Micro-Encapsulated Phase Change Materials: Validation of Pressure Apparatus Design

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Background

- Over 50% of all energy sources within the USA comes from fossil fuels with energy consumption estimated to increase 15% by the end of 2050
- A solution to the growing need for energy is usage of High-Temperature Latent Heat Thermal Energy Storage (HT-LHTES) systems
- Comprises of metal microparticles that are encapsulated in silicate glass with diameters less than 100µm

Motivation

- Current methods of producing micro-encapsulated phase change materials (PCMs) are too costly for mass production and are constrained by material selection, for example:
  - Thermal Oxidation, Chemical Vapor Deposition, Phase Separation
- A pressure vessel was designed to integrate Flow - Focus Coaxial Continuous Casting as a method for producing Phase Change Materials, as seen in Figure 1.
- The design will allow smaller designs of Thermal Energy Storage systems with higher energy capacity of Latent Heat
- To ensure the pressure vessel design falls within the standards provided by American Society of Mechanical Engineers, simulations were done in ANSYS Static Structural, followed by Ansys Fluent Simulations to better understand the flow through the nozzle of the Pressure Apparatus

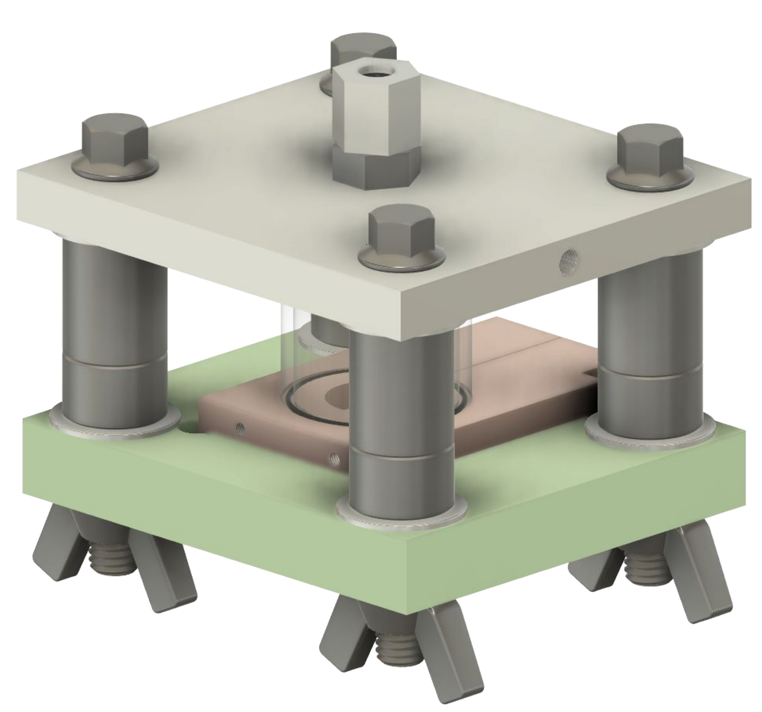

Figure 1. Pressure Apparatus

Methods - Finite Element Analysis

1. According to the ASME Boiler and Pressure Vessel Code, Division 1, the pressure apparatus must withstand 3.5 times the max operating pressure.
2. With the given standard, the max operating pressure is set at 10 atm in order to eliminate bubble nucleation that occurs when metal is heated close to boiling point.
3. Finite Element Analysis was done in Ansys Static Structural on the Quartz-Infused Glass. The material properties for the material is shown in Table 1, and inputted as Engineering Data in Static Structural Solver. A mesh size of 0.5mm was used to generate the mesh and the boundary conditions for the glass tube are shown in Figure 2.
4. The simulations were performed showing the von-Mises stress and safety factor.

Table1. Material Properties of Quartz-Infused Glass

Material	Quartz-Infused Glass
Density (kg/m^{3})	2201
Young's Modulus (MPa)	72000
Poisson's Ratio	0.17
Tensile Yield Strength (MPa)	48
Tensile Ultimate Strength (MPa)	50
Compressive Ultimate Strength (MPa)	1100

Boundary Conditions - Finite Element Analysis

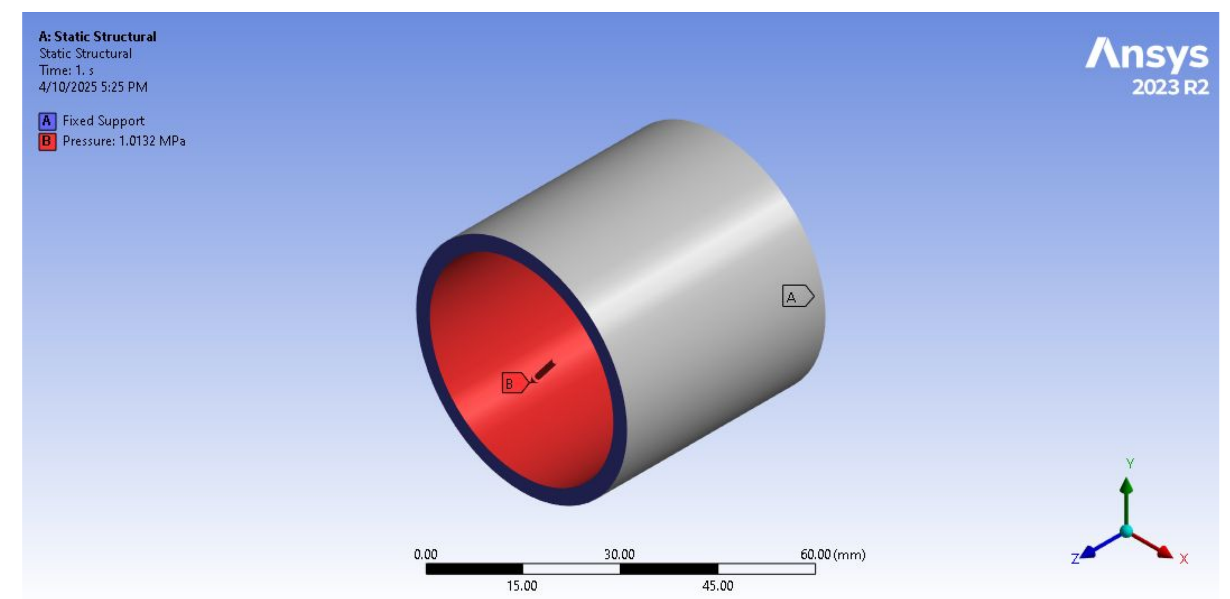

Figure 2. Boundary Conditions for Quartz-infused Glass

Results - Finite Element Analysis

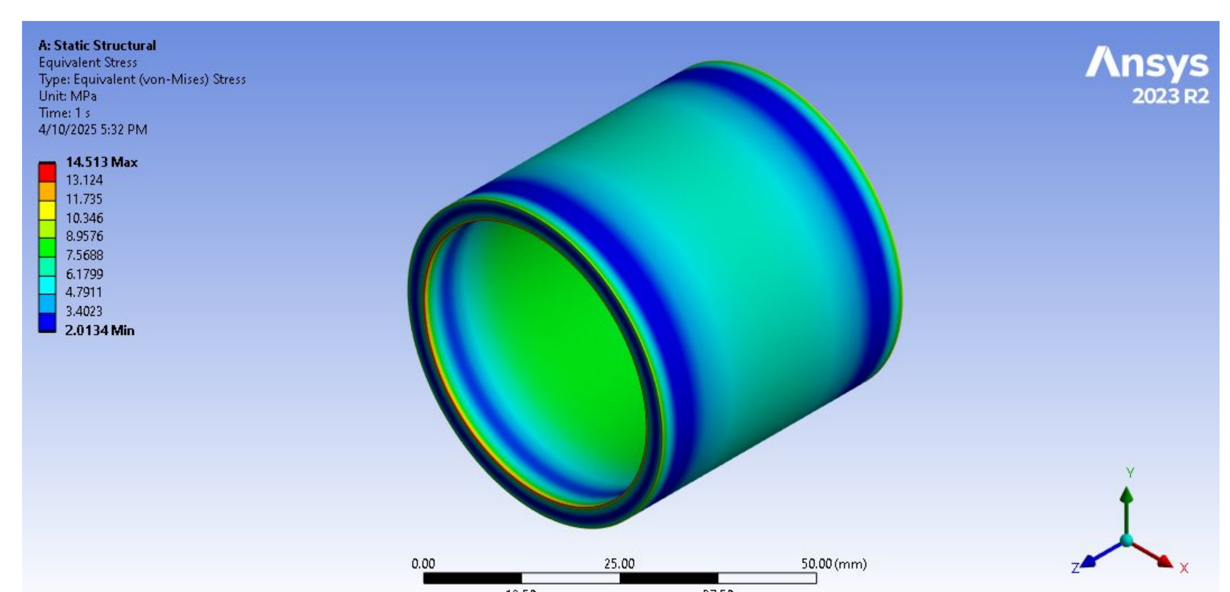

Figure 3. Equivalent (von-Mises) Stress of Quartz-infused Glass at 10 atm

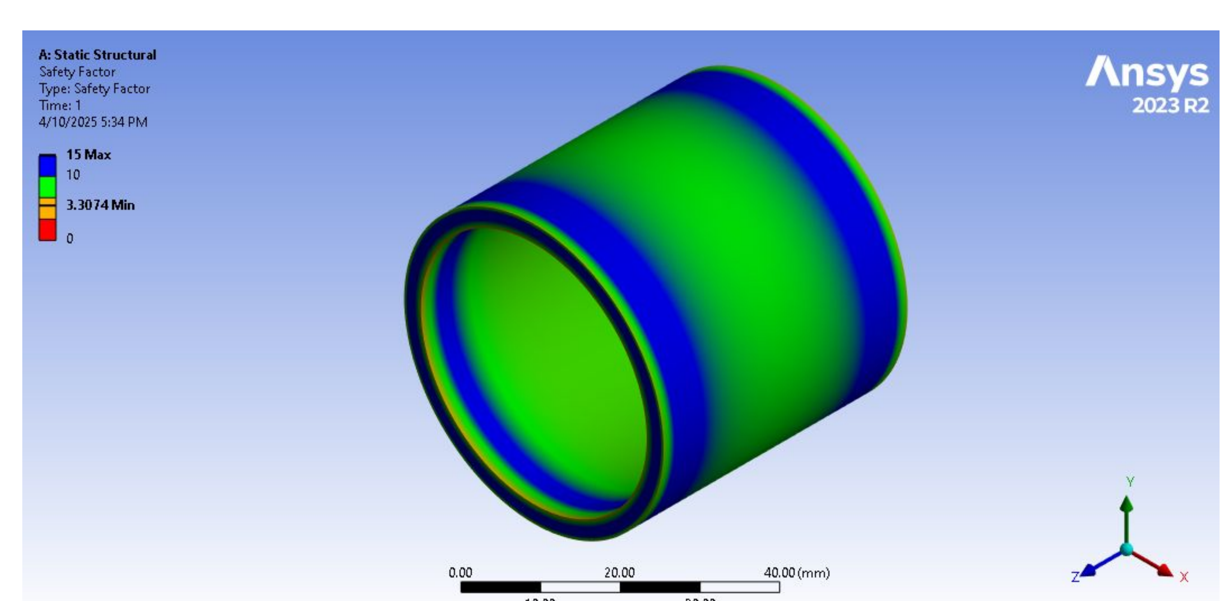

Figure 4. Equivalent (von-Mises) Stress of Quartz-infused Glass at 10 atm

Methods - Computational Fluid Dynamics

1. To generate the pressure within the apparatus, argon gas is used and the flow through the nozzle is compressible. A 2-D axisymmetric model of the nozzle was build in the geometry section of Fluent with a spline used to represent the melting and pulling of the microwire.
2. Face meshing and a face sizing of 0.01mm was set on the 2D surface.
3. In the fluent, the pressure-based solver was used due to divergence issues occurring with the density based solver. The problem is set as steady state and axisymmetric. The energy equation and inviscid models were used. The properties for argon were taken from Ansys Fluent database and the density of the gas was set to ideal-gas. The boundary conditions used for the inlet and outlet are shown in Table 2.

Table2. Boundary Conditions

Boundary Conditions	
Inlet Gauge Pressure (atm)	10
Inlet Temperature (°C)	300
Outlet Gauge Pressure (atm)	0
Outlet Temperature (°C)	27

Results - Computational Fluid Dynamics

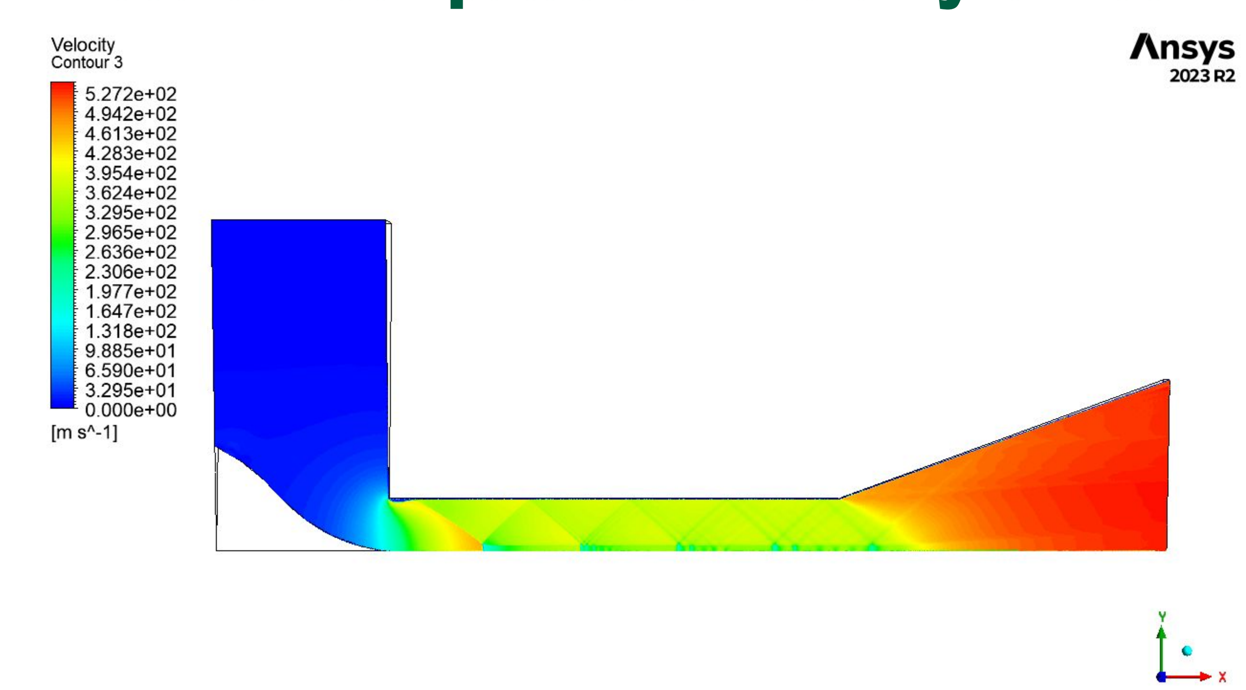

Figure 5. Velocity Profile

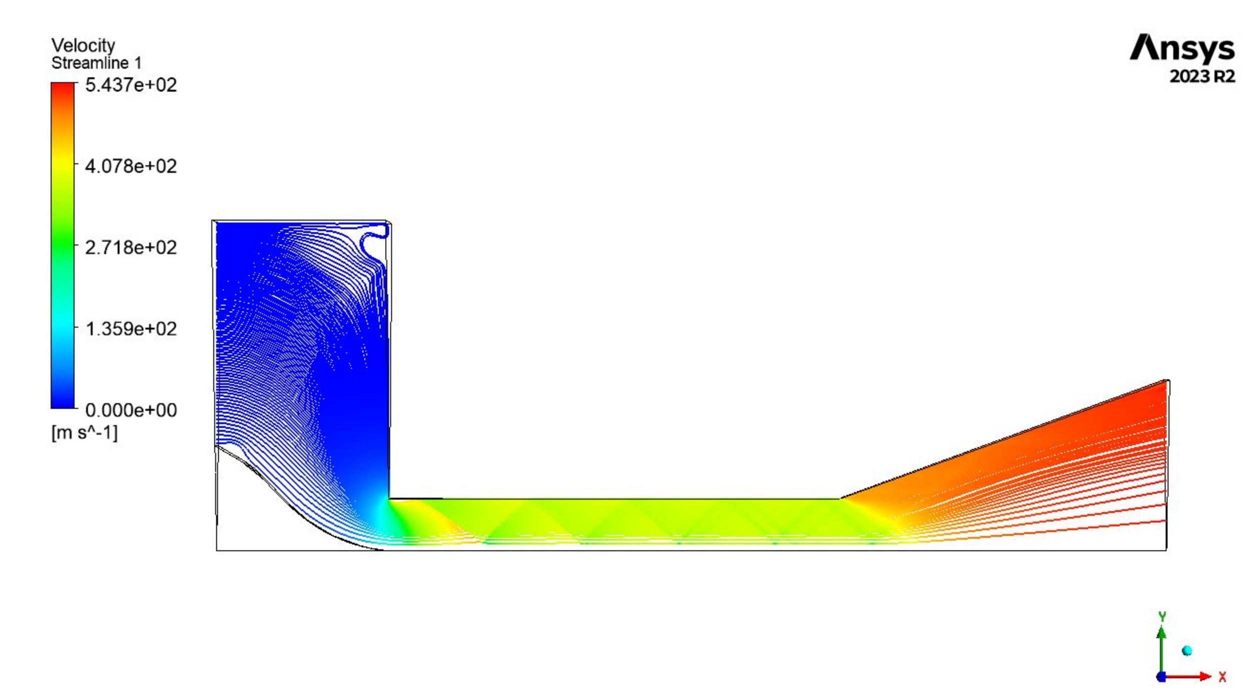

Figure 6. Velocity Streamlines

Conclusion and Future

- Verified the safety limits of the pressure apparatus in that the safety factor was somewhat below the designated 3.5, but was deemed acceptable
- Simulated the potential characteristics of compressible flow within the current nozzle configuration and temperature difference between the inlet and outlet
- Continue simulations of the nozzle to optimize its geometry