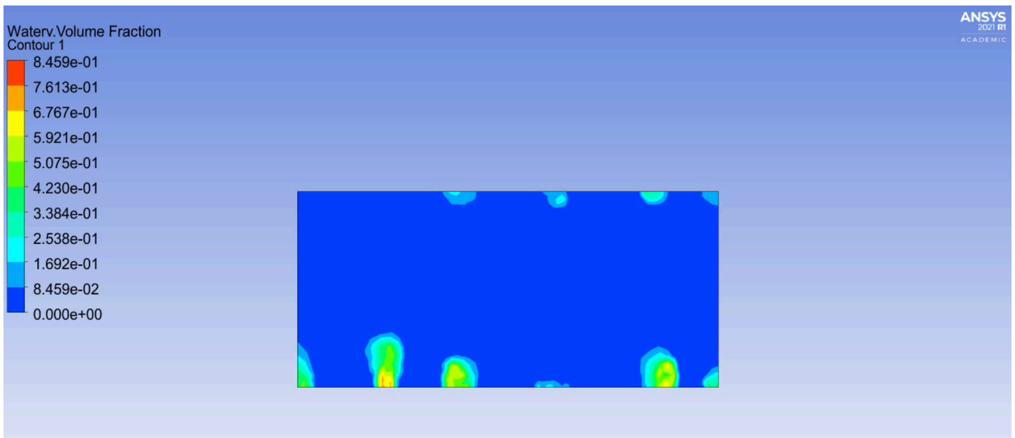
CFD Final Project: Hot Pot



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MECH 301B - Computational Fluid Dynamics

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Introduction:

The premise of this project is to change in velocity, density, and temperature of water as it is beginning to boil. The goal is to compare the simulation to real-world data to see if it was accurately made. Since water is the main focus and were are converting it from one phase to another we need to input valus for each. Ansys Fluent has values for both in its material database which are, “water-liquid” and “water-vapor”. The important values to highlight are density, specific heat, and thermal conductivity. All are constant properties except for the specific heat for the water vapor which is a piecewise-polynomial.

	Density (ϱ) $\frac{kg}{m^3}$	Specific Heat (Cp) $\frac{J}{kg-K}$	Thermal Conductivity (h) $\frac{W}{m-K}$
Liquid Water	998.2	4182	.6
Water Vapor	.5542	Piecewise-polynomial	.0261

Table 1: Fluid Properties

The surface tension of water, .0728 N/m, was added to act as a penalty when the water turns to a gas a rises. The initial temperatures are as follows, stove(heat source) 535K, initial water temp 295K, and 295K.

Methods:

This simulation was tricky to get working so there were a few compromises that had to be made. One is that the pot used is not to scale. The pot used for the empirical data was twice the size of the one generated in Ansys. Another is that the pot is full and isn’t losing any mass from escaping water vapor. Lastly, the simulation is acting as if the pot would be directly on the stovetop so the water is directly touching the heat source and the wall is not producing any heat.

The geometry for this is very simple. It is a 2D box that is .07m wide and .0325m tall. The mesh has an overall element size of .002m and both the top and bottom have an element size of .0005m. They vary from the rest of the mesh due to those areas experiencing more variable at a given time compared to the middle of the mesh which is relatively constant and shouldn't be more refined as it will drastically increase the processing time and for this simulation, a courser mesh will do just fine. There are also 4 name selections one for the top, the bottom, the two walls, and the body of the object. There are a total of 2128 nodes and 2025 elements in this mesh.

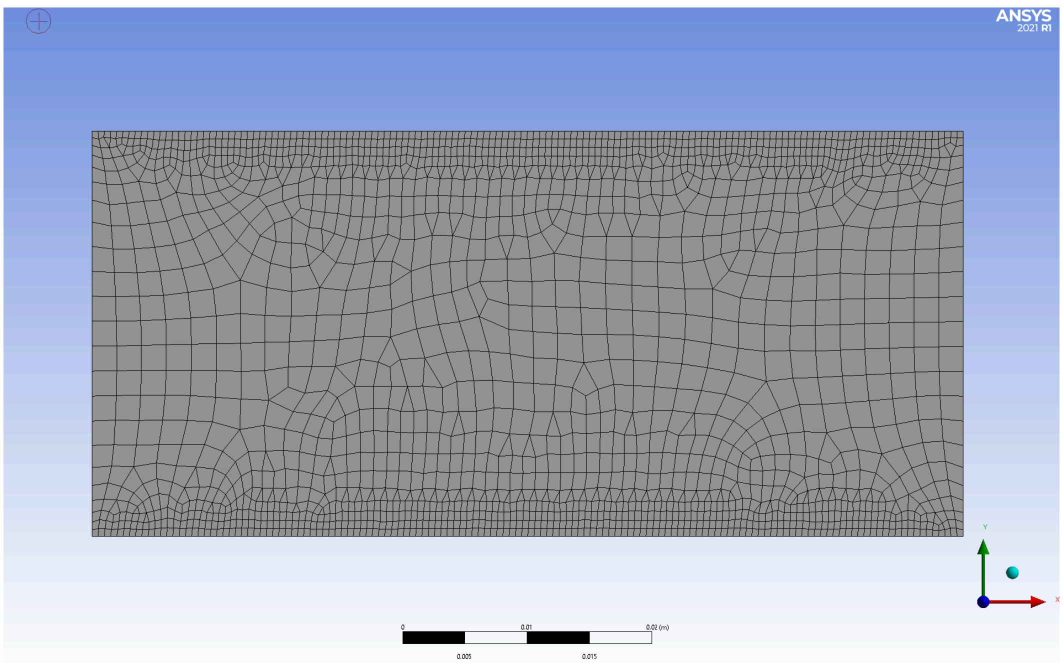


Figure 1: Mesh of object

In the setup, there is quite a lot that has been done. In the general tab, gravity has been turned on and time is set to transient since there will be an animation over a period of time. Multiple phases were turned on and set to volume of fluid and implicit. For viscous k-epsilon was chosen as well as enhanced wall treatment and thermal effects which was added to try and get the walls to radiate some heat. Water vapor and liquid were added to the material list from the Ansys database and were set to their default values. These values were selected since they were around the same value as other sources. Boundary condition the bottom edge is set to 535K and the top is set to 295K as those were about temperatures gathered for a stove at medium-low heat and an ambient temperature. The initial temperature is set to 295K which was the temperature of tap water. In calculation activities “Autosave” is set to save a data file every 20 time steps. In calculations, the number of time steps is set to 2000 and the size of them is .0005. The calculation was run twice to provide more data for the animation and the other graphics. Still in fluent, there was a vector field and two contour plots were made to show the data that was gathered. As a result, an animated video was created. After those data points were gathered the mesh was refined based on the curvatures of the velocity and the simulation was repeated for another 1000 time steps.

Results:

Figures 2-7 show the change of the water from a liquid to a gas starting at the initial time, .6 seconds into the simulation, to near the end, about 2 seconds. The animation can be viewed from the link provided in the appendix. Figures 8-13 show the temperature, density, and velocity vectors before and after the mesh was refined.

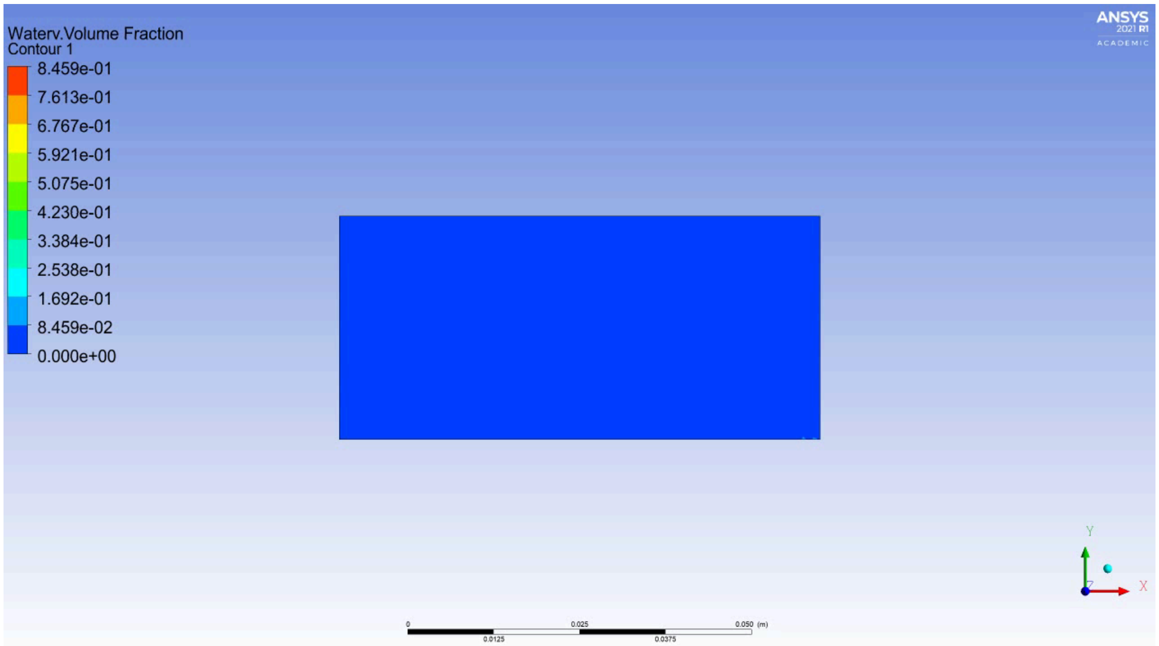


Figure 2: Volume Fraction at T initial

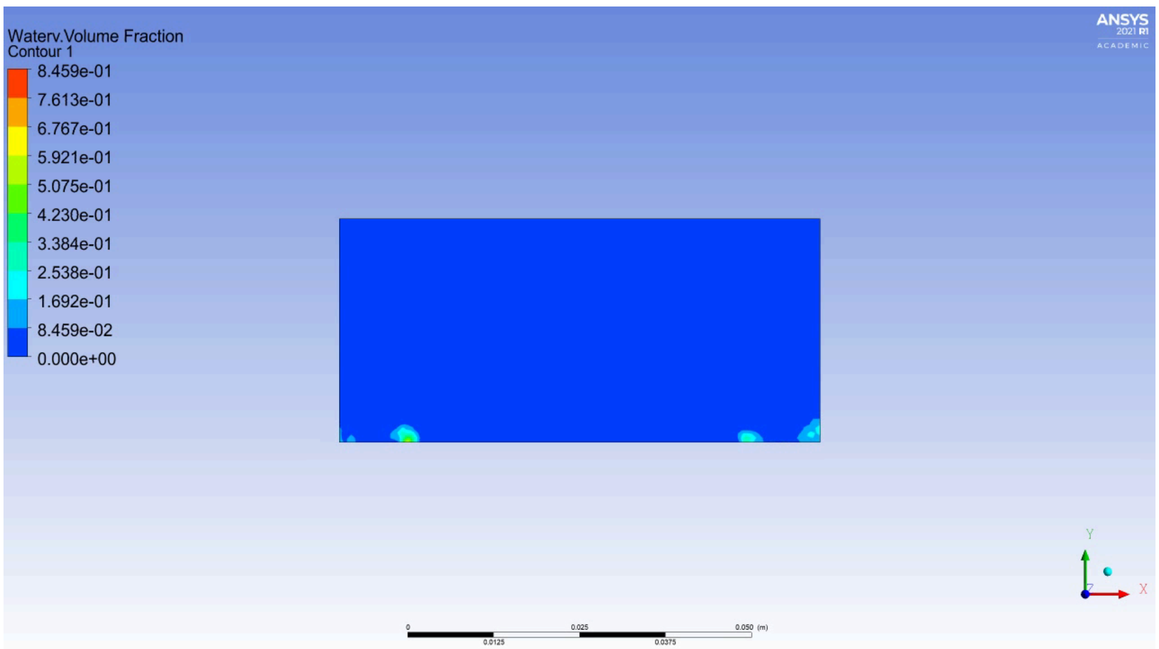


Figure 3: Volume Fraction at T2

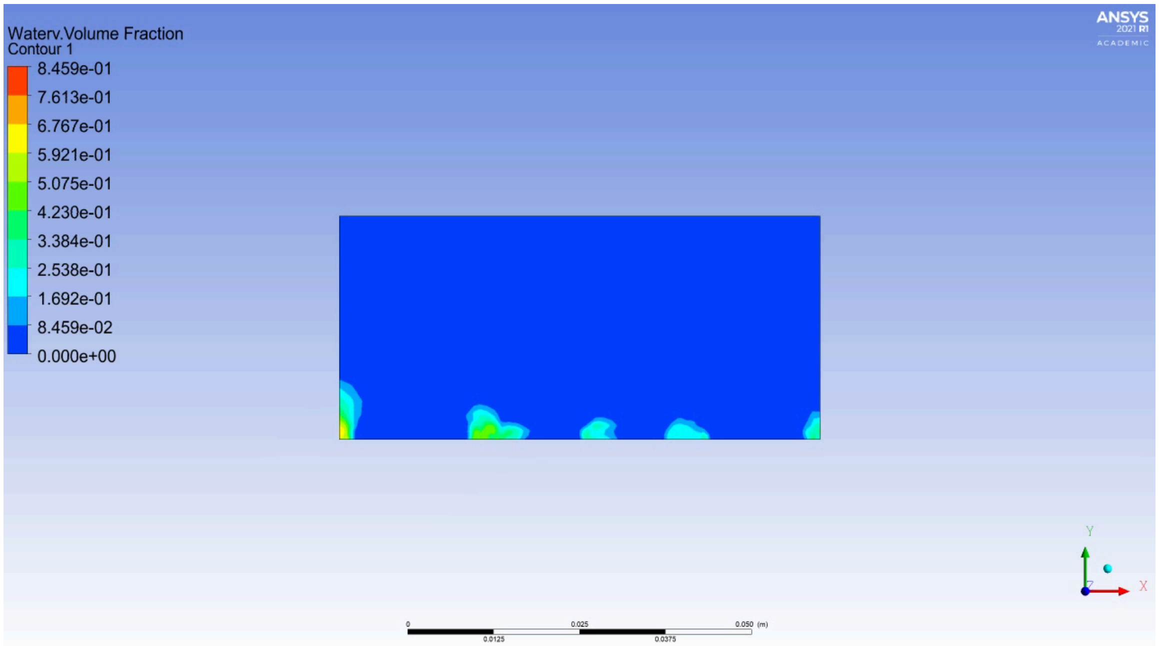


Figure 4: Volume Fraction at T3

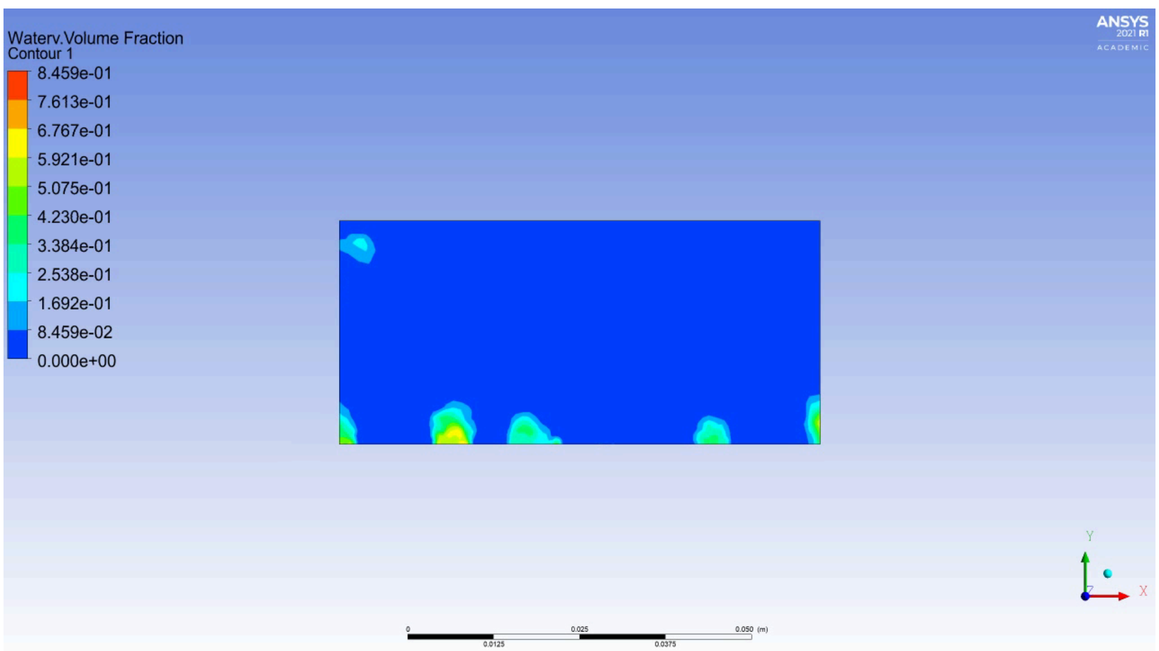


Figure 5: Volume Fraction at T4

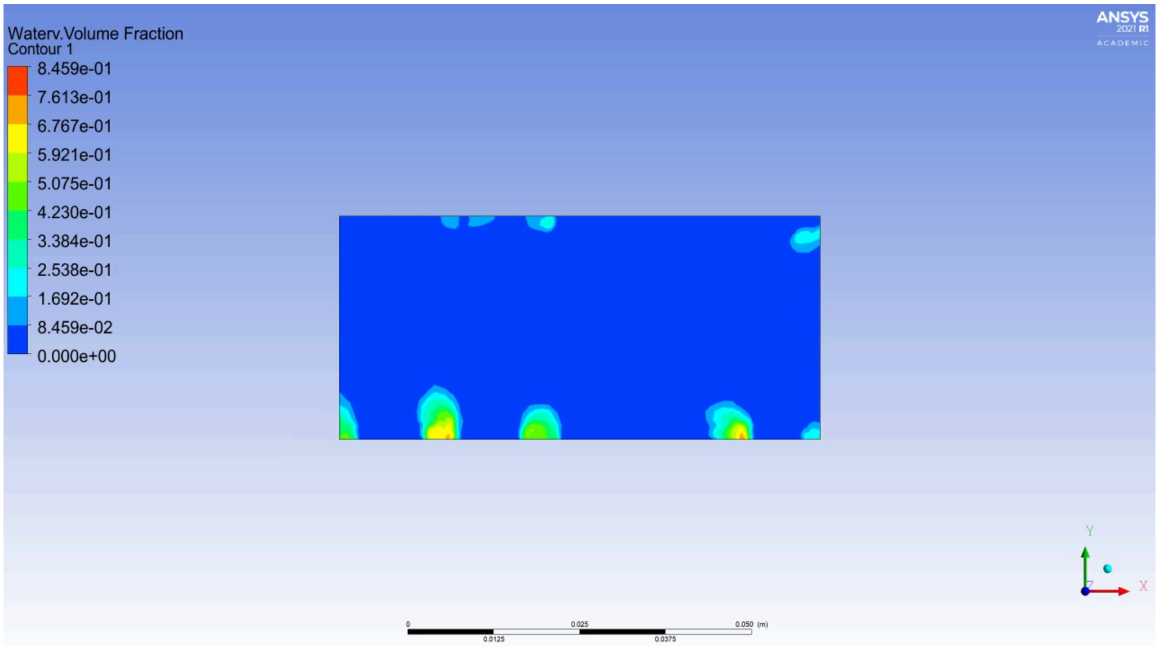


Figure 6: Volume Fraction at T5

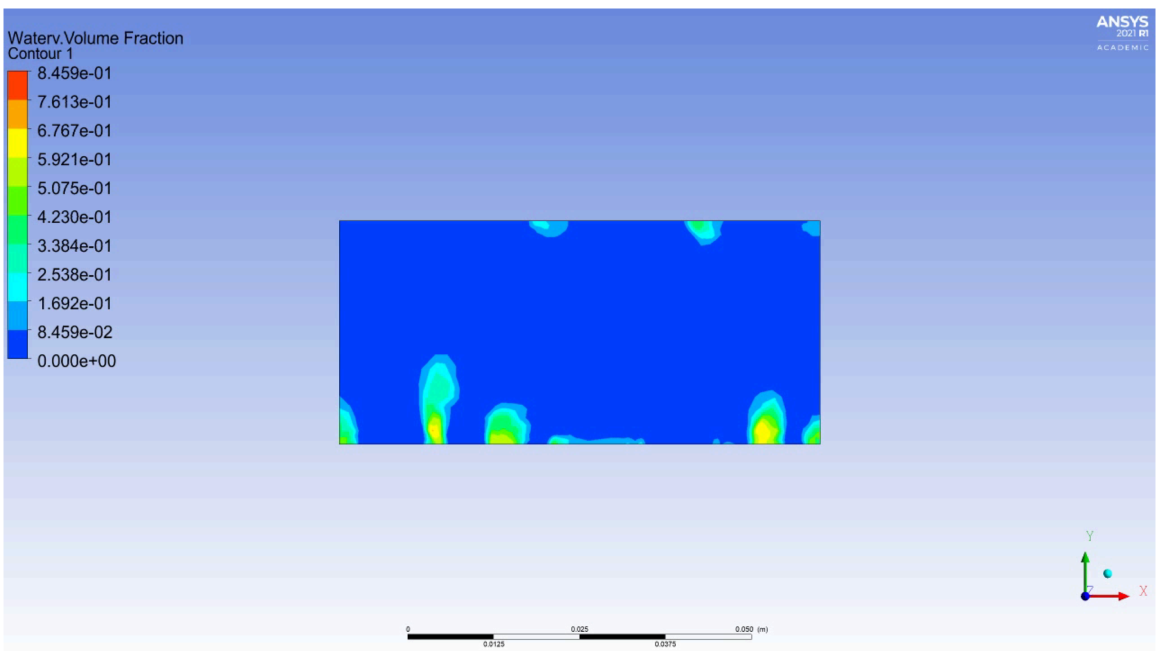
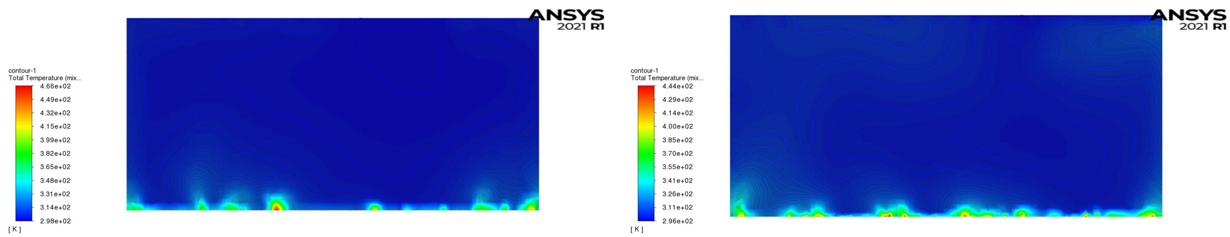
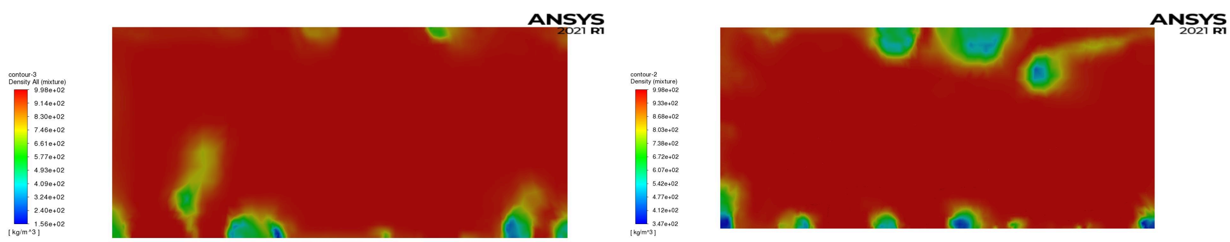


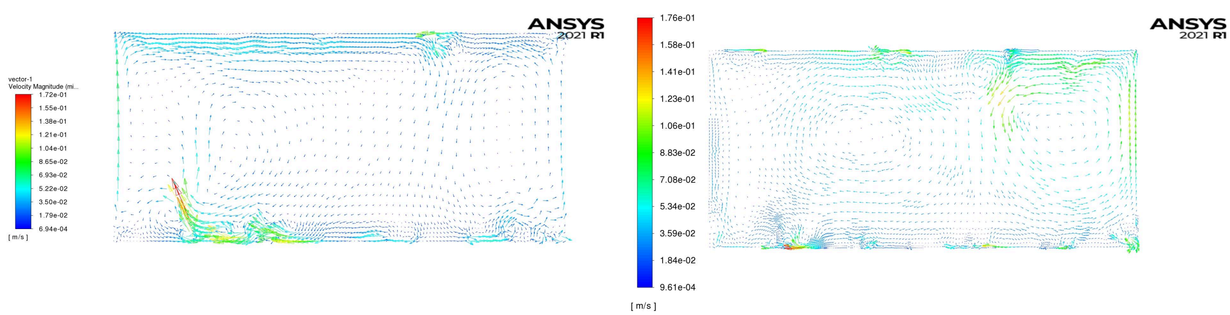
Figure 7: Volume Fraction at T6



Figures 8 & 9: Temperature Contours Before and After Mesh Refinement



Figures 10 & 11: Density Contours Before and After Mesh Refinement



Figures 12 & 13: Velocity Vectors Before and After Mesh Refinement

<u>Verification and Validation</u>

When compared to real-world data the simulation does as one would expect. As the bottom of the pot heats up, bubbles of water vapor start to form and rise to the top, making the fluid around fluctuate to accommodate the phase change and the rise of the pockets of water vapor rising to the top. Figures 14 and 15 show a top-down view of the water as it starts to boil and the thin layer of water that is in direct contact with the metallic surface and changes phases. The figures also show how the surface tension of the water holds back the pockets of water vapor.

Figure 14: Bubbles Formation

Figure 15: Bubbles Rising

Since this simulation, there aren't any specific value that is being solved for and just looking at the effect of the phase changes the mesh refinement probably did something but it is difficult to tell the impact it had. The simulation did move forward in time and that did change the results but the impact of the refinement is unknown for this setup. One big factor that would help with validating this experiment is to have the pot be about 65-75% full to allow for the water vapor to build up to show more effects of the temperature, density, and even the pressure build-up that can occur when the pot is sealed completely. This will add more visual verification to the simulation to the real-world test as more points of interest can be visually verified.

Discussion:

Boil water is something that is done for a variety of reasons and it seems extremely simple on the surface but can be quite complex. This model is simplified to show the general idea of what takes place. The results do a good job of showing the phases of changes and some rough estimates can be made to ballpark any other information needed such as the temperature needed to boil or in other cases melt. It also shows the reverse in the form of condensation which will further give an idea of when temperature is needed to maintain a state. The change in the density can show what kind of vessel is needed to pressurize the steam to translate it into a more useful form such as converting the pressure into electricity. To achieve this a geometry that better fits the question and a more refined mesh is needed to obtain the estimates for these inquiries which is above the scope of this simulation.

Appendix:

Video of the animation: https://youtu.be/A60ACjb3EaA