Doni Tapederi

Project 1

Applied Computational Fluid Dynamics

Collaboration

Name of collaborator: Surya Sarvajith	
Tasks, Specific Detail	Contribution to collaborative effort
Task 1	Reviewed and discussed results
Task 2	Reviewed and discussed results
Task 3	Reviewed and discussed results
Task 4	Reviewed and discussed results

Problem: A cylindrical water heater has one inlet and one outlet. Water at 0.05 m/s and 288.15K flow into the tank and out of the outlet. The base of the water heater is held at a constant 323.5K and all other surfaces are perfectly insulated. The energy equation is turned on and the K epsilon model is used for the simulations. In task 1, a steady-state simulation is conducted in both flow directions. In task 2, gravity is turned off and buoyancy effect is neglected. A transient simulation is run in task 3 and finally, the bottom plate of the water heater has its boundary condition changed from a constant temperature to a constant heat flux.

General Mesh Set Up: The mesh was refined by decreasing element size to 0.025m, turning on "capture curvature", and activating the program-controlled inflation setting.

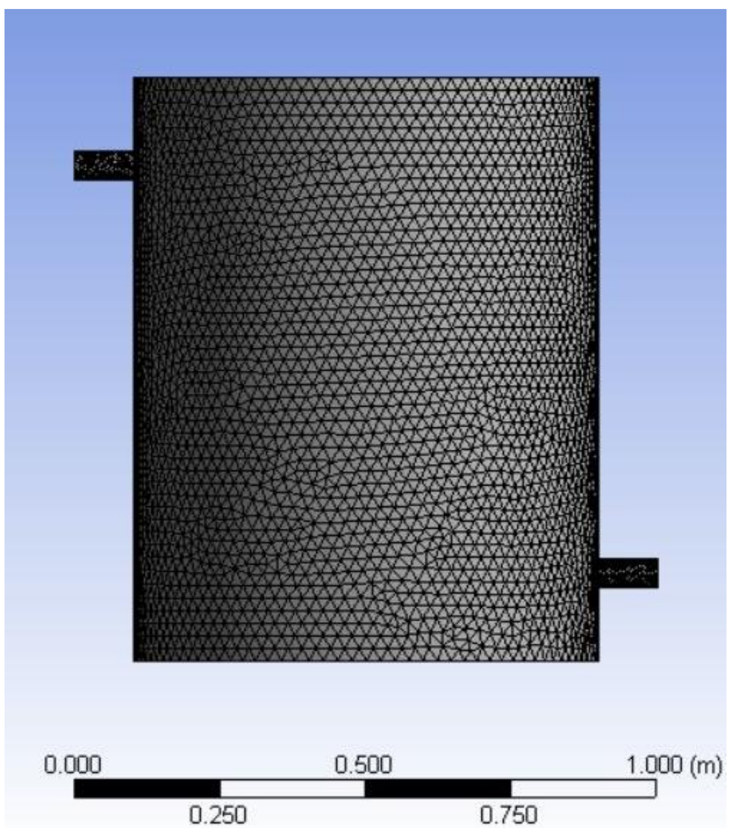

Figure 1: General Mesh

Although the mesh produced prior to starting FLUENT is rather fine with respect to its resolution, in this problem, there is a gradient of temperature due to the constant high temperature of the base plate which means refining the mesh near the bottom of the tank is certainly worth the effort. To do this "Adapt Region" option was invoked and thus a volume within the mesh was defined to have a height of 0.15 meters which would be the region FLUENT would further refine the mesh

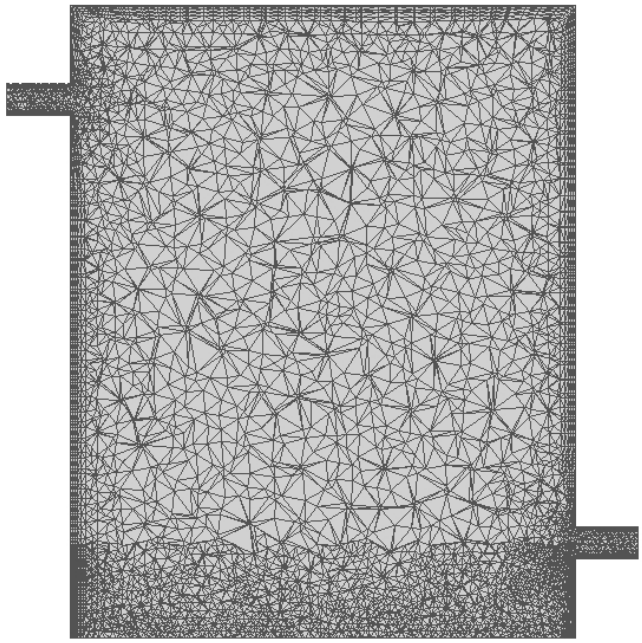

Figure 2: Further refined mesh in FLUENT

Task 1 In task 1, a steady-state simulation is set with the gravity parameter turned on. Since the bottom of the plate is held at 323.15 K, there will be a temperature gradient within the tank thus the density of water will not remain constant. To use the standard pressure-based solver and still capture the variation in density with respect to temperature, the boussinesq feature will be used under the density parameter instead of "constant". It's noteworthy to mention that the boussinesq approach does simplify computation quite a bit by invoking the principle that density will change only linearly as a function of temperature, however, it can only be practically used when the density change with respect to temperature is small. To utilize this feature, three properties of the fluid must be inputted into FLUENT. These properties are *operating temperature, operating viscosity and thermal coefficient of expansion* of the water.

operating temperature: A reasonable operating temperature value for a steady-state model would be the average of the two extreme ends of the temperature spectrum within the system which are the temperature at the inlet and the temperature of the baseplate.

$$\frac{288.15(inlet) + 323.15(base\ plate)}{2} = \mathbf{305.65\ K = 32.5\ C}$$

operating viscosity: This value can be found from the following density as function of temperature equation provided by reference (1).

$$\rho = 999.85308 + 6.32693 * 10^{-2}T - 8.523829 * 10^{-3}T^2 + 6.943248 * 10^{-5}T^3 - 3.821216 * 10^{-7}T^4$$

$$\rho(32.5) = \mathbf{994.86\frac{kg}{m^3}}$$

Thermal Coefficient of Expansion: This value was found by the following equation

$$-\beta = \frac{1}{\rho}\frac{d\rho}{dT}\ (at\ operating\ temperature)$$

Where

$$\frac{d\rho}{dT} = 6.32693 * 10^{-2} - 0.017047658T + 2.0829744 * 10^{-4}T - 1.5284864 * 10^{-6}T^3$$

$$\frac{d\rho}{dT}(32.5) = -0.3232354862$$

$$-\beta = \frac{1}{994.86} * -0.3232354862$$

$$\boldsymbol{\beta = 0.00032490}$$

Through some initial trial and error, it was found that leaving the default residual tolerance of 0.001 for the continity equation would result in a solution converagnce in about 205 iterations. Since further enhancement of the solution could be afforded, the continuity tolerance was decreased to $1 * 10^{-5}$ which allowed the solution to run for a full 1000 iterations. The simulation was now ready for hybird initiliazation and was ready to run. The deliverables for the first simulation are show below.

Simulation 1 Deliverables

The area-weighted average outlet temperature was **298.9253 K** which is reasonable considering the plate is heating up the initially cool water

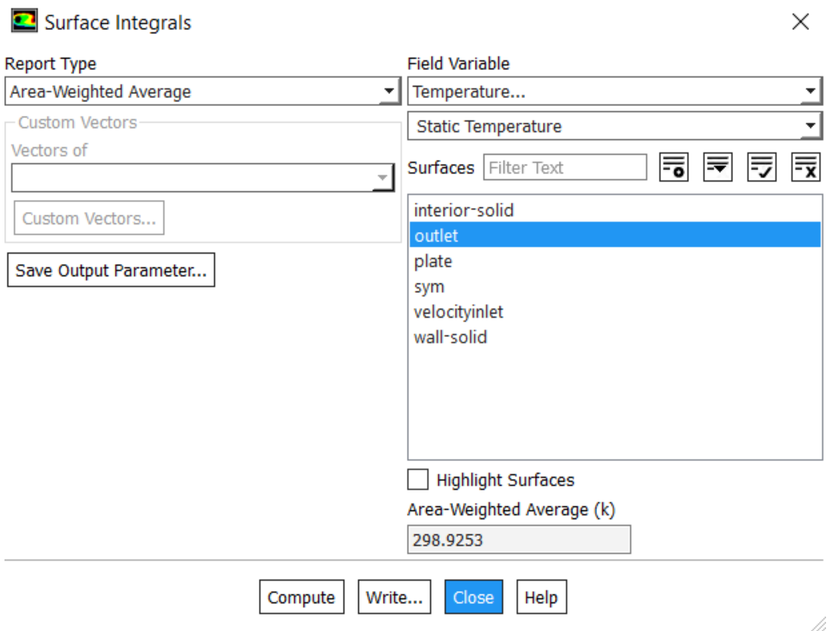

Figure 3: Area average temperature across outlet

The temperature contour plot outlines the “water-fall” effect in the variation of temperature within the tank

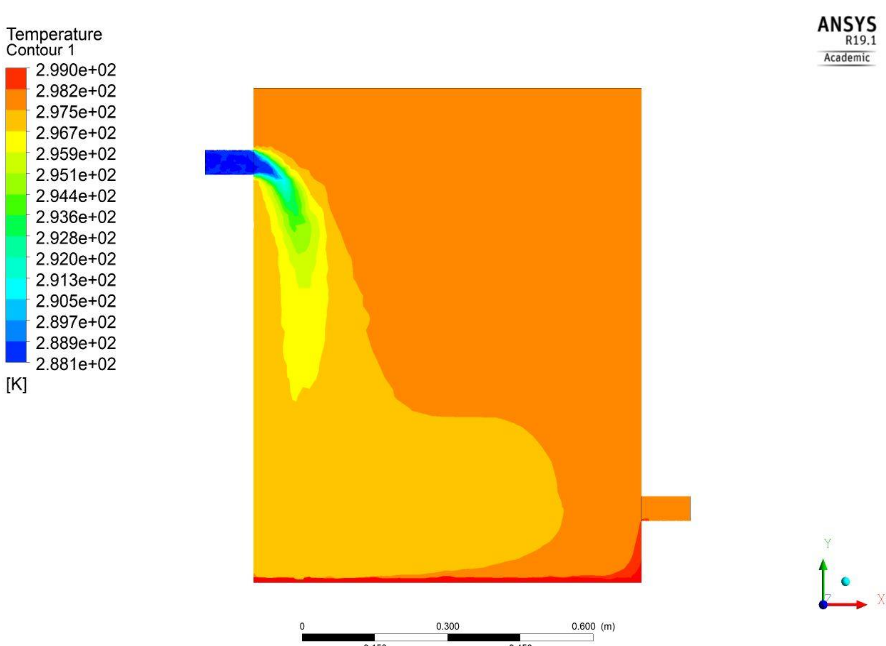

Figure 4: Temperature Plot

The Y velocity contour plot shows that Y velocity is relatively higher near the inlet where water is initially entering the system

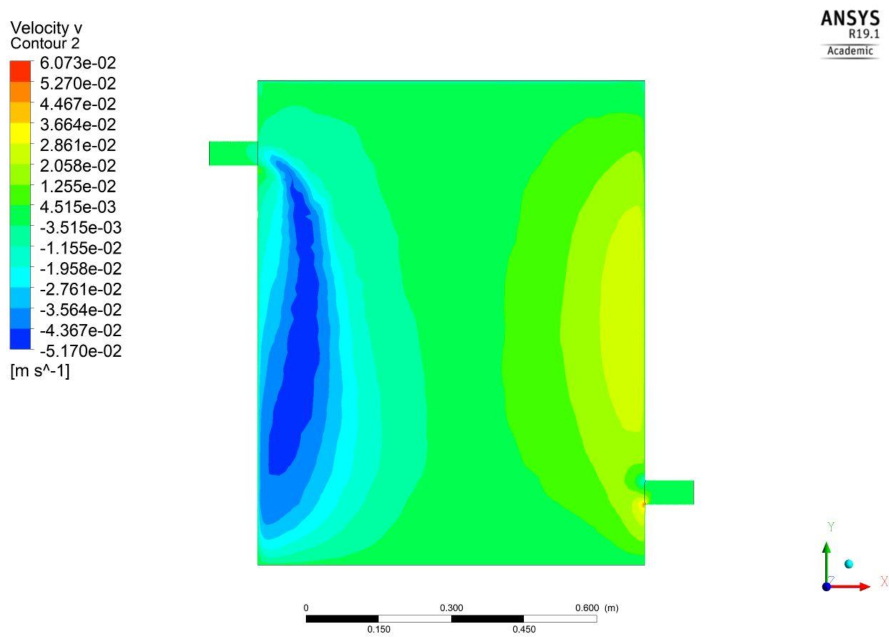

Figure 5: Y component of velocity plot

Simulation 1 was repeated, this time the outlet and inlet were reversed.

Simulation 2 Deliverables

The outlet temperature in the reverse direction was **298.1845 K** which is nearly identical to simulation 1. This pattern makes sense given that the same thermal energy is contributed into the tank and the behavior is observed over a very long period.

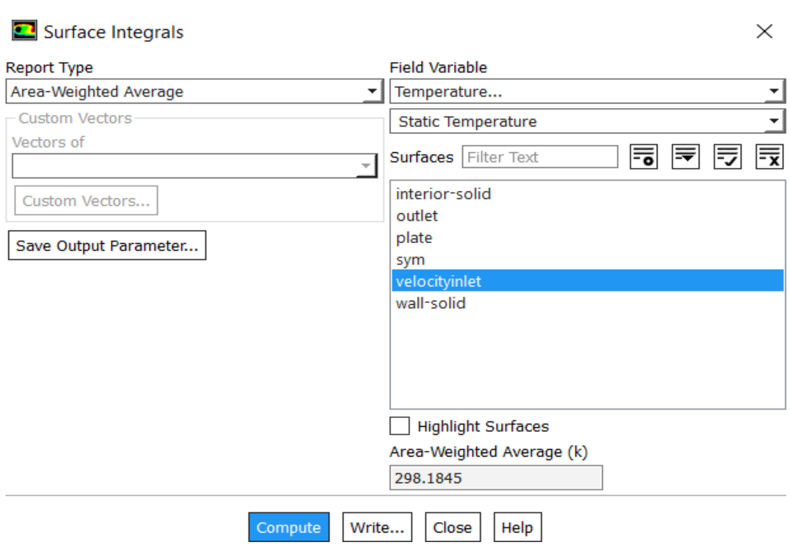

Figure 6: Area average temperature across outlet(reversed)

Temperature plot again shows a neat waterfall effect at the inlet with regards to temperature

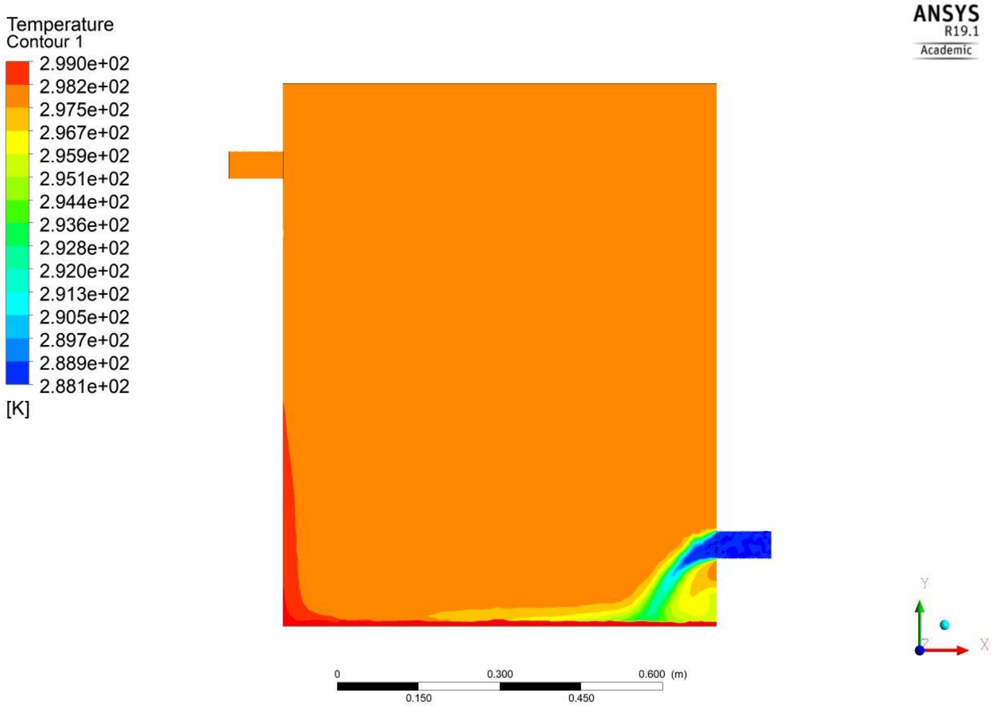

Figure 7: Temperature plot (Reversed)

Y velocity is high below the inlet, also relatively high near the opposite wall were circulation is occurring

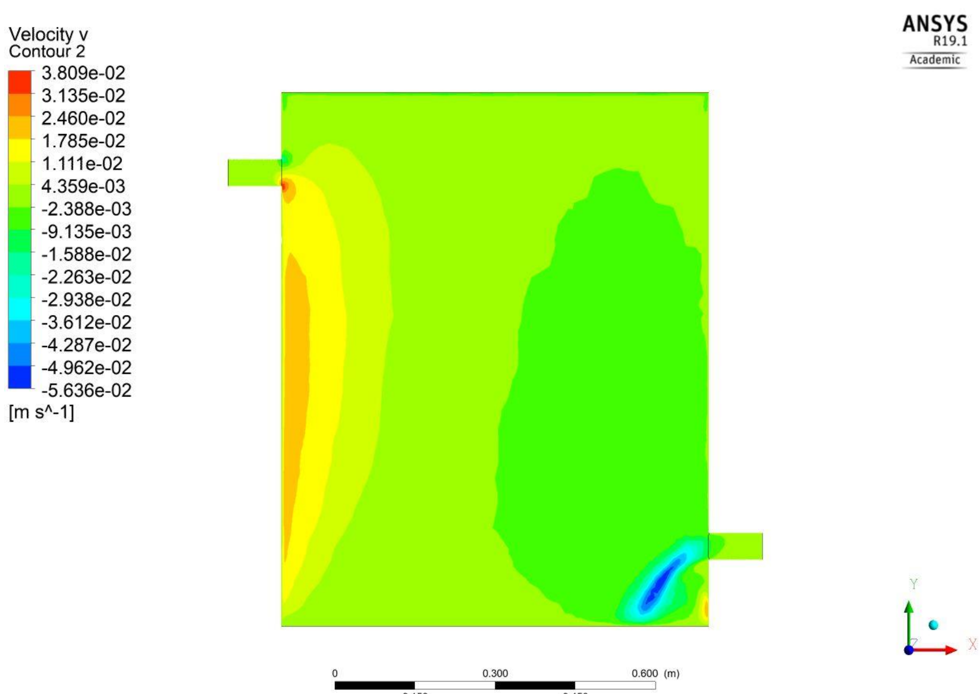

Figure 8: Y component of velocity

Task 2 In task 2, the same set up was used again to run a constant density steady state simulation with gravity turned off. The operating density from task 1 was used again, however, since gravity was now "off", buoyance affects would not be captured and the hotter water near the bottom of the plate would not rise due to negligible density difference.

Task 2 Deliverables

The average outlet temperature here is **292.4233 K**

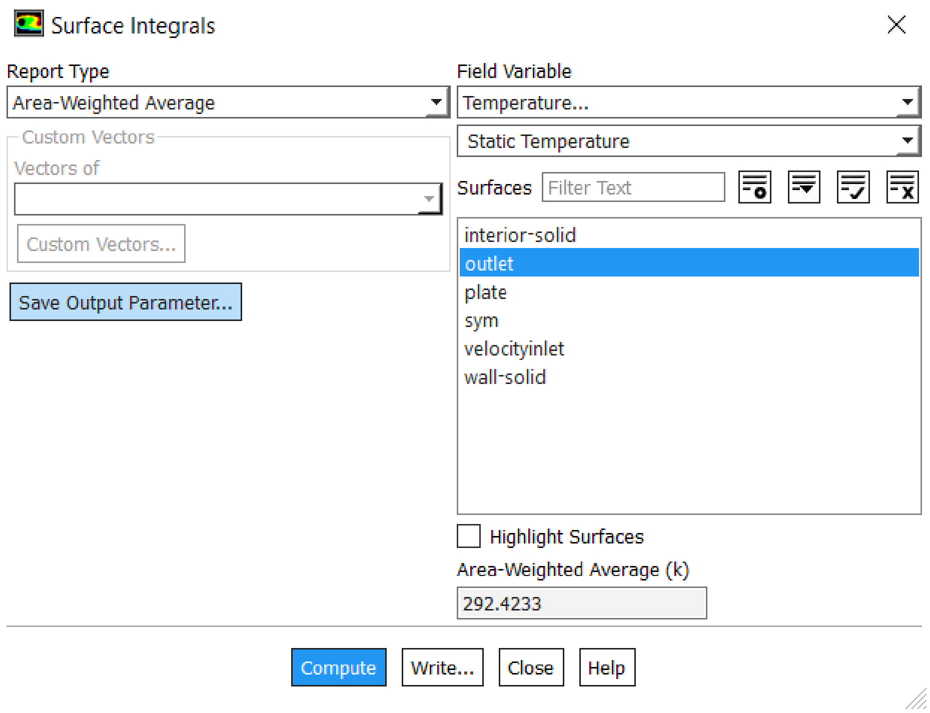

Figure 9: Temperature across outlet

Y velocity does not vary much since neglecting density change prohibits hotter water rising and the fact that gravity is also turned off

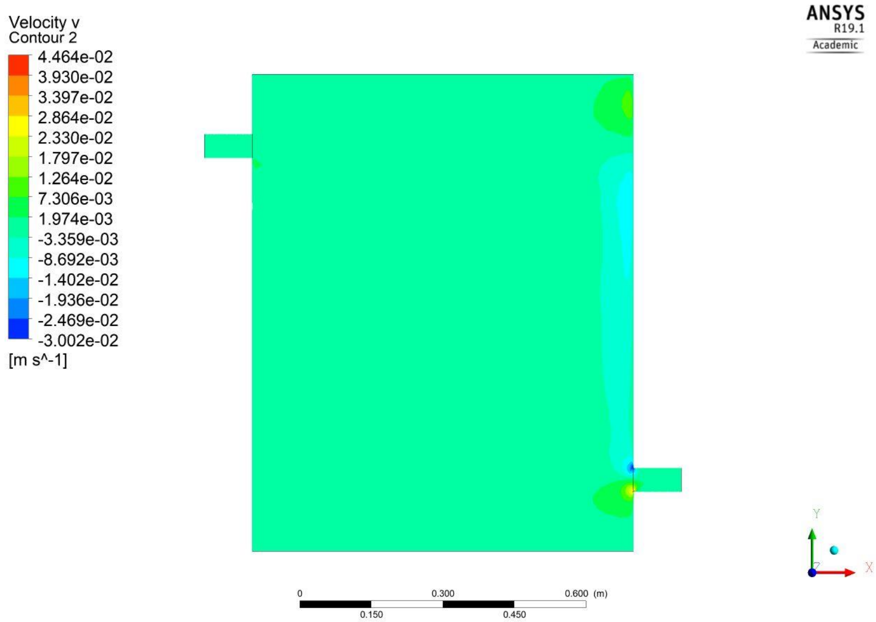

Figure 10: Y component of velocity

The X velocity plot shows the no slip condition inside the inlet and outlet pipe and a max value in the outlet due to the high pressure near the bottom of the tank

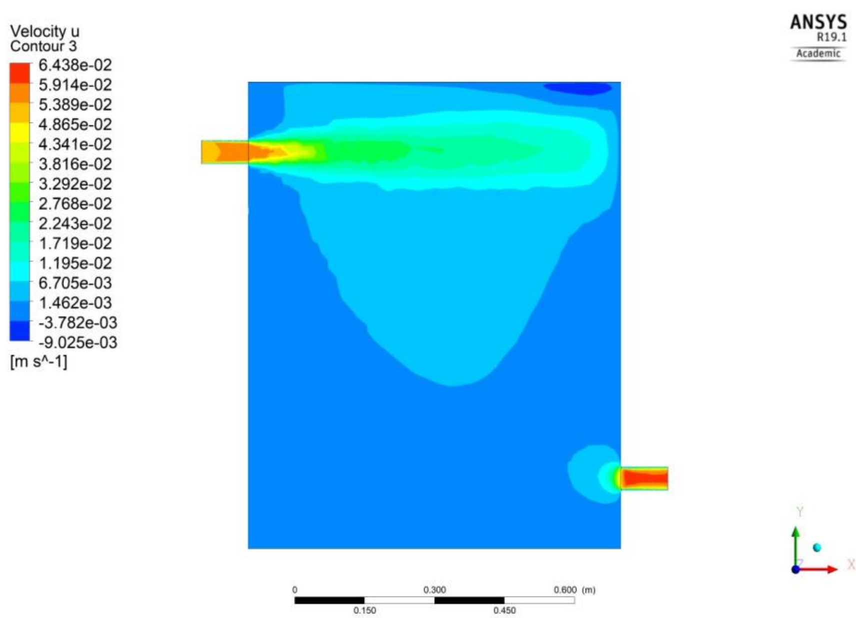

Figure 11: X component of velocity

Task 3 Thus far only steady-state simulations were conducted. In task 3, a transient simulation is set which means the time derivates are now non-negligible in the governing equations. Running a transient simulation requires unique inputs such as number of time steps and time step size. A time step size of 60 was used in this simulation as it allows for reasonable computation time. If a certain desired output is not within reach during the first run, one can simply increase the number of time steps until the target value is reached. In this case, the target value was the area average temperature of the outlet that was computed in task 1 simulation 1 which was 298.925 K. The transient simulation was set up to run until it was within 2 degrees of this value.

Task 3 Deliverables

Using a time step size of 60 seconds, it took a total of 6600 seconds or 1070 iterations for the outlet temperature to have less than a 2-degree difference when compared to the steady state solution.

Time(seconds)	T_{Out} **(K)**
6600	297.143

$$|T_s - T_{Out}(t)| \leq 2$$

$$|298.925 - 297.143| = 1.782 \leq 2$$

Figure 12 shows that the temperature is slowly reaching its steady state value

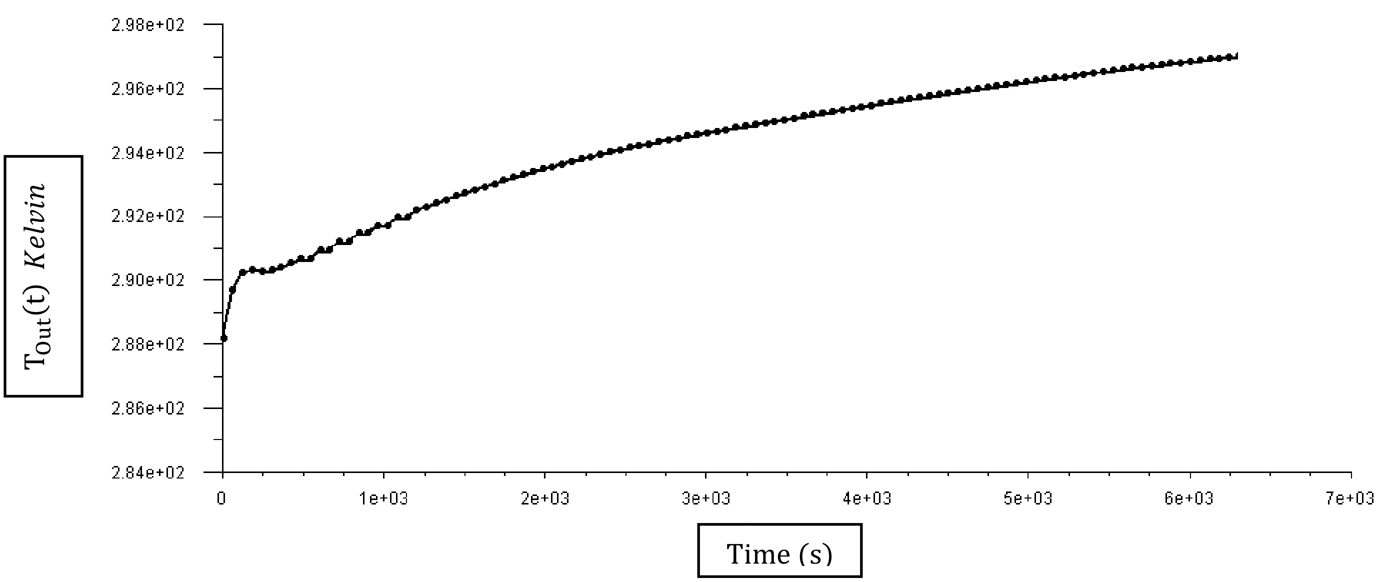

Figure 12: Outlet temperature as a function of time

The Y velocity profile also closely resembles the steady state solution

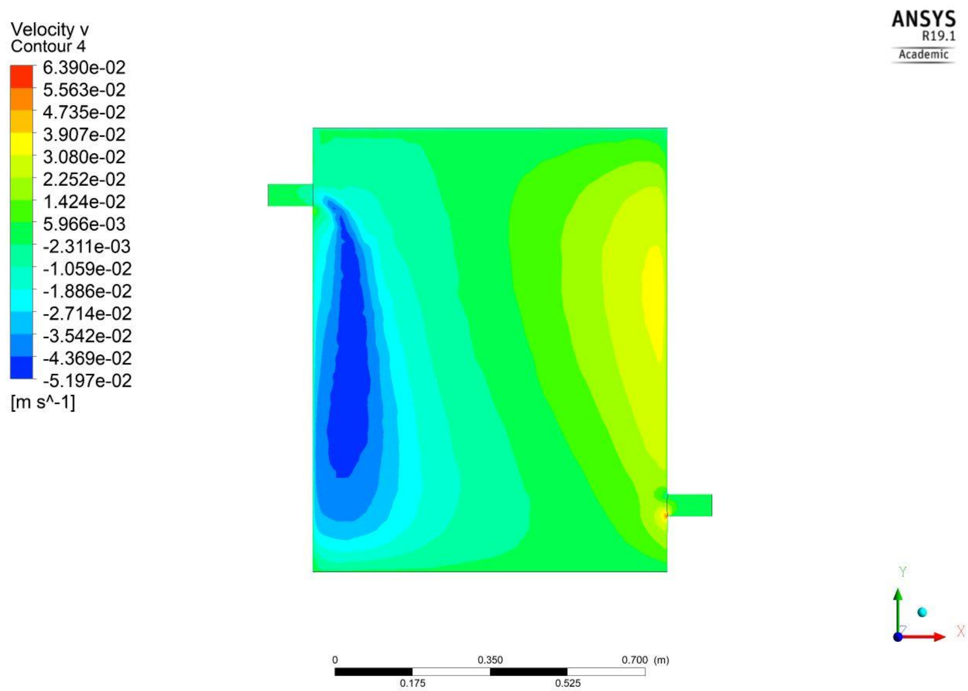

Figure 13: Y velocity plot

Next the strength of the downward velocity within the tank was computed using the following equation which was defined as a custom function in fluent and set as an output parameter during the transient simulation. The downward strength continues to increase through out the run before leveling off

$$S = \frac{1}{A} \iint_A \frac{(|V| - V)}{2} \, dA$$

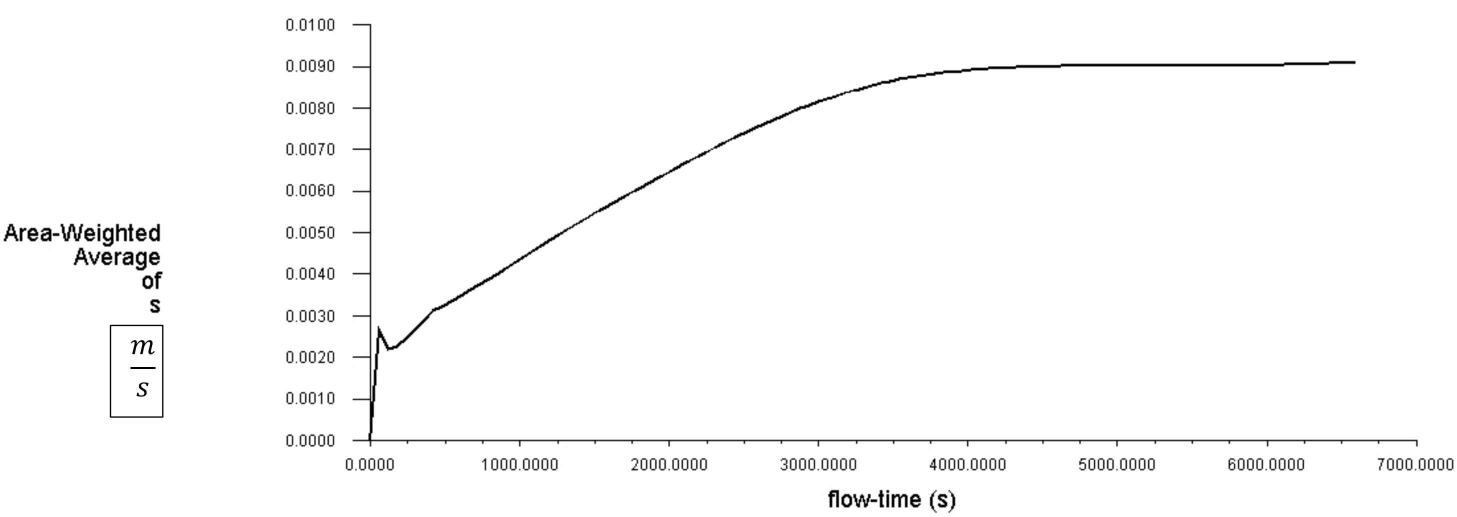

Figure 14: S vs Time plot

<u>Task 4</u> In task 4, the total rate of heat transfer of the bottom plate was computed from *Flux Reports.* This value was then divided by the base area to determine the total heat flux that the bottom plate contributes to the water tank system.

Task 4 deliverables

The total rate of heat transfer due to the bottom plate was **4325.422 Watts.**

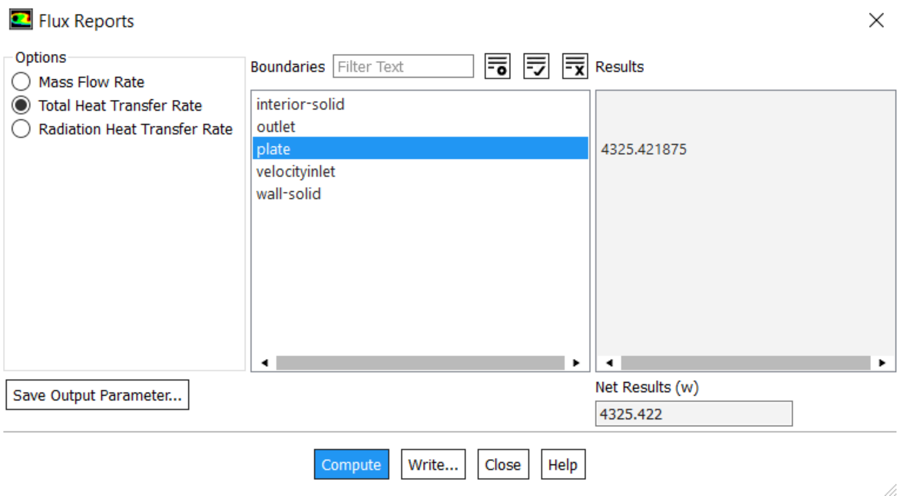

Figure 15: Heat transfer rate from bottom plate

Total Equivalent Heat Flux

$$Heat\ flux = \frac{Heat\ transfer\ rate}{Area} = \frac{4325.422\ Watts}{\pi(.4)^2} = \mathbf{8605.153}\,\frac{\boldsymbol{watts}}{\boldsymbol{m^2}}$$

Next, the temperature constraint of the bottom plate was replaced with an equivalent heat flux value and the simulation was run again. The new average outlet temperature is **298.9186 K** which remains nearly identical with both conditions. This is sensical given the fact that the heat flux value was taken directly from observing the heat transfer rate due to the constant temperature condition of the hot plate.

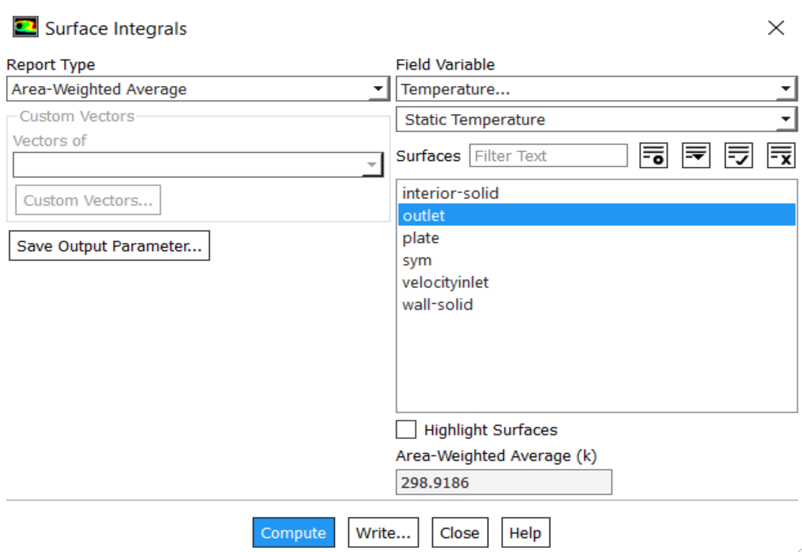

Figure 16: Outlet temperature with constant flux bottom plate

References

(1) *Jones, F., & Harris, G. (1992). ITS-90 density of water formulation for volumetric standards calibration. Journal of Research of the National Institute of Standards and Technology, 97(3), 335. doi:10.6028/jres.097.013*