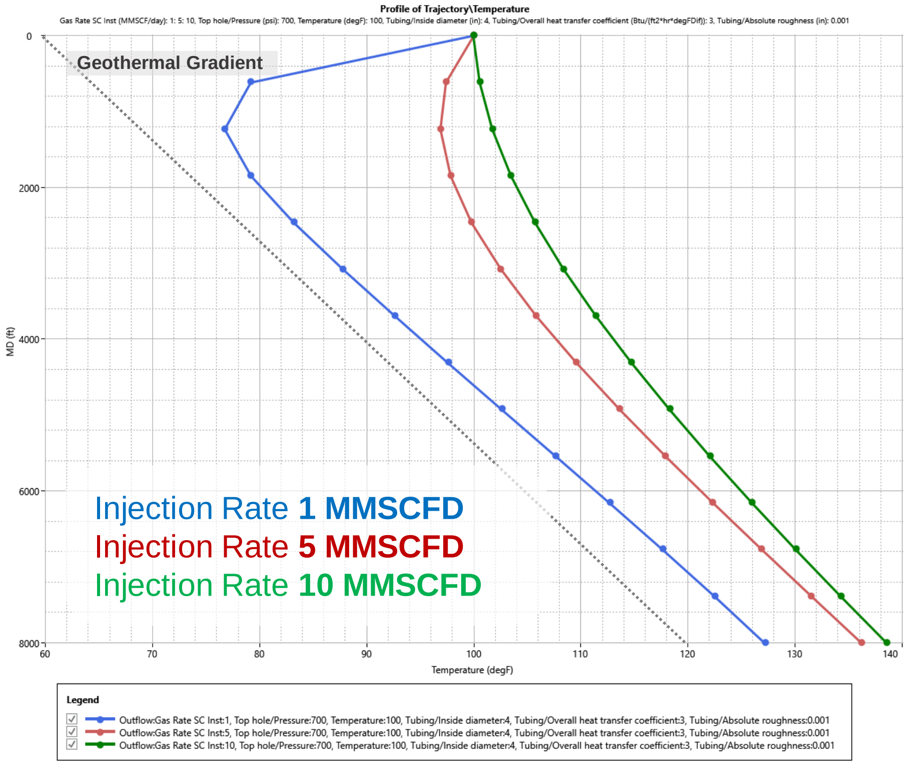
- Both approaches work fine.
- However, using lift tables is recommended when pure CO_2 is intended to be injected.
- Lift tables will result in more accurate WHP calculation

Temperature Profile

Main parameters playing a role in heat exchange in wellbore during $\boldsymbol{CO_2}$ injection:

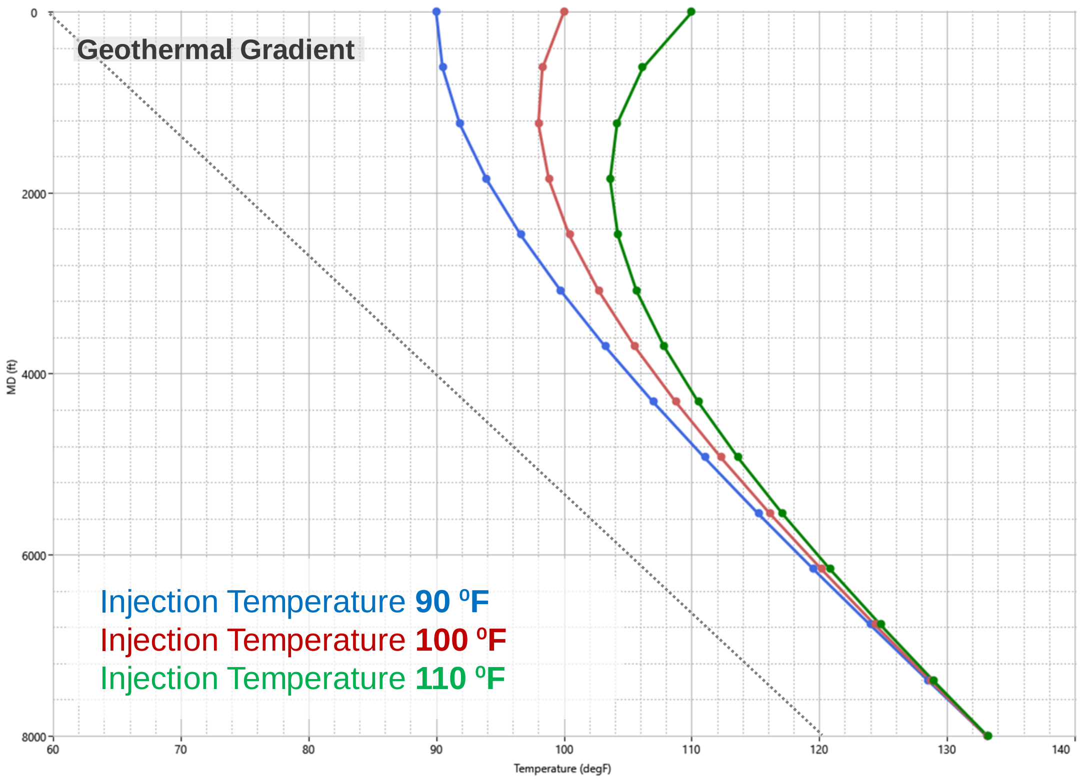
1. Adiabatic compression of CO_2
2. Conductive heat exchange between wellbore and the formation
3. Frictional energy loss

Injection at 100 F

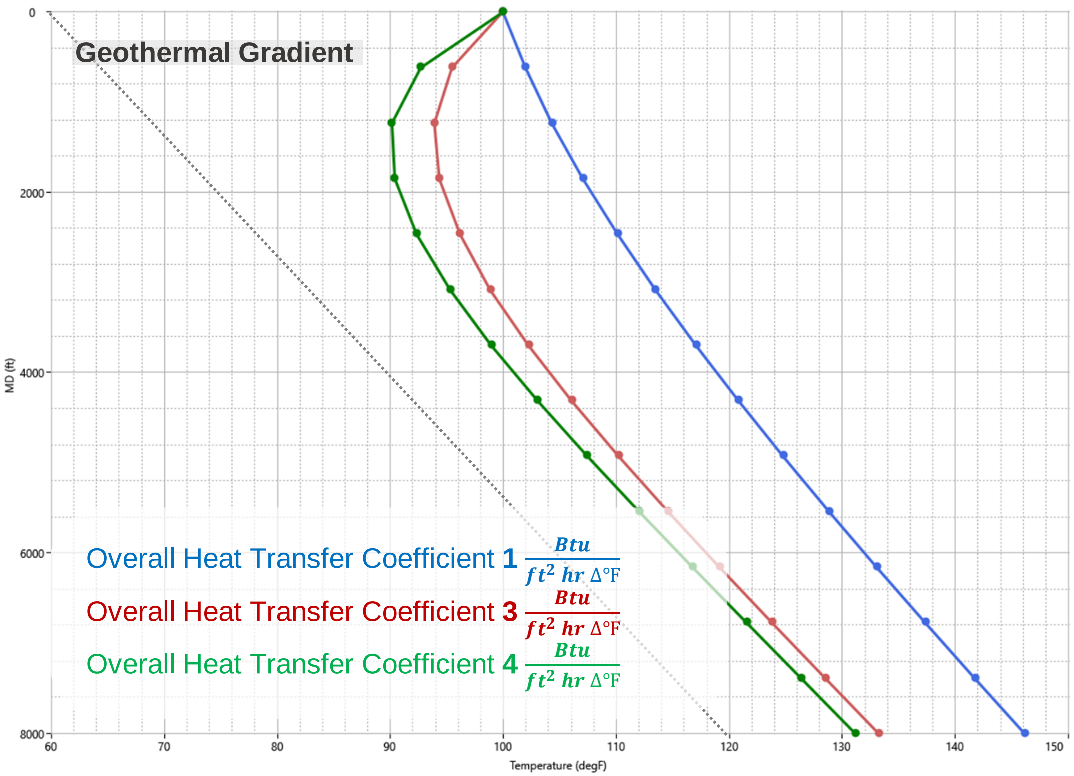


Adiabatic compression results in higher temperature at the bottom hole. At lower rates **conductive heat transfer** determines the overall thermal profile of the well.

Temperature Profile – Sensitivities

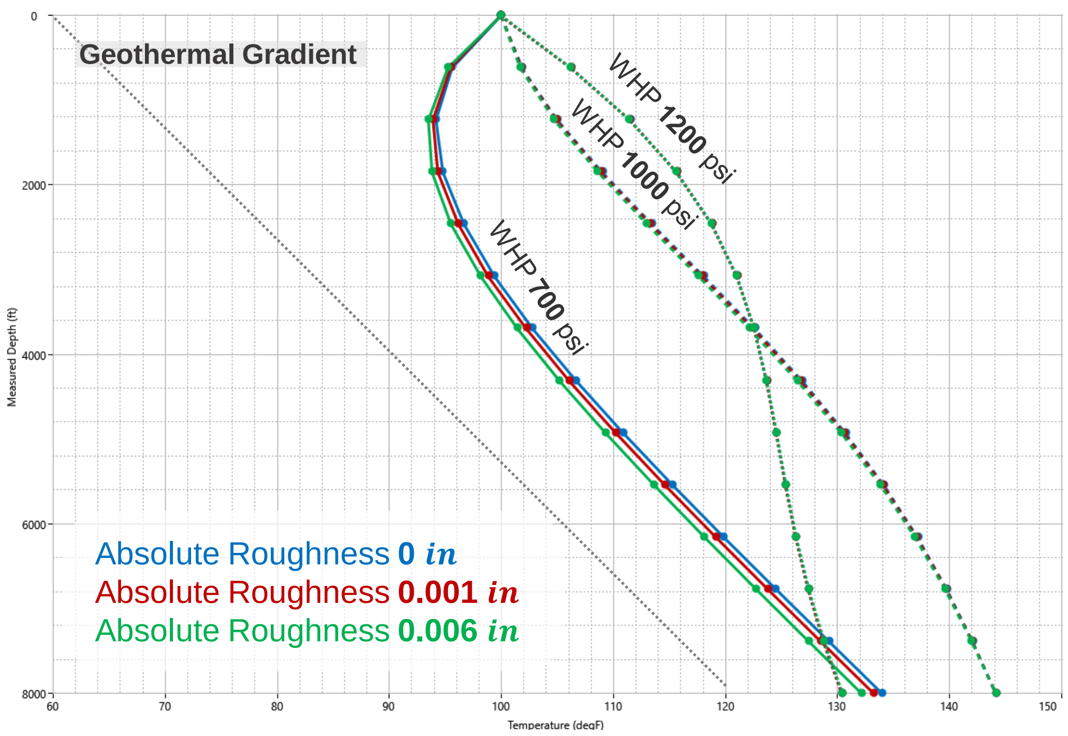


Injection Temperature

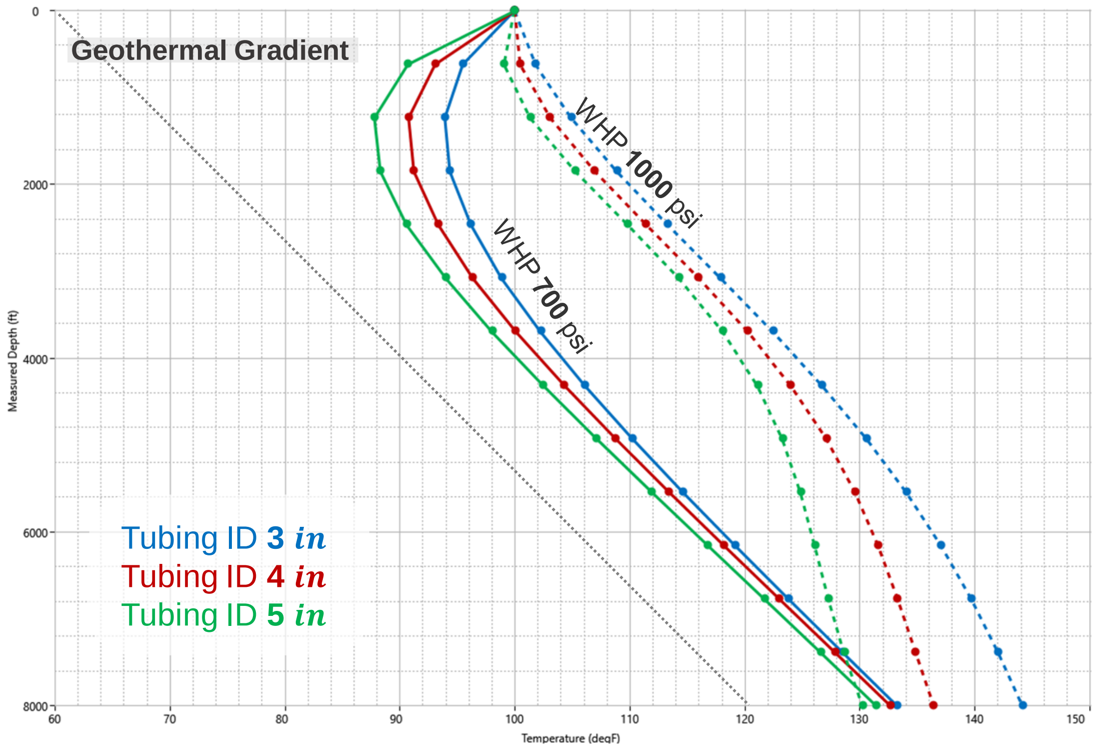


Overall Heat Transfer Coefficient

Temperature Profile – Sensitivities

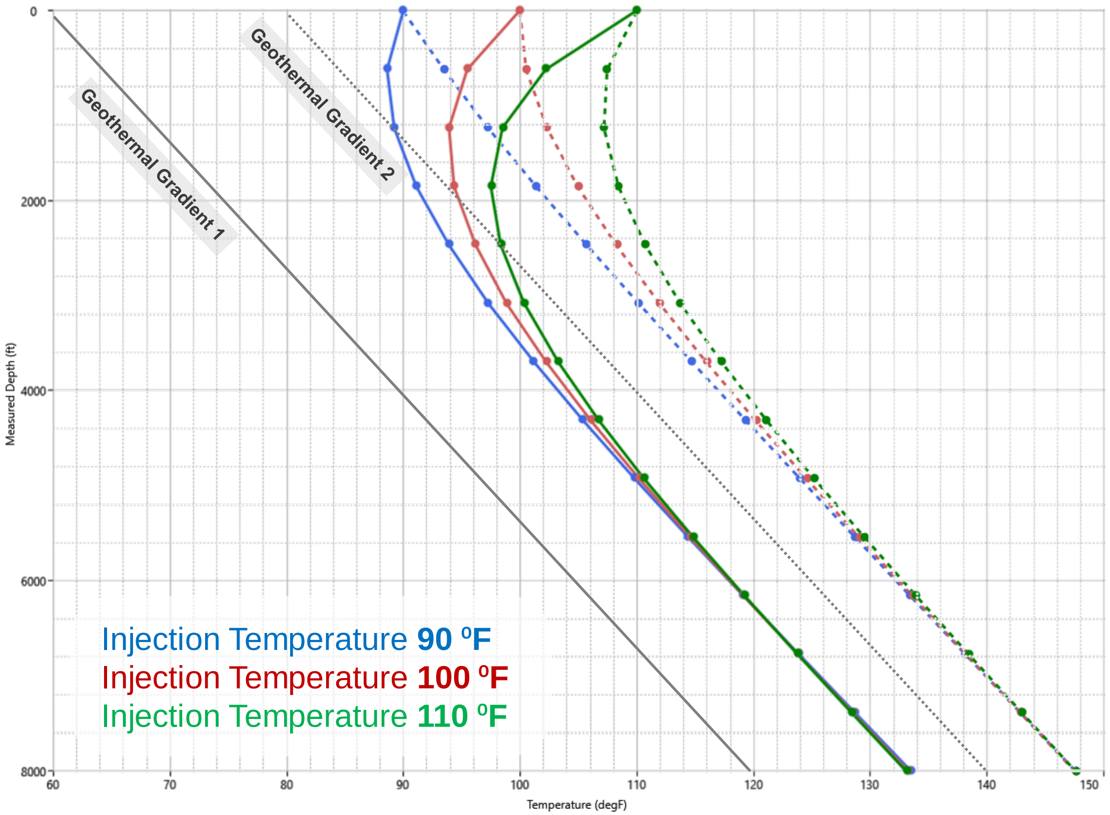


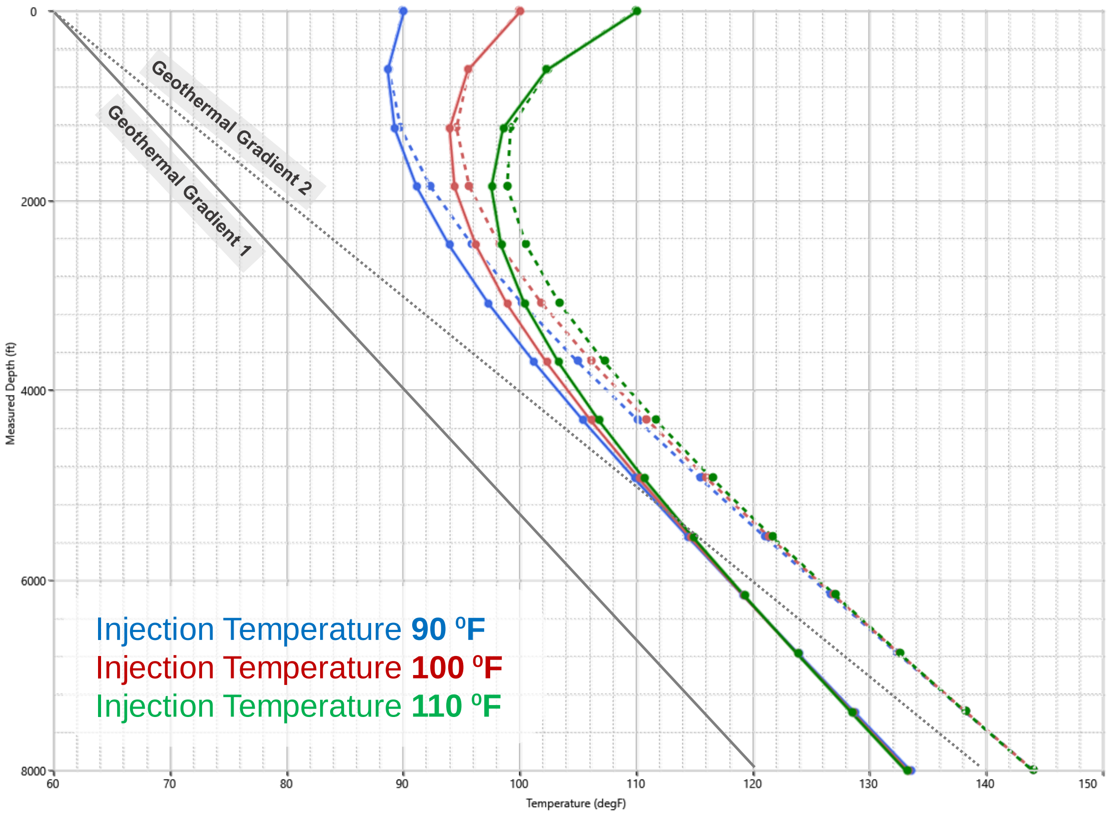
Tubing Roughness



Tubing Size

Temperature Profile (Formation Temperature Gradient)





Results & Conclusions

- CO_2 behavior in wellbores for DGRs was studied using coupled reservoir-wellbore modelling, as well as standalone wellbore modelling.
- Challenges to modelling as well as operations were identified and the reasons leading to those were investigated.
- Impact of injection rate, well-head pressure, well-head temperature, and tubing size on the wellbore pressure and temperature behavior was quantified – Operational and modelling challenges were analyzed
- Possible solutions for these challenges - both from operational as well as modelling perspectives, were proposed

Thank You for Your Attention.