Backflow and Clean-up of Golden Eagle water injection wells using Nitrogen gas-lift

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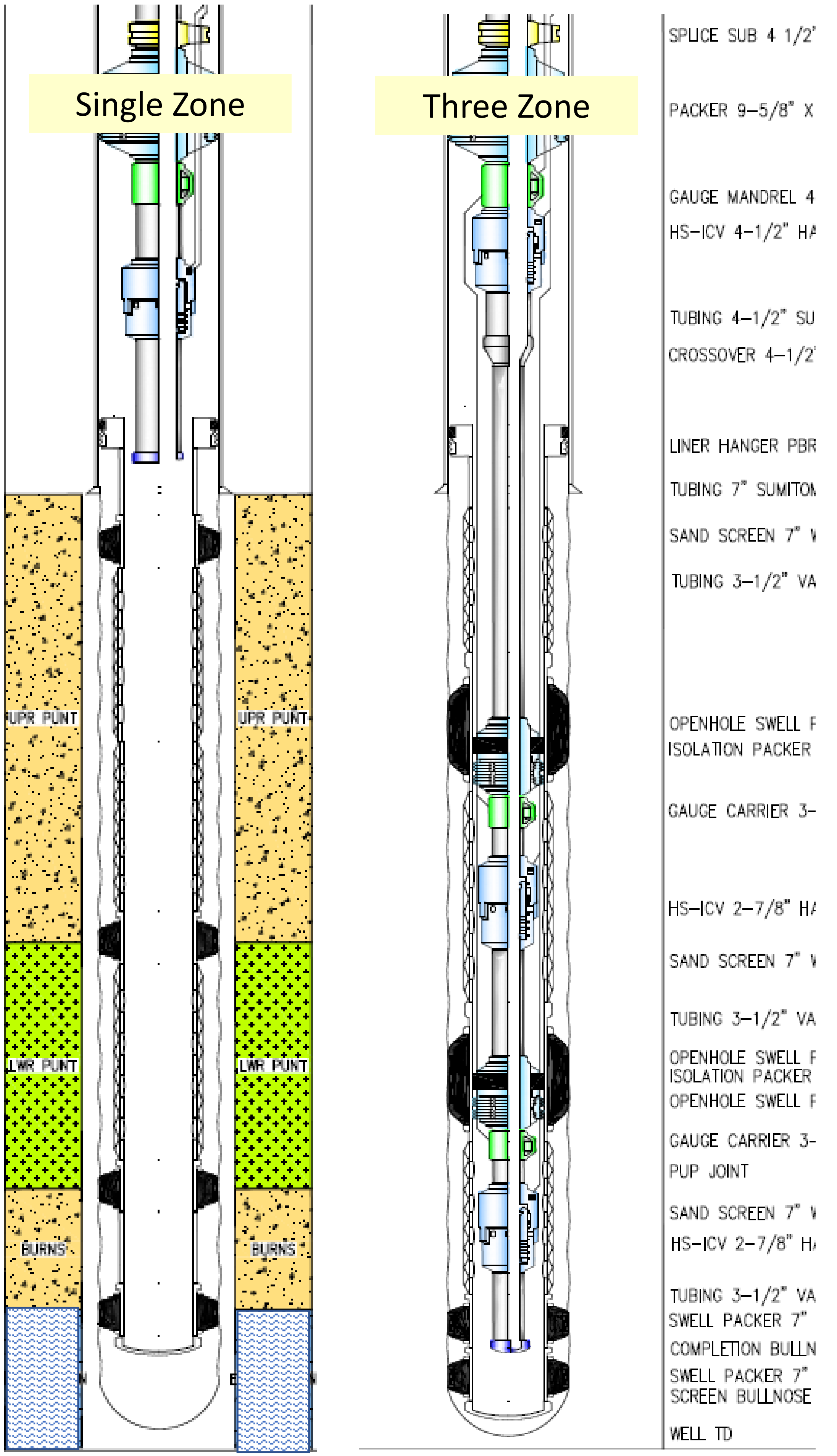
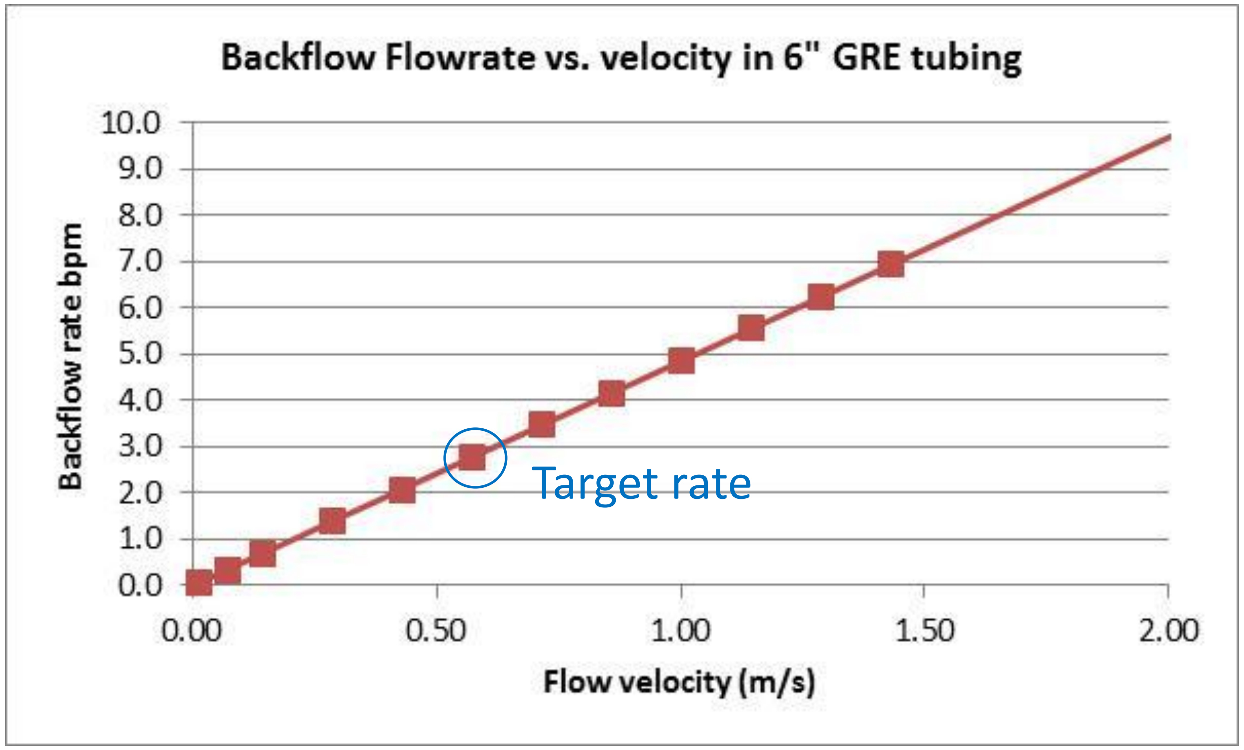
PETROLEUM TECHNOLOGY COMPANY

Background

- Golden Eagle water injection wells were completed with standalone screens run in an oil based mud. Some wells were single zone, others were 3-zone with interval control valves (ICV's)
- Punt intervals were oil bearing, Burns intervals were in the aquifer (water bearing)
- Removal of the drilling fluid and filter cake prior to water injection was key to good injection performance
- Back-flowing was considered a better option than mud breaker fluids
- 4 Platform wells and 1 Subsea well were back-flowed in this way



Velocity & Flowrate required to Clean Up Solids from Well



- 200 micron solids particle lifted from well if flow velocity > 0.5 m/s*
- 4000 b/d (~3bpm) target rate gives 0.6 m/s
- Maximum backflow rate is limited by three factors:
  - 2" temporary pipework between the injector and production well.
  - Filtration capacity on the temporary well test package (to achieve <30 mg/L oil in water prior to discharge).
  - N_2 tank storage, which is limited by deck space
- Backflow up to 5 tubing volumes to clean up the well (~10 hrs)

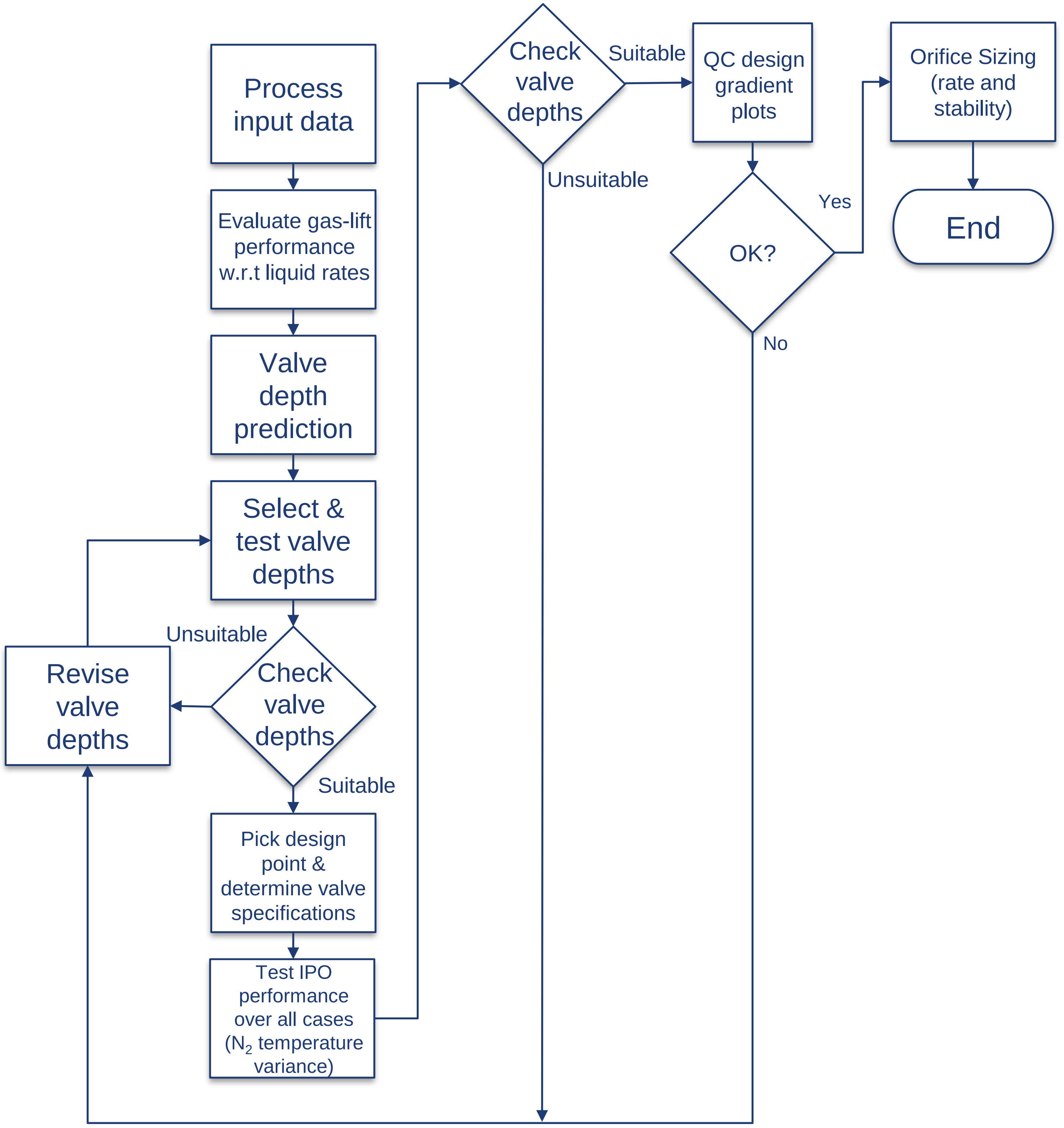
* Flow velocity must be greater than the particle settling velocity. Stokes Law for spherical objects is typically used to calculate settling velocity but Jimenez & Madsen (2003 Journal of Waterway, Port, Coastal & Ocean Engineering) formula gives a higher velocity i.e. worst case

$$W_* = \frac{w_s}{\sqrt{(s-1)gd_N}} = \left(A + \frac{B}{S_*}\right)^{-1}$$

$$S_* = \frac{d_N}{4\nu}\sqrt{(s-1)gd_N}$$

Gas-Lift Design Parameters & Workflow

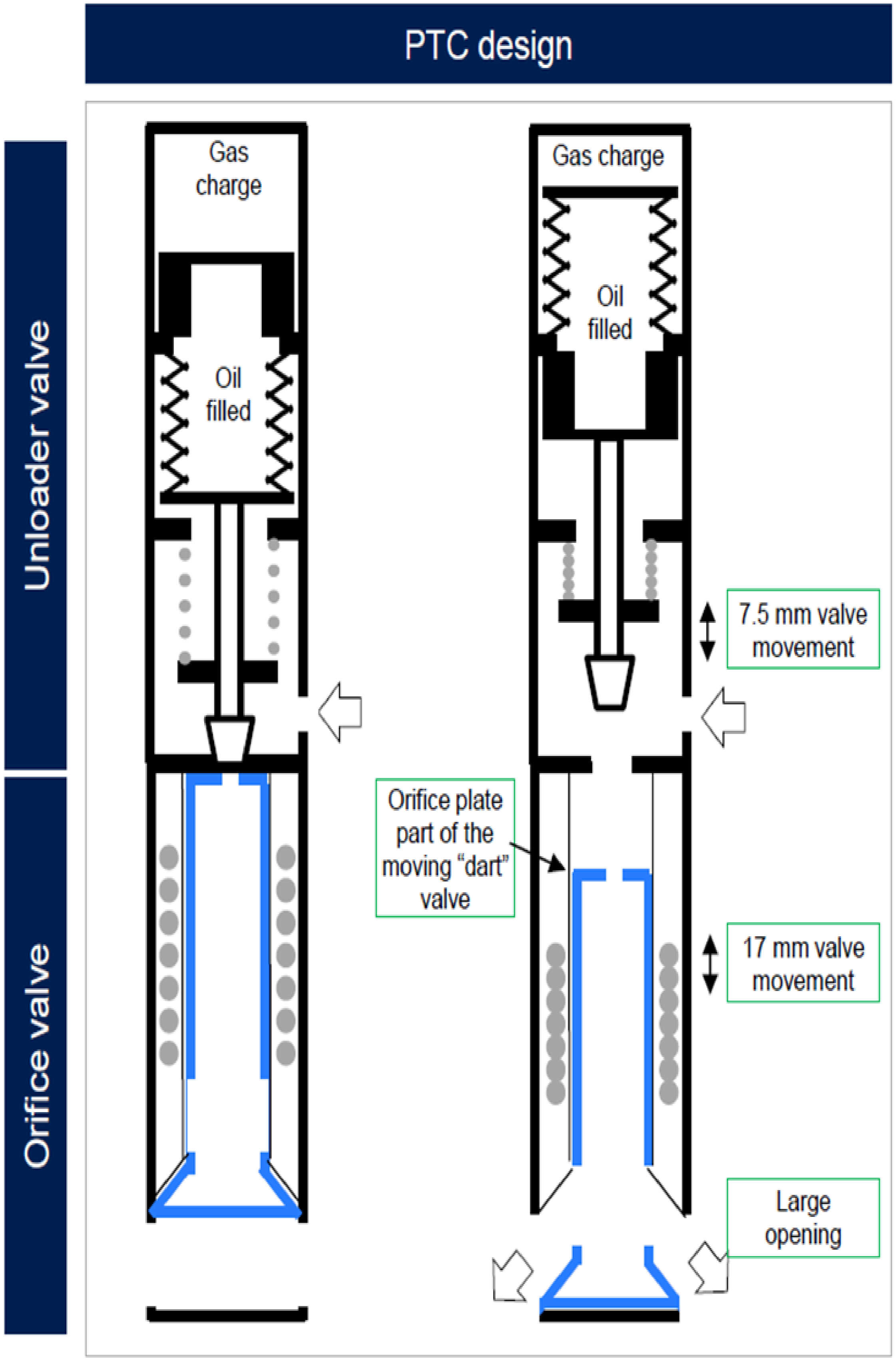
Input	Value
Design Backflow / Clean-Up Rate	4000 b/d oil or water
N_2 Lift Rate	1 MMscf/d (~750 scf/min)
THP min	300 psi
CHP max (A Annulus HP Alarm set point)	2500 psi
Unloading Gradient	9.6 - 9.8 ppg (~0.5 psi/ft)
Max IPO Valve depth	~4500 ft TVD to stay closed against a column of brine in Water Injection mode)



IPO Valve Design Objectives

- During gas lift/backflow operation:
  - Check valve to remain fully open during N_2 injection and the bellows are fully compressed and protected
  - Dome pressure set to ensure full valve stem opening (7.5 mm travel) achievable during backflow with available CHP
  - Over-pressure of IPO bellows during backflow is sufficient and achievable with available annulus pressure

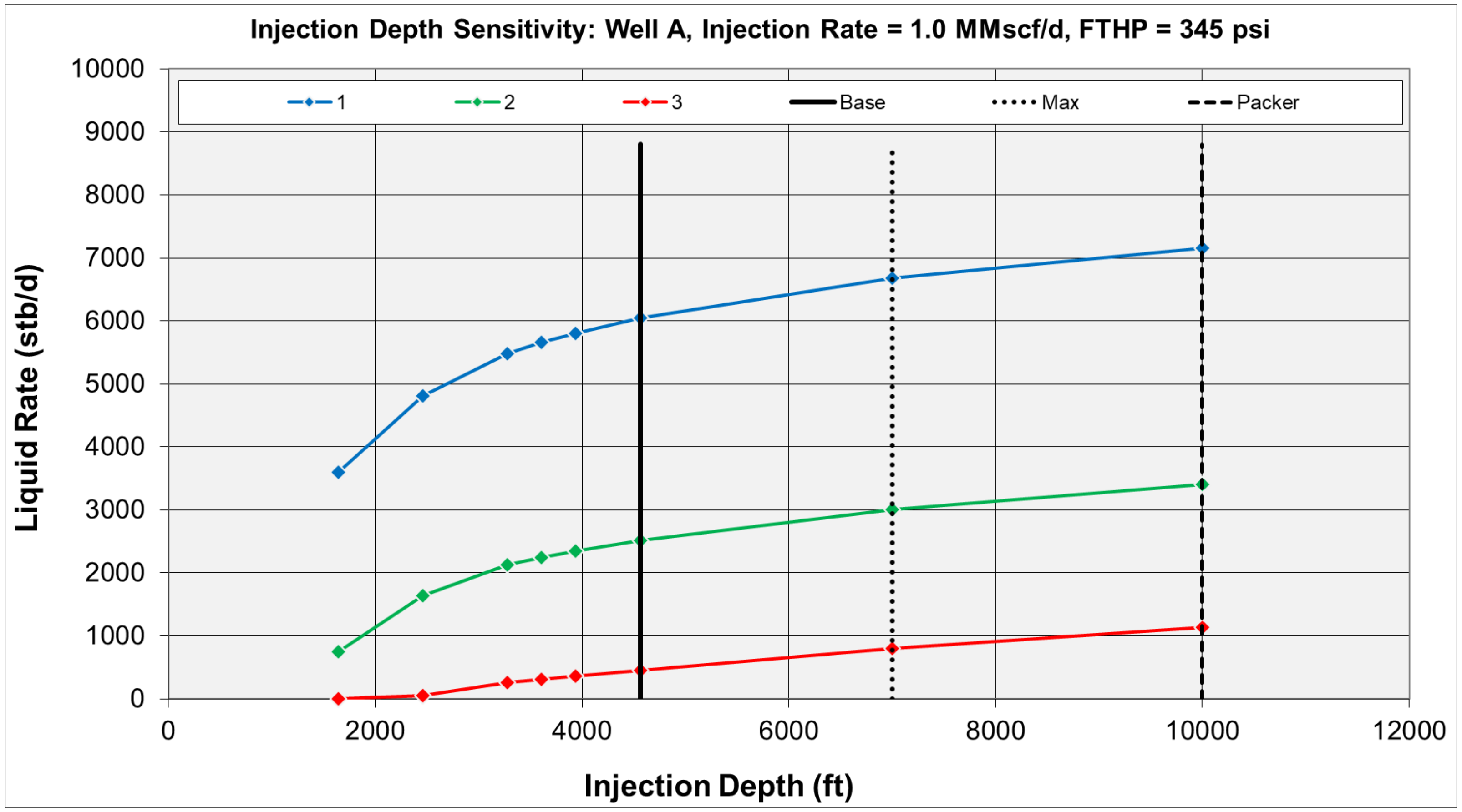
- Post gas lift/backflow operations (injection):
  - Retain a column of completion brine once the annulus was topped up with 9.3 ppg brine prior to water injection
  - Dome pressure is set high enough to ensure that the valve does not re-open once on injection causing the annulus fluid level to drop (a standard orifice valve will open with minimal ΔP between annulus and tubing)
  - Dome pressure required to accommodate the temperature range between back flow (~70°C) and minimum water injection (~20°C)

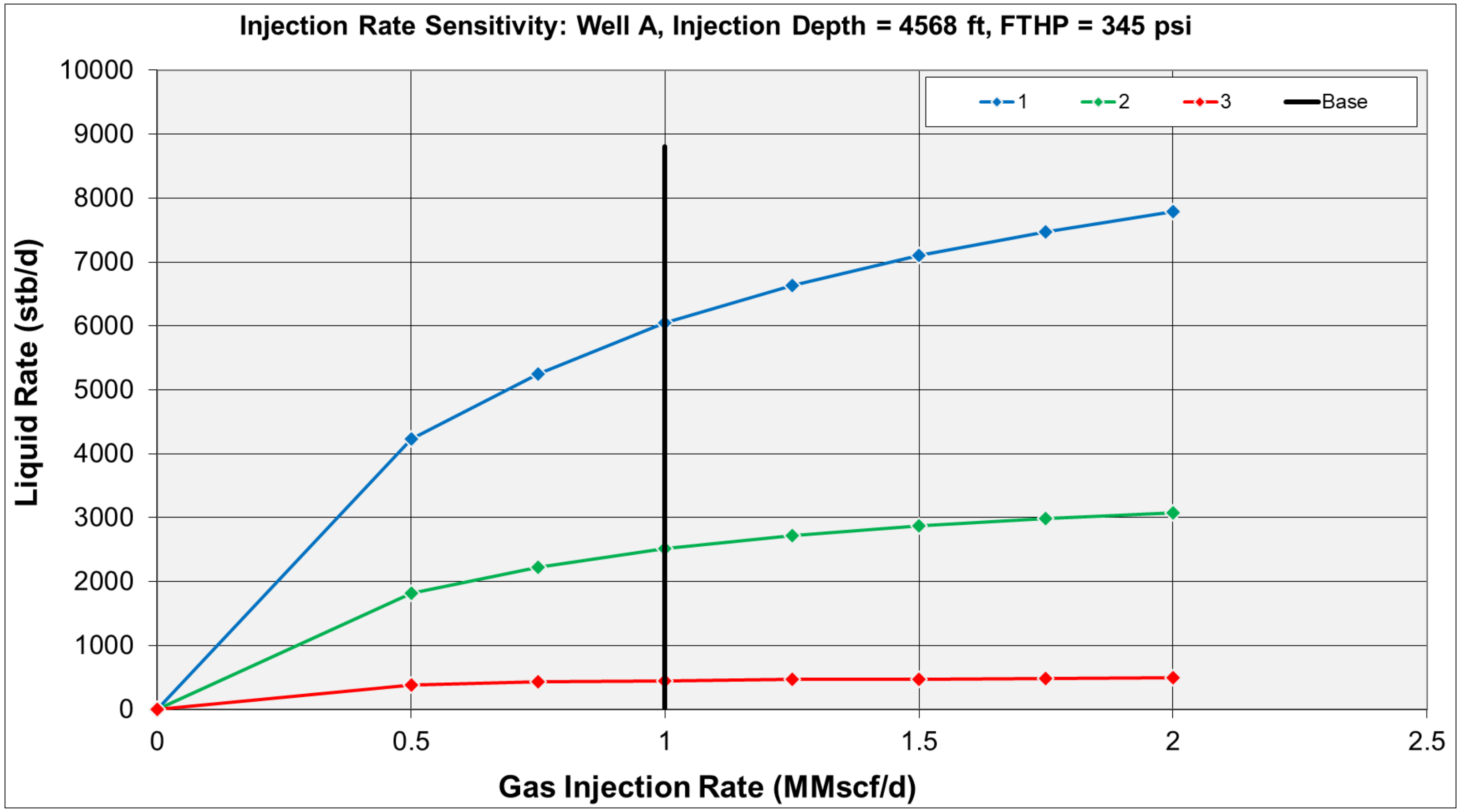


Tubing Shearable IPO Unloading Valve

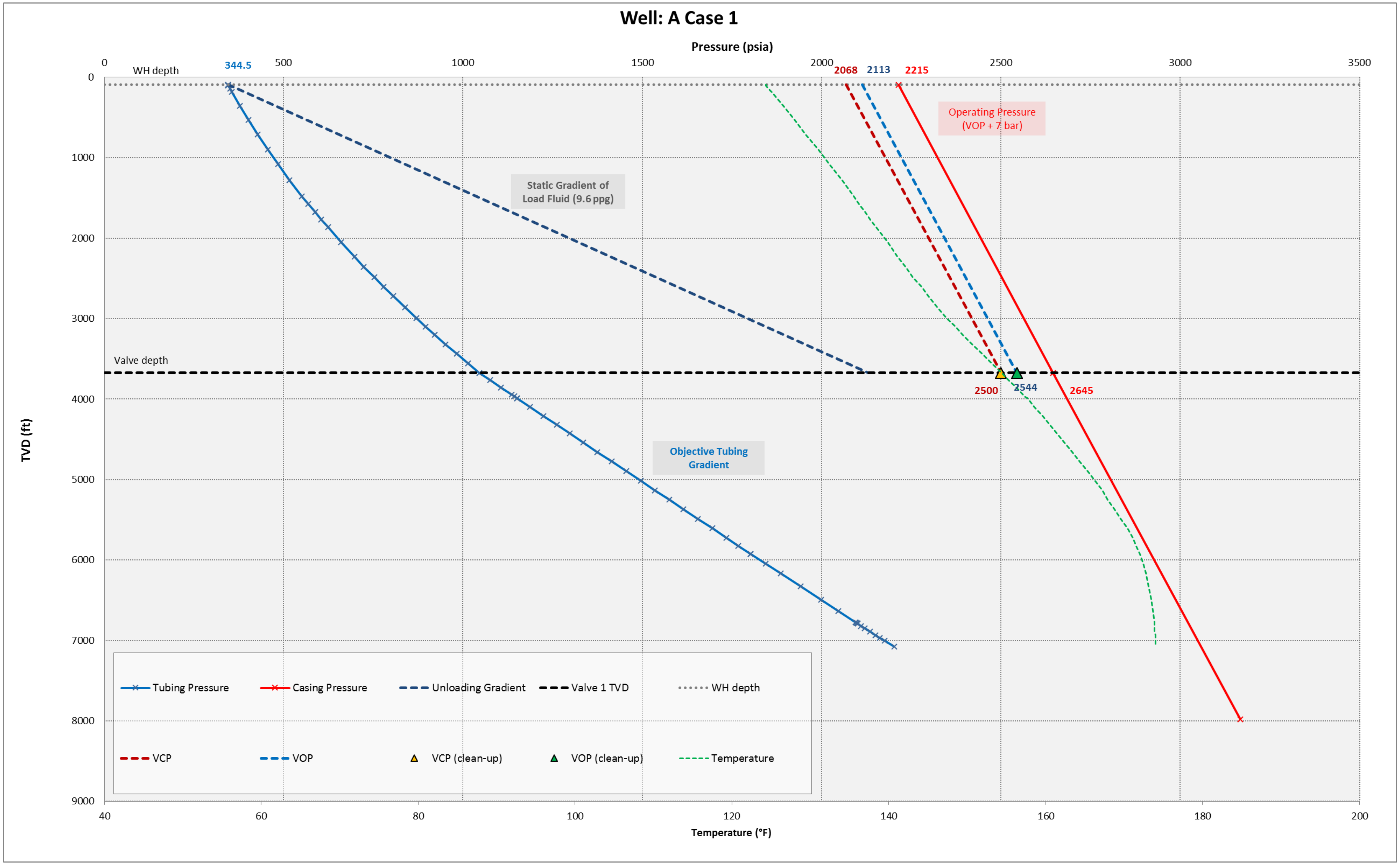
Gas-Lift Design

- Evaluate sensitivity on injection rate and depth
- Three cases with varying PRes / PI & WC considered
- Maximum depth of injection limited to ~4500 ft TVD to ensure IPO valve holds a column of brine during water injection phase
- Maximum lift gas rate limited by Nitrogen tank on deck storage capacity (3 tanks gives ~ 1.5 MMscf working volume, 24 hrs pumping)
- 4000 b/d minimum backflow rate not achievable in all cases



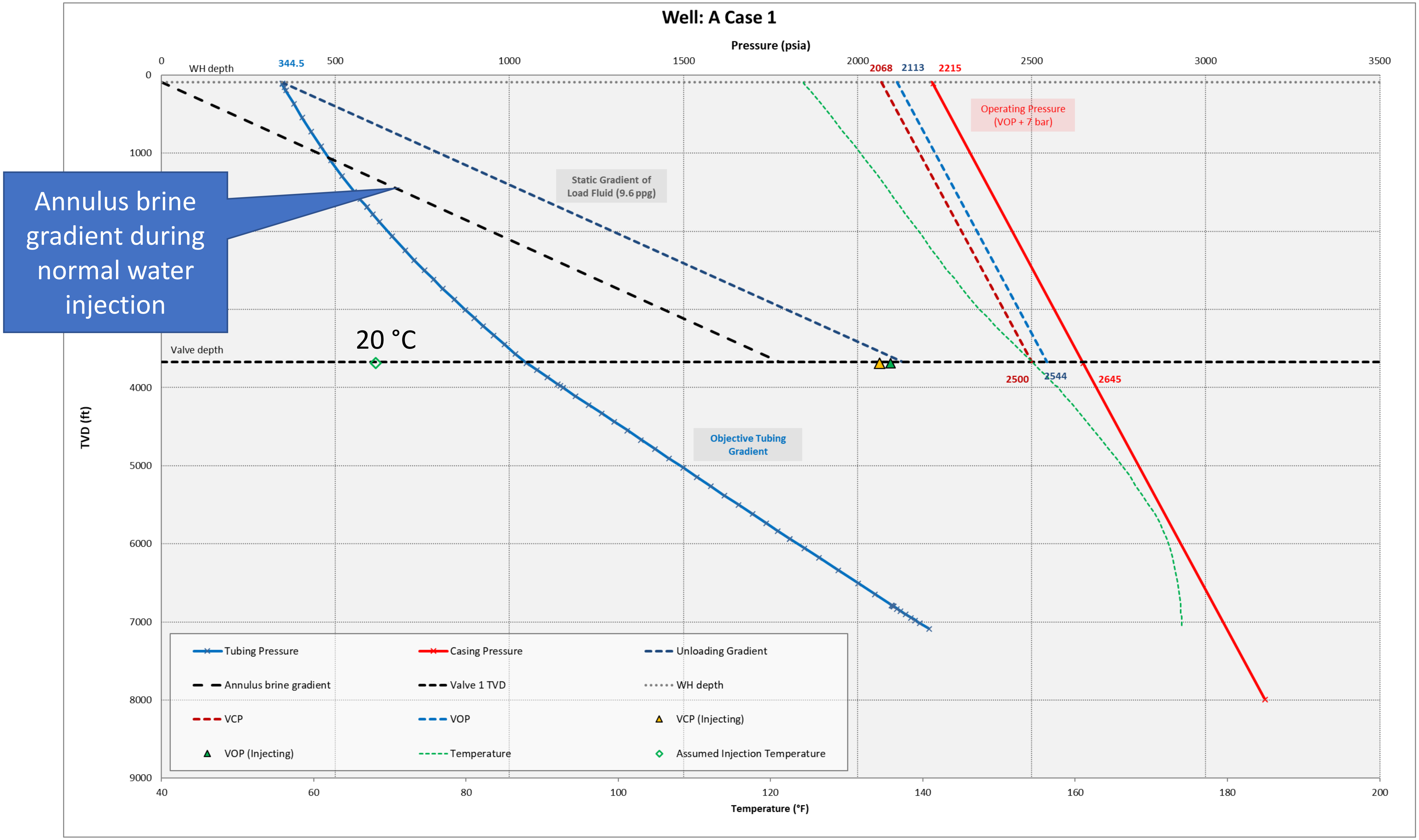


Gas-Lift Design – clean-up phase



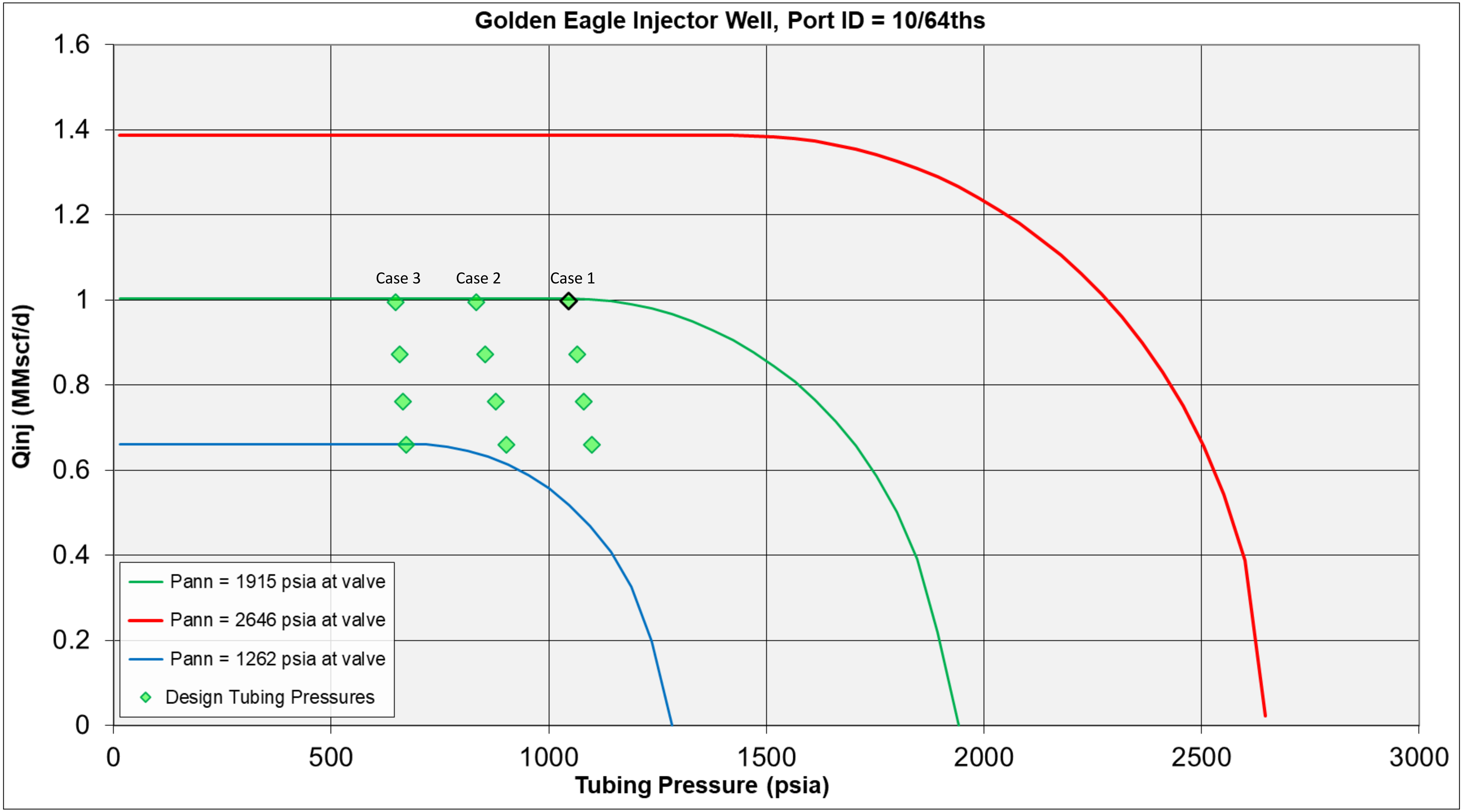
- Use IPO valve to unload annulus of brine
- Inject N_2 at 100 psi above the valve opening pressure during clean-up (c. 2215 psi on surface)
- Opening/closing pressures calculated at 68°C (flowing temperature)
- Slight IPO over-pressure (7 bar) to ensure protection of bellows from cyclic stress

Gas-Lift Valve Opening/Closing range during Water Injection



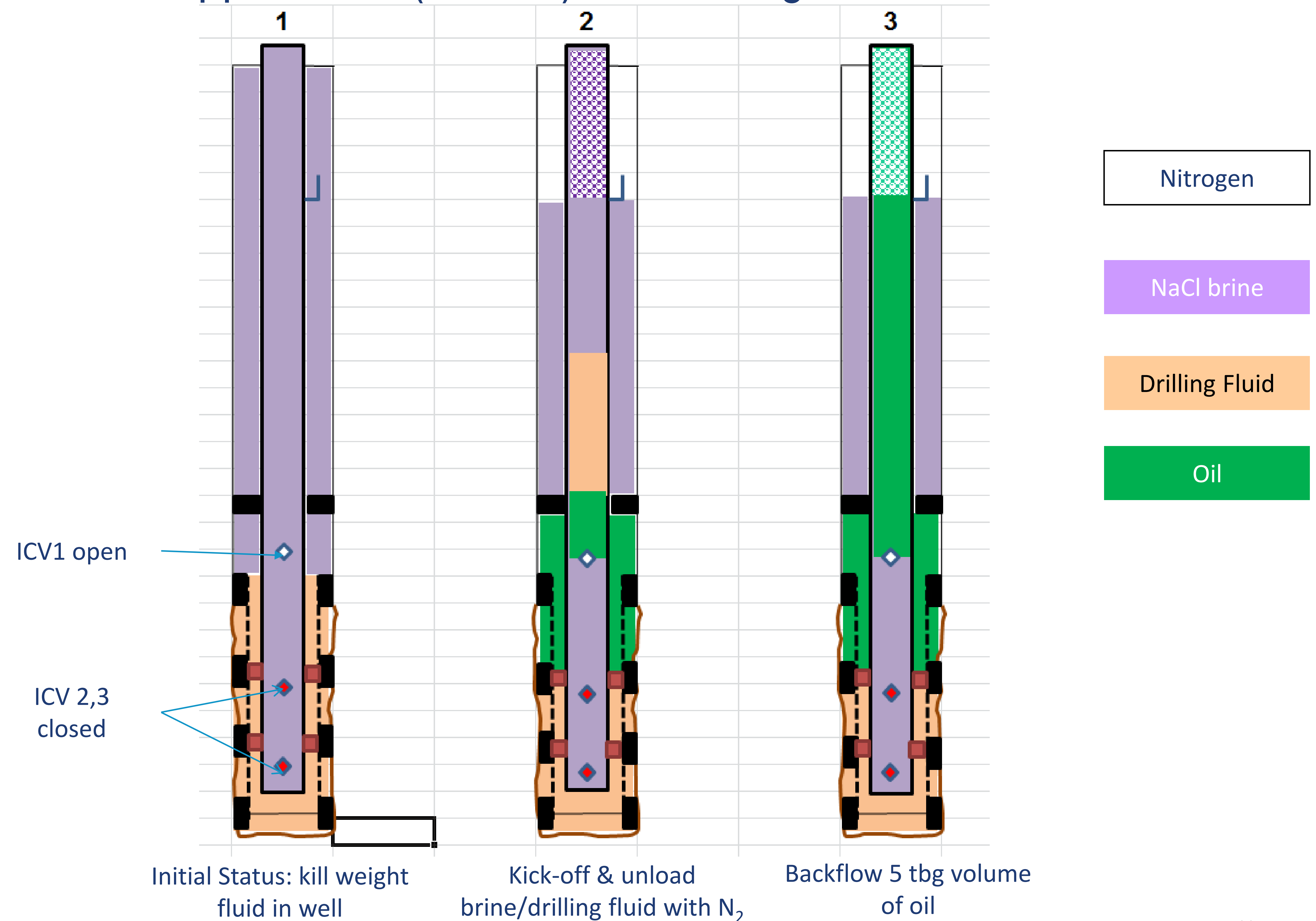
- IPO opening & closing pressures re-calculated at 20 °C (lowest water injection temperature)
- Annulus brine gradient c. 290 psi lower than Valve Closing Pressure (worst case @ 20 °C)
- A deeper IPO would give higher back-flow rates but reduce the safety factor for holding a brine column

Gas-Lift Design

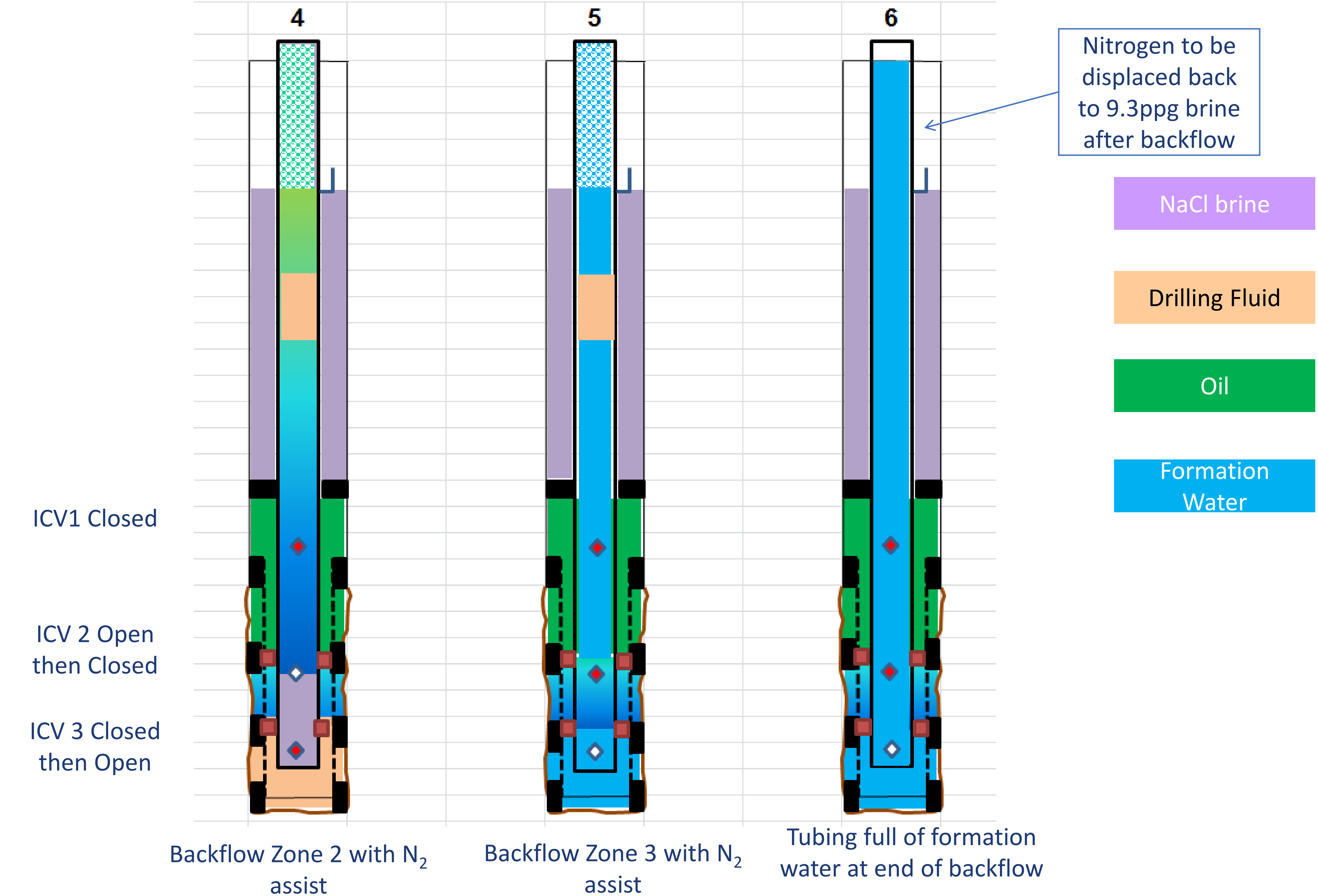


- Orifice sizing for 1 MMscf/d (~700 scf/min)
- 10/64" minimum size available
- Flow is critical for design case
- Injection of 2215 psi at surface required to fully compress the IPO bellows and protect from cyclic stress

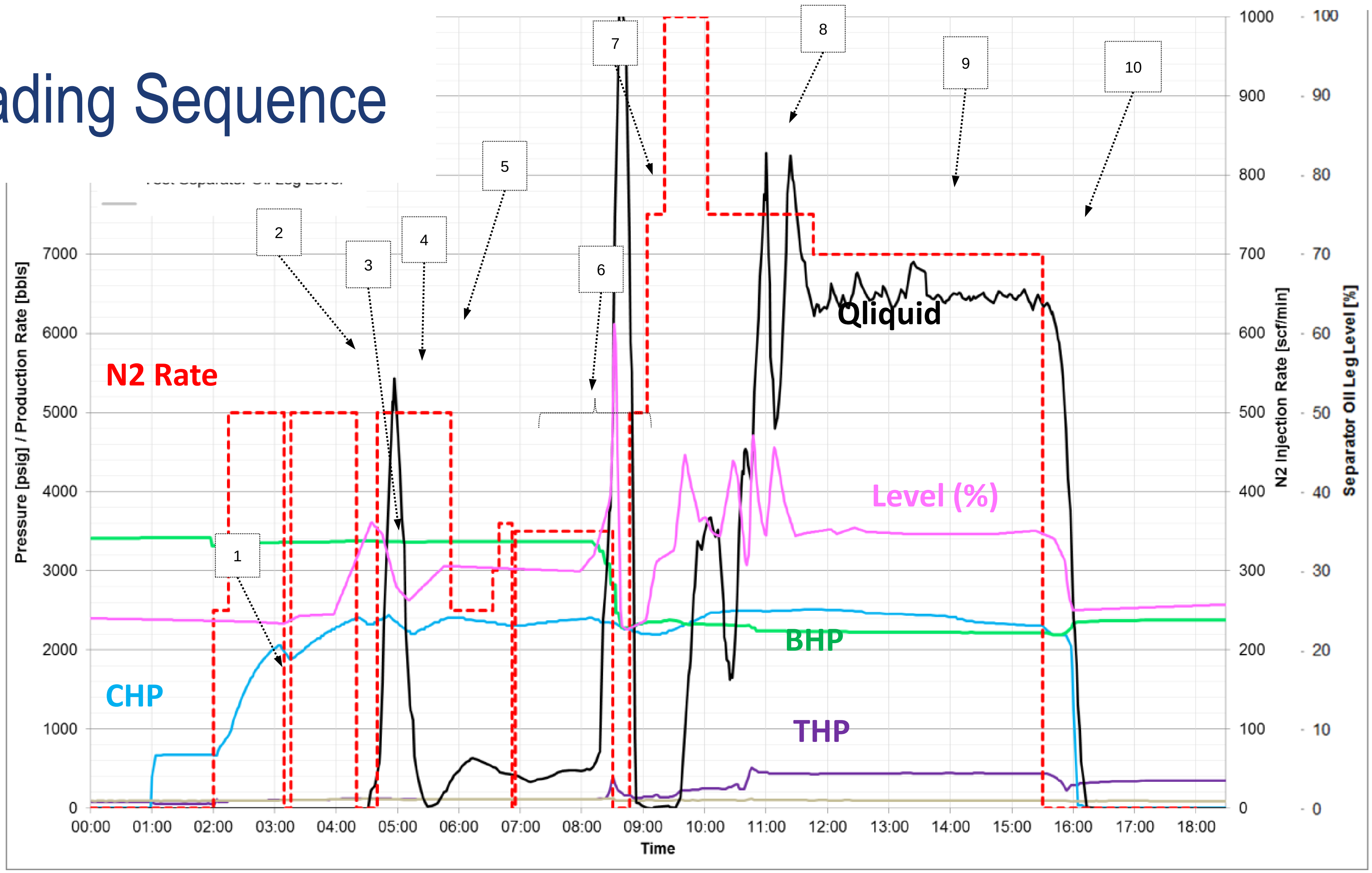
Backflow Upper Zone (Zone 1) With Nitrogen Assist



Backflow Middle & Lower Zones (2 & 3) With Nitrogen Assist



Unloading Sequence



- Start N_2 injection, CHP increasing [1]
- First flow from well at CHP = 2370 psi, higher pressure than expected [2]
- Test separator level control valve (LCV) opened. Large liquid slug and sharp drop in CHP [3]
- Stable brine unloading rate established at c. 0.3 bpm (< 1 bpm limit for valve flow cutting) [5]
- Annulus unloaded, a sharp drop in BHP and a large slug of fluid in the separator [6]
- Stable flow achieved at an average rate of 6400 bpd, 700-750 scf/min [9]
- N_2 injection stopped after 5-6 tubing volumes well shut-in [10]

Summary Results

Well	Zones	Valve MD ft	Valve TVD ft	Orifice Size	TRO @ 18 °C (psi)	N_2 Rate (scf/min)	Back Flow Rate (b/d)	Backflow to
HIE	1	3574	3200	10/64	1773	1000	5000 (water)	Well Test Package to burners or filtration
BIA	3	3998	3978	13/64	2070	1300	3500 (water) 4000 (oil)	Platform Test Separator via piggy back well
BIB	3	4227	3665	12/64	2063	1000	3000 (water) 3800 (oil)	Platform Test Separator via piggy back well
DIA (subsea)	3	4051	3769	12/64	2195	750	5000 (oil & water)	Well Test Package to burners or filtration
CIA	1	4522	3616	10/64	2088	750	6400 (oil)	Platform Test Separator via piggy back well

Observations:

- The CHP limit of 2500 psi should be reviewed and if possible increased to give a wider operational window to work with
- 2” temporary flowline creates a higher THP than expected (450 psi vs 300 psi design)
- 10/64” orifice has a nitrogen injection limit of around 750 scf/min (injecting at higher rates increased the pressure in the annulus, with no rate increase through the valve)
- Water injection achieved target rates with no evidence of mud impairment

Acknowledgements

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