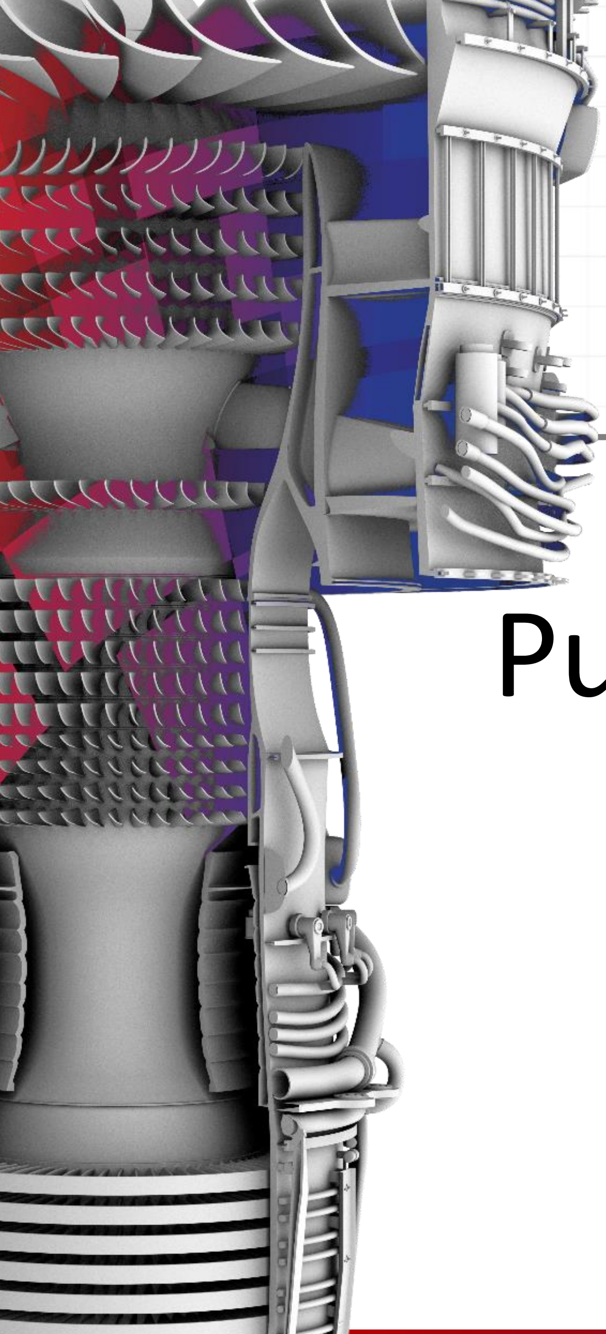


TURBOMACHINERY & PUMP SYMPOSIA

Testing and Troubleshooting of Pump Dry Gas Seals Operating with sCO_2

Stefan D. Cich, Dr. Jeff Moore, and Meera Towler

TEXAS A&M UNIVERSITY
TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

Authors

- Stefan Cich is a Senior Research Engineer in the Machinery Section at Southwest Research Institute (SwRI) in San Antonio, TX. He holds a B.S. in Aerospace Engineering from the University of Texas at Austin. While at SwRI, Mr. Cich has led the design and testing of various high speed turbines and compressors for power applications
- Dr. Jeffrey Moore is an Institute Engineer in the Machinery Section at Southwest Research Institute in San Antonio, TX. He holds a B.S., M.S., and Ph.D. in Mechanical Engineering from Texas A&M University. He is also a member of the Turbomachinery Symposium Advisory Committee, the IFToMM International Rotordynamics Conference Committee, and the API 616 and 684 Task Forces.
- Meera Day Towler, P.E. is a Research Engineer in the Machinery Section at SwRI. She has a B.S. in Mechanical Engineering and Mathematics and a M.S. in Controls and Dynamic systems from Southern Methodist University. While at SwRI, her research has included instrumentation, data acquisition, control systems, and performance testing for applications such as

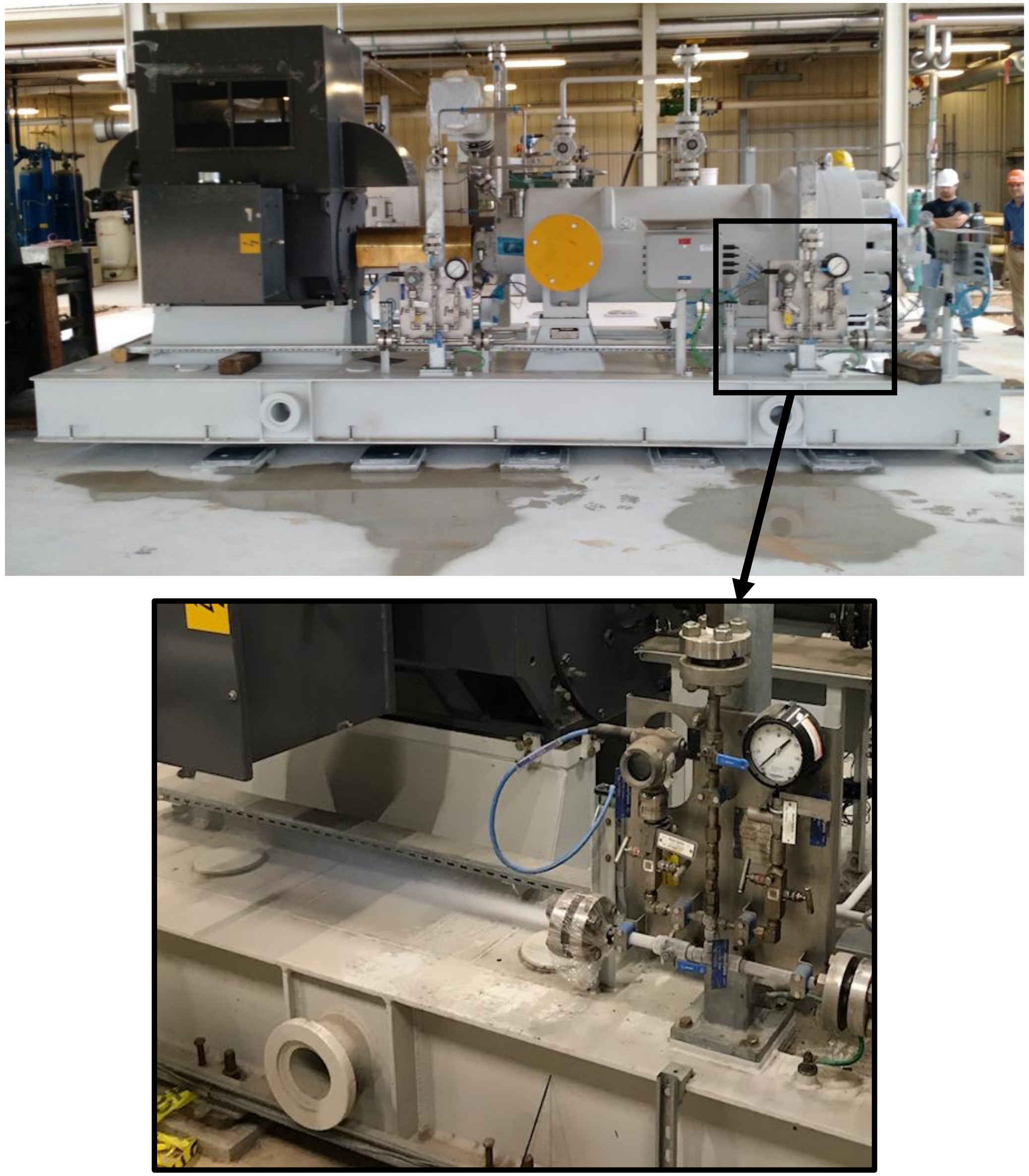
Stefan Cich

Jeff Moore, PhD

Meera Day Towler, P.E.

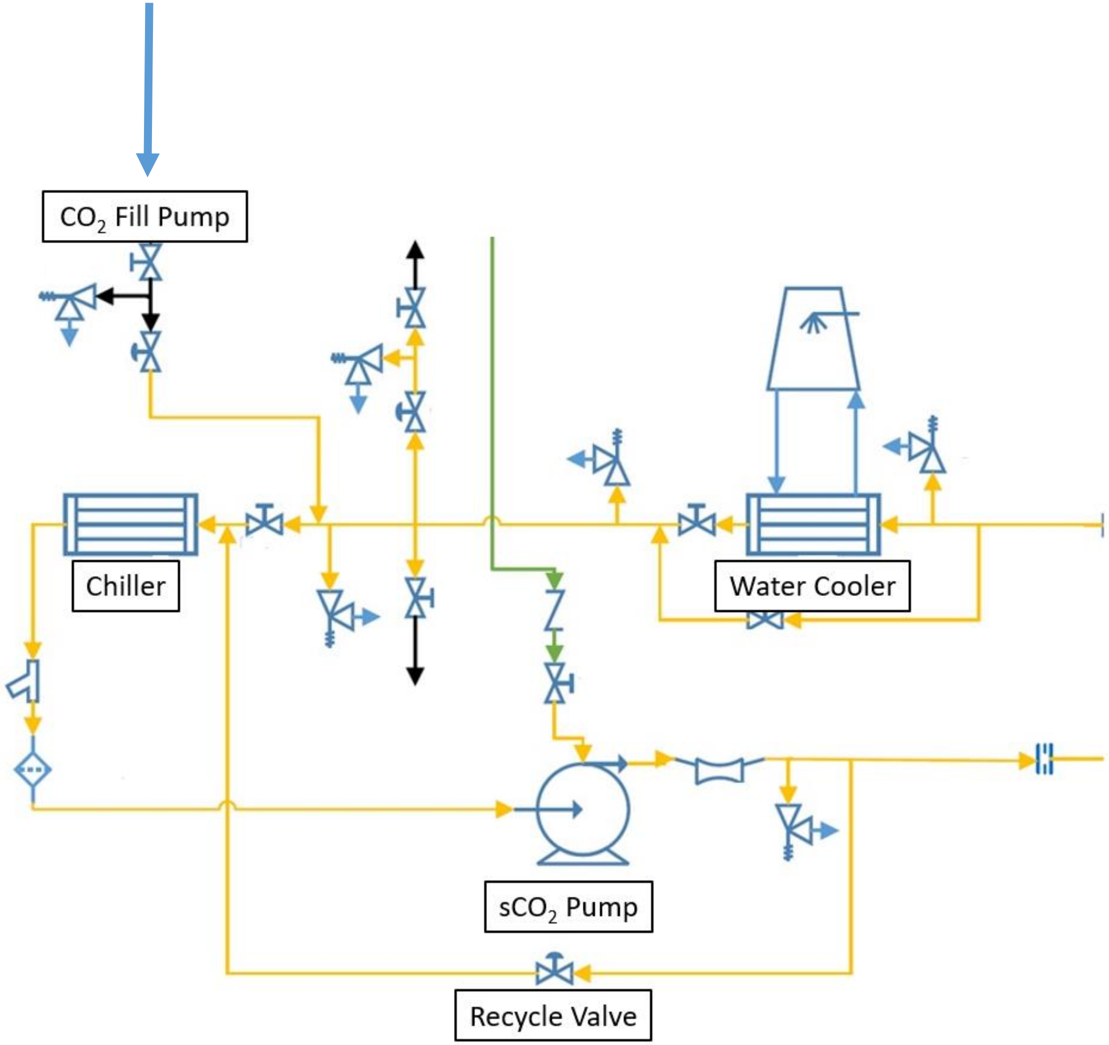
Problem Statement

- During filling and pressurizing of a supercritical carbon dioxide (sCO_2) test loop, the dry gas seals on the pump were opening and venting down the loop
- This delayed testing and required a detailed look at what was causing the dry gas seal faces to open up
- Initial assumption was the formation of dry ice in the seal

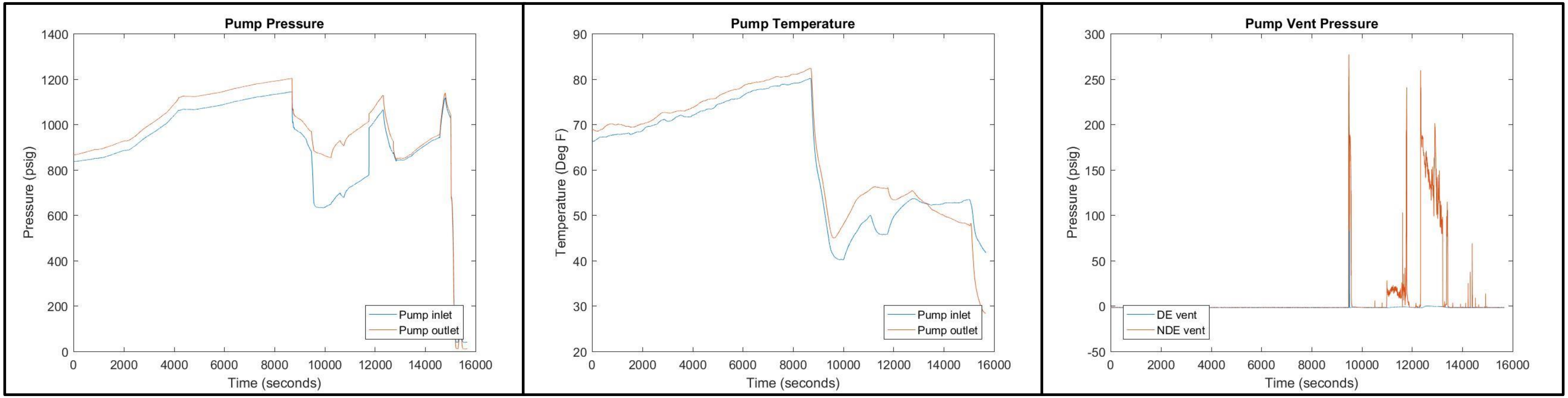


Analysis – Fill Procedure

1) Fill entire loop through single control valve from positive displacement fill pump
2) Pump dry gas seals are supplied by pump discharge which is equal to fill pressure
3) Turn on pump once pressure reaches >1200 psi and bring up to speed and head rise



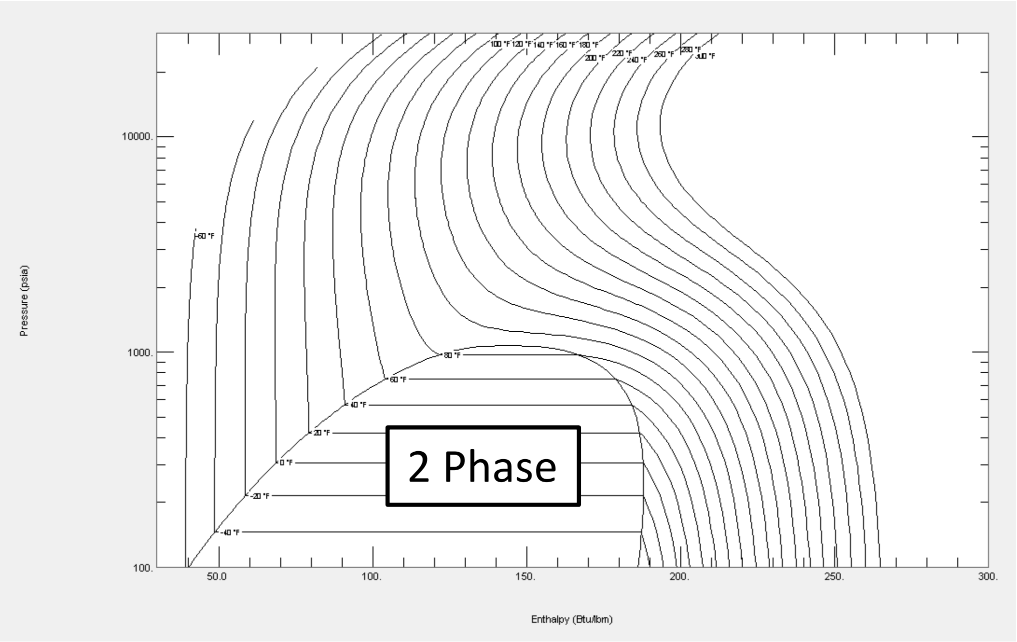
Analysis – Fill Procedure

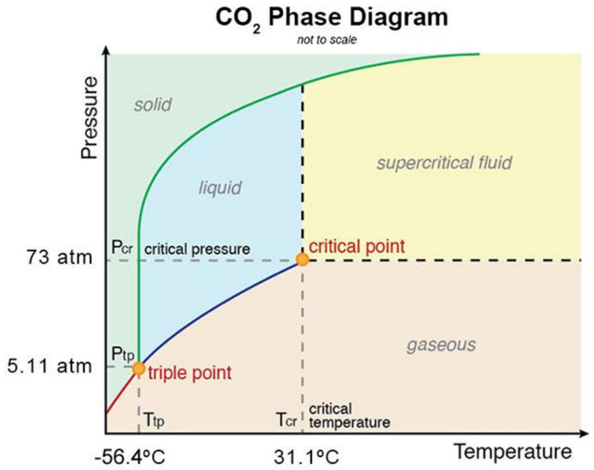


- Venting would occur around 1200 psi near 80F (Enthalpy = 115.2 Btu/lbm)
- Venting would continue until pressure dropped to around 600 psi and temperature around 40F once the seal would reseat itself

Analysis – CO_2 Phases

- Isenthalpic expansion across an orifice to atmosphere
- Orifice is the axial seal gap of the dry gas seal
- When dropping from high pressure to atmosphere, need to avoid dropping into two phase, solid and gas, region
- At enthalpy < 190 Btu/lbm, this can occur

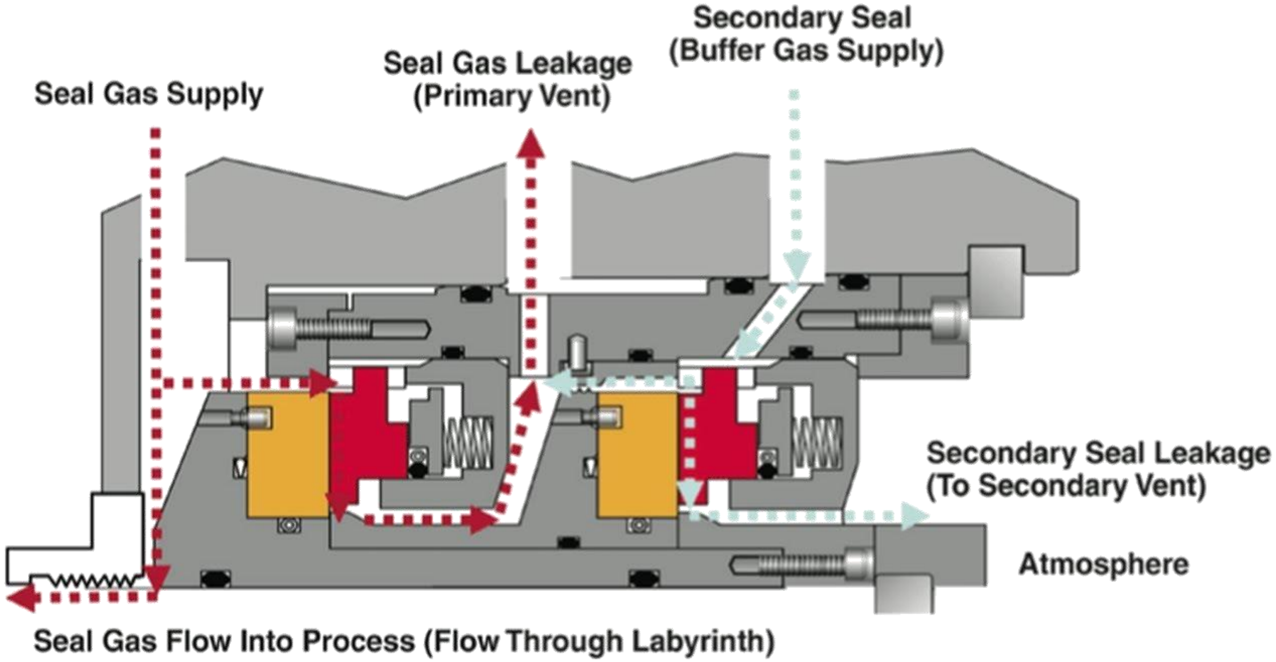




Analysis – Dry Gas Seal Overview

Understand how the dry gas seal operates

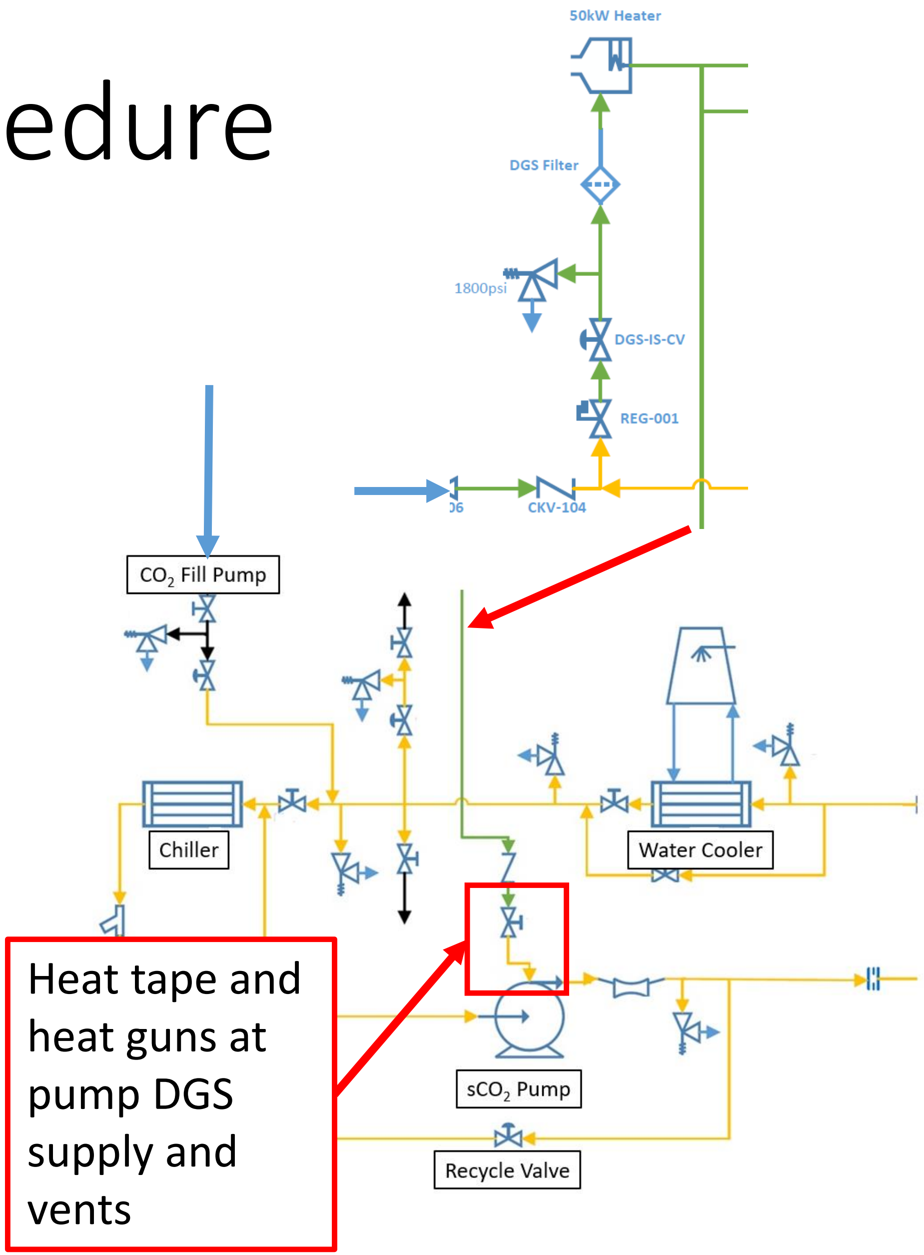
- Dry gas seal components
  1) Rotating ring
  2) Stator cart
  3) Axial face seal
- Dry gas seal flows
  1) Seal gas supply – High pressure
  2) Seal gas leakage- Atmosphere
  3) Secondary seal – Low pressure
- Possible dry ice formation in primary vent
- Upset pressure balance in the seal



Courtesy of youtube.com

Solution – Updated Fill Procedure

1) Simultaneously fill the main loop and pump dry gas seals
2) Dry gas seals are supplied with warm flow through a 50 kW heater
3) Once pump is turned out and builds head, it will supply its own seals
4) Heat generator from rotation and heat tape / heat guns



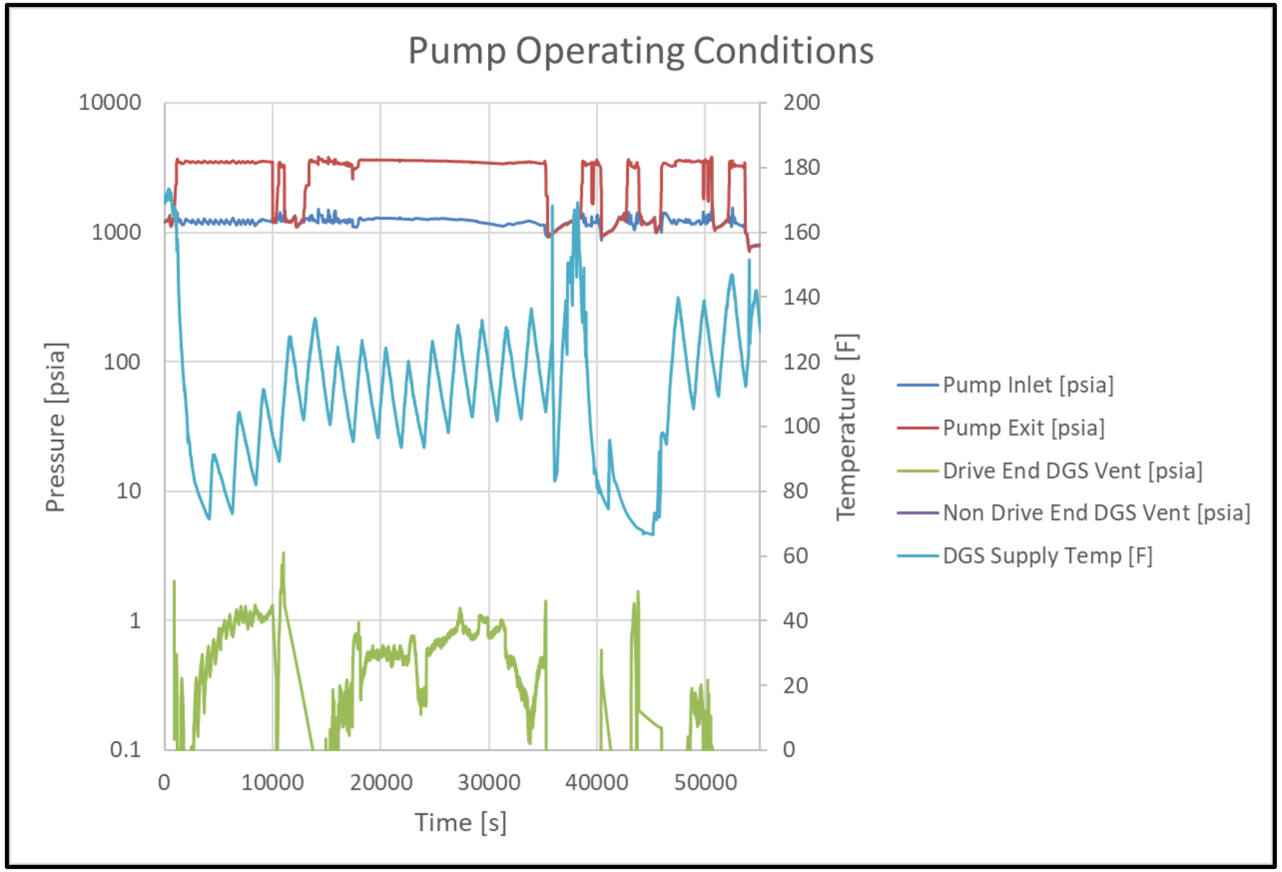
Solution – DGS Heater

- Dry gas seal supply temperature was monitored at the fill pump
- This chart shows the minimum temperature when filling to ensure no dry ice formations

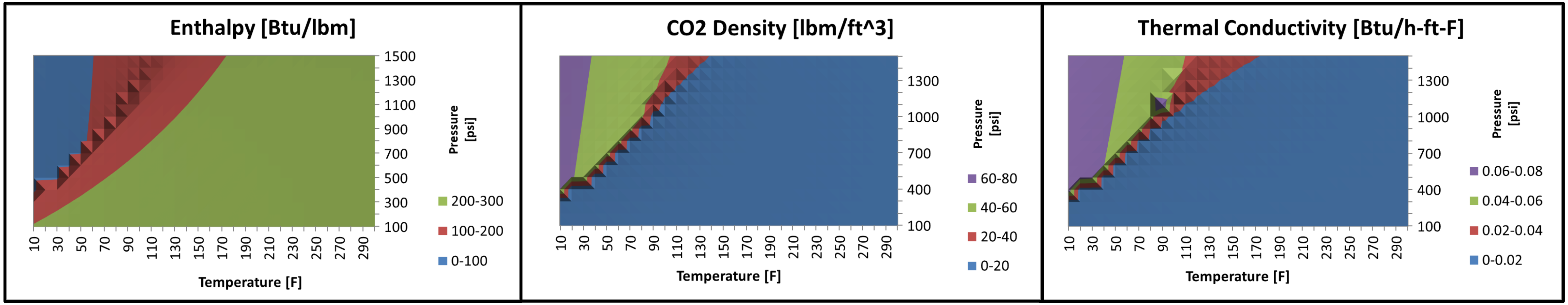
Temperature	Pressure	Density	Enthalpy	Entropy
F	psia	lbm/ft^3	Btu/lbm	Btu/lbm-R
-54.4	50	0.53	190.0	0.541
-40.5	100	1.07	190.0	0.511
-27.8	150	1.61	190.0	0.495
-15.9	200	2.17	190.0	0.484
5.7	300	3.29	190.0	0.468
25.0	400	4.44	190.0	0.458
42.4	500	5.60	190.0	0.451
58.2	600	6.77	190.0	0.445
72.7	700	7.95	190.0	0.440
86.0	800	9.12	190.0	0.436
98.2	900	10.28	190.0	0.433
109.5	1,000	11.43	190.0	0.429
120.0	1,100	12.56	190.0	0.427
129.7	1,200	13.66	190.0	0.424
138.7	1,300	14.74	190.0	0.422
147.0	1,400	15.79	190.0	0.420
154.8	1,500	16.82	190.0	0.418

Results

- With warm supply flow and extra heat from heat guns and heat tape, dry gas seal vent pressure never got above 5 psi
- This indicates no blockage or dry ice build up that would lead to seal failure
- Supply temperature is warmer when pump is not spinning
- Once spinning, seals will continue to generate heat



Lessons Learned – CO_2 Properties



- Important to understand CO_2 properties when determining required heat input for dry gas seals
- Large changes in required enthalpy, velocities with constant mass flow, and thermal conductivity of the fluid
- Size heater for nominal conditions but understand that it needs to have enough capacity during liquid phases

Lessons Learned – Heat Transfer

- With constant mass flow, more heat input required at higher pressures
  - At 70F, enthalpy is around 190 btu/lbm up to 700 psi
  - Above 700 psi, enthalpy drops to 100 btu/lbm
- Important to understand nominal and off design performance of heater to ensure enough heat input with high density flows

$$Q_{in} = \dot{m}(h_2 - h_1)$$

$$htc = \frac{N_u \mathrm{k}}{L}$$

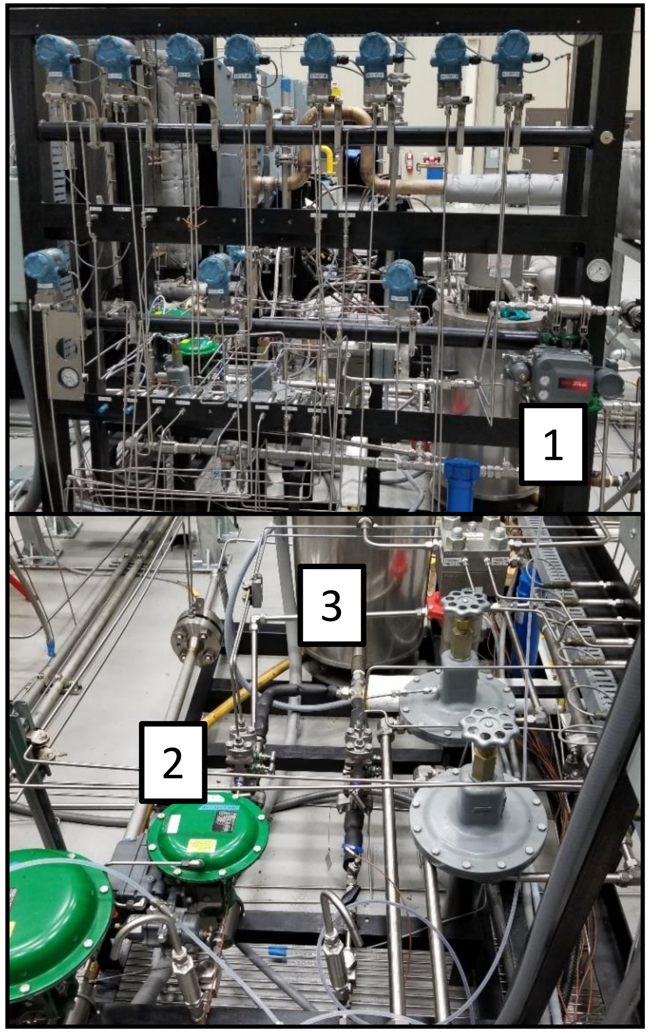
$$N_u = 0.023 {Re_D}^{4/5} Pr^n$$

$$Re_D = \frac{DV\rho}{\mu}$$

Lessons Learned – DGS Heater Placement

1. Main control valve
2. Control valve after heater
3. Dry gas seal heater

- Account for Joule Thompson Cooling
- Supplying from 3700+ psi to 1200 psi
- Take bulk of pressure drop prior to heater



Conclusion

- With a cold supply of CO_2, dry gas seals will require a heat source
- In the case of a higher temperature compressor, the inlet flow could by warm enough during operation but still needed for filling and steady holds
- With interest in Supercritical CO_2 growing, heater requirements for dry gas seals are important to consider win determining the thermal efficiency of a complete cycle
- For a pump with cold flow, a dry gas seal opening up will not always lead to other component failure, but for a turbine, the failure could lead to complete failure of the machine

Questions?