High Pressure Rinsing of Accelerator Cavities

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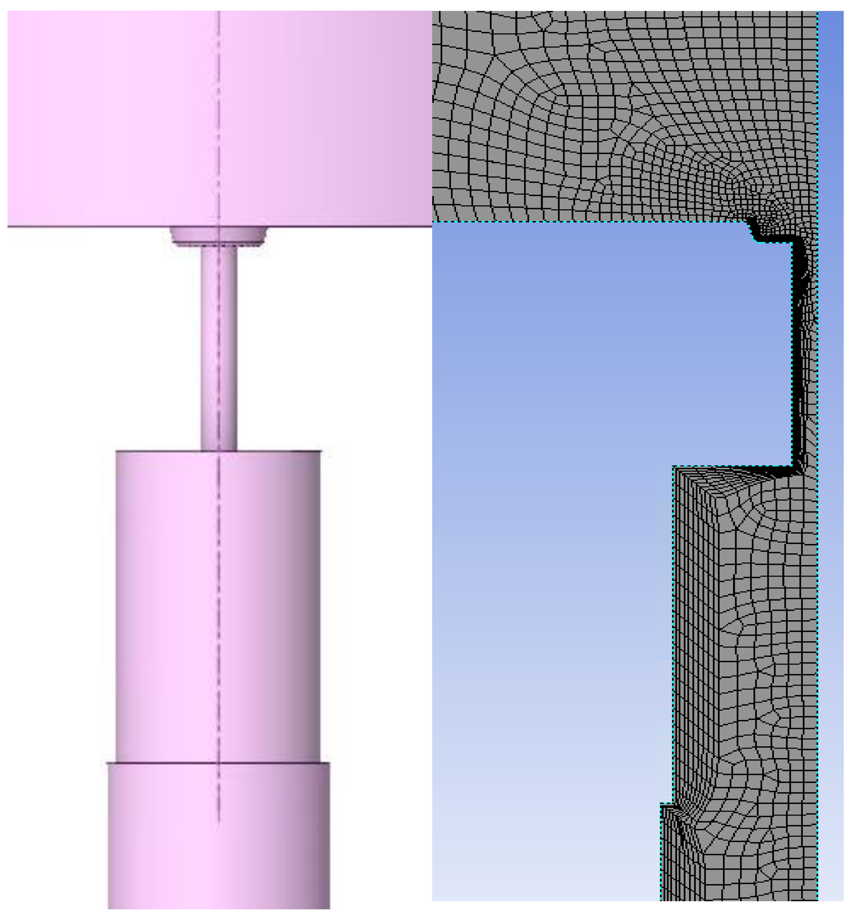
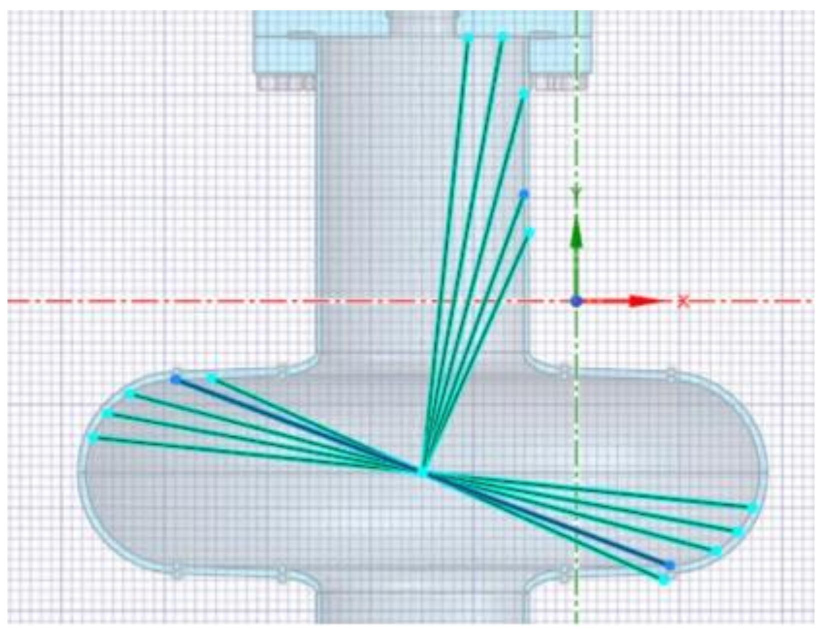
Background

PIP-II is an effort for Fermilab to upgrade the capabilities of the linear accelerator used to perform high energy physics experiments. Niobium is used to create accelerator cavities because it is a superconducting material with good mechanical properties. Imperfections during manufacturing the cavities limit performance. High Pressure Rinsing (HPR) with water is one step of the manufacturing process used to remove any particle contaminates, which are electron field emitters and limit performance.

Niobium Cavities in HPR chamber.



3D model (left) of nozzle internal fluid volume attached to volume of influence. 2D simplified mesh (right).



Visualization of potential nozzle spray pattern. Showcasing different jet impact distances.

Computational Fluid Dynamics (CFD) can be used to predict jet behavior during HPR. CFD can allow a quicker and less expensive alternative to using physical testing to optimize the rinsing process. One of the challenges with CFD is finding the most accurate way to define the problem, while receiving results in a reasonable amount of time. This is done by having a fine mesh resolution in critical areas while keeping a coarse mesh in others, minimizing computation time. Since the jet nozzle and the cavity are both cylindrical, the problem can be represented in 2D and solved using axisymmetric formulae. This simplification further decreases processing time.

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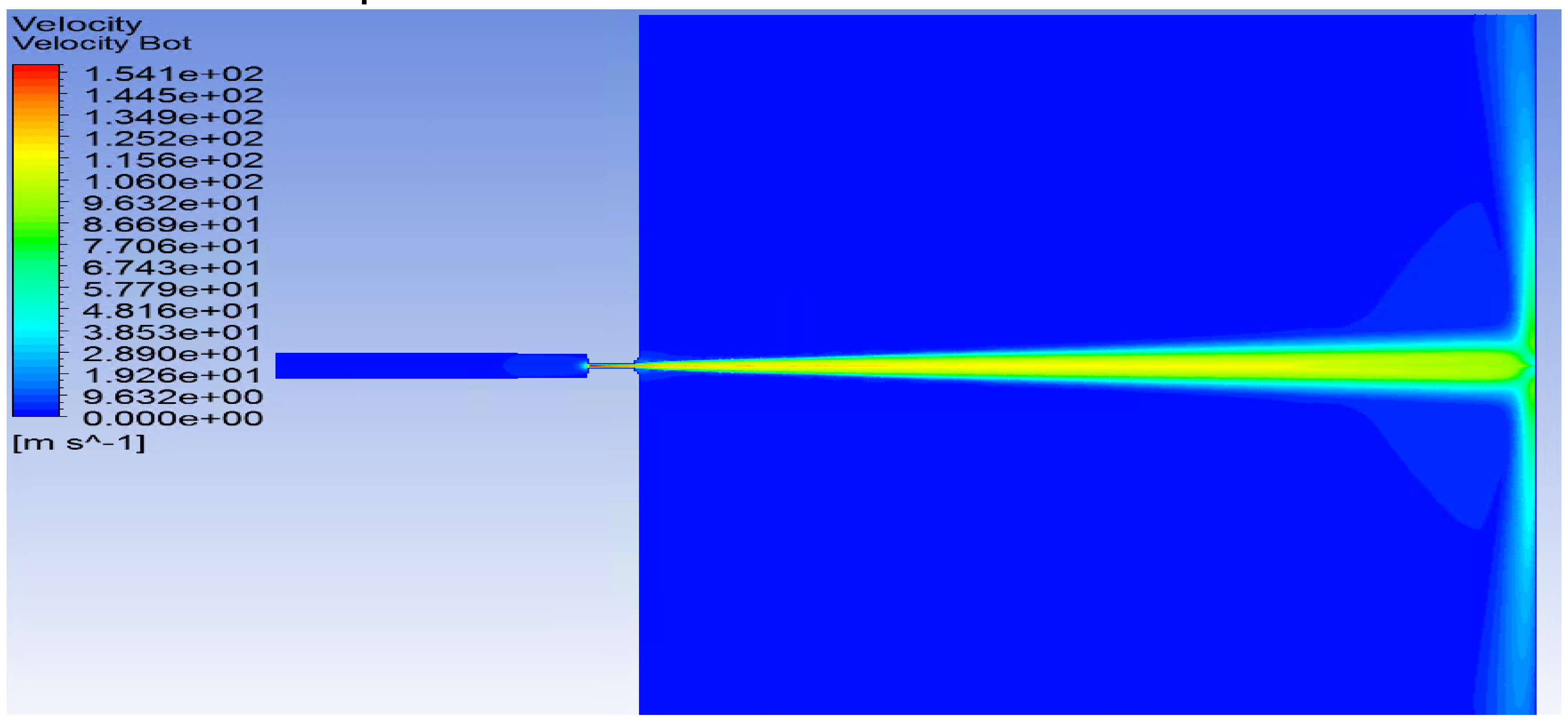
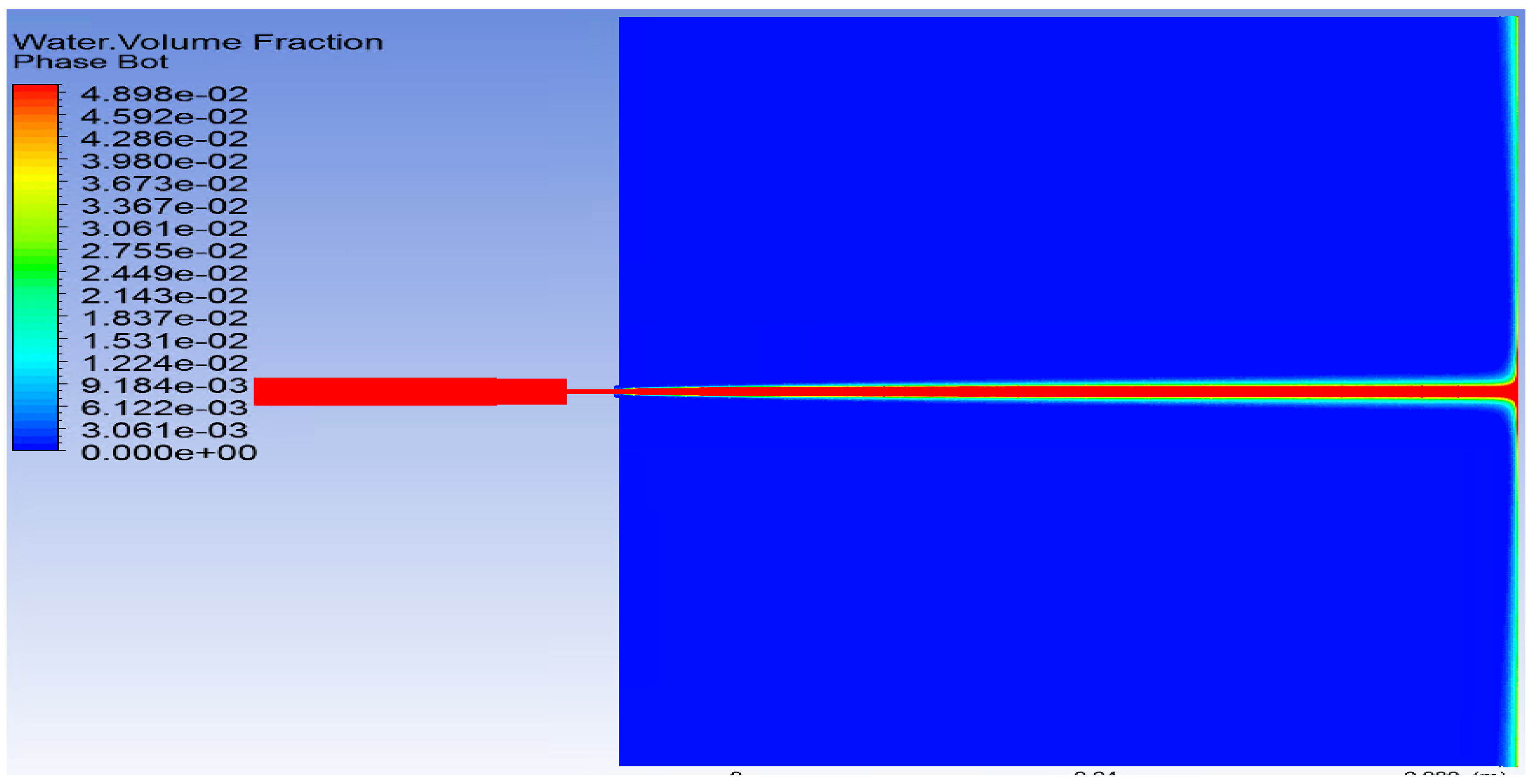
Results

From experimental data, the pressure at the inlet to the nozzle is known to be 1250 psi (8.62 MPa). The force the jet exerts on a near wall was measured to be approximately 9 N. Using known conditions, the expected fluid velocity at the nozzle inlet is 2.79 m/s and the expected mass flow rate at the inlet is 4.17 L/min.





Mirrored results from simulation, velocity contours (top) and phase contours (bottom).

The results above are steady state solutions calculated using known inlet pressure conditions. Using the Ansys multiphase “mixture” solution method gave the closest results to physical data.

In the simulation, the inlet velocity is set to 2.8 m/s. The calculated pressure is 10.9 MPa. The mass flow rate at the inlet is 4.17 L/min and the force on the impacted wall is 7.42 N.

Understanding how effective rinsing is requires understanding of the shear force the jet has with the walls. Y+ is a non-dimensional parameter used to indicate how well the shear force on the wall was predicted, with a target value of 1. The simulation above showed a maximum Y+ value of 11.

Moving Forward

While 2D simulations are great tools to reduce computational time, they are restricted to cylindrical nozzles. Using a 3D nozzle, such as a flat fan, could allow for better HPR. Improving shear fidelity will increase confidence in CFD and acceptance of more complex simulations..