CPDLR

NUCLEATE BOILING SIMULATION

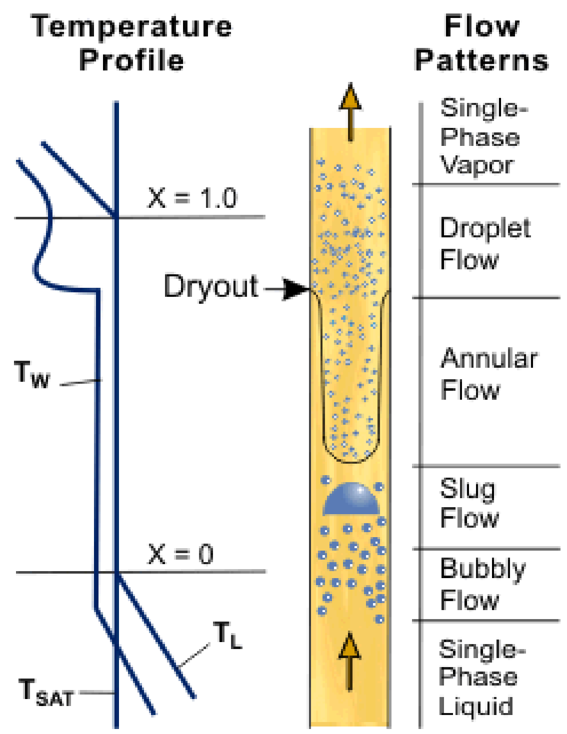
USING ANSYS FLUENT

INTRODUCTION TO NUCLEATE BOILING

- Nucleate boiling is a phenomenon that occurs when the wall temperature is higher than the saturation temperature of the fluid while the temperature of the bulk fluid is below saturation temperature.

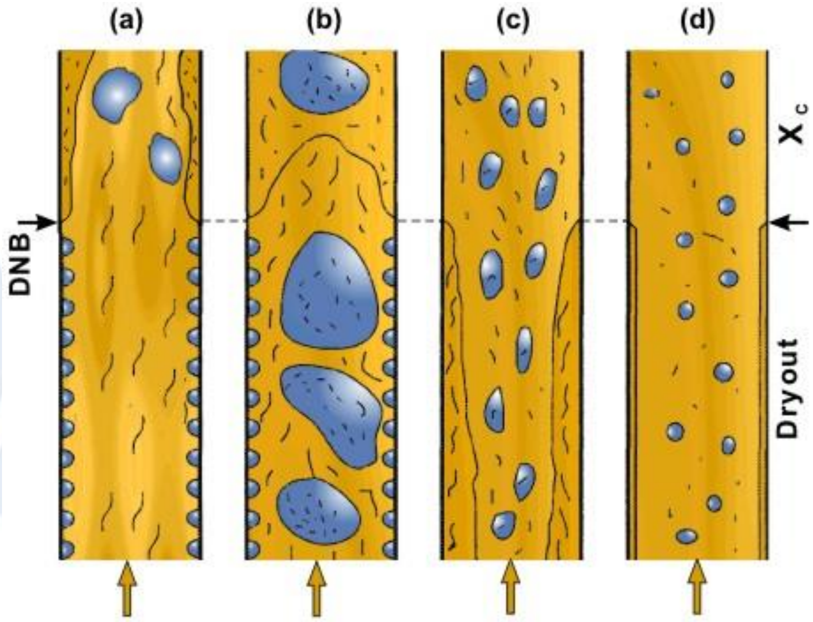
$$T_{bulk} \leq T_{saturation} \leq T_{wall}$$

- Nucleate boiling regime is desirable for boiler tubes because it involves higher heat transfer rate.



DEPARTURE FROM NUCLEATE BOILING (DNB)

- If nucleate boiling regime is exceeded than it results into sudden increase in the wall temperature and may cause its melting which is not desirable. This is due to film of steam (low thermal conductivity) acting as insulation between bulk fluid and heating wall. This phenomenon is called **Departure From Nucleate Boiling (DNB)**.
- Therefore it is very important to avoid DNB in tubes where heat transfer occurs with phase change (Boiling).



CASE OBJECTIVE

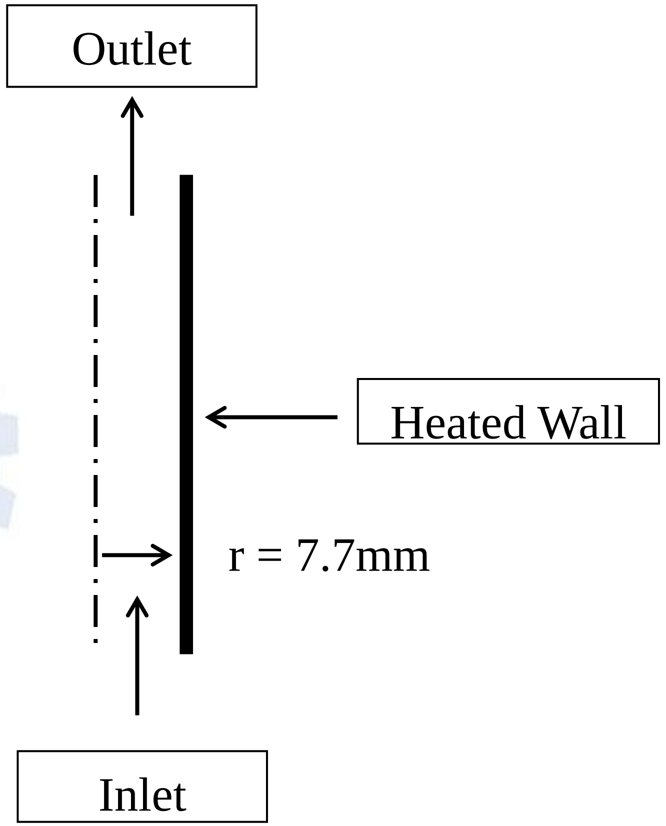
- ✓ **Objective of this case study is to understand the concept of heat transfer through boiling and simulating it using Ansys Fluent.**
- ✓ **To check whether departure from nucleate boiling will occur or not.**

PROBLEM STATEMENT

The pipe is 15.4mm in diameter & 2000mm in length. The flow is vertically upward through the heated pipe. Two cases are made,

1. p45_q570 &
2. p15_q380,

for which heat flux at the wall are 570KW/m^2 & 380KW/m^2 & the operating conditions are 45Bar & 15Bar respectively.



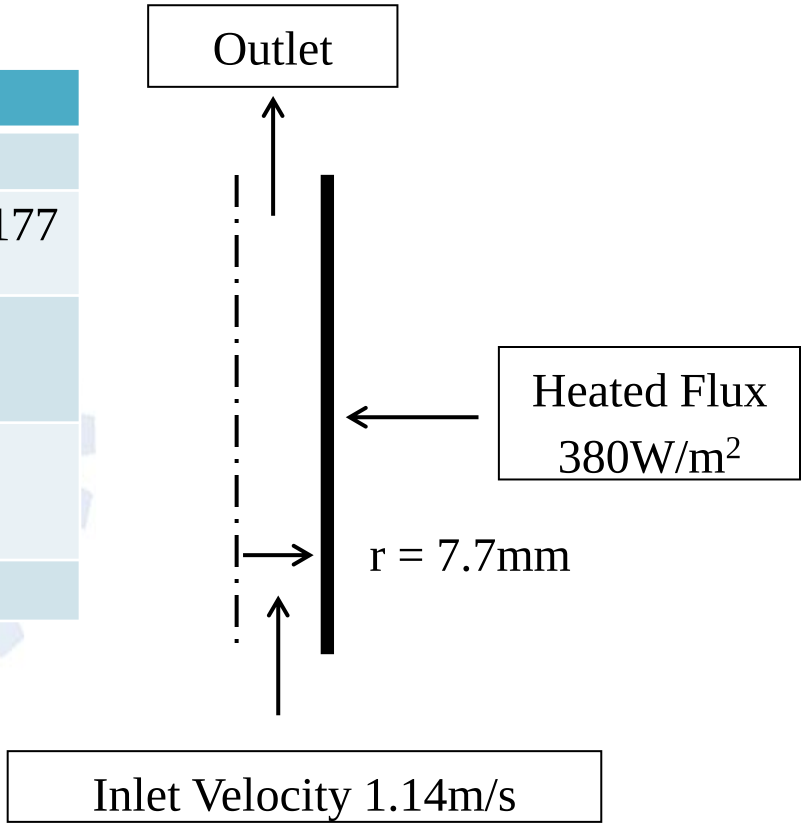
CASE 1 (p45_q570)

- ✓ The operating pressure for this case is 45 Bar
- ✓ Heat flux at the heated wall is 570 W/m^2
- ✓ Inlet sub-cooling 60°C
- ✓ Mass flux is 900 $Kg/m^2/s$

Properties At 45 Bar

Properties	Water	Steam
Density (kg/m^3)	787.6	22.6
Dynamic Viscosity (kg/m-s)	0.000103	0.0000177
Specific Heat Capacity (J/kg-k)	4949.2	4227.9
Thermal Conductivity (W/m-k)	0.612	0.0533
Latent Heat (KJ/kg)	1122.1	2798.0

Saturation Temperature At 45 Bar
257.4°C or 530.6°K
Therefore Inlet Temperature Will Be
197.4°C



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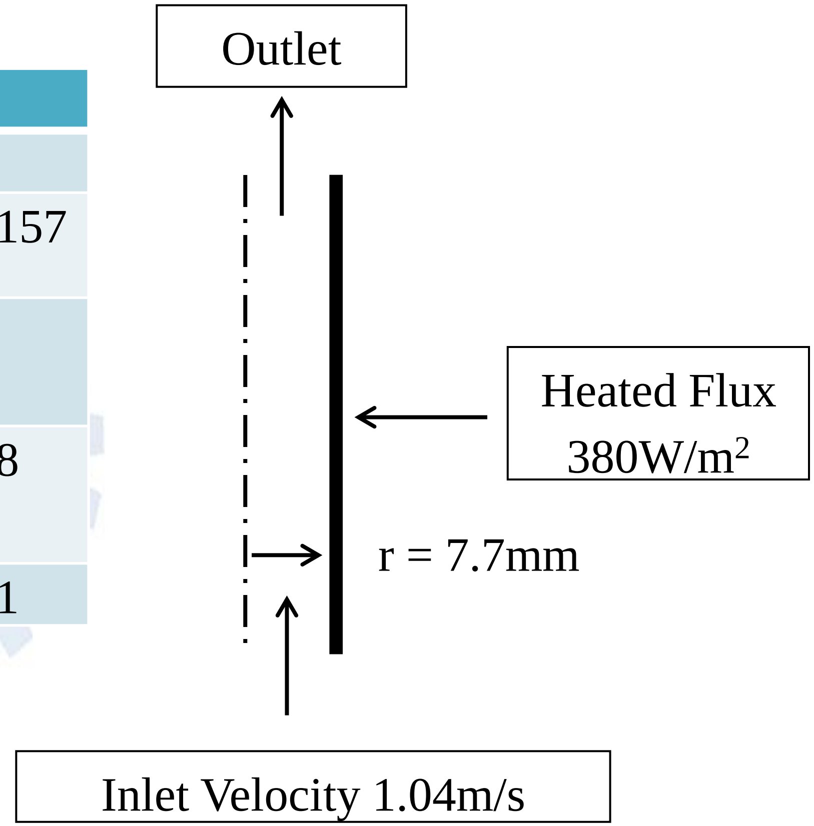
CASE 2 (p15_q380)

- ✓ The operating pressure for this case is 15 Bar
- ✓ Heat flux at the heated wall is 380 W/m^2
- ✓ Inlet sub-cooling 60°C
- ✓ Mass flux is 900 $Kg/m^2/s$

Properties At 15 Bar

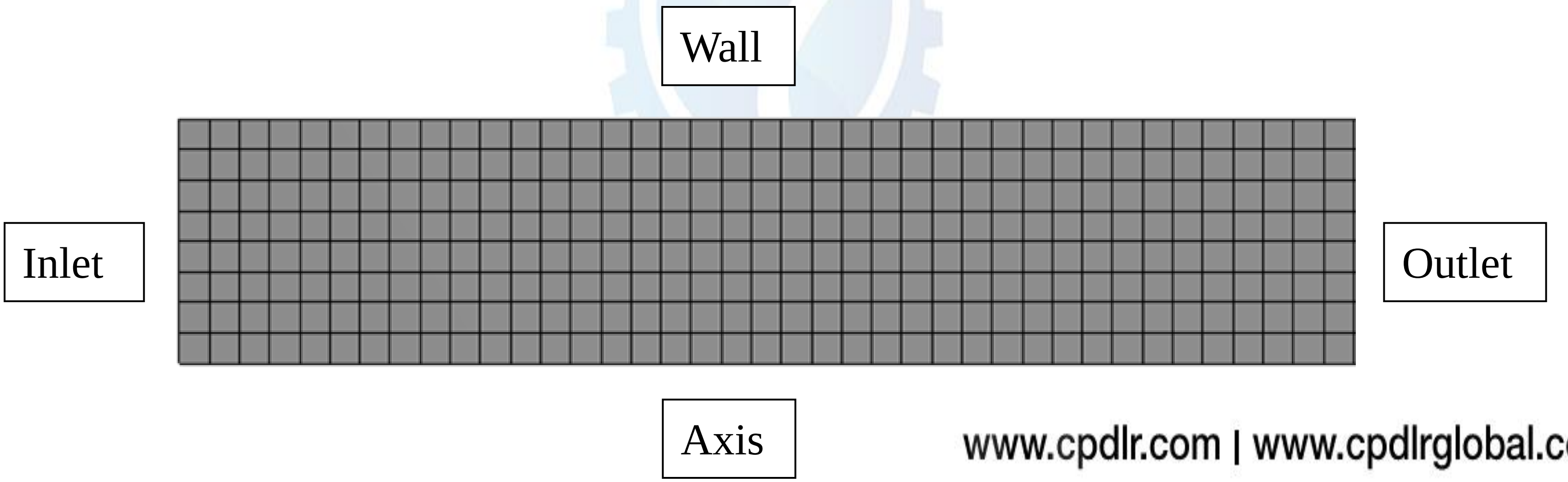
Properties	Water	Steam
Density (kg/m^3)	866.6	7.6
Dynamic Viscosity (kg/m-s)	0.000136	0.0000157
Specific Heat Capacity (J/kg-k)	4485.5	2964.5
Thermal Conductivity (W/m-k)	0.6643	0.03978
Latent Heat (KJ/kg)	844.72	2791.01

Saturation Temperature At 15 Bar
198.3°C or 471.4°K
Therefore Inlet Temperature Will Be
138.3°C



GEOMETRY & MESH

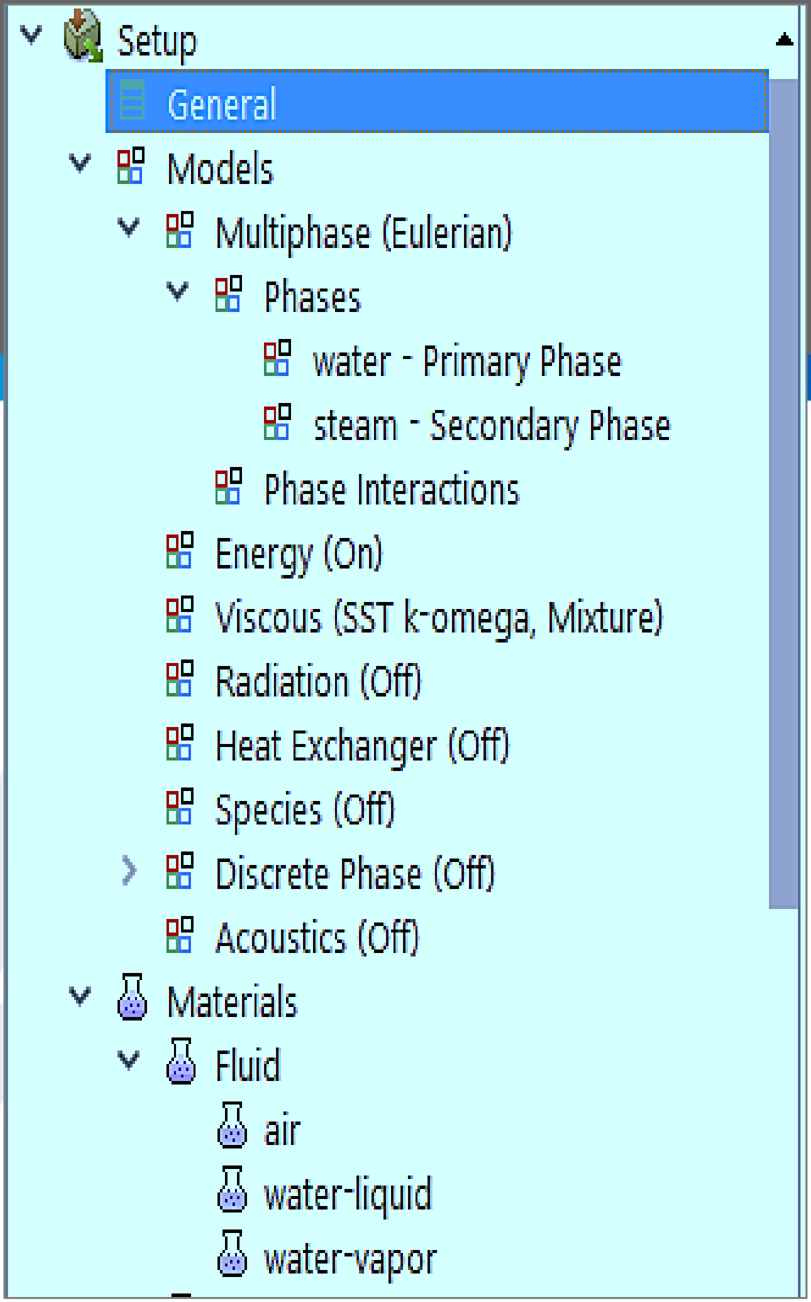
- The geometry considered for this study was made in design modeler and axis-symmetric assumption was taken into account to simplify the 3D pipe into 2D.
- A high quality structured grid was generated in the ANSYS Mesh. The mesh count is 16000 in this grid.
- Following names were assigned to the boundaries in ANSYS Mesh.



FLUENT CASE SETUP

Models & Materials

- The given flow boiling problem was simulated using RPI Boiling Model Under Eulerian Multiphase Model. (EMM)
- Recommended Turbulence Model was k-w SST.
- Gravity was enabled.
- Water-liquid & Water-vapor were selected as primary & secondary phase respectively.
- Properties were given according to the operating pressure.



FLUENT CASE SETUP

Phase Interactions

- In the Phase Interaction Panel, following pre-defined correlations were used to model boiling.
- The saturation temperature was also set according to the operating condition.
- Surface tension between the interacting phases is important and must be carefully entered. (0.038 N/m for current case)

Model	Eulerian
Boiling Model Option	RPI Boiling Model
Wall Lubrication	Antal-at-al
Interfacial Drag Force	Ishii
Interfacial Lift Force	Tomiyama
Turbulent Dispersion	Lopez-De-Bertodano
Turbulent Interaction	Troshko-Hassan
Interfacial Heat Transfer Coefficient	Ranz-Marshall
Interfacial Area	Particle
Bubble Departure Diameter	Tolubinski-Kostanchuk
Frequency Of Bubble Departure	Cole
Nucleation Site Density	Lemmart-Chawla
Area Influence Coefficient	Delvalle-Kenning

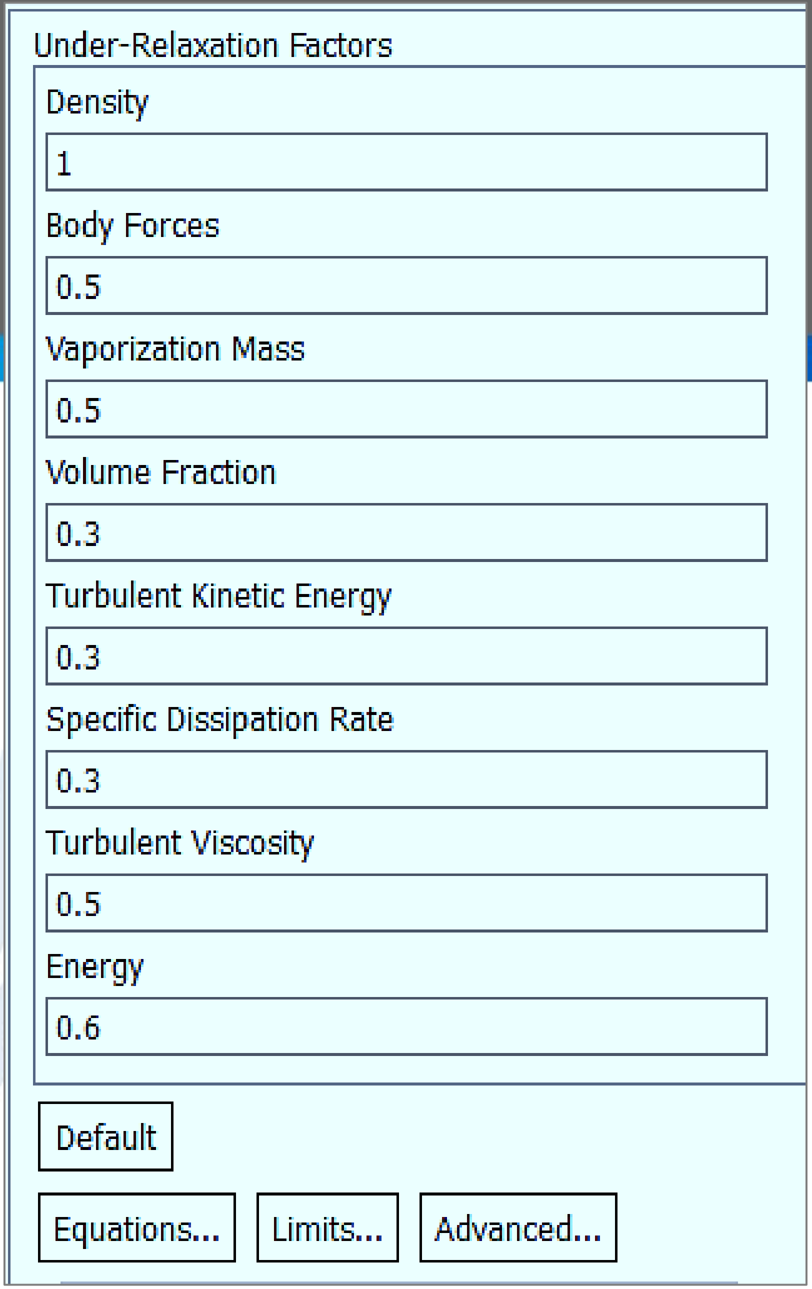
FLUENT CASE SETUP

Solution Methods & Controls

- In the solution methods, “Coupled” pressure-velocity coupling scheme was used.

- First Order Discretization schemes for all the equations was used.

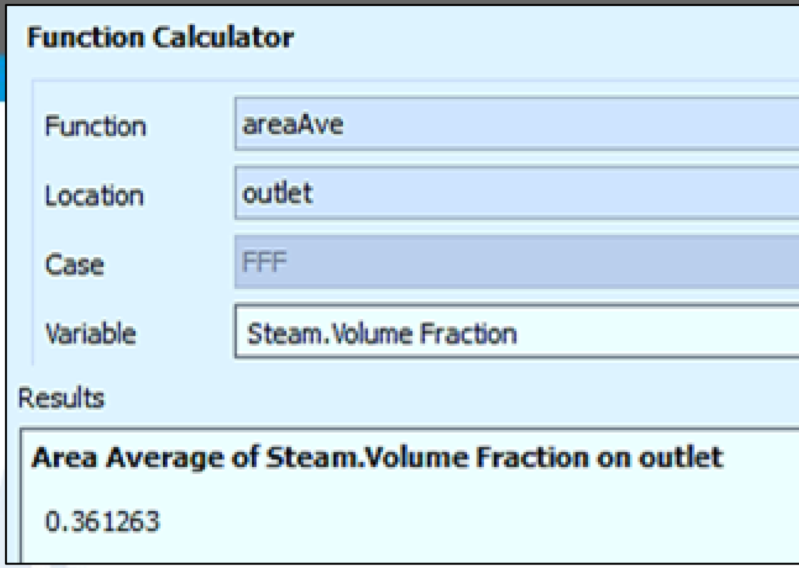
- In the solution controls, Flow Courant Number was set to 10 & following under relaxation factors were used as shown in picture.



RESULTS CASE 1 : p45_q570

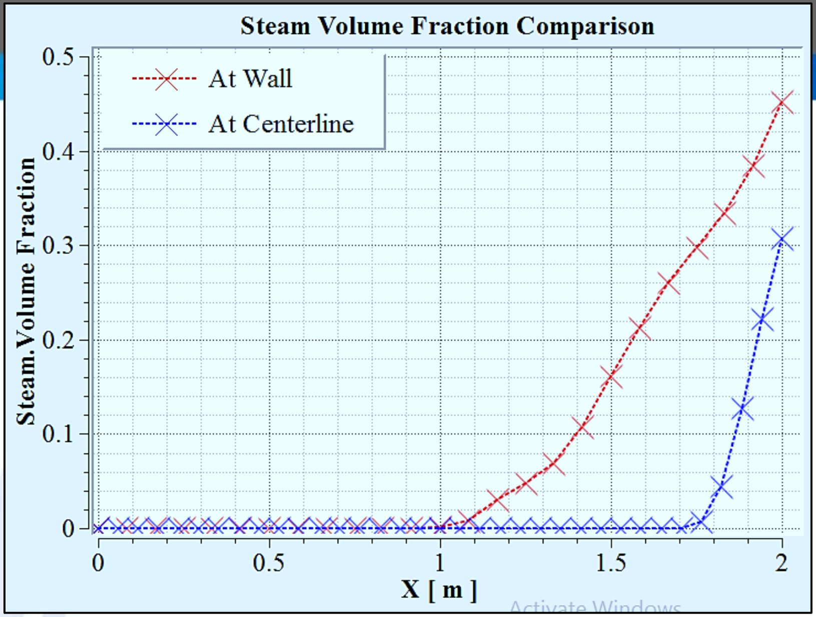
RESULTS: Steam Volume Fraction (Case p45_q570)

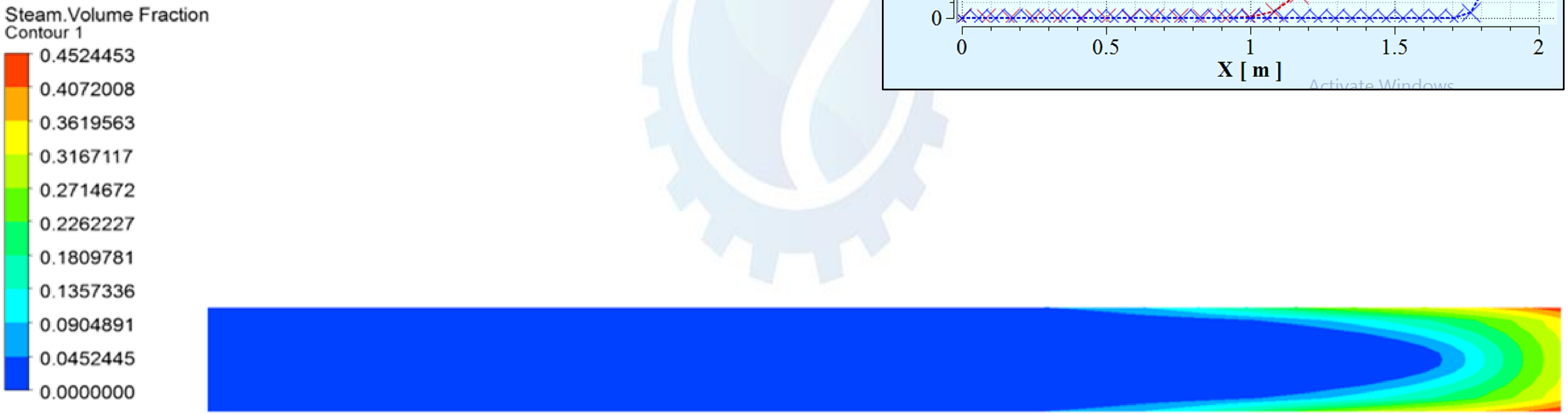
- In the contour below, the blue colored area indicates zero volume fraction of steam which means water has still not converted into steam in that area.
- The red color indicates maximum conversion of water into steam in that area which is about 0.45.



RESULTS: Steam Volume Fraction (Case p45_q570)

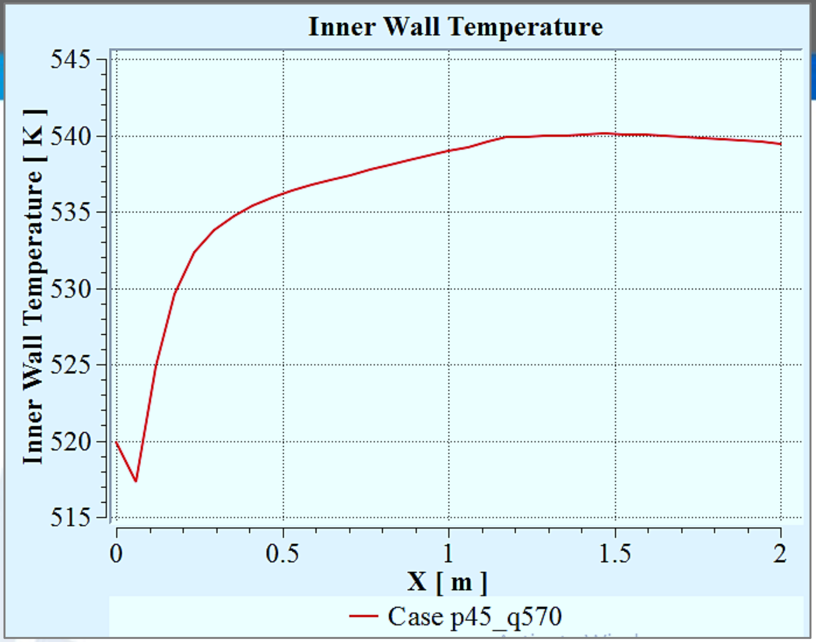
From the chart, we can clearly observe that the steam has started forming near the wall at a distance half the length of the pipe whereas it appears at the center at about 1.8m from the inlet. The maximum conversion of water into steam is 0.45 by volume fraction near the outlet walls.





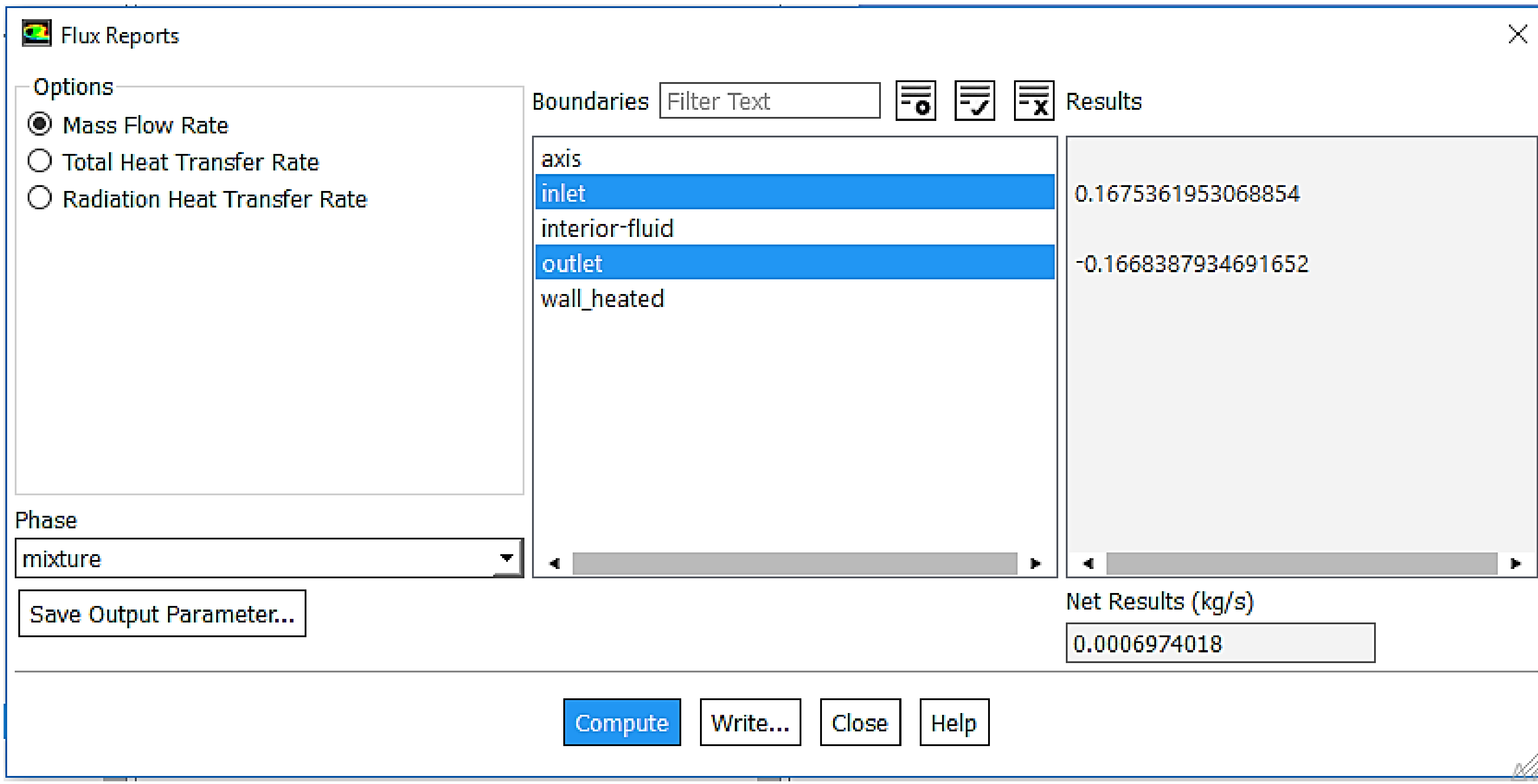
RESULTS: Steam Temperature (Case p45_q570)

For this case, the T_{sat} was 530.6°K & the $T_{wall,max}$ reached is 540.1°K. Therefore ∇T_{wall} is not more than 9.5°k anywhere along the pipe length. Hence the heat transfer will occur in nucleate boiling regime & departure from nucleate boiling will not occur for these conditions.



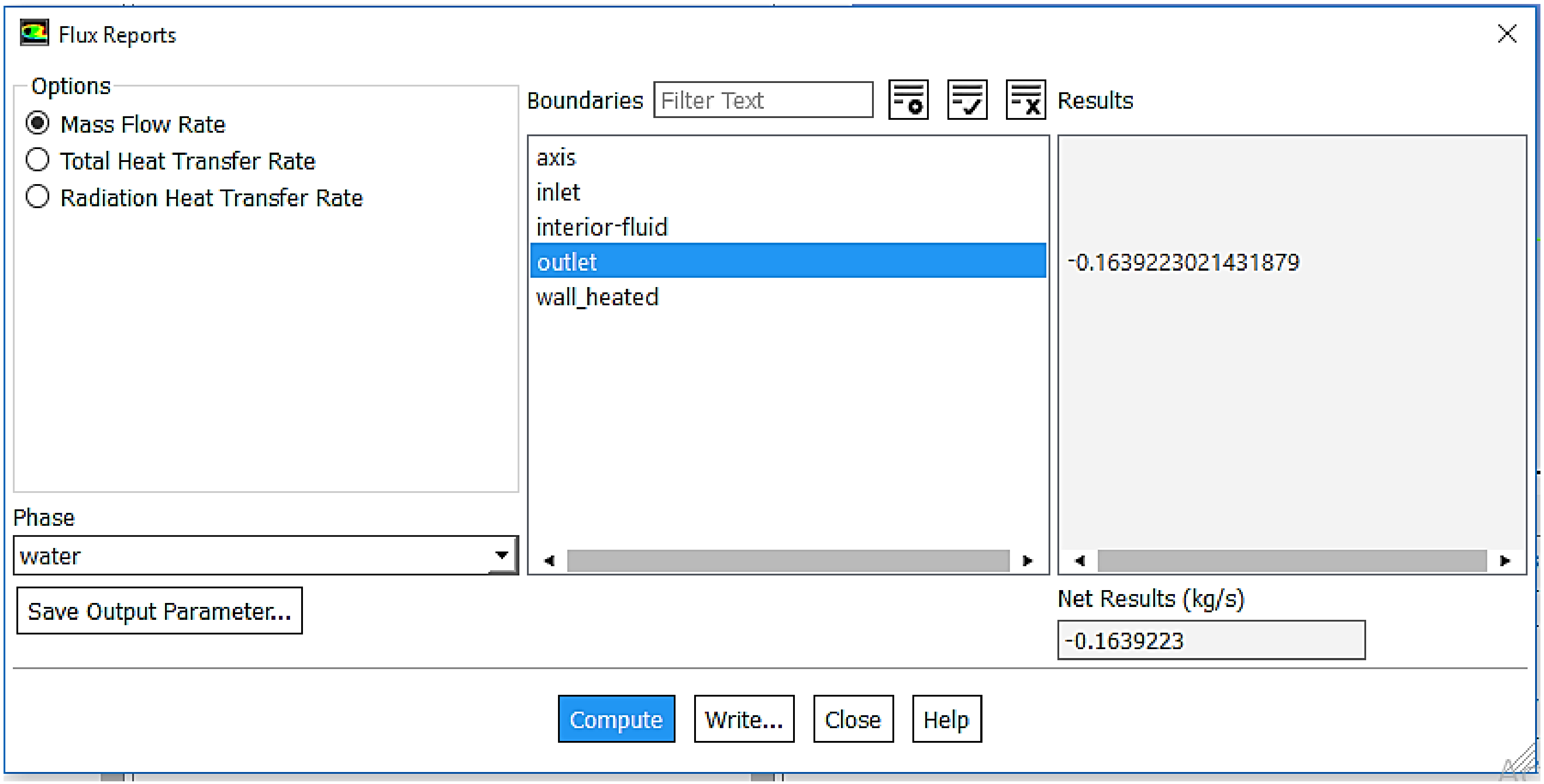
RESULTS: Case p45_q570

- ✓ Cross Sectional Area Of Pipe (Ac):- 3.14x(0.0077)^2=0.0001862 m^2
- ✓ Mass Flow Rate:- Ac X Mass Flux = 0.0001862 X 900 = 0.16755 kg/s or 603.2 kg/h
- ✓ From the Flux Report for mass flow rate of mixture, mass conservation can be seen.



RESULTS: Case p45_q570

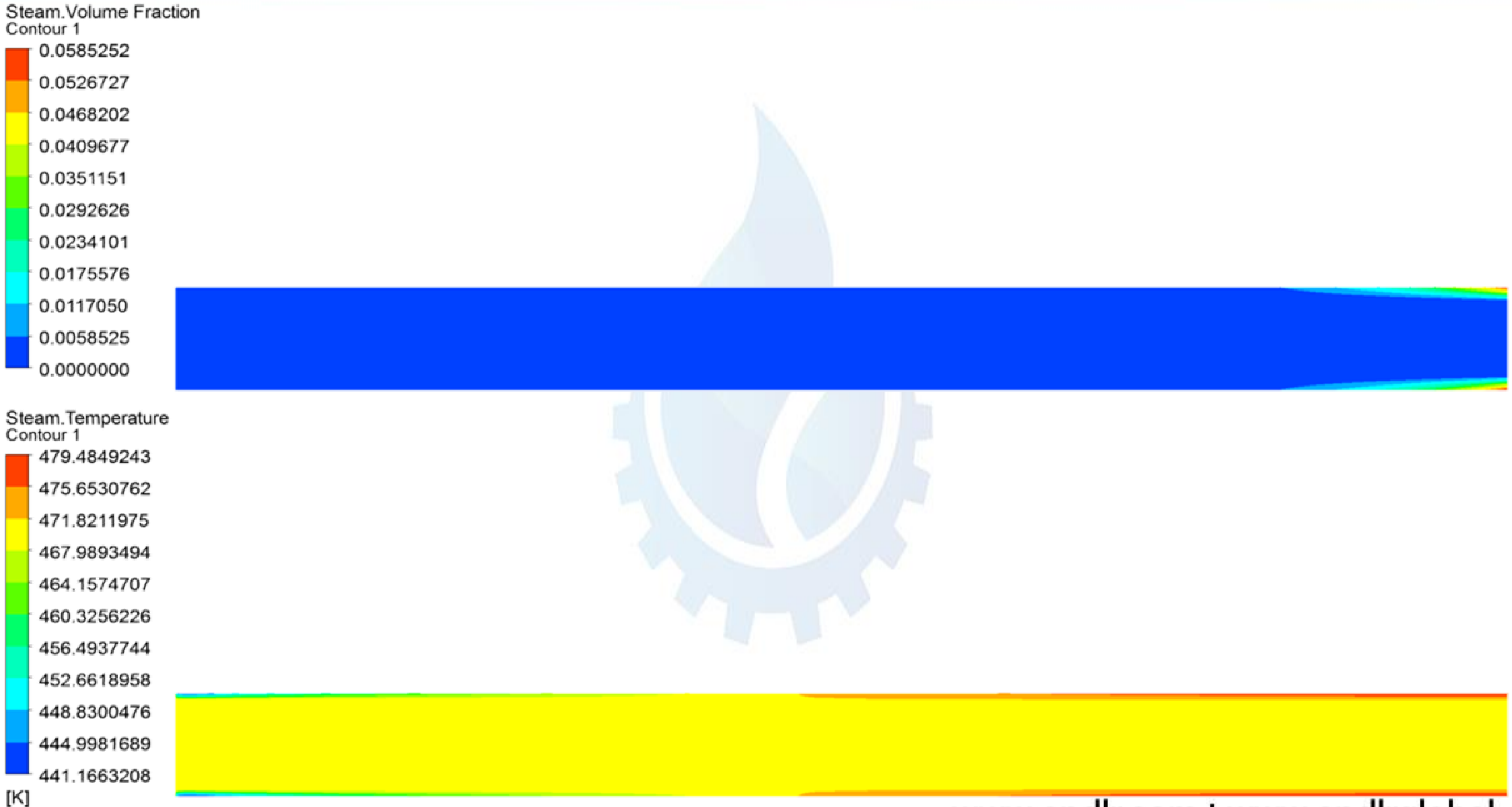
- ✓ Also the water content at the outlet mixture can be seen in the flux report. It is about 0.164 kg/s or 590.12 kg/h.
- ✓ So we can say that the steam content in the outlet mixture is 603.20-590.12 =13.08 kg/hr.



RESULTS CASE 2 : p15_q380

RESULTS: Case p15_q380

For this case, it can be clearly observed that the steam has just started forming at the wall near the outlet and the volume fraction is still very low. The nucleate boiling has just initiated at the end of the pipe.



RESULTS: Case p15_q380

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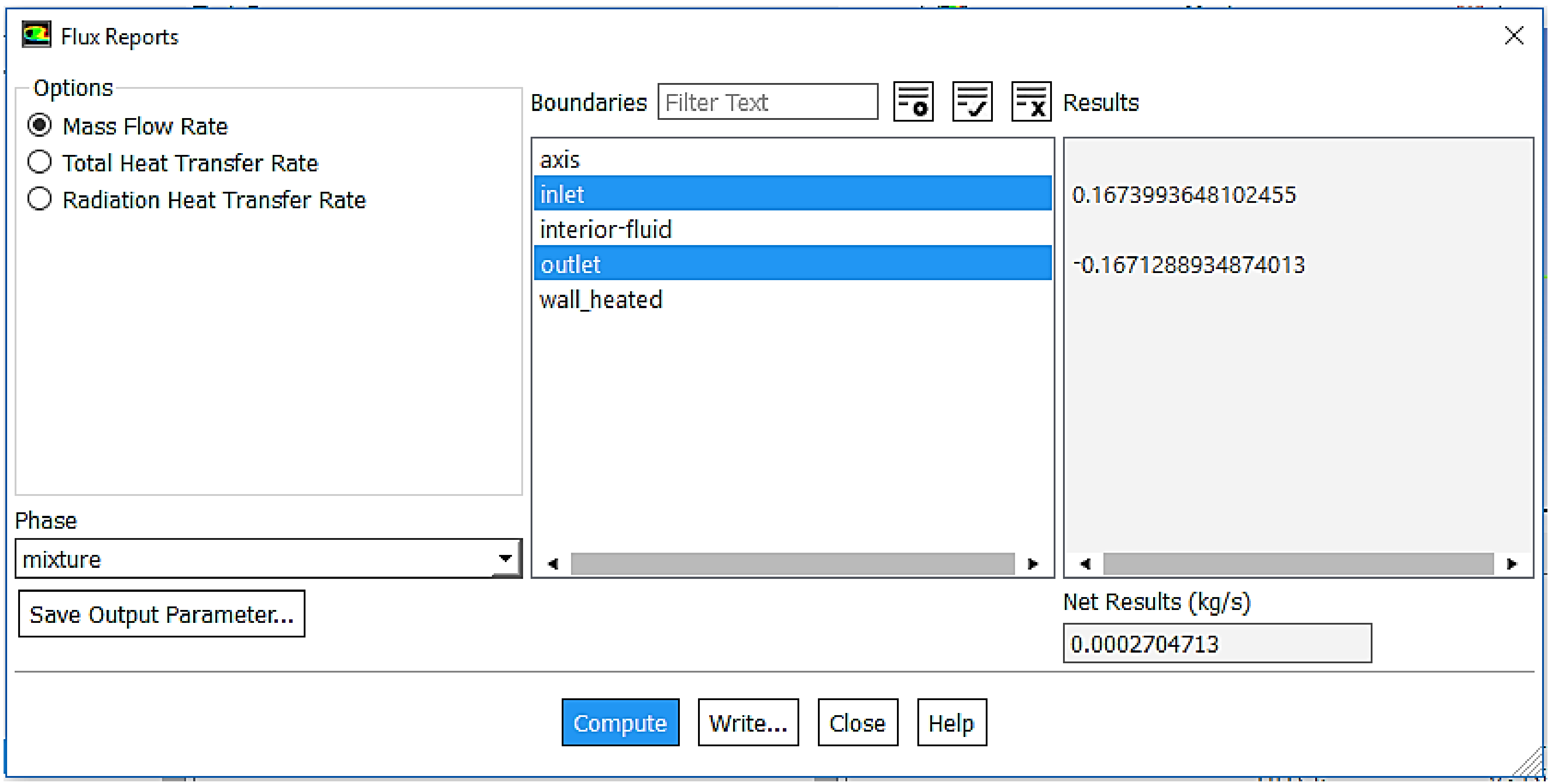
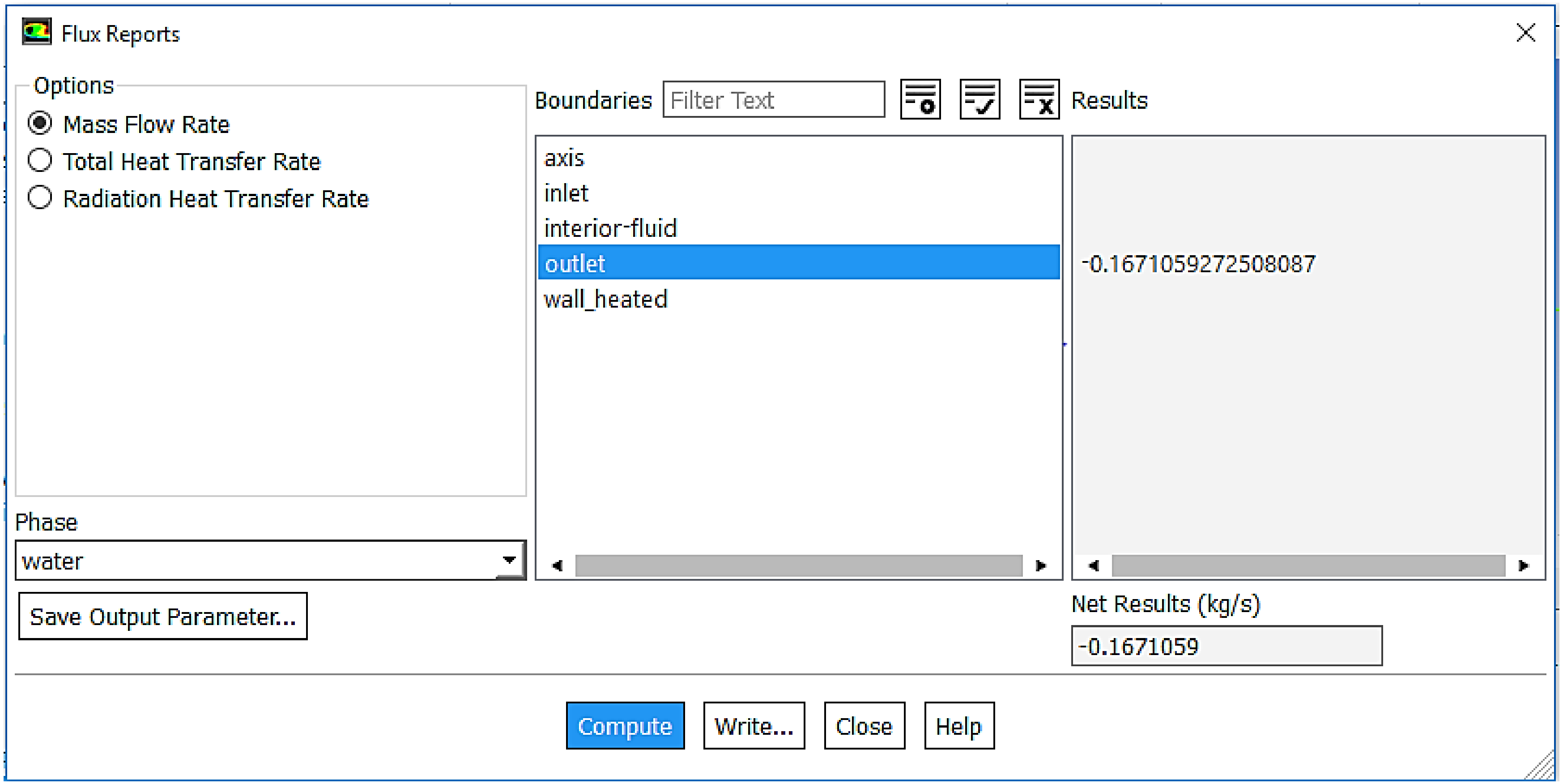


RESULTS: Case p15_q380

- ✓ Also the water content at the outlet mixture can be seen in the flux report. It is about 0.167106 kg/s or 601.58 kg/h.
- ✓ So we can say that the steam content in the outlet mixture is 603.20-601.58 =1.62 kg/hr.



CONCLUSION

- Nucleate boiling was simulated for both the cases in ANSYS Fluent Solver using the RPI Boiling Model & the k-w SST Turbulence Model.

- In both the cases, the difference between wall temperature and saturation temperature is well below the critical temperature. So the departure from nucleate boiling will not occur in both the cases.

- As expected, the steam generation rate in case 1 (p45_q580) is much higher than in the case 2 (p15_q370). It is about 12.4% higher due to high operating pressure and high heat flux rate. The steam generation has just initiated at the end of the pipe in second case.