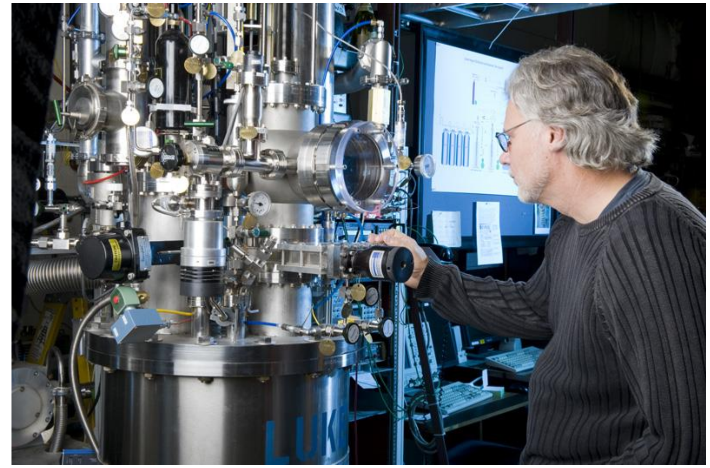
Noble Liquid Test Facility Fill Rate Optimization

Shawn McPoyle
Student Undergraduate Laboratory Internship Presentation – Fall 2022
7th December 2022

Nobile Liquid Test Facility – Cryogenic System

Fermilab. (n.d.). *Tall Bo Cryostat*. Fermilab Neutrino Physics - Liquid Argon Facilities. Retrieved August 31, 2022, from https://neutrinophysics.fnal.gov/wp-content/uploads/2017/05/tallbo.jpg.

Nobile Liquid Test Facility – Cryogenic System



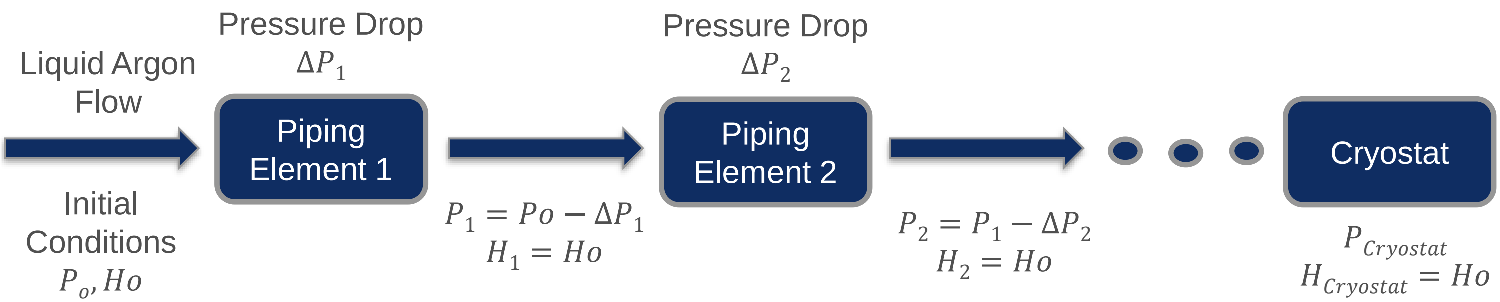
Fermilab. (n.d.). *Luke Cryostat*. Fermilab Neutrino Physics - Liquid Argon Facilities. Retrieved August 31, 2022, from https://neutrinophysics.fnal.gov/wp-content/uploads/2017/05/luke.jpg.

Nobile Liquid Test Facility – Cryogenic System

Project Goals and Methods

Project Goals

- Create a physical model of the cryogenic system to
  - Improve understanding of the system
  - Identify the most impactful factors in the system
- Make recommendations for upgrades to
  - The cryogenic system itself
  - Sensors and data collection equipment




```python
#For loop to iterate through cryostat path
for elementNum, element in enumerate(cryostatArray):
    elementType, elementID, elementL, elementAngle = element

    fluid.update_kw(P=P_element, Hmass=fluid.Hmass)
    Q = fluid.Q
    k  = K2(elementType, elementL, elementID, elementAngle, Qt, fluid)
    dP = dP_Darcy(elementType, elementL, elementID, k, Qt, CvValve(elementType), fluid)
    P_element -= dP

    sensorP = sensorDict.get(elementNum, 0*ureg.Pa)
    Results.append([elementNum, element[0], k, dP.m_as(pressure_unit), P_element.m_as(pressure_unit),
                    sensorP.m_as(pressure_unit), Q.m_as(ureg.dimensionless)])
```


Fermilab

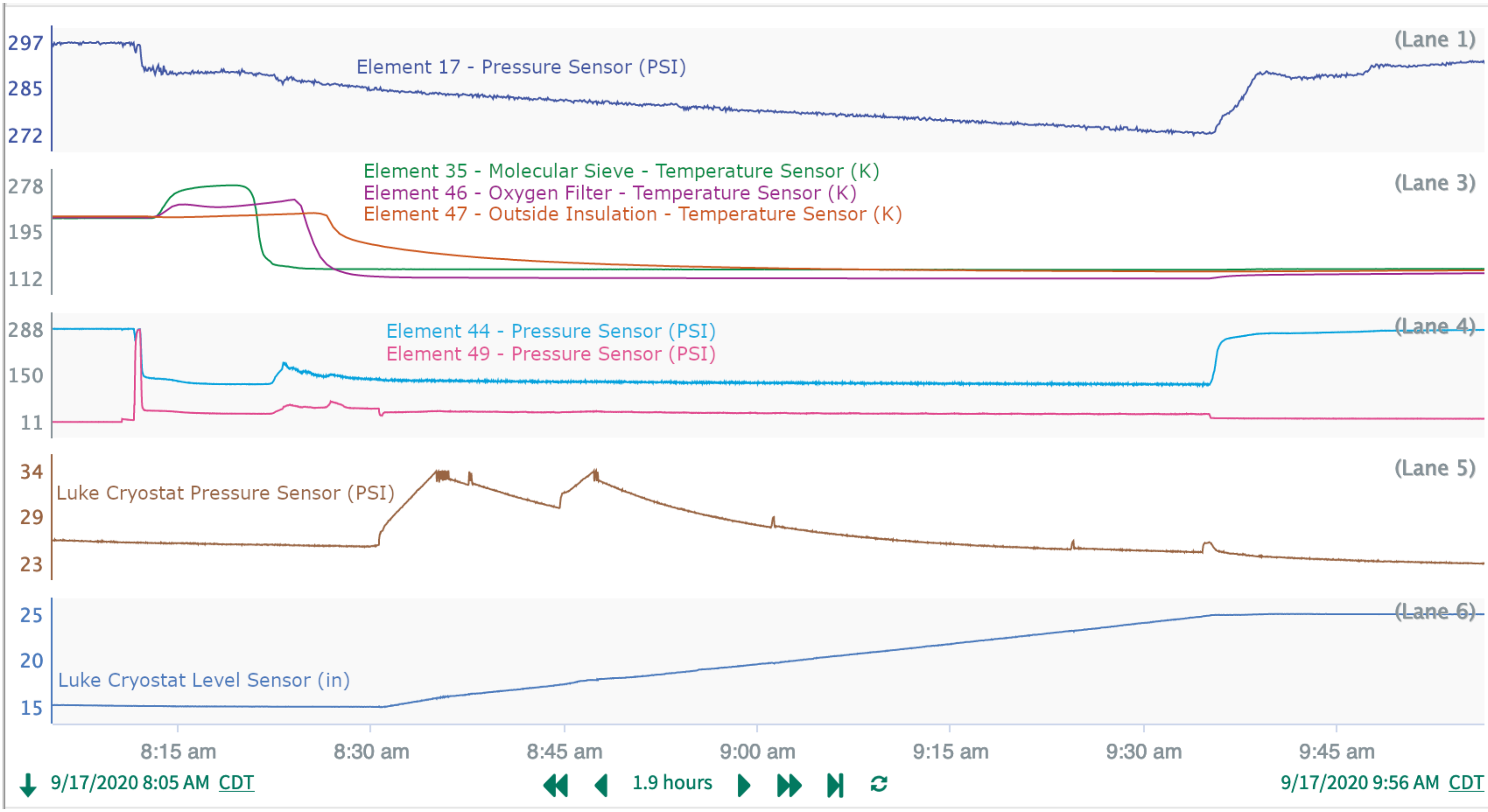
Assumptions

1. Saturated liquid argon enters the system
2. Flashing and boiloff/evaporation are not significant in the transfer line
3. Density and viscosity of liquid argon is held as constant
4. Changes of elevation are not significant
5. The system is perfectly insulated and the flow has constant enthalpy
6. Fully turbulent flow through the system

Assumptions

1. Saturated liquid argon enters the system
2. Flashing and boiloff/evaporation are not significant in the transfer line
3. Density and viscosity of liquid argon is held as constant
4. Changes of elevation are not significant
5. The system is perfectly insulated and the flow has constant enthalpy
6. Fully turbulent flow through the system

Seeq Data Example

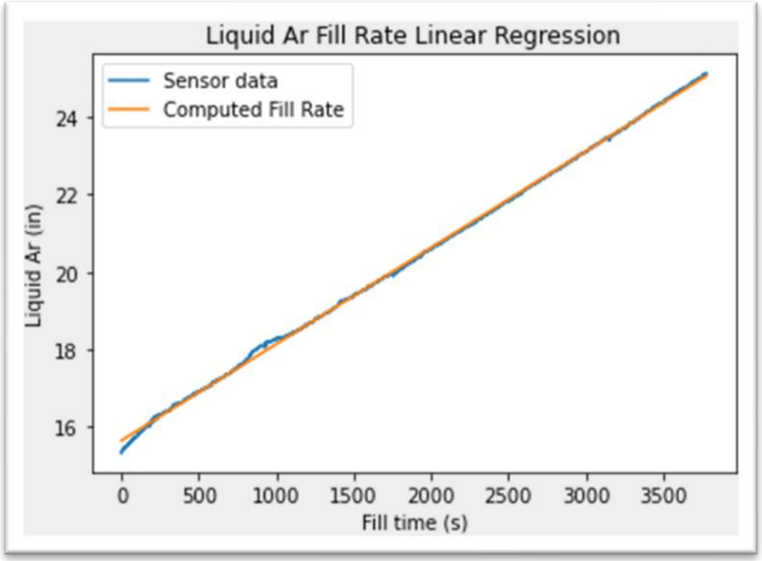


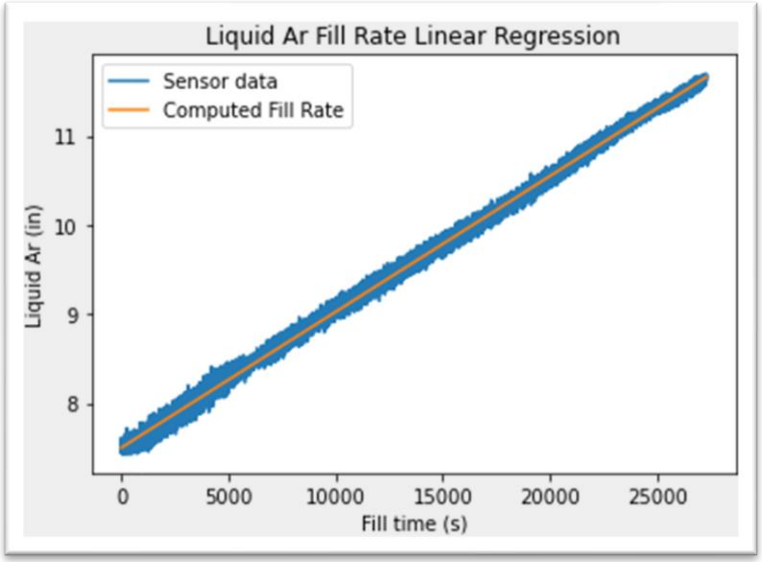
Luke Cryostat fill from 9/17/2020

Fermilab

Sensor Data Processing

- Pressure and temperature sensors are averaged over the data range
  - Temperature sensor data is converted into pressures
- Level sensor data is processed to get the average liquid fill rate over the time range



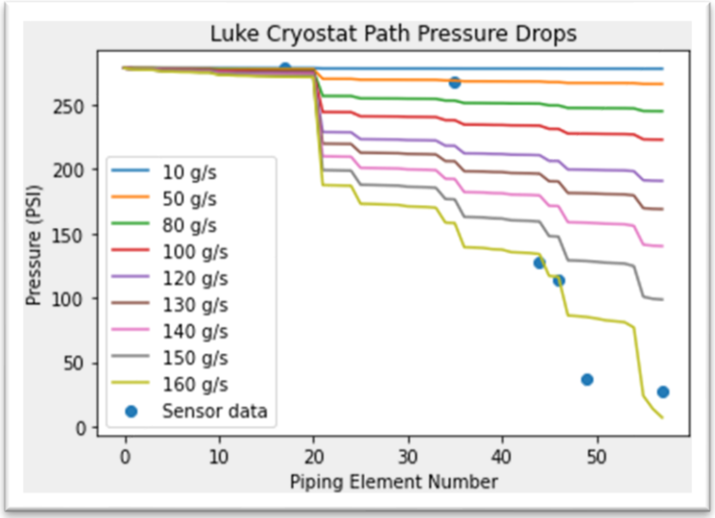


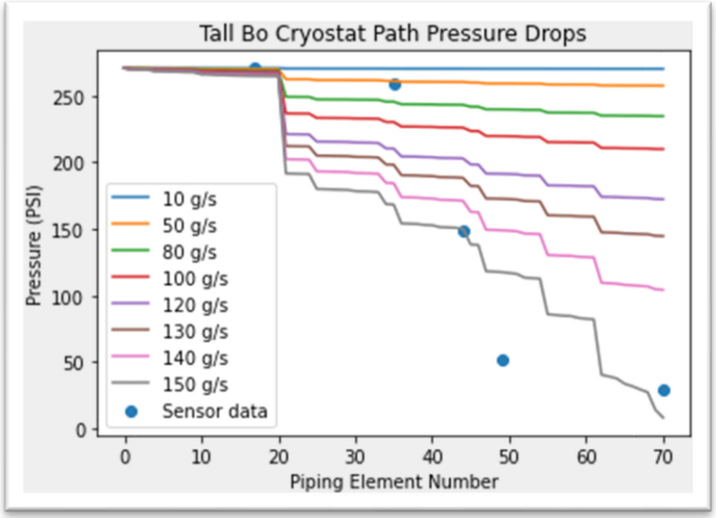
Liquid level Sensor Processing for Luke (left) and Iceberg (right) cryostats

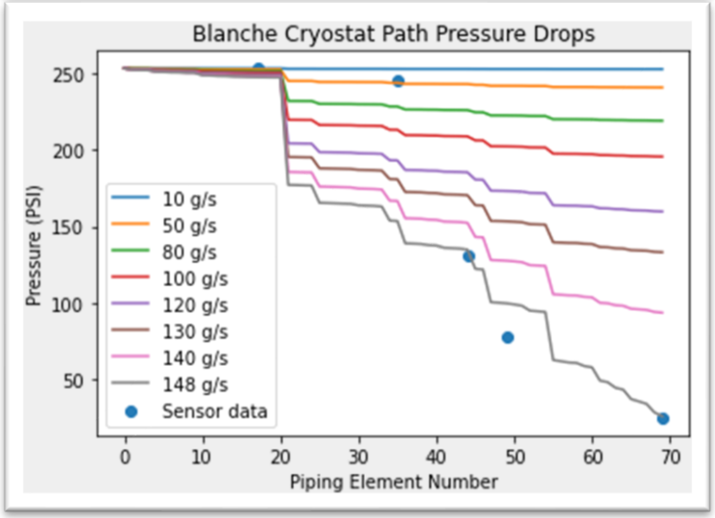
Example Output Data

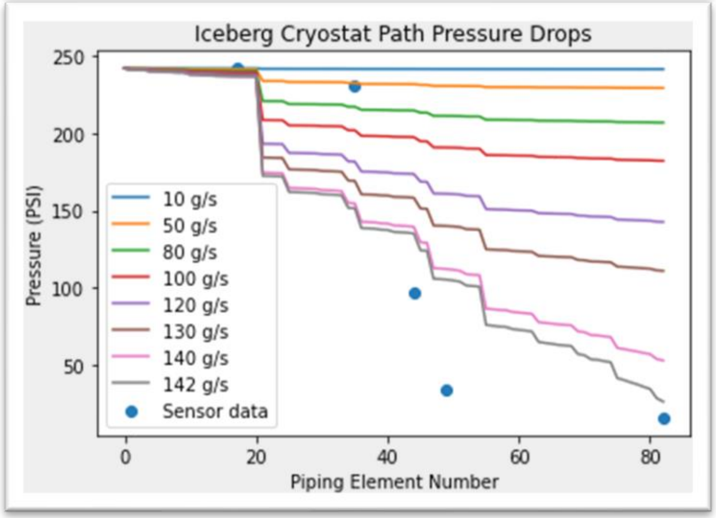
Element #	Element Type	K	dP (psi)	Pressure (psi)	Sensor Pressure (psi)	Q
30	Pipe	3.968	0.005	277.276	0.000	0.001
31	Elbow	0.827	0.001	277.275	0.000	0.001
32	Elbow	0.827	0.001	277.274	0.000	0.001
33	Pipe	1.984	0.002	277.272	0.000	0.001
34	Molecular Sieve	0.000	0.063	277.209	0.000	0.001
35	Pipe	1.323	0.002	277.207	267.768	0.001
36	Swagelock Valve	0.000	0.069	277.138	0.000	0.001
37	Pipe	0.661	0.001	277.137	0.000	0.001
38	Elbow	0.827	0.001	277.136	0.000	0.001
39	Pipe	2.315	0.003	277.133	0.000	0.001
40	Elbow	0.827	0.001	277.132	0.000	0.001
41	Pipe	4.630	0.006	277.126	0.000	0.001
42	Elbow	0.827	0.001	277.125	0.000	0.001
43	Elbow	0.827	0.001	277.124	0.000	0.001
44	Pipe	1.984	0.002	277.121	127.559	0.001
45	Oxygen Filter	0.000	0.063	277.058	0.000	0.001
46	Pipe	1.323	0.002	277.057	113.661	0.001
47	Swagelock Valve	0.000	0.069	276.987	347.553	0.001
48	Pipe	0.661	0.001	276.986	0.000	0.001
49	Elbow	0.827	0.001	276.985	37.639	0.001
50	Pipe	1.323	0.002	276.984	0.000	0.001
51	TeeBranch	1.690	0.002	276.982	0.000	0.001
52	Elbow	0.827	0.001	276.981	0.000	0.001
53	Elbow	0.827	0.001	276.980	0.000	0.001
54	Pipe	4.630	0.006	276.974	0.000	0.001
55	Swagelock Valve	0.000	0.069	276.904	0.000	0.001
56	Pipe	2.646	0.003	276.901	0.000	0.001
57	Exit	1.000	0.001	276.900	27.797	0.001

Example Output Data









Recommendations and Future Work

- Analyze vapor mass flow rate in the system
  - Direct measurements
  - Heat load analysis
- Optimize oxygen deficiency mitigation strategy
  - Substitute orifice with different system
- Redesign filters
  - Add filter bypass
  - Optimize design for lower pressure drop

References

[1] Crane Co. (2022). *Flow of fluids through valves, fittings and pipe. Technical Paper No. 410*.

[2] Reader-Harris, M. J., & Sattary, J. A. (1990). The orifice plate discharge coefficient equation. *Flow Measurement and Instrumentation*, *1*(2), 67–76. https://doi.org/10.1016/0955-5986(90)90031-2

[3] Fermilab. (n.d.). *Noble Liquid Test Facility*. Neutrino physics. Retrieved December 6, 2022, from https://neutrinophysics.fnal.gov/facilities/liquid-argon-facilities/

[4] Ergun, Sabri. "Fluid flow through packed columns." Chem. Eng. Prog. 48 (1952).

[5] Thome, J. R. (2004). *Engineering Data Book III*. Wolverine Tube Inc.

[6] Bell, I. H., Wronski, J., Quoilin, S., & Lemort, V. (2014). Pure and pseudo-pure fluid thermophysical property evaluation and the open-source Thermophysical Property Library coolprop. *Industrial & Engineering Chemistry Research*, *53*(6), 2498–2508. https://doi.org/10.1021/ie4033999