Computational Analysis of Fluid Transients in Nuclear Waste Transfer Pipelines at Hanford Site

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Abstract

- A computational fluid dynamics simulation was produced to simulate pressure profiles in a pipeline caused by a plug removing device.
- The unplugging device created pulses in a fluid and gas two-phase pipeline using hydraulic cylinders. .

Background

- As a result of nuclear weapons production a significant amount of nuclear waste was produced and stored in underground tanks in various sites across the country.
- These storage tanks are now degrading which necessitates pumping the radioactive wastes stored within to new sites.
- A common problem found in the piping systems that achieve this task is that they produce clogs in the pipeline which are referred to as a “plug.” These plugs create a blockage in the line which puts a halt to all fluid transfer within.
- The Applied Research Center and Department of Energy have developed a method to remove said plugs with a device known as the Asynchronous Pulsing Unit (APU).
- This device simultaneously sends a positive pressure pulse to one side of the plug while creating a negative pressure at the other side to dislodge it.

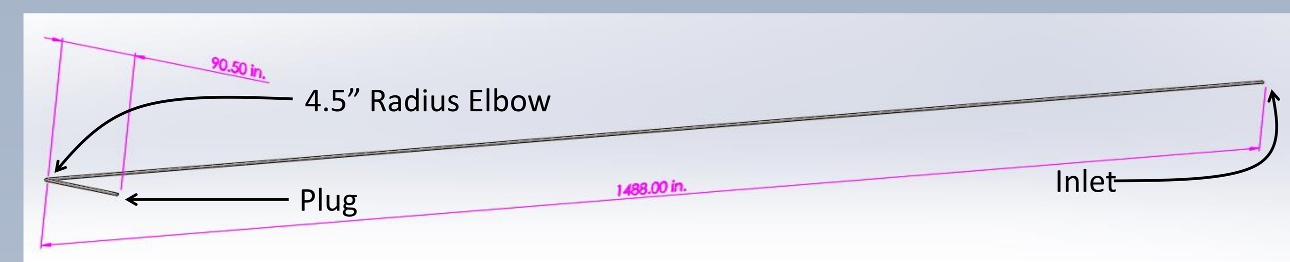
Objective

The motivation for simulating this process takes on multiple facets:

- Investigating the effect that entrained air has on the pulse generation and transfer of pressure wave propagation to the plug.
- Dynamically model and monitor variations of the APU systems without physically building or modifying anything, resulting in a highly efficient and stream-lined process for characterization and development.
- Producing a CFD method that can be extrapolated and implemented in a variety of APU piping systems determining the amplification and delay characteristics of said systems.

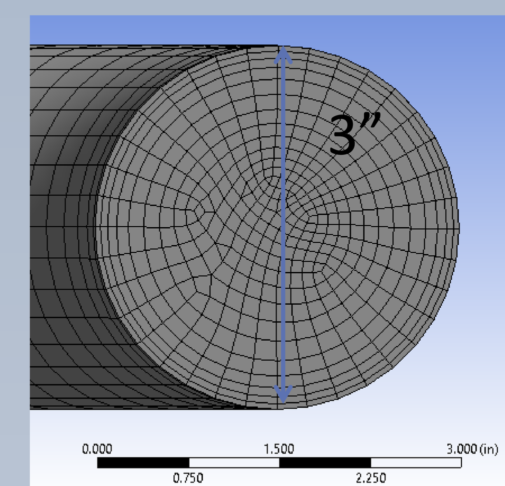
Methodology

1) Computational Domain



2) Mesh Characteristics

- Sweep Method
  - Minimum Element Size: 0.1”
  - Maximum Element Size: 2”
  - Number of Elements: 731,900



3) Governing Equations:

- *Volume of Fluid Equation (Continuity)*

$$\frac{1}{\rho_q}\left[\frac{\partial}{\partial t}(\alpha_q\rho_q) + \nabla\cdot(\alpha_q\rho_q\vec{v}_q) = S_{\alpha_q} + \sum_{p=1}^{n}(\dot{m}_{pq}-\dot{m}_{qp})\right]$$

- *Momentum Equation*

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla\cdot(\rho\vec{v}\vec{v}) = -\nabla p + \nabla\cdot\left[\mu(\nabla\vec{v}+\nabla\vec{v}^T)\right] + \rho\vec{g} + \vec{F}$$

- *Energy*

$$\frac{\partial}{\partial t}(\rho E) + \nabla\cdot(\vec{v}(\rho E + p)) = \nabla\cdot(k_{eff}\nabla T) + S_h$$

$$E = \frac{\sum_{q=1}^{n}\alpha_q\rho_q E_q}{\sum_{q=1}^{n}\alpha_q\rho_q}$$

4) Finite Volume Method

- Computation domain divided into finite number of control volumes with variable of interest at centroid.
  - $V_r, r = 1, \ldots, N$
  - $u_r = \frac{1}{V_r}\int u(x)dx$
- With governing equation, $\frac{\partial u}{\partial t} + \frac{\partial f}{\partial x} = 0$, integration occurs to produce,

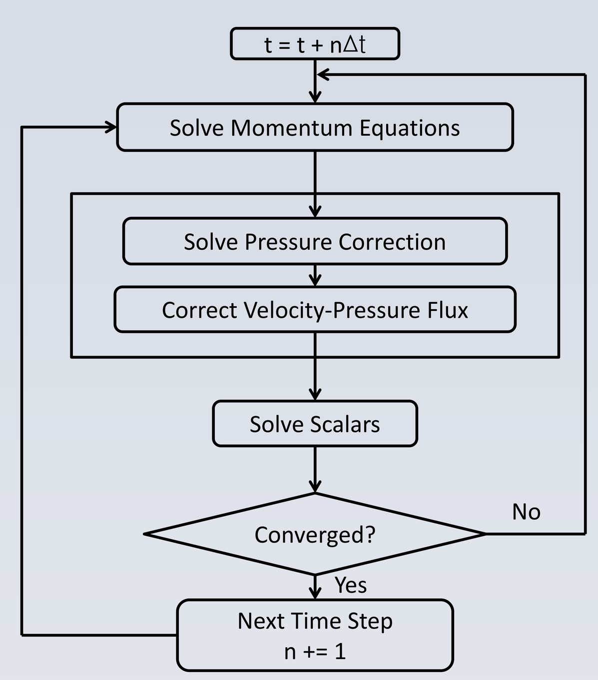
  $\frac{\partial}{\partial t}\int_V u dx + \oint_{\partial V} f_i n_i ds = 0$, where u is the variable of interest and f is the flux function associated with that variable.
- Interpolation profiles are then assumed to describe variation between one node and the next, which is known as the discretization equation.
- It is this discretized equation that expresses the conservation of the variable of interest at a particular node.

5) Pressure-Implicit with Splitting of Operators (PISO) Solver[1]

- Pressure implicit scheme
- Pressure-velocity coupling.
- Pressure-velocity correction

occurs at each time step.

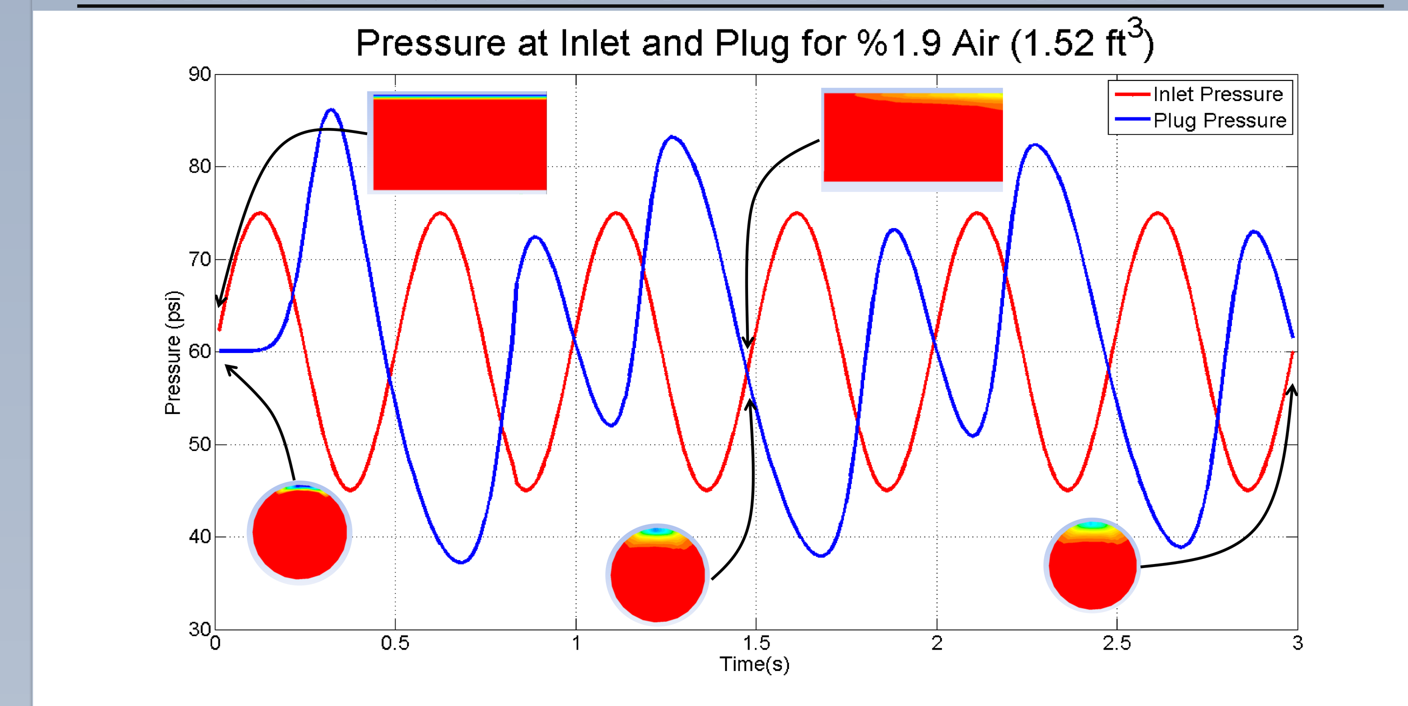
- Satisfies Momentum Balance

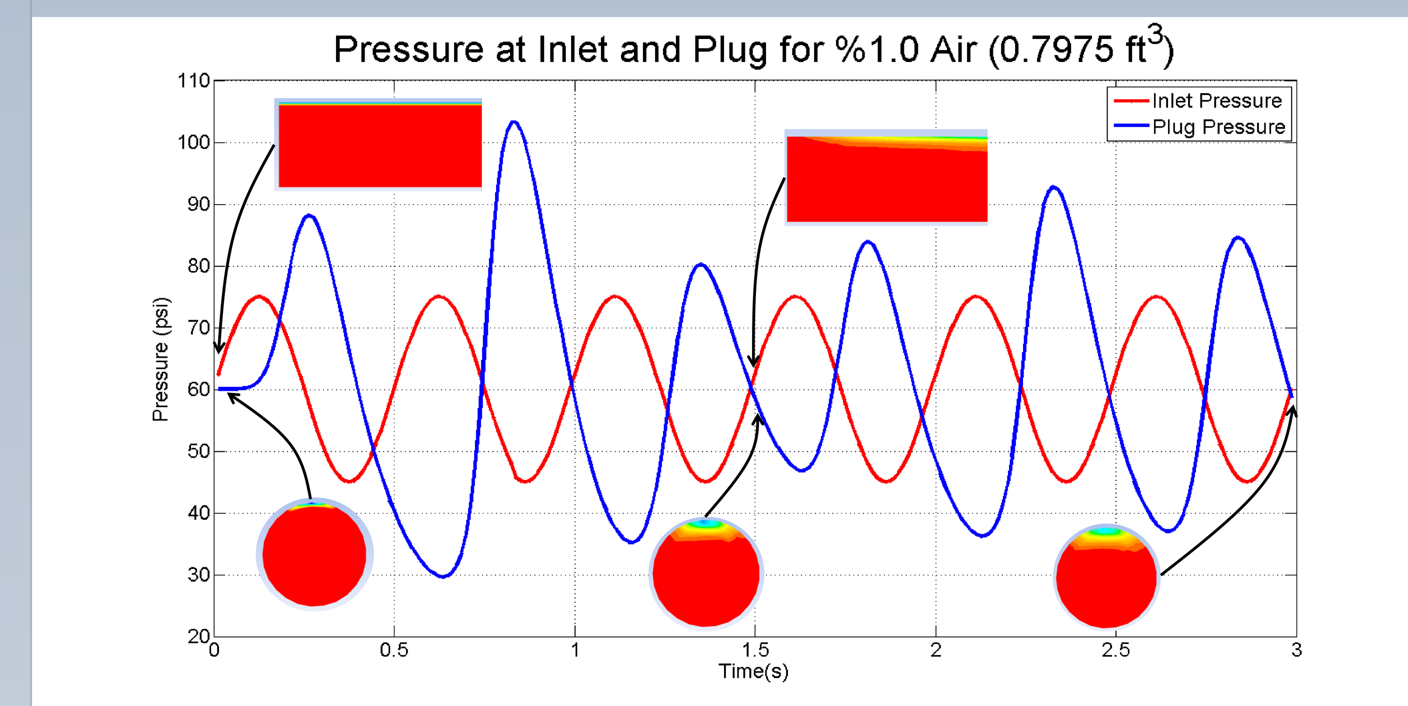


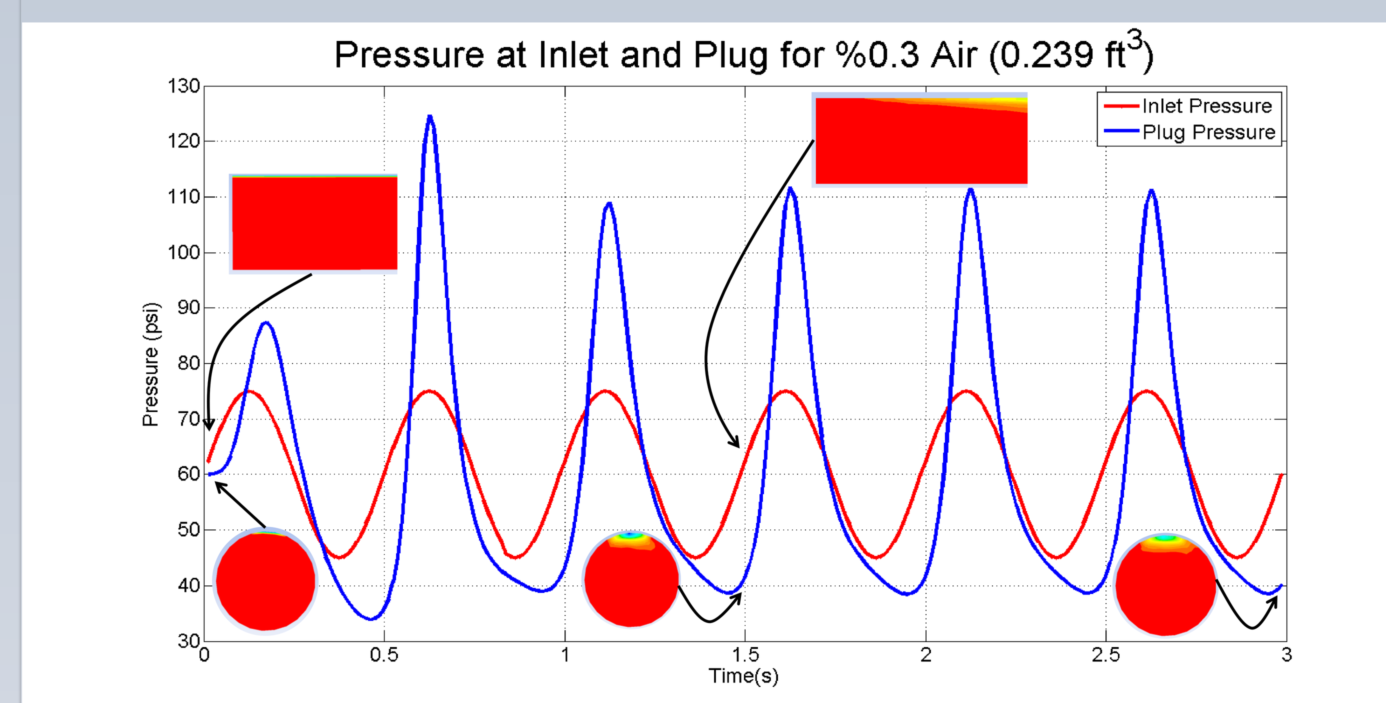
[1]*ANSYS Theory Guide,*

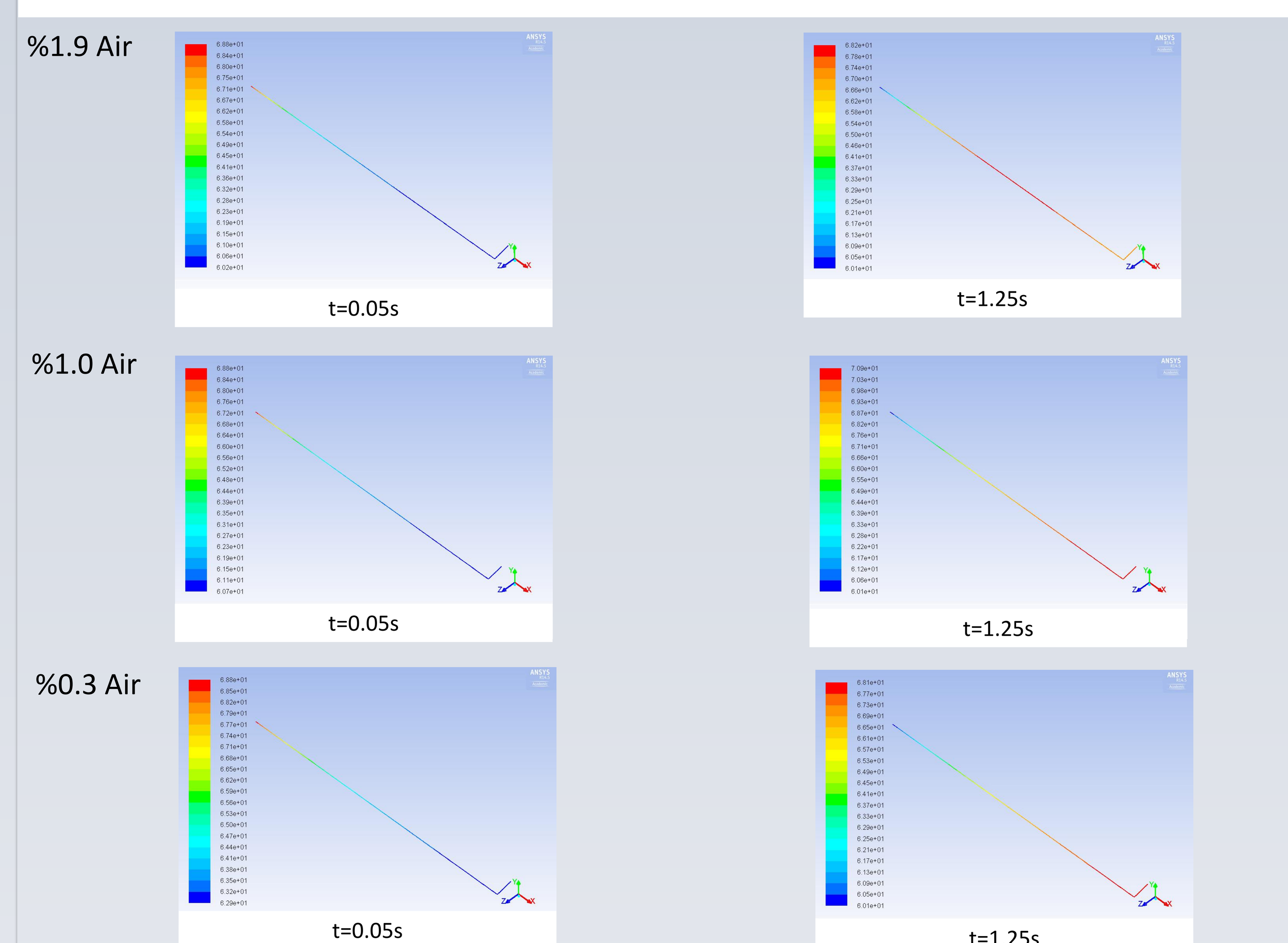
ANSYS Inc., Canonsburg PA, V14.5

Pressure and Volume Fraction Profiles at 2Hz

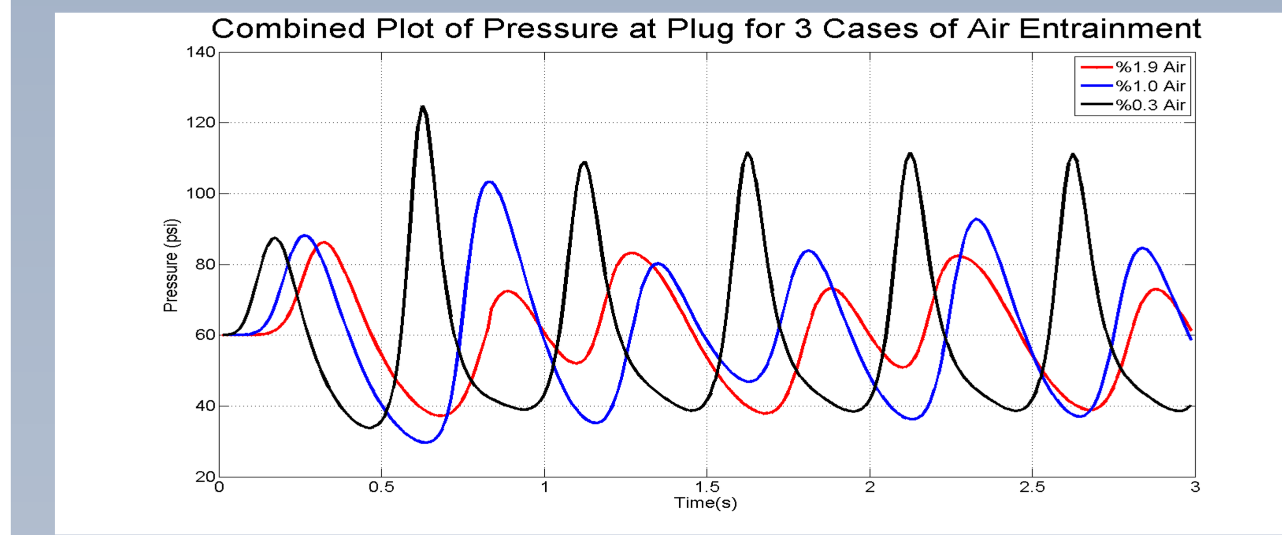


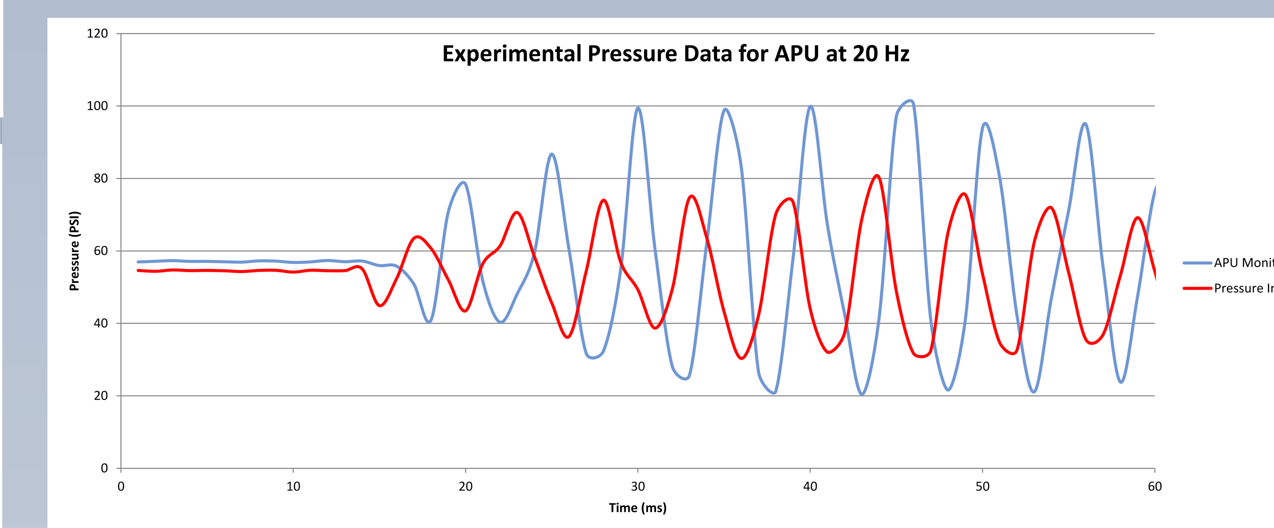






Discussion, Conclusion, and Benefits





- Both the amplification and pulse delay are observed in the experimental data as well as the simulation data.
- Increasing the amount of air entrained in the system will not only reduce the amplitude of the pressure wave being sent down the line, but also effects the speed at which the wave propagates due to the difference in the speed of sound for water and air.[3]
- CFD results and analysis have proven to be a quality tool to determine amplification and wave propagation in piping systems for unplugging. This methodology can be extrapolated and employed for the piping systems found at the Hanford sites.

[3]Wylie, Evan Benjamin, and Victor Lyle Streeter. Fluid Transients.

New York: McGraw Hill, International Book, 1978. Print.

Future Work

- Acquire experimental data to relate simulation results to similar frequency.
- Add mirrored side of APU system.
- Incorporate Grade to accommodate for buoyancy of gas phase.

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