



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**TRANSIENT COMPUTATIONAL FLUID DYNAMICS  
MODELING OF WET STEAM IN A PIPING SYSTEM**

by

Jeremy D. Kmitta

September 2023

Thesis Advisor:

Co-Advisor:

Second Reader:

Walter C. Smith

Anthony J. Gannon

Garth V. Hobson

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**TRANSIENT COMPUTATIONAL FLUID DYNAMICS MODELING  
OF WET STEAM IN A PIPING SYSTEM**

Jeremy D. Kmitta  
Ensign, United States Navy  
BS, United States Naval Academy, 2022

Submitted in partial fulfillment of the  
requirements for the degree of

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**NAVAL POSTGRADUATE SCHOOL  
September 2023**

Approved by: Walter C. Smith  
Advisor

Anthony J. Gannon  
Co-Advisor

Garth V. Hobson  
Second Reader

Brian S. Bingham  
Chair, Department of Mechanical and Aerospace Engineering

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## **ABSTRACT**

The U.S. Navy's current design of steam pipe systems onboard ships is based upon conservative estimates of moisture presence. To increase efficiency while maintaining a safe system, an analysis was done on one section of the piping system. The focus of this research was to determine the location and quantity of excess moisture accumulation to inform future design of piping systems. Using the computational fluid dynamics software, ANSYS CFX, a sample piping system was designed and tested with high quality steam. The computational mesh was refined at steady-state conditions to improve the efficiency of future computational fluid dynamics research efforts. The piping system was tested using transient analysis to determine the moisture accumulation as a result of inlet quality and pressure variation to simulate changes in steam plant operation. The results of this research will inform the future design of these piping systems and advise the necessity and location of steam traps and piping bends.

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## NOMENCLATURE

|        |                            |
|--------|----------------------------|
| D      | diameter                   |
| F      | Darcy friction factor      |
| g      | gravitational acceleration |
| $\rho$ | density                    |
| P      | pressure                   |
| Re     | Reynold's number           |
| $\tau$ | shear stress               |
| T      | temperature                |
| U      | velocity                   |
| $u^*$  | friction velocity          |
| $\mu$  | dynamic viscosity          |
| X      | steam quality              |
| $\nu$  | kinematic viscosity        |

## ACRONYMS

|       |                                                                 |
|-------|-----------------------------------------------------------------|
| CCL   | CFX command language                                            |
| CEL   | CFX expression language                                         |
| CFD   | computational fluid dynamics                                    |
| EOS   | equations of state                                              |
| HPC   | high performance computing                                      |
| IAPWS | International Association for the Properties of Water and Steam |
| IF97  | International Formulation 1997                                  |
| RMS   | root mean square                                                |

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# **I. INTRODUCTION**

## **A. MOTIVATION**

The U.S. Navy utilizes nuclear powered propulsion onboard all aircraft carriers and submarines today. These complex, nuclear power plants are constantly under review to increase efficiency. Efficient reactor systems extend the life of the nuclear core and create potential for increased power output. Using advanced computational fluid mechanics (CFD), the respective components in these onboard nuclear reactors can be analyzed and optimized. CFD enables complex fluid modeling which is specifically useful in modeling the multiphase flows seen in these reactor steam systems.

These steam turbine propulsion plants consist of multiple stages, each with their own potential for inefficiencies. One area of interest is moisture removal. Within the piping system, saturated steam has the potential to condense to droplets. If not removed properly, these droplets will collect and erode turbine blades over time. The quantity and location of these droplets change as the steam plant operation is modified, introducing pressure and temperature fluctuations, which raise questions about the effectiveness of moisture removal systems. By using CFD to simulate these transient characteristics, the steam trap locations can be altered to improve moisture removal. CFD allows for the complex relationship between the wall and steam to be observed with varied conditions. The accuracy of these results can be tested using experimental validation later on.

## **B. OBJECTIVE**

This research aimed to generate meaningful transient solutions for both pressure and quality variations in a piping system. ANSYS CFX was chosen due to its capability to solve steady-state and transient solutions, model two-phase flows, and represent complicated flow relationships. This research focused on determining the setup of these transient solutions while providing an initial perspective on the functionality of existing steam traps. Steady-state analyses were required to set up these transient simulations and understand the general concepts at play. The work done here is only one step in a broader mission to understand the response of the steam piping system when excess moisture or

pressure are introduced into the system. The results will inform the future design and operation of these systems and their ability to remove this excess moisture. The outcome will be the fundamental understanding of the complex, multiphase system enabling designs that are conservative, efficient, and safe.

### **C. THESIS OVERVIEW**

This research effort simulated transient pressure and quality measurements for saturated steam in a piping system. The effect of steam traps, pressure, and inlet quality were examined to determine their effect on the liquid mass accumulated within the pipe. The result of this research will be used to determine the usefulness of the current size and location of these steam traps. Chapter II discusses the theory of two-phase flows in piping systems and the applicable solving methods using ANSYS CFX. Chapter III covers the methods used to setup and solve these CFD simulations. Chapter IV analyzes a case study that contains experimental results for a pressure transient experiment with saturated steam. Chapter V discusses the full piping system modeled at steady state conditions. Chapter VI describes the transient results and conclusions for the full steam pipe geometry. Chapter VII concludes this work and advises what the next steps are to continue this research.

## II. LITERATURE REVIEW

Previous research on two-phase flows in pipe systems is limited for the type of flow seen here. Empirical models exist to predict the phase change at piping junctions and particle dispersion within these flows, but there are few models that represent wet saturated steam in a piping system without non-condensable gas constituents. In order to evaluate the effectiveness of a transient CFD model produced by this research, a review of available literature was performed to describe the flow and examine the solver software that would be used to model this system.

Steam is used in powerplants to generate power and is created when a heat source boils the water. In a pressurized water reactor (PWR), heat is generated through nuclear fission in the reactor core [1]. This heat is transferred to the surrounding coolant, which in the case of a PWR, is pressurized water [1]. The heated pressurized water flows through the primary loop of the reactor, where it passes through the steam generator [1]. In the steam generator, the hot water transfers its thermal energy to a secondary loop of water, which does not come into direct contact with the radioactive materials [1]. The secondary loop water is converted into steam as it absorbs the heat from the primary loop [1]. The high-pressure steam then drives a turbine [1]. The mechanical energy from the turbine is transformed into electrical energy by the generator [1].

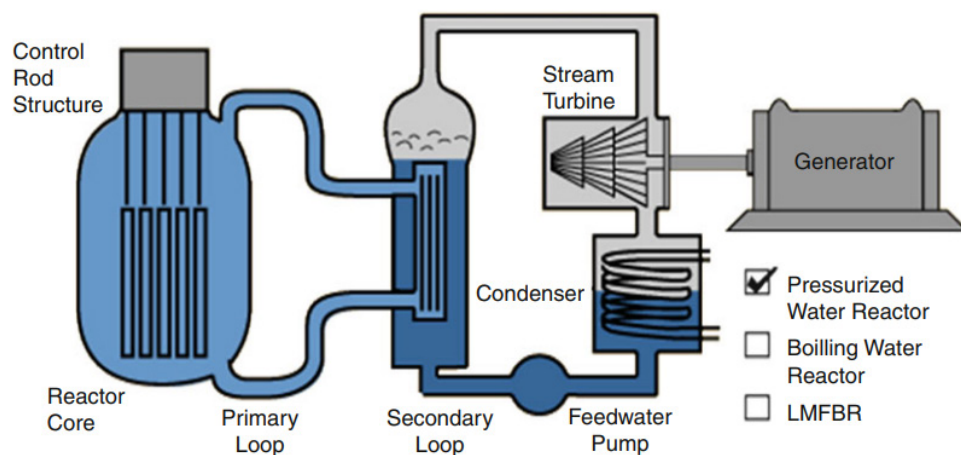


Figure 1. Typical layout of a heavy water reactor. Source: [1].

Multiphase flow is where two or more thermodynamic phases are present within one flow. While multiphase flows must adhere to the same conservation equations as single-phase flows, each fluid component in a multiphase flow consists of its own, unique set of equations [2]. These fluid dependent equation sets are then connected by interfacial and inertial forces that represent the interaction between flows [2]. Two-phase gas-liquid flows commonly occur in phase flows transitioning due to heat addition or removal, flows that are separated, and in flows where one phase is being carried by the other either as bubbles or droplets [2]. Two-phase flows are generally turbulent and experience complex interactions between the “carrier fluid” and the dispersed phase [2]. There are a variety of assumptions and approximations that must be made to model these turbulent flows and determine what type of flow they are [2]. Figure 2 displays the temperature, pressure, and specific volume diagram for two-phase water flows. Water is in the saturated liquid state, or a quality of zero, along the left side of the curve and saturated gas state along the right side of the curve with a quality of one. The area between the curves is the transition region. Constant pressure lines pass through the temperature-specific volume curve to represent the transition of the fluid through the two phases.

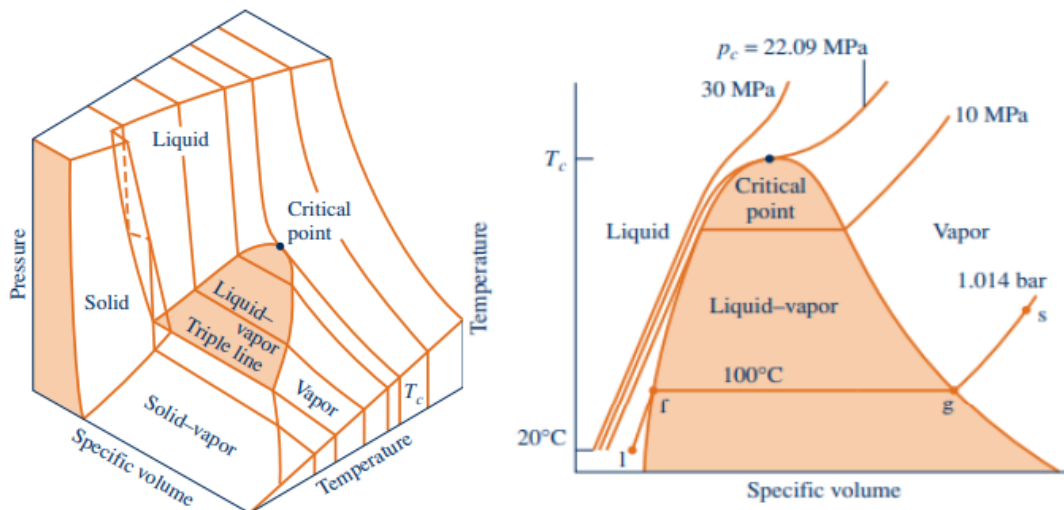


Figure 2. Water T-s diagram. Source: [3].

Two-phase flow within a pipe can be described by four different flow regimes: bubble, churn, plug, and annular. In two-phase flows, the flow rate is the most important factor in determining the flow regime [4]. The fluid properties and pipe diameter are also important, but do not play as large a role as flow rate [4]. Annular flow and dry wall mist are the flow regimes of concern in this research. Frankum et al. [5] described annular flow as a “vapor core” at the center of the pipe that potentially has dispersed droplets, while a liquid film layer covers the pipe wall [5]. Dry-wall mist on the other hand is a flow that consists of a high quantity of one phase carrying along droplets of the other. Figure 3 depicts a two-phase flow map. High quality flows consist of mainly the gaseous flow phase. For high quality steam, the two phases are liquid and gas, where the liquid water is being carried along as droplets.

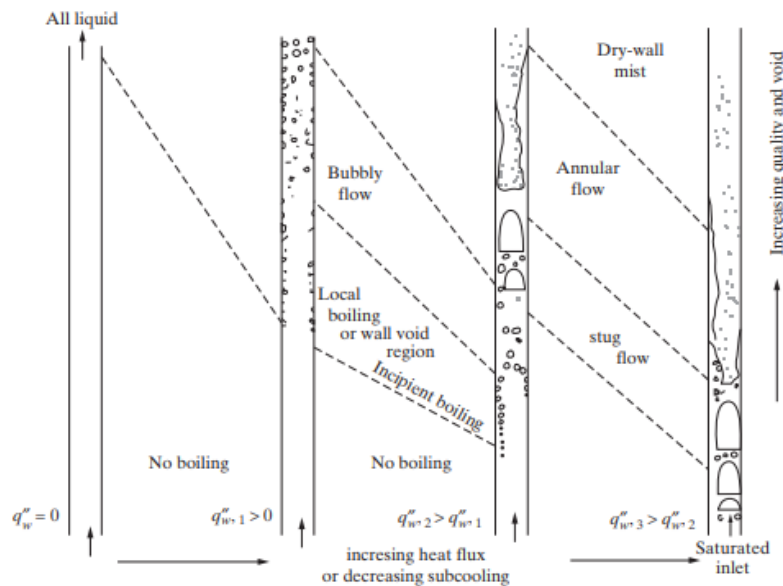


Figure 3. Two-phase flow map for vertical pipes. Source: [6].

A relevant issue in this research was the behavior of two-phase flow at a T-junction. Azzopardi [7] conducted research on air-water flows and their interactions in a T-junction set-up as in Figure 4. Azzopardi [7] found that while the fraction of liquid and gas removed from the main pipe is directly related to the diameter of the branch, the quality of the flow within the branch was related more so to the quality in the main pipe immediately before

the branch. Azzopardi also found that the liquid film at the wall in annular flows was the primary source of fluid entering the branch. Higher momentum flows with entrained droplets made it more difficult for droplets to divert into pipe branches.

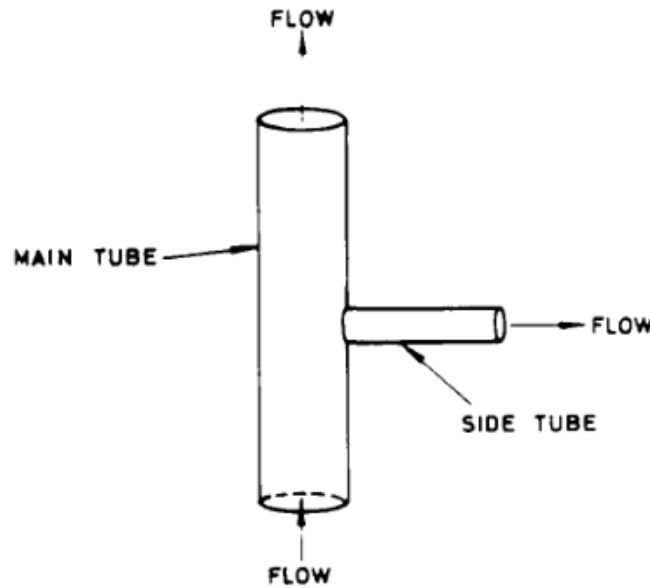


Figure 4. Schematic of vertical T-junction. Source: [8].

Two-phase flows often undergo conjugate convective heat transfer as a result of temperature differences between the wall and the fluid. This leads to changes in the phase of the fluid. Where the fluid meets the pipe wall, the fluid comes to thermal equilibrium with the wall [9]. A temperature gradient extends from the wall towards the center of the pipe and creates a thermal boundary layer similar to a velocity boundary layer [9]. Wall temperatures that exceed the boiling temperature of the fluid at the wall lead to droplet boiling. Droplet boiling changes the phase of the liquid lining the wall of the pipe to gas. In two-phase flows, there is pool boiling and flow boiling. Flow boiling is distinguished by an “imposed forced flow” and is the applicable boiling model for this research [6]. Flow boiling can occur in both vertical and horizontal pipes.

Droplet entrainment occurs when the liquid droplets are trapped within the gas and moved along the system. Droplet entrainment is of utmost importance in nuclear reactors

because in transient thermal hydraulic systems, the droplet entrainment rate affects the nuclear reactor safety code as calculated by a computer [10]. Both the critical heat flux and post critical heat flux are significantly affected in light-water reactors and the entrainment determines the effectiveness of the emergency cooling system in light-water reactors [10]. This is a well-studied phenomenon that occurs in a very particular set of analyses in the reactor core. However, the droplet entrainment within moderately high-quality flows, such as the flow seen at the inlet of a steam turbine during a transient, is not well studied.

ANSYS CFX is one software used to model these types of fluid characteristics. This software discretizes the solver domain via the finite volume method [11]. To do this, a mesh is generated that divides the domain into a number of finite volumes. The conservation equations are then performed on each finite volume to ensure conservation of mass, momentum, and energy [11]. For multiphase flows, ANSYS CFX uses either an Eulerian-Eulerian model or a Lagrangian Particle Tracking multiphase model [11]. The Lagrangian method tracks individual particles as they move throughout the domain and is computationally inefficient [12]. Thus, this modeling method is only used when precise modeling of particle behavior is required [12]. The Lagrangian Particle Tracking multiphase model is not suited for simulations that involve a large number of particles with turbulence and high particle volume fractions [12]. The Eulerian-Eulerian multiphase model assumes that the two phases are “interpenetrating continua” [12]. That is, equations are generated separately for each fluid phase and solved together with the effects of surface tension, droplet size, and other droplet characteristics based on the volume fraction of an individual element [12]. This model tracks fluid continuum concentrations in and out of the elements instead of tracking each individual particle. Eulerian-Eulerian is suitable for a wide range of volume fractions so long as there are not many different particle sizes [12].

The  $k-\epsilon$  model was used as the turbulence model for this research. The  $k-\epsilon$  turbulence model contains a scalable wall function to improve the robustness of the model [11]. This wall function is most accurate when the near-wall mesh is very fine [11]. The  $k-\epsilon$  model is considered the industry standard but is not well-suited to solve flows that contain boundary layer separation, sudden changes in mean strain rate, rotating fluids, or flows over curved surfaces [11]. This makes the  $k-\epsilon$  model suitable for many pipe flows. The

desirable mesh for a simulation using the k- $\epsilon$  turbulence model will have a  $y^+$  value between 30 and 300 at the first layer height. As shown in Figure 5, this is the region that contains the overlap layer [13]. The  $y^+$  value is a non-dimensional measurement of the fidelity of the finite elements used to approximate turbulent flows as a function of  $y$  as the distance from the wall,  $u^*$  as the friction velocity, and  $\nu$  as the kinematic viscosity [13]. The model itself resolves the inner layer of flow from the wall, but they must be contained within a single cell. For a  $y^+$  value of less than 30 at the wall, the mesh is too fine. If the first layer height at the wall is greater than 300, the mesh should be refined.

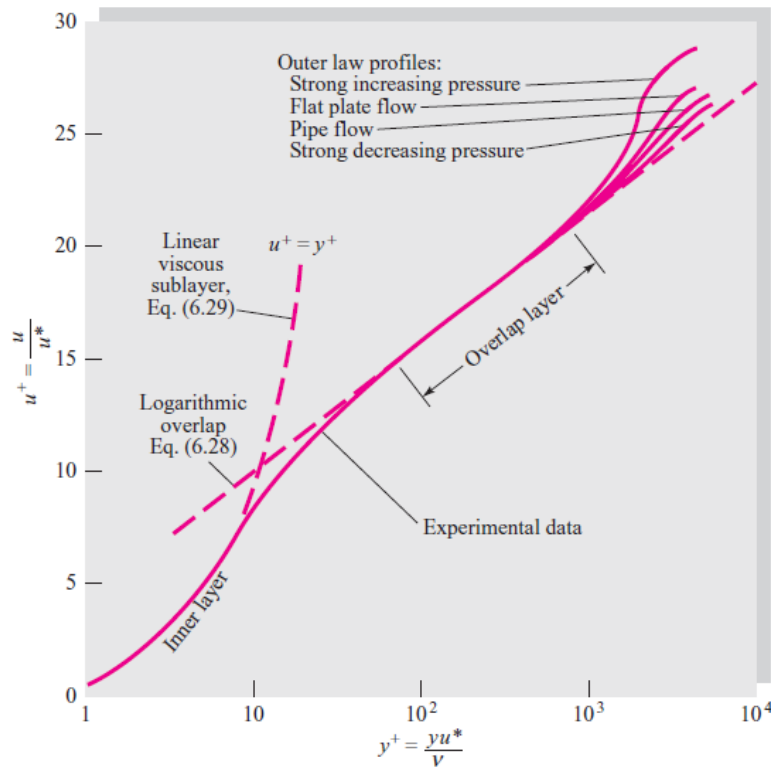


Figure 5. Plot of the  $y^+$  relation to boundary layer velocity profiles.  
Source: [13].

The ANSYS CFX solver can model both steady-state and transient conditions. A steady-state simulation is one where all boundary conditions are constant. These simulations are assumed to achieve steady-state conditions after a certain time interval and do not require a physical timescale to achieve this state [12]. The steady-state timescale

feature in CFX “applies a false timestep as a means of under-relaxing the equations as they iterate towards the final solution” [12]. When the residuals are “bouncy” or otherwise not converging, the timescale setting should be reduced [12]. The reduced timescale allows a slower, and more refined calculation of the flow characteristics across the geometry. This increase in fidelity is due to the relationship between the timescale in ANSYS CFX and the Courant number. The Courant number describes the fraction of a cell that the flow has passed through over the course of one timestep. The Courant number is given by

$$Co = \frac{u\Delta t}{\Delta x} \quad (1)$$

where  $u$  is the flow velocity,  $\Delta t$  is the length of the time step, and  $\Delta x$  is the cell length. A low Courant number would be below one. Courant numbers above one are acceptable, but should be compared against the relevant geometry and mesh size for validity. For example, if the Courant number is 30, but there are only 20 mesh elements along the length of the geometry, the particle would enter and exit the geometry in a single, calculated timestep.

Axelsson [14] conducted a stability analysis on two geometries with multiple mesh sizes and Courant numbers. The result was that a lower Courant number and finer mesh increased the stability of the solver for both geometries [14]. A Courant number of 1 means that the flow has passed through one cell over one timestep. A Courant number of 100 means that the flow has passed through 100 cells over one timestep. Just as an integral with smaller step sizes results in a more accurate solution, the fewer cells that a flow jumps through in each timestep increases the fidelity of the solver’s calculations.

Transient simulations occur when at least one boundary condition is changing. These simulations require physical time settings such as length of simulation and timestep size in order to model the changing boundary condition [12]. While in steady-state simulations the non-physical time scale runs for a finite number of iterations, transient simulations calculate each defined timestep for a set number of coefficient loops [12].

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### III. METHODS

In order to enable an effective transient analysis of the pre-determined piping system, the solver physics and equations were set in accordance with the determinations in Axelsson's work [14]. The experimental work done by Guo et al. [15] was chosen as a case study with similar boundary conditions. The final step before working on the full piping system was to conduct a mesh sensitivity study to optimize the solver process. These methods would refine the strategy of performing effective steady-state and transient analyses on the full piping system with steam traps.

#### A. SOLVER METHODOLOGY

Axelsson [14] performed a steady-state analysis on the steam pipe system to determine the appropriate geometry, physics, and boundary conditions for future work. User-defined variables were created to allow expressions to define stable fluid properties [14]. The expressions and fluid properties designed by Axelsson are included in Appendices A and B. These properties were defined by International Association for the Properties of Water and Steam (IAPWS) International Formulation 1997 (IF97) Equations of State (EOS) [16]. These equations of state referenced a specific input table that was then extrapolated upon in order to determine either the liquid or vapor properties at a given point [14]. Multiple drag and lift models were observed to model the droplets in this research. The Ishii-Zuber model was chosen as the drag model due to its ability to model “sparsely distributed droplets” and “densely packed droplets” while accounting for particle deformation [14]. The Legendre-Magnaudet lift model was chosen for its ability to resolve small, spherical droplets in flow [14]. The thermal energy model was used as the heat transfer method. This model accounts for enthalpy transfer between phases for low-Mach number flows [11]. The reference pressure setting found in the boundary conditions was set to 0 MPa [14]. This was done in order to test the user defined “Press” variable that would control the saturation temperature [14]. The two-resistance model was chosen as the fluid pair heat model to determine the heat transfer between the vapor and liquid phases

[14]. The Ranz-Marshall model was selected to model the vapor phase and the zero-resistance model was chosen to model the liquid phase [14].

The various boundary conditions and their respective settings were determined and tested to ensure that the model would create an accurate picture of the piping system. The geometry was modeled to represent a short section of the piping system for realistic computational strength while also modeling the effect of a complex geometry on wet steam [14]. Two geometries were generated. The first did not contain steam traps, meant for removing excess saturated liquid, while the second included two, 0.75 m length steam traps. These geometries are shown in Figure 6 and Figure 7.

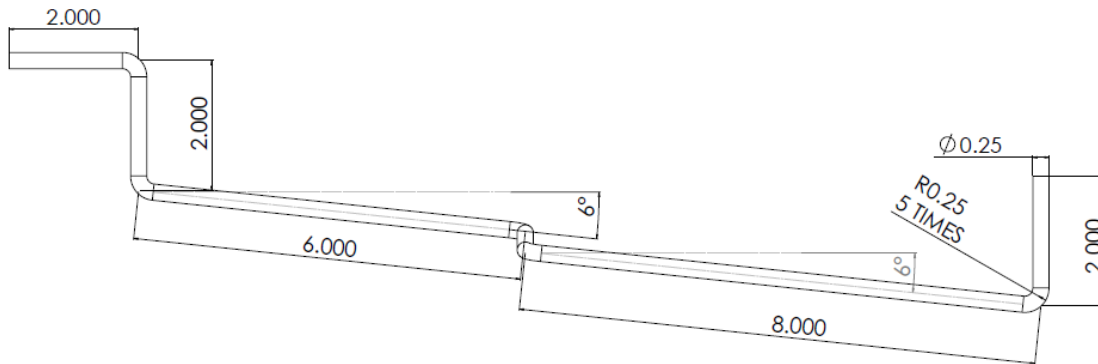


Figure 6. Geometry with measurements in meters, no steam traps.  
Source: [14].

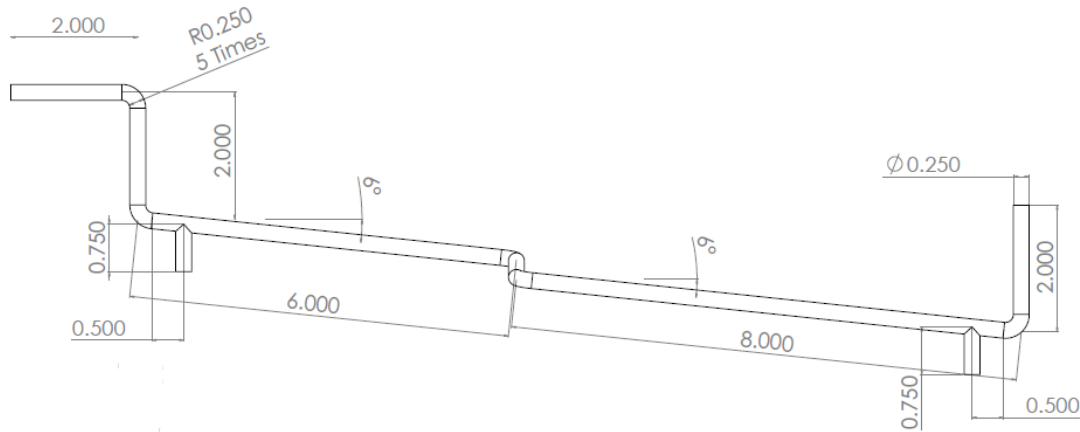


Figure 7. Geometry with steam trap and all measurements in meters.  
Source: [14].

Both geometries were tested and used to determine the stability of the solver with respect to mesh size and Courant number. Lower Courant numbers and smaller mesh sizes resulted in more stable solutions [14]. Following a Weber number analysis, Axelsson [14] determined  $1\text{ }\mu\text{m}$  and  $10\text{ }\mu\text{m}$  to be adequate droplet diameters for the piping system of this study. The steam pipe geometry with the steam traps produced recirculation of the liquid due to the steam traps being too short. This led to liquid being brought back into the pipe that would have been removed by the trap. To resolve this, the bottom surface of the trap was changed from a “Wall” boundary to an “Outlet” boundary with a fluid dependent condition. The liquid velocity of these outlets was calculated using the inlet quality, area of the outlets, density of the liquid, and the mass flow rate of the liquid [14]. No vapor was let out of this boundary. This change in the steam trap boundary condition succeeded in removing the desired amount of liquid from the trap to prevent re-entrainment. There was however a recirculation pattern similar to the one seen with the Wall boundary condition due to the solver changing approximately 60% of the steam trap outlets to walls [14]. The recommendation from this steady-state analysis was to increase the length of the steam traps while maintaining the Outlet boundary condition [14].

## **B. CASE STUDY COMPARISON**

The transient analysis, conducted in ANSYS CFX for this research, was compared to the transient convective heat transfer study done by Guo et al. [15]. This study covered both single and two-phase steam-water flow in a helical tube under pressure drop oscillations. A steady-state analysis predicated the transient simulation. The characteristics of this steady-state simulation were determined by the pressure drop versus the mass flow rate [15]. The steady-state simulation was then used to locate instability boundaries which then predicted the steady and unsteady regions for the range of transient properties [15].

A 15 mm diameter, 2 mm thick, insulated, helical tube at a length of 6448 mm was placed horizontally and put through pressure oscillations from a compressible volume placed immediately before the test section [15]. The pressure values, represented as  $P$ , for the transient analysis ranged from 0.5 MPa to 3.5 MPa [15]. The value  $G$ , for mass flux, ranged from 150 kg/m<sup>2</sup>s to 2500 kg/m<sup>2</sup>s and the value  $q$ , for heat flux, from 0 kW/m<sup>2</sup> to 540 kW/m<sup>2</sup> [15]. A plot of the results from the transient analysis can be seen in Figure 8.

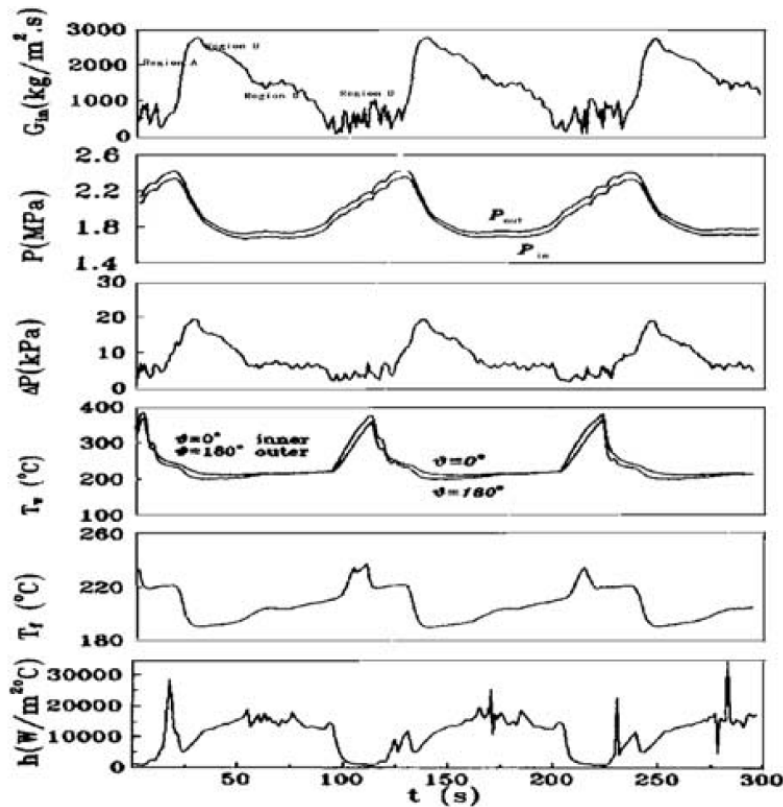


Figure 8. Guo et al. variable fluctuations as a result of pressure oscillations.  
Source: [15].

Guo et al. [15] concluded that the primary factors effecting the oscillatory heat transfer were the Reynolds number, Prandtl number, oscillatory frequency and amplitude. It was also found that the local heat transfer coefficients oscillated in the reverse phase of the flow rate oscillations. The temperature and pressure oscillations however, were in phase.

### C. MESH SENSITIVITY STUDY

In order to efficiently conduct a transient analysis of the piping system, a study was conducted to optimize the bulk mesh size for consistent and accurate results. ANSYS CFX is a finite volume solver [11]. The software divides the geometry into smaller volume elements [11]. The equations are then discretized and solved iteratively across all control volumes [11]. A large bulk mesh generates larger control volumes which fill the whole geometry with fewer control volumes than a small bulk mesh would. Larger bulk mesh

sizes create a more efficient simulation but may not resolve gradients within the geometry. This can lead to inaccurate results. Large mesh elements can result in larger errors between computed values from element to element. As a result, the solver residuals will not converge to the lower values desired.

To determine the most efficient bulk mesh size for this geometry, multiple bulk mesh sizes were examined. These different meshes were all tested separately in a steady-state simulation and run until the residual values converged. The pressure loss, velocity of the fluid, and mass of liquid in the pipe were used to determine the maximum viable bulk mesh size that could be used on the geometry to retain computational accuracy.

### **1. Mesh Sensitivity Parameters**

The mesh sensitivity analysis was performed on a short segment of the full steam pipe geometry. This test segment consisted of the first two bends of the pipe, a total of 6 m of the approximately 23m long piping system. The selected geometry is shown in Figure 9. The shortened geometry was chosen to conserve computational time in determining the optimal bulk mesh size while also representing the features of the full geometry.

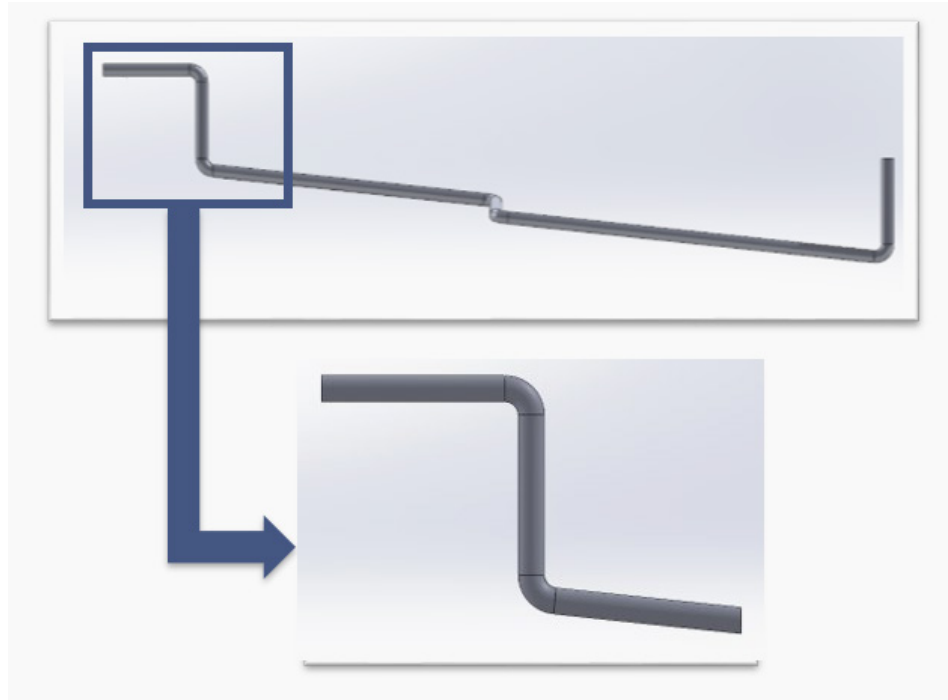


Figure 9. Mesh sensitivity study geometry

The boundary conditions for the steady-state analysis were chosen using the previous research done by Axelsson and would match the boundary conditions used on the full geometry later [14]. All mesh sensitivity studies were done using 99% inlet quality steam. The boundary conditions were set up as seen in Table 1. The full variable and boundary condition settings list can be found in the CCL file located in Appendix C. CCL files are output by CFX-Pre and contain all variables and settings used to define the problem.

Table 1. Mesh sensitivity study boundary conditions

|                                   |                                                                                                                        |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------|
| <b>Default Domain Settings</b>    | P <sub>ref</sub> : 0 MPa<br>T <sub>sat</sub> : 500 K                                                                   |
| <b>Inlet Boundary Conditions</b>  | V <sub>in</sub> : 40 m/s<br>T <sub>static</sub> : 500 K<br>Vapor Vol. Fraction: 0.9999<br>Liquid Vol. Fraction: 0.0001 |
| <b>Outlet Boundary Conditions</b> | P <sub>sat</sub> : 2.6389 MPa<br>Pres. Profile Blend: 0.05                                                             |
| <b>Wall Boundary Conditions</b>   | No Slip Wall<br>Smooth Wall<br>Adiabatic                                                                               |

Using these boundary conditions, a series of calculations were performed in order to determine the  $y^+$  value based upon a layer height. The purpose of this calculation was to determine the first layer height of the mesh inflation layer. Placing an inflation layer on the mesh would resolve the intricate interactions of the fluid near the wall. As the fluid extends away from the wall, the flow becomes uniform and a lower fidelity of mesh was required. Equations (2)-(6) detail the calculations performed to determine the  $y^+$  value at various layer heights [13]. The Reynold's number,  $Re$ , was calculated as

$$Re = \frac{\rho_{vapor}UD}{\mu} \quad (2)$$

where  $\rho_{vapor}$  was the vapor density,  $U$  was the velocity,  $D$  was the diameter of the pipe, and dynamic viscosity of the vapor was symbolized by  $\mu$ . The Reynold's number is a non-dimensional value that describes the flow speed as laminar or turbulent based on the flow and geometry characteristics [13]. The Darcy friction factor was calculated as

$$f = (1.8 \log(\frac{Re}{6.9}))^{-2} \quad (3)$$

with dependence on the calculated Reynold's number. The Darcy friction factor is a non-dimensional value that describes the friction losses within a pipe [13]. The Darcy Friction

factor enabled the calculation of  $\tau$ , the shear stress at the wall. The shear stress was calculated by

$$\tau = \frac{\rho_{\text{vapor}} V^2 f}{8} \quad (4)$$

where the vapor density, flow velocity, and Darcy friction factor are seen again. The shear stress describes the stress parallel to the pipe wall surface. The friction velocity, notated as  $u^*$ , was calculated as

$$u^* = \left( \frac{\tau}{\rho_{\text{vapor}}} \right)^{0.5} \quad (5)$$

with dependence upon the vapor density and shear force. Friction velocity is used as a scaling velocity to calculate the difference between free flow velocities and velocities near the wall with high shear forces. Finally, the  $y^+$  value was calculated as

$$y^+ = \frac{y u^*}{\nu} \quad (6)$$

where  $y$  was the distance from the wall,  $u^*$  was the friction velocity, and  $\nu$  was the kinematic viscosity. The kinematic viscosity was a fluid constant and can be found in Appendix B.

The  $y^+$  formulation was used to determine the layer height with a  $y^+$  value of thirty. The desired  $y^+$  at the first layer height chosen based upon the turbulence model. For the  $k-\epsilon$  turbulence model, the minimum  $y^+$  value to resolve the boundary layer is thirty [13]. The bulk mesh sizes were chosen to reflect a range of sizes with vast differences in computational time. Table 2 displays the bulk mesh sizes tested and the respective inflation layer data.

Table 2. Mesh inflation layer input settings

| Bulk Mesh Size (mm) | Growth Rate | First Layer Thickness (m) | y <sup>+</sup> Value at First Layer | Number of Layers | y <sup>+</sup> Value at Final Layer | Final Layer Distance from Wall (mm) |
|---------------------|-------------|---------------------------|-------------------------------------|------------------|-------------------------------------|-------------------------------------|
| 15                  | 1.25        | 2.91E-05                  | 30                                  | 29               | 15 509.63                           | 75.11                               |
| 5                   | 1.2         | 2.91E-05                  | 30                                  | 29               | 4 945.33                            | 28.63                               |
| 4                   | 1.19        | 2.91E-05                  | 30                                  | 29               | 3 912.33                            | 23.61                               |
| 3                   | 1.18        | 2.91E-05                  | 30                                  | 29               | 3 088.99                            | 19.48                               |

Figure 10 displays a typical mesh cross-section of the pipe. The first layer thickness is applied at the outer wall with each layer thickness being multiplied by the growth rate. The final inflation layer is designed to match the bulk mesh size. Larger bulk mesh sizes result in fewer elements needed to fill the geometry.

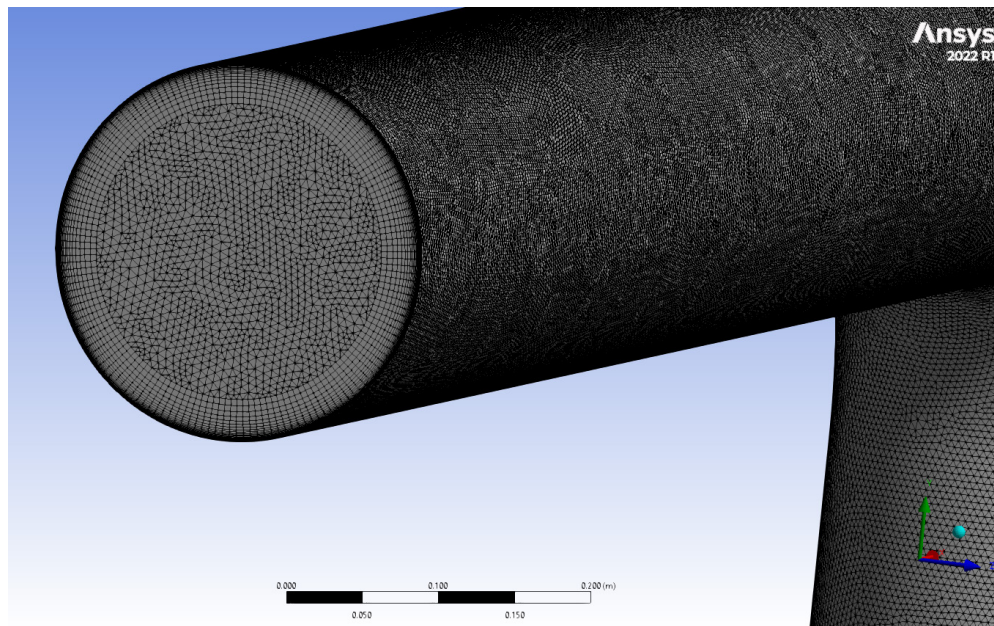


Figure 10. Mesh profile with inflation layer for 5 mm bulk mesh simulation

## 2. Mesh Sensitivity Results

Each bulk mesh test was generated separately and used the same CFX-Pre settings. Variables of interest for this comparison were the pressure drop from the inlet to the outlet, the mass of liquid in the pipe, and the velocity of both liquid and vapor at the outlet. These values were inspected because they were the same variables that would be of interest in a full geometry simulation later on. Table 3 shows the results of this test.

Table 3. Mesh sensitivity study results

| Bulk Mesh Size (mm) | Avg Inlet Pressure (MPa) | Avg Outlet Pressure (MPa) | Pressure Drop (kPa) | Mass of Pipe Liquid (kg) | Vapor Velocity Out (m/s) | Liquid Velocity Out (m/s) |
|---------------------|--------------------------|---------------------------|---------------------|--------------------------|--------------------------|---------------------------|
| 15                  | 2.6423                   | 2.63896                   | 3.340               | 0.023747                 | 40.2536                  | 40.2534                   |
| 5                   | 2.64244                  | 2.63897                   | 3.470               | 0.023746                 | 40.2538                  | 40.2537                   |
| 4                   | 2.64245                  | 2.63896                   | 3.490               | 0.023751                 | 40.2509                  | 40.2508                   |
| 3                   | 2.64246                  | 2.63894                   | 3.520               | 0.023747                 | 40.2503                  | 40.2502                   |

As expected, the smaller bulk mesh sizes took significantly longer to converge to a solution. Generally, there was very little variation between the metrics of each bulk mesh size. The largest variation was in the pressure drop for the 15 mm bulk mesh geometry. Here, the pressure drop was underestimated by 180 Pa as compared to the highest fidelity mesh. This difference is small when compared to the advantage in computational efficiency. The 15 mm bulk mesh geometry took approximately 20 minutes to generate the mesh, using 16 cores, when applied to the mesh sensitivity study geometry. The 3 mm bulk mesh took over 2 hours to generate a mesh using the same resources. The solver speed followed the same pattern. Each iteration of the 15 mm bulk mesh for this study, with the sectioned geometry took  $2.90 \times 10^7$  CPU seconds per solver iteration while the 3 mm bulk mesh took  $3.96 \times 10^7$  CPU seconds per solver iteration. The 3 mm bulk mesh also required smaller timesteps to maintain the average Courant number below one. The combination of these two factors led to a longer solver time for the 3 mm bulk mesh.

Within these simulations, convergence of residuals was an important metric of consideration for each simulation. While the mass and momentum and turbulence residuals

looked to be converged quite early, the liquid mass in the pipe was not. Due to the pseudo-transient nature of the CFX solver, it took many iterations to collect liquid mass in the pipe compared to the iterations required for the other residuals to converge. Figure 11 shows the mass and momentum residuals, as continued from a .bak file, for the 15 mm bulk mesh simulation. A .bak file is a backup file of residuals from a previous simulation. Figure 12 on the other hand shows the liquid mass monitor for the same simulation. While the mass and momentum residuals converged to  $10^{-5}$  by iteration 7 500, the liquid mass was still building up until iteration 8 000. The liquid mass at that point was overestimated and continued to decrease slowly past the iteration 9 500 iteration mark. Once the liquid mass was nearly converged, the mass and momentum residuals began to converge more rapidly. The difference between these two convergences was small in the short, 6 m geometry studied here. On the 23 m full geometry, the effect was expected to be magnified.

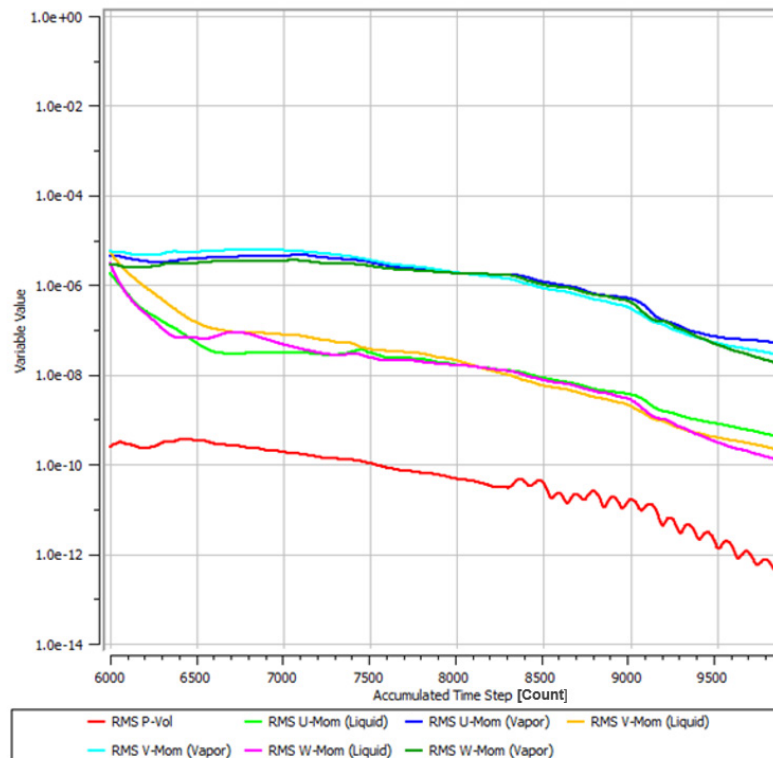


Figure 11. Mass and momentum residuals from 15 mm bulk mesh simulation

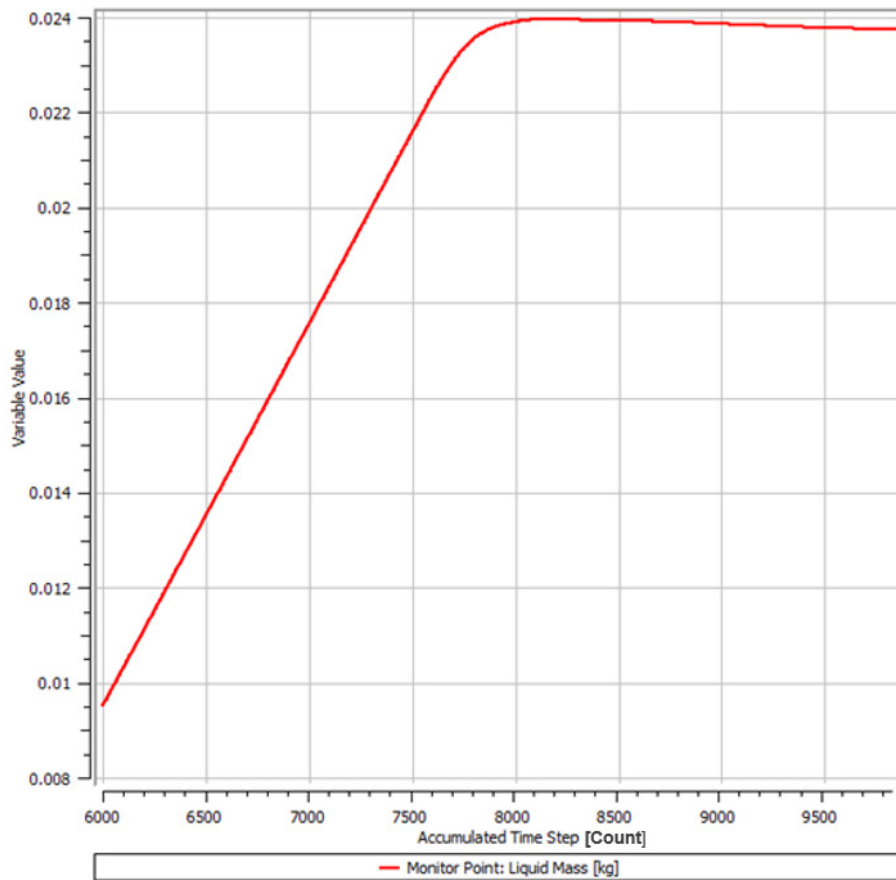


Figure 12. Liquid mass monitor residual from 15 mm bulk mesh simulation

As a result, the Courant number became an important value for these simulations. To alter this number, the “Timescale Factor” setting in CFX-Pre was adjusted. Lower values for the “Timescale Factor” decreased the Courant number but increased the computation time. For each simulation, the desired final average Courant number was one with the maximum courant number not exceeding ten. Larger bulk mesh simulations were also able to run at higher “Timescale Factor” settings while retaining the desired criteria for the Courant number. The reduced timescale on the smaller bulk mesh simulations increased the computational time further.

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## **IV. PRESSURE TRANSIENT CASE STUDY**

An experimental case study was replicated in CFX to verify the approach to transient analysis and ensure that the methods used would yield realistic results. A simulation of the work done by Guo et al. was chosen because of the multiple characteristics that matched the simulation of the steam pipe. The pressure range, transient analysis, and fluid were all similar to the research done for the steam pipe analysis here.

### **A. CASE STUDY DESCRIPTION**

Guo et al. [15] conducted a pressure transient analysis on a helical pipe using a steam-water two-phase flow. The experiment was conducted in a closed loop with a pressurized tank to maintain system pressure. A preheater was placed immediately before the helical test section to increase the temperature of the fluid via alternating electric current. The helical pipe itself was insulated. Within the test section, mass flux was measured at three points, pressure was measured with two manometers, pressure drop by a differential pressure transducer, and three thermocouples. There were 102 thermocouples installed on the outer wall. Initial tests were done at steady-state before moving to a transient analysis of pressure drop oscillations. The pressure oscillations were plotted against mass flux, temperature, and enthalpy.

### **B. MODEL GEOMETRY**

The helical tube section was modeled in SolidWorks. The pipe was modeled as two separate components. The pipe wall was modeled as one component with the inner fluid section modeled separately. The pipe had an inner diameter of 15 mm with a wall thickness of 2 mm. The pipe had a helix diameter of 4.27°, a pitch of 60 mm, and a coil diameter of 256 mm. The total pipe height was 0.48 m. The tube was positioned horizontally with the inlet facing vertically up in the positive y-direction and the outlet facing vertically down in the negative y-direction. Figures 13 and 14 show both geometries in SolidWorks.

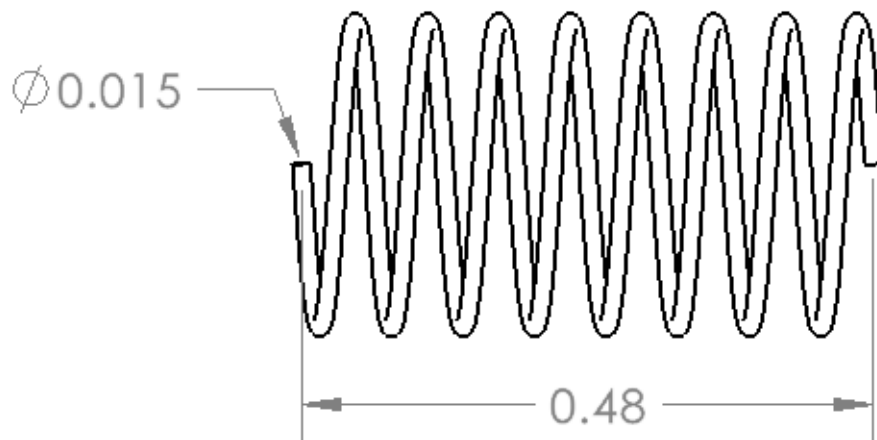


Figure 13. Case study fluid model geometry with all dimensions in meters

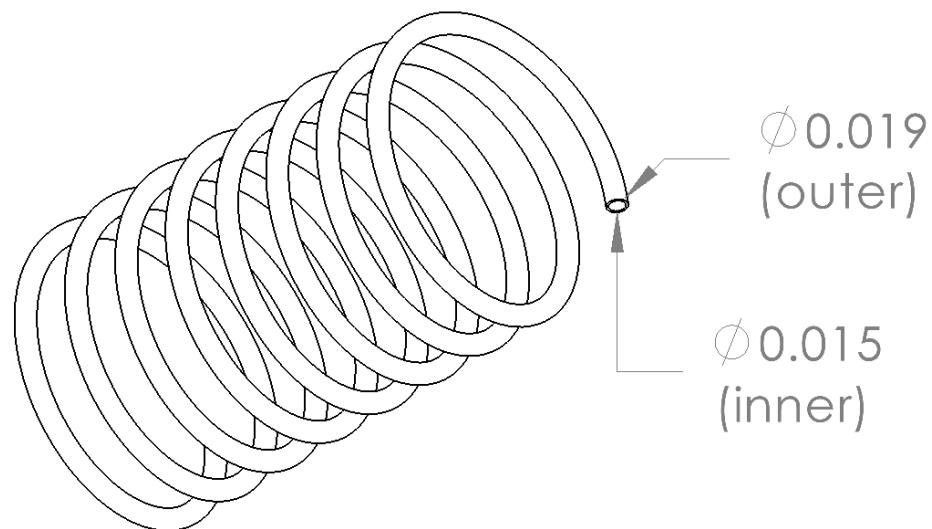


Figure 14. Case study pipe wall model geometry with all dimensions in meters

### C. MODEL MESH

The fluid model was set to a bulk mesh of 1 mm. The curvature normal angle was reduced to  $6^\circ$  to resolve the curved edges. All other mesh settings remained at the default conditions. An inflation layer was added to increase the resolution near the outer wall of

the fluid. The first layer thickness was set to 0.2 mm, with 10 inflation layers and growth rate of 1.2.

The pipe wall geometry was also fitted with a 1 mm bulk mesh. The curvature normal angle was again reduced to 6°. All other mesh settings remained at their default conditions. No inflation layer was added to this geometry because it was a solid surface. Therefore, there would be no boundary layer profile to resolve on this surface.

#### D. STEADY-STATE PHYSICS AND RESULTS

Before conducting the transient analysis, a steady state analysis was performed to determine the initial conditions for the transient solver. Without a steady state initial condition, the transient conditions would begin right away while the solver is trying to satisfy the initial conditions. The result would be an inaccurate transient analysis.

Besides the boundary conditions and saturation values, all other physics principles were consistent with the system physics designed by Axelsson [14]. The helical wall and helical fluid were joined in CFX-Pre using a fluid/solid interface. This fluid/solid interface did allow for heat transfer as conservative interface flux, but no interfacial model was assigned. The wall was set as a no slip, smooth wall. The rest of the pipe wall was modeled as an adiabatic wall. The inlet, outlet, and fluid conditions were extracted from Figure 8 and are described in Table 4. The full CCL file for the steady state case study simulation is listed in Appendix D.

Table 4. Case study steady-state boundary conditions

|                                       |                                                                     |
|---------------------------------------|---------------------------------------------------------------------|
| <b>Default Domain Settings</b>        | P <sub>ref</sub> : 1.72 MPa<br>T <sub>sat</sub> : 477.2207 K        |
| <b>Inlet Boundary Conditions</b>      | P <sub>stat</sub> : 1.72 MPa<br>T <sub>fluid</sub> : 477.2207 K     |
| <b>Outlet Boundary Conditions</b>     | P <sub>stat</sub> : 1.6915 MPa<br>Pres. Profile Blend: 0.05         |
| <b>Pipe Walls Boundary Conditions</b> | No Slip Wall<br>Smooth Wall<br>Adiabatic                            |
| <b>Interface Boundary Conditions</b>  | Fluid Solid Interface<br>Heat Transfer: Conservative Interface Flux |

The steady state analysis yielded the expected results. Pressure was lost from the beginning to the end of the pipe as seen in Figure 15. The total pressure loss across the helical pipe was 28.5 kPa. This pressure drop was determined by the boundary conditions as seen in Table 4. The pressure loss was higher than the expected 6.317 kPa loss extracted from Figure 8. This is due to the undeveloped flow entering the simulated helical pipe. The experimental conditions provided by Guo et al. created a fully developed flow prior to the helical pipe entrance. This resulted in less pressure drop for the experimental conditions.

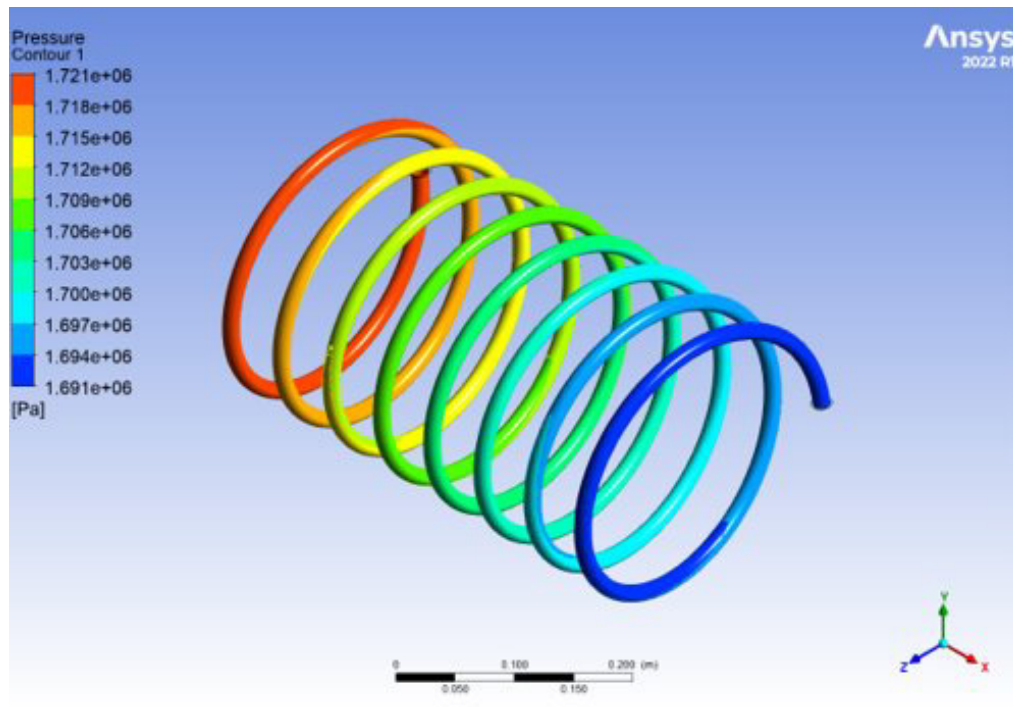


Figure 15. Pressure variation for the case study steady-state analysis

The Dean cell in Figure 16 depicts the velocity in the XY plane. This cell displays the swirl of the fluid as it progresses through the helical pipe. While some flow passes through the middle, the bulk of the velocity in this plane follows the curvature of the outer wall. Lower swirling velocities are seen near the top and bottom of this slice which represents the outer and center boundaries of the helical pipe respectively. The highest swirling velocities come from the left and right sides of the pipe. The mean direction of this flow is to the right due to the fact that the pipe outlet is towards the right and the fluid

is therefore progressing in the positive x-direction. Figure 17 illustrates the overhead view of the helical pipe and shows the mean flow direction.

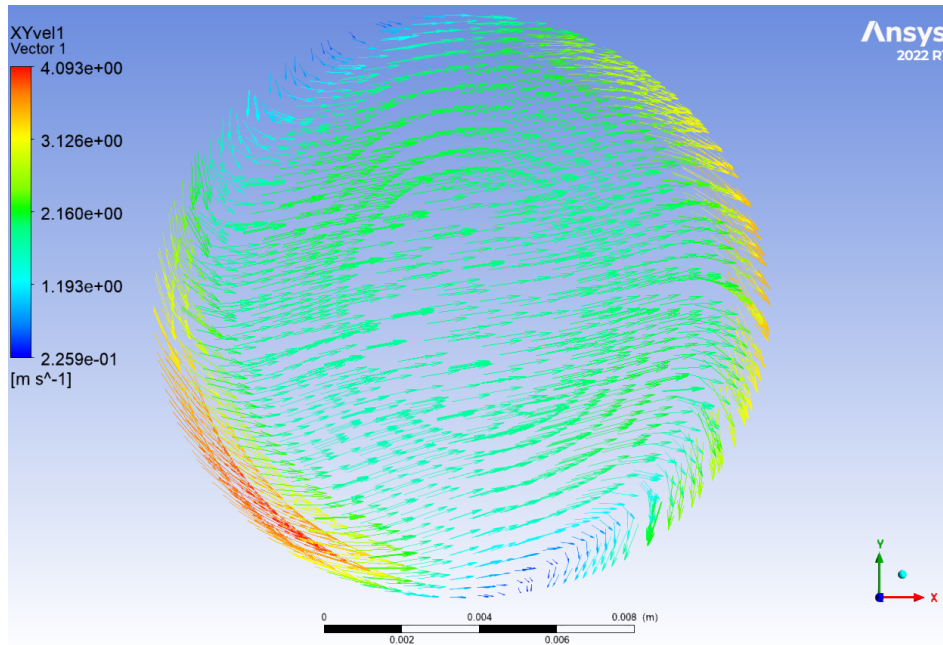


Figure 16. Dean cell of one slice in the helical tube for case study steady-state analysis

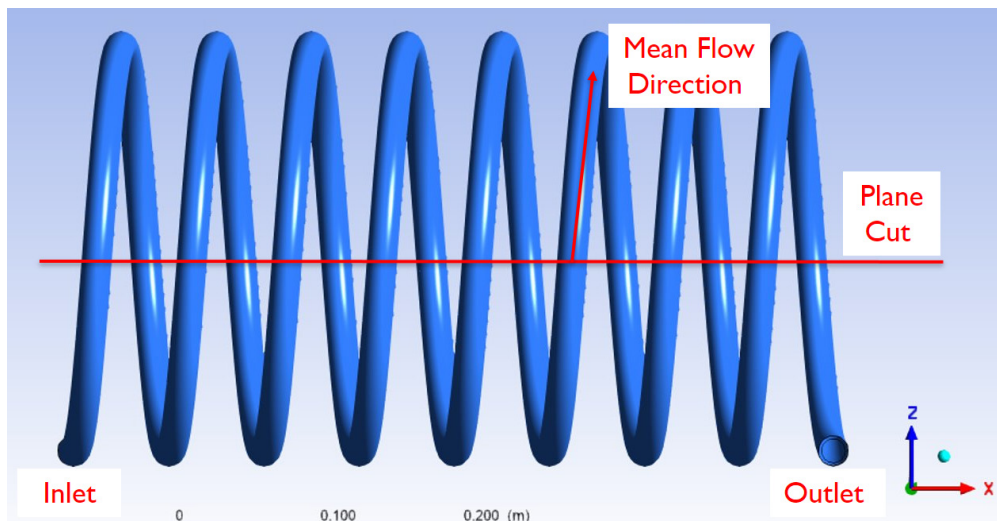


Figure 17. Overhead view of helical pipe geometry with annotated mean flow direction

The vapor mass fraction of the same slice in the helical pipe is shown in Figure 18. The lowest quality is near the center of the pipe helix, or the bottom of this image. A thin layer liquid film lines the outer wall of the pipe. This liquid film matches the expectation for annular flows as discussed previously. The two regions at the center of this slice with higher vapor mass fractions are split by a centered region of liquid. This center liquid region is caused by two opposing vortices within the helical pipe pushing liquid off the wall and towards the center of the pipe before returning to the outer wall.

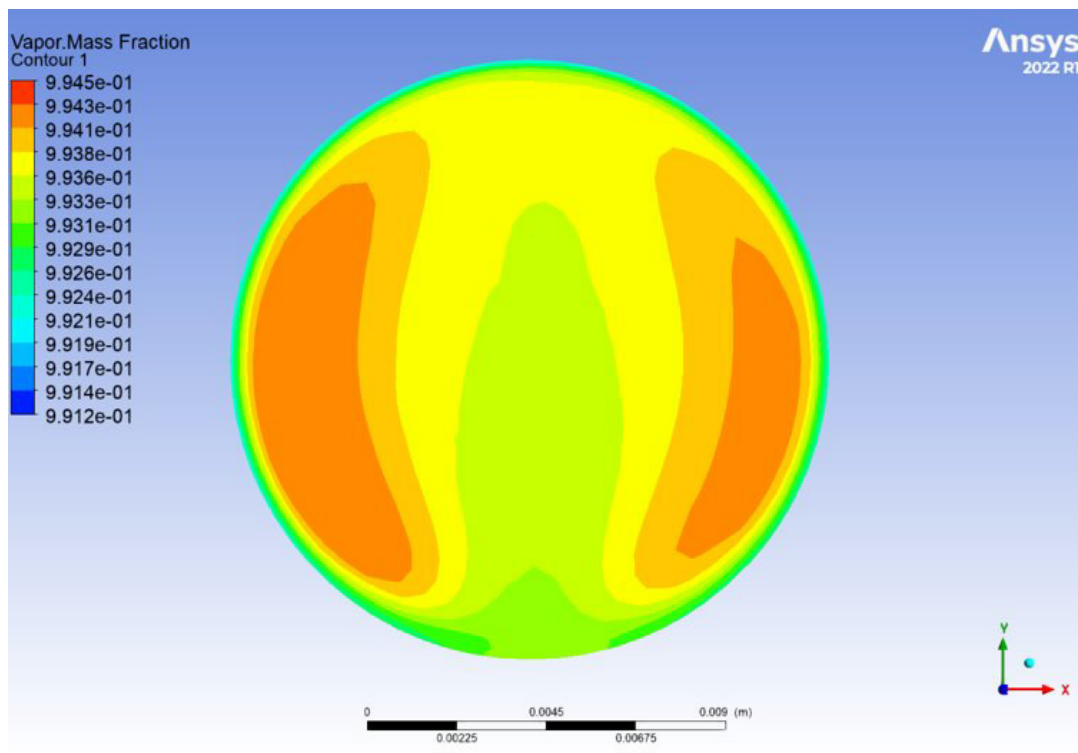


Figure 18. Vapor mass fraction of single slice through helical tube where lower surface of the slice is the inner side of the helix

## E. TRANSIENT PHYSICS AND RESULTS

Only the inlet and outlet conditions changed from the boundary conditions and physics set by the steady-state analysis. As seen in Appendix E, the outlet of the helical pipe was set to initialize at 1.6915 MPa but fluctuate in response to an “if statement” expression as seen in Appendix E. The outlet pressure was set to increase for 60 seconds

and decrease back to the initial conditions for another 60 seconds. This was performed by using another “if statement” expression that was reliant on the time value of the simulation. For the first 60 seconds, a differential pressure value was added to the pressure measurement. Once 60 seconds had passed, the same differential pressure was subtracted from the measured pressure at the outlet. The differential pressure was calculated by dividing the difference between the baseline and maximum outlet pressure by 60 seconds. The baseline pressure was measured as 1.6915 MPa from Figure 8 and the maximum pressure was measured as 2.3626 MPa. The timestep at these values was 75 and 128 seconds respectively from Figure 8.

To model the pressure oscillation, four expressions designed in CFX-Pre. The expressions generated varying conditions for the inlet pressure, outlet pressure, pressure drop across the pipe, and the saturation temperature based on the timestep. The outlet pressure setting was designed to match the profile of the Guo et al. [15] experimental data. Figure 19 displays the extracted data from Guo et al. in comparison to the expression designed to match this behavior. The expression for the outlet pressure is included in Appendix E.

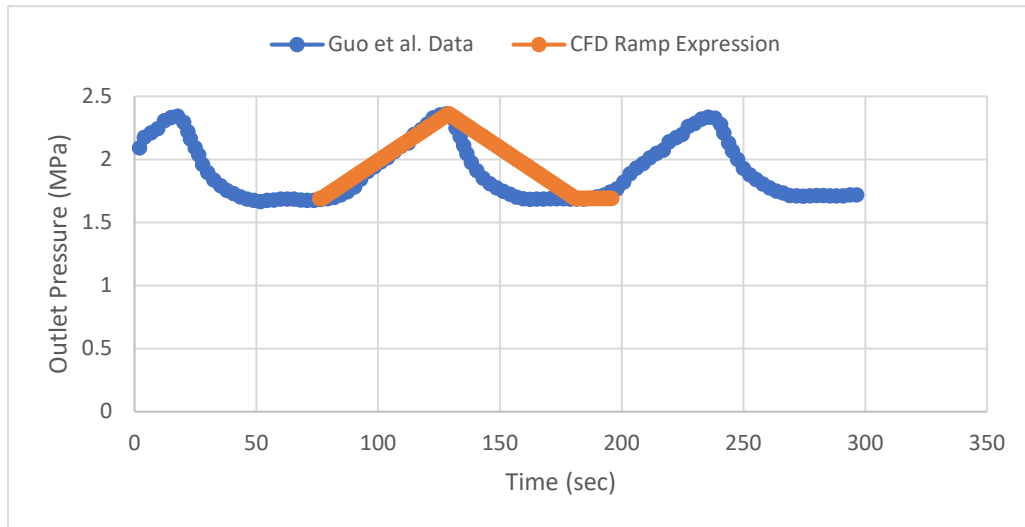


Figure 19. Guo et al. experimental outlet pressure data vs. CFD outlet pressure ramp expression over time. Adapted from Guo et al. [15].

The varied pressure values within the pipe would result in different saturation temperatures within the pipe. In order to respond to this, a ramp of the saturation temperature was designed. This ramp was directly related to the outlet pressure. The saturation temperature for the initial and peak outlet pressures were found using the National Institute of Standards and Technology (NIST) webbook [17]. A ramp was then generated between these points to follow the ramp of the outlet pressure. Figure 20 displays the saturation temperature ramp as coded in CFX-Pre and shown in Appendix E.

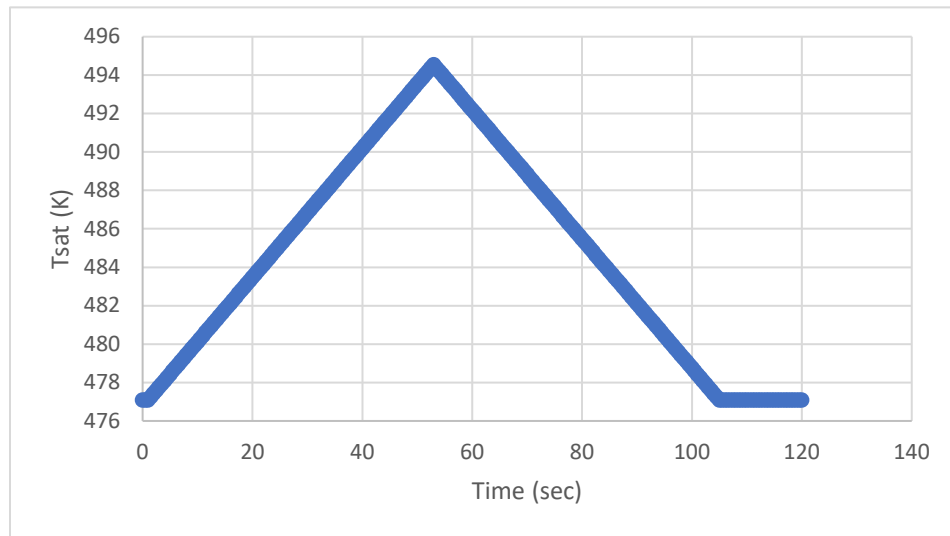


Figure 20. CFD saturation temperature setting over time for the case study

Guo et al. [15] monitored the pressure drop change over time as shown in Figure 8 previously. Since only one pressure oscillation was being modeled, an expression was generated to follow a single pressure oscillation. The pressure drop was at two constant values before ramping up and back down within the area of interest. Layered “if-statements” were used within CFX-Pre to model these changing conditions. The inlet pressure setting for the helical pipe was determined by addition of the pressure drop and the outlet pressure expressions. Appendix E includes the pressure drop and inlet pressure expressions.

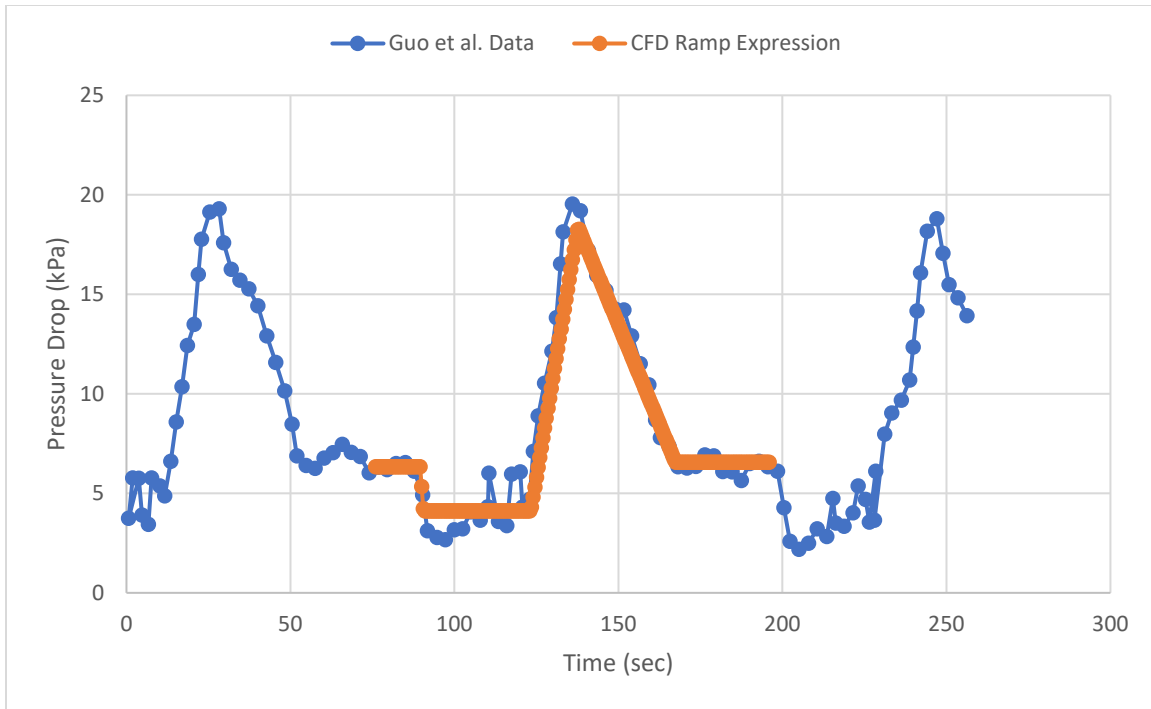


Figure 21. Guo et al. experimental pressure drop data vs. CFD pressure drop expression over time. Adapted from Guo et al. [15].

Due to time constraints, the transient analysis of the case study was not completed. The CFX-Pre settings were completely prepared and can be found in Appendix E. It is recommended that this simulation is run with HPC due to the magnitude of this calculation. The simulation will model over 100 seconds in a fairly large mesh.

## F. SINGLE HELIX ROTATION STEADY-STATE ANALYSIS

Due to the significant amount of time it would take to simulate the full helix geometry as a steady state simulation, the idea of simulating just one rotation of the helical pipe was explored. This single rotation of the helical pipe was again modeled in SolidWorks. All measurements remained consistent with the original helical pipe geometry besides the number of rotations. The previous geometry featured eight rotations of the pipe while this geometry featured one single rotation. Figure 22 displays this single rotation geometry.

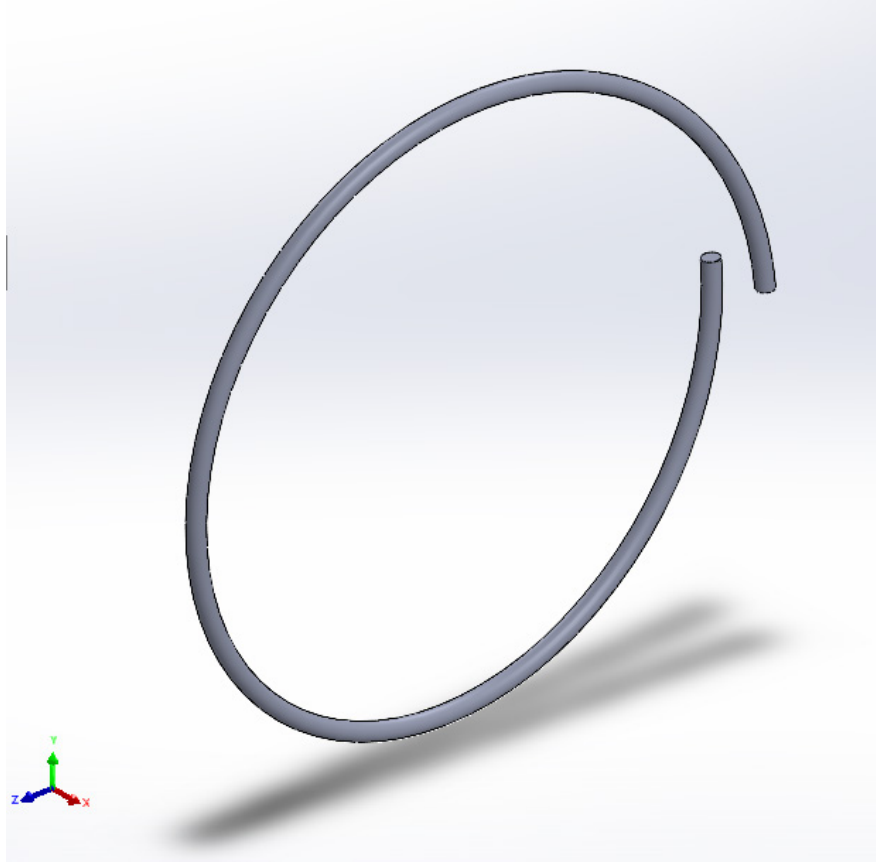


Figure 22. Single loop helical geometry in SolidWorks

The single rotation helical pipe was imported into CFX and a course mesh was designed to align with the idea that this simulation should run much more quickly. Both the wall geometry and fluid geometry were designed for this single rotation geometry. The fluid geometry bulk mesh was set to 5 mm with 5 inflation layers. The first inflation layer height was set at 0.2 mm with an growth rate of 1.25. These settings generated 2 714 241 total elements for the fluid geometry. The wall mesh maintained the same settings as in the full helical pipe geometry. The bulk mesh for the wall was 1 mm which resulted in 303 213 total mesh elements for the wall geometry. Figure 23 shows the mesh for the fluid section of the geometry.

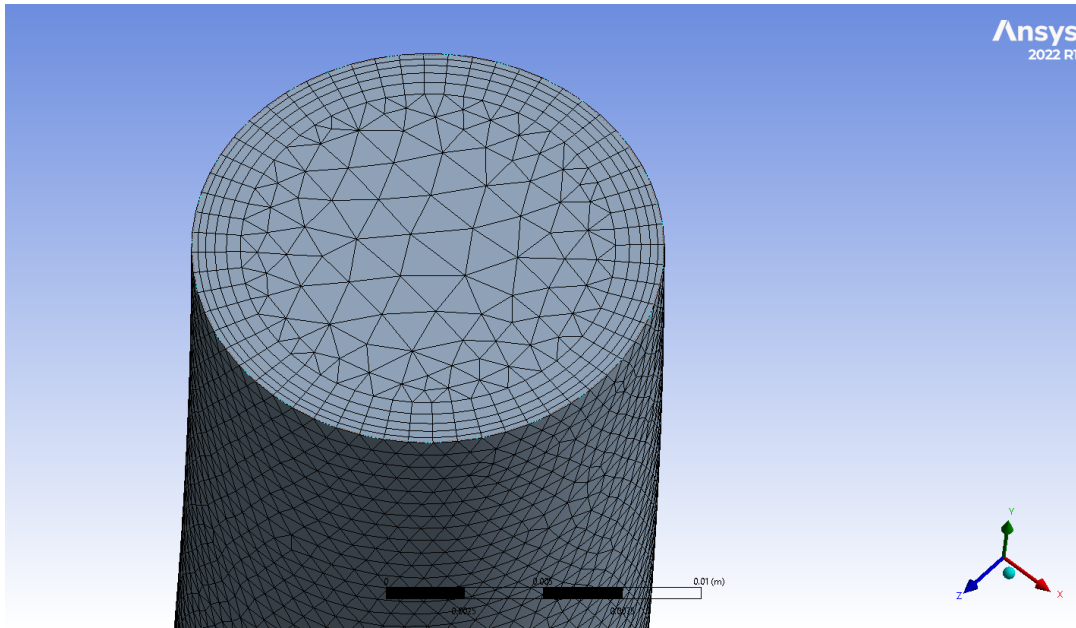


Figure 23. Course mesh profile for the single loop helical geometry

The CFX-Pre settings were copied from the full helical pipe setup. The inlet condition was changed from a static pressure condition to an inlet velocity condition. This change was made to avoid a calculation in determining the pressure drop across just one final loop of the helical pipe. The inlet velocity was determined by the mass flux at the inlet take from Figure 8. The inlet velocity was set to 101.38 m/s. All other boundary conditions, including the interface between the fluid and solid, remained consistent with the full helical pipe settings.

Initial errors were encountered when starting the solver software with this shortened simulation. A finite measurement error was displayed following the first 6 iterations of the solver software. This error was resolved only by reducing the timescale significantly and starting only from the initial conditions described by CFX-Pre. The timescale was set at 1E-12 initially and increased by a factor of 10 for every 10 iterations that were run smoothly. The final timescale that the solver was set to run the simulation at was 1E-04. The solver ran for 8149 iterations over the course of 4 days, 16 hours and 53 minutes. Figure 24 displays the mass and momentum residuals. Initially, these residuals spiked between 1E+03 and 5E-07. This vast jump was occurring during the period when the

timescale was set at 1E-12. The reason for this unsteady initial solver error was the high speed of the flow in the short geometry. At this velocity, a single particle would pass through this approximately 806 mm length geometry in 7.95 milliseconds. For this reason, the timescale had to be reduced significantly such that there was some resident time in the pipe to be measured. Once the residuals began to drop considerably, the timescale was able to be increased slowly.

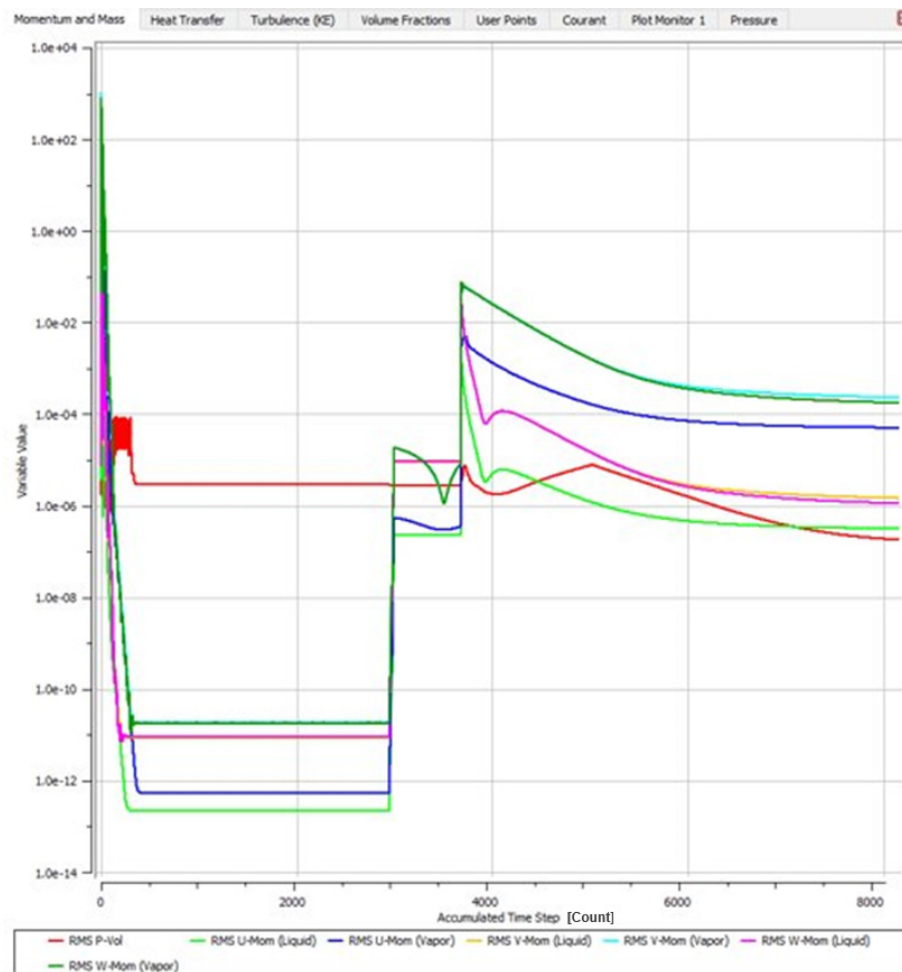


Figure 24. Mass and momentum residuals for single helical loop, steady-state analysis

The pressure monitors at the inlet and outlet pressure monitors also jumped significantly in the initial simulation of the short helical pipe. This error corresponded to

the error seen in the mass and momentum residuals. The final inlet pressure was 1.7990 MPa and the final outlet pressure was calculated at 1.6916 MPa. This difference comes out to a 107.4 kPa pressure drop across this shortened section of pipe. This pressure drop is higher than the expected pressure drop of 6.317 kPa seen at the 75 second point in the experimental data from Figure 8. This difference is due to the undeveloped flow that entered the pipe in this CFD simulation. The experimental work consisted of an entire test loop that allowed for the fluid to become fully developed before entering the test section. Within this simulation, the flow entered and was pushed out of the pipe in only 806 mm. Fully developed flows generate less shear at the wall [13]. The entrance region of a pipe therefore has higher pressure losses and has the thinnest boundary layer [13]. Figure 25 displays the pressure contour across the geometry.

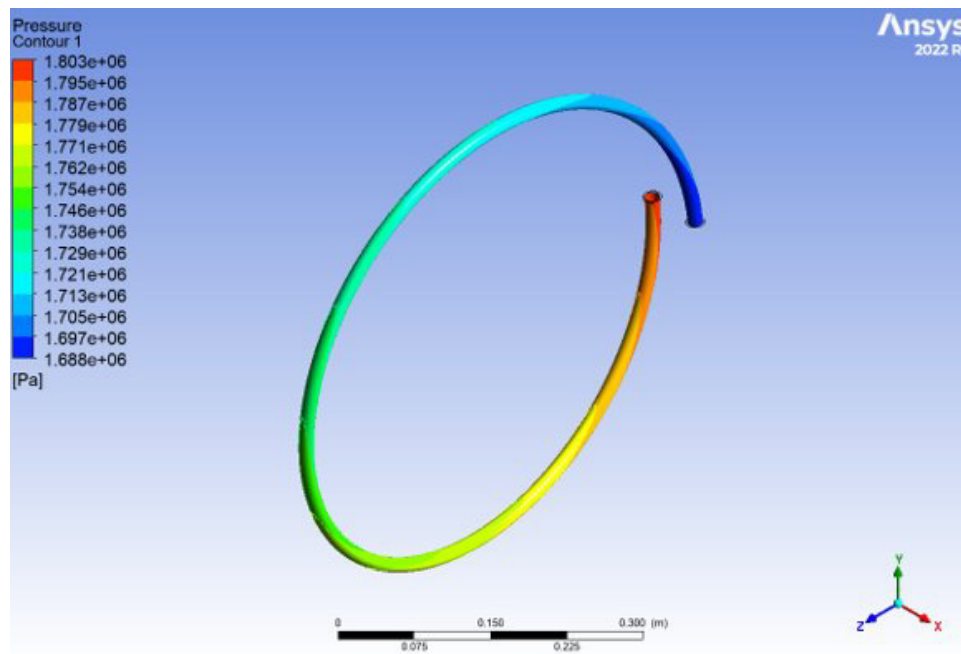


Figure 25. Pressure profile for single helical loop, steady-state analysis

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## **V. FULL GEOMETRY STEADY-STATE ANALYSIS**

Before conducting a transient inlet quality analysis of the full geometry, a steady-state analysis of each inlet quality was tested. The purpose of these simulations was to understand the expected variable outputs at the maximum and minimum quality settings. The maximum inlet quality tested was 99% and the minimum inlet quality tested was 85%. These simulations were also used as the initial conditions for the later transient inlet quality analysis. Lower qualities were not tested because they were not realistic for the steam expected in this piping system.

### **A. MODEL GEOMETRY**

The steam pipe design was taken from the work done by Axelsson and modified slightly [14]. This geometry was designed to model the complex response of steam intricate geometric features. The 25 cm diameter piping system is a total of 23 m. The piping path begins with a 2 m long inlet that leads to the first 90° bend downward. This leads to another 2 m long vertical pipe section that flows into a 90° bend in the pipe. This bend leads to the 6° below horizontal that continues for 6 m, turns horizontally at 90° to another 3 m section of 6° down angle. After another 90° bend horizontal, the pipe continues 6° below horizontal for 8 m. The final 90° bend in the pipe turns the flow vertically upwards for 2 m. There are 2 steam traps of 0.75 m length. One is located 0.5 m following the beginning of the 6° decline and the other is 0.5 m from the 90° bend that ends the 6° down angle piping. At the end of his research, Axelsson [14] suggested lengthening the steam traps from their original 0.75 m length as shown in Figure 7 and 8. The geometry for this research, with steam traps lengthened to 1.5 m is shown in Figure 26 and 27. All dimensions besides steam trap length remained constant from Axelsson's work.

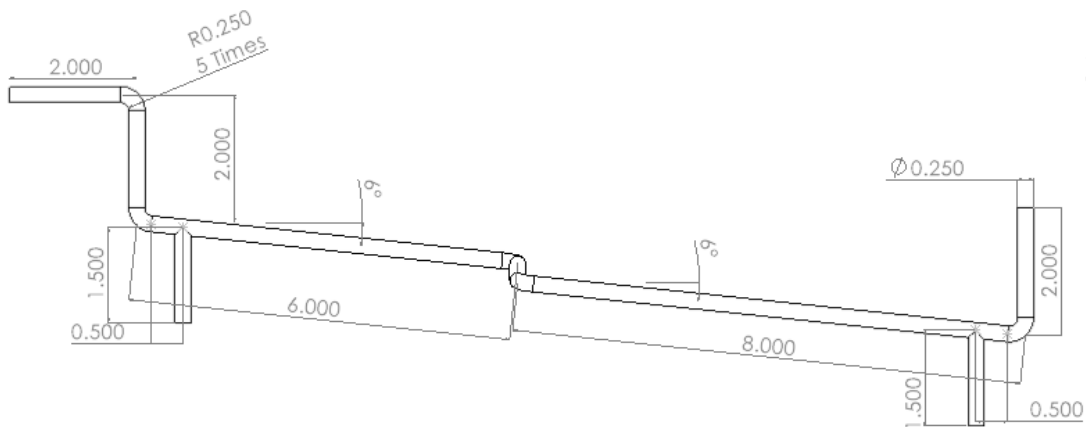


Figure 26. Profile view of extended steam trap geometry with all measurements in meters

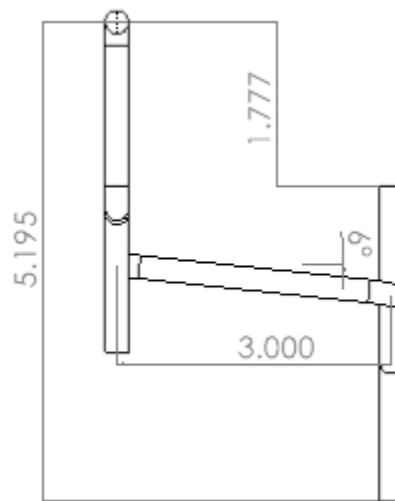


Figure 27. Front view of extended steam trap geometry with branches showing changes in elevation with all measurements in meters

## B. MODEL MESH

The mesh sensitivity study suggested that a 15 mm bulk mesh pipe should be imparted to obtain sufficiently accurate readings on the fluid response. This mesh was generated on the full geometry, but solver issues and time constraints necessitated a larger bulk mesh size to complete the desired simulations in time. For this reason, the bulk mesh

was enlarged to 20 mm and the inflation layer settings were scaled accordingly. This determination is explained in Appendix F. The curvature normal angle setting was reduced to 6° to follow the curved geometry adequately. The bulk mesh size and inflation layer settings were the only other values changed from the ANSYS CFX default conditions. Table 5 details the altered mesh settings.

Table 5. Mesh inflation layer settings for full geometry simulations

| Bulk Mesh Size (mm) | Growth Rate | First Layer Thickness (m) | Number of Layers |
|---------------------|-------------|---------------------------|------------------|
| 20                  | 1.2         | 2.91E-05                  | 29               |

### C. MODEL PHYSICS

The flow physics were designed and tested for stability in previous research [14]. The pipe inlet was set to accept steam flow at 40 m/s at 500 K. The pipe walls and steam trap walls were modeled as smooth walls with a no slip condition. The upward facing fluid exit at the end of the pipe was modeled an outlet with a saturation pressure of 2.64 MPa. The bottom of each steam trap was modeled as an outlet, vice wall boundaries, to prevent the liquid from recirculating into the main piping system [14]. A fluid dependent condition was set at these outlets such that only liquid would be allowed to exit at a specified velocity. The trap velocity is given by

$$V_{trap\ outlets} = \frac{\dot{m}}{\rho_{liquid}A} \quad (7)$$

where  $\dot{m}$  is the mass flow rate of the liquid,  $A$  is the cross-sectional area, and  $\rho_{liquid}$  is the density of the liquid. For the 99% inlet quality flow, the trap outlet velocity of liquid was determined to be 0.00201 m/s. The 85% inlet quality flow simulation had a trap outlet velocity of 0.0559 m/s. The fluid domain settings are listed in Table 6. The CCL file for these settings is included in Appendices I and J.

Table 6. Steady-state, full geometry boundary conditions

|                                                                  |                                                                                                                            |
|------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| <b>Default Domain Settings</b>                                   | P <sub>ref</sub> : 0 MPa<br>T <sub>sat</sub> : 500 K                                                                       |
| <b>Inlet Boundary Conditions (X = 99%)</b>                       | V <sub>in</sub> : 40 m/s<br>T <sub>static</sub> : 500 K<br><br>Vapor Vol. Fraction: 0.9999<br>Liquid Vol. Fraction: 0.0001 |
| <b>Inlet Boundary Conditions (X = 85%)</b>                       | V <sub>in</sub> : 40 m/s<br>T <sub>static</sub> : 500 K<br>Vapor Vol. Fraction: 0.9972<br>Liquid Vol. Fraction: 0.0028     |
| <b>Outlet Boundary Conditions</b>                                | P <sub>sat</sub> : 2.6389 MPa<br>Pres. Profile Blend: 0.05                                                                 |
| <b>Wall Boundary Conditions</b>                                  | No Slip Wall<br>Smooth Wall<br>Adiabatic                                                                                   |
| <b>Trap Outlet Boundary Conditions (X<sub>inlet</sub> = 99%)</b> | Fluid Dependent Outlet<br>Vapor Velocity = 0 m/s<br>Liquid Velocity = 0.00201 m/s                                          |
| <b>Trap Outlet Boundary Conditions (X<sub>inlet</sub> = 85%)</b> | Fluid Dependent Outlet<br>Vapor Velocity = 0 m/s<br>Liquid Velocity = 0.0559 m/s                                           |

## D. FULL GEOMETRY STEADY-STATE RESULTS

The same steam pipe geometry was analyzed for the 99% and 85% inlet quality scenarios. Each simulation was run separately. These results were analyzed and saved to compare against the later inlet quality transient analysis. The variables of interest were the pressure, vapor mass fraction, and velocity.

### 1. 99% Inlet Quality Steady-State Results

The 99% inlet quality simulation concluded after 50 000 iterations. This simulation was run in multiple groups as the maximum iteration setting was initially too low. Each 10,000 iterations of this simulation took 3 days and 3 hours to complete. The Auto-Timescale setting for this simulation was set at 0.01 to obtain an average Courant number of 0.41714 and a maximum Courant number of 72.672. Figure 28 displays the mass and momentum residuals for this simulation while Figure 29 shows the accumulation of liquid

mass within the pipe. As mentioned previously, the liquid mass took significantly longer to settle out in comparison to the mass and momentum residuals. The mass and momentum residuals were settled within the first 10 000 iterations. The liquid mass continued to level out for the remaining 40 000 iterations. While the change over these additional iterations was only about 0.006 kg of liquid added to the pipe, the definition in the solution changed significantly. This effect was only magnified in the 85% inlet quality solution due to more liquid being pushed through the piping system. The final liquid mass within the entire pipe was 0.10035 kg for this steady-state simulation.

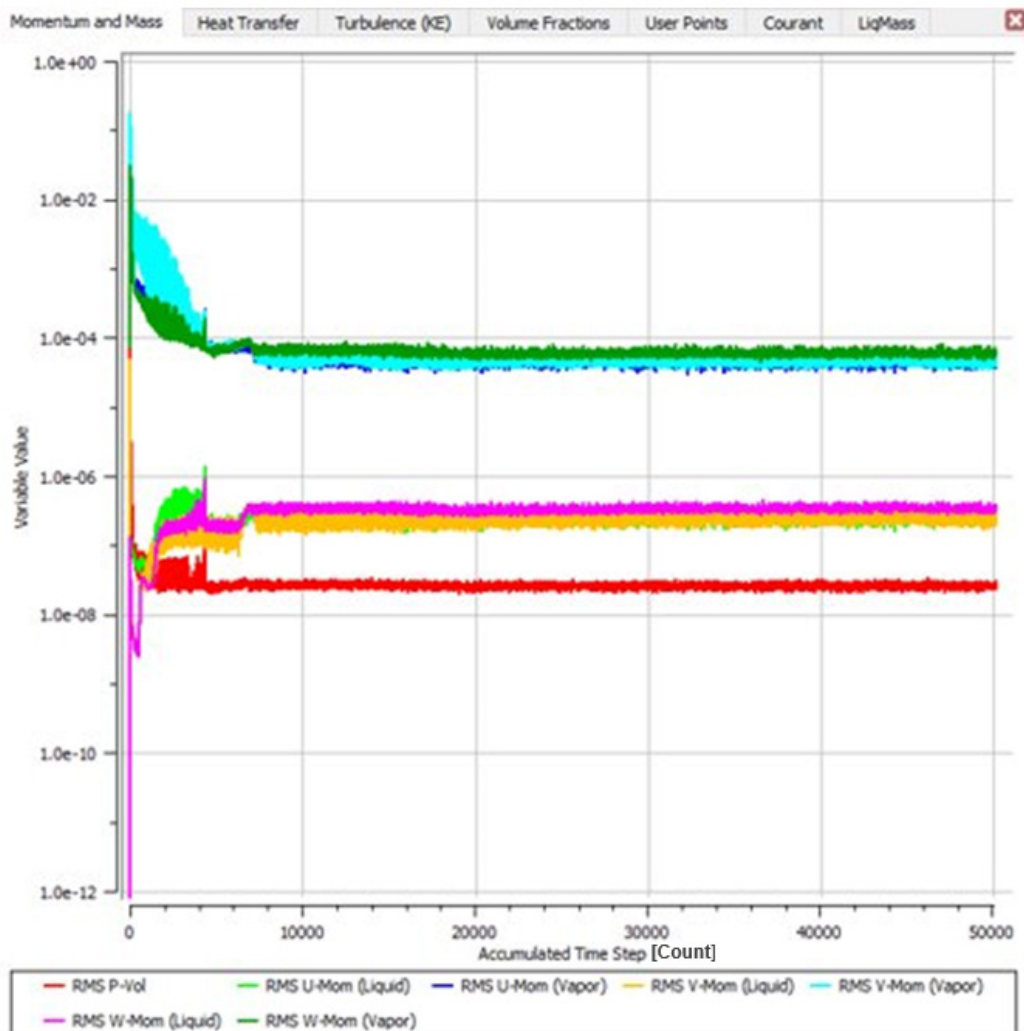


Figure 28. Mass and momentum residuals for 99% inlet quality, steady-state analysis of the full geometry

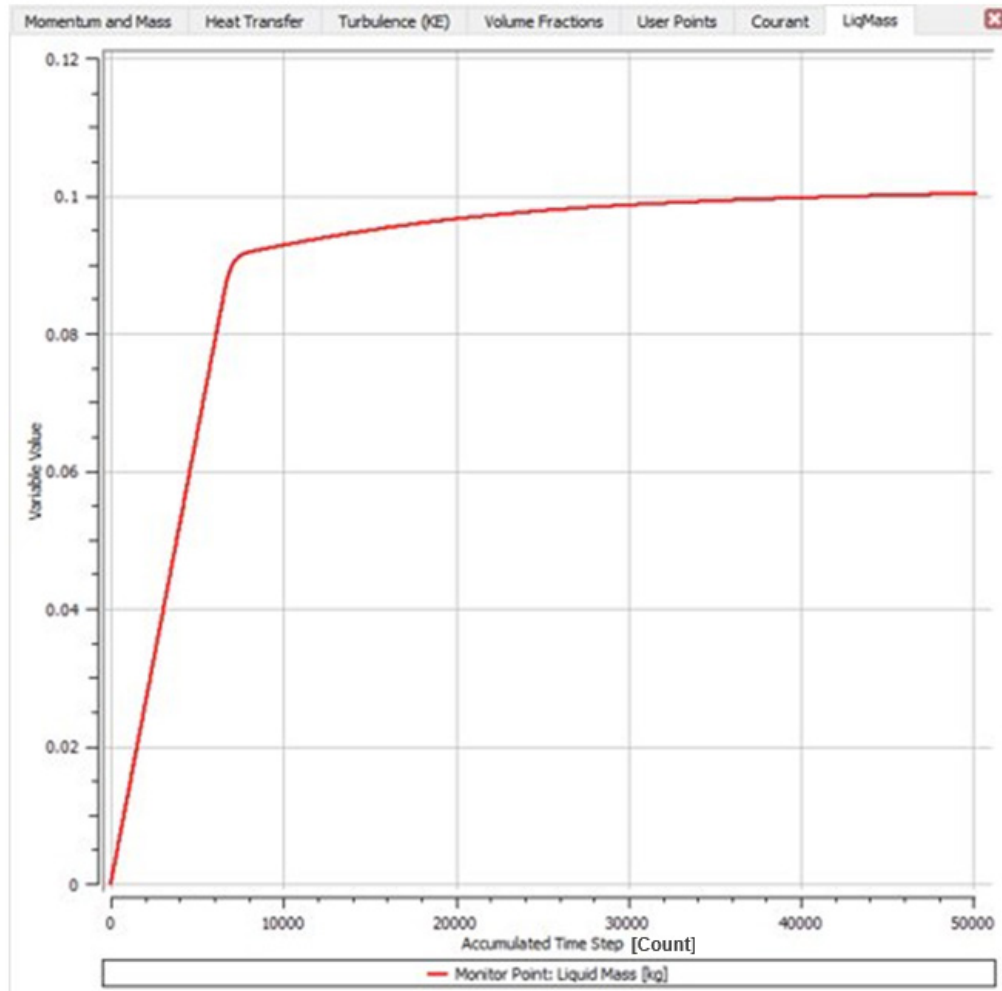


Figure 29. Liquid mass accumulation for 99% inlet quality, steady-state analysis of the full geometry

Figure 30 displays the vapor mass fraction at the wall at the conclusion of this simulation. The dark blue regions represent higher liquid concentration while the lighter areas of yellow and orange represent a higher concentration of vapor. Generally, the liquid accumulated near the pipe bends. There are regions of significantly high vapor concentration in the traps.

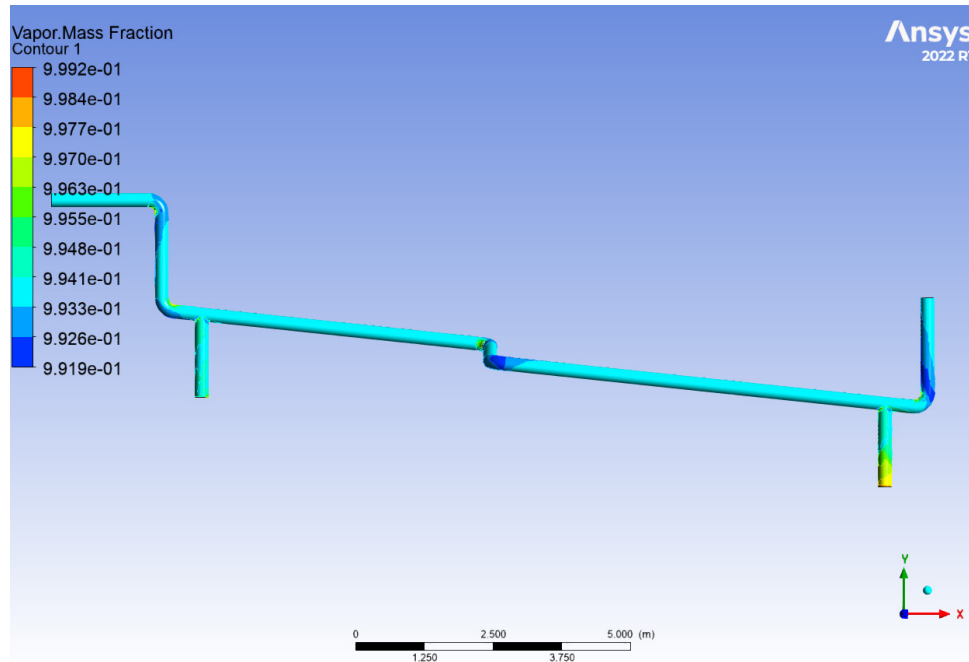


Figure 30. Vapor mass fraction at the wall for the 99% inlet quality, steady-state analysis of the full geometry

The high vapor concentration in the traps was examined by taking an XY plane through the pipe section containing the first steam trap and another XY plane through the section of pipe containing the second steam trap. The plane cutting through the first steam trap was offset 0.0 m from the origin while the second plane was offset 3.0 m from the origin in the positive x-direction. These plane views of the vapor mass fraction are seen in Figure 31 and 32.

The cause of this lack of liquid in the bottom of the traps is due to the Outlet boundary condition that was placed at these locations. To prevent excessive liquid concentration and recirculation into the flow, the liquid was removed from each trap bottom at a rate of 0.002 m/s. While the liquid was removed from the trap, the vapor that entered the trap with the liquid was not let out of the Outlet. The accumulation of vapor at this boundary therefore signals that the recirculation of the traps into the main flow of the pipe was no longer occurring. As a result, the vapor was trapped in the bottom of the steam trap while the liquid was removed.

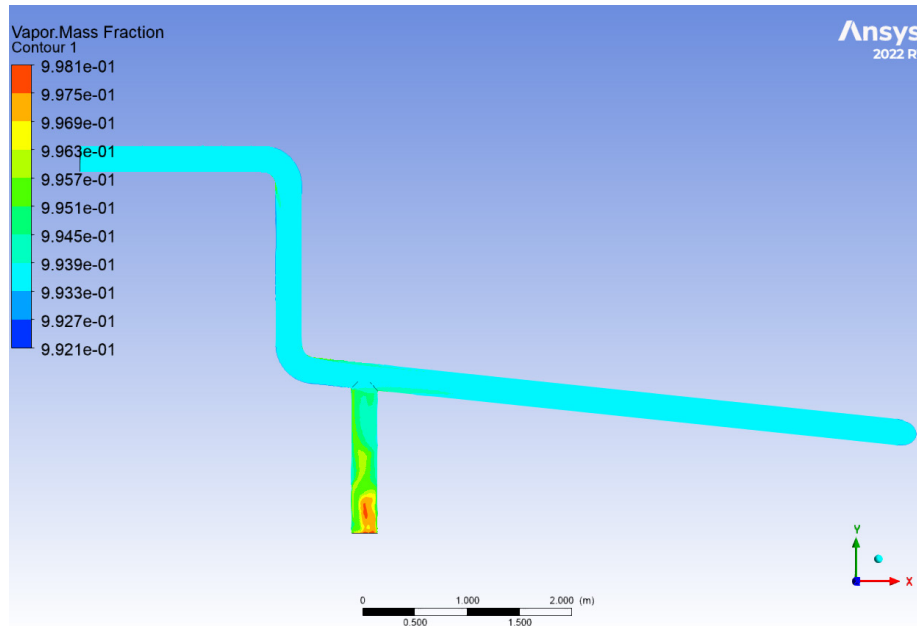


Figure 31. Front steam trap vapor mass fraction profile for the 99% inlet quality, steady-state analysis of the full geometry

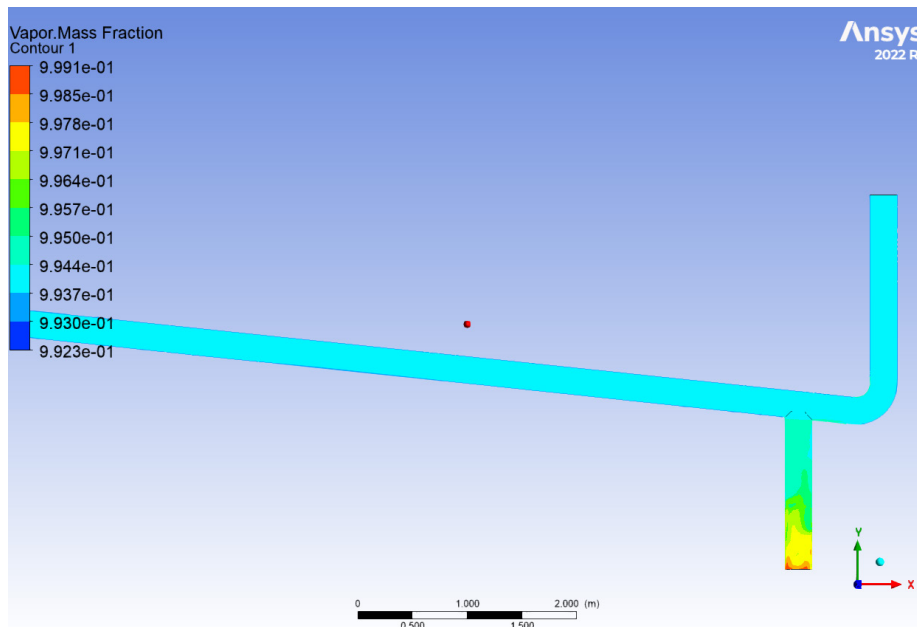


Figure 32. Rear steam trap vapor mass fraction profile for the 99% inlet quality, steady-state analysis of the full geometry

The liquid velocity streamline plot in Figure 33 helps explain the lack of recirculation in the pipe. There are distinct low velocity regions within the traps. While the flow within the main pipe is at a fairly consistent velocity, the velocity within the traps is mainly stagnant. This aligns with the goal of preventing liquid recirculation back into the main piping system. At the pipe bends, the velocity increases as the fluid turns. The inlet quality of the pipe was 99.374% and the outlet quality of the pipe was 99.379%.

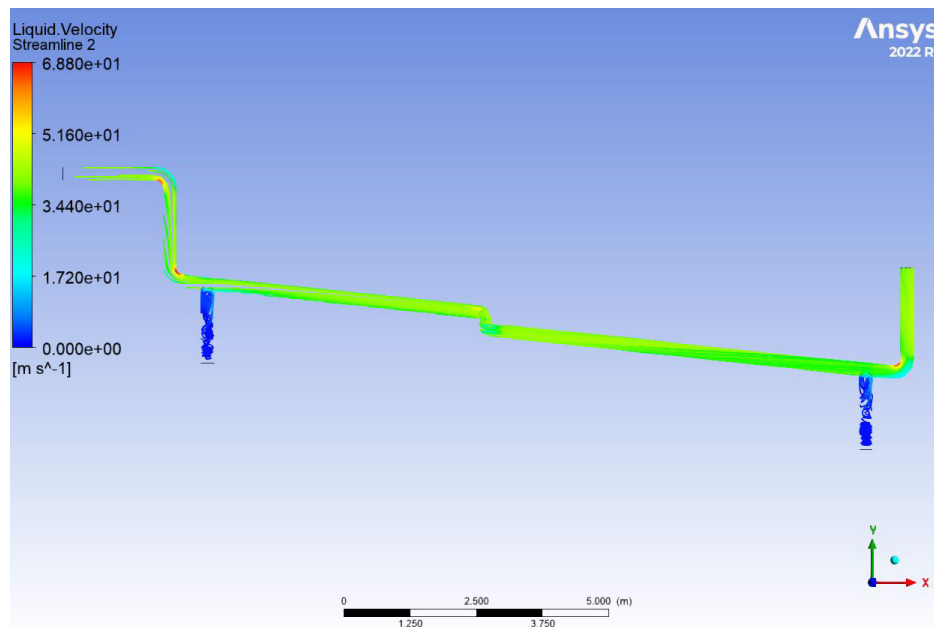


Figure 33. Liquid velocity streamline profile for 99% inlet quality, steady-state analysis of the full geometry

The pressure plot follows the expected pattern of pressure loss throughout a piping system. The pressure is higher at each bend in the pipe, but generally decreases as the distance through the pipe increases. The total pressure loss from the inlet to the outlet of the pipe was 14.39 kPa. This is a small pressure drop relative to the inlet and outlet designated pressures which were set two orders of magnitude higher.

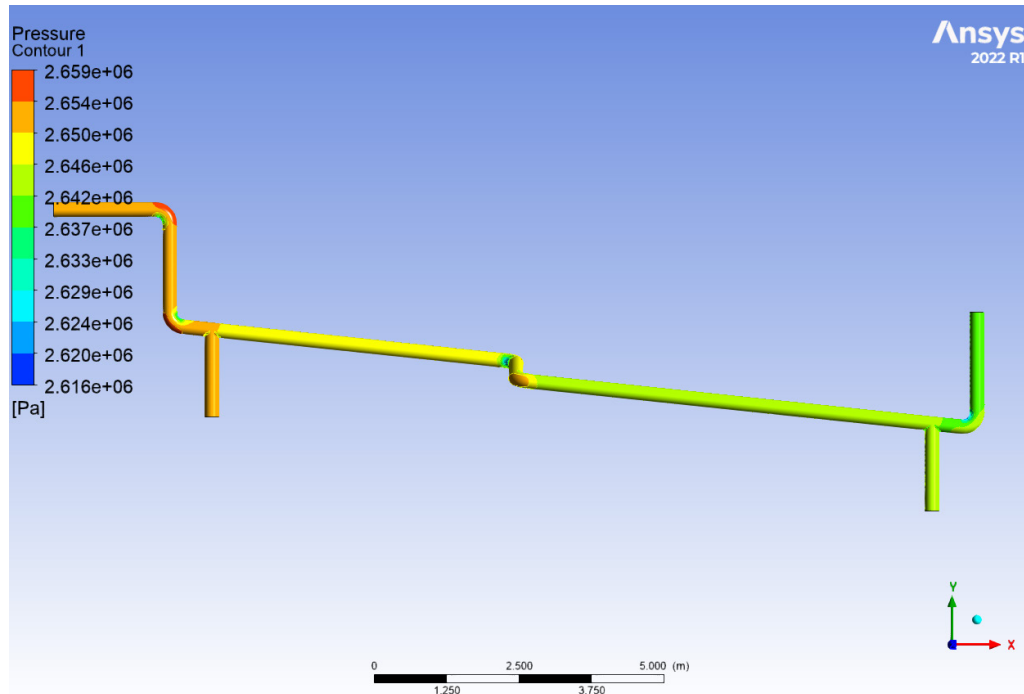


Figure 34. Pressure contour at the wall for 99% inlet quality, steady-state analysis of the full geometry

## 2. 85% Inlet Quality Steady-State Results

The 85% inlet quality flow followed many of the same patterns as seen in the 99% inlet quality flow, however one addition was made. In the meshing process, the traps were cut off and added separately. This allowed for the two steam traps to be identified as their own domains in CFX-Pre. Within CFX-Pre, an additional monitor point for the liquid mass in each trap was added. As a result, while the solver was running, the user was able to see the liquid accumulation in each trap to better determine when the steady-state solution had been obtained. Figure 35 displays the liquid mass plot of the full piping system with these additional monitor points. While the total liquid mass seemed to be converged by 40 000 iterations, the liquid in each trap continued to increase. The final liquid mass in the pipe was 2.5332 kg.

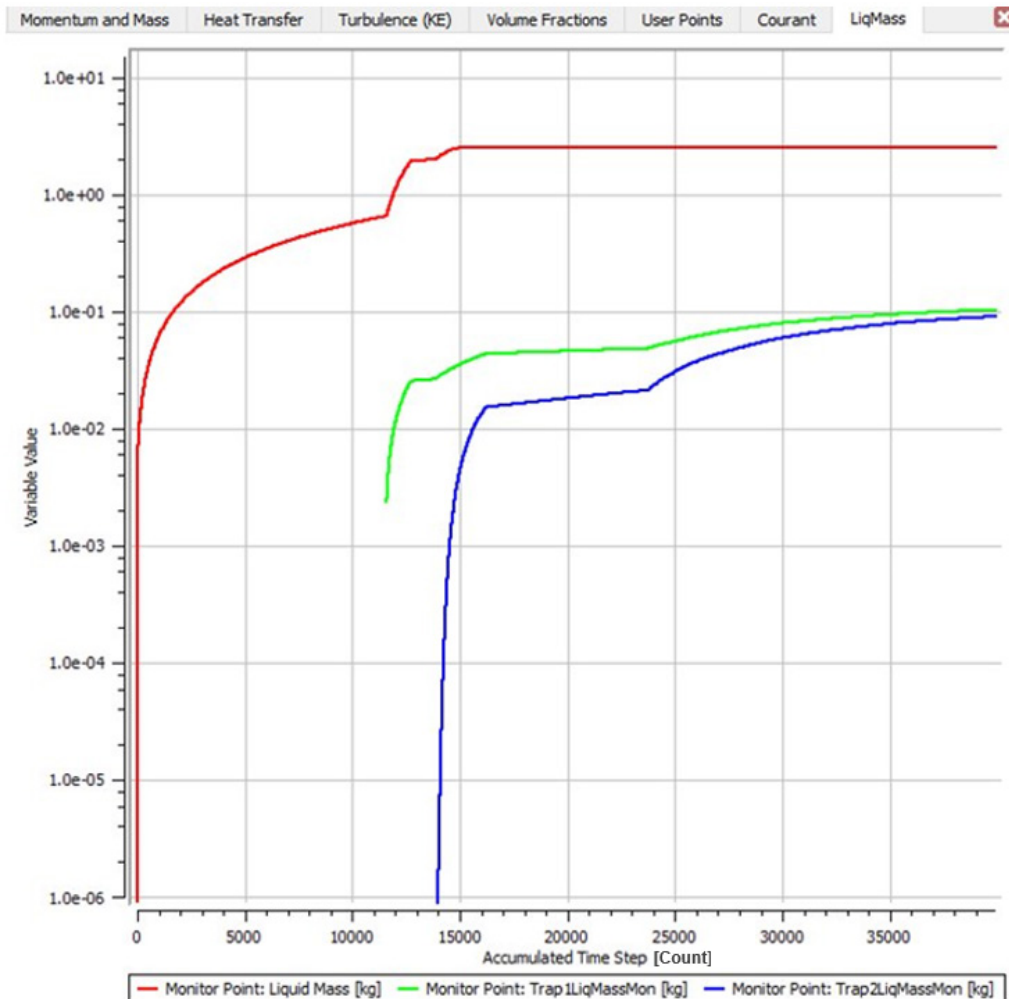


Figure 35. Liquid mass accumulation in the 85% inlet quality, steady-state analysis of the full geometry

Figure 36 and Figure 37 display the difference in these profiles. A premature end to these simulations based on the total liquid mass alone would not represent the steady-state condition of the steam pipe. At 24 000 iterations, approximately 80% of the steam traps were filled with pure vapor. Later on, at 34 500 iterations, only 30% of the steam traps were filled with pure vapor. This development is due to the slow rate of fluid deposition in the pipes. The fluid within these pipes was being deposited at a constant rate, but it took a significant amount of time for the liquid within the pipe to be sorted into the steam traps and out of the main flow of the pipe.

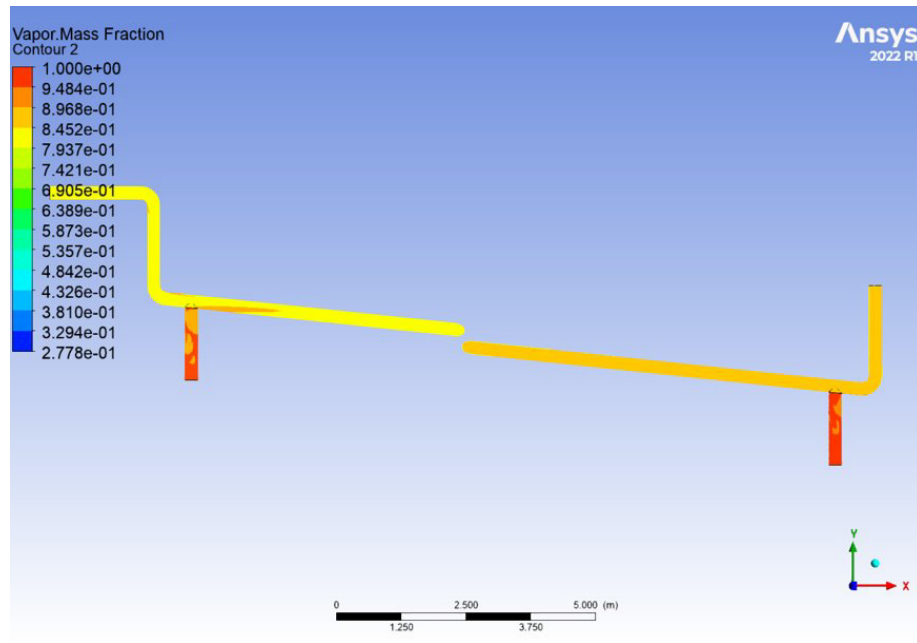


Figure 36. Vapor mass fraction profile at 24 000 iterations for 85% inlet quality, steady-state analysis for the full geometry

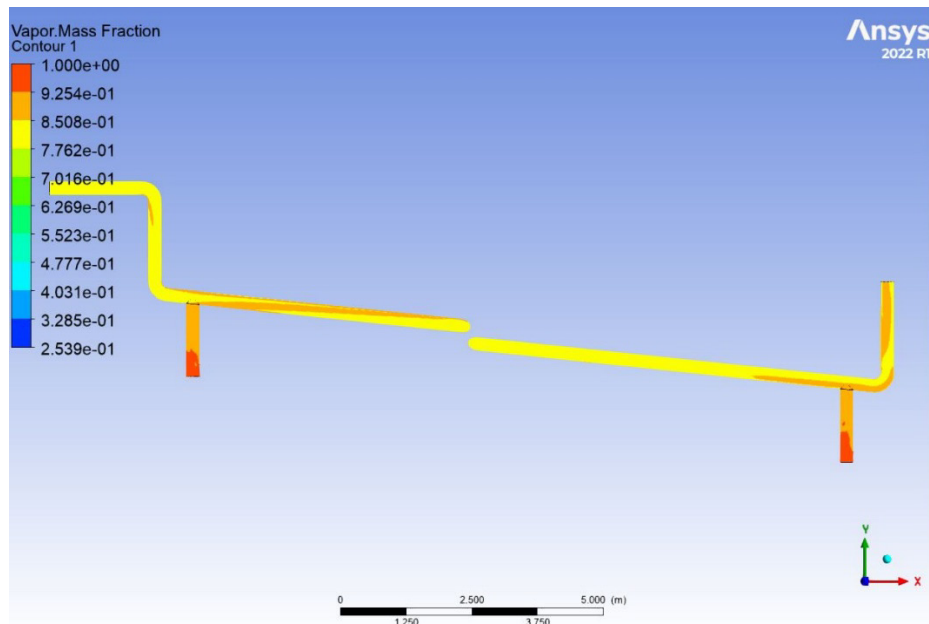


Figure 37. Vapor mass fraction profile at 34 500 iterations for 85% inlet quality, steady-state analysis for the full geometry

Figure 38 and Figure 39 display the vapor velocity for the 85% inlet quality simulation. Again, the velocity was consistent throughout the main section of the pipe at about 37 m/s. The vapor also increased in velocity as it turned through the pipe bends similarly to the 99% inlet quality, steady-state simulation. The steam traps exhibited different results based on where in the steam trap the focus was turned. At the bottom of the trap, the velocity is zero in most areas. Near the top of the steam trap, there is some recirculation into the main pipe flow and also liquid falling into the trap. Figure 38 displays the front steam trap velocity streamline profile and Figure 39 displays the rear steam trap velocity streamline profile.

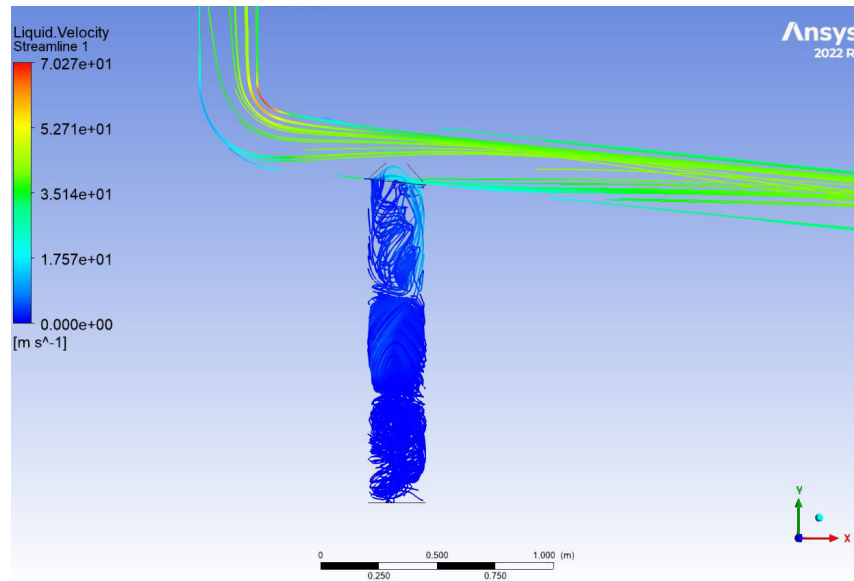


Figure 38. Front trap velocity streamline profile for 85% inlet quality, steady-state analysis of the full geometry

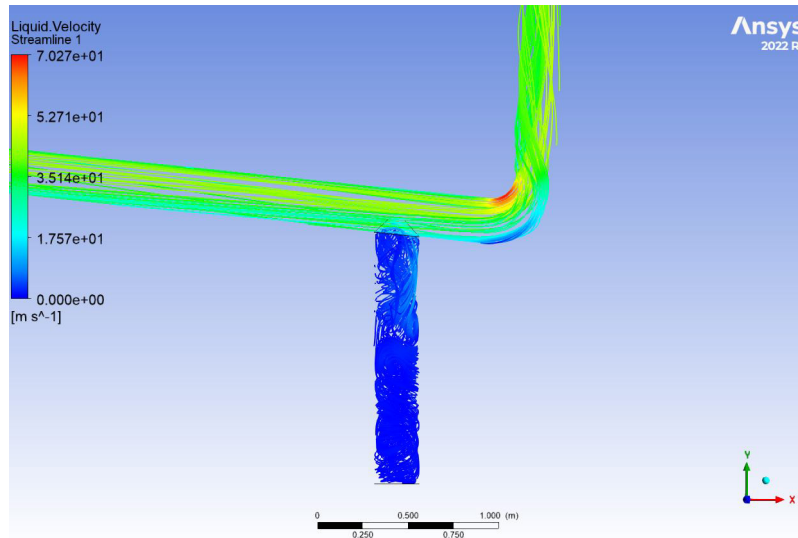


Figure 39. Rear trap velocity streamline profile for 85% inlet quality, steady-state analysis of the full geometry

The pressure profile for the 85% inlet quality, steady state analysis proved to be nearly identical to the 99% inlet quality, steady-state simulation. The pressure did not change because the velocity at the inlet and the pressure at the outlet remained constant. The pressure was therefore not expected to vary from the 99% inlet quality condition.

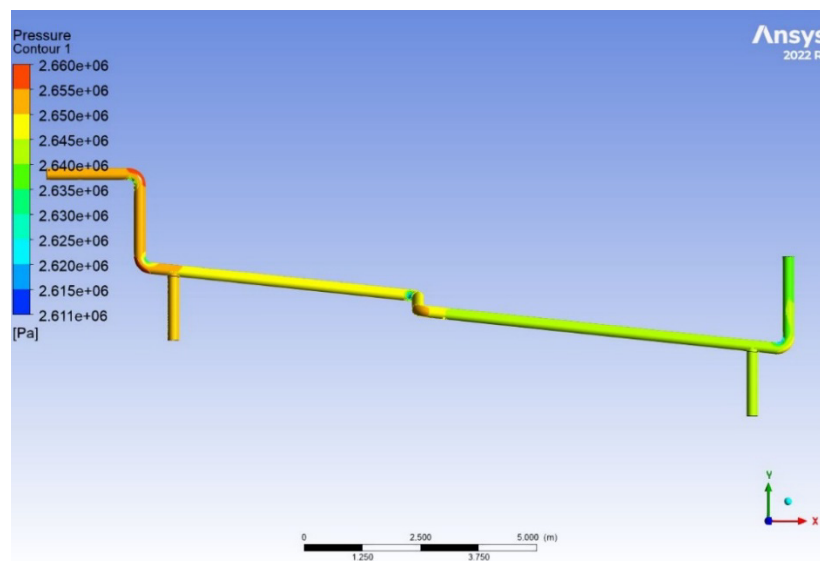


Figure 40. Pressure profile at the wall for 85% inlet quality, steady-state analysis of the full geometry

## **VI. FULL GEOMETRY TRANSIENT ANALYSIS**

### **A. MODEL GEOMETRY AND MESH**

The model geometry for the transient analysis remained consistent with the model used in the full geometry, steady-state analysis. No changes were made. The 20 mm bulk mesh with inflation layer was consistent with the steady-state analysis. These settings developed 3 961 619 mesh elements. The only changes made were in the model physics setup.

### **B. MODEL PHYSICS**

The bulk of the CFX-Pre settings remained the same for the transient analysis. The only settings changed besides the transient timestep values were the transient conditions for each scenario. For the inlet quality transient analysis, a variable inlet quality expression was designed, and an inlet pressure expression was designed to model the inlet pressure transient. Both simulations were initialized using the 99% inlet quality, full geometry, steady-state results file.

#### **1. Inlet Quality Transient Settings**

The inlet quality transient modeled a linear ramp from 99% inlet quality to 85% inlet quality with a mirrored return to 99% inlet quality. Both the quality decrease and return stretched across 20 second linear ramps. Ten seconds of 99% inlet quality were added to the end of the simulation to monitor the full response of the piping system as it returned to the steady state conditions. Figure 41 depicts the transient inlet quality setting. The simulation began at zero seconds, where the flatline at 99% inlet quality at negative five seconds in Figure 41 represents the 99% inlet quality, steady-state results file that was used as the initial condition.

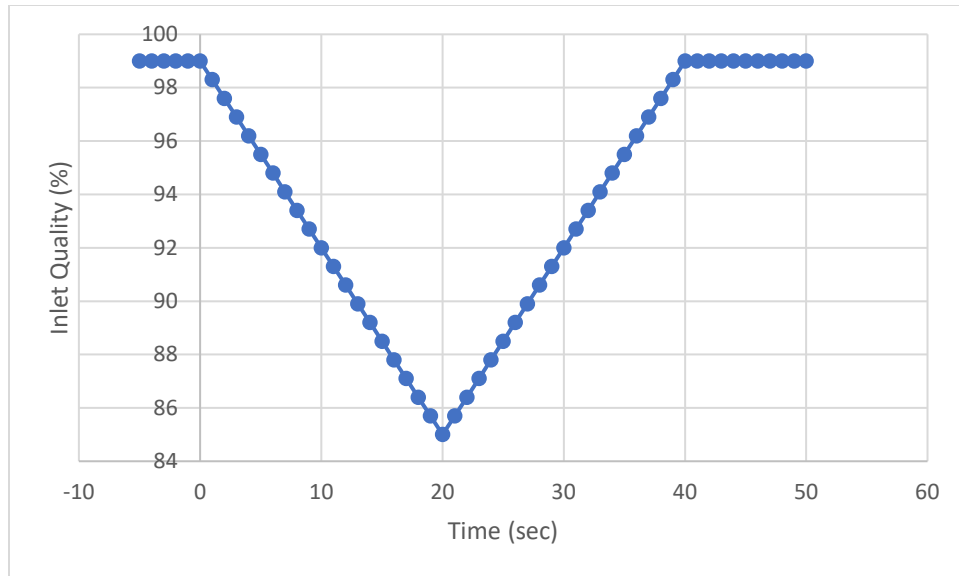


Figure 41. Transient inlet quality ramp over time

The inlet quality was defined using an expression in CFX-Pre. This expression was dependent on the time and produced a linear ramp. The CCL file with the relevant expression values can be found in Appendix K. The complete transient time was set at 50 seconds to account for the transient decrease and increase in inlet quality with the flatline at 99% inlet quality for ten seconds at the conclusion of the transient. The transient was designed to have 1 millisecond time steps in order to obtain the desired average Courant number below ten.

## 2. Inlet Pressure Transient Settings

The inlet pressure transient was also defined using expressions in CFX-Pre. Again, a time dependent expression was developed to model the transient boundary conditions. In this case, the inlet pressure began at 2.64 MPa and performed a linear decrease to 2.24 MPa before returning to the initial inlet pressure. Each linear ramp lasted 30 seconds. Following the linear return, the inlet pressure was left at 2.64 MPa to allow for a complete observation of the return to initial conditions. Figure 42 depicts this transient inlet pressure setting. The region from negative five seconds to zero seconds on Figure 42 represents the 99% inlet quality, steady-state results file that was used as the initial conditions for this transient simulation.

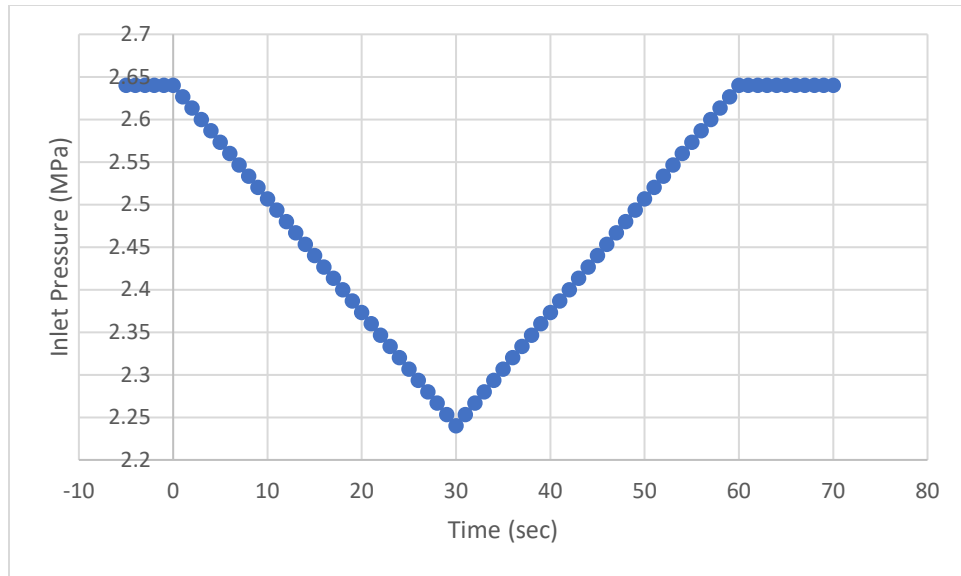


Figure 42. Transient inlet pressure ramp over time

The transient expression was defined in CFX-Pre. Similar to the inlet quality transient, the pressure transient was designed as a time dependent expression. The CCL file with the relevant expression values can be found in Appendix L. The complete transient time was set to 70 seconds with 1 millisecond timesteps.

### C. TRANSIENT RESULTS

Due to time constraints, only partial results were obtained for the transient inlet quality simulation. The transient inlet pressure simulation was not started. Due to the steady-state complications on Hamming, as described in Appendix F, all analyses were run on a local computer. The inlet quality simulation was run across 32 cores. Based on the inlet quality transient analysis, the inlet pressure simulation would take approximately 35 days to run to completion with the same computational resources. These computational resources were not efficient for this simulation and it is advisable that either the issues in Appendix F are addressed, or more computational power is reserved to solve this simulation on local machines.

The inlet quality transient simulation was stopped at 50 960 solver iterations which equated to 15.306 seconds of real time results. This simulation was run with a timestep of 1 millisecond with 3 iterations per timestep. Each two second interval of real time results

took 24 hours to calculate. The timestep was left at this interval such that the average Courant number would remain below ten. For this timestep, the average Courant number was 8.62 and the maximum Courant number was 902.40. Figure 43 displays the mass and momentum residuals for this simulation. The high iteration count is due to the simulation being started from the 99% inlet quality, steady-state results file. The jump in residuals at the 36 000 iteration point marks where the ramp up of inlet quality began. The vapor and density residuals remained consistent while the liquid residuals trended to a higher residual value.

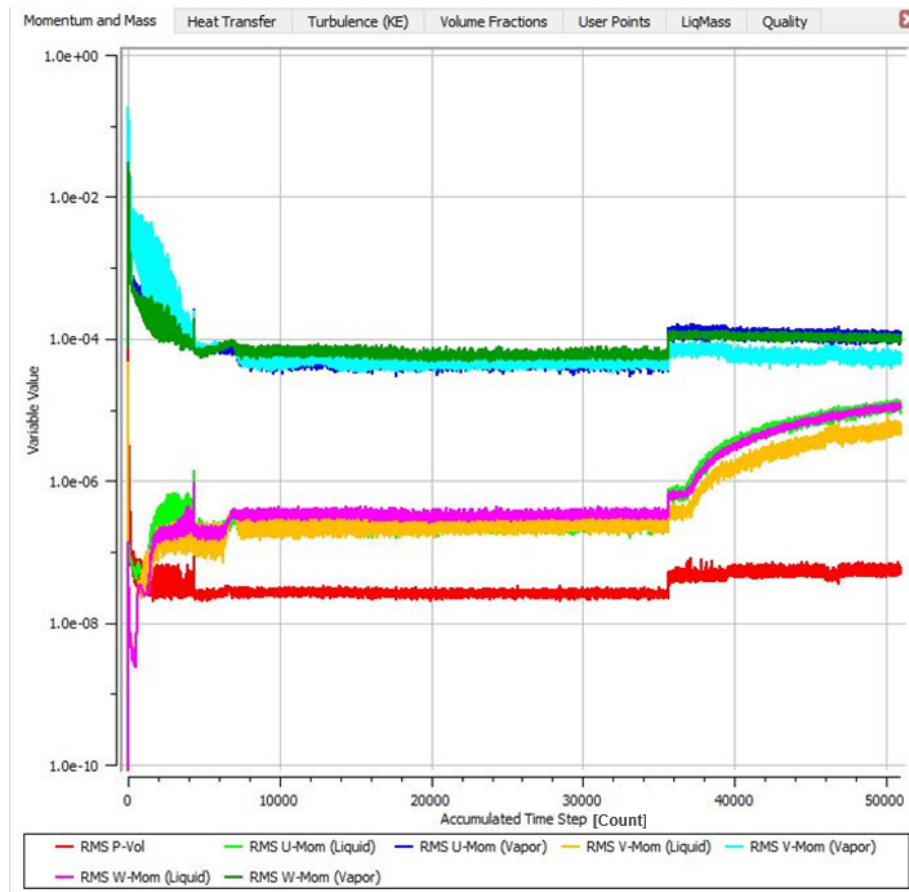


Figure 43. Mass and momentum residuals for inlet quality transient analysis of full geometry

The liquid mass of the pipe is shown in Figure 44 and the inlet and outlet quality of the pipe is plotted in Figure 45. The liquid mass and quality have an inverse relationship

as expected. The decreased inlet quality equates to greater liquid mass input to the piping system. The transient inlet quality expression did not increase begin to increase the inlet quality until 20 seconds of simulation. Since the simulation was terminated at 15.306 seconds, only the decrease in inlet quality was modeled at this point. The liquid mass at the final timestep in this transient simulation was 1.9991 kg. This liquid mass was 1.89875 kg greater than the initial liquid mass of 0.10035 kg. The 85% inlet quality, steady-state simulation output a liquid mass of 2.5332 kg. At this final 15.306 second point of the simulation, the inlet quality was only down to 88.636%. The expected liquid mass at this 15.306 second timestep was 1.4967 kg. The liquid mass was higher than expected at the cutoff in this testing, but it is due to the liquid only being removed from the steam traps at 0.002 m/s as originally designed for 99% inlet quality.

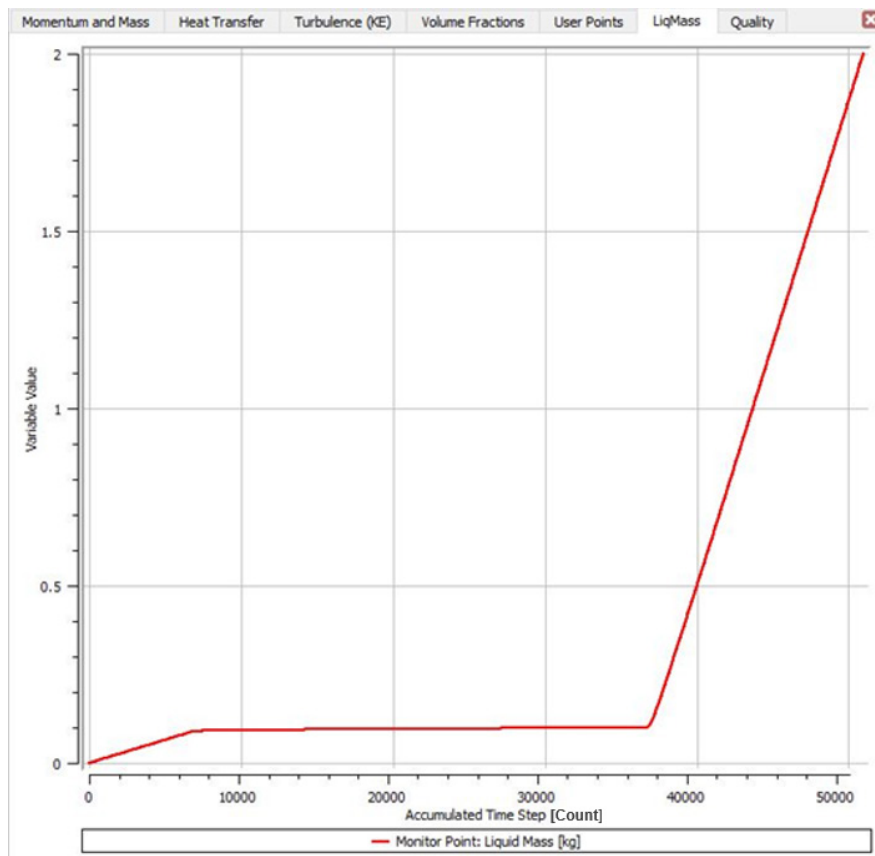


Figure 44. Liquid mass monitor plot for inlet quality transient analysis of full geometry

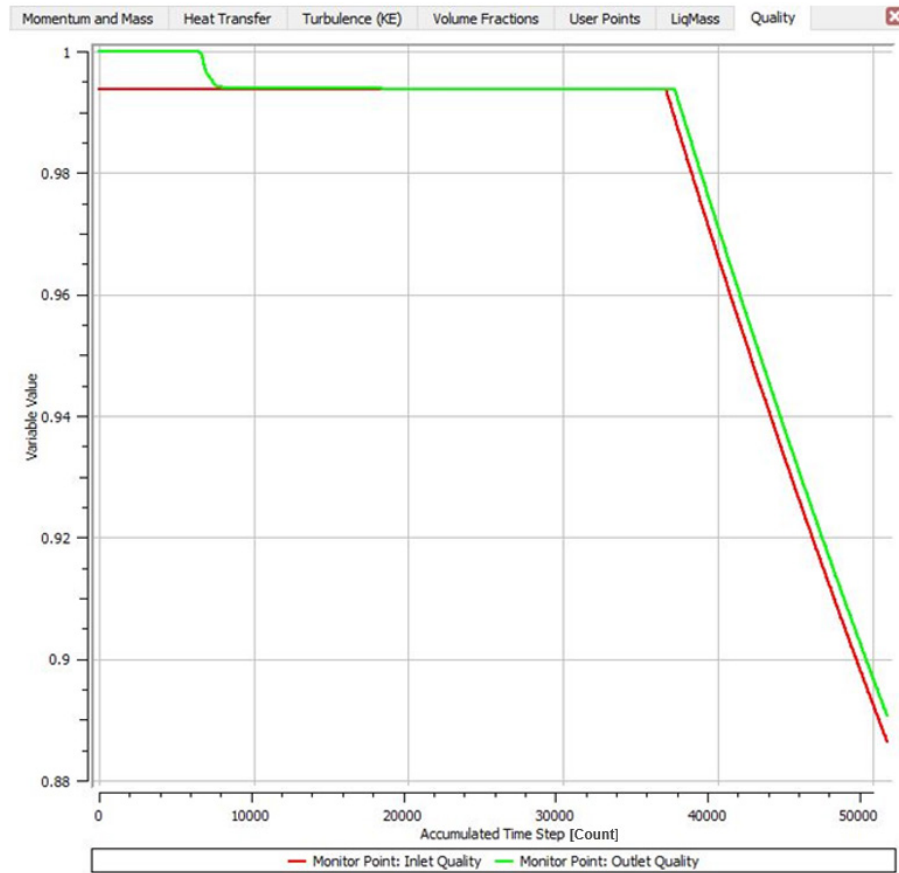


Figure 45. Inlet and outlet quality monitor plot for inlet quality transient analysis of full geometry

The vapor mass fraction at varied timesteps is shown in Figures 46–48. As the time increases, and the inlet quality decreases, the vapor mass fraction reflects a greater inflow of liquid. Of note, the fluid dependent condition within the steam traps remained at a constant 0.002 m/s. This setting was consistent with the 99% inlet quality, steady-state setting. As a result, it is expected that inlet qualities lower than 99% would result in liquid filling the traps at a higher rate than the fluid was emptied from the steam trap outlets. The vapor mass fraction at 0.593 seconds was identical to the steam trap profile seen in the 99% inlet quality, steady-state analysis. There is a vapor base at the bottom of the trap due to the lack of recirculation. The middle of the trap shows what could be an unsteady flow of vapor and liquid. The 10.546 second timestep shows a very similar profile, but with very different vapor mass fraction values. While the maximum vapor mass fraction is

approximately the same, as seen in the bottom of the steam traps, the main pipe flow quality dropped significantly from the 0.593 second profile. At this halfway point of the inlet quality drop, the main pipe flow quality dropped from 99.41% to 92.70%. This comes out to a 6.71% quality drop. While the inlet quality setting at this point was 91.5%, the steam traps were consistently removing liquid. As a result, the quality increased. This was only a slight quality increase, so the effectiveness of the steam traps does appear to have been limited. This pattern continued into the 15.306 second profile. Again, there remained a vapor core at the bottom of the steam trap with a consistent main body quality. The main pipe quality was 89.69% where the inlet quality setting was 87.75%. This shows that the steam traps did cause the quality of the flow to lag behind the inlet quality slightly.

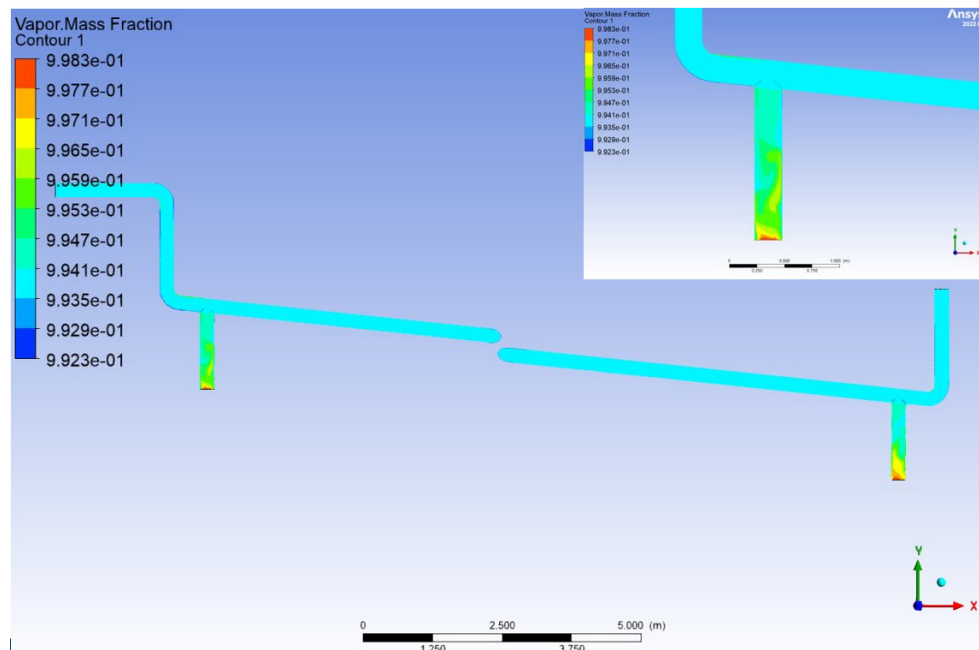
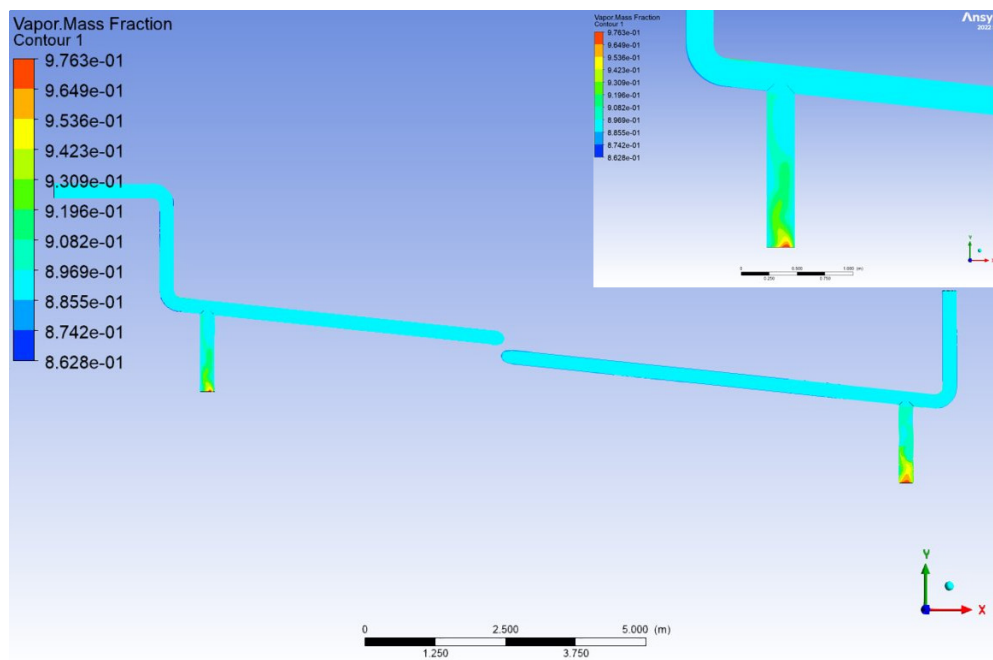
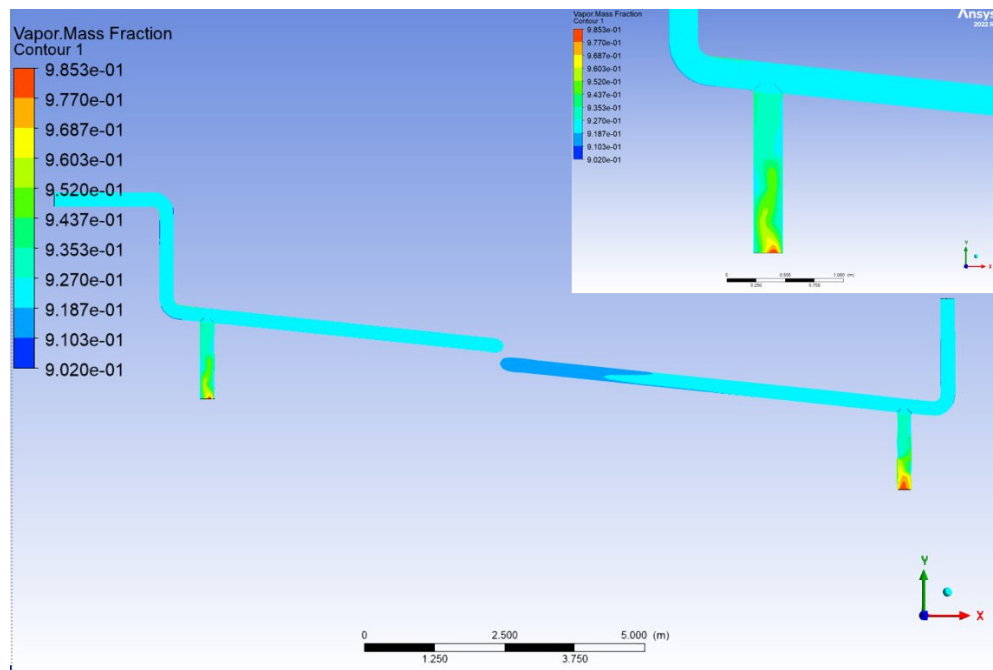


Figure 46. Vapor mass fraction profile at 0.593 seconds through inlet quality transient analysis of full geometry



The liquid velocity within the front steam trap is shown in Figure 49. This profile stayed fairly consistent across all time steps. There was a small increase in liquid velocity within the traps as time increased. This was due to the increase of liquid mass within the steam traps as more and more liquid was added through the inlet.

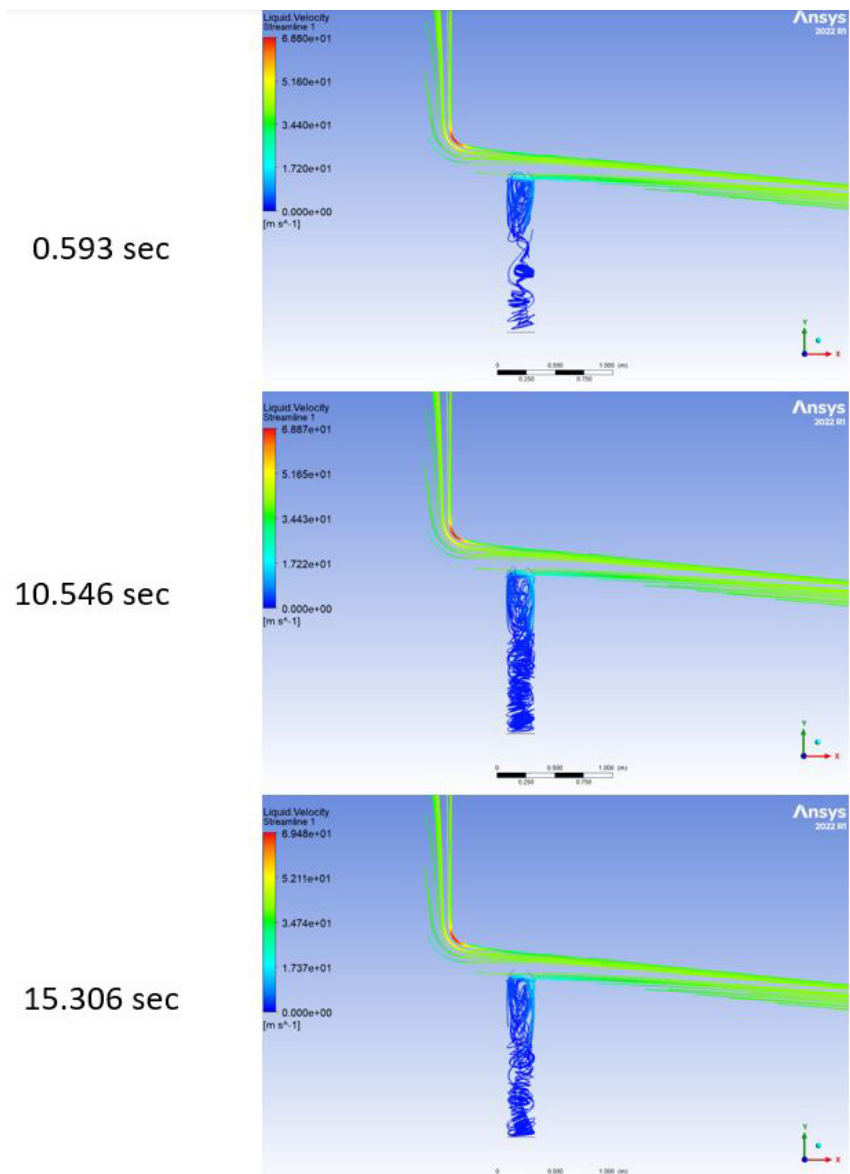


Figure 49. Velocity streamlines through front steam trap for three timesteps across inlet quality transient analysis of full geometry

Table 7 displays the quality at the inlet and outlet in addition to the mass flowrate into the steam traps at the three observed timesteps. Of interest, the quality difference between the inlet and outlet was approximately the same for the 10.546 second time frame and the 15.306 second time frame. The quality difference at these two timesteps was 0.4558% and 0.4268% respectively. The quality difference was much smaller at the first timestep due to the inlet setting containing almost no liquid mass to be removed. The mass flowrate of each steam trap was performed by cutting a plane through each trap individually and calculating the average mass flow of either vapor or liquid. In both traps, the liquid mass flow rate increased slightly while the vapor mass flow rate decreased. This follows the expectation of higher liquid presence in the steam traps as the inlet quality was decreased. Figure 50 displays the inlet quality setting and the measured inlet quality for the 15 seconds of simulation recorded for this transient analysis. The two values are very close with the measured inlet quality lagging slightly behind the setting.

Table 7. Quality and mass flowrate data for inlet quality transient analysis

| <b>Simulation Time (sec)</b> | <b>Inlet Quality (%)</b> | <b>Outlet Quality (%)</b> | <b>Liquid Mass Flowrate into Trap 1 (kg/s)</b> | <b>Vapor Mass Flowrate into Trap 1 (kg/s)</b> | <b>Liquid Mass Flowrate into Trap 2 (kg/s)</b> | <b>Vapor Mass Flowrate into Trap 2 (kg/s)</b> |
|------------------------------|--------------------------|---------------------------|------------------------------------------------|-----------------------------------------------|------------------------------------------------|-----------------------------------------------|
| 0.593                        | 99.3740                  | 99.3774                   | 2.818E-08                                      | 3.214E-05                                     | 1.649E-07                                      | 6.070E-06                                     |
| 10.546                       | 91.9459                  | 92.4017                   | 4.100E-07                                      | 2.335E-05                                     | 2.714E-06                                      | 5.255E-06                                     |
| 15.306                       | 88.6358                  | 89.0626                   | 5.653E-07                                      | 3.068E-05                                     | 2.930E-06                                      | 4.950E-06                                     |

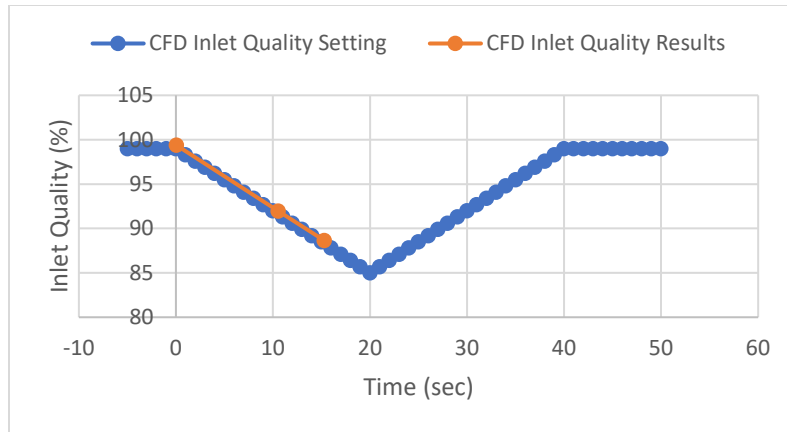


Figure 50. Inlet quality setting vs. measured inlet quality results for inlet quality transient analysis of the full geometry

The pressure profile across the entire pipe stayed fairly consistent across all timesteps. While there were small changes due to the transient nature of the problem, the pressure drop remained at about 14.87 kPa for the piping system. Figure 51 displays one pressure profile from the 10.546 second timestep that is representative of all pressure profiles in this simulation. The pressure losses are higher at the pipe bends and fairly consistent throughout the remainder of the main piping system. Some pressure loss is also seen after each steam trap.

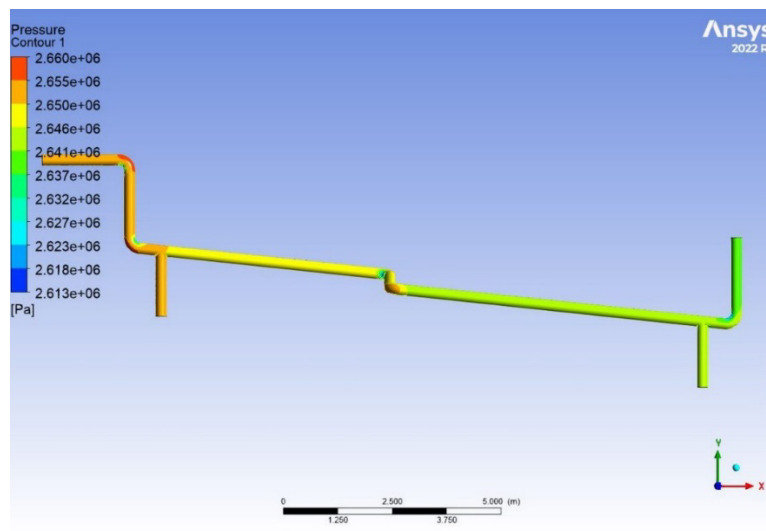


Figure 51. Pressure profile on the wall at 10.546 seconds of inlet quality transient analysis of the full geometry

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## VII. CONCLUSIONS AND RECOMMENDATIONS

Following this work, the importance of the Courant number and its effect on computational speed became readily apparent. For the large, multi-million element meshes seen in this work, smaller timescale factors and timesteps had to be used. Default timescales resulted in finite measurement errors that led to crashing solutions. Meshes that are too large, but can run larger timescale factors and timesteps could be viable, but must be checked in a mesh sensitivity study to determine their accuracy. Transient analyses took significantly longer to compute in comparison to steady-state analyses. While the two-phase flows took extensive periods of time for the liquid to fill up in the steam pipe, the calculation of short, millisecond time steps on transient analyses took even longer. The complicated nature of three-dimensional modeling and the errors seen in transferring the problem to an HPC argue that ANSYS CFX may not be the optimal software for rapid steam pipe design.

Resolving the issues seen in this research could prove to increase the feasibility of ANSYS CFX as a design tool for these steam pipe systems. First off, for steady-state analyses, a more extensive mesh sensitivity study could be done to determine the accuracy of the 20 mm bulk mesh and larger meshes. The steam traps should also be set with an initial condition of 100% liquid mass. This initial condition would resolve the issue of waiting for tens of thousands of iterations for the liquid mass in the steam traps to fill. Instead, the steam traps would be emptying out the liquid from this initial condition until steady-state is reached. Finally, a deeper look into the creation and transfer of the .def file should be done. This error slowed down the pace of research significantly. Without being able to transfer the files to Hamming, the local computing cluster, only local resources were able to be used to calculate both the steady-state and transient analyses.

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## APPENDIX A. CCL FOR STEAM PIPE USER EXPRESSIONS

The following is a CCL file that describes the general expressions used to calculate various properties of the steam flow. These settings were designed by Axelsson and applied as a base setting for this research [14]. This file is exported from CFX-Pre.

LIBRARY:

CEL:

EXPRESSIONS:

```
CourantAve = ave(Courant Number )@Default Domain Modified
CourantMax = maxVal(Courant Number )@Default Domain Modified
CourantRMS = rmsAve(Courant Number )@Default Domain Modified
LiquidVFinlet = 1-VaporVFinlet
LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
MassFlowInlet = massFlow()@Inlet
MassFlowOutlet = -massFlow()@Outlet
Press = 2.6389[MPa]
QualityEquilInlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
  t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityEquilOutlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
  t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityInlet = \
  Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
QualityOutlet = \
  Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
  let)
SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain Modified
Tsat = \
  1[K]*(0.5*(650.17534844798+((2*((-724213.16703206*((Press/1[MPa])^0.25\
  )^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))/(-(11\
  67.0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa]\
  )^0.25))-4823.2657361591)-((1167.0521452767*((Press/1[MPa])^0.25)^2)+\
  (12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)^2-(4*((Press\
  /1[MPa])^0.25)^2+(-17.073846940092*((Press/1[MPa])^0.25))+14.915108613\
  530)*((-724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((P\
  ress/1[MPa])^0.25))+405113.40542057)))^0.5)-((650.17534844798+((2*((-\
  724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[M\
  Pa])^0.25))+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25\
  )^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.\
  0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0\
  .25))-4823.2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092\
  *((Press/1[MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[\
  MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.4054205\
  7)))^0.5)))^2-4*(-0.23855557567849+(650.17534844798*((2*((-724213.1670\
  3206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25)\
  )+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25)^2)+(12020\
  .824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.0521452767*\
  ((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.\
  2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[\
  MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[MPa])^0.25)\
  ^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))^0.5)))\
  )^0.5))
VaporVFinlet = if(Accumulated Iteration Number <= 100, \
```

```

        .9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
WallHeatFlux = if(Accumulated Iteration Number <=250, \
    0[W/m^2]-(Accumulated Iteration Number*123.6)[W/m^2], -30900[W/m^2])
WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
    Iteration Number*0.008)[K], 498[K])
    END
END
END
COMMAND FILE:
    Version = 22.1
END

```

## APPENDIX B. CCL FOR STEAM PIPE FLUID PROPERTIES

The following is a CCL file that describes the fluid properties of the steam flow. These settings were designed by Axelsson and applied as a base setting for this research [14]. This file is exported from CFX-Pre.

```
LIBRARY:
MATERIAL: LIQUIDCONST
  MATERIAL GROUP = CONSTANT PROPERTY LIQUIDS,WET STEAM
  OPTION = PURE SUBSTANCE
  THERMODYNAMIC STATE = LIQUID
  PROPERTIES:
    OPTION = GENERAL MATERIAL
    EQUATION OF STATE:
      DENSITY = 831.318 [KG M^-3]
      MOLAR MASS = 18.02 [KG KMOL^-1]
      OPTION = VALUE
    END
    SPECIFIC HEAT CAPACITY:
      OPTION = VALUE
      SPECIFIC HEAT CAPACITY = 4659 [J KG^-1 K^-1]
      SPECIFIC HEAT TYPE = CONSTANT PRESSURE
    END
    REFERENCE STATE:
      OPTION = SPECIFIED POINT
      REFERENCE PRESSURE = 2.6389 [MPA]
      REFERENCE SPECIFIC ENTHALPY = 975465 [J KG^-1]
      REFERENCE SPECIFIC ENTROPY = 2581.1 [J KG^-1 K^-1]
      REFERENCE TEMPERATURE = 500 [K]
    END
    DYNAMIC VISCOSITY:
      DYNAMIC VISCOSITY = 0.0001179 [PA S]
      OPTION = VALUE
    END
    THERMAL CONDUCTIVITY:
      OPTION = VALUE
      THERMAL CONDUCTIVITY = 0.6421 [W M^-1 K^-1]
    END
  END
END
MATERIAL: LIQUIDVAR
  MATERIAL GROUP = IAPWS IF97,WET STEAM
  OPTION = PURE SUBSTANCE
  THERMODYNAMIC STATE = LIQUID
  PROPERTIES:
    OPTION = IAPWS LIBRARY
    REFERENCE STATE:
      OPTION = AUTOMATIC
    END
    TABLE GENERATION:
      MAXIMUM ABSOLUTE PRESSURE = 12.345 [MPA]
      MAXIMUM POINTS = 100
      MAXIMUM TEMPERATURE = 600 [K]
      MINIMUM ABSOLUTE PRESSURE = 0.0035368 [MPA]
      MINIMUM TEMPERATURE = 300 [K]
      PRESSURE EXTRAPOLATION = ON
```

```

    TEMPERATURE EXTRAPOLATION = YES
END
END
END
MATERIAL: VAPORCONST
MATERIAL GROUP = WET STEAM, CONSTANT PROPERTY GASES
OPTION = PURE SUBSTANCE
THERMODYNAMIC STATE = GAS
PROPERTIES:
    OPTION = GENERAL MATERIAL
    EQUATION OF STATE:
        DENSITY = 13.1976 [KG M^-3]
        MOLAR MASS = 18.02 [KG KMOL^-1]
        OPTION = VALUE
    END
    SPECIFIC HEAT CAPACITY:
        OPTION = VALUE
        SPECIFIC HEAT CAPACITY = 3462.6 [J KG^-1 K^-1]
        SPECIFIC HEAT TYPE = CONSTANT PRESSURE
    END
    REFERENCE STATE:
        OPTION = SPECIFIED POINT
        REFERENCE PRESSURE = 2.6389 [MPA]
        REFERENCE SPECIFIC ENTHALPY = 2802590 [J KG^-1]
        REFERENCE SPECIFIC ENTROPY = 6235.4 [J KG^-1 K^-1]
        REFERENCE TEMPERATURE = 500 [K]
    END
    DYNAMIC VISCOSITY:
        DYNAMIC VISCOSITY = 1.6594E-5 [PA S]
        OPTION = VALUE
    END
    THERMAL CONDUCTIVITY:
        OPTION = VALUE
        THERMAL CONDUCTIVITY = 0.044952 [W M^-1 K^-1]
    END
    THERMAL EXPANSIVITY:
        OPTION = VALUE
        THERMAL EXPANSIVITY = 0.001686 [K^-1]
    END
END
END
MATERIAL: VAPORVAR
MATERIAL GROUP = IAPWS IF97, WET STEAM
OPTION = PURE SUBSTANCE
THERMODYNAMIC STATE = GAS
PROPERTIES:
    OPTION = IAPWS LIBRARY
    REFERENCE STATE:
        OPTION = AUTOMATIC
    END
    TABLE GENERATION:
        MAXIMUM ABSOLUTE PRESSURE = 12.345 [MPA]
        MAXIMUM POINTS = 1000
        MAXIMUM TEMPERATURE = 600 [K]
        MINIMUM ABSOLUTE PRESSURE = 0.0035368 [MPA]
        MINIMUM TEMPERATURE = 300 [K]
        PRESSURE EXTRAPOLATION = ON
        TEMPERATURE EXTRAPOLATION = YES
    END
END
END
END
END

```

COMMAND FILE:  
VERSION = 22.1  
END

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## APPENDIX C. CCL FOR MESH SENSITIVITY STUDY

The following is a CCL file that describes the boundary conditions and expressions used for the mesh sensitivity analysis. This file is exported from CFX-Pre.

LIBRARY:

CEL:

EXPRESSIONS:

```
CourantAve = ave(Courant Number )@Default Domain Modified
CourantMax = maxVal(Courant Number )@Default Domain Modified
CourantRMS = rmsAve(Courant Number )@Default Domain Modified
LiquidVFinlet = 1-VaporVFinlet
LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
MassFlowInlet = massFlow()@Inlet
MassFlowOutlet = -massFlow()@Outlet
Press = 2.6389[MPa]
QualityEquilInlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
   t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityEquilOutlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
   t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityInlet = \
  Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
QualityOutlet = \
  Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
   let)
SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain Modified
Tsat = \
  1[K]*(0.5*(650.17534844798+((2*((-724213.16703206*((Press/1[MPa])^0.25\
   )^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))/(-(11\
   67.0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa]\
   )^0.25))-4823.2657361591)-((1167.0521452767*((Press/1[MPa])^0.25)^2)+\
   (12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)^2-(4*((Press\
   /1[MPa])^0.25)^2+(-17.073846940092*((Press/1[MPa])^0.25))+14.915108613\
   530)*((-724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((P\
   ress/1[MPa])^0.25))+405113.40542057))^0.5)-((650.17534844798+((2*((-\
   724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[M\
   Pa])^0.25))+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25\
   )^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.\
   0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0\
   .25))-4823.2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092\
   *((Press/1[MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[\
   MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.4054205\
   7))^0.5))^2-4*(-0.23855557567849+(650.17534844798*((2*((-724213.1670\
   3206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))\
   +405113.40542057))/(-(1167.0521452767*((Press/1[MPa])^0.25)^2)+(12020\
   .824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.0521452767\
   *((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.\
   2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[\
   MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[MPa])^0.25)\
   ^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057))^0.5))\
   )^0.5))
VaporVFinlet = if(Accumulated Iteration Number <= 100, \
  .9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
```

```

    VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
    WallHeatFlux = if(Accumulated Iteration Number <=250, \
        0[W/m^2]-(Accumulated Iteration Number*123.6)[W/m^2], -30900[W/m^2])
    WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
        Iteration Number*0.008)[K], 498[K])
END
END
ADDITIONAL VARIABLE: MassTotal
    Option = Definition
    Tensor Type = SCALAR
    Units = [kg]
    Variable Type = Specific
END
MATERIAL GROUP: Air Data
    Group Description = Ideal gas and constant property air. Constant \
        properties are for dry air at STP (0 C, 1 atm) and 25 C, 1 atm.
END
MATERIAL GROUP: CHT Solids
    Group Description = Pure solid substances that can be used for conjugate \
        heat transfer.
END
MATERIAL GROUP: Calorically Perfect Ideal Gases
    Group Description = Ideal gases with constant specific heat capacity. \
        Specific heat is evaluated at STP.
END
MATERIAL GROUP: Constant Property Gases
    Group Description = Gaseous substances with constant properties. \
        Properties are calculated at STP (0C and 1 atm). Can be combined with \
        NASA SP-273 materials for combustion modelling.
END
MATERIAL GROUP: Constant Property Liquids
    Group Description = Liquid substances with constant properties.
END
MATERIAL GROUP: Dry Peng Robinson
    Group Description = Materials with properties specified using the built \
        in Peng Robinson equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Redlich Kwong equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Soave Redlich Kwong equation of state. Suitable for dry real gas \
        modelling.
END
MATERIAL GROUP: Dry Steam
    Group Description = Materials with properties specified using the IAPWS \
        equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Gas Phase Combustion
    Group Description = Ideal gas materials which can be use for gas phase \
        combustion. Ideal gas specific heat coefficients are specified using \
        the NASA SP-273 format.
END
MATERIAL GROUP: IAPWS IF97
    Group Description = Liquid, vapour and binary mixture materials which use \
        the IAPWS IF-97 equation of state. Materials are suitable for \
        compressible liquids, phase change calculations and dry steam flows.
END
MATERIAL GROUP: Interphase Mass Transfer
    Group Description = Materials with reference properties suitable for \

```

```

    performing either Eulerian or Lagrangian multiphase mass transfer \
    problems. Examples include cavitation, evaporation or condensation.
END
MATERIAL GROUP: Liquid Phase Combustion
    Group Description = Liquid and homogenous binary mixture materials which \
    can be included with Gas Phase Combustion materials if combustion \
    modelling also requires phase change (eg: evaporation) for certain \
    components.
END
MATERIAL GROUP: Particle Solids
    Group Description = Pure solid substances that can be used for particle \
    tracking
END
MATERIAL GROUP: Peng Robinson Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Peng Robinson Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Real Gas Combustion
    Group Description = Real gas materials which can be use for gas phase \
    combustion. Ideal gas specific heat coefficients are specified using \
    the NASA SP-273 format.
END
MATERIAL GROUP: Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Steam
    Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END

```

```

MATERIAL GROUP: Redlich Kwong Wet Steam
  Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Hydrocarbons
  Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Refrigerants
  Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Steam
  Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Hydrocarbons
  Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Refrigerants
  Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Steam
  Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soot
  Group Description = Solid substances that can be used when performing \
    soot modelling
END
MATERIAL GROUP: User
  Group Description = Materials that are defined by the user
END
MATERIAL GROUP: Water Data
  Group Description = Liquid and vapour water materials with constant \
    properties. Can be combined with NASA SP-273 materials for combustion \
    modelling.
END
MATERIAL GROUP: Wet Peng Robinson
  Group Description = Materials with properties specified using the built \
    in Peng Robinson equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Redlich Kwong
  Group Description = Materials with properties specified using the built \
    in Redlich Kwong equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Soave Redlich Kwong
  Group Description = Materials with properties specified using the built \
    in Soave Redlich Kwong equation of state. Suitable for wet real gas \
    modelling.
END
MATERIAL GROUP: Wet Steam
  Group Description = Materials with properties specified using the IAPWS \
    equation of state. Suitable for wet steam modelling.
END
MATERIAL: Air Ideal Gas
  Material Description = Air Ideal Gas (constant Cp)
  Material Group = Air Data, Calorically Perfect Ideal Gases
  Option = Pure Substance
  Thermodynamic State = Gas

```

```

PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Molar Mass = 28.96 [kg kmol^-1]
  Option = Ideal Gas
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 1.0044E+03 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1 [atm]
  Reference Specific Enthalpy = 0. [J/kg]
  Reference Specific Entropy = 0. [J/kg/K]
  Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 2.61E-2 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
  Absorption Coefficient = 0.01 [m^-1]
  Option = Value
END
SCATTERING COEFFICIENT:
  Option = Value
  Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
  Option = Value
  Refractive Index = 1.0 [m m^-1]
END
END
MATERIAL: Air at 25 C
  Material Description = Air at 25 C and 1 atm (dry)
  Material Group = Air Data, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Density = 1.185 [kg m^-3]
  Molar Mass = 28.96 [kg kmol^-1]
  Option = Value
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 1.0044E+03 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1 [atm]
  Reference Specific Enthalpy = 0. [J/kg]
  Reference Specific Entropy = 0. [J/kg/K]

```

```

    Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 2.61E-02 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0.01 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 0.003356 [K^-1]
END
END
MATERIAL: Aluminium
    Material Group = CHT Solids, Particle Solids
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:
            Density = 2702 [kg m^-3]
            Molar Mass = 26.98 [kg kmol^-1]
            Option = Value
        END
        SPECIFIC HEAT CAPACITY:
            Option = Value
            Specific Heat Capacity = 9.03E+02 [J kg^-1 K^-1]
        END
        REFERENCE STATE:
            Option = Specified Point
            Reference Specific Enthalpy = 0 [J/kg]
            Reference Specific Entropy = 0 [J/kg/K]
            Reference Temperature = 25 [C]
        END
        THERMAL CONDUCTIVITY:
            Option = Value
            Thermal Conductivity = 237 [W m^-1 K^-1]
        END
    END
END
MATERIAL: Copper
    Material Group = CHT Solids, Particle Solids
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:

```

```

    Density = 8933 [kg m^-3]
    Molar Mass = 63.55 [kg kmol^-1]
    Option = Value
END
SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 3.85E+02 [J kg^-1 K^-1]
END
REFERENCE STATE:
    Option = Specified Point
    Reference Specific Enthalpy = 0 [J/kg]
    Reference Specific Entropy = 0 [J/kg/K]
    Reference Temperature = 25 [C]
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 401.0 [W m^-1 K^-1]
END
END
MATERIAL: LiquidConst
    Material Group = Constant Property Liquids,Wet Steam
    Option = Pure Substance
    Thermodynamic State = Liquid
    PROPERTIES:
        Option = General Material
    EQUATION OF STATE:
        Density = 831.318 [kg m^-3]
        Molar Mass = 18.02 [kg kmol^-1]
        Option = Value
    END
    SPECIFIC HEAT CAPACITY:
        Option = Value
        Specific Heat Capacity = 4659 [J kg^-1 K^-1]
        Specific Heat Type = Constant Pressure
    END
    REFERENCE STATE:
        Option = Specified Point
        Reference Pressure = 2.6389 [MPa]
        Reference Specific Enthalpy = 975465 [J kg^-1]
        Reference Specific Entropy = 2581.1 [J kg^-1 K^-1]
        Reference Temperature = 500 [K]
    END
    DYNAMIC VISCOSITY:
        Dynamic Viscosity = 0.0001179 [Pa s]
        Option = Value
    END
    THERMAL CONDUCTIVITY:
        Option = Value
        Thermal Conductivity = 0.6421 [W m^-1 K^-1]
    END
END
MATERIAL: LiquidVar
    Material Group = IAPWS IF97,Wet Steam
    Option = Pure Substance
    Thermodynamic State = Liquid
    PROPERTIES:
        Option = IAPWS Library
    REFERENCE STATE:
        Option = Automatic
    END

```

```

TABLE GENERATION:
  Maximum Absolute Pressure = 12.345 [MPa]
  Maximum Points = 100
  Maximum Temperature = 600 [K]
  Minimum Absolute Pressure = 0.0035368 [MPa]
  Minimum Temperature = 300 [K]
  Pressure Extrapolation = On
  Temperature Extrapolation = Yes
END
END
END
MATERIAL: Soot
  Material Group = Soot
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 2000 [kg m-3]
      Molar Mass = 12 [kg kmol-1]
      Option = Value
    END
    REFERENCE STATE:
      Option = Automatic
    END
    ABSORPTION COEFFICIENT:
      Absorption Coefficient = 0 [m-1]
      Option = Value
    END
  END
END
MATERIAL: Steel
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 7854 [kg m-3]
      Molar Mass = 55.85 [kg kmol-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 4.34E+02 [J kg-1 K-1]
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Specific Enthalpy = 0 [J/kg]
      Reference Specific Entropy = 0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 60.5 [W m-1 K-1]
    END
  END
END
MATERIAL: VaporConst
  Material Group = Wet Steam, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas

```

```

PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Density = 13.1976 [kg m^-3]
  Molar Mass = 18.02 [kg kmol^-1]
  Option = Value
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 3462.6 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 2.6389 [MPa]
  Reference Specific Enthalpy = 2802590 [J kg^-1]
  Reference Specific Entropy = 6235.4 [J kg^-1 K^-1]
  Reference Temperature = 500 [K]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 1.6594e-5 [Pa s]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 0.044952 [W m^-1 K^-1]
END
THERMAL EXPANSIVITY:
  Option = Value
  Thermal Expansivity = 0.001686 [K^-1]
END
END
MATERIAL: VaporVar
  Material Group = IAPWS IF97, Wet Steam
  Option = Pure Substance
  Thermodynamic State = Gas
PROPERTIES:
  Option = IAPWS Library
REFERENCE STATE:
  Option = Automatic
END
TABLE GENERATION:
  Maximum Absolute Pressure = 12.345 [MPa]
  Maximum Points = 1000
  Maximum Temperature = 600 [K]
  Minimum Absolute Pressure = 0.0035368 [MPa]
  Minimum Temperature = 300 [K]
  Pressure Extrapolation = On
  Temperature Extrapolation = Yes
END
END
MATERIAL: Water
  Material Description = Water (liquid)
  Material Group = Water Data, Constant Property Liquids
  Option = Pure Substance
  Thermodynamic State = Liquid
PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Density = 997.0 [kg m^-3]

```

```

    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
END
SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 4181.7 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0.0 [J/kg]
    Reference Specific Entropy = 0.0 [J/kg/K]
    Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 8.899E-4 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.6069 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 2.57E-04 [K^-1]
END
END
END
MATERIAL: Water Ideal Gas
    Material Description = Water Vapour Ideal Gas (100 C and 1 atm)
    Material Group = Calorically Perfect Ideal Gases, Water Data
    Option = Pure Substance
    Thermodynamic State = Gas
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:
            Molar Mass = 18.02 [kg kmol^-1]
            Option = Ideal Gas
        END
        SPECIFIC HEAT CAPACITY:
            Option = Value
            Specific Heat Capacity = 2080.1 [J kg^-1 K^-1]
            Specific Heat Type = Constant Pressure
        END
        REFERENCE STATE:
            Option = Specified Point
            Reference Pressure = 1.014 [bar]
            Reference Specific Enthalpy = 0. [J/kg]
            Reference Specific Entropy = 0. [J/kg/K]

```

```

    Reference Temperature = 100 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 9.4E-06 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 193E-04 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
END
END
FLOW: Flow Analysis 1
    SOLUTION UNITS:
        Angle Units = [rad]
        Length Units = [m]
        Mass Units = [kg]
        Solid Angle Units = [sr]
        Temperature Units = [K]
        Time Units = [s]
    END
    ANALYSIS TYPE:
        Option = Steady State
    EXTERNAL SOLVER COUPLING:
        Option = None
    END
END
DOMAIN: Default Domain Modified
    Coord Frame = Coord 0
    Domain Type = Fluid
    Location = B4
    BOUNDARY MODELS:
        WALL BOILING MODEL:
            Option = None
        END
    END
    BOUNDARY: Inlet
        Boundary Type = INLET
        Location = Inlet
    BOUNDARY CONDITIONS:
        FLOW REGIME:
            Option = Subsonic
        END
        HEAT TRANSFER:
            Option = Static Temperature
            Static Temperature = 500 [K]
        END
        MASS AND MOMENTUM:
            Normal Speed = 40 [m s^-1]

```

```

    Option = Normal Speed
END
TURBULENCE:
    Option = Medium Intensity and Eddy Viscosity Ratio
END
END
FLUID: Liquid
    BOUNDARY CONDITIONS:
        VOLUME FRACTION:
            Option = Value
            Volume Fraction = 0.0001
        END
    END
END
FLUID: Vapor
    BOUNDARY CONDITIONS:
        VOLUME FRACTION:
            Option = Value
            Volume Fraction = 0.9999
        END
    END
END
BOUNDARY: Outlet
    Boundary Type = OUTLET
    Location = Outlet
    BOUNDARY CONDITIONS:
        FLOW REGIME:
            Option = Subsonic
        END
        MASS AND MOMENTUM:
            Option = Average Static Pressure
            Pressure Profile Blend = 0.05
            Relative Pressure = 2.6389 [MPa]
        END
        PRESSURE AVERAGING:
            Option = Average Over Whole Outlet
        END
    END
END
BOUNDARY: Wall
    Boundary Type = WALL
    Location = Wall
    BOUNDARY CONDITIONS:
        HEAT TRANSFER:
            Option = Adiabatic
        END
        MASS AND MOMENTUM:
            Option = No Slip Wall
        END
        WALL CONTACT MODEL:
            Option = Use Volume Fraction
        END
        WALL ROUGHNESS:
            Option = Smooth Wall
        END
    END
END
DOMAIN MODELS:
    BUOYANCY MODEL:
        Buoyancy Reference Density = 0 [kg m-3]
        Gravity X Component = 0 [m s-2]

```

```

Gravity Y Component = -9.81 [m s^-2]
Gravity Z Component = 0 [m s^-2]
Option = Buoyant
BUOYANCY REFERENCE LOCATION:
    Option = Automatic
END
END
DOMAIN MOTION:
    Option = Stationary
END
MESH DEFORMATION:
    Option = None
END
REFERENCE PRESSURE:
    Reference Pressure = 0 [MPa]
END
END
FLUID DEFINITION: Liquid
    Material = LiquidConst
    Option = Material Library
MORPHOLOGY:
    Mean Diameter = 1 [micron]
    Minimum Volume Fraction = 1e-9
    Option = Dispersed Fluid
END
END
FLUID DEFINITION: Vapor
    Material = VaporConst
    Option = Material Library
MORPHOLOGY:
    Minimum Volume Fraction = 1e-9
    Option = Continuous Fluid
END
END
FLUID MODELS:
    ADDITIONAL VARIABLE: MassTotal
        Option = Fluid Dependent
    END
    COMBUSTION MODEL:
        Option = None
    END
    FLUID: Liquid
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
                *Volume Fraction
            Option = Algebraic Equation
        END
        FLUID BUOYANCY MODEL:
            Option = Density Difference
        END
        HEAT TRANSFER MODEL:
            Option = Thermal Energy
        END
        TURBULENCE MODEL:
            Option = Laminar
        END
    END
    FLUID: Vapor
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
                *Volume Fraction
            Option = Algebraic Equation

```

```

END
FLUID BUOYANCY MODEL:
    Option = Density Difference
END
HEAT TRANSFER MODEL:
    Option = Thermal Energy
END
TURBULENCE MODEL:
    Option = k epsilon
    BUOYANCY TURBULENCE:
        Option = None
    END
END
TURBULENT WALL FUNCTIONS:
    Option = Scalable
END
END
HEAT TRANSFER MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
    Option = None
END
TURBULENCE MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
END
FLUID PAIR: Liquid | Vapor
Surface Tension Coefficient = 0.013472 [N m-1]
INTERPHASE HEAT TRANSFER:
    Option = Two Resistance
    FLUID1 INTERPHASE HEAT TRANSFER:
        Option = Zero Resistance
    END
    FLUID2 INTERPHASE HEAT TRANSFER:
        Option = Ranz Marshall
    END
END
INTERPHASE TRANSFER MODEL:
    Option = Particle Model
END
MASS TRANSFER:
    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None

```

```

    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
MULTIPHASE MODELS:
    Homogeneous Model = False
    FREE SURFACE MODEL:
        Option = None
    END
END
OUTPUT CONTROL:
    BACKUP DATA RETENTION:
        Option = Delete Old Files
    END
    BACKUP RESULTS: Backup Results 1
        File Compression Level = Default
        Option = Standard
        Output Equation Residuals = All
    OUTPUT FREQUENCY:
        Iteration Interval = 200
        Option = Iteration Interval
    END
END
MONITOR OBJECTS:
    MONITOR BALANCES:
        Option = Full
    END
    MONITOR FORCES:
        Option = Full
    END
    MONITOR PARTICLES:
        Option = Full
    END
    MONITOR POINT: CourantAveMon
        Coord Frame = Coord 0
        Expression Value = CourantAve
        Option = Expression
    END
    MONITOR POINT: CourantMaxMon
        Coord Frame = Coord 0
        Expression Value = CourantMax
        Option = Expression
    END
    MONITOR POINT: CourantRMSMon
        Coord Frame = Coord 0
        Expression Value = CourantRMS
        Option = Expression
    END
    MONITOR POINT: Inlet Pressure
        Coord Frame = Coord 0
        Expression Value = areaAve(Pressure)@Inlet
        Option = Expression
    END
    MONITOR POINT: Inlet Quality

```

```

    Coord Frame = Coord 0
    Expression Value = QualityInlet
    Option = Expression
END
MONITOR POINT: Liquid Inlet Velocity
    Coord Frame = Coord 0
    Expression Value = LiquidVelInlet
    Option = Expression
END
MONITOR POINT: Liquid Mass
    Coord Frame = Coord 0
    Expression Value = SumLiqMassTotal
    Option = Expression
END
MONITOR POINT: Liquid Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = LiquidVelOutlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate In
    Coord Frame = Coord 0
    Expression Value = MassFlowInlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate Out
    Coord Frame = Coord 0
    Expression Value = MassFlowOutlet
    Option = Expression
END
MONITOR POINT: Outlet Pressure
    Coord Frame = Coord 0
    Expression Value = areaAve(Pressure)@Outlet
    Option = Expression
END
MONITOR POINT: Outlet Quality
    Coord Frame = Coord 0
    Expression Value = QualityOutlet
    Option = Expression
END
MONITOR POINT: Outlet Temperature
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Saturation Temp
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Liquid | Vapor.Saturation \
    Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Vapor Inlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelInlet
    Option = Expression
END
MONITOR POINT: Vapor Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelOutlet
    Option = Expression
END
MONITOR RESIDUALS:
    Option = Full

```

```

    END
    MONITOR TOTALS:
        Option = Full
    END
END
RESULTS:
    File Compression Level = Default
    Option = Standard
    Output Equation Residuals = All
END
END
SOLVER CONTROL:
    Turbulence Numerics = High Resolution
ADVECTION SCHEME:
    Option = High Resolution
END
CONVERGENCE CONTROL:
    Length Scale Option = Conservative
    Maximum Number of Iterations = 4327
    Minimum Number of Iterations = 1
    Timescale Control = Auto Timescale
    Timescale Factor = 0.2
END
CONVERGENCE CRITERIA:
    Residual Target = 1e-15
    Residual Type = RMS
END
DYNAMIC MODEL CONTROL:
    Global Dynamic Model Control = On
END
INTERRUPT CONTROL:
    Option = Any Interrupt
CONVERGENCE CONDITIONS:
    Option = Default Conditions
END
END
END
COMMAND FILE:
    Version = 22.1
END

```

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## APPENDIX D. CCL FOR CASE STUDY STEADY-STATE

The following is a CCL file that describes the boundary conditions and expressions used for the case study, steady-state analysis. This file is exported from CFX-Pre.

LIBRARY:

CEL:

EXPRESSIONS:

```
CourantAve = ave(Courant Number )@Default Domain Modified
CourantMax = maxVal(Courant Number )@Default Domain Modified
CourantRMS = rmsAve(Courant Number )@Default Domain Modified
LiquidVFinlet = 1-VaporVFinlet
LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
MassFlowInlet = massFlow()@Inlet
MassFlowOutlet = -massFlow()@Outlet
Press = 2.6389[MPa]
QualityEquilInlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
   t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityEquilOutlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
   t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityInlet = \
  Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
QualityOutlet = \
  Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
   let)
SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain Modified
Tsat = \
  1[K]*(0.5*(650.17534844798+((2*((-724213.16703206*((Press/1[MPa])^0.25\
   )^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))/(-(11\
   67.0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa]\
   )^0.25))-4823.2657361591)-(((1167.0521452767*((Press/1[MPa])^0.25)^2)+\
   (12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)^2-(4*((Press\
   /1[MPa])^0.25)^2+(-17.073846940092*((Press/1[MPa])^0.25))+14.915108613\
   530)*((-724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((P\
   ress/1[MPa])^0.25))+405113.40542057)))^0.5)-((650.17534844798+((2*((-\
   724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[M\
   Pa])^0.25))+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25\
   )^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-(((1167.\
   0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0\
   .25))-4823.2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092\
   *((Press/1[MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[\
   MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.4054205\
   7)))^0.5)))^2-4*(-0.23855557567849+(650.17534844798*((2*((-724213.1670\
   3206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))\
   +405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25)^2)+(12020\
   .824702470*((Press/1[MPa])^0.25))-4823.2657361591)-(((1167.0521452767\
   *((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.\
   2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[\
   MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[MPa])^0.25)\
   ^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))^0.5)))\
   )^0.5))
VaporVFinlet = if(Accumulated Iteration Number <= 100, \
  .9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
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    VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
    WallHeatFlux = if(Accumulated Iteration Number <=250, \
        0[W/m^2]-(Accumulated Iteration Number*123.6)[W/m^2], -30900[W/m^2])
    WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
        Iteration Number*0.008)[K], 498[K])
END
END
ADDITIONAL VARIABLE: MassTotal
    Option = Definition
    Tensor Type = SCALAR
    Units = [kg]
    Variable Type = Specific
END
MATERIAL GROUP: Air Data
    Group Description = Ideal gas and constant property air. Constant \
        properties are for dry air at STP (0 C, 1 atm) and 25 C, 1 atm.
END
MATERIAL GROUP: CHT Solids
    Group Description = Pure solid substances that can be used for conjugate \
        heat transfer.
END
MATERIAL GROUP: Calorically Perfect Ideal Gases
    Group Description = Ideal gases with constant specific heat capacity. \
        Specific heat is evaluated at STP.
END
MATERIAL GROUP: Constant Property Gases
    Group Description = Gaseous substances with constant properties. \
        Properties are calculated at STP (0C and 1 atm). Can be combined with \
        NASA SP-273 materials for combustion modelling.
END
MATERIAL GROUP: Constant Property Liquids
    Group Description = Liquid substances with constant properties.
END
MATERIAL GROUP: Dry Peng Robinson
    Group Description = Materials with properties specified using the built \
        in Peng Robinson equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Redlich Kwong equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Soave Redlich Kwong equation of state. Suitable for dry real gas \
        modelling.
END
MATERIAL GROUP: Dry Steam
    Group Description = Materials with properties specified using the IAPWS \
        equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Gas Phase Combustion
    Group Description = Ideal gas materials which can be use for gas phase \
        combustion. Ideal gas specific heat coefficients are specified using \
        the NASA SP-273 format.
END
MATERIAL GROUP: IAPWS IF97
    Group Description = Liquid, vapour and binary mixture materials which use \
        the IAPWS IF-97 equation of state. Materials are suitable for \
        compressible liquids, phase change calculations and dry steam flows.
END
MATERIAL GROUP: Interphase Mass Transfer
    Group Description = Materials with reference properties suitable for \

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    performing either Eulerian or Lagrangian multiphase mass transfer \
    problems. Examples include cavitation, evaporation or condensation.
END
MATERIAL GROUP: Liquid Phase Combustion
    Group Description = Liquid and homogenous binary mixture materials which \
    can be included with Gas Phase Combustion materials if combustion \
    modelling also requires phase change (eg: evaporation) for certain \
    components.
END
MATERIAL GROUP: Particle Solids
    Group Description = Pure solid substances that can be used for particle \
    tracking
END
MATERIAL GROUP: Peng Robinson Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Peng Robinson Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Real Gas Combustion
    Group Description = Real gas materials which can be use for gas phase \
    combustion. Ideal gas specific heat coefficients are specified using \
    the NASA SP-273 format.
END
MATERIAL GROUP: Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Steam
    Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END

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MATERIAL GROUP: Redlich Kwong Wet Steam
  Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Hydrocarbons
  Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Refrigerants
  Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Steam
  Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Hydrocarbons
  Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Refrigerants
  Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Steam
  Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soot
  Group Description = Solid substances that can be used when performing \
    soot modelling
END
MATERIAL GROUP: User
  Group Description = Materials that are defined by the user
END
MATERIAL GROUP: Water Data
  Group Description = Liquid and vapour water materials with constant \
    properties. Can be combined with NASA SP-273 materials for combustion \
    modelling.
END
MATERIAL GROUP: Wet Peng Robinson
  Group Description = Materials with properties specified using the built \
    in Peng Robinson equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Redlich Kwong
  Group Description = Materials with properties specified using the built \
    in Redlich Kwong equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Soave Redlich Kwong
  Group Description = Materials with properties specified using the built \
    in Soave Redlich Kwong equation of state. Suitable for wet real gas \
    modelling.
END
MATERIAL GROUP: Wet Steam
  Group Description = Materials with properties specified using the IAPWS \
    equation of state. Suitable for wet steam modelling.
END
MATERIAL: Air Ideal Gas
  Material Description = Air Ideal Gas (constant Cp)
  Material Group = Air Data, Calorically Perfect Ideal Gases
  Option = Pure Substance
  Thermodynamic State = Gas

```

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PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Molar Mass = 28.96 [kg kmol^-1]
  Option = Ideal Gas
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 1.0044E+03 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1 [atm]
  Reference Specific Enthalpy = 0. [J/kg]
  Reference Specific Entropy = 0. [J/kg/K]
  Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 2.61E-2 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
  Absorption Coefficient = 0.01 [m^-1]
  Option = Value
END
SCATTERING COEFFICIENT:
  Option = Value
  Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
  Option = Value
  Refractive Index = 1.0 [m m^-1]
END
END
MATERIAL: Air at 25 C
  Material Description = Air at 25 C and 1 atm (dry)
  Material Group = Air Data, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Density = 1.185 [kg m^-3]
  Molar Mass = 28.96 [kg kmol^-1]
  Option = Value
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 1.0044E+03 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1 [atm]
  Reference Specific Enthalpy = 0. [J/kg]
  Reference Specific Entropy = 0. [J/kg/K]

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```

    Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 2.61E-02 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0.01 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 0.003356 [K^-1]
END
END
MATERIAL: Aluminium
    Material Group = CHT Solids, Particle Solids
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:
            Density = 2702 [kg m^-3]
            Molar Mass = 26.98 [kg kmol^-1]
            Option = Value
        END
        SPECIFIC HEAT CAPACITY:
            Option = Value
            Specific Heat Capacity = 9.03E+02 [J kg^-1 K^-1]
        END
        REFERENCE STATE:
            Option = Specified Point
            Reference Specific Enthalpy = 0 [J/kg]
            Reference Specific Entropy = 0 [J/kg/K]
            Reference Temperature = 25 [C]
        END
        THERMAL CONDUCTIVITY:
            Option = Value
            Thermal Conductivity = 237 [W m^-1 K^-1]
        END
    END
END
MATERIAL: Copper
    Material Group = CHT Solids, Particle Solids
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:

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    Density = 8933 [kg m^-3]
    Molar Mass = 63.55 [kg kmol^-1]
    Option = Value
END
SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 3.85E+02 [J kg^-1 K^-1]
END
REFERENCE STATE:
    Option = Specified Point
    Reference Specific Enthalpy = 0 [J/kg]
    Reference Specific Entropy = 0 [J/kg/K]
    Reference Temperature = 25 [C]
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 401.0 [W m^-1 K^-1]
END
END
MATERIAL: LiquidConst
    Material Group = Constant Property Liquids,Wet Steam
    Option = Pure Substance
    Thermodynamic State = Liquid
    PROPERTIES:
        Option = General Material
    EQUATION OF STATE:
        Density = 831.318 [kg m^-3]
        Molar Mass = 18.02 [kg kmol^-1]
        Option = Value
    END
    SPECIFIC HEAT CAPACITY:
        Option = Value
        Specific Heat Capacity = 4659 [J kg^-1 K^-1]
        Specific Heat Type = Constant Pressure
    END
    REFERENCE STATE:
        Option = Specified Point
        Reference Pressure = 2.6389 [MPa]
        Reference Specific Enthalpy = 975465 [J kg^-1]
        Reference Specific Entropy = 2581.1 [J kg^-1 K^-1]
        Reference Temperature = 500 [K]
    END
    DYNAMIC VISCOSITY:
        Dynamic Viscosity = 0.0001179 [Pa s]
        Option = Value
    END
    THERMAL CONDUCTIVITY:
        Option = Value
        Thermal Conductivity = 0.6421 [W m^-1 K^-1]
    END
END
MATERIAL: LiquidVar
    Material Group = IAPWS IF97,Wet Steam
    Option = Pure Substance
    Thermodynamic State = Liquid
    PROPERTIES:
        Option = IAPWS Library
    REFERENCE STATE:
        Option = Automatic
    END

```

```

TABLE GENERATION:
  Maximum Absolute Pressure = 12.345 [MPa]
  Maximum Points = 100
  Maximum Temperature = 600 [K]
  Minimum Absolute Pressure = 0.0035368 [MPa]
  Minimum Temperature = 300 [K]
  Pressure Extrapolation = On
  Temperature Extrapolation = Yes
END
END
END
MATERIAL: Soot
  Material Group = Soot
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 2000 [kg m-3]
      Molar Mass = 12 [kg kmol-1]
      Option = Value
    END
    REFERENCE STATE:
      Option = Automatic
    END
    ABSORPTION COEFFICIENT:
      Absorption Coefficient = 0 [m-1]
      Option = Value
    END
  END
END
MATERIAL: Steel
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 7854 [kg m-3]
      Molar Mass = 55.85 [kg kmol-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 4.34E+02 [J kg-1 K-1]
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Specific Enthalpy = 0 [J/kg]
      Reference Specific Entropy = 0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 60.5 [W m-1 K-1]
    END
  END
END
MATERIAL: VaporConst
  Material Group = Wet Steam, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas

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```

PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Density = 13.1976 [kg m^-3]
  Molar Mass = 18.02 [kg kmol^-1]
  Option = Value
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 3462.6 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 2.6389 [MPa]
  Reference Specific Enthalpy = 2802590 [J kg^-1]
  Reference Specific Entropy = 6235.4 [J kg^-1 K^-1]
  Reference Temperature = 500 [K]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 1.6594e-5 [Pa s]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 0.044952 [W m^-1 K^-1]
END
THERMAL EXPANSIVITY:
  Option = Value
  Thermal Expansivity = 0.001686 [K^-1]
END
END
MATERIAL: VaporVar
  Material Group = IAPWS IF97,Wet Steam
  Option = Pure Substance
  Thermodynamic State = Gas
PROPERTIES:
  Option = IAPWS Library
REFERENCE STATE:
  Option = Automatic
END
TABLE GENERATION:
  Maximum Absolute Pressure = 12.345 [MPa]
  Maximum Points = 1000
  Maximum Temperature = 600 [K]
  Minimum Absolute Pressure = 0.0035368 [MPa]
  Minimum Temperature = 300 [K]
  Pressure Extrapolation = On
  Temperature Extrapolation = Yes
END
END
MATERIAL: Water
  Material Description = Water (liquid)
  Material Group = Water Data, Constant Property Liquids
  Option = Pure Substance
  Thermodynamic State = Liquid
PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Density = 997.0 [kg m^-3]

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    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
END
SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 4181.7 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0.0 [J/kg]
    Reference Specific Entropy = 0.0 [J/kg/K]
    Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 8.899E-4 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.6069 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 2.57E-04 [K^-1]
END
END
END
MATERIAL: Water Ideal Gas
    Material Description = Water Vapour Ideal Gas (100 C and 1 atm)
    Material Group = Calorically Perfect Ideal Gases, Water Data
    Option = Pure Substance
    Thermodynamic State = Gas
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:
            Molar Mass = 18.02 [kg kmol^-1]
            Option = Ideal Gas
        END
        SPECIFIC HEAT CAPACITY:
            Option = Value
            Specific Heat Capacity = 2080.1 [J kg^-1 K^-1]
            Specific Heat Type = Constant Pressure
        END
        REFERENCE STATE:
            Option = Specified Point
            Reference Pressure = 1.014 [bar]
            Reference Specific Enthalpy = 0. [J/kg]
            Reference Specific Entropy = 0. [J/kg/K]

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    Reference Temperature = 100 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 9.4E-06 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 193E-04 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
END
END
FLOW: Flow Analysis 1
    SOLUTION UNITS:
        Angle Units = [rad]
        Length Units = [m]
        Mass Units = [kg]
        Solid Angle Units = [sr]
        Temperature Units = [K]
        Time Units = [s]
    END
    ANALYSIS TYPE:
        Option = Steady State
    EXTERNAL SOLVER COUPLING:
        Option = None
    END
END
DOMAIN: Default Domain Modified
    Coord Frame = Coord 0
    Domain Type = Fluid
    Location = B4
    BOUNDARY MODELS:
        WALL BOILING MODEL:
            Option = None
        END
    END
    BOUNDARY: Inlet
        Boundary Type = INLET
        Location = Inlet
    BOUNDARY CONDITIONS:
        FLOW REGIME:
            Option = Subsonic
        END
        HEAT TRANSFER:
            Option = Static Temperature
            Static Temperature = 500 [K]
        END
        MASS AND MOMENTUM:
            Normal Speed = 40 [m s^-1]

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    Option = Normal Speed
END
TURBULENCE:
    Option = Medium Intensity and Eddy Viscosity Ratio
END
END
FLUID: Liquid
    BOUNDARY CONDITIONS:
        VOLUME FRACTION:
            Option = Value
            Volume Fraction = 0.0001
        END
    END
END
FLUID: Vapor
    BOUNDARY CONDITIONS:
        VOLUME FRACTION:
            Option = Value
            Volume Fraction = 0.9999
        END
    END
END
BOUNDARY: Outlet
    Boundary Type = OUTLET
    Location = Outlet
    BOUNDARY CONDITIONS:
        FLOW REGIME:
            Option = Subsonic
        END
        MASS AND MOMENTUM:
            Option = Average Static Pressure
            Pressure Profile Blend = 0.05
            Relative Pressure = 2.6389 [MPa]
        END
        PRESSURE AVERAGING:
            Option = Average Over Whole Outlet
        END
    END
END
BOUNDARY: Wall
    Boundary Type = WALL
    Location = Wall
    BOUNDARY CONDITIONS:
        HEAT TRANSFER:
            Option = Adiabatic
        END
        MASS AND MOMENTUM:
            Option = No Slip Wall
        END
        WALL CONTACT MODEL:
            Option = Use Volume Fraction
        END
        WALL ROUGHNESS:
            Option = Smooth Wall
        END
    END
END
DOMAIN MODELS:
    BUOYANCY MODEL:
        Buoyancy Reference Density = 0 [kg m-3]
        Gravity X Component = 0 [m s-2]

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Gravity Y Component = -9.81 [m s^-2]
Gravity Z Component = 0 [m s^-2]
Option = Buoyant
BUOYANCY REFERENCE LOCATION:
    Option = Automatic
END
END
DOMAIN MOTION:
    Option = Stationary
END
MESH DEFORMATION:
    Option = None
END
REFERENCE PRESSURE:
    Reference Pressure = 0 [MPa]
END
END
FLUID DEFINITION: Liquid
    Material = LiquidConst
    Option = Material Library
MORPHOLOGY:
    Mean Diameter = 1 [micron]
    Minimum Volume Fraction = 1e-9
    Option = Dispersed Fluid
END
END
FLUID DEFINITION: Vapor
    Material = VaporConst
    Option = Material Library
MORPHOLOGY:
    Minimum Volume Fraction = 1e-9
    Option = Continuous Fluid
END
END
FLUID MODELS:
    ADDITIONAL VARIABLE: MassTotal
        Option = Fluid Dependent
    END
    COMBUSTION MODEL:
        Option = None
    END
    FLUID: Liquid
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation
        END
        FLUID BUOYANCY MODEL:
            Option = Density Difference
        END
        HEAT TRANSFER MODEL:
            Option = Thermal Energy
        END
        TURBULENCE MODEL:
            Option = Laminar
        END
    END
    FLUID: Vapor
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation

```

```

END
FLUID BUOYANCY MODEL:
    Option = Density Difference
END
HEAT TRANSFER MODEL:
    Option = Thermal Energy
END
TURBULENCE MODEL:
    Option = k epsilon
    BUOYANCY TURBULENCE:
        Option = None
    END
END
TURBULENT WALL FUNCTIONS:
    Option = Scalable
END
END
HEAT TRANSFER MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
    Option = None
END
TURBULENCE MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
END
FLUID PAIR: Liquid | Vapor
Surface Tension Coefficient = 0.013472 [N m-1]
INTERPHASE HEAT TRANSFER:
    Option = Two Resistance
    FLUID1 INTERPHASE HEAT TRANSFER:
        Option = Zero Resistance
    END
    FLUID2 INTERPHASE HEAT TRANSFER:
        Option = Ranz Marshall
    END
END
INTERPHASE TRANSFER MODEL:
    Option = Particle Model
END
MASS TRANSFER:
    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None

```

```

    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
MULTIPHASE MODELS:
    Homogeneous Model = False
    FREE SURFACE MODEL:
        Option = None
    END
END
OUTPUT CONTROL:
    BACKUP DATA RETENTION:
        Option = Delete Old Files
    END
    BACKUP RESULTS: Backup Results 1
        File Compression Level = Default
        Option = Standard
        Output Equation Residuals = All
    OUTPUT FREQUENCY:
        Iteration Interval = 200
        Option = Iteration Interval
    END
END
MONITOR OBJECTS:
    MONITOR BALANCES:
        Option = Full
    END
    MONITOR FORCES:
        Option = Full
    END
    MONITOR PARTICLES:
        Option = Full
    END
    MONITOR POINT: CourantAveMon
        Coord Frame = Coord 0
        Expression Value = CourantAve
        Option = Expression
    END
    MONITOR POINT: CourantMaxMon
        Coord Frame = Coord 0
        Expression Value = CourantMax
        Option = Expression
    END
    MONITOR POINT: CourantRMSMon
        Coord Frame = Coord 0
        Expression Value = CourantRMS
        Option = Expression
    END
    MONITOR POINT: Inlet Pressure
        Coord Frame = Coord 0
        Expression Value = areaAve(Pressure)@Inlet
        Option = Expression
    END
    MONITOR POINT: Inlet Quality

```

```

    Coord Frame = Coord 0
    Expression Value = QualityInlet
    Option = Expression
END
MONITOR POINT: Liquid Inlet Velocity
    Coord Frame = Coord 0
    Expression Value = LiquidVelInlet
    Option = Expression
END
MONITOR POINT: Liquid Mass
    Coord Frame = Coord 0
    Expression Value = SumLiqMassTotal
    Option = Expression
END
MONITOR POINT: Liquid Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = LiquidVelOutlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate In
    Coord Frame = Coord 0
    Expression Value = MassFlowInlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate Out
    Coord Frame = Coord 0
    Expression Value = MassFlowOutlet
    Option = Expression
END
MONITOR POINT: Outlet Pressure
    Coord Frame = Coord 0
    Expression Value = areaAve(Pressure)@Outlet
    Option = Expression
END
MONITOR POINT: Outlet Quality
    Coord Frame = Coord 0
    Expression Value = QualityOutlet
    Option = Expression
END
MONITOR POINT: Outlet Temperature
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Saturation Temp
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Liquid | Vapor.Saturation \
    Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Vapor Inlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelInlet
    Option = Expression
END
MONITOR POINT: Vapor Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelOutlet
    Option = Expression
END
MONITOR RESIDUALS:
    Option = Full

```

```

    END
    MONITOR TOTALS:
        Option = Full
    END
END
RESULTS:
    File Compression Level = Default
    Option = Standard
    Output Equation Residuals = All
END
END
SOLVER CONTROL:
    Turbulence Numerics = High Resolution
ADVECTION SCHEME:
    Option = High Resolution
END
CONVERGENCE CONTROL:
    Length Scale Option = Conservative
    Maximum Number of Iterations = 4327
    Minimum Number of Iterations = 1
    Timescale Control = Auto Timescale
    Timescale Factor = 0.2
END
CONVERGENCE CRITERIA:
    Residual Target = 1e-15
    Residual Type = RMS
END
DYNAMIC MODEL CONTROL:
    Global Dynamic Model Control = On
END
INTERRUPT CONTROL:
    Option = Any Interrupt
CONVERGENCE CONDITIONS:
    Option = Default Conditions
END
END
END
COMMAND FILE:
    Version = 22.1
END

```

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## APPENDIX E. CCL FOR CASE STUDY TRANSIENT

The following is a CCL file that describes the boundary conditions and expressions used for the case study, transient analysis. This file is exported from CFX-Pre.

```
LIBRARY:
CEL:
  EXPRESSIONS:
    CourantAve = ave(Courant Number )@Default Domain
    CourantMax = maxVal(Courant Number )@Default Domain
    CourantRMS = rmsAve(Courant Number )@Default Domain
    HalfTime = 52[s]
    InletPsetting = if(Time < HalfTime, (OutletPsetting+dP) , \
      (OutletPsetting+dP) )
    LiquidVFinlet = 1-VaporVFinlet
    LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
    LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
    MassFlowInlet = massFlow()@Inlet
    MassFlowOutlet = -massFlow()@Outlet
    OutletPsetting = if(Time<105 [s], 1.6915[MPa], if(Time<1 [s], 1.6915 \
      [MPa], if(Time<53 [s], (-0.01291*(Time/ 1[s])+3.046606) [MPa], \
      (0.012906*(Time/1[s])+1.678594) [MPa])))
    QualityEquilInlet = \
      ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
      t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
    QualityEquilOutlet = \
      ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
      t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
    QualityInlet = \
      Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
    QualityOutlet = \
      Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
      let)
    SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain
    Tsat = ((2.602*10E-5 [K/MPa])*OutletPsetting)+433.07957 [K]
    VaporVFinlet = if(Accumulated Iteration Number <= 100, \
      .9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
    VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
    VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
    WallHeatFlux = if(Accumulated Iteration Number <=250, \
      0[W/m^2]-(Accumulated Iteration Number*123.6) [W/m^2], -30900[W/m^2])
    WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
      Iteration Number*0.008) [K], 498[K])
    dP = (1/8)*if(Time<13.55 [s], (0*(Time/1[s])+6.33188) [MPa], \
      if(Time<14.55[s], (-2.20829*(Time/1[s])+36.25421) [MPa], \
      if(Time<47.3129[s], (0*(Time/1[s])+4.12359) [MPa], if(Time<61.669[s], \
      (0.994282*(Time/1[s])-42.9188) [MPa], if(Time<91.38[s], \
      (-0.39858*(Time/1[s])+42.97755) [MPa], 6.55543[MPa] )))))
  END
END
ADDITIONAL VARIABLE: MassTotal
  Option = Definition
  Tensor Type = SCALAR
  Units = [kg]
  Variable Type = Specific
END
MATERIAL GROUP: Air Data
```

```

    Group Description = Ideal gas and constant property air. Constant \
    properties are for dry air at STP (0 C, 1 atm) and 25 C, 1 atm.
END
MATERIAL GROUP: CHT Solids
    Group Description = Pure solid substances that can be used for conjugate \
    heat transfer.
END
MATERIAL GROUP: Calorically Perfect Ideal Gases
    Group Description = Ideal gases with constant specific heat capacity. \
    Specific heat is evaluated at STP.
END
MATERIAL GROUP: Constant Property Gases
    Group Description = Gaseous substances with constant properties. \
    Properties are calculated at STP (0C and 1 atm). Can be combined with \
    NASA SP-273 materials for combustion modelling.
END
MATERIAL GROUP: Constant Property Liquids
    Group Description = Liquid substances with constant properties.
END
MATERIAL GROUP: Dry Peng Robinson
    Group Description = Materials with properties specified using the built \
    in Peng Robinson equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Redlich Kwong equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Soave Redlich Kwong equation of state. Suitable for dry real gas \
    modelling.
END
MATERIAL GROUP: Dry Steam
    Group Description = Materials with properties specified using the IAPWS \
    equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Gas Phase Combustion
    Group Description = Ideal gas materials which can be use for gas phase \
    combustion. Ideal gas specific heat coefficients are specified using \
    the NASA SP-273 format.
END
MATERIAL GROUP: IAPWS IF97
    Group Description = Liquid, vapour and binary mixture materials which use \
    the IAPWS IF-97 equation of state. Materials are suitable for \
    compressible liquids, phase change calculations and dry steam flows.
END
MATERIAL GROUP: Interphase Mass Transfer
    Group Description = Materials with reference properties suitable for \
    performing either Eulerian or Lagrangian multiphase mass transfer \
    problems. Examples include cavitation, evaporation or condensation.
END
MATERIAL GROUP: Liquid Phase Combustion
    Group Description = Liquid and homogenous binary mixture materials which \
    can be included with Gas Phase Combustion materials if combustion \
    modelling also requires phase change (eg: evaporation) for certain \
    components.
END
MATERIAL GROUP: Particle Solids
    Group Description = Pure solid substances that can be used for particle \
    tracking
END
MATERIAL GROUP: Peng Robinson Dry Hydrocarbons

```

```

    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Peng Robinson Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Real Gas Combustion
    Group Description = Real gas materials which can be use for gas phase \
    combustion. Ideal gas specific heat coefficients are specified using \
    the NASA SP-273 format.
END
MATERIAL GROUP: Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Steam
    Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Steam
    Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Steam
    Group Description = Water materials which use the Soave Redlich Kwong \

```

```

equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Hydrocarbons
  Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Refrigerants
  Group Description = Common refrigerants which use the Soave Redlich Kwong \
equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Steam
  Group Description = Water materials which use the Soave Redlich Kwong \
equation of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soot
  Group Description = Solid substances that can be used when performing \
soot modelling
END
MATERIAL GROUP: User
  Group Description = Materials that are defined by the user
END
MATERIAL GROUP: Water Data
  Group Description = Liquid and vapour water materials with constant \
properties. Can be combined with NASA SP-273 materials for combustion \
modelling.
END
MATERIAL GROUP: Wet Peng Robinson
  Group Description = Materials with properties specified using the built \
in Peng Robinson equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Redlich Kwong
  Group Description = Materials with properties specified using the built \
in Redlich Kwong equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Soave Redlich Kwong
  Group Description = Materials with properties specified using the built \
in Soave Redlich Kwong equation of state. Suitable for wet real gas \
modelling.
END
MATERIAL GROUP: Wet Steam
  Group Description = Materials with properties specified using the IAPWS \
equation of state. Suitable for wet steam modelling.
END
MATERIAL: Air Ideal Gas
  Material Description = Air Ideal Gas (constant Cp)
  Material Group = Air Data, Calorically Perfect Ideal Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
  EQUATION OF STATE:
    Molar Mass = 28.96 [kg kmol^-1]
    Option = Ideal Gas
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 1.0044E+03 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]

```

```

Reference Specific Enthalpy = 0. [J/kg]
Reference Specific Entropy = 0. [J/kg/K]
Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 2.61E-2 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
Absorption Coefficient = 0.01 [m^-1]
Option = Value
END
SCATTERING COEFFICIENT:
Option = Value
Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
Option = Value
Refractive Index = 1.0 [m m^-1]
END
END
MATERIAL: Air at 25 C
Material Description = Air at 25 C and 1 atm (dry)
Material Group = Air Data, Constant Property Gases
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 1.185 [kg m^-3]
Molar Mass = 28.96 [kg kmol^-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 1.0044E+03 [J kg^-1 K^-1]
Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
Option = Specified Point
Reference Pressure = 1 [atm]
Reference Specific Enthalpy = 0. [J/kg]
Reference Specific Entropy = 0. [J/kg/K]
Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 2.61E-02 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
Absorption Coefficient = 0.01 [m^-1]
Option = Value
END

```

```

SCATTERING COEFFICIENT:
  Option = Value
  Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
  Option = Value
  Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
  Option = Value
  Thermal Expansivity = 0.003356 [K^-1]
END
END
MATERIAL: Aluminium
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 2702 [kg m^-3]
      Molar Mass = 26.98 [kg kmol^-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 9.03E+02 [J kg^-1 K^-1]
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Specific Enthalpy = 0 [J/kg]
      Reference Specific Entropy = 0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 237 [W m^-1 K^-1]
    END
  END
END
MATERIAL: Copper
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 8933 [kg m^-3]
      Molar Mass = 63.55 [kg kmol^-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 3.85E+02 [J kg^-1 K^-1]
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Specific Enthalpy = 0 [J/kg]
      Reference Specific Entropy = 0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
  END

```

```

THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 401.0 [W m^-1 K^-1]
END
END
MATERIAL: LiquidConst
  Material Group = Constant Property Liquids,Wet Steam
  Option = Pure Substance
  Thermodynamic State = Liquid
  PROPERTIES:
    Option = General Material
  EQUATION OF STATE:
    Density = 831.318 [kg m^-3]
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 4659 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 2.6389 [MPa]
    Reference Specific Enthalpy = 975465 [J kg^-1]
    Reference Specific Entropy = 2581.1 [J kg^-1 K^-1]
    Reference Temperature = 500 [K]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 0.0001179 [Pa s]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.6421 [W m^-1 K^-1]
  END
END
MATERIAL: LiquidVar
  Material Group = IAPWS IF97,Wet Steam
  Option = Pure Substance
  Thermodynamic State = Liquid
  PROPERTIES:
    Option = IAPWS Library
  REFERENCE STATE:
    Option = Automatic
  END
  TABLE GENERATION:
    Maximum Absolute Pressure = 12.345 [MPa]
    Maximum Points = 100
    Maximum Temperature = 600 [K]
    Minimum Absolute Pressure = 0.0035368 [MPa]
    Minimum Temperature = 300 [K]
    Pressure Extrapolation = On
    Temperature Extrapolation = Yes
  END
END
MATERIAL: Soot
  Material Group = Soot
  Option = Pure Substance

```

```

Thermodynamic State = Solid
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Density = 2000 [kg m^-3]
    Molar Mass = 12 [kg kmol^-1]
    Option = Value
  END
  REFERENCE STATE:
    Option = Automatic
  END
  ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0 [m^-1]
    Option = Value
  END
END
MATERIAL: Steel
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 7854 [kg m^-3]
      Molar Mass = 55.85 [kg kmol^-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 4.34E+02 [J kg^-1 K^-1]
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Specific Enthalpy = 0 [J/kg]
      Reference Specific Entropy = 0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 60.5 [W m^-1 K^-1]
    END
  END
MATERIAL: VaporConst
  Material Group = Wet Steam, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 13.1976 [kg m^-3]
      Molar Mass = 18.02 [kg kmol^-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 3462.6 [J kg^-1 K^-1]
      Specific Heat Type = Constant Pressure
    END
    REFERENCE STATE:
      Option = Specified Point

```

```

Reference Pressure = 2.6389 [MPa]
Reference Specific Enthalpy = 2802590 [J kg-1]
Reference Specific Entropy = 6235.4 [J kg-1 K-1]
Reference Temperature = 500 [K]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 1.6594e-5 [Pa s]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 0.044952 [W m-1 K-1]
END
THERMAL EXPANSIVITY:
Option = Value
Thermal Expansivity = 0.001686 [K-1]
END
END
MATERIAL: VaporVar
Material Group = IAPWS IF97,Wet Steam
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
Option = IAPWS Library
REFERENCE STATE:
Option = Automatic
END
TABLE GENERATION:
Maximum Absolute Pressure = 12.345 [MPa]
Maximum Points = 1000
Maximum Temperature = 600 [K]
Minimum Absolute Pressure = 0.0035368 [MPa]
Minimum Temperature = 300 [K]
Pressure Extrapolation = On
Temperature Extrapolation = Yes
END
END
MATERIAL: Water
Material Description = Water (liquid)
Material Group = Water Data, Constant Property Liquids
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 997.0 [kg m-3]
Molar Mass = 18.02 [kg kmol-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 4181.7 [J kg-1 K-1]
Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
Option = Specified Point
Reference Pressure = 1 [atm]
Reference Specific Enthalpy = 0.0 [J/kg]
Reference Specific Entropy = 0.0 [J/kg/K]
Reference Temperature = 25 [C]

```

```

END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 8.899E-4 [kg m^-1 s^-1]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 0.6069 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
  Absorption Coefficient = 1.0 [m^-1]
  Option = Value
END
SCATTERING COEFFICIENT:
  Option = Value
  Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
  Option = Value
  Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
  Option = Value
  Thermal Expansivity = 2.57E-04 [K^-1]
END
END
MATERIAL: Water Ideal Gas
  Material Description = Water Vapour Ideal Gas (100 C and 1 atm)
  Material Group = Calorically Perfect Ideal Gases, Water Data
  Option = Pure Substance
  Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
EQUATION OF STATE:
  Molar Mass = 18.02 [kg kmol^-1]
  Option = Ideal Gas
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 2080.1 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1.014 [bar]
  Reference Specific Enthalpy = 0. [J/kg]
  Reference Specific Entropy = 0. [J/kg/K]
  Reference Temperature = 100 [C]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 9.4E-06 [kg m^-1 s^-1]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 193E-04 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
  Absorption Coefficient = 1.0 [m^-1]
  Option = Value
END

```

```

    SCATTERING COEFFICIENT:
      Option = Value
      Scattering Coefficient = 0.0 [m^-1]
    END
    REFRACTIVE INDEX:
      Option = Value
      Refractive Index = 1.0 [m m^-1]
    END
  END
END
FLOW: Flow Analysis 1
  SOLUTION UNITS:
    Angle Units = [rad]
    Length Units = [m]
    Mass Units = [kg]
    Solid Angle Units = [sr]
    Temperature Units = [K]
    Time Units = [s]
  END
  ANALYSIS TYPE:
    Option = Transient
  EXTERNAL SOLVER COUPLING:
    Option = None
  END
  INITIAL TIME:
    Option = Value
    Time = 0 [s]
  END
  TIME DURATION:
    Option = Total Time
    Total Time = 105 [s]
  END
  TIME STEPS:
    Option = Timesteps
    Timesteps = 0.001 [s]
  END
END
DOMAIN: Default Domain
  Coord Frame = Coord 0
  Domain Type = Fluid
  Location = B33
  BOUNDARY MODELS:
    WALL BOILING MODEL:
      Option = None
    END
  END
  BOUNDARY: Domain Interface 1 Side 1
    Boundary Type = INTERFACE
    Location = Interface
    BOUNDARY CONDITIONS:
      HEAT TRANSFER:
        Option = Conservative Interface Flux
      END
      MASS AND MOMENTUM:
        Option = Fluid Dependent
      END
      WALL CONTACT MODEL:
        Option = Use Volume Fraction
      END
      WALL ROUGHNESS:
        Option = Smooth Wall

```

```

    END
END
FLUID: Liquid
    BOUNDARY CONDITIONS:
        MASS AND MOMENTUM:
            Option = No Slip Wall
        END
    END
END
FLUID: Vapor
    BOUNDARY CONDITIONS:
        MASS AND MOMENTUM:
            Option = No Slip Wall
        END
    END
END
BOUNDARY: Inlet
    Boundary Type = INLET
    Location = Inlet
    BOUNDARY CONDITIONS:
        FLOW DIRECTION:
            Option = Zero Gradient
        END
        FLOW REGIME:
            Option = Subsonic
        END
        HEAT TRANSFER:
            Option = Static Temperature
            Static Temperature = 477.2207 [K]
        END
        MASS AND MOMENTUM:
            Option = Static Pressure
            Relative Pressure = InletPsetting
        END
        TURBULENCE:
            Option = Medium Intensity and Eddy Viscosity Ratio
        END
    END
FLUID: Liquid
    BOUNDARY CONDITIONS:
        VOLUME FRACTION:
            Option = Value
            Volume Fraction = 0.0001
        END
    END
FLUID: Vapor
    BOUNDARY CONDITIONS:
        VOLUME FRACTION:
            Option = Value
            Volume Fraction = 0.9999
        END
    END
END
BOUNDARY: Outlet
    Boundary Type = OUTLET
    Location = Outlet
    BOUNDARY CONDITIONS:
        FLOW REGIME:
            Option = Subsonic

```

```

END
MASS AND MOMENTUM:
    Option = Average Static Pressure
    Pressure Profile Blend = 0.05
    Relative Pressure = OutletPsetting
END
PRESSURE AVERAGING:
    Option = Average Over Whole Outlet
END
END
DOMAIN MODELS:
    BUOYANCY MODEL:
        Buoyancy Reference Density = 0 [kg m^-3]
        Gravity X Component = 0 [m s^-2]
        Gravity Y Component = -9.81 [m s^-2]
        Gravity Z Component = 0 [m s^-2]
        Option = Buoyant
    BUOYANCY REFERENCE LOCATION:
        Option = Automatic
    END
    END
    DOMAIN MOTION:
        Option = Stationary
    END
    MESH DEFORMATION:
        Option = None
    END
    REFERENCE PRESSURE:
        Reference Pressure = 0 [MPa]
    END
    END
    FLUID DEFINITION: Liquid
        Material = LiquidConst
        Option = Material Library
    MORPHOLOGY:
        Mean Diameter = 1 [micron]
        Minimum Volume Fraction = 1e-9
        Option = Dispersed Fluid
    END
    END
    FLUID DEFINITION: Vapor
        Material = VaporConst
        Option = Material Library
    MORPHOLOGY:
        Minimum Volume Fraction = 1e-9
        Option = Continuous Fluid
    END
    END
    FLUID MODELS:
        ADDITIONAL VARIABLE: MassTotal
            Option = Fluid Dependent
        END
        COMBUSTION MODEL:
            Option = None
        END
        FLUID: Liquid
            ADDITIONAL VARIABLE: MassTotal
                Additional Variable Value = Volume of Finite Volumes *Density \
                *Volume Fraction
            Option = Algebraic Equation
        END

```

```

FLUID BUOYANCY MODEL:
    Option = Density Difference
END
HEAT TRANSFER MODEL:
    Option = Thermal Energy
END
TURBULENCE MODEL:
    Option = Laminar
END
END
FLUID: Vapor
    ADDITIONAL VARIABLE: MassTotal
        Additional Variable Value = Volume of Finite Volumes *Density \
        *Volume Fraction
        Option = Algebraic Equation
    END
    FLUID BUOYANCY MODEL:
        Option = Density Difference
    END
    HEAT TRANSFER MODEL:
        Option = Thermal Energy
    END
    TURBULENCE MODEL:
        Option = k epsilon
        BUOYANCY TURBULENCE:
            Option = None
        END
    END
    TURBULENT WALL FUNCTIONS:
        Option = Scalable
    END
END
HEAT TRANSFER MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
    Option = None
END
TURBULENCE MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
END
FLUID PAIR: Liquid | Vapor
    Surface Tension Coefficient = 0.013472 [N m^-1]
    INTERPHASE HEAT TRANSFER:
        Option = Two Resistance
        FLUID1 INTERPHASE HEAT TRANSFER:
            Option = Zero Resistance
        END
        FLUID2 INTERPHASE HEAT TRANSFER:
            Option = Ranz Marshall
        END
    END
    INTERPHASE TRANSFER MODEL:
        Option = Particle Model
    END
    MASS TRANSFER:
        Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change

```

```

    Saturation Temperature = 477.2207 [K]
END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None
    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
INITIALISATION:
    Option = Automatic
    FLUID: Liquid
        INITIAL CONDITIONS:
            Velocity Type = Cartesian
            CARTESIAN VELOCITY COMPONENTS:
                Option = Automatic with Value
                U = 0 [m s-1]
                V = 0 [m s-1]
                W = 0 [m s-1]
            END
            TEMPERATURE:
                Option = Automatic with Value
                Temperature = 477.22 [K]
            END
            VOLUME FRACTION:
                Option = Automatic with Value
                Volume Fraction = 0.0001
            END
        END
    END
    FLUID: Vapor
        INITIAL CONDITIONS:
            Velocity Type = Cartesian
            CARTESIAN VELOCITY COMPONENTS:
                Option = Automatic with Value
                U = 0 [m s-1]
                V = 0 [m s-1]
                W = 0 [m s-1]
            END
            TEMPERATURE:
                Option = Automatic with Value
                Temperature = 477.22 [K]
            END
        END
        TURBULENCE INITIAL CONDITIONS:
            Option = Medium Intensity and Eddy Viscosity Ratio

```

```

        END
        VOLUME FRACTION:
            Option = Automatic with Value
            Volume Fraction = 0.9999
        END
    END
END
INITIAL CONDITIONS:
    STATIC PRESSURE:
        Option = Automatic with Value
        Relative Pressure = 1.72 [MPa]
    END
END
MULTIPHASE MODELS:
    Homogeneous Model = False
    FREE SURFACE MODEL:
        Option = None
    END
END
DOMAIN: TubeWall
    Coord Frame = Coord 0
    Domain Type = Solid
    Location = B19
    BOUNDARY: Domain Interface 1 Side 2
        Boundary Type = INTERFACE
        Location = Interface_Wall
        BOUNDARY CONDITIONS:
            HEAT TRANSFER:
                Option = Conservative Interface Flux
            END
        END
    END
    BOUNDARY: Wall
        Boundary Type = WALL
        Location = Wall
        BOUNDARY CONDITIONS:
            HEAT TRANSFER:
                Option = Adiabatic
            END
        END
    END
DOMAIN MODELS:
    DOMAIN MOTION:
        Option = Stationary
    END
    MESH DEFORMATION:
        Option = None
    END
END
INITIALISATION:
    Option = Automatic
    INITIAL CONDITIONS:
        TEMPERATURE:
            Option = Automatic with Value
            Temperature = 491.7957 [K]
        END
    END
END
SOLID DEFINITION: Solid 1
    Material = Steel

```

```

    Option = Material Library
MORPHOLOGY:
    Option = Continuous Solid
END
END
SOLID MODELS:
    HEAT TRANSFER MODEL:
        Option = Thermal Energy
    END
    THERMAL RADIATION MODEL:
        Option = None
    END
END
DOMAIN INTERFACE: Domain Interface 1
    Boundary List1 = Domain Interface 1 Side 1
    Boundary List2 = Domain Interface 1 Side 2
    Interface Type = Fluid Solid
INTERFACE MODELS:
    Option = General Connection
FRAME CHANGE:
    Option = None
END
HEAT TRANSFER:
    Option = Conservative Interface Flux
HEAT TRANSFER INTERFACE MODEL:
    Option = None
END
END
PITCH CHANGE:
    Option = None
END
END
MESH CONNECTION:
    Option = GGI
END
END
OUTPUT CONTROL:
    BACKUP DATA RETENTION:
        Option = Delete Old Files
    END
    BACKUP RESULTS: Backup Results 1
        File Compression Level = Default
        Option = Standard
        Output Equation Residuals = All
    OUTPUT FREQUENCY:
        Option = Timestep Interval
        Timestep Interval = 1000
    END
END
MONITOR OBJECTS:
    MONITOR BALANCES:
        Option = Full
    END
    MONITOR FORCES:
        Option = Full
    END
    MONITOR PARTICLES:
        Option = Full
    END
    MONITOR POINT: CourantAveMon
        Coord Frame = Coord 0

```

```

    Expression Value = CourantAve
    Option = Expression
END
MONITOR POINT: CourantMaxMon
    Coord Frame = Coord 0
    Expression Value = CourantMax
    Option = Expression
END
MONITOR POINT: CourantRMSMon
    Coord Frame = Coord 0
    Expression Value = CourantRMS
    Option = Expression
END
MONITOR POINT: Inlet Pressure
    Coord Frame = Coord 0
    Expression Value = areaAve(Pressure)@Inlet
    Option = Expression
END
MONITOR POINT: Inlet Quality
    Coord Frame = Coord 0
    Expression Value = QualityInlet
    Option = Expression
END
MONITOR POINT: Liquid Inlet Velocity
    Coord Frame = Coord 0
    Expression Value = LiquidVelInlet
    Option = Expression
END
MONITOR POINT: Liquid Mass
    Coord Frame = Coord 0
    Expression Value = SumLiqMassTotal
    Option = Expression
END
MONITOR POINT: Liquid Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = LiquidVelOutlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate In
    Coord Frame = Coord 0
    Expression Value = MassFlowInlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate Out
    Coord Frame = Coord 0
    Expression Value = MassFlowOutlet
    Option = Expression
END
MONITOR POINT: Outlet Pressure
    Coord Frame = Coord 0
    Expression Value = areaAve(Pressure)@Outlet
    Option = Expression
END
MONITOR POINT: Outlet Quality
    Coord Frame = Coord 0
    Expression Value = QualityOutlet
    Option = Expression
END
MONITOR POINT: Outlet Temperature
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Temperature)@Outlet
    Option = Expression

```

```

END
MONITOR POINT: Saturation Temp
  Coord Frame = Coord 0
  Expression Value = massFlowAve(Liquid | Vapor.Saturation \
    Temperature)@Outlet
  Option = Expression
END
MONITOR POINT: Vapor Inlet Velocity
  Coord Frame = Coord 0
  Expression Value = VaporVelInlet
  Option = Expression
END
MONITOR POINT: Vapor Outlet Velocity
  Coord Frame = Coord 0
  Expression Value = VaporVelOutlet
  Option = Expression
END
MONITOR RESIDUALS:
  Option = Full
END
MONITOR TOTALS:
  Option = Full
END
RESULTS:
  File Compression Level = Default
  Option = Standard
  Output Equation Residuals = All
END
TRANSIENT RESULTS: Transient Results 1
  File Compression Level = Default
  Option = Standard
  OUTPUT FREQUENCY:
    Option = Timestep Interval
    Timestep Interval = 1000
  END
END
TRANSIENT STATISTICS: LiqMassTrn
  Option = Arithmetic Average
  Output Variables List = Liquid.MassTotal
END
TRANSIENT STATISTICS: PressureTrn
  Option = Arithmetic Average
  Output Variables List = Absolute Pressure
END
TRANSIENT STATISTICS: TempTrn
  Option = Arithmetic Average
  Output Variables List = Temperature
END
TRANSIENT STATISTICS: VelTrn
  Option = Arithmetic Average
  Output Variables List = Velocity
END
SOLVER CONTROL:
  Turbulence Numerics = High Resolution
  ADVECTION SCHEME:
    Option = High Resolution
  END
CONVERGENCE CONTROL:
  Maximum Number of Coefficient Loops = 3
  Minimum Number of Coefficient Loops = 1

```

```
    Timescale Control = Coefficient Loops
END
CONVERGENCE CRITERIA:
    Residual Target = 1e-15
    Residual Type = RMS
END
INTERRUPT CONTROL:
    Option = Any Interrupt
CONVERGENCE CONDITIONS:
    Option = Default Conditions
END
END
TRANSIENT SCHEME:
    Option = Second Order Backward Euler
TIMESTEP INITIALISATION:
    Option = Automatic
END
END
END
COMMAND FILE:
    Version = 22.1
END
```

## **APPENDIX F. DEVIATION FROM MESH SENSITIVITY EXPLAINED**

Initially, the 15 mm bulk mesh was generated on the full geometry as dictated by the results of the mesh sensitivity study. The settings explained previously were imparted on the geometry and the simulation was submitted to the Naval Postgraduate School's supercomputer, Hamming. Appendix G details the process to submit an ANSYS CFX job onto Hamming. Once submitted, Hamming would run these simulations for 6 iterations and then exit with a "FINMES error." This finite measurement is due to some fatal overflow in the solver. According to the ANSYS forums, this could have been the result of not allocating enough space for the problem, needing a reduced timestep to start the solver, initial condition errors, or any physics or mesh errors. Within Hamming, increased memory was tested up to four nodes of 64 cores, each with reserving 2 gigabytes of memory. The additional memory allocation did not resolve the error. The reduced timestep was also tested to fix the error. The timestep was reduced to 0.001, where 1.0 is the default timestep, but still the error persisted. The mesh was generated multiple times, but the error remained after every simulation. The physics was successfully tested and run by LT Axelsson, and the same CCL file was used for this work. In order to determine the source of the error, a .bak file was taken at the 5<sup>th</sup> iteration of the solver was taken before it could fail without giving a .res file. Upon examination of this .bak file, small holes in the mesh were noticed throughout. Fig. 52 shows an example of this output.

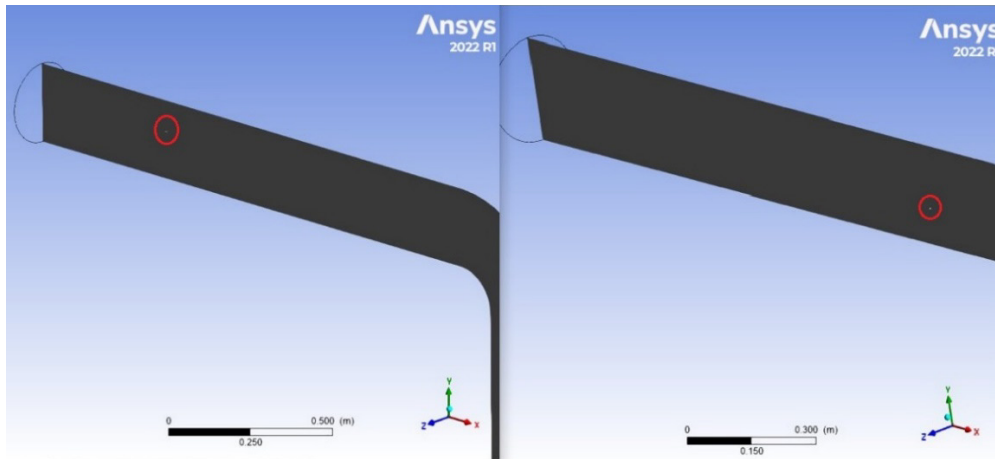


Figure 52. Mesh holes from .bak files of two simulations of the same problem started from separately generated .def files on Hamming with holes in the mesh circled in red

The error was due to the solver not being able to resolve equations in this hollow space that should have been meshed. The geometry was meshed again, and the simulation still failed, but the location of the holes changes. Each .bak file contained about four holes along the center plane only. There were likely more holes in the output throughout the pipe. This proved that the error was not in the mesh itself, but in the file transfer. The simulation ran continuously, albeit slowly, when run on the local computer. Because of this, the .def file was generated and this time run on the local computer instead of Hamming. This simulation failed after 6 iterations and showed that there was some error in the generation of the .def file. This error is likely due to the magnitude of the mesh since there were no errors running the verification case on Hamming. Due to time constraints, the bulk mesh was enlarged to 20 mm and all subsequent simulations were run on the local machine.

## APPENDIX G. HAMMING JOB SUBMISSION PROCESS FOR ANSYS CFX

1. Create an account on Hamming.
  - a. Register for an account at: <https://hamming.uc.nps.edu/ssar/>
  - b. Hamming Admin will email back after an account and username are generated.
2. Open Workbench, navigate to your CFX file and open it.
3. Check CFX-Pre for errors. Ensure that an Execution Control has been created to dictate the solver method.
4. Run at least two iterations in CFX Solver to ensure that setup is correct.
5. Stop solver and save project.
6. Open CFX-Pre standalone, navigate to .cfx file desired and open it.
7. Navigate to Tools>Solve>Write Solver Input File.
8. Save the .def file as a specified name and note the file's location.
9. Open File Explorer and navigate to the .def file.
10. Open MobaXTERM and log on to Hamming.
  - a. Download MobaXTERM to SSH to talk to Hamming:  
<https://mobaxterm.mobatek.net/download.html>
  - b. Open MobaXTERM.
  - c. Select "Session".
  - d. Select "SSH".
  - e. Enter the location as "hamming-sub1.uc.nps.edu" and put in username, leave port as default.
11. Drag .def file from File Explorer to the file tree in MobaXTERM.
12. Drag SH file, as a .txt file, from File Explorer to file tree on MobaXTERM (see Appendix H for sample SH file).
13. Check SH file within MobaXTERM using the command "nano SHFILENAME.txt". This check should include a review of the memory requested on Hamming and file names for submission and output.

14. Save edits to SH file using CTRL+O and ENTER.
15. Exit the SH File editing using CTRL+X and ENTER.
16. Type “sbatch SHFILENAME” to submit run.
17. Type “squeue -u USERNAME” to check that simulation is submitted and running.
18. Type “tail -f FILENAME\_00X.out” to output residuals in MobaXTERM where 00X can be changed to represent the .out file number. The current number can be found using the ls command. \*Or use “cat FILENAME\_00X.out” to see the residuals of a concluded run.
19. Type CTRL+C to exit the “tail -f” or “cat” command.
20. Stop a run in progress with “scancel JOBIDNUMBER” where the job ID is found by the “squeue -u USERNAME” command.
21. For an interactive CFX session on Hamming, type “salloc --mem=500000M --x11=all” where mem is determined by how much memory you require.
  - a. Type “module purge”.
  - b. Type “module load app/ansys/20.2”.
  - c. Type “cfx5post”

## APPENDIX H. SAMPLE SH FILE FOR HAMMING SUBMISSION

The following is a sample SH file. This file acts as a replacement for the CFX-Solver Manager run definition. This file describes the memory allocation and problem partitioning. This script allows the submission of a CFX project onto HPC without physically opening an interactive node on the HPC.

```
#!/usr/bin/csh
#SBATCH --job-name=FullGeom99Qual
#SBATCH --error=FullGeom99Qual.err.%j
#SBATCH --output=FullGeom99Qual.out.%j
#SBATCH --time=500:10:00
#SBATCH --nodes=2
#SBATCH --ntasks=64
#SBATCH --tasks-per-node=64
#SBATCH --mem-per-cpu=1024M
#SBATCH --mail-type=END
#SBATCH --no-requeue
###SBATCH --exclude=compute-2-39,compute-7-9
###. /etc/profile
module purge
module load app/ansys/20.2
set MYFILEHOSTS="hosts.${SLURM_JOB_ID}"
srun hostname | sort > $MYFILEHOSTS
###echo $MYFILEHOSTS > test.hostlist.txt
###echo $MYFILEHOSTS
###set PARLIST=`cat $MYFILEHOSTS`
###echo $PARLIST
Wait
foreach i (`scontrol show hostname "$SLURM_NODELIST" | tr "\n" " ")
    set compnode=`grep "^${i}.hamming.cluster" ~/.ssh/known_hosts`
    if ("${compnode}" == "" ) then
        ssh-keyscan -t ecdsa "${i}.hamming.cluster" | tee -a
        ~/.ssh/known_hosts;
    endif
end
sed -z 's/\n/,/g;s/,,$/\n/' $MYFILEHOSTS > tmp.hosts
wait
set PARLIST=`cat tmp.hosts`
echo $PARLIST
wait
cfx5solve -size 2 -def 99Qual.def -parallel -par-dist $PARLIST -start-method
"Intel MPI Distributed Parallel"
```

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## APPENDIX I. CCL FOR 99% INLET QUALITY, FULL GEOMETRY, STEADY-STATE

The following is a CCL file that describes the boundary conditions and expressions used for the 99% inlet quality, steady-state analysis. This file is exported from CFX-Pre.

LIBRARY:

CEL:

EXPRESSIONS:

```
CourantAve = ave(Courant Number )@Default Domain
CourantMax = maxVal(Courant Number )@Default Domain
CourantRMS = rmsAve(Courant Number )@Default Domain
LiquidVFinlet = 1-VaporVFinlet
LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
MassFlowInlet = massFlow()@Inlet
MassFlowOutlet = -massFlow()@Outlet
Press = 2.6389[MPa]
QualityEquilInlet = \
    ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
    t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityEquilOutlet = \
    ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
    t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityInlet = \
    Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
QualityOutlet = \
    Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
    let)
SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain
Tsat = \
    1[K]*(0.5*(650.17534844798+((2*((-724213.16703206*((Press/1[MPa])^0.25\
    )^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))/(-(11\
    67.0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa]\
    )^0.25))-4823.2657361591)-((1167.0521452767*((Press/1[MPa])^0.25)^2)+\
    (12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)^2-(4*((Press\
    /1[MPa])^0.25)^2+(-17.073846940092*((Press/1[MPa])^0.25))+14.915108613\
    530)*((-724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((P\
    ress/1[MPa])^0.25))+405113.40542057)))^0.5))-((650.17534844798+((2*((-\
    724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[M\
    Pa])^0.25))+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25\
    )^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.\
    0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0\
    .25))-4823.2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092\
    *((Press/1[MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[\
    MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.4054205\
    7)))^0.5))^2-4*(-0.23855557567849+(650.17534844798*((2*((-724213.1670\
    3206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25)\
    +405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25)^2)+(12020\
    .824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.0521452767*\
    ((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.\
    2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[\
    MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[MPa])^0.25)\
    ^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))^0.5)\
    )^0.5))
VaporVFinlet = if(Accumulated Iteration Number <= 100, \
```

```

        .9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
WallHeatFlux = if(Accumulated Iteration Number <=250, \
    0[W/m^2]-(Accumulated Iteration Number*123.6)[W/m^2], -30900[W/m^2])
WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
    Iteration Number*0.008)[K], 498[K])
END
END
ADDITIONAL VARIABLE: MassTotal
    Option = Definition
    Tensor Type = SCALAR
    Units = [kg]
    Variable Type = Specific
END
MATERIAL GROUP: Air Data
    Group Description = Ideal gas and constant property air. Constant \
        properties are for dry air at STP (0 C, 1 atm) and 25 C, 1 atm.
END
MATERIAL GROUP: CHT Solids
    Group Description = Pure solid substances that can be used for conjugate \
        heat transfer.
END
MATERIAL GROUP: Calorically Perfect Ideal Gases
    Group Description = Ideal gases with constant specific heat capacity. \
        Specific heat is evaluated at STP.
END
MATERIAL GROUP: Constant Property Gases
    Group Description = Gaseous substances with constant properties. \
        Properties are calculated at STP (0C and 1 atm). Can be combined with \
        NASA SP-273 materials for combustion modelling.
END
MATERIAL GROUP: Constant Property Liquids
    Group Description = Liquid substances with constant properties.
END
MATERIAL GROUP: Dry Peng Robinson
    Group Description = Materials with properties specified using the built \
        in Peng Robinson equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Redlich Kwong equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Soave Redlich Kwong equation of state. Suitable for dry real gas \
        modelling.
END
MATERIAL GROUP: Dry Steam
    Group Description = Materials with properties specified using the IAPWS \
        equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Gas Phase Combustion
    Group Description = Ideal gas materials which can be use for gas phase \
        combustion. Ideal gas specific heat coefficients are specified using \
        the NASA SP-273 format.
END
MATERIAL GROUP: IAPWS IF97
    Group Description = Liquid, vapour and binary mixture materials which use \
        the IAPWS IF-97 equation of state. Materials are suitable for \
        compressible liquids, phase change calculations and dry steam flows.
END

```

```

MATERIAL GROUP: Interphase Mass Transfer
  Group Description = Materials with reference properties suitable for \
    performing either Eulerian or Lagrangian multiphase mass transfer \
    problems. Examples include cavitation, evaporation or condensation.
END
MATERIAL GROUP: Liquid Phase Combustion
  Group Description = Liquid and homogenous binary mixture materials which \
    can be included with Gas Phase Combustion materials if combustion \
    modelling also requires phase change (eg: evaporation) for certain \
    components.
END
MATERIAL GROUP: Particle Solids
  Group Description = Pure solid substances that can be used for particle \
    tracking
END
MATERIAL GROUP: Peng Robinson Dry Hydrocarbons
  Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Refrigerants
  Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Steam
  Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Peng Robinson Wet Hydrocarbons
  Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Refrigerants
  Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Steam
  Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Real Gas Combustion
  Group Description = Real gas materials which can be use for gas phase \
    combustion. Ideal gas specific heat coefficients are specified using \
    the NASA SP-273 format.
END
MATERIAL GROUP: Redlich Kwong Dry Hydrocarbons
  Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Refrigerants
  Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Steam
  Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Redlich Kwong Wet Hydrocarbons
  Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Refrigerants
  Group Description = Common refrigerants which use the Redlich Kwong \

```

```

    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Steam
    Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soot
    Group Description = Solid substances that can be used when performing \
    soot modelling
END
MATERIAL GROUP: User
    Group Description = Materials that are defined by the user
END
MATERIAL GROUP: Water Data
    Group Description = Liquid and vapour water materials with constant \
    properties. Can be combined with NASA SP-273 materials for combustion \
    modelling.
END
MATERIAL GROUP: Wet Peng Robinson
    Group Description = Materials with properties specified using the built \
    in Peng Robinson equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Redlich Kwong equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Soave Redlich Kwong equation of state. Suitable for wet real gas \
    modelling.
END
MATERIAL GROUP: Wet Steam
    Group Description = Materials with properties specified using the IAPWS \
    equation of state. Suitable for wet steam modelling.
END
MATERIAL: Air Ideal Gas
    Material Description = Air Ideal Gas (constant Cp)
    Material Group = Air Data, Calorically Perfect Ideal Gases

```

```

Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Molar Mass = 28.96 [kg kmol-1]
    Option = Ideal Gas
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0. [J/kg]
    Reference Specific Entropy = 0. [J/kg/K]
    Reference Temperature = 25 [C]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.831E-05 [kg m-1 s-1]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 2.61E-2 [W m-1 K-1]
  END
  ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0.01 [m-1]
    Option = Value
  END
  SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m-1]
  END
  REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m-1]
  END
END
END
MATERIAL: Air at 25 C
  Material Description = Air at 25 C and 1 atm (dry)
  Material Group = Air Data, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 1.185 [kg m-3]
      Molar Mass = 28.96 [kg kmol-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]
      Specific Heat Type = Constant Pressure
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Pressure = 1 [atm]

```

```

Reference Specific Enthalpy = 0. [J/kg]
Reference Specific Entropy = 0. [J/kg/K]
Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 2.61E-02 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
Absorption Coefficient = 0.01 [m^-1]
Option = Value
END
SCATTERING COEFFICIENT:
Option = Value
Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
Option = Value
Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
Option = Value
Thermal Expansivity = 0.003356 [K^-1]
END
END
END
MATERIAL: Aluminium
Material Group = CHT Solids, Particle Solids
Option = Pure Substance
Thermodynamic State = Solid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 2702 [kg m^-3]
Molar Mass = 26.98 [kg kmol^-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 9.03E+02 [J kg^-1 K^-1]
END
REFERENCE STATE:
Option = Specified Point
Reference Specific Enthalpy = 0 [J/kg]
Reference Specific Entropy = 0 [J/kg/K]
Reference Temperature = 25 [C]
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 237 [W m^-1 K^-1]
END
END
END
MATERIAL: Copper
Material Group = CHT Solids, Particle Solids
Option = Pure Substance
Thermodynamic State = Solid
PROPERTIES:

```

```

Option = General Material
EQUATION OF STATE:
  Density = 8933 [kg m^-3]
  Molar Mass = 63.55 [kg kmol^-1]
  Option = Value
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 3.85E+02 [J kg^-1 K^-1]
END
REFERENCE STATE:
  Option = Specified Point
  Reference Specific Enthalpy = 0 [J/kg]
  Reference Specific Entropy = 0 [J/kg/K]
  Reference Temperature = 25 [C]
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 401.0 [W m^-1 K^-1]
END
END
MATERIAL: LiquidConst
Material Group = Constant Property Liquids,Wet Steam
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Density = 831.318 [kg m^-3]
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 4659 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 2.6389 [MPa]
    Reference Specific Enthalpy = 975465 [J kg^-1]
    Reference Specific Entropy = 2581.1 [J kg^-1 K^-1]
    Reference Temperature = 500 [K]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 0.0001179 [Pa s]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.6421 [W m^-1 K^-1]
  END
END
MATERIAL: LiquidVar
Material Group = IAPWS IF97,Wet Steam
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
  Option = IAPWS Library
  REFERENCE STATE:

```

```

    Option = Automatic
END
TABLE GENERATION:
    Maximum Absolute Pressure = 12.345 [MPa]
    Maximum Points = 100
    Maximum Temperature = 600 [K]
    Minimum Absolute Pressure = 0.0035368 [MPa]
    Minimum Temperature = 300 [K]
    Pressure Extrapolation = On
    Temperature Extrapolation = Yes
END
END
END
MATERIAL: Soot
    Material Group = Soot
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
    EQUATION OF STATE:
        Density = 2000 [kg m^-3]
        Molar Mass = 12 [kg kmol^-1]
        Option = Value
    END
    REFERENCE STATE:
        Option = Automatic
    END
    ABSORPTION COEFFICIENT:
        Absorption Coefficient = 0 [m^-1]
        Option = Value
    END
END
END
MATERIAL: Steel
    Material Group = CHT Solids, Particle Solids
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
    EQUATION OF STATE:
        Density = 7854 [kg m^-3]
        Molar Mass = 55.85 [kg kmol^-1]
        Option = Value
    END
    SPECIFIC HEAT CAPACITY:
        Option = Value
        Specific Heat Capacity = 4.34E+02 [J kg^-1 K^-1]
    END
    REFERENCE STATE:
        Option = Specified Point
        Reference Specific Enthalpy = 0 [J/kg]
        Reference Specific Entropy = 0 [J/kg/K]
        Reference Temperature = 25 [C]
    END
    THERMAL CONDUCTIVITY:
        Option = Value
        Thermal Conductivity = 60.5 [W m^-1 K^-1]
    END
END
END
MATERIAL: VaporConst
    Material Group = Wet Steam, Constant Property Gases

```

```

Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Density = 13.1976 [kg m^-3]
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 3462.6 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 2.6389 [MPa]
    Reference Specific Enthalpy = 2802590 [J kg^-1]
    Reference Specific Entropy = 6235.4 [J kg^-1 K^-1]
    Reference Temperature = 500 [K]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.6594e-5 [Pa s]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.044952 [W m^-1 K^-1]
  END
  THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 0.001686 [K^-1]
  END
END
END
MATERIAL: VaporVar
  Material Group = IAPWS IF97,Wet Steam
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = IAPWS Library
    REFERENCE STATE:
      Option = Automatic
    END
    TABLE GENERATION:
      Maximum Absolute Pressure = 12.345 [MPa]
      Maximum Points = 1000
      Maximum Temperature = 600 [K]
      Minimum Absolute Pressure = 0.0035368 [MPa]
      Minimum Temperature = 300 [K]
      Pressure Extrapolation = On
      Temperature Extrapolation = Yes
    END
  END
END
MATERIAL: Water
  Material Description = Water (liquid)
  Material Group = Water Data, Constant Property Liquids
  Option = Pure Substance
  Thermodynamic State = Liquid
  PROPERTIES:
    Option = General Material

```

```

EQUATION OF STATE:
  Density = 997.0 [kg m^-3]
  Molar Mass = 18.02 [kg kmol^-1]
  Option = Value
END
SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 4181.7 [J kg^-1 K^-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1 [atm]
  Reference Specific Enthalpy = 0.0 [J/kg]
  Reference Specific Entropy = 0.0 [J/kg/K]
  Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 8.899E-4 [kg m^-1 s^-1]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 0.6069 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
  Absorption Coefficient = 1.0 [m^-1]
  Option = Value
END
SCATTERING COEFFICIENT:
  Option = Value
  Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
  Option = Value
  Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
  Option = Value
  Thermal Expansivity = 2.57E-04 [K^-1]
END
END
END
MATERIAL: Water Ideal Gas
Material Description = Water Vapour Ideal Gas (100 C and 1 atm)
Material Group = Calorically Perfect Ideal Gases, Water Data
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Ideal Gas
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 2080.1 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1.014 [bar]

```

```

    Reference Specific Enthalpy = 0. [J/kg]
    Reference Specific Entropy = 0. [J/kg/K]
    Reference Temperature = 100 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 9.4E-06 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 193E-04 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
END
END
FLOW: Flow Analysis 1
    SOLUTION UNITS:
        Angle Units = [rad]
        Length Units = [m]
        Mass Units = [kg]
        Solid Angle Units = [sr]
        Temperature Units = [K]
        Time Units = [s]
    END
    ANALYSIS TYPE:
        Option = Steady State
    EXTERNAL SOLVER COUPLING:
        Option = None
    END
    DOMAIN: Default Domain
        Coord Frame = Coord 0
        Domain Type = Fluid
        Location = B4
    BOUNDARY MODELS:
        WALL BOILING MODEL:
            Option = None
        END
    END
    BOUNDARY: Default Domain Default
        Boundary Type = OUTLET
        Location = F24.4,F41.4
    BOUNDARY CONDITIONS:
        FLOW REGIME:
            Option = Subsonic
        END
        MASS AND MOMENTUM:
            Option = Fluid Velocity
        END
    END
END

```

```

FLUID: Liquid
  BOUNDARY CONDITIONS:
    VELOCITY:
      Normal Speed = 0.02 [m s-1]
      Option = Normal Speed
    END
  END
END
FLUID: Vapor
  BOUNDARY CONDITIONS:
    VELOCITY:
      Normal Speed = 0 [m s-1]
      Option = Normal Speed
    END
  END
END
BOUNDARY: Inlet
  Boundary Type = INLET
  Location = Inlet
  BOUNDARY CONDITIONS:
    FLOW REGIME:
      Option = Subsonic
    END
    HEAT TRANSFER:
      Option = Static Temperature
      Static Temperature = 500 [K]
    END
    MASS AND MOMENTUM:
      Normal Speed = 40 [m s-1]
      Option = Normal Speed
    END
    TURBULENCE:
      Option = Medium Intensity and Eddy Viscosity Ratio
    END
  END
FLUID: Liquid
  BOUNDARY CONDITIONS:
    VOLUME FRACTION:
      Option = Value
      Volume Fraction = 0.0001
    END
  END
FLUID: Vapor
  BOUNDARY CONDITIONS:
    VOLUME FRACTION:
      Option = Value
      Volume Fraction = 0.9999
    END
  END
END
BOUNDARY: Outlet
  Boundary Type = OUTLET
  Location = Outlet
  BOUNDARY CONDITIONS:
    FLOW REGIME:
      Option = Subsonic
    END
    MASS AND MOMENTUM:
      Option = Average Static Pressure

```

```

        Pressure Profile Blend = 0.05
        Relative Pressure = 2.6389 [MPa]
    END
    PRESSURE AVERAGING:
        Option = Average Over Whole Outlet
    END
END
BOUNDARY: Wall
    Boundary Type = WALL
    Location = Wall
    BOUNDARY CONDITIONS:
        HEAT TRANSFER:
            Option = Adiabatic
        END
        MASS AND MOMENTUM:
            Option = No Slip Wall
        END
        WALL CONTACT MODEL:
            Option = Use Volume Fraction
        END
        WALL ROUGHNESS:
            Option = Smooth Wall
        END
    END
END
DOMAIN MODELS:
    BUOYANCY MODEL:
        Buoyancy Reference Density = 0 [kg m-3]
        Gravity X Component = 0 [m s-2]
        Gravity Y Component = -9.81 [m s-2]
        Gravity Z Component = 0 [m s-2]
        Option = Buoyant
    BUOYANCY REFERENCE LOCATION:
        Option = Automatic
    END
END
DOMAIN MOTION:
    Option = Stationary
END
MESH DEFORMATION:
    Option = None
END
REFERENCE PRESSURE:
    Reference Pressure = 0 [MPa]
END
END
FLUID DEFINITION: Liquid
    Material = LiquidConst
    Option = Material Library
    MORPHOLOGY:
        Mean Diameter = 1 [micron]
        Minimum Volume Fraction = 1e-9
        Option = Dispersed Fluid
    END
END
FLUID DEFINITION: Vapor
    Material = VaporConst
    Option = Material Library
    MORPHOLOGY:
        Minimum Volume Fraction = 1e-9
        Option = Continuous Fluid

```

```

END
END
FLUID MODELS:
  ADDITIONAL VARIABLE: MassTotal
    Option = Fluid Dependent
  END
  COMBUSTION MODEL:
    Option = None
  END
  FLUID: Liquid
    ADDITIONAL VARIABLE: MassTotal
      Additional Variable Value = Volume of Finite Volumes *Density \
        *Volume Fraction
      Option = Algebraic Equation
    END
    FLUID BUOYANCY MODEL:
      Option = Density Difference
    END
    HEAT TRANSFER MODEL:
      Option = Thermal Energy
    END
    TURBULENCE MODEL:
      Option = Laminar
    END
  END
  FLUID: Vapor
    ADDITIONAL VARIABLE: MassTotal
      Additional Variable Value = Volume of Finite Volumes *Density \
        *Volume Fraction
      Option = Algebraic Equation
    END
    FLUID BUOYANCY MODEL:
      Option = Density Difference
    END
    HEAT TRANSFER MODEL:
      Option = Thermal Energy
    END
    TURBULENCE MODEL:
      Option = k epsilon
    BUOYANCY TURBULENCE:
      Option = None
    END
  END
  TURBULENT WALL FUNCTIONS:
    Option = Scalable
  END
END
HEAT TRANSFER MODEL:
  Homogeneous Model = False
  Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
  Option = None
END
TURBULENCE MODEL:
  Homogeneous Model = False
  Option = Fluid Dependent
END
FLUID PAIR: Liquid | Vapor
  Surface Tension Coefficient = 0.013472 [N m^-1]
  INTERPHASE HEAT TRANSFER:

```

```

    Option = Two Resistance
    FLUID1 INTERPHASE HEAT TRANSFER:
        Option = Zero Resistance
    END
    FLUID2 INTERPHASE HEAT TRANSFER:
        Option = Ranz Marshall
    END
END
INTERPHASE TRANSFER MODEL:
    Option = Particle Model
END
MASS TRANSFER:
    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None
    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
MULTIPHASE MODELS:
    Homogeneous Model = False
    FREE SURFACE MODEL:
        Option = None
    END
END
OUTPUT CONTROL:
    BACKUP DATA RETENTION:
        Option = Keep All Files
    END
    BACKUP RESULTS: Backup Results 1
        File Compression Level = Default
        Option = Standard
        Output Equation Residuals = All
    OUTPUT FREQUENCY:
        Iteration Interval = 300
        Option = Iteration Interval
    END
END
MONITOR OBJECTS:

```

```

MONITOR BALANCES:
  Option = Full
END
MONITOR FORCES:
  Option = Full
END
MONITOR PARTICLES:
  Option = Full
END
MONITOR POINT: CourantAveMon
  Coord Frame = Coord 0
  Expression Value = CourantAve
  Option = Expression
END
MONITOR POINT: CourantMaxMon
  Coord Frame = Coord 0
  Expression Value = CourantMax
  Option = Expression
END
MONITOR POINT: CourantRMSMon
  Coord Frame = Coord 0
  Expression Value = CourantRMS
  Option = Expression
END
MONITOR POINT: Inlet Pressure
  Coord Frame = Coord 0
  Expression Value = areaAve(Pressure)@Inlet
  Option = Expression
END
MONITOR POINT: Inlet Quality
  Coord Frame = Coord 0
  Expression Value = QualityInlet
  Option = Expression
END
MONITOR POINT: Liquid Inlet Velocity
  Coord Frame = Coord 0
  Expression Value = LiquidVelInlet
  Option = Expression
END
MONITOR POINT: Liquid Mass
  Coord Frame = Coord 0
  Expression Value = SumLiqMassTotal
  Option = Expression
END
MONITOR POINT: Liquid Outlet Velocity
  Coord Frame = Coord 0
  Expression Value = LiquidVelOutlet
  Option = Expression
END
MONITOR POINT: Mass Flow Rate In
  Coord Frame = Coord 0
  Expression Value = MassFlowInlet
  Option = Expression
END
MONITOR POINT: Mass Flow Rate Out
  Coord Frame = Coord 0
  Expression Value = MassFlowOutlet
  Option = Expression
END
MONITOR POINT: Outlet Pressure
  Coord Frame = Coord 0
  Expression Value = areaAve(Pressure)@Outlet

```

```

    Option = Expression
END
MONITOR POINT: Outlet Quality
    Coord Frame = Coord 0
    Expression Value = QualityOutlet
    Option = Expression
END
MONITOR POINT: Outlet Temperature
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Saturation Temp
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Liquid | Vapor.Saturation \
    Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Vapor Inlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelInlet
    Option = Expression
END
MONITOR POINT: Vapor Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelOutlet
    Option = Expression
END
MONITOR RESIDUALS:
    Option = Full
END
MONITOR TOTALS:
    Option = Full
END
RESULTS:
    File Compression Level = Default
    Option = Standard
    Output Equation Residuals = All
END
END
SOLVER CONTROL:
    Turbulence Numerics = High Resolution
ADVECTION SCHEME:
    Option = High Resolution
END
CONVERGENCE CONTROL:
    Length Scale Option = Conservative
    Maximum Number of Iterations = 30000
    Minimum Number of Iterations = 1
    Timescale Control = Auto Timescale
    Timescale Factor = 0.01
END
CONVERGENCE CRITERIA:
    Residual Target = 1e-15
    Residual Type = RMS
END
DYNAMIC MODEL CONTROL:
    Global Dynamic Model Control = On
END
INTERRUPT CONTROL:
    Option = Any Interrupt

```

```
CONVERGENCE CONDITIONS:  
  Option = Default Conditions  
END  
END  
END  
COMMAND FILE:  
  Version = 22.1  
END
```

## APPENDIX J. CCL FOR 85% INLET QUALITY, FULL GEOMETRY, STEADY-STATE

The following is a CCL file that describes the boundary conditions and expressions used for the 85% inlet quality, steady-state analysis. This file is exported from CFX-Pre.

LIBRARY:

CEL:

EXPRESSIONS:

```

CourantAve = ave(Courant Number )@Default Domain
CourantMax = maxVal(Courant Number )@Default Domain
CourantRMS = rmsAve(Courant Number )@Default Domain
Expression 1 = sum(Liquid.MassTotal)@Domain2
LiquidVFinlet = 1-VaporVFinlet
LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
MassFlowInlet = massFlow()@Inlet
MassFlowOutlet = -massFlow()@Outlet
MassFlowTrap1 = -massFlow()@Outlet1
MassFlowTrap2 = -massFlow()@Outlet2
Press = 2.6389[MPa]
QualityEquilInlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
   t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityEquilOutlet = \
  ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
   t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityInlet = \
  Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
QualityOutlet = \
  Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
   let)
SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain
Trap1LiqMass = sum(Liquid.MassTotal)@Domain 1
Trap2LiqMass = sum(Liquid.MassTotal)@Domain 2
Tsat = \
  1[K]*(0.5*(650.17534844798+((2*((-724213.16703206*((Press/1[MPa])^0.25\
   )^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))/(-(11\
   67.0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa]\
   )^0.25))-4823.2657361591)-(((1167.0521452767*((Press/1[MPa])^0.25)^2)+\
   (12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)^2-4*((Press\
   /1[MPa])^0.25)^2+(-17.073846940092*((Press/1[MPa])^0.25))+14.915108613\
   530)*((-724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((P\
   ress/1[MPa])^0.25))+405113.40542057)))^0.5)-((650.17534844798+((2*((-\
   724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[M\
   Pa])^0.25))+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25\
   )^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-(((1167.\
   0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0\
   .25))-4823.2657361591)^2-4*((Press/1[MPa])^0.25)^2+(-17.073846940092\
   *((Press/1[MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[\
   MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.4054205\
   7)))^0.5)))^2-4*(-0.23855557567849+(650.17534844798*((2*((-724213.1670\
   3206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))\
   +405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25)^2)+(12020\
   .824702470*((Press/1[MPa])^0.25))-4823.2657361591)-(((1167.0521452767*\
   ((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.\

```

```

2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[
MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[MPa])^0.25)\
^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))^0.5))\
)^0.5))
VaporVFInlet = if(Accumulated Iteration Number <= 100, \
.9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
WallHeatFlux = if(Accumulated Iteration Number <=250, \
0[W/m^2]-(Accumulated Iteration Number*123.6)[W/m^2], -30900[W/m^2])
WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
Iteration Number*0.008)[K], 498[K])
END
END
ADDITIONAL VARIABLE: MassTotal
Option = Definition
Tensor Type = SCALAR
Units = [kg]
Variable Type = Specific
END
MATERIAL GROUP: Air Data
Group Description = Ideal gas and constant property air. Constant \
properties are for dry air at STP (0 C, 1 atm) and 25 C, 1 atm.
END
MATERIAL GROUP: CHT Solids
Group Description = Pure solid substances that can be used for conjugate \
heat transfer.
END
MATERIAL GROUP: Calorically Perfect Ideal Gases
Group Description = Ideal gases with constant specific heat capacity. \
Specific heat is evaluated at STP.
END
MATERIAL GROUP: Constant Property Gases
Group Description = Gaseous substances with constant properties. \
Properties are calculated at STP (0C and 1 atm). Can be combined with \
NASA SP-273 materials for combustion modelling.
END
MATERIAL GROUP: Constant Property Liquids
Group Description = Liquid substances with constant properties.
END
MATERIAL GROUP: Dry Peng Robinson
Group Description = Materials with properties specified using the built \
in Peng Robinson equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Redlich Kwong
Group Description = Materials with properties specified using the built \
in Redlich Kwong equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Soave Redlich Kwong
Group Description = Materials with properties specified using the built \
in Soave Redlich Kwong equation of state. Suitable for dry real gas \
modelling.
END
MATERIAL GROUP: Dry Steam
Group Description = Materials with properties specified using the IAPWS \
equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Gas Phase Combustion
Group Description = Ideal gas materials which can be use for gas phase \
combustion. Ideal gas specific heat coefficients are specified using \
the NASA SP-273 format.
END

```

MATERIAL GROUP: IAPWS IF97  
 Group Description = Liquid, vapour and binary mixture materials which use \  
 the IAPWS IF-97 equation of state. Materials are suitable for \  
 compressible liquids, phase change calculations and dry steam flows.  
 END

MATERIAL GROUP: Interphase Mass Transfer  
 Group Description = Materials with reference properties suitable for \  
 performing either Eulerian or Lagrangian multiphase mass transfer \  
 problems. Examples include cavitation, evaporation or condensation.  
 END

MATERIAL GROUP: Liquid Phase Combustion  
 Group Description = Liquid and homogenous binary mixture materials which \  
 can be included with Gas Phase Combustion materials if combustion \  
 modelling also requires phase change (eg: evaporation) for certain \  
 components.  
 END

MATERIAL GROUP: Particle Solids  
 Group Description = Pure solid substances that can be used for particle \  
 tracking  
 END

MATERIAL GROUP: Peng Robinson Dry Hydrocarbons  
 Group Description = Common hydrocarbons which use the Peng Robinson \  
 equation of state. Suitable for dry real gas models.  
 END

MATERIAL GROUP: Peng Robinson Dry Refrigerants  
 Group Description = Common refrigerants which use the Peng Robinson \  
 equation of state. Suitable for dry real gas models.  
 END

MATERIAL GROUP: Peng Robinson Dry Steam  
 Group Description = Water materials which use the Peng Robinson equation \  
 of state. Suitable for dry steam modelling.  
 END

MATERIAL GROUP: Peng Robinson Wet Hydrocarbons  
 Group Description = Common hydrocarbons which use the Peng Robinson \  
 equation of state. Suitable for condensing real gas models.  
 END

MATERIAL GROUP: Peng Robinson Wet Refrigerants  
 Group Description = Common refrigerants which use the Peng Robinson \  
 equation of state. Suitable for condensing real gas models.  
 END

MATERIAL GROUP: Peng Robinson Wet Steam  
 Group Description = Water materials which use the Peng Robinson equation \  
 of state. Suitable for condensing steam modelling.  
 END

MATERIAL GROUP: Real Gas Combustion  
 Group Description = Real gas materials which can be use for gas phase \  
 combustion. Ideal gas specific heat coefficients are specified using \  
 the NASA SP-273 format.  
 END

MATERIAL GROUP: Redlich Kwong Dry Hydrocarbons  
 Group Description = Common hydrocarbons which use the Redlich Kwong \  
 equation of state. Suitable for dry real gas models.  
 END

MATERIAL GROUP: Redlich Kwong Dry Refrigerants  
 Group Description = Common refrigerants which use the Redlich Kwong \  
 equation of state. Suitable for dry real gas models.  
 END

MATERIAL GROUP: Redlich Kwong Dry Steam  
 Group Description = Water materials which use the Redlich Kwong equation \  
 of state. Suitable for dry steam modelling.  
 END

MATERIAL GROUP: Redlich Kwong Wet Hydrocarbons

```

    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Steam
    Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soot
    Group Description = Solid substances that can be used when performing \
    soot modelling
END
MATERIAL GROUP: User
    Group Description = Materials that are defined by the user
END
MATERIAL GROUP: Water Data
    Group Description = Liquid and vapour water materials with constant \
    properties. Can be combined with NASA SP-273 materials for combustion \
    modelling.
END
MATERIAL GROUP: Wet Peng Robinson
    Group Description = Materials with properties specified using the built \
    in Peng Robinson equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Redlich Kwong equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Soave Redlich Kwong equation of state. Suitable for wet real gas \
    modelling.
END
MATERIAL GROUP: Wet Steam
    Group Description = Materials with properties specified using the IAPWS \

```

```

equation of state. Suitable for wet steam modelling.
END
MATERIAL: Air Ideal Gas
Material Description = Air Ideal Gas (constant Cp)
Material Group = Air Data, Calorically Perfect Ideal Gases
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Molar Mass = 28.96 [kg kmol-1]
Option = Ideal Gas
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]
Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
Option = Specified Point
Reference Pressure = 1 [atm]
Reference Specific Enthalpy = 0. [J/kg]
Reference Specific Entropy = 0. [J/kg/K]
Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 1.831E-05 [kg m-1 s-1]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 2.61E-2 [W m-1 K-1]
END
ABSORPTION COEFFICIENT:
Absorption Coefficient = 0.01 [m-1]
Option = Value
END
SCATTERING COEFFICIENT:
Option = Value
Scattering Coefficient = 0.0 [m-1]
END
REFRACTIVE INDEX:
Option = Value
Refractive Index = 1.0 [m m-1]
END
END
MATERIAL: Air at 25 C
Material Description = Air at 25 C and 1 atm (dry)
Material Group = Air Data, Constant Property Gases
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 1.185 [kg m-3]
Molar Mass = 28.96 [kg kmol-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]

```

```

    Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0. [J/kg]
    Reference Specific Entropy = 0. [J/kg/K]
    Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 2.61E-02 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0.01 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 0.003356 [K^-1]
END
END
END
MATERIAL: Aluminium
    Material Group = CHT Solids, Particle Solids
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:
            Density = 2702 [kg m^-3]
            Molar Mass = 26.98 [kg kmol^-1]
            Option = Value
        END
        SPECIFIC HEAT CAPACITY:
            Option = Value
            Specific Heat Capacity = 9.03E+02 [J kg^-1 K^-1]
        END
        REFERENCE STATE:
            Option = Specified Point
            Reference Specific Enthalpy = 0 [J/kg]
            Reference Specific Entropy = 0 [J/kg/K]
            Reference Temperature = 25 [C]
        END
        THERMAL CONDUCTIVITY:
            Option = Value
            Thermal Conductivity = 237 [W m^-1 K^-1]
        END
    END
END
END

```

```

MATERIAL: Copper
Material Group = CHT Solids, Particle Solids
Option = Pure Substance
Thermodynamic State = Solid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 8933 [kg m-3]
Molar Mass = 63.55 [kg kmol-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 3.85E+02 [J kg-1 K-1]
END
REFERENCE STATE:
Option = Specified Point
Reference Specific Enthalpy = 0 [J/kg]
Reference Specific Entropy = 0 [J/kg/K]
Reference Temperature = 25 [C]
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 401.0 [W m-1 K-1]
END
END
MATERIAL: LiquidConst
Material Group = Constant Property Liquids,Wet Steam
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 831.318 [kg m-3]
Molar Mass = 18.02 [kg kmol-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 4659 [J kg-1 K-1]
Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
Option = Specified Point
Reference Pressure = 2.6389 [MPa]
Reference Specific Enthalpy = 975465 [J kg-1]
Reference Specific Entropy = 2581.1 [J kg-1 K-1]
Reference Temperature = 500 [K]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 0.0001179 [Pa s]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 0.6421 [W m-1 K-1]
END
END
MATERIAL: LiquidVar
Material Group = IAPWS IF97,Wet Steam

```

```

Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
  Option = IAPWS Library
  REFERENCE STATE:
    Option = Automatic
  END
  TABLE GENERATION:
    Maximum Absolute Pressure = 12.345 [MPa]
    Maximum Points = 100
    Maximum Temperature = 600 [K]
    Minimum Absolute Pressure = 0.0035368 [MPa]
    Minimum Temperature = 300 [K]
    Pressure Extrapolation = On
    Temperature Extrapolation = Yes
  END
END
END
MATERIAL: Soot
  Material Group = Soot
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 2000 [kg m-3]
      Molar Mass = 12 [kg kmol-1]
      Option = Value
    END
    REFERENCE STATE:
      Option = Automatic
    END
    ABSORPTION COEFFICIENT:
      Absorption Coefficient = 0 [m-1]
      Option = Value
    END
  END
END
MATERIAL: Steel
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 7854 [kg m-3]
      Molar Mass = 55.85 [kg kmol-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 4.34E+02 [J kg-1 K-1]
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Specific Enthalpy = 0 [J/kg]
      Reference Specific Entropy = 0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 60.5 [W m-1 K-1]

```

```

END
END
END
MATERIAL: VaporConst
  Material Group = Wet Steam, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
  EQUATION OF STATE:
    Density = 13.1976 [kg m-3]
    Molar Mass = 18.02 [kg kmol-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 3462.6 [J kg-1 K-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 2.6389 [MPa]
    Reference Specific Enthalpy = 2802590 [J kg-1]
    Reference Specific Entropy = 6235.4 [J kg-1 K-1]
    Reference Temperature = 500 [K]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.6594e-5 [Pa s]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.044952 [W m-1 K-1]
  END
  THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 0.001686 [K-1]
  END
END
END
MATERIAL: VaporVar
  Material Group = IAPWS IF97, Wet Steam
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = IAPWS Library
  REFERENCE STATE:
    Option = Automatic
  END
  TABLE GENERATION:
    Maximum Absolute Pressure = 12.345 [MPa]
    Maximum Points = 1000
    Maximum Temperature = 600 [K]
    Minimum Absolute Pressure = 0.0035368 [MPa]
    Minimum Temperature = 300 [K]
    Pressure Extrapolation = On
    Temperature Extrapolation = Yes
  END
END
END
MATERIAL: Water
  Material Description = Water (liquid)

```

```

Material Group = Water Data, Constant Property Liquids
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Density = 997.0 [kg m^-3]
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 4181.7 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0.0 [J/kg]
    Reference Specific Entropy = 0.0 [J/kg/K]
    Reference Temperature = 25 [C]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 8.899E-4 [kg m^-1 s^-1]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.6069 [W m^-1 K^-1]
  END
  ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
  END
  SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
  END
  REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
  END
  THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 2.57E-04 [K^-1]
  END
END
MATERIAL: Water Ideal Gas
Material Description = Water Vapour Ideal Gas (100 C and 1 atm)
Material Group = Calorically Perfect Ideal Gases, Water Data
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Ideal Gas
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 2080.1 [J kg^-1 K^-1]

```

```

        Specific Heat Type = Constant Pressure
    END
REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1.014 [bar]
    Reference Specific Enthalpy = 0. [J/kg]
    Reference Specific Entropy = 0. [J/kg/K]
    Reference Temperature = 100 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 9.4E-06 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 193E-04 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
END
END
FLOW: Flow Analysis 1
    SOLUTION UNITS:
        Angle Units = [rad]
        Length Units = [m]
        Mass Units = [kg]
        Solid Angle Units = [sr]
        Temperature Units = [K]
        Time Units = [s]
    END
    ANALYSIS TYPE:
        Option = Steady State
    EXTERNAL SOLVER COUPLING:
        Option = None
    END
END
DOMAIN: Default Domain
    Coord Frame = Coord 0
    Domain Type = Fluid
    Location = B32
    BOUNDARY MODELS:
        WALL BOILING MODEL:
            Option = None
        END
    END
    BOUNDARY: Domain Interface 1 Side 1
        Boundary Type = INTERFACE
        Location = F33.32,F34.32
    BOUNDARY CONDITIONS:
        HEAT TRANSFER:
            Option = Conservative Interface Flux

```

```

END
MASS AND MOMENTUM:
  Option = Conservative Interface Flux
END
TURBULENCE:
  Option = Conservative Interface Flux
END
END
END
BOUNDARY: Inlet
  Boundary Type = INLET
  Location = Inlet
  BOUNDARY CONDITIONS:
    FLOW REGIME:
      Option = Subsonic
    END
    HEAT TRANSFER:
      Option = Static Temperature
      Static Temperature = 500 [K]
    END
    MASS AND MOMENTUM:
      Normal Speed = 40 [m s-1]
      Option = Normal Speed
    END
    TURBULENCE:
      Option = Medium Intensity and Eddy Viscosity Ratio
    END
  END
END
FLUID: Liquid
  BOUNDARY CONDITIONS:
    VOLUME FRACTION:
      Option = Value
      Volume Fraction = 0.0028
    END
  END
END
FLUID: Vapor
  BOUNDARY CONDITIONS:
    VOLUME FRACTION:
      Option = Value
      Volume Fraction = 0.9972
    END
  END
END
END
BOUNDARY: Outlet
  Boundary Type = OUTLET
  Location = Outlet
  BOUNDARY CONDITIONS:
    FLOW REGIME:
      Option = Subsonic
    END
    MASS AND MOMENTUM:
      Option = Average Static Pressure
      Pressure Profile Blend = 0.05
      Relative Pressure = 2.6389 [MPa]
    END
    PRESSURE AVERAGING:
      Option = Average Over Whole Outlet
    END
  END
END
END

```

```

BOUNDARY: Wall
  Boundary Type = WALL
  Location = Wall
  BOUNDARY CONDITIONS:
    HEAT TRANSFER:
      Option = Adiabatic
    END
    MASS AND MOMENTUM:
      Option = Fluid Dependent
    END
    WALL CONTACT MODEL:
      Option = Use Volume Fraction
    END
    WALL ROUGHNESS:
      Option = Smooth Wall
    END
  END
FLUID: Liquid
  BOUNDARY CONDITIONS:
    MASS AND MOMENTUM:
      Option = No Slip Wall
    END
  END
FLUID: Vapor
  BOUNDARY CONDITIONS:
    MASS AND MOMENTUM:
      Option = No Slip Wall
    END
  END
END
DOMAIN MODELS:
  BUOYANCY MODEL:
    Buoyancy Reference Density = 0 [kg m-3]
    Gravity X Component = 0 [m s-2]
    Gravity Y Component = -9.81 [m s-2]
    Gravity Z Component = 0 [m s-2]
    Option = Buoyant
    BUOYANCY REFERENCE LOCATION:
      Option = Automatic
    END
  END
  DOMAIN MOTION:
    Option = Stationary
  END
  MESH DEFORMATION:
    Option = None
  END
  REFERENCE PRESSURE:
    Reference Pressure = 0 [MPa]
  END
END
FLUID DEFINITION: Liquid
  Material = LiquidConst
  Option = Material Library
  MORPHOLOGY:
    Mean Diameter = 1 [micron]
    Minimum Volume Fraction = 1e-9
    Option = Dispersed Fluid
  END
END

```

```

FLUID DEFINITION: Vapor
  Material = VaporConst
  Option = Material Library
MORPHOLOGY:
  Minimum Volume Fraction = 1e-9
  Option = Continuous Fluid
END
END
FLUID MODELS:
  ADDITIONAL VARIABLE: MassTotal
    Option = Fluid Dependent
  END
  COMBUSTION MODEL:
    Option = None
  END
  FLUID: Liquid
    ADDITIONAL VARIABLE: MassTotal
      Additional Variable Value = Volume of Finite Volumes *Density \
        *Volume Fraction
      Option = Algebraic Equation
    END
    FLUID BUOYANCY MODEL:
      Option = Density Difference
    END
    HEAT TRANSFER MODEL:
      Option = Thermal Energy
    END
    TURBULENCE MODEL:
      Option = Laminar
    END
  END
  FLUID: Vapor
    ADDITIONAL VARIABLE: MassTotal
      Additional Variable Value = Volume of Finite Volumes *Density \
        *Volume Fraction
      Option = Algebraic Equation
    END
    FLUID BUOYANCY MODEL:
      Option = Density Difference
    END
    HEAT TRANSFER MODEL:
      Option = Thermal Energy
    END
    TURBULENCE MODEL:
      Option = k epsilon
    BUOYANCY TURBULENCE:
      Option = None
    END
  END
  TURBULENT WALL FUNCTIONS:
    Option = Scalable
  END
END
HEAT TRANSFER MODEL:
  Homogeneous Model = False
  Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
  Option = None
END
TURBULENCE MODEL:
  Homogeneous Model = False

```

```

    Option = Fluid Dependent
END
END
FLUID PAIR: Liquid | Vapor
Surface Tension Coefficient = 0.013472 [N m^-1]
INTERPHASE HEAT TRANSFER:
    Option = Two Resistance
    FLUID1 INTERPHASE HEAT TRANSFER:
        Option = Zero Resistance
    END
    FLUID2 INTERPHASE HEAT TRANSFER:
        Option = Ranz Marshall
    END
END
INTERPHASE TRANSFER MODEL:
    Option = Particle Model
END
MASS TRANSFER:
    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None
    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
MULTIPHASE MODELS:
    Homogeneous Model = False
    FREE SURFACE MODEL:
        Option = None
    END
END
DOMAIN: Domain 1
Coord Frame = Coord 0
Domain Type = Fluid
Location = B62
BOUNDARY MODELS:
    WALL BOILING MODEL:
        Option = None
    END

```

```

END
BOUNDARY: Domain 1 Default
  Boundary Type = WALL
  Location = F63.62
  BOUNDARY CONDITIONS:
    HEAT TRANSFER:
      Option = Adiabatic
    END
    MASS AND MOMENTUM:
      Option = Fluid Dependent
    END
    WALL CONTACT MODEL:
      Option = Use Volume Fraction
    END
    WALL ROUGHNESS:
      Option = Smooth Wall
    END
  END
FLUID: Liquid
  BOUNDARY CONDITIONS:
    MASS AND MOMENTUM:
      Option = No Slip Wall
    END
  END
FLUID: Vapor
  BOUNDARY CONDITIONS:
    MASS AND MOMENTUM:
      Option = No Slip Wall
    END
  END
END
BOUNDARY: Domain Interface 1 in Domain 1 Side 2
  Boundary Type = INTERFACE
  Location = F64.62
  BOUNDARY CONDITIONS:
    HEAT TRANSFER:
      Option = Conservative Interface Flux
    END
    MASS AND MOMENTUM:
      Option = Conservative Interface Flux
    END
    TURBULENCE:
      Option = Conservative Interface Flux
    END
  END
END
BOUNDARY: Outlet1
  Boundary Type = OUTLET
  Location = TrapOutlet1
  BOUNDARY CONDITIONS:
    FLOW REGIME:
      Option = Subsonic
    END
    MASS AND MOMENTUM:
      Option = Fluid Velocity
    END
  END
FLUID: Liquid
  BOUNDARY CONDITIONS:
    VELOCITY:

```

```

        Normal Speed = 0.0559 [m s-1]
        Option = Normal Speed
    END
END
FLUID: Vapor
    BOUNDARY CONDITIONS:
        VELOCITY:
            Normal Speed = 0 [m s-1]
            Option = Normal Speed
        END
    END
END
DOMAIN MODELS:
    BUOYANCY MODEL:
        Buoyancy Reference Density = 0 [kg m-3]
        Gravity X Component = 0 [m s-2]
        Gravity Y Component = -9.81 [m s-2]
        Gravity Z Component = 0 [m s-2]
        Option = Buoyant
        BUOYANCY REFERENCE LOCATION:
            Option = Automatic
        END
    END
    DOMAIN MOTION:
        Option = Stationary
    END
    MESH DEFORMATION:
        Option = None
    END
    REFERENCE PRESSURE:
        Reference Pressure = 0 [MPa]
    END
END
FLUID DEFINITION: Liquid
    Material = LiquidConst
    Option = Material Library
    MORPHOLOGY:
        Mean Diameter = 1 [micron]
        Minimum Volume Fraction = 1e-9
        Option = Dispersed Fluid
    END
END
FLUID DEFINITION: Vapor
    Material = VaporConst
    Option = Material Library
    MORPHOLOGY:
        Minimum Volume Fraction = 1e-9
        Option = Continuous Fluid
    END
END
FLUID MODELS:
    ADDITIONAL VARIABLE: MassTotal
        Option = Fluid Dependent
    END
    COMBUSTION MODEL:
        Option = None
    END
    FLUID: Liquid
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \

```

```

        *Volume Fraction
        Option = Algebraic Equation
    END
    FLUID BUOYANCY MODEL:
        Option = Density Difference
    END
    HEAT TRANSFER MODEL:
        Option = Thermal Energy
    END
    TURBULENCE MODEL:
        Option = Laminar
    END
END
FLUID: Vapor
    ADDITIONAL VARIABLE: MassTotal
        Additional Variable Value = Volume of Finite Volumes *Density \
        *Volume Fraction
        Option = Algebraic Equation
    END
    FLUID BUOYANCY MODEL:
        Option = Density Difference
    END
    HEAT TRANSFER MODEL:
        Option = Thermal Energy
    END
    TURBULENCE MODEL:
        Option = k epsilon
        BUOYANCY TURBULENCE:
            Option = None
        END
    END
    TURBULENT WALL FUNCTIONS:
        Option = Scalable
    END
END
HEAT TRANSFER MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
    Option = None
END
TURBULENCE MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
FLUID PAIR: Liquid | Vapor
    Surface Tension Coefficient = 0.013472 [N m^-1]
    INTERPHASE HEAT TRANSFER:
        Option = Two Resistance
        FLUID1 INTERPHASE HEAT TRANSFER:
            Option = Zero Resistance
        END
        FLUID2 INTERPHASE HEAT TRANSFER:
            Option = Ranz Marshall
        END
    END
    INTERPHASE TRANSFER MODEL:
        Option = Particle Model
    END
    MASS TRANSFER:

```

```

    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None
    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
MULTIPHASE MODELS:
    Homogeneous Model = False
    FREE SURFACE MODEL:
        Option = None
    END
END
DOMAIN: Domain 2
    Coord Frame = Coord 0
    Domain Type = Fluid
    Location = B68
    BOUNDARY MODELS:
        WALL BOILING MODEL:
            Option = None
        END
    END
    BOUNDARY: Domain 2 Default
        Boundary Type = WALL
        Location = F69.68
        BOUNDARY CONDITIONS:
            HEAT TRANSFER:
                Option = Adiabatic
            END
            MASS AND MOMENTUM:
                Option = Fluid Dependent
            END
            WALL CONTACT MODEL:
                Option = Use Volume Fraction
            END
            WALL ROUGHNESS:
                Option = Smooth Wall
            END
        END
    END
END

```

```

FLUID: Liquid
  BOUNDARY CONDITIONS:
    MASS AND MOMENTUM:
      Option = No Slip Wall
    END
  END
END
FLUID: Vapor
  BOUNDARY CONDITIONS:
    MASS AND MOMENTUM:
      Option = No Slip Wall
    END
  END
END
BOUNDARY: Domain Interface 1 in Domain 2 Side 2
  Boundary Type = INTERFACE
  Location = F71.68
  BOUNDARY CONDITIONS:
    HEAT TRANSFER:
      Option = Conservative Interface Flux
    END
    MASS AND MOMENTUM:
      Option = Conservative Interface Flux
    END
    TURBULENCE:
      Option = Conservative Interface Flux
    END
  END
END
BOUNDARY: Outlet2
  Boundary Type = OUTLET
  Location = TrapOutlet2
  BOUNDARY CONDITIONS:
    FLOW REGIME:
      Option = Subsonic
    END
    MASS AND MOMENTUM:
      Option = Fluid Velocity
    END
  END
FLUID: Liquid
  BOUNDARY CONDITIONS:
    VELOCITY:
      Normal Speed = 0.0559 [m s-1]
      Option = Normal Speed
    END
  END
END
FLUID: Vapor
  BOUNDARY CONDITIONS:
    VELOCITY:
      Normal Speed = 0 [m s-1]
      Option = Normal Speed
    END
  END
END
DOMAIN MODELS:
  BUOYANCY MODEL:
    Buoyancy Reference Density = 0 [kg m-3]
    Gravity X Component = 0 [m s-2]

```

```

Gravity Y Component = -9.81 [m s^-2]
Gravity Z Component = 0 [m s^-2]
Option = Buoyant
BUOYANCY REFERENCE LOCATION:
    Option = Automatic
END
END
DOMAIN MOTION:
    Option = Stationary
END
MESH DEFORMATION:
    Option = None
END
REFERENCE PRESSURE:
    Reference Pressure = 0 [MPa]
END
END
FLUID DEFINITION: Liquid
    Material = LiquidConst
    Option = Material Library
MORPHOLOGY:
    Mean Diameter = 1 [micron]
    Minimum Volume Fraction = 1e-9
    Option = Dispersed Fluid
END
END
FLUID DEFINITION: Vapor
    Material = VaporConst
    Option = Material Library
MORPHOLOGY:
    Minimum Volume Fraction = 1e-9
    Option = Continuous Fluid
END
END
FLUID MODELS:
    ADDITIONAL VARIABLE: MassTotal
        Option = Fluid Dependent
    END
    COMBUSTION MODEL:
        Option = None
    END
    FLUID: Liquid
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation
        END
        FLUID BUOYANCY MODEL:
            Option = Density Difference
        END
        HEAT TRANSFER MODEL:
            Option = Thermal Energy
        END
        TURBULENCE MODEL:
            Option = Laminar
        END
    END
    FLUID: Vapor
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation

```

```

END
FLUID BUOYANCY MODEL:
    Option = Density Difference
END
HEAT TRANSFER MODEL:
    Option = Thermal Energy
END
TURBULENCE MODEL:
    Option = k epsilon
    BUOYANCY TURBULENCE:
        Option = None
    END
END
TURBULENT WALL FUNCTIONS:
    Option = Scalable
END
END
HEAT TRANSFER MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
    Option = None
END
TURBULENCE MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
END
FLUID PAIR: Liquid | Vapor
Surface Tension Coefficient = 0.013472 [N m^-1]
INTERPHASE HEAT TRANSFER:
    Option = Two Resistance
    FLUID1 INTERPHASE HEAT TRANSFER:
        Option = Zero Resistance
    END
    FLUID2 INTERPHASE HEAT TRANSFER:
        Option = Ranz Marshall
    END
END
INTERPHASE TRANSFER MODEL:
    Option = Particle Model
END
MASS TRANSFER:
    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None

```

```

        END
        WALL LUBRICATION FORCE:
            Option = None
        END
    END
    TURBULENCE TRANSFER:
        ENHANCED TURBULENCE PRODUCTION MODEL:
            Option = None
        END
    END
    MULTIPHASE MODELS:
        Homogeneous Model = False
        FREE SURFACE MODEL:
            Option = None
        END
    END
    DOMAIN INTERFACE: Domain Interface 1
        Boundary List1 = Domain Interface 1 Side 1
        Boundary List2 = Domain Interface 1 in Domain 1 Side 2, Domain Interface 1 \
            in Domain 2 Side 2
        Interface Type = Fluid Fluid
        INTERFACE MODELS:
            Option = General Connection
            FRAME CHANGE:
                Option = None
            END
            MASS AND MOMENTUM:
                Option = Conservative Interface Flux
            MOMENTUM INTERFACE MODEL:
                Option = None
            END
        END
        PITCH CHANGE:
            Option = None
        END
    END
    MESH CONNECTION:
        Option = GGI
    END
    OUTPUT CONTROL:
        BACKUP DATA RETENTION:
            Option = Delete Old Files
        END
        BACKUP RESULTS: Backup Results 1
            File Compression Level = Default
            Option = Standard
            Output Equation Residuals = All
        OUTPUT FREQUENCY:
            Iteration Interval = 300
            Option = Iteration Interval
        END
    END
    MONITOR OBJECTS:
        MONITOR BALANCES:
            Option = Full
        END
        MONITOR FORCES:
            Option = Full
        END
    END

```

```

MONITOR PARTICLES:
  Option = Full
END
MONITOR POINT: CourantAveMon
  Coord Frame = Coord 0
  Expression Value = CourantAve
  Option = Expression
END
MONITOR POINT: CourantMaxMon
  Coord Frame = Coord 0
  Expression Value = CourantMax
  Option = Expression
END
MONITOR POINT: CourantRMSMon
  Coord Frame = Coord 0
  Expression Value = CourantRMS
  Option = Expression
END
MONITOR POINT: Inlet Pressure
  Coord Frame = Coord 0
  Expression Value = areaAve(Pressure)@Inlet
  Option = Expression
END
MONITOR POINT: Inlet Quality
  Coord Frame = Coord 0
  Expression Value = QualityInlet
  Option = Expression
END
MONITOR POINT: Liquid Inlet Velocity
  Coord Frame = Coord 0
  Expression Value = LiquidVelInlet
  Option = Expression
END
MONITOR POINT: Liquid Mass
  Coord Frame = Coord 0
  Expression Value = SumLiqMassTotal
  Option = Expression
END
MONITOR POINT: Liquid Outlet Velocity
  Coord Frame = Coord 0
  Expression Value = LiquidVelOutlet
  Option = Expression
END
MONITOR POINT: Mass Flow Rate In
  Coord Frame = Coord 0
  Expression Value = MassFlowInlet
  Option = Expression
END
MONITOR POINT: Mass Flow Rate Out
  Coord Frame = Coord 0
  Expression Value = MassFlowOutlet
  Option = Expression
END
MONITOR POINT: MassFlowTrap1Mon
  Coord Frame = Coord 0
  Expression Value = MassFlowTrap1
  Option = Expression
END
MONITOR POINT: MassFlowTrap2Mon
  Coord Frame = Coord 0
  Expression Value = MassFlowTrap2
  Option = Expression

```

```

END
MONITOR POINT: Outlet Pressure
  Coord Frame = Coord 0
  Expression Value = areaAve(Pressure)@Outlet
  Option = Expression
END
MONITOR POINT: Outlet Quality
  Coord Frame = Coord 0
  Expression Value = QualityOutlet
  Option = Expression
END
MONITOR POINT: Outlet Temperature
  Coord Frame = Coord 0
  Expression Value = massFlowAve(Temperature)@Outlet
  Option = Expression
END
MONITOR POINT: Saturation Temp
  Coord Frame = Coord 0
  Expression Value = massFlowAve(Liquid | Vapor.Saturation \
    Temperature)@Outlet
  Option = Expression
END
MONITOR POINT: Trap1LiqMassMon
  Coord Frame = Coord 0
  Expression Value = Trap1LiqMass
  Option = Expression
END
MONITOR POINT: Trap2LiqMassMon
  Coord Frame = Coord 0
  Expression Value = Trap2LiqMass
  Option = Expression
END
MONITOR POINT: Vapor Inlet Velocity
  Coord Frame = Coord 0
  Expression Value = VaporVelInlet
  Option = Expression
END
MONITOR POINT: Vapor Outlet Velocity
  Coord Frame = Coord 0
  Expression Value = VaporVelOutlet
  Option = Expression
END
MONITOR RESIDUALS:
  Option = Full
END
MONITOR TOTALS:
  Option = Full
END
RESULTS:
  File Compression Level = Default
  Option = Standard
  Output Equation Residuals = All
END
SOLVER CONTROL:
  Turbulence Numerics = High Resolution
ADVECTION SCHEME:
  Option = High Resolution
END
CONVERGENCE CONTROL:
  Length Scale Option = Conservative

```

```
Maximum Number of Iterations = 70000
Minimum Number of Iterations = 1
Timescale Control = Auto Timescale
Timescale Factor = 0.01
END
CONVERGENCE CRITERIA:
  Residual Target = 1e-15
  Residual Type = RMS
END
DYNAMIC MODEL CONTROL:
  Global Dynamic Model Control = On
END
INTERRUPT CONTROL:
  Option = Any Interrupt
  CONVERGENCE CONDITIONS:
    Option = Default Conditions
  END
END
END
COMMAND FILE:
  Version = 22.1
END
```

## APPENDIX K. CCL FILE FOR FULL GEOMETRY INLET QUALITY TRANSIENT

The following is a CCL file that describes the boundary conditions and expressions used for the transient inlet quality analysis. This file is exported from CFX-Pre.

LIBRARY:

CEL:

EXPRESSIONS:

```

CourantAve = ave(Courant Number )@Default Domain
CourantMax = maxVal(Courant Number )@Default Domain
CourantRMS = rmsAve(Courant Number )@Default Domain
LiquidRamp = 1-VaporRamp
LiquidVFinlet = 1-VaporVFinlet
LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
MassFlowInlet = massFlow()@Inlet
MassFlowOutlet = -massFlow()@Outlet
Press = 2.6389[MPa]
QualityEquilInlet = \
    ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
    t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityEquilOutlet = \
    ((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
    t ) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityInlet = \
    Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
QualityOutlet = \
    Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
    let)
SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain
Tsat = \
    1[K]*(0.5*(650.17534844798+((2*((-724213.16703206*((Press/1[MPa])^0.25\
    )^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))/(-(11\
    67.0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa]\
    )^0.25))-4823.2657361591)-((1167.0521452767*((Press/1[MPa])^0.25)^2)+\
    (12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)^2-(4*((Press\
    /1[MPa])^0.25)^2+(-17.073846940092*((Press/1[MPa])^0.25))+14.915108613\
    530)*((-724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((P\
    ress/1[MPa])^0.25))+405113.40542057)))^0.5)-((650.17534844798+((2*((-\
    724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[M\
    Pa])^0.25))+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25\
    )^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.\
    0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0\
    .25))-4823.2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092\
    *((Press/1[MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[\
    MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.4054205\
    7)))^0.5)))^2-4*(-0.2385557567849+(650.17534844798*((2*((-724213.1670\
    3206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25)\
    +405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25)^2)+(12020\
    .824702470*((Press/1[MPa])^0.25))-4823.2657361591)-((1167.0521452767*\
    ((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.\
    2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[\
    MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[MPa])^0.25)\
    ^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))^0.5)))\
    )^0.5))

```

```

VaporRamp = if(Time <1[s],0.9999, VaporRamp2)
VaporRamp2 = if(Time <21[s],0.9999-(dQuality*(Time-1[s])/1[s]), \
    VaporRamp3)
VaporRamp3 = if(Time <41[s],0.9972+(dQuality*(Time-21[s])/1[s]), \
    VaporRamp4)
VaporRamp4 = 0.9999
VaporVFINlet = if(Accumulated Iteration Number <= 100, \
    .9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
WallHeatFlux = if(Accumulated Iteration Number <=250, \
    0[W/m^2]-(Accumulated Iteration Number*123.6)[W/m^2], -30900[W/m^2])
WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
    Iteration Number*0.008)[K], 498[K])
dQuality = (0.0028-0.0001)/20
END
END
ADDITIONAL VARIABLE: MassTotal
Option = Definition
Tensor Type = SCALAR
Units = [kg]
Variable Type = Specific
END
MATERIAL GROUP: Air Data
Group Description = Ideal gas and constant property air. Constant \
    properties are for dry air at STP (0 C, 1 atm) and 25 C, 1 atm.
END
MATERIAL GROUP: CHT Solids
Group Description = Pure solid substances that can be used for conjugate \
    heat transfer.
END
MATERIAL GROUP: Calorically Perfect Ideal Gases
Group Description = Ideal gases with constant specific heat capacity. \
    Specific heat is evaluated at STP.
END
MATERIAL GROUP: Constant Property Gases
Group Description = Gaseous substances with constant properties. \
    Properties are calculated at STP (0C and 1 atm). Can be combined with \
    NASA SP-273 materials for combustion modelling.
END
MATERIAL GROUP: Constant Property Liquids
Group Description = Liquid substances with constant properties.
END
MATERIAL GROUP: Dry Peng Robinson
Group Description = Materials with properties specified using the built \
    in Peng Robinson equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Redlich Kwong
Group Description = Materials with properties specified using the built \
    in Redlich Kwong equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Soave Redlich Kwong
Group Description = Materials with properties specified using the built \
    in Soave Redlich Kwong equation of state. Suitable for dry real gas \
    modelling.
END
MATERIAL GROUP: Dry Steam
Group Description = Materials with properties specified using the IAPWS \
    equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Gas Phase Combustion
Group Description = Ideal gas materials which can be use for gas phase \

```

```

        combustion. Ideal gas specific heat coefficients are specified using \
        the NASA SP-273 format.
END
MATERIAL GROUP: IAPWS IF97
    Group Description = Liquid, vapour and binary mixture materials which use \
    the IAPWS IF-97 equation of state. Materials are suitable for \
    compressible liquids, phase change calculations and dry steam flows.
END
MATERIAL GROUP: Interphase Mass Transfer
    Group Description = Materials with reference properties suitable for \
    performing either Eulerian or Lagrangian multiphase mass transfer \
    problems. Examples include cavitation, evaporation or condensation.
END
MATERIAL GROUP: Liquid Phase Combustion
    Group Description = Liquid and homogenous binary mixture materials which \
    can be included with Gas Phase Combustion materials if combustion \
    modelling also requires phase change (eg: evaporation) for certain \
    components.
END
MATERIAL GROUP: Particle Solids
    Group Description = Pure solid substances that can be used for particle \
    tracking
END
MATERIAL GROUP: Peng Robinson Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Peng Robinson Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Refrigerants
    Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Steam
    Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Real Gas Combustion
    Group Description = Real gas materials which can be use for gas phase \
    combustion. Ideal gas specific heat coefficients are specified using \
    the NASA SP-273 format.
END
MATERIAL GROUP: Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Steam
    Group Description = Water materials which use the Redlich Kwong equation \

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```

    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Steam
    Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
    equation of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soot
    Group Description = Solid substances that can be used when performing \
    soot modelling
END
MATERIAL GROUP: User
    Group Description = Materials that are defined by the user
END
MATERIAL GROUP: Water Data
    Group Description = Liquid and vapour water materials with constant \
    properties. Can be combined with NASA SP-273 materials for combustion \
    modelling.
END
MATERIAL GROUP: Wet Peng Robinson
    Group Description = Materials with properties specified using the built \
    in Peng Robinson equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Redlich Kwong equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
    in Soave Redlich Kwong equation of state. Suitable for wet real gas \
    modelling.

```

```

END
MATERIAL GROUP: Wet Steam
  Group Description = Materials with properties specified using the IAPWS \
    equation of state. Suitable for wet steam modelling.
END
MATERIAL: Air Ideal Gas
  Material Description = Air Ideal Gas (constant Cp)
  Material Group = Air Data, Calorically Perfect Ideal Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
  EQUATION OF STATE:
    Molar Mass = 28.96 [kg kmol-1]
    Option = Ideal Gas
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0. [J/kg]
    Reference Specific Entropy = 0. [J/kg/K]
    Reference Temperature = 25 [C]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.831E-05 [kg m-1 s-1]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 2.61E-2 [W m-1 K-1]
  END
  ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0.01 [m-1]
    Option = Value
  END
  SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m-1]
  END
  REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m-1]
  END
END
MATERIAL: Air at 25 C
  Material Description = Air at 25 C and 1 atm (dry)
  Material Group = Air Data, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
  EQUATION OF STATE:
    Density = 1.185 [kg m-3]
    Molar Mass = 28.96 [kg kmol-1]
    Option = Value
  END

```

```

SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1 [atm]
  Reference Specific Enthalpy = 0. [J/kg]
  Reference Specific Entropy = 0. [J/kg/K]
  Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 1.831E-05 [kg m-1 s-1]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 2.61E-02 [W m-1 K-1]
END
ABSORPTION COEFFICIENT:
  Absorption Coefficient = 0.01 [m-1]
  Option = Value
END
SCATTERING COEFFICIENT:
  Option = Value
  Scattering Coefficient = 0.0 [m-1]
END
REFRACTIVE INDEX:
  Option = Value
  Refractive Index = 1.0 [m m-1]
END
THERMAL EXPANSIVITY:
  Option = Value
  Thermal Expansivity = 0.003356 [K-1]
END
END
MATERIAL: Aluminium
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
  EQUATION OF STATE:
    Density = 2702 [kg m-3]
    Molar Mass = 26.98 [kg kmol-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 9.03E+02 [J kg-1 K-1]
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Specific Enthalpy = 0 [J/kg]
    Reference Specific Entropy = 0 [J/kg/K]
    Reference Temperature = 25 [C]
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 237 [W m-1 K-1]

```

```

END
END
END
MATERIAL: Copper
Material Group = CHT Solids, Particle Solids
Option = Pure Substance
Thermodynamic State = Solid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 8933 [kg m^-3]
Molar Mass = 63.55 [kg kmol^-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 3.85E+02 [J kg^-1 K^-1]
END
REFERENCE STATE:
Option = Specified Point
Reference Specific Enthalpy = 0 [J/kg]
Reference Specific Entropy = 0 [J/kg/K]
Reference Temperature = 25 [C]
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 401.0 [W m^-1 K^-1]
END
END
MATERIAL: LiquidConst
Material Group = Constant Property Liquids, Wet Steam
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 831.318 [kg m^-3]
Molar Mass = 18.02 [kg kmol^-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 4659 [J kg^-1 K^-1]
Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
Option = Specified Point
Reference Pressure = 2.6389 [MPa]
Reference Specific Enthalpy = 975465 [J kg^-1]
Reference Specific Entropy = 2581.1 [J kg^-1 K^-1]
Reference Temperature = 500 [K]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 0.0001179 [Pa s]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 0.6421 [W m^-1 K^-1]
END
END

```

```

END
MATERIAL: LiquidVar
  Material Group = IAPWS IF97,Wet Steam
  Option = Pure Substance
  Thermodynamic State = Liquid
  PROPERTIES:
    Option = IAPWS Library
    REFERENCE STATE:
      Option = Automatic
  END
  TABLE GENERATION:
    Maximum Absolute Pressure = 12.345 [MPa]
    Maximum Points = 100
    Maximum Temperature = 600 [K]
    Minimum Absolute Pressure = 0.0035368 [MPa]
    Minimum Temperature = 300 [K]
    Pressure Extrapolation = On
    Temperature Extrapolation = Yes
  END
END
MATERIAL: Soot
  Material Group = Soot
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 2000 [kg m-3]
      Molar Mass = 12 [kg kmol-1]
      Option = Value
  END
  REFERENCE STATE:
    Option = Automatic
  END
  ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0 [m-1]
    Option = Value
  END
END
MATERIAL: Steel
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 7854 [kg m-3]
      Molar Mass = 55.85 [kg kmol-1]
      Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 4.34E+02 [J kg-1 K-1]
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Specific Enthalpy = 0 [J/kg]
    Reference Specific Entropy = 0 [J/kg/K]
    Reference Temperature = 25 [C]
  END

```

```

THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 60.5 [W m^-1 K^-1]
END
END
MATERIAL: VaporConst
  Material Group = Wet Steam,Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
  EQUATION OF STATE:
    Density = 13.1976 [kg m^-3]
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 3462.6 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 2.6389 [MPa]
    Reference Specific Enthalpy = 2802590 [J kg^-1]
    Reference Specific Entropy = 6235.4 [J kg^-1 K^-1]
    Reference Temperature = 500 [K]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.6594e-5 [Pa s]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.044952 [W m^-1 K^-1]
  END
  THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 0.001686 [K^-1]
  END
END
MATERIAL: VaporVar
  Material Group = IAPWS IF97,Wet Steam
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = IAPWS Library
  REFERENCE STATE:
    Option = Automatic
  END
  TABLE GENERATION:
    Maximum Absolute Pressure = 12.345 [MPa]
    Maximum Points = 1000
    Maximum Temperature = 600 [K]
    Minimum Absolute Pressure = 0.0035368 [MPa]
    Minimum Temperature = 300 [K]
    Pressure Extrapolation = On
    Temperature Extrapolation = Yes
  END
END

```

```

END
MATERIAL: Water
  Material Description = Water (liquid)
  Material Group = Water Data, Constant Property Liquids
  Option = Pure Substance
  Thermodynamic State = Liquid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 997.0 [kg m-3]
      Molar Mass = 18.02 [kg kmol-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 4181.7 [J kg-1 K-1]
      Specific Heat Type = Constant Pressure
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Pressure = 1 [atm]
      Reference Specific Enthalpy = 0.0 [J/kg]
      Reference Specific Entropy = 0.0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
    DYNAMIC VISCOSITY:
      Dynamic Viscosity = 8.899E-4 [kg m-1 s-1]
      Option = Value
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 0.6069 [W m-1 K-1]
    END
    ABSORPTION COEFFICIENT:
      Absorption Coefficient = 1.0 [m-1]
      Option = Value
    END
    SCATTERING COEFFICIENT:
      Option = Value
      Scattering Coefficient = 0.0 [m-1]
    END
    REFRACTIVE INDEX:
      Option = Value
      Refractive Index = 1.0 [m m-1]
    END
    THERMAL EXPANSIVITY:
      Option = Value
      Thermal Expansivity = 2.57E-04 [K-1]
    END
  END
END
MATERIAL: Water Ideal Gas
  Material Description = Water Vapour Ideal Gas (100 C and 1 atm)
  Material Group = Calorically Perfect Ideal Gases, Water Data
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Molar Mass = 18.02 [kg kmol-1]
      Option = Ideal Gas
    END

```

```

SPECIFIC HEAT CAPACITY:
  Option = Value
  Specific Heat Capacity = 2080.1 [J kg-1 K-1]
  Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
  Option = Specified Point
  Reference Pressure = 1.014 [bar]
  Reference Specific Enthalpy = 0. [J/kg]
  Reference Specific Entropy = 0. [J/kg/K]
  Reference Temperature = 100 [C]
END
DYNAMIC VISCOSITY:
  Dynamic Viscosity = 9.4E-06 [kg m-1 s-1]
  Option = Value
END
THERMAL CONDUCTIVITY:
  Option = Value
  Thermal Conductivity = 193E-04 [W m-1 K-1]
END
ABSORPTION COEFFICIENT:
  Absorption Coefficient = 1.0 [m-1]
  Option = Value
END
SCATTERING COEFFICIENT:
  Option = Value
  Scattering Coefficient = 0.0 [m-1]
END
REFRACTIVE INDEX:
  Option = Value
  Refractive Index = 1.0 [m m-1]
END
END
END
END
FLOW: Flow Analysis 1
  SOLUTION UNITS:
    Angle Units = [rad]
    Length Units = [m]
    Mass Units = [kg]
    Solid Angle Units = [sr]
    Temperature Units = [K]
    Time Units = [s]
  END
  ANALYSIS TYPE:
    Option = Transient
  EXTERNAL SOLVER COUPLING:
    Option = None
  END
  INITIAL TIME:
    Option = Automatic with Value
    Time = 0 [s]
  END
  TIME DURATION:
    Option = Total Time
    Total Time = 50 [s]
  END
  TIME STEPS:
    Option = Timesteps
    Timesteps = 0.001 [s]
  END
END
END

```

```

DOMAIN: Default Domain
Coord Frame = Coord 0
Domain Type = Fluid
Location = B4
BOUNDARY MODELS:
    WALL BOILING MODEL:
        Option = None
    END
END
BOUNDARY: Default Domain Default
Boundary Type = OUTLET
Location = F24.4,F41.4
BOUNDARY CONDITIONS:
    FLOW REGIME:
        Option = Subsonic
    END
    MASS AND MOMENTUM:
        Option = Fluid Velocity
    END
END
FLUID: Liquid
BOUNDARY CONDITIONS:
    VELOCITY:
        Normal Speed = 0.02 [m s-1]
        Option = Normal Speed
    END
END
FLUID: Vapor
BOUNDARY CONDITIONS:
    VELOCITY:
        Normal Speed = 0 [m s-1]
        Option = Normal Speed
    END
END
BOUNDARY: Inlet
Boundary Type = INLET
Location = Inlet
BOUNDARY CONDITIONS:
    FLOW REGIME:
        Option = Subsonic
    END
    HEAT TRANSFER:
        Option = Static Temperature
        Static Temperature = 500 [K]
    END
    MASS AND MOMENTUM:
        Normal Speed = 40 [m s-1]
        Option = Normal Speed
    END
    TURBULENCE:
        Option = Medium Intensity and Eddy Viscosity Ratio
    END
END
FLUID: Liquid
BOUNDARY CONDITIONS:
    VOLUME FRACTION:
        Option = Value
        Volume Fraction = LiquidRamp
    END

```

```

    END
  END
  FLUID: Vapor
  BOUNDARY CONDITIONS:
    VOLUME FRACTION:
      Option = Value
      Volume Fraction = VaporRamp
    END
  END
END
BOUNDARY: Outlet
Boundary Type = OUTLET
Location = Outlet
BOUNDARY CONDITIONS:
  FLOW REGIME:
    Option = Subsonic
  END
  MASS AND MOMENTUM:
    Option = Average Static Pressure
    Pressure Profile Blend = 0.05
    Relative Pressure = 2.6389 [MPa]
  END
  PRESSURE AVERAGING:
    Option = Average Over Whole Outlet
  END
END
BOUNDARY: Wall
Boundary Type = WALL
Location = Wall
BOUNDARY CONDITIONS:
  HEAT TRANSFER:
    Option = Adiabatic
  END
  MASS AND MOMENTUM:
    Option = No Slip Wall
  END
  WALL CONTACT MODEL:
    Option = Use Volume Fraction
  END
  WALL ROUGHNESS:
    Option = Smooth Wall
  END
END
DOMAIN MODELS:
  BUOYANCY MODEL:
    Buoyancy Reference Density = 0 [kg m-3]
    Gravity X Component = 0 [m s-2]
    Gravity Y Component = -9.81 [m s-2]
    Gravity Z Component = 0 [m s-2]
    Option = Buoyant
    BUOYANCY REFERENCE LOCATION:
      Option = Automatic
    END
  END
  DOMAIN MOTION:
    Option = Stationary
  END
  MESH DEFORMATION:
    Option = None

```

```

END
REFERENCE PRESSURE:
    Reference Pressure = 0 [MPa]
END
END
FLUID DEFINITION: Liquid
    Material = LiquidConst
    Option = Material Library
MORPHOLOGY:
    Mean Diameter = 1 [micron]
    Minimum Volume Fraction = 1e-9
    Option = Dispersed Fluid
END
END
FLUID DEFINITION: Vapor
    Material = VaporConst
    Option = Material Library
MORPHOLOGY:
    Minimum Volume Fraction = 1e-9
    Option = Continuous Fluid
END
END
FLUID MODELS:
    ADDITIONAL VARIABLE: MassTotal
        Option = Fluid Dependent
    END
    COMBUSTION MODEL:
        Option = None
    END
    FLUID: Liquid
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation
        END
        FLUID BUOYANCY MODEL:
            Option = Density Difference
        END
        HEAT TRANSFER MODEL:
            Option = Thermal Energy
        END
        TURBULENCE MODEL:
            Option = Laminar
        END
    END
    FLUID: Vapor
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation
        END
        FLUID BUOYANCY MODEL:
            Option = Density Difference
        END
        HEAT TRANSFER MODEL:
            Option = Thermal Energy
        END
        TURBULENCE MODEL:
            Option = k epsilon
        BUOYANCY TURBULENCE:
            Option = None
        END

```

```

END
TURBULENT WALL FUNCTIONS:
    Option = Scalable
END
END
HEAT TRANSFER MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
    Option = None
END
TURBULENCE MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
END
FLUID PAIR: Liquid | Vapor
Surface Tension Coefficient = 0.013472 [N m^-1]
INTERPHASE HEAT TRANSFER:
    Option = Two Resistance
    FLUID1 INTERPHASE HEAT TRANSFER:
        Option = Zero Resistance
    END
    FLUID2 INTERPHASE HEAT TRANSFER:
        Option = Ranz Marshall
    END
END
INTERPHASE TRANSFER MODEL:
    Option = Particle Model
END
MASS TRANSFER:
    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None
    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
END
INITIALISATION:

```

```

Option = Automatic
FLUID: Liquid
  INITIAL CONDITIONS:
    Velocity Type = Cartesian
    CARTESIAN VELOCITY COMPONENTS:
      Option = Automatic with Value
      U = 40 [m s-1]
      V = 0 [m s-1]
      W = 0 [m s-1]
    END
    TEMPERATURE:
      Option = Automatic with Value
      Temperature = 500 [K]
    END
    VOLUME FRACTION:
      Option = Automatic with Value
      Volume Fraction = 0.0001
    END
  END
FLUID: Vapor
  INITIAL CONDITIONS:
    Velocity Type = Cartesian
    CARTESIAN VELOCITY COMPONENTS:
      Option = Automatic with Value
      U = 40 [m s-1]
      V = 0 [m s-1]
      W = 0 [m s-1]
    END
    TEMPERATURE:
      Option = Automatic with Value
      Temperature = 500 [K]
    END
    TURBULENCE INITIAL CONDITIONS:
      Option = Medium Intensity and Eddy Viscosity Ratio
    END
    VOLUME FRACTION:
      Option = Automatic with Value
      Volume Fraction = 0.9999
    END
  END
  INITIAL CONDITIONS:
    STATIC PRESSURE:
      Option = Automatic with Value
      Relative Pressure = 2.6389 [MPa]
    END
  END
MULTIPHASE MODELS:
  Homogeneous Model = False
  FREE SURFACE MODEL:
    Option = None
  END
END
OUTPUT CONTROL:
  BACKUP DATA RETENTION:
    Option = Delete Old Files
  END
  BACKUP RESULTS: Backup Results 1
  File Compression Level = Default

```

```

Option = Standard
Output Equation Residuals = All
OUTPUT FREQUENCY:
    Option = Timestep Interval
    Timestep Interval = 1000
END
END
MONITOR OBJECTS:
    MONITOR BALANCES:
        Option = Full
    END
    MONITOR FORCES:
        Option = Full
    END
    MONITOR PARTICLES:
        Option = Full
    END
    MONITOR POINT: CourantAveMon
        Coord Frame = Coord 0
        Expression Value = CourantAve
        Option = Expression
    END
    MONITOR POINT: CourantMaxMon
        Coord Frame = Coord 0
        Expression Value = CourantMax
        Option = Expression
    END
    MONITOR POINT: CourantRMSMon
        Coord Frame = Coord 0
        Expression Value = CourantRMS
        Option = Expression
    END
    MONITOR POINT: Inlet Pressure
        Coord Frame = Coord 0
        Expression Value = areaAve(Pressure)@Inlet
        Option = Expression
    END
    MONITOR POINT: Inlet Quality
        Coord Frame = Coord 0
        Expression Value = QualityInlet
        Option = Expression
    END
    MONITOR POINT: Liquid Inlet Velocity
        Coord Frame = Coord 0
        Expression Value = LiquidVelInlet
        Option = Expression
    END
    MONITOR POINT: Liquid Mass
        Coord Frame = Coord 0
        Expression Value = SumLiqMassTotal
        Option = Expression
    END
    MONITOR POINT: Liquid Outlet Velocity
        Coord Frame = Coord 0
        Expression Value = LiquidVelOutlet
        Option = Expression
    END
    MONITOR POINT: Mass Flow Rate In
        Coord Frame = Coord 0
        Expression Value = MassFlowInlet
        Option = Expression
    END
END

```

```

MONITOR POINT: Mass Flow Rate Out
  Coord Frame = Coord 0
  Expression Value = MassFlowOutlet
  Option = Expression
END
MONITOR POINT: Outlet Pressure
  Coord Frame = Coord 0
  Expression Value = areaAve(Pressure)@Outlet
  Option = Expression
END
MONITOR POINT: Outlet Quality
  Coord Frame = Coord 0
  Expression Value = QualityOutlet
  Option = Expression
END
MONITOR POINT: Outlet Temperature
  Coord Frame = Coord 0
  Expression Value = massFlowAve(Temperature)@Outlet
  Option = Expression
END
MONITOR POINT: Saturation Temp
  Coord Frame = Coord 0
  Expression Value = massFlowAve(Liquid | Vapor.Saturation \
    Temperature)@Outlet
  Option = Expression
END
MONITOR POINT: Vapor Inlet Velocity
  Coord Frame = Coord 0
  Expression Value = VaporVelInlet
  Option = Expression
END
MONITOR POINT: Vapor Outlet Velocity
  Coord Frame = Coord 0
  Expression Value = VaporVelOutlet
  Option = Expression
END
MONITOR RESIDUALS:
  Option = Full
END
MONITOR TOTALS:
  Option = Full
END
RESULTS:
  File Compression Level = Default
  Option = Standard
  Output Equation Residuals = All
END
TRANSIENT RESULTS: Transient Results 1
  File Compression Level = Default
  Option = Standard
  OUTPUT FREQUENCY:
    Option = Timestep Interval
    Timestep Interval = 100
  END
END
TRANSIENT STATISTICS: MassTotTrn
  Option = Arithmetic Average
  Output Variables List = MassTotal
END
TRANSIENT STATISTICS: PressureTrn
  Option = Arithmetic Average

```

```

    Output Variables List = Pressure
END
TRANSIENT STATISTICS: VapVolFracTrn
    Option = Arithmetic Average
    Output Variables List = Vapor.Volume Fraction
END
END
SOLVER CONTROL:
    Turbulence Numerics = High Resolution
ADVECTION SCHEME:
    Option = High Resolution
END
CONVERGENCE CONTROL:
    Maximum Number of Coefficient Loops = 6
    Minimum Number of Coefficient Loops = 1
    Timescale Control = Coefficient Loops
END
CONVERGENCE CRITERIA:
    Residual Target = 1e-15
    Residual Type = RMS
END
INTERRUPT CONTROL:
    Option = Any Interrupt
CONVERGENCE CONDITIONS:
    Option = Default Conditions
END
END
TRANSIENT SCHEME:
    Option = Second Order Backward Euler
TIMESTEP INITIALISATION:
    Option = Automatic
END
END
END
COMMAND FILE:
    Version = 22.1
END

```

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## APPENDIX L. CCL FILE FOR FULL GEOMETRY INLET PRESSURE TRANSIENT

The following is a CCL file that describes the boundary conditions and expressions used for the transient inlet pressure analysis. This file is exported from CFX-Pre.

LIBRARY:

CEL:

EXPRESSIONS:

```
CourantAve = ave(Courant Number )@Default Domain
CourantMax = maxVal(Courant Number )@Default Domain
CourantRMS = rmsAve(Courant Number )@Default Domain
InletPsetting = if(Time<30 [s], 2.64 [MPa]-(0.013333*(Time/1 \
[s]))[MPa], if(Time<60 [s], 2.24 [MPa]+(0.013333*((Time-30 [s])/1 \
[s]))[MPa], 2.64 [MPa]))
LiquidVFInlet = 1-VaporVFInlet
LiquidVelInlet = massFlowAve(Liquid.Velocity)@Inlet
LiquidVelOutlet = massFlowAve(Liquid.Velocity)@Outlet
MassFlowInlet = massFlow()@Inlet
MassFlowOutlet = -massFlow()@Outlet
OutletPsetting = InletPsetting-14.39 [kPa]
Press = 2.6389[MPa]
QualityEquilInlet = \
((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Inle\
t) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityEquilOutlet = \
((massFlowAve(Liquid.enthalpy*Liquid.mf+Vapor.enthalpy*Vapor.mf)@Outle\
t) - 975465[J kg^-1])/(2.80259e+6 [J kg^-1] -975465[J kg^-1] )
QualityInlet = \
Vapor.massFlow()@Inlet/(Vapor.massFlow()@Inlet+Liquid.massFlow()@Inlet)
QualityOutlet = \
Vapor.massFlow()@Outlet/(Vapor.massFlow()@Outlet+Liquid.massFlow()@Out\
let)
SumLiqMassTotal = sum(Liquid.MassTotal)@Default Domain
Tsat = \
1 [K]*(0.5*(650.17534844798+((2*((-724213.16703206*((Press/1[MPa])^0.25\
)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))/(-(11\
67.0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa]\
)^0.25))-4823.2657361591)-(((1167.0521452767*((Press/1[MPa])^0.25)^2)+\
(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)^2-4*((Press\
/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[MPa])^0.25))+14.915108613\
530)*((-724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((P\
ress/1[MPa])^0.25))+405113.40542057)))^0.5)-((650.17534844798+((2*((-\
724213.16703206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[M\
Pa])^0.25))+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25\
)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-(((1167.\
0521452767*((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0\
.25))-4823.2657361591)^2-4*((Press/1[MPa])^0.25)^2+(-17.073846940092\
*((Press/1[MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[\
MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.4054205\
7)))^0.5))^2-4*(-0.23855557567849+(650.17534844798*((2*((-724213.1670\
3206*((Press/1[MPa])^0.25)^2)+(-3232555.0322333*((Press/1[MPa])^0.25)\
+405113.40542057)))/(-(1167.0521452767*((Press/1[MPa])^0.25)^2)+(12020\
.824702470*((Press/1[MPa])^0.25))-4823.2657361591)-(((1167.0521452767*\
((Press/1[MPa])^0.25)^2)+(12020.824702470*((Press/1[MPa])^0.25))-4823.\
```

```

2657361591)^2-(4*((Press/1[MPa])^0.25)^2+(-17.073846940092*((Press/1[
MPa])^0.25))+14.915108613530)*((-724213.16703206*((Press/1[MPa])^0.25)\
^2)+(-3232555.0322333*((Press/1[MPa])^0.25))+405113.40542057)))^0.5))\
)^0.5))
VaporVFinlet = if(Accumulated Iteration Number <= 100, \
.9999-((Accumulated Iteration Number-300)*0.000007), 0.9992)
VaporVelInlet = massFlowAve(Vapor.Velocity)@Inlet
VaporVelOutlet = massFlowAve(Vapor.Velocity)@Outlet
WallHeatFlux = if(Accumulated Iteration Number <=250, \
0[W/m^2]-(Accumulated Iteration Number*123.6)[W/m^2], -30900[W/m^2])
WallTemp = if(Accumulated Iteration Number <=250, 500[K]-(Accumulated \
Iteration Number*0.008)[K], 498[K])
END
END
ADDITIONAL VARIABLE: MassTotal
Option = Definition
Tensor Type = SCALAR
Units = [kg]
Variable Type = Specific
END
MATERIAL GROUP: Air Data
Group Description = Ideal gas and constant property air. Constant \
properties are for dry air at STP (0 C, 1 atm) and 25 C, 1 atm.
END
MATERIAL GROUP: CHT Solids
Group Description = Pure solid substances that can be used for conjugate \
heat transfer.
END
MATERIAL GROUP: Calorically Perfect Ideal Gases
Group Description = Ideal gases with constant specific heat capacity. \
Specific heat is evaluated at STP.
END
MATERIAL GROUP: Constant Property Gases
Group Description = Gaseous substances with constant properties. \
Properties are calculated at STP (0C and 1 atm). Can be combined with \
NASA SP-273 materials for combustion modelling.
END
MATERIAL GROUP: Constant Property Liquids
Group Description = Liquid substances with constant properties.
END
MATERIAL GROUP: Dry Peng Robinson
Group Description = Materials with properties specified using the built \
in Peng Robinson equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Redlich Kwong
Group Description = Materials with properties specified using the built \
in Redlich Kwong equation of state. Suitable for dry real gas modelling.
END
MATERIAL GROUP: Dry Soave Redlich Kwong
Group Description = Materials with properties specified using the built \
in Soave Redlich Kwong equation of state. Suitable for dry real gas \
modelling.
END
MATERIAL GROUP: Dry Steam
Group Description = Materials with properties specified using the IAPWS \
equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Gas Phase Combustion
Group Description = Ideal gas materials which can be use for gas phase \
combustion. Ideal gas specific heat coefficients are specified using \
the NASA SP-273 format.
END

```

```

MATERIAL GROUP: IAPWS IF97
  Group Description = Liquid, vapour and binary mixture materials which use \
    the IAPWS IF-97 equation of state. Materials are suitable for \
    compressible liquids, phase change calculations and dry steam flows.
END
MATERIAL GROUP: Interphase Mass Transfer
  Group Description = Materials with reference properties suitable for \
    performing either Eulerian or Lagrangian multiphase mass transfer \
    problems. Examples include cavitation, evaporation or condensation.
END
MATERIAL GROUP: Liquid Phase Combustion
  Group Description = Liquid and homogenous binary mixture materials which \
    can be included with Gas Phase Combustion materials if combustion \
    modelling also requires phase change (eg: evaporation) for certain \
    components.
END
MATERIAL GROUP: Particle Solids
  Group Description = Pure solid substances that can be used for particle \
    tracking
END
MATERIAL GROUP: Peng Robinson Dry Hydrocarbons
  Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Refrigerants
  Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Peng Robinson Dry Steam
  Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Peng Robinson Wet Hydrocarbons
  Group Description = Common hydrocarbons which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Refrigerants
  Group Description = Common refrigerants which use the Peng Robinson \
    equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Peng Robinson Wet Steam
  Group Description = Water materials which use the Peng Robinson equation \
    of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Real Gas Combustion
  Group Description = Real gas materials which can be use for gas phase \
    combustion. Ideal gas specific heat coefficients are specified using \
    the NASA SP-273 format.
END
MATERIAL GROUP: Redlich Kwong Dry Hydrocarbons
  Group Description = Common hydrocarbons which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Refrigerants
  Group Description = Common refrigerants which use the Redlich Kwong \
    equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Redlich Kwong Dry Steam
  Group Description = Water materials which use the Redlich Kwong equation \
    of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Redlich Kwong Wet Hydrocarbons

```

```

    Group Description = Common hydrocarbons which use the Redlich Kwong \
        equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Redlich Kwong \
        equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Redlich Kwong Wet Steam
    Group Description = Water materials which use the Redlich Kwong equation \
        of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
        equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
        equation of state. Suitable for dry real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Dry Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
        equation of state. Suitable for dry steam modelling.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Hydrocarbons
    Group Description = Common hydrocarbons which use the Soave Redlich Kwong \
        equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Refrigerants
    Group Description = Common refrigerants which use the Soave Redlich Kwong \
        equation of state. Suitable for condensing real gas models.
END
MATERIAL GROUP: Soave Redlich Kwong Wet Steam
    Group Description = Water materials which use the Soave Redlich Kwong \
        equation of state. Suitable for condensing steam modelling.
END
MATERIAL GROUP: Soot
    Group Description = Solid substances that can be used when performing \
        soot modelling
END
MATERIAL GROUP: User
    Group Description = Materials that are defined by the user
END
MATERIAL GROUP: Water Data
    Group Description = Liquid and vapour water materials with constant \
        properties. Can be combined with NASA SP-273 materials for combustion \
        modelling.
END
MATERIAL GROUP: Wet Peng Robinson
    Group Description = Materials with properties specified using the built \
        in Peng Robinson equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Redlich Kwong equation of state. Suitable for wet real gas modelling.
END
MATERIAL GROUP: Wet Soave Redlich Kwong
    Group Description = Materials with properties specified using the built \
        in Soave Redlich Kwong equation of state. Suitable for wet real gas \
        modelling.
END
MATERIAL GROUP: Wet Steam
    Group Description = Materials with properties specified using the IAPWS \

```

```

equation of state. Suitable for wet steam modelling.
END
MATERIAL: Air Ideal Gas
Material Description = Air Ideal Gas (constant Cp)
Material Group = Air Data, Calorically Perfect Ideal Gases
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Molar Mass = 28.96 [kg kmol-1]
Option = Ideal Gas
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]
Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
Option = Specified Point
Reference Pressure = 1 [atm]
Reference Specific Enthalpy = 0. [J/kg]
Reference Specific Entropy = 0. [J/kg/K]
Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 1.831E-05 [kg m-1 s-1]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 2.61E-2 [W m-1 K-1]
END
ABSORPTION COEFFICIENT:
Absorption Coefficient = 0.01 [m-1]
Option = Value
END
SCATTERING COEFFICIENT:
Option = Value
Scattering Coefficient = 0.0 [m-1]
END
REFRACTIVE INDEX:
Option = Value
Refractive Index = 1.0 [m m-1]
END
END
MATERIAL: Air at 25 C
Material Description = Air at 25 C and 1 atm (dry)
Material Group = Air Data, Constant Property Gases
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 1.185 [kg m-3]
Molar Mass = 28.96 [kg kmol-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 1.0044E+03 [J kg-1 K-1]

```

```

    Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0. [J/kg]
    Reference Specific Entropy = 0. [J/kg/K]
    Reference Temperature = 25 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 1.831E-05 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 2.61E-02 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 0.01 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 0.003356 [K^-1]
END
END
END
MATERIAL: Aluminium
    Material Group = CHT Solids, Particle Solids
    Option = Pure Substance
    Thermodynamic State = Solid
    PROPERTIES:
        Option = General Material
        EQUATION OF STATE:
            Density = 2702 [kg m^-3]
            Molar Mass = 26.98 [kg kmol^-1]
            Option = Value
        END
        SPECIFIC HEAT CAPACITY:
            Option = Value
            Specific Heat Capacity = 9.03E+02 [J kg^-1 K^-1]
        END
        REFERENCE STATE:
            Option = Specified Point
            Reference Specific Enthalpy = 0 [J/kg]
            Reference Specific Entropy = 0 [J/kg/K]
            Reference Temperature = 25 [C]
        END
        THERMAL CONDUCTIVITY:
            Option = Value
            Thermal Conductivity = 237 [W m^-1 K^-1]
        END
    END
END
END

```

```

MATERIAL: Copper
Material Group = CHT Solids, Particle Solids
Option = Pure Substance
Thermodynamic State = Solid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 8933 [kg m^-3]
Molar Mass = 63.55 [kg kmol^-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 3.85E+02 [J kg^-1 K^-1]
END
REFERENCE STATE:
Option = Specified Point
Reference Specific Enthalpy = 0 [J/kg]
Reference Specific Entropy = 0 [J/kg/K]
Reference Temperature = 25 [C]
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 401.0 [W m^-1 K^-1]
END
END
MATERIAL: LiquidConst
Material Group = Constant Property Liquids, Wet Steam
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
Option = General Material
EQUATION OF STATE:
Density = 831.318 [kg m^-3]
Molar Mass = 18.02 [kg kmol^-1]
Option = Value
END
SPECIFIC HEAT CAPACITY:
Option = Value
Specific Heat Capacity = 4659 [J kg^-1 K^-1]
Specific Heat Type = Constant Pressure
END
REFERENCE STATE:
Option = Specified Point
Reference Pressure = 2.6389 [MPa]
Reference Specific Enthalpy = 975465 [J kg^-1]
Reference Specific Entropy = 2581.1 [J kg^-1 K^-1]
Reference Temperature = 500 [K]
END
DYNAMIC VISCOSITY:
Dynamic Viscosity = 0.0001179 [Pa s]
Option = Value
END
THERMAL CONDUCTIVITY:
Option = Value
Thermal Conductivity = 0.6421 [W m^-1 K^-1]
END
END
MATERIAL: LiquidVar
Material Group = IAPWS IF97, Wet Steam

```

```

Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
  Option = IAPWS Library
  REFERENCE STATE:
    Option = Automatic
  END
  TABLE GENERATION:
    Maximum Absolute Pressure = 12.345 [MPa]
    Maximum Points = 100
    Maximum Temperature = 600 [K]
    Minimum Absolute Pressure = 0.0035368 [MPa]
    Minimum Temperature = 300 [K]
    Pressure Extrapolation = On
    Temperature Extrapolation = Yes
  END
END
END
MATERIAL: Soot
  Material Group = Soot
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 2000 [kg m-3]
      Molar Mass = 12 [kg kmol-1]
      Option = Value
    END
    REFERENCE STATE:
      Option = Automatic
    END
    ABSORPTION COEFFICIENT:
      Absorption Coefficient = 0 [m-1]
      Option = Value
    END
  END
END
MATERIAL: Steel
  Material Group = CHT Solids, Particle Solids
  Option = Pure Substance
  Thermodynamic State = Solid
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 7854 [kg m-3]
      Molar Mass = 55.85 [kg kmol-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 4.34E+02 [J kg-1 K-1]
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Specific Enthalpy = 0 [J/kg]
      Reference Specific Entropy = 0 [J/kg/K]
      Reference Temperature = 25 [C]
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 60.5 [W m-1 K-1]

```

```

END
END
END
MATERIAL: VaporConst
  Material Group = Wet Steam, Constant Property Gases
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = General Material
    EQUATION OF STATE:
      Density = 13.1976 [kg m-3]
      Molar Mass = 18.02 [kg kmol-1]
      Option = Value
    END
    SPECIFIC HEAT CAPACITY:
      Option = Value
      Specific Heat Capacity = 3462.6 [J kg-1 K-1]
      Specific Heat Type = Constant Pressure
    END
    REFERENCE STATE:
      Option = Specified Point
      Reference Pressure = 2.6389 [MPa]
      Reference Specific Enthalpy = 2802590 [J kg-1]
      Reference Specific Entropy = 6235.4 [J kg-1 K-1]
      Reference Temperature = 500 [K]
    END
    DYNAMIC VISCOSITY:
      Dynamic Viscosity = 1.6594e-5 [Pa s]
      Option = Value
    END
    THERMAL CONDUCTIVITY:
      Option = Value
      Thermal Conductivity = 0.044952 [W m-1 K-1]
    END
    THERMAL EXPANSIVITY:
      Option = Value
      Thermal Expansivity = 0.001686 [K-1]
    END
  END
END
MATERIAL: VaporVar
  Material Group = IAPWS IF97, Wet Steam
  Option = Pure Substance
  Thermodynamic State = Gas
  PROPERTIES:
    Option = IAPWS Library
    REFERENCE STATE:
      Option = Automatic
    END
    TABLE GENERATION:
      Maximum Absolute Pressure = 12.345 [MPa]
      Maximum Points = 1000
      Maximum Temperature = 600 [K]
      Minimum Absolute Pressure = 0.0035368 [MPa]
      Minimum Temperature = 300 [K]
      Pressure Extrapolation = On
      Temperature Extrapolation = Yes
    END
  END
END
MATERIAL: Water
  Material Description = Water (liquid)

```

```

Material Group = Water Data, Constant Property Liquids
Option = Pure Substance
Thermodynamic State = Liquid
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Density = 997.0 [kg m^-3]
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Value
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 4181.7 [J kg^-1 K^-1]
    Specific Heat Type = Constant Pressure
  END
  REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1 [atm]
    Reference Specific Enthalpy = 0.0 [J/kg]
    Reference Specific Entropy = 0.0 [J/kg/K]
    Reference Temperature = 25 [C]
  END
  DYNAMIC VISCOSITY:
    Dynamic Viscosity = 8.899E-4 [kg m^-1 s^-1]
    Option = Value
  END
  THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 0.6069 [W m^-1 K^-1]
  END
  ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
  END
  SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
  END
  REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
  END
  THERMAL EXPANSIVITY:
    Option = Value
    Thermal Expansivity = 2.57E-04 [K^-1]
  END
END
MATERIAL: Water Ideal Gas
Material Description = Water Vapour Ideal Gas (100 C and 1 atm)
Material Group = Calorically Perfect Ideal Gases, Water Data
Option = Pure Substance
Thermodynamic State = Gas
PROPERTIES:
  Option = General Material
  EQUATION OF STATE:
    Molar Mass = 18.02 [kg kmol^-1]
    Option = Ideal Gas
  END
  SPECIFIC HEAT CAPACITY:
    Option = Value
    Specific Heat Capacity = 2080.1 [J kg^-1 K^-1]

```

```

        Specific Heat Type = Constant Pressure
    END
REFERENCE STATE:
    Option = Specified Point
    Reference Pressure = 1.014 [bar]
    Reference Specific Enthalpy = 0. [J/kg]
    Reference Specific Entropy = 0. [J/kg/K]
    Reference Temperature = 100 [C]
END
DYNAMIC VISCOSITY:
    Dynamic Viscosity = 9.4E-06 [kg m^-1 s^-1]
    Option = Value
END
THERMAL CONDUCTIVITY:
    Option = Value
    Thermal Conductivity = 193E-04 [W m^-1 K^-1]
END
ABSORPTION COEFFICIENT:
    Absorption Coefficient = 1.0 [m^-1]
    Option = Value
END
SCATTERING COEFFICIENT:
    Option = Value
    Scattering Coefficient = 0.0 [m^-1]
END
REFRACTIVE INDEX:
    Option = Value
    Refractive Index = 1.0 [m m^-1]
END
END
END
FLOW: Flow Analysis 1
SOLUTION UNITS:
    Angle Units = [rad]
    Length Units = [m]
    Mass Units = [kg]
    Solid Angle Units = [sr]
    Temperature Units = [K]
    Time Units = [s]
END
ANALYSIS TYPE:
    Option = Transient
EXTERNAL SOLVER COUPLING:
    Option = None
END
INITIAL TIME:
    Option = Automatic with Value
    Time = 0 [s]
END
TIME DURATION:
    Option = Total Time
    Total Time = 70 [s]
END
TIME STEPS:
    Option = Timesteps
    Timesteps = 0.001 [s]
END
END
DOMAIN: Default Domain
    Coord Frame = Coord 0
    Domain Type = Fluid

```

```

Location = B4
BOUNDARY MODELS:
  WALL BOILING MODEL:
    Option = None
  END
END
BOUNDARY: Default Domain Default
  Boundary Type = OUTLET
  Location = F24.4,F41.4
  BOUNDARY CONDITIONS:
    FLOW REGIME:
      Option = Subsonic
    END
    MASS AND MOMENTUM:
      Option = Fluid Velocity
    END
  END
  FLUID: Liquid
    BOUNDARY CONDITIONS:
      VELOCITY:
        Normal Speed = 0.02 [m s-1]
        Option = Normal Speed
      END
    END
  FLUID: Vapor
    BOUNDARY CONDITIONS:
      VELOCITY:
        Normal Speed = 0 [m s-1]
        Option = Normal Speed
      END
    END
  END
  BOUNDARY: Inlet
    Boundary Type = INLET
    Location = Inlet
    BOUNDARY CONDITIONS:
      FLOW DIRECTION:
        Option = Zero Gradient
      END
      FLOW REGIME:
        Option = Subsonic
      END
      HEAT TRANSFER:
        Option = Static Temperature
        Static Temperature = 500 [K]
      END
      MASS AND MOMENTUM:
        Option = Static Pressure
        Relative Pressure = InletPsetting
      END
      TURBULENCE:
        Option = Medium Intensity and Eddy Viscosity Ratio
      END
    END
  FLUID: Liquid
    BOUNDARY CONDITIONS:
      VOLUME FRACTION:
        Option = Value
        Volume Fraction = 0.0001
      END

```

```

    END
  END
  FLUID: Vapor
  BOUNDARY CONDITIONS:
    VOLUME FRACTION:
      Option = Value
      Volume Fraction = 0.9999
    END
  END
END
BOUNDARY: Outlet
Boundary Type = OUTLET
Location = Outlet
BOUNDARY CONDITIONS:
  FLOW REGIME:
    Option = Subsonic
  END
  MASS AND MOMENTUM:
    Option = Average Static Pressure
    Pressure Profile Blend = 0.05
    Relative Pressure = 2.6389 [MPa]
  END
  PRESSURE AVERAGING:
    Option = Average Over Whole Outlet
  END
END
BOUNDARY: Wall
Boundary Type = WALL
Location = Wall
BOUNDARY CONDITIONS:
  HEAT TRANSFER:
    Option = Adiabatic
  END
  MASS AND MOMENTUM:
    Option = No Slip Wall
  END
  WALL CONTACT MODEL:
    Option = Use Volume Fraction
  END
  WALL ROUGHNESS:
    Option = Smooth Wall
  END
END
DOMAIN MODELS:
  BUOYANCY MODEL:
    Buoyancy Reference Density = 0 [kg m-3]
    Gravity X Component = 0 [m s-2]
    Gravity Y Component = -9.81 [m s-2]
    Gravity Z Component = 0 [m s-2]
    Option = Buoyant
    BUOYANCY REFERENCE LOCATION:
      Option = Automatic
    END
  END
  DOMAIN MOTION:
    Option = Stationary
  END
  MESH DEFORMATION:
    Option = None

```

```

END
REFERENCE PRESSURE:
    Reference Pressure = 0 [MPa]
END
END
FLUID DEFINITION: Liquid
    Material = LiquidConst
    Option = Material Library
MORPHOLOGY:
    Mean Diameter = 1 [micron]
    Minimum Volume Fraction = 1e-9
    Option = Dispersed Fluid
END
END
FLUID DEFINITION: Vapor
    Material = VaporConst
    Option = Material Library
MORPHOLOGY:
    Minimum Volume Fraction = 1e-9
    Option = Continuous Fluid
END
END
FLUID MODELS:
    ADDITIONAL VARIABLE: MassTotal
        Option = Fluid Dependent
    END
    COMBUSTION MODEL:
        Option = None
    END
    FLUID: Liquid
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation
        END
        FLUID BUOYANCY MODEL:
            Option = Density Difference
        END
        HEAT TRANSFER MODEL:
            Option = Thermal Energy
        END
        TURBULENCE MODEL:
            Option = Laminar
        END
    END
    FLUID: Vapor
        ADDITIONAL VARIABLE: MassTotal
            Additional Variable Value = Volume of Finite Volumes *Density \
            *Volume Fraction
            Option = Algebraic Equation
        END
        FLUID BUOYANCY MODEL:
            Option = Density Difference
        END
        HEAT TRANSFER MODEL:
            Option = Thermal Energy
        END
        TURBULENCE MODEL:
            Option = k epsilon
        BUOYANCY TURBULENCE:
            Option = None
        END
    END

```

```

END
TURBULENT WALL FUNCTIONS:
    Option = Scalable
END
END
HEAT TRANSFER MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
THERMAL RADIATION MODEL:
    Option = None
END
TURBULENCE MODEL:
    Homogeneous Model = False
    Option = Fluid Dependent
END
END
FLUID PAIR: Liquid | Vapor
Surface Tension Coefficient = 0.013472 [N m^-1]
INTERPHASE HEAT TRANSFER:
    Option = Two Resistance
    FLUID1 INTERPHASE HEAT TRANSFER:
        Option = Zero Resistance
    END
    FLUID2 INTERPHASE HEAT TRANSFER:
        Option = Ranz Marshall
    END
END
INTERPHASE TRANSFER MODEL:
    Option = Particle Model
END
MASS TRANSFER:
    Option = Phase Change
    PHASE CHANGE MODEL:
        Option = Thermal Phase Change
        Saturation Temperature = 500 [K]
    END
END
MOMENTUM TRANSFER:
    DRAG FORCE:
        Option = Schiller Naumann
    END
    LIFT FORCE:
        Option = Legendre Magnaudet
    END
    TURBULENT DISPERSION FORCE:
        Option = None
    END
    VIRTUAL MASS FORCE:
        Option = None
    END
    WALL LUBRICATION FORCE:
        Option = None
    END
END
TURBULENCE TRANSFER:
    ENHANCED TURBULENCE PRODUCTION MODEL:
        Option = None
    END
END
MULTIPHASE MODELS:

```

```

Homogeneous Model = False
FREE SURFACE MODEL:
    Option = None
END
END
OUTPUT CONTROL:
    BACKUP DATA RETENTION:
        Option = Delete Old Files
    END
    BACKUP RESULTS: Backup Results 1
        File Compression Level = Default
        Option = Standard
        Output Equation Residuals = All
    OUTPUT FREQUENCY:
        Option = Timestep Interval
        Timestep Interval = 1000
    END
END
MONITOR OBJECTS:
    MONITOR BALANCES:
        Option = Full
    END
    MONITOR FORCES:
        Option = Full
    END
    MONITOR PARTICLES:
        Option = Full
    END
    MONITOR POINT: CourantAveMon
        Coord Frame = Coord 0
        Expression Value = CourantAve
        Option = Expression
    END
    MONITOR POINT: CourantMaxMon
        Coord Frame = Coord 0
        Expression Value = CourantMax
        Option = Expression
    END
    MONITOR POINT: CourantRMSMon
        Coord Frame = Coord 0
        Expression Value = CourantRMS
        Option = Expression
    END
    MONITOR POINT: Inlet Pressure
        Coord Frame = Coord 0
        Expression Value = areaAve(Pressure)@Inlet
        Option = Expression
    END
    MONITOR POINT: Inlet Quality
        Coord Frame = Coord 0
        Expression Value = QualityInlet
        Option = Expression
    END
    MONITOR POINT: Liquid Inlet Velocity
        Coord Frame = Coord 0
        Expression Value = LiquidVelInlet
        Option = Expression
    END
    MONITOR POINT: Liquid Mass
        Coord Frame = Coord 0
        Expression Value = SumLiqMassTotal

```

```

    Option = Expression
END
MONITOR POINT: Liquid Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = LiquidVelOutlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate In
    Coord Frame = Coord 0
    Expression Value = MassFlowInlet
    Option = Expression
END
MONITOR POINT: Mass Flow Rate Out
    Coord Frame = Coord 0
    Expression Value = MassFlowOutlet
    Option = Expression
END
MONITOR POINT: Outlet Pressure
    Coord Frame = Coord 0
    Expression Value = areaAve(Pressure)@Outlet
    Option = Expression
END
MONITOR POINT: Outlet Quality
    Coord Frame = Coord 0
    Expression Value = QualityOutlet
    Option = Expression
END
MONITOR POINT: Outlet Temperature
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Saturation Temp
    Coord Frame = Coord 0
    Expression Value = massFlowAve(Liquid | Vapor.Saturation \
    Temperature)@Outlet
    Option = Expression
END
MONITOR POINT: Vapor Inlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelInlet
    Option = Expression
END
MONITOR POINT: Vapor Outlet Velocity
    Coord Frame = Coord 0
    Expression Value = VaporVelOutlet
    Option = Expression
END
MONITOR RESIDUALS:
    Option = Full
END
MONITOR TOTALS:
    Option = Full
END
RESULTS:
    File Compression Level = Default
    Option = Standard
    Output Equation Residuals = All
END
TRANSIENT RESULTS: Transient Results 1
    File Compression Level = Default

```

```

    Option = Standard
    OUTPUT FREQUENCY:
        Option = Timestep Interval
        Timestep Interval = 1000
    END
END
TRANSIENT STATISTICS: LiqMassTrans
    Option = Full
    Output Variables List = Liquid.MassTotal
END
TRANSIENT STATISTICS: PressureTrans
    Option = Arithmetic Average
    Output Variables List = Total Pressure
END
END
SOLVER CONTROL:
    Turbulence Numerics = High Resolution
    ADVECTION SCHEME:
        Option = High Resolution
    END
    CONVERGENCE CONTROL:
        Maximum Number of Coefficient Loops = 10
        Minimum Number of Coefficient Loops = 1
        Timescale Control = Coefficient Loops
    END
    CONVERGENCE CRITERIA:
        Residual Target = 1e-15
        Residual Type = RMS
    END
    INTERRUPT CONTROL:
        Option = Any Interrupt
    CONVERGENCE CONDITIONS:
        Option = Default Conditions
    END
END
TRANSIENT SCHEME:
    Option = Second Order Backward Euler
    TIMESTEP INITIALISATION:
        Option = Automatic
    END
END
END
COMMAND FILE:
    Version = 22.1
END

```

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