PROJECT 1

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No collaboration

Geometry

Geometry shown below is a prototype of a water heater which has a main cylindrical tank and two cylindrical side pipes for the water to flow into and out of the tank. The same geometry is used for carrying out the simulation in all the tasks. The tank is heated up by the hot plate at the bottom and all the other surfaces are thermally insulated. Generally the inlet temperature of the water is maintained at 15°C for all the simulations.
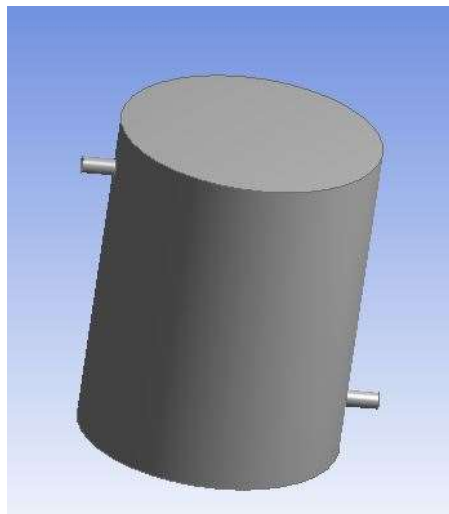

Figure 1: Geometry

Meshing

Element size are reduced to make the mesh finer but this does not provide with finer mesh at the bottom surface of the tank. Since the tank is heated at the bottom, the mesh should be made much finer at this region. Mesh refinement is done for this region using **"Region"** option in **"Adapt cells"** and it is shown below,
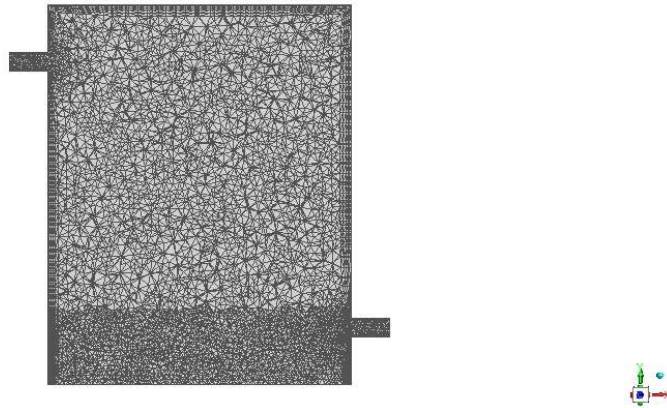
Figure 2: Refined Mesh

Task 1

Simulation 1:

General setup:

PARAMETERS	DIRECTION	VALUE	UNITS
Inlet velocity	+X direction	0.05	m/s
Gravity	-Y direction	9.81	m/s^2
Height of the Inlet pipe from base	+Y direction	0.85	m
Height of the Outlet pipe from base	+Y direction	0.15	m

The bottom plate is maintained at a constant temperature of **323.15K**.

Since water is modelled as a compressible substance, the effect of density as a function of temperature should be considered. This is done by using **Boussinesq approximation** which allows buoyancy driven thermal convection and also pressure based solver can be used thereby reducing the complexity of the boundary conditions associated with density based solver. The use of Boussinesq approximation requires operating temperature, operating density and thermal expansion coefficient to be given as an input. The following are the values of those properties,

$$Operating\ density = 994.3\frac{kg}{m^3}$$

$$Operating\ temperature = 305.65\ K$$

$$\beta = \frac{0.0003235}{°C}$$

Also it can be seen that the value of the thermal expansion coefficient is very low and this indicates change of density with respect to temperature is much lower. Hence this small fractional change of density will be accounted in the simulation by the use of boussinesq approximation.

Solution:

Using the above mentioned general setup, 1000 iterations are carried out. Even though the simulation is carried out at steady state, running the simulation for lower number of iteration will not provide desired result. Hence larger number of iterations are given in order to obtain desired results.

Results:

a) The outlet temperature can be found by performing integration over the surface of the outlet and this can be done in fluent using the **surface integral of area weighted average** which comes around **300.821K**. The following equation is used in computing the outlet temperature,
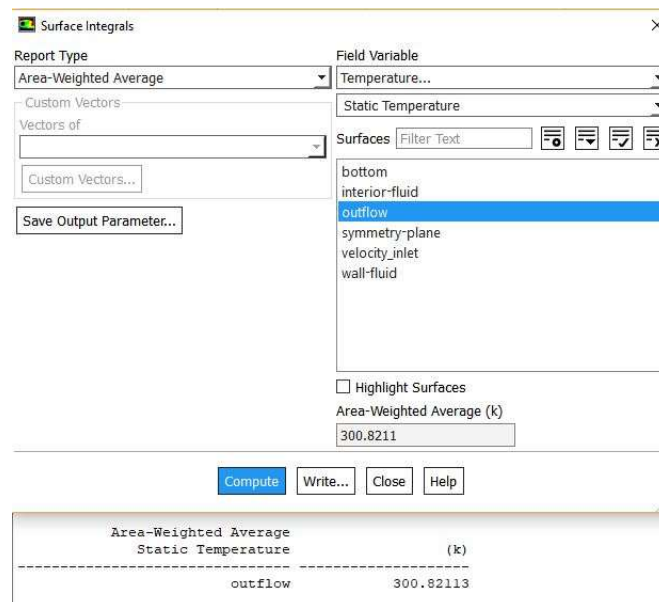
$$T_{out} = \frac{1}{A} \iint_A T \, dA$$

Figure 3: Outlet temperature

b) A contour plot of temperature taken on the symmetrical plane is shown below. Due to the effect of gravity, the water flows to the bottom of the tank and it gets heated up. Due to this, density of the water decreases thereby rising up which results in flow of water through the outlet.
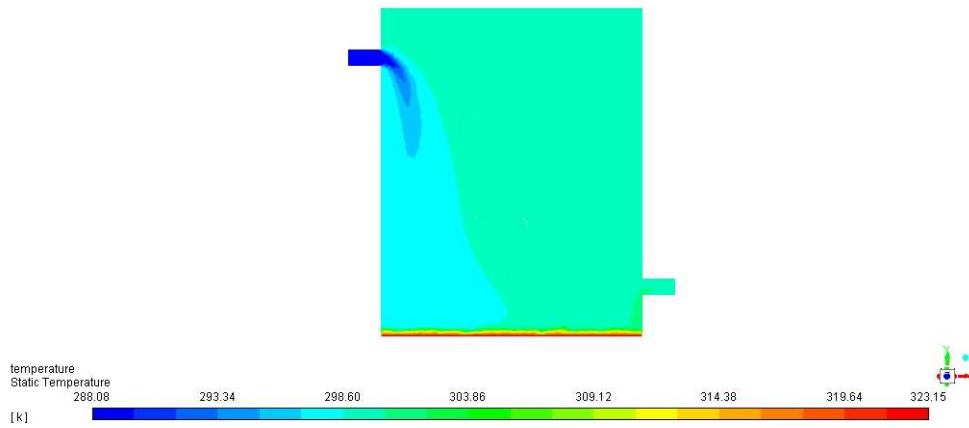
temperature
Static Temperature

288.08 293.34 298.60 303.86 309.12 314.38 319.64 323.15
[k]

Figure 4: Contour plot of temperature

c) A contour plot of Y velocity on the symmetrical plane is shown in the following figure. The negative velocity indicates the flow influenced by the force of gravity whereas the positive velocity indicates the flow influenced by buoyancy effect.
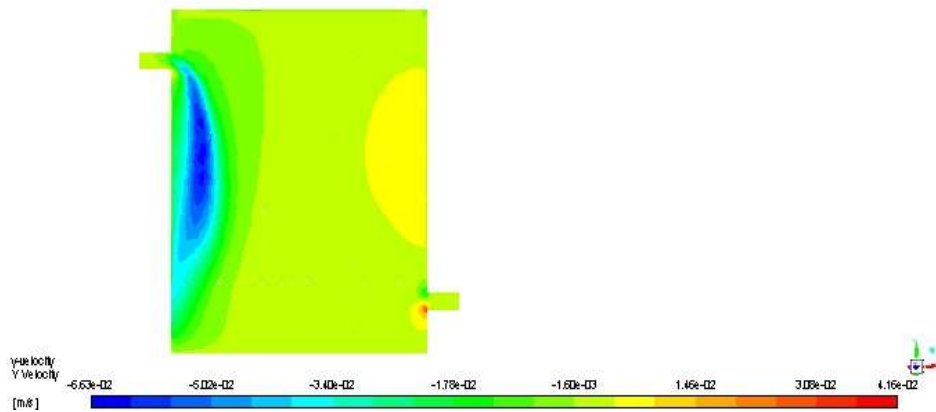

y-velocity
Y Velocity

-5.63e-02 -5.02e-02 -3.40e-02 -1.78e-02 -1.60e-03 1.45e-02 3.08e-02 4.16e-02
[m/s]

Figure 5: Contour plot of Y velocity magnitude

Simulation 2:

General setup:

PARAMETERS	DIRECTION	VALUE	UNITS
Inlet velocity	-X direction	0.05	m/s
Gravity	-Y direction	9.81	m/s^2
Height of the Inlet pipe from base	+Y direction	0.15	m
Height of the Outlet pipe from base	+Y direction	0.85	m

Other than the direction of inlet velocity, height of the inlet and outlet pipe remaining parameters and approximations are same.

Results:

a) The outlet temperature determined by performing integration over the surface using surface integral of area weighted average is **300.069K** and it is shown in the following figure. It could be observed that the outlet temperature in simulation 1 is greater than the outlet temperature in simulation 2. The inlet is very close to the bottom surface in simulation 2 and in this case, the hot water rising due to the change in density has to travel larger distance to come out of the outlet. Hence there might be loss of heat to the surrounding water parcels thereby resulting in reduction of temperature at the outlet. On the otherhand, in the case of simulation 1, the outlet is very close to the bottom surface and hence there will not be much loss of heat to the surrounding parcels as that of the outlet at some greater distance from the bottom surface.
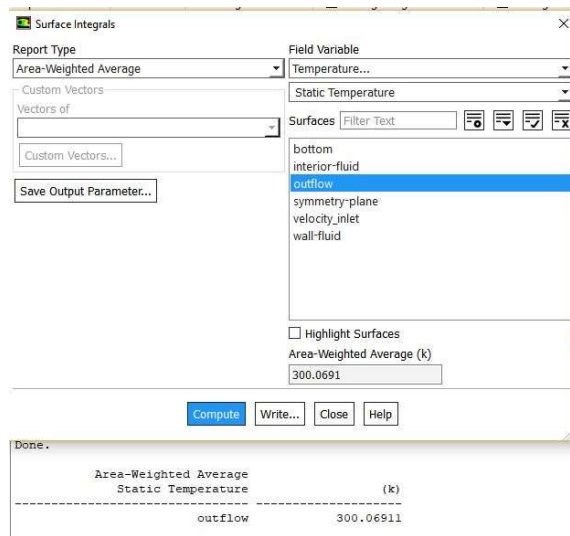

Figure 6: Outlet temperature

b) Contour plot of temperature on symmetrical plane clearly shows the cool water flow from the inlet onto the tank.
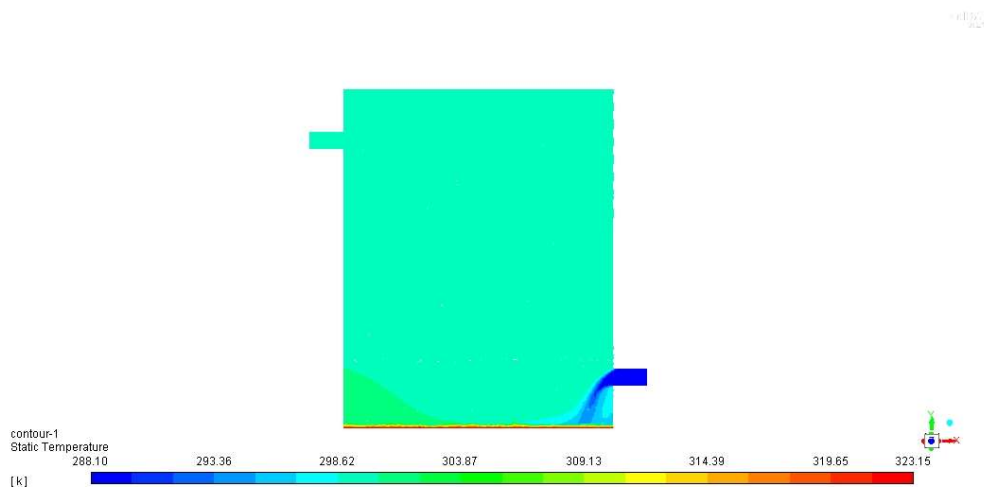

Figure 7: Contour plot of temperature

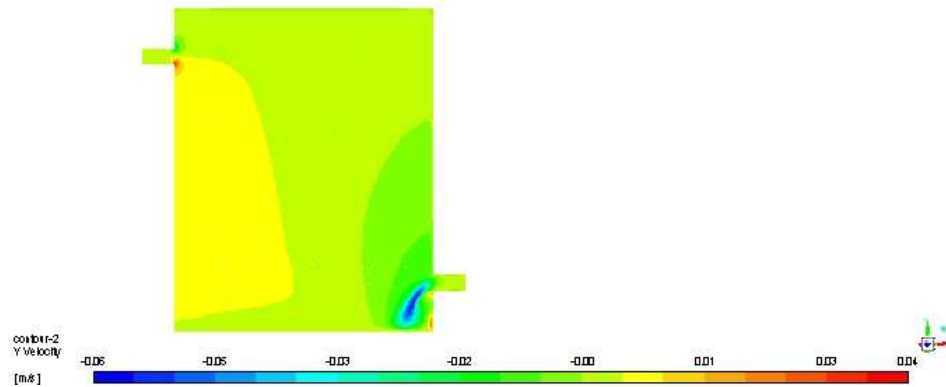c) Contour plot of Y velocity magnitude on symmetrical plane

Figure 8: Contour plot of Y- velocity

Task 2

The same setup of simulation 1 is used for this task, except the fact that the gravity is not taken into consideration and density is set to constant equal to that of operating density from simulation 1. Owing to this, boussinesq approximation is not used in this simulation.

Results:

a) The outlet temperature is found using the same surface integral technique which yields the temperature to be **292.80K**. This temperature is lower than the temperature obtained from simulation 1. This is because, water will enter the tank but not try to reach the bottom surface as there is no gravity to influence its motion. Also buoyancy driven thermal convection will not be taken into the simulation due to the absence of boussinesq approximation.
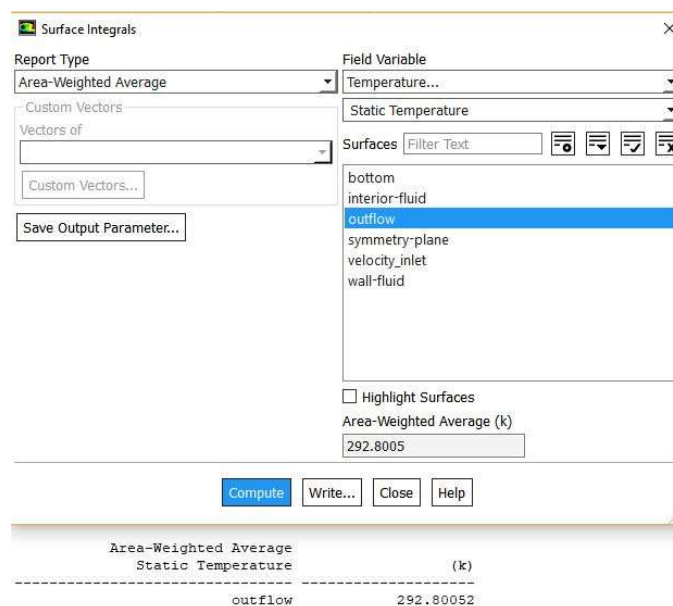

Figure 9:Outlet temperature
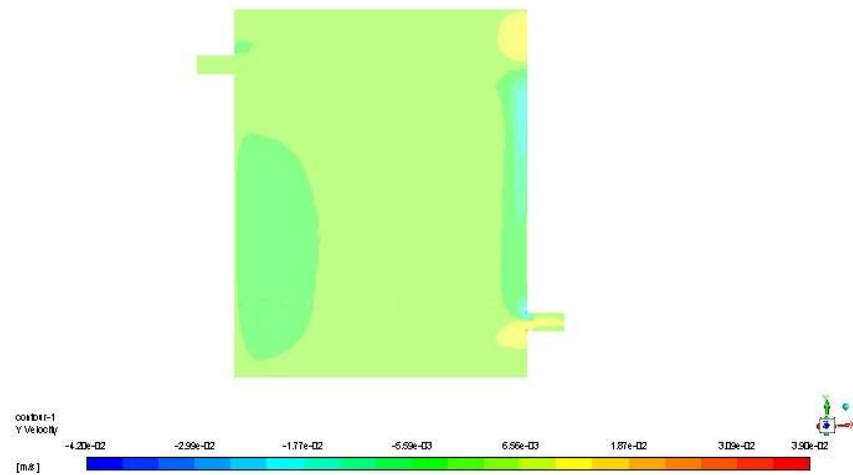
b) Contour plot of Y velocity on symmetrical plane

Figure 10: Contour plot of Y- velocity

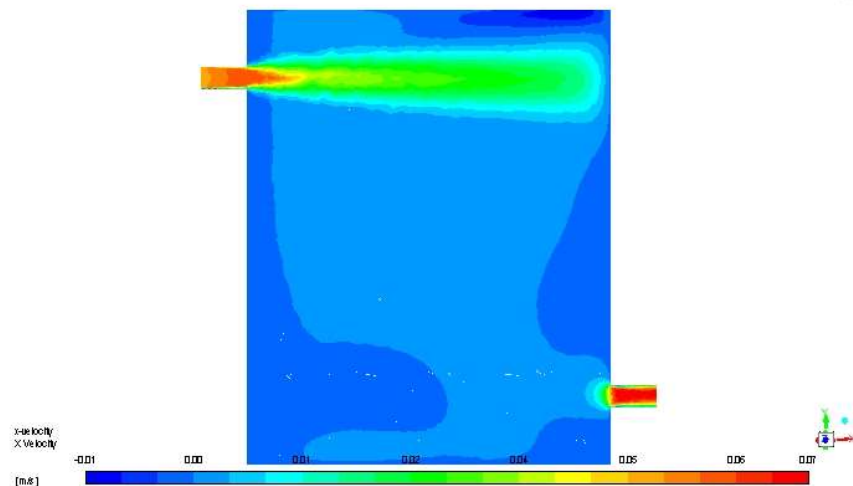c) Contour plot of X- velocity on symmetrical plane

Figure 11: Contour plot of X- velocity

Task 3:

The setup used for simulation 1 is used again but now for the transient condition. Time is taken into consideration and boussienesq approximation is used to reduce the complexity associated with density based solver. In order to visualize the transient behaviour at the start of the simulation, very low time steps of 2s and the maximum number of iteration per time step of 10 is considered. This particular setting is used until the flow time reaches 5000s (i.e. 2500 time steps). After reaching 5000s, the slope of the curve starts to decrease which indicates the steady state behaviour. Owing to this, time step of 15s is considered after 5000s to reduce the computation time.

a) Transient simulation is made to run until the magnitude of difference between the time dependent outlet temperature and outlet temperature from steady state solution of simulation 1 is less than or equal to 2℃. The temperature at the end of transient simulation found using surface integral function is **299.16K**. The contour plot of Y-velocity magnitude taken on the symmetrical plane is shown below,
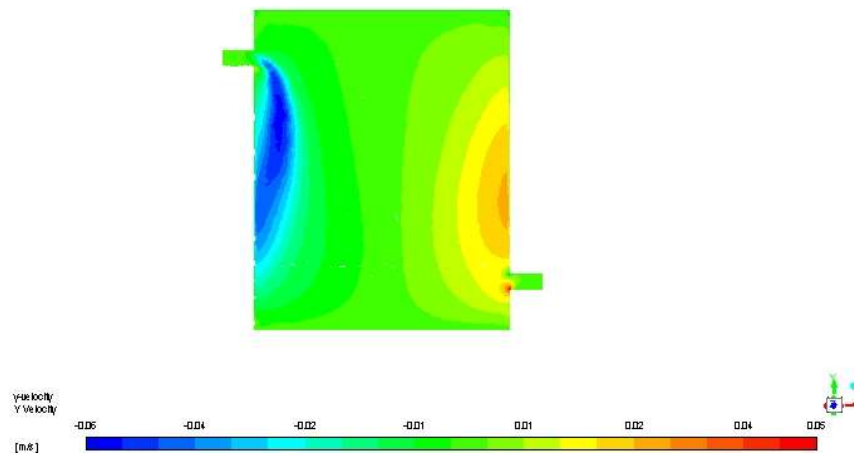
Figure 12: Contour plot of Y- velocity

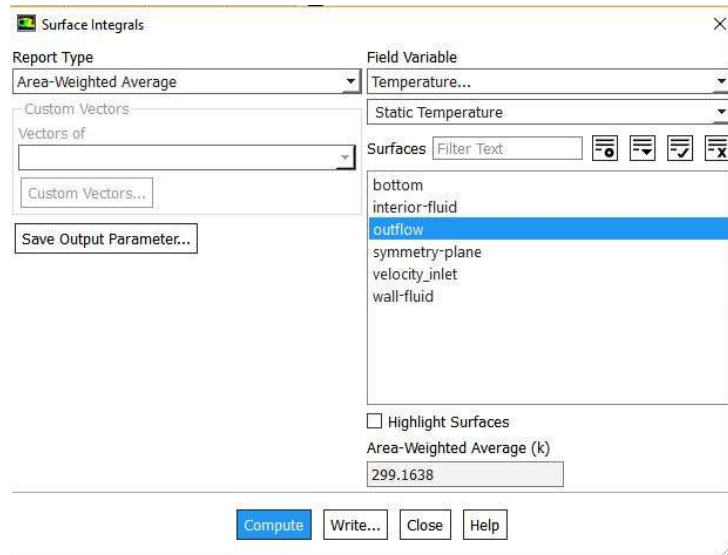Outlet temperature at the end of transient simulation:

Figure 13: Outlet temperature

b) Plot of outlet temperature as a function of time is shown below. The transient behaviour can be clearly seen at the start of the simulation and as the time proceeds, the curve becomes smoother.
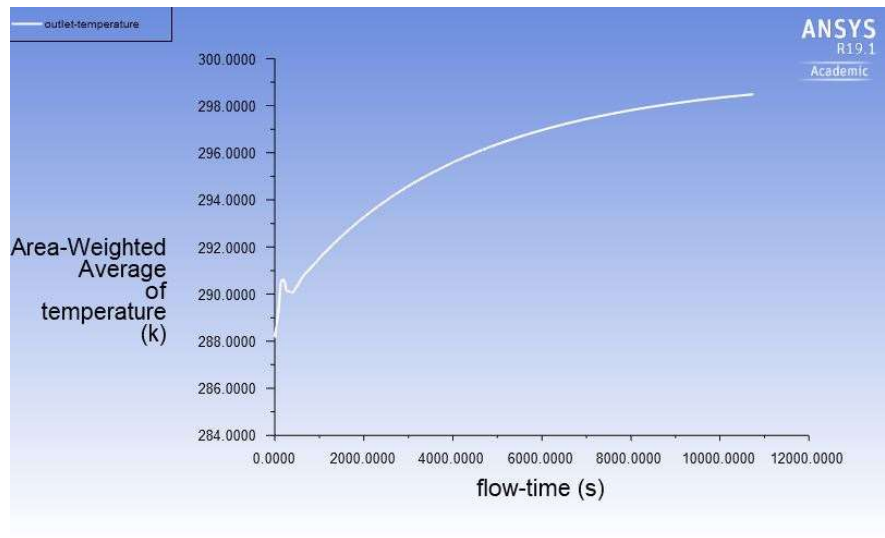
Figure 14: Outlet temperature as a function of time

c) A custom field function for measuring the strength of downward velocity is created using "**user defined function**" and the plot of the strength of downward velocity over the entire range of time for transient simulation is taken and it is shown below,
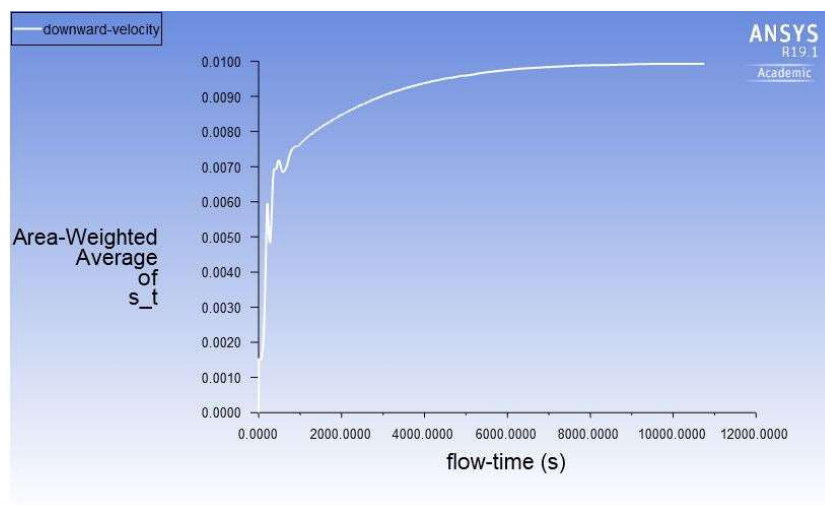
$$S = \frac{1}{A} \iint_A \frac{(|V| - V)}{2} \, dA$$

Figure 15: Strength of downward velocity as a function of time

Task 4

The similar setup of simulation 1 is carried out in this task. But the boundary condition at the bottom surface is constant heat flux and not the temperature. This heat flux has to be calculated from simulation 1. Using "**fluxes**" option, total heat transfer rate at the bottom is found. Since the area of the bottom surface is known, the total flux can be calculated by dividing the total heat transfer rate by the area of the bottom surface. Total heat flux is determined to be **10147.2298** W/m^2. These calculation done on "Fluent" is shown below,
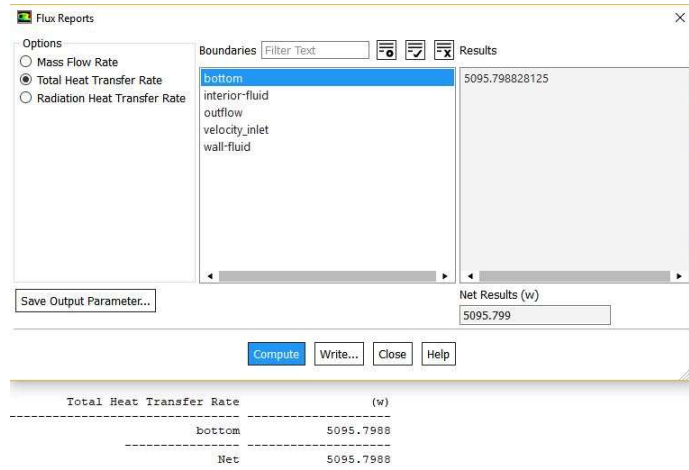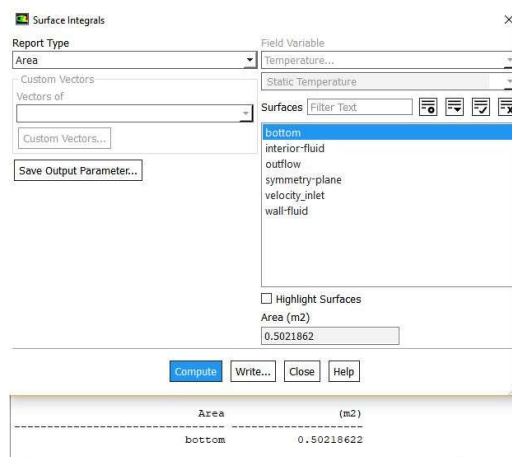
Figure 16: Total heat transfer rate at bottom

Figure 17: Area at bottom surface

After carrying out the simulation using the heat flux condition at the bottom, the temperature at the outlet is found to be **300.8271K**.
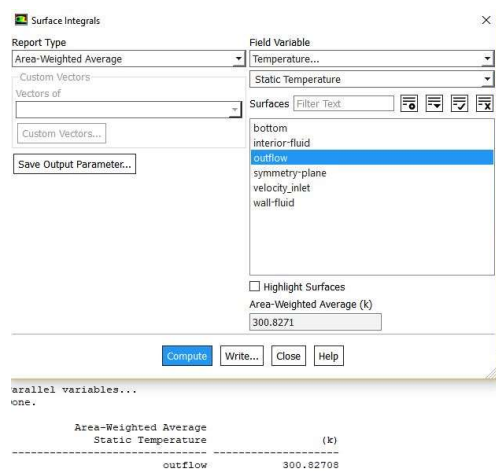

Figure 18: Outlet temperature

b) **Total heat transfer rate:** Click on "**reports**" and then "**fluxes**". Enable total heat transfer rate and choose the boundary as "**bottom**". Clicking on the "**compute**" option displays the total heat transfer rate at bottom surface in W. These are done within the solution of simulation 1.

Equivalent heat flux: Click on "**reports**" and then "**surface integral**". Select the report type to be Area and surface as bottom. Now clicking on compute will display the area of the bottom surface. Since the total heat transfer rate is known, dividing that by area of bottom gives equivalent heat flux at the bottom surface.

Outlet temperature: Click on "**reports**" and then "**surface integral**". Select the report type to be **Area weighted average** and surface as **Outlet**. Now clicking on compute will display the outlet temperature.

It is found that the outlet temperature obtained in the case of constant heat flux condition is same as that of the temperature obtained in constant temperature condition. In the case of constant temperature, heat flux varies in order to maintain constant temperature condition. On the other hand, in the case of constant heat flux, temperature will vary to keep the heat flux constant. In both these cases, the rise in temperature of the water is due to the rate of heat transfer into the water and it remains same in both the conditions. Owing to this, Outlet temperature is same.