EDF R&D

Fluid Dynamics, Power Generation and Environment Department
Single Phase Thermal-Hydraulics Group

6, quai Watier
F-78401 Chatou Cedex

Tel: 33 1 30 87 75 40
Fax: 33 1 30 87 79 16

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code_saturne documentation

code_saturne version 8.0 tutorial: stratified junction

contact: saturne-support@edf.fr

http://code-saturne.org/

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Part I

Introduction

1 Introduction

1.1 code_saturne short presentation

code_saturne is a system designed to solve the Navier-Stokes equations in the cases of 2D, 2D axisymmetric or 3D flows. Its main module is designed for the simulation of flows which may be steady or unsteady, laminar or turbulent, incompressible or potentially dilatable, isothermal or not. Scalars and turbulent fluctuations of scalars can be taken into account. The code includes specific modules, referred to as "specific physics", for the treatment of lagrangian particle tracking, semi-transparent radiative transfer, gas, pulverized coal and heavy fuel oil combustion, electricity effects (Joule effect and electric arcs) and compressible flows. code_saturne relies on a finite volume discretization and allows the use of various mesh types which may be hybrid (containing several kinds of elements) and may have structural non-conformities (hanging nodes).

1.2 About this document

The present document is a tutorial for code_saturne version 8.0. It presents a simple test case of a stratified flow in a T-junction and guides the future code_saturne user step by step into the preparation and the computation of the case.

The test case directories, containing the necessary meshes and data are available in the `examples/3-stratified_junction` directory in code_saturne source directory.

This tutorial focuses on the procedure and the preparation of the code_saturne computations with or without SALOME. For more elements on the structure of the code and the definition of the different variables, it is higly recommended to refer to the user manual.

1.3 code_saturne copyright informations

Part II

Stratified junction

1 Study description

1.1 Objective

The aim of this case is to train the code_saturne user on a simplified but real 3D computation. It corresponds to a stratified flow in a T-junction. The test case will be used to present some advanced post-processing techniques.

1.2 Description of the configuration

The configuration is based on a real mock-up designed to characterize thermal stratification phenomena and associated fluctuations. The geometry is shown on figure II.1.

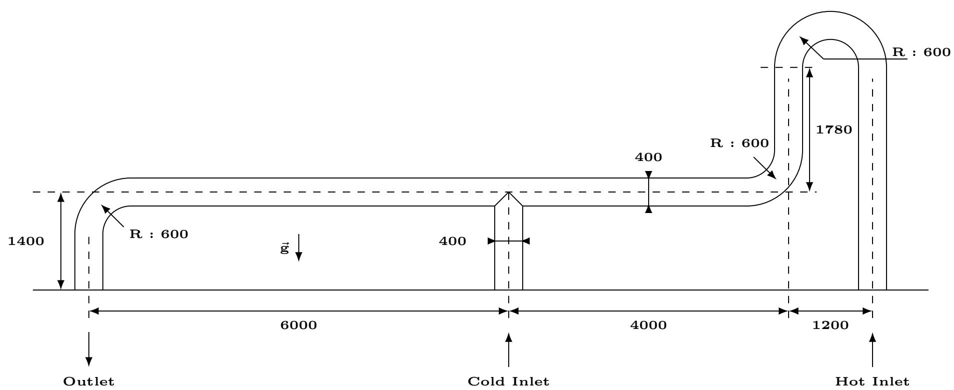


Figure II.1: Geometry of the case, with dimensions in mm

There are two inlets, a hot one in the main pipe and a cold one in the vertical nozzle. The volumic flow rate is identical in both inlets. It is chosen small enough so that gravity effects are important with respect to inertia forces. Therefore cold water creeps backwards from the junction towards the elbow until the flow reaches a stable stratified state.

1.3 Geometry

Characteristics of the geometry:

Diameter of the pipe	$D_b = 0.40\ m$

1.4 Data settings

The boundary conditions of the flow are as follows:

Cold branch volume flow rate	$Dv_{cb} = 4\ l.s^{-1}$
Hot branch volume flow rate	$Dv_{hb} = 4\ l.s^{-1}$
Cold branch temperature	$T_{cb} = 18.6°\text{C}$
Hot branch temperature	$T_{hb} = 38.5°\text{C}$

The initial water temperature in the domain is equal to 38.5°C.

Water specific heat and thermal conductivity are considered constant and calculated at 38.5°C and $10^5\ Pa$:

- heat capacity: $C_p = 4{,}178\ J.kg^{-1}.°\mathrm{C}^{-1}$
- thermal conductivity: $\lambda = 0.628\ W.m^{-1}.°\mathrm{C}^{-1}$

The water density and dynamic viscosity are variable with the temperature. The functions are given below.

2 Mesh characteristics

The mesh used in the actual study had 125 000 elements. It has been coarsened for this example in order for calculations to run faster. The mesh used here contains 16 320 elements.

Type: unstructured mesh

Coordinates system: cartesian, origin on the middle of the horizontal pipe at the intersection with the nozzle.

Mesh generator used: SIMAIL

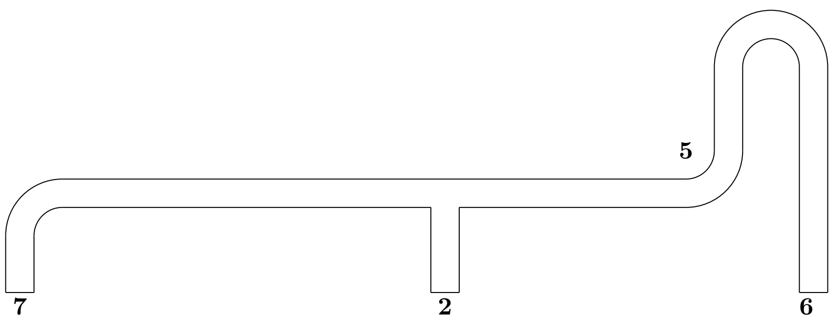


Figure II.2: References of the boundary faces

3 Computation of the Stratified junction configuration

In this case, advanced post-processing features will be used. A specific post-processing sub-mesh will be created, containing all the cells with a temperature lower than 21°C, so that it can be visualized (with ParaView for instance). The variable **temperature** will be post-processed on this sub-mesh. A 2D clip plane will also be extracted along the symmetry plane of the domain and the temperature will be written on it.

3.1 Options and models

The following options are considered for the case:

Modeling feature	**choice**
Flow type	unsteady flow
Time step	variable in time and uniform in space
Turbulence model	$k - \varepsilon$ LP
Thermal model	Temperature (°C)
Physical properties	uniform and constant for specific heat and thermal conductivity and variable for density and dynamic viscosity
Global parameters	Improved pressure interpolation for stratified flows

References	Type of boundary conditions
2	Cold inlet
6	Hot inlet
7	Outlet
5	Wall

Table II.1: Boundary faces colors and associated references

3.2 Initial and boundary conditions

The temperature should be initialized at 38.5°C in the whole domain.

The boundary conditions are defined as follows:

- **Flow inlet**: Dirichlet condition
  - Velocity of 0.03183 $m.s^{-1}$ for both inlets
  - Temperature of 38.5°C for the hot inlet
  - Temperature of 18.6°C for the cold inlet
- **Outlet**: default value
- **Walls**: default value

Figure II.2 shows the references used for boundary conditions and table II.1 defines the which type of boundary conditions is imposed for each reference.

3.3 Physical properties

In this case the density and the dynamic viscosity are functions of the temperature.

The following variation law for the density needs to be specified in the Graphical User Interface:

$$\rho = T(AT + B) + C \tag{II.1}$$

where ρ is the density, T is the temperature, $A = -4.0668\times10^{-3}$, $B = -5.0754\times10^{-2}$ and $C = 1\,000.9$.

For the dynamic viscosity, the variation law is:

$$\mu = T(T(AMT + BM) + CM) + DM \tag{II.2}$$

where μ is the dynamic viscosity, T is the temperature, $AM = -3.4016 \times 10^{-9}$, $BM = 6.2332 \times 10^{-7}$, $CM = -4.5577 \times 10^{-5}$ and $DM = 1.6935 \times 10^{-3}$.

In order for the variable density to have an effect on the flow, gravity must be set to a non-zero value. $\underline{g} = -9.81\underline{e}_z$ will be specified in the Graphical Interface.

3.4 Time stepping parameters

All the parameters necessary to this study can be defined through the Graphical Interface, except the advanced post-processing features, that have to be specified in user routines.

time stepping parameters	
Reference time step	0.1 s
Number of iterations	100
Maximal CFL number	20
Maximal Fourier number	60
Minimal time step factor $\frac{dt_{min}}{dt_{ref}}$	0.01
Maximal time step factor $\frac{dt_{max}}{dt_{ref}}$	70
Time step maximal variation	0.1

The time step limitation by gravity effects will also be enabled.

3.5 Output management

In a first step, standard options for output management will be used. Four monitoring points will be created at the following coordinates:

Probe	x(m)	y(m)	z(m)
1	0.010025	0.01534	-0.011765
2	1.625	0.01534	-0.031652
3	3.225	0.01534	-0.031652
4	3.8726	0.047481	0.725

Two vertical temperature profiles will be extracted, at the following locations:

Profile	x(m)	y(m)	z(m)
`profil16`	1.6	0	$-0.2 \leqslant z \leqslant 0.2$
`profil32`	3.2	0	$-0.2 \leqslant z \leqslant 0.2$

A period of 10 will be associated to the output writer.

3.6 User routines for advanced post-processing

The following file must to be copied from the folder 🗀`SRC/EXAMPLES` into the folder 🗀`SRC`[1]:

- `cs_user_postprocess.c`;

In this test case, advanced post-processing features will be used. An additional writer will be created, with a periodicity of 5 iterations. It will only contain one part (*i.e.* one sub-mesh): the set of cells where the temperature is lower than 21°C. The temperature will be written on this part. The interest of this part is that it is time dependent as for the cells it contains.

The following user functions and subroutines will be used:

- **cs_user_postprocess_meshes** (in `cs_user_postprocess.c`)
  This function is called only once, at the beginning of the calculation. It allows to define the different writers and parts.

  In this function, adapt the block using the **cs_post_define_volume_mesh_by_func**, replacing `He_fraction_05` with `T_lt_21` (do not forget to set the enclosing test to `true`). If the argument matching **the automatic variables output** is set to **true**, all variables (including temperature) postprocessed on the main output will be added to this one. For finer control, we set it

[1] Only when they appear in the 🗀`SRC` directory will they be taken into account by the code.

to **false** here, and we will use a user-defined output with **cs_user_postprocess_values**. The associated writer list should contain writer 1, which may be created either using the GUI, or the **cs_user_postprocess_writers** (in the same file). Make sure this writers allows for **transient connectivity**. The **_he_fraction_05_select** near the beginning of the file must also be adapted, renaming it to **_t_lt_21_select**, and adapting its contents (mainly calling **cs_field_by_name** on **temperature** instead of **He_fraction**, and replacing **> 5.e-2** with **< 21**). This selection function is called automatically at each output time step so as to update the selected sub-mesh.

3.7 Results

Figure II.3 shows the evolution of temperature in a clip plane created along the symmetry plane of the domain. The evolution of the stratification is clearly visible.

Figure II.4 shows the cells where the temperature is lower than 21°C. It is not an isosurface created from the full domain, but a visualization of the full sub-domain created through the post-processing routines.

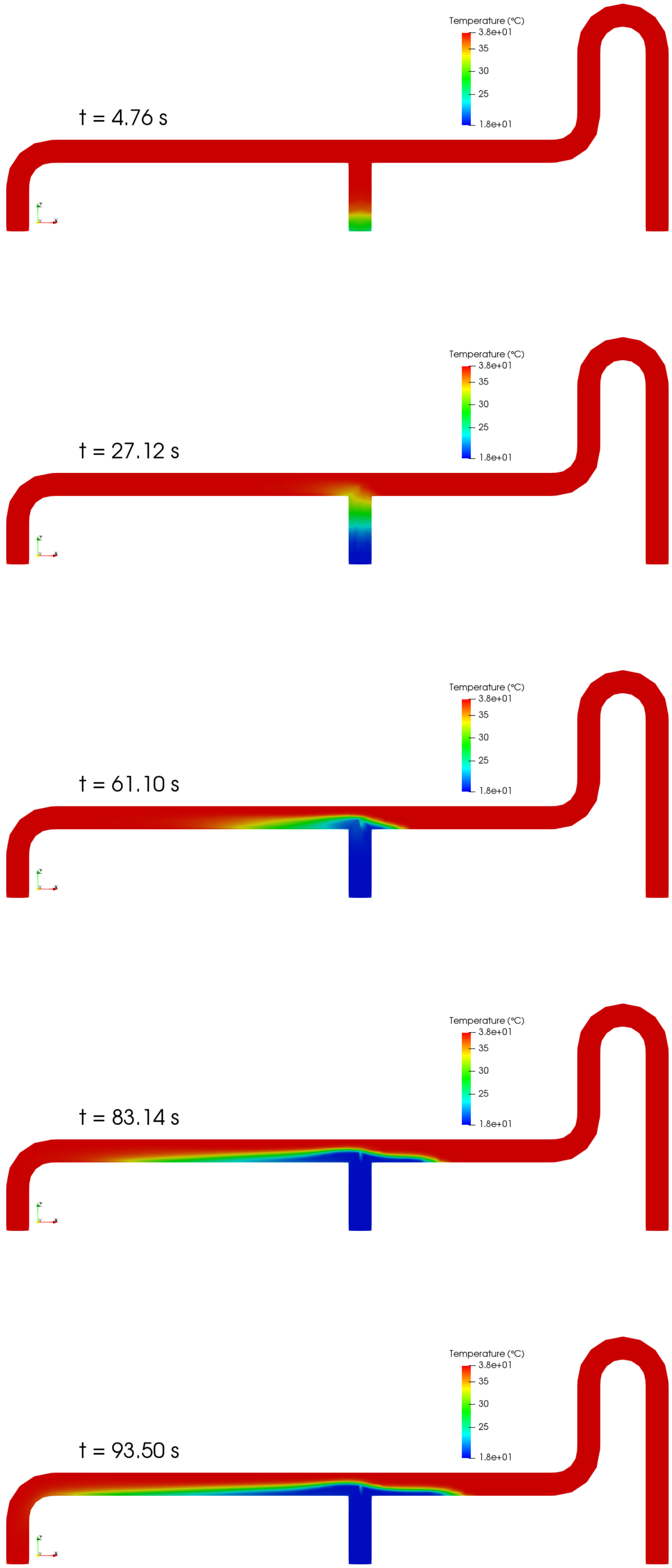


Figure II.3: Evolution of the temperature

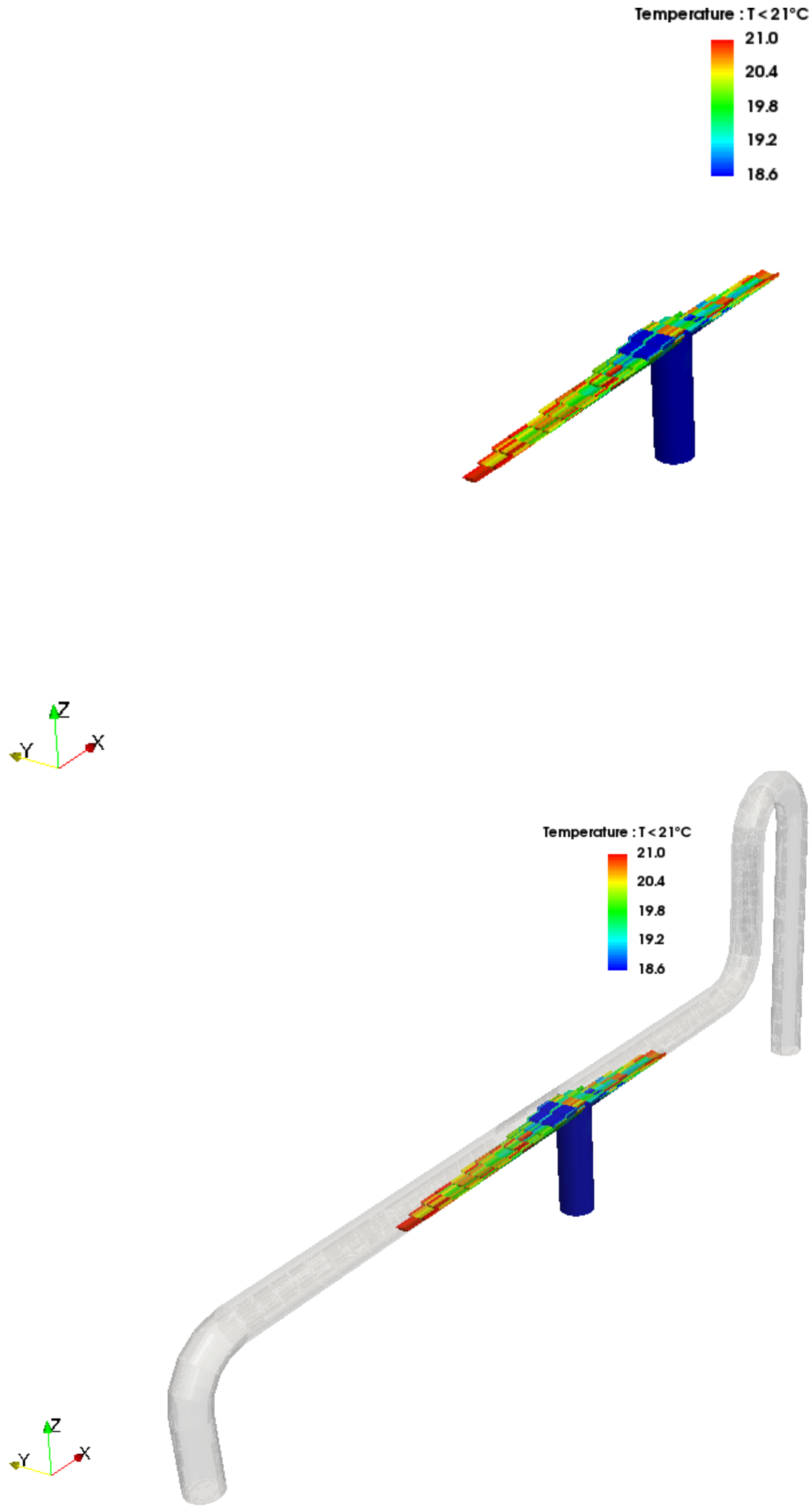


Figure II.4: Sub-domain where the temperature is lower than 21°C (upper figure) and localization in the full domain (lower figure)

Part III

Step by step solution

1 Detailed tutorial step by step

1.1 Creation of the study in a terminal

This tutorial will be set up within code_saturne but you could also open and use SALOME using CFDSTUDY module. Most of the picture inside this tutorial are taken extracted from code_saturne but you will find some picture extracted from SALOME to illustrate the model.
The first thing to do is to prepare the computation directories. In this example, the study directory 🗁 `T_junction` will be created, containing a single calculation directory 🗁 `case1`. It can be directly done in the terminal using the following commands:

```
$ code_saturne create -s T_junction -c case1
$ cd T_junction
```

Then, the mesh of the tutorial (sn_total.des) can be moved into the directory 🗁 `MESH` of the study in order to be used later.

You can launch code_saturne Graphical User Interface (GUI) via the usual following command :

```
$ code_saturne gui &
```

1.2 Preparing and launching code_saturne computation

SALOME and Mesh viewer After that, you could use SALOME GUI to display the mesh. The figure III.1 illustrate SALOME GUI with the mesh via CFDSTUDY module. The latest can be useful in case you need to check some geometry and meshing aspects.

Note: If needed do not hesitate to open the Shear driven cavity tutorial. The latest explain how to use SALOME with CFDSTUDY module.

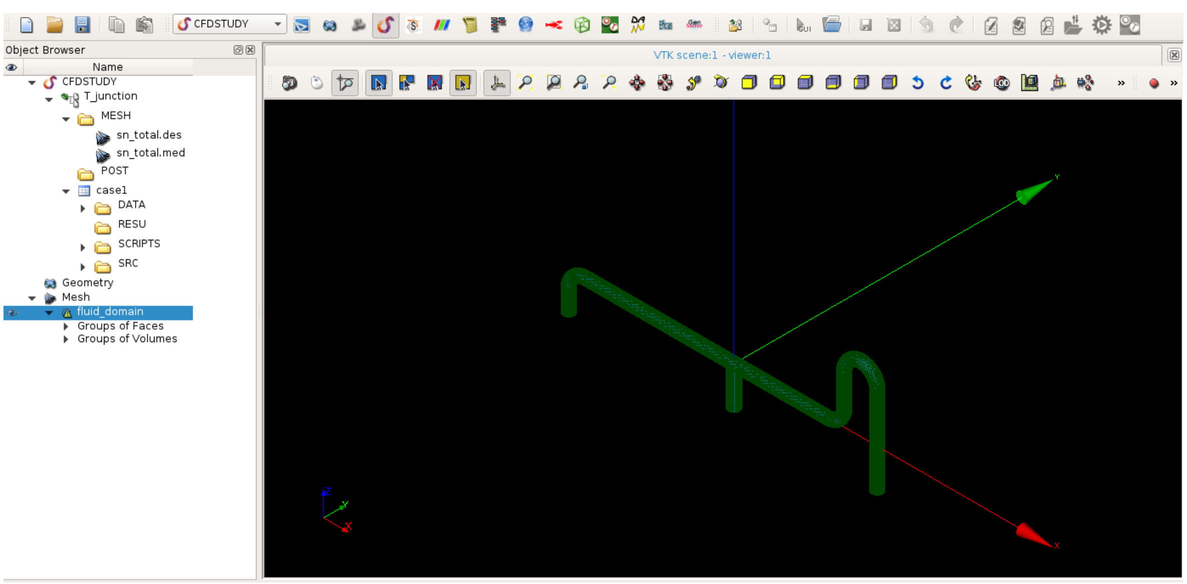


Figure III.1: Display of the mesh in *SALOME*

1.3 Calculation environment Tab

Once code_saturne is opened the first step is to verify all directories as follows.

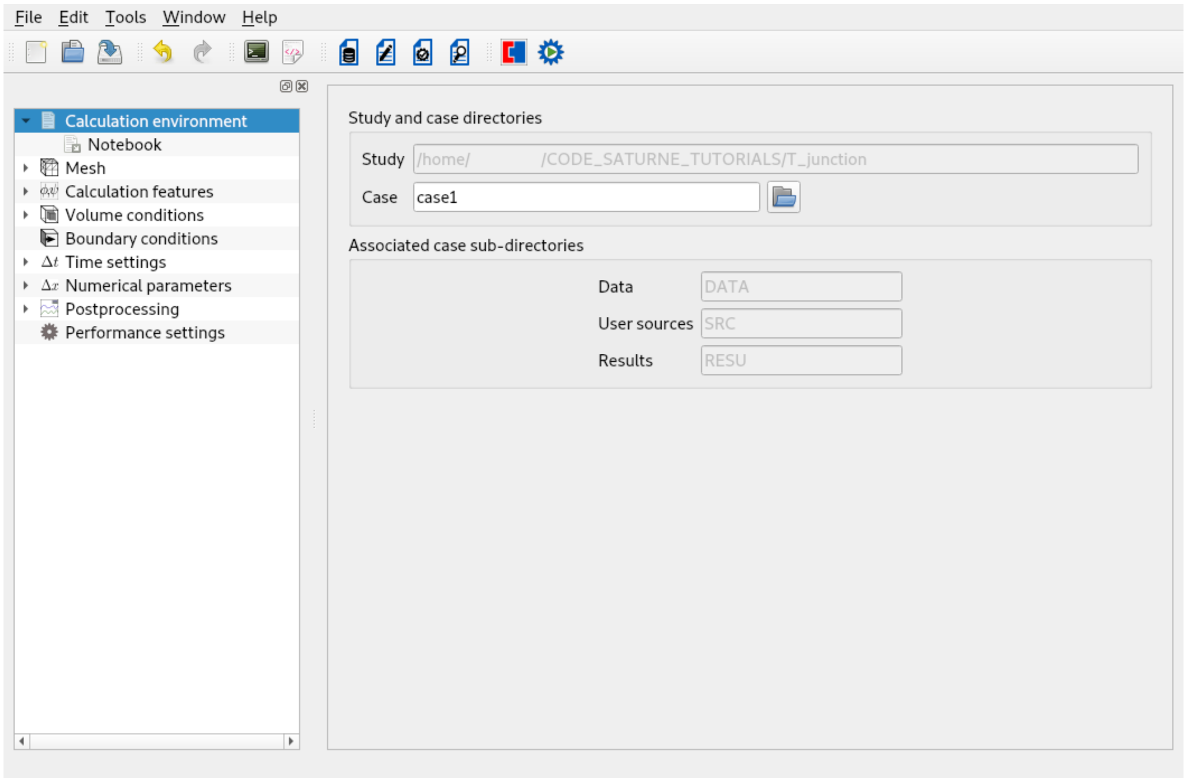


Figure III.2: Calculation environment - directories

1.4 Mesh Tab

The next step is to specify the mesh. Like in previous tutorial you need to click on the heading **Mesh** tab then add the mesh to the list of meshes.
In this case the mesh is **sn_total.des**.

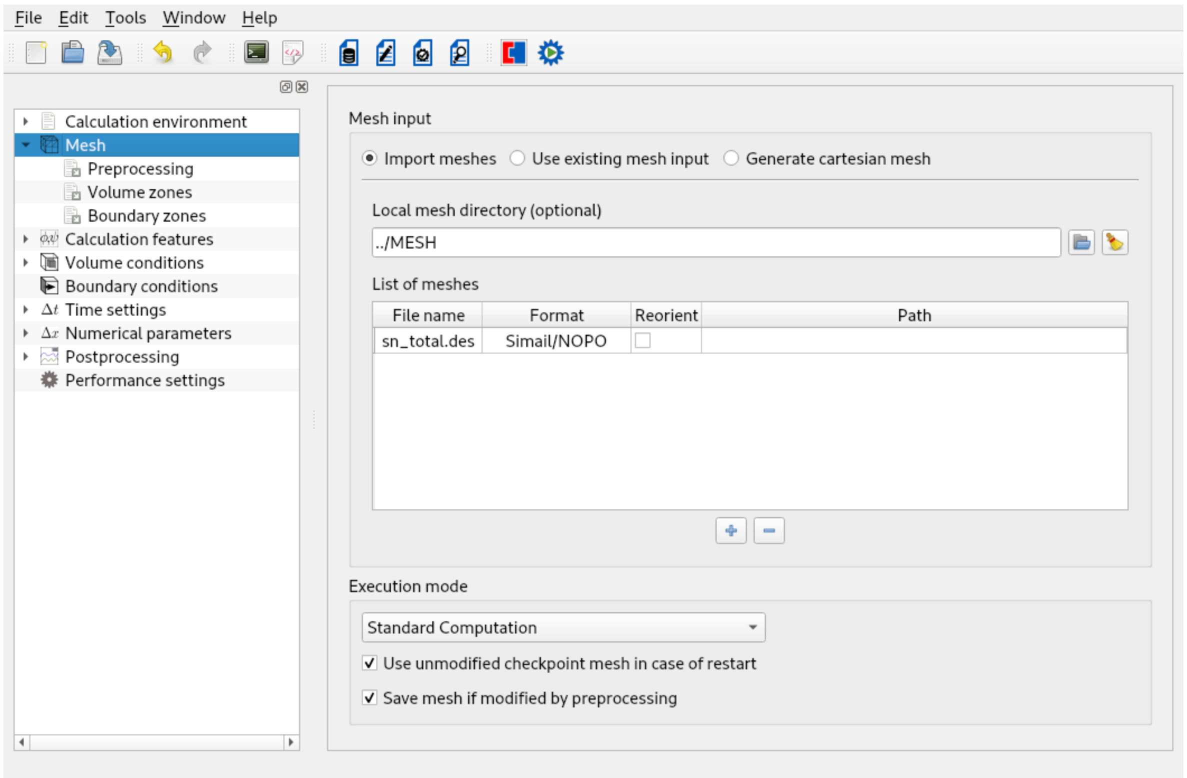
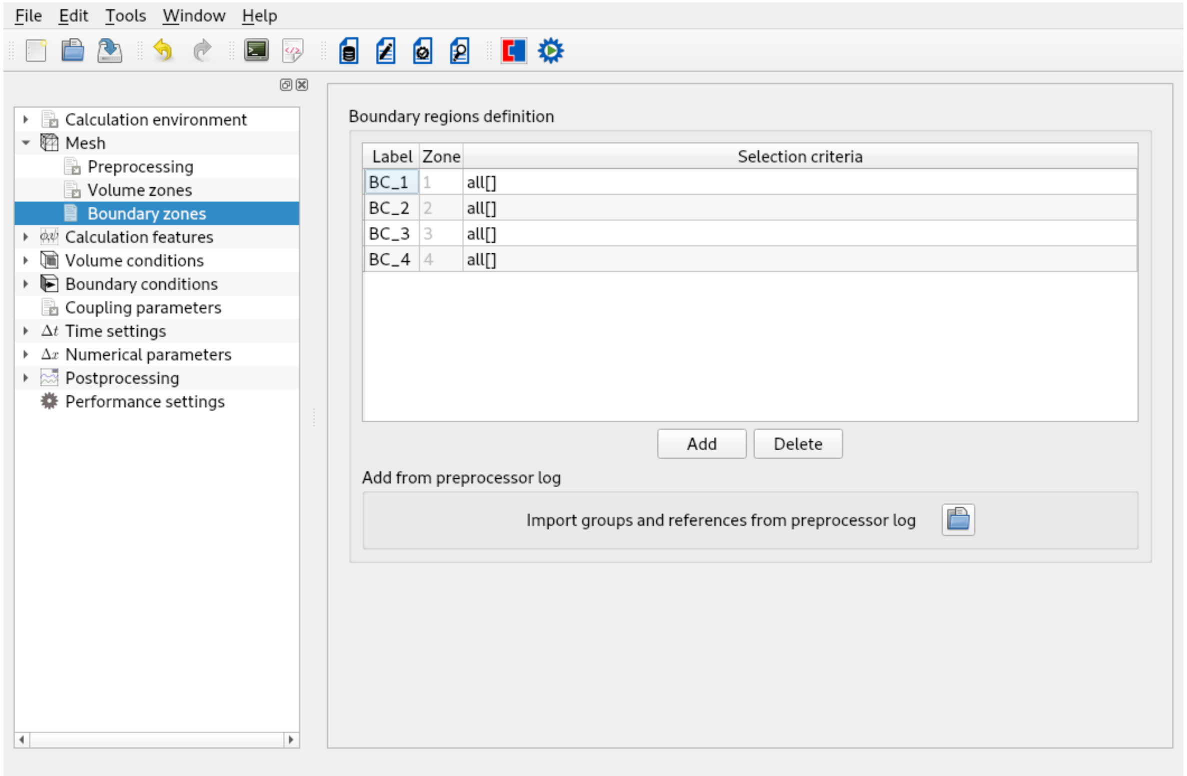


Figure III.3: Mesh - import mesh

Boundary zones The boundary regions should be defined as in figure III.4 based on the following table. The process remains the same as the previous tutorials if you want to rename the label and or to set selection criteria.

Colors	Label
2	inlet
6	inlet
7	outlet
5	wall



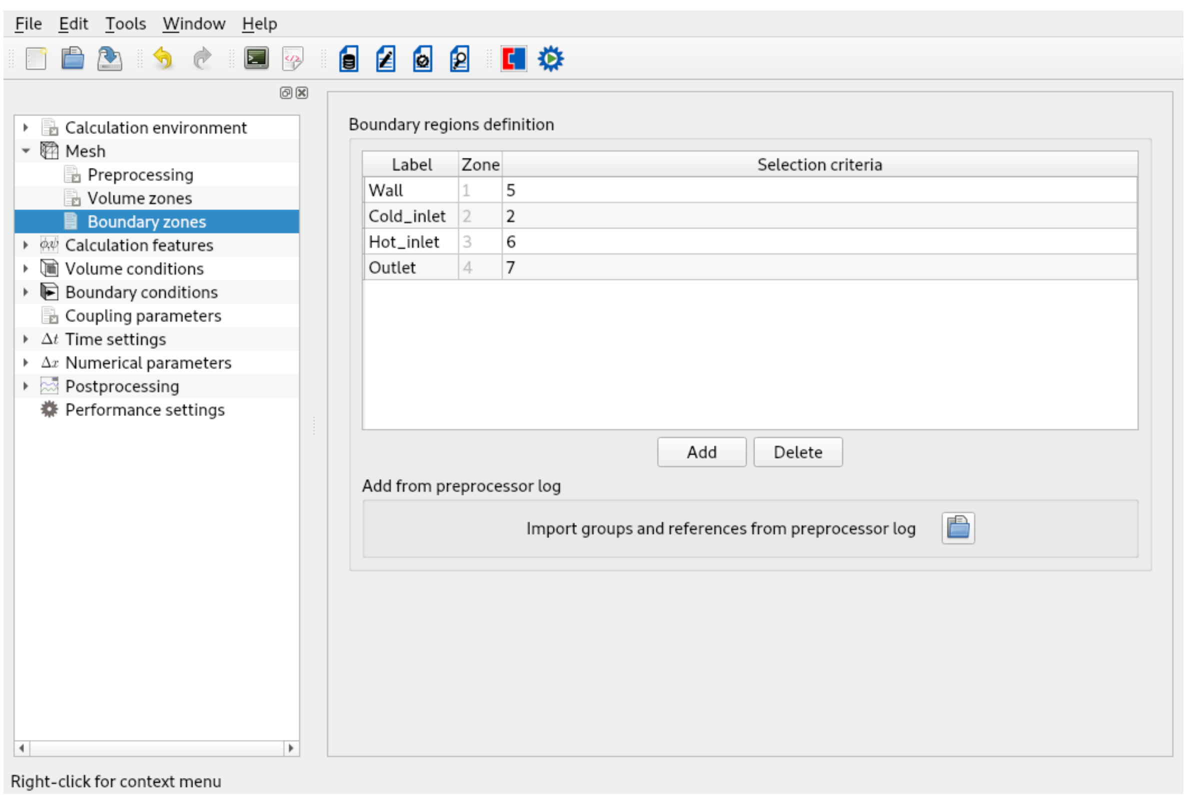


Figure III.4: Boundary zones definition

Note: The boundary zones can also be directly defined from the mesh by using *SALOME*. To do so, first click on the heading **Boundary Zones**. Then open the object browser of *SALOME* and click on the group of faces *'5'* for instance.

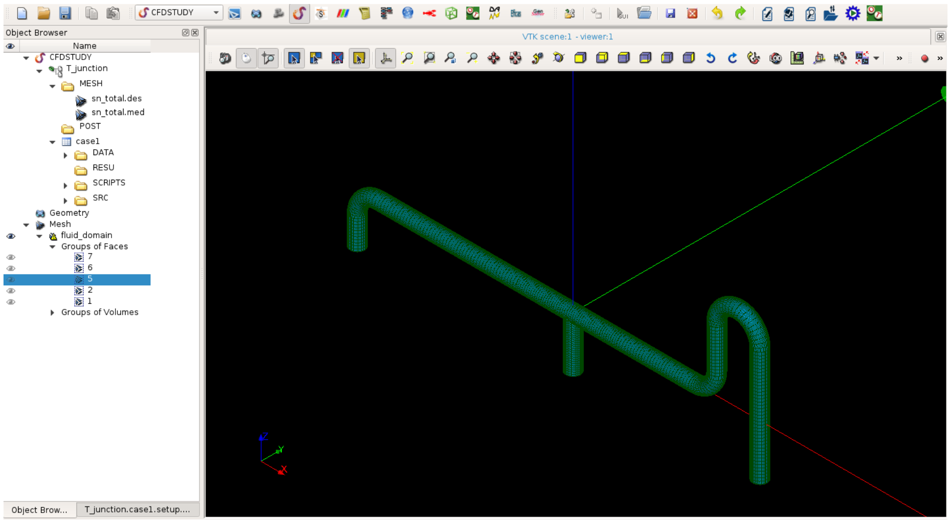


Figure III.5: Select a boundary regions from Salome

Once the group of faces is selected, go back to the **Boundary Zones** section and click on *'Add from Salome'* in the code_saturne GUI as shown in figure III.6.

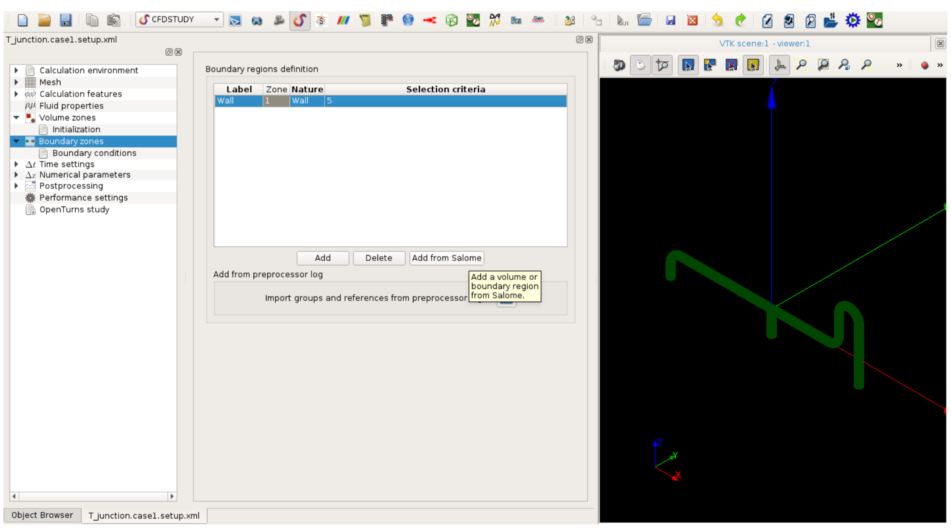


Figure III.6: Select a boundary regions from Salome

Then the type of boundary condition can be defined then with the zone *Nature*. Repeat the same process for the other boundary regions listed in the table 1.4.

1.5 Calculation features Tab

Turbulence models **Turbulence models** Under **Calculation features** tab, select **Turbulence models**. Choose *k-ε Linear Production* as turbulence model and set the velocity scale to 0.03182 $m.s^{-1}$ as shown in figure III.11.

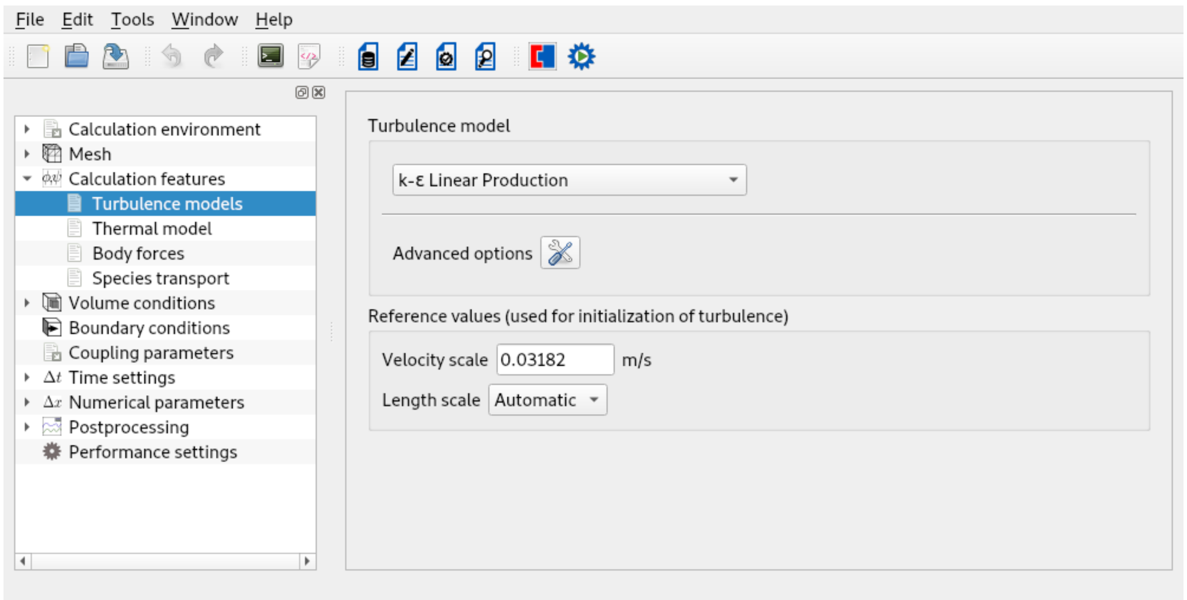


Figure III.7: Calculation feature : Turbulence models

Thermal model Under the same tab, select **Thermal model** item, then add a thermal scalar in Celsius degrees.

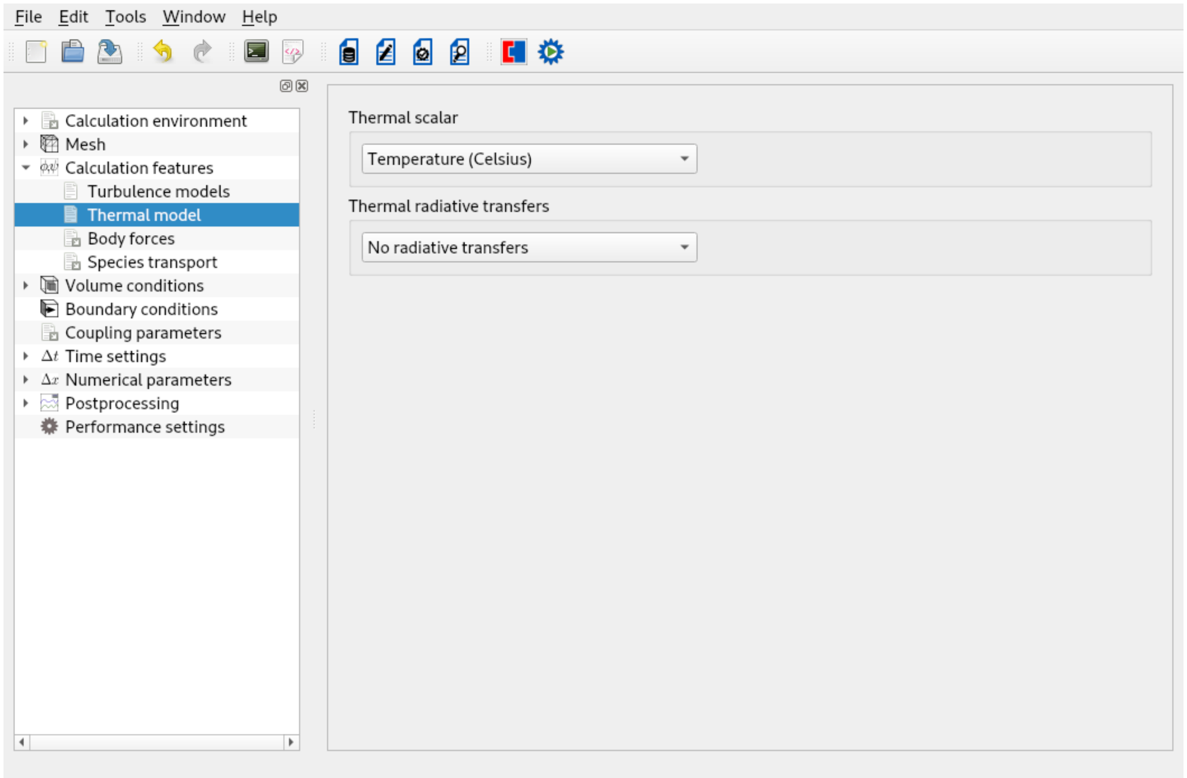


Figure III.8: Calculation feature : Thermal model

Body forces The aim of the calculation is to simulate a stratified flow. It is therefore necessary to have gravity. Set it to the right value in the item **Body forces** under **Calculation features** tab.

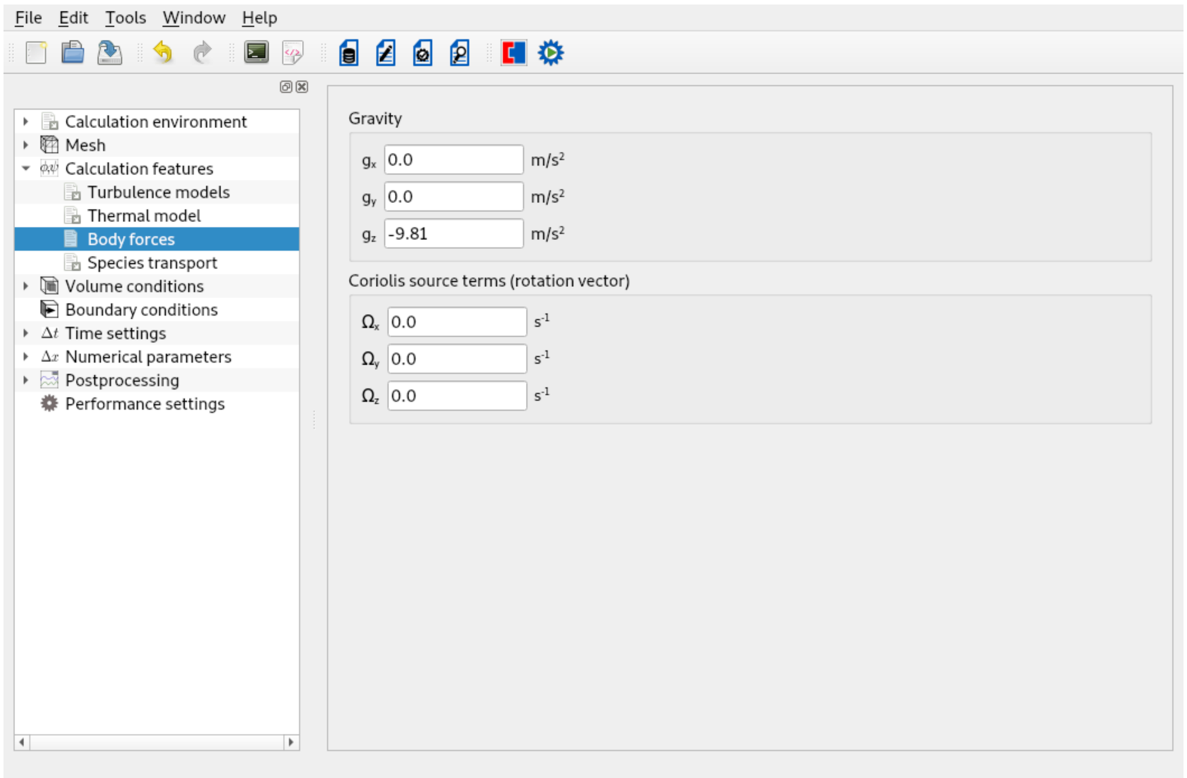


Figure III.9: Calculation features: Body forces

1.6 Volume conditions

Do not forget to tick **Initialization** and **Physical properties**. See III.10

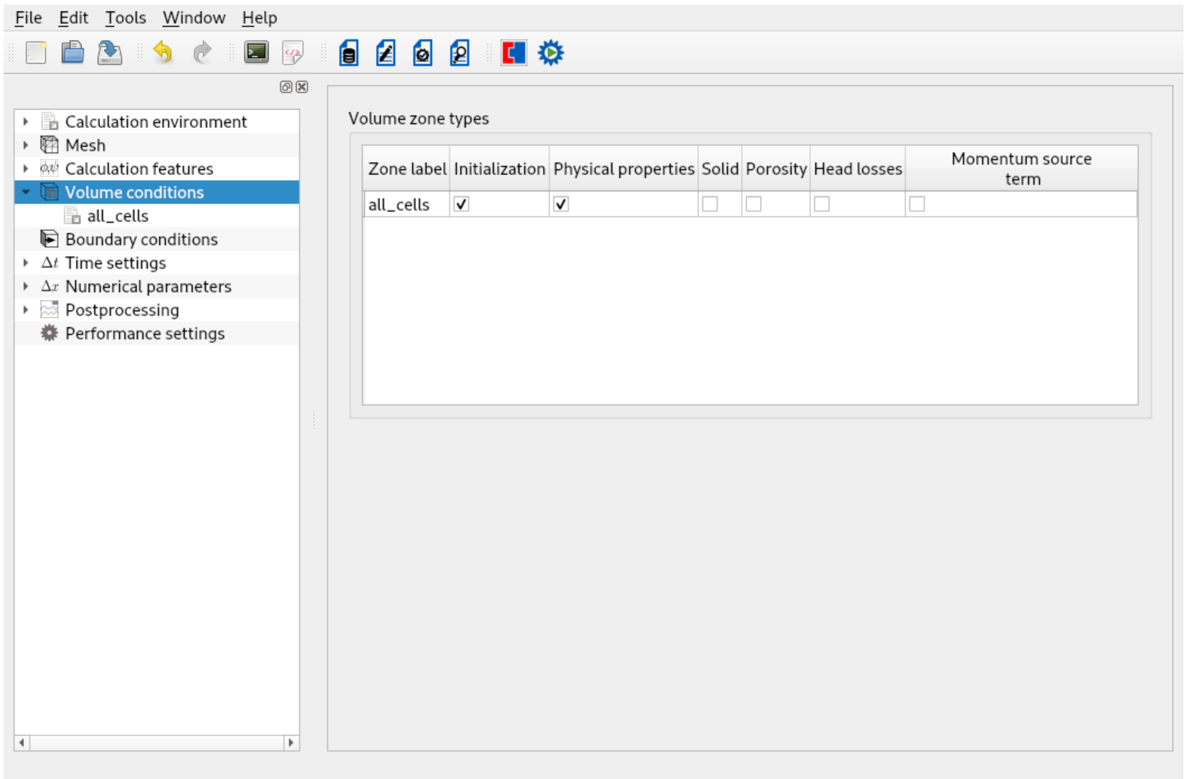


Figure III.10: Volume conditions

Physical properties Under the heading **Physical properties**, enter the following information:

Variable	Type	Reference value
Density	User law	$992.91\ kg.m^{-3}$
Viscosity	User law	$6.68 \times 10^{-4}\ kg.m^{-1}.s^{-1}$
Specific Heat	Constant	$4\,178\ J.kg^{-1}.°\mathrm{C}^{-1}$
Thermal Conductivity	Constant	$0.628\ W.m^{-1}.K^{-1}$

For density and viscosity, the value given here will serve as a reference value (see user manual for details).

In addition for the **density** and **viscosity**, enter the expressions of the user laws as shown in figures III.12 in the pop-up window while clicking on the green highlighted boxes

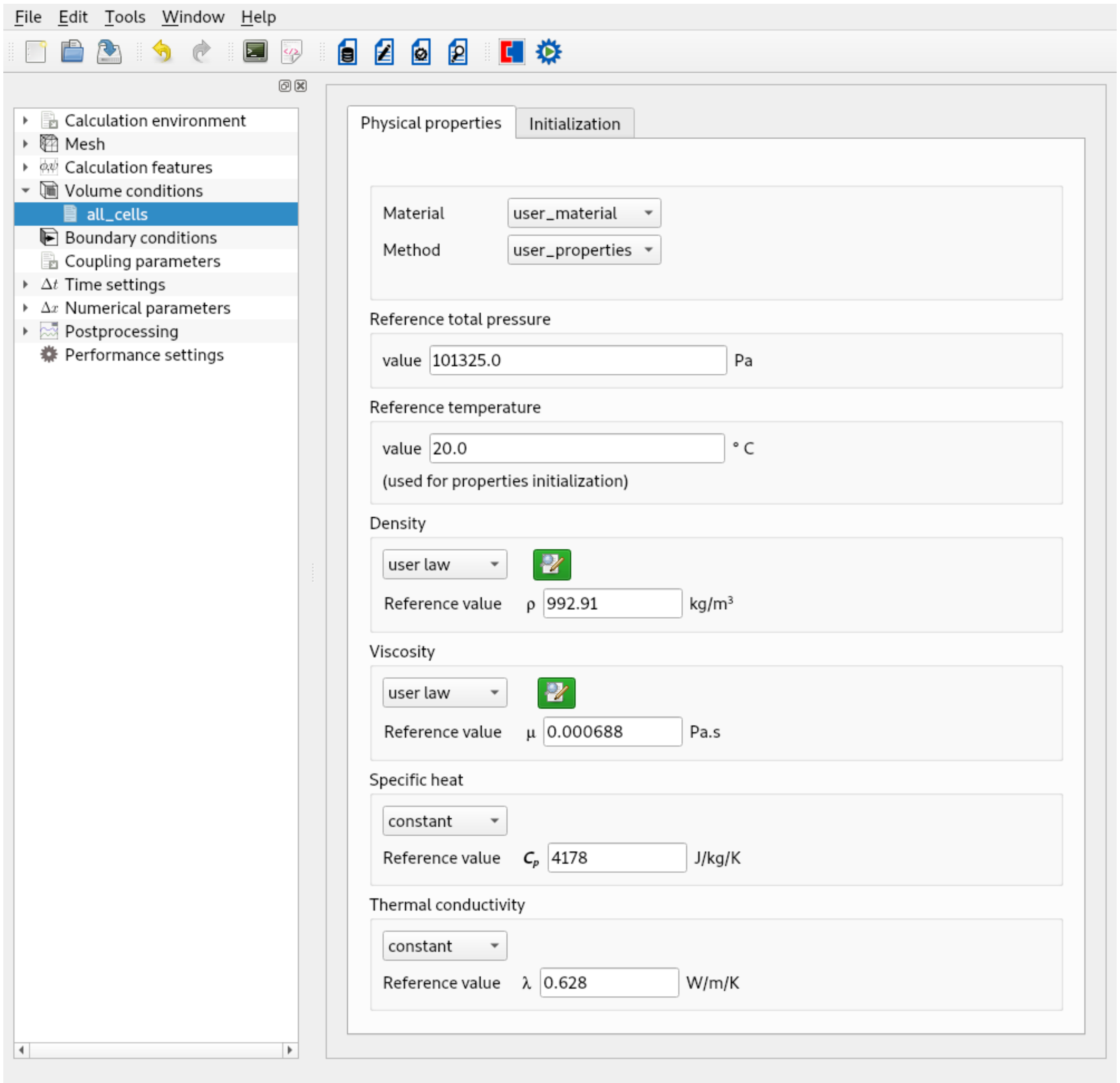


Figure III.11: Fluid properties

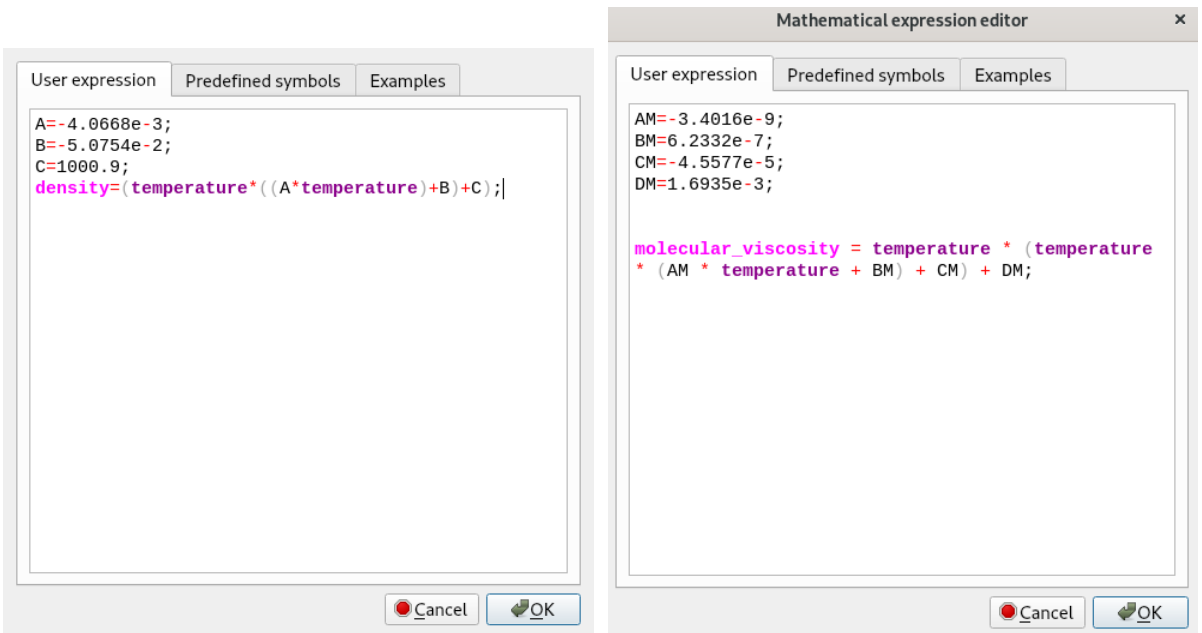


Figure III.12: Variable density and Viscosity

Initialization In the item **Initialization** under the heading **Volume conditions**, set the initial value of the temperature in the domain to 38.5°C. Initialize the turbulence with the reference velocity previously defined

Note: To set user expressions you need to click on the green icon  next to the selected field.

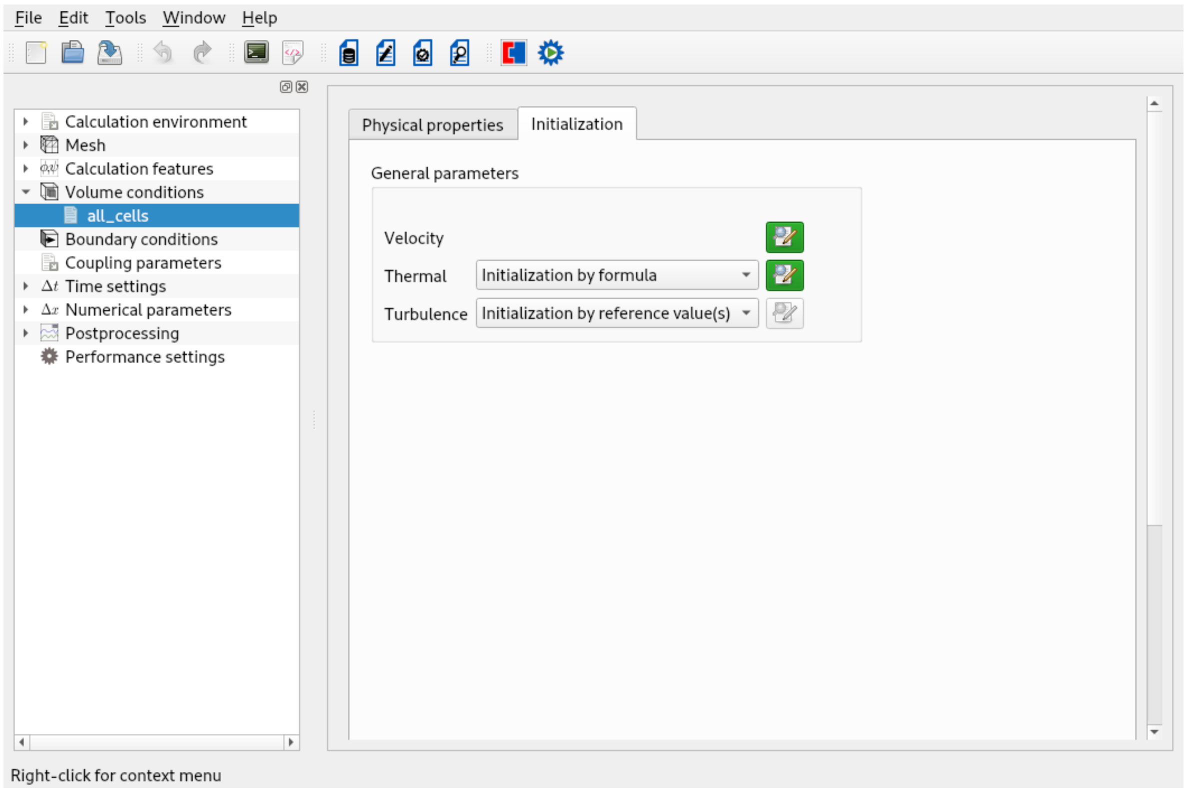


Figure III.13: Volume conditions: Initialization

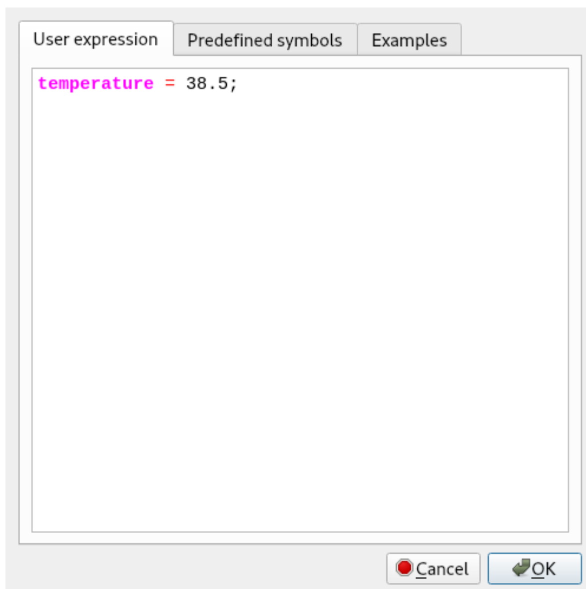


Figure III.14: Volume zones: Initialization - Thermal value

1.7 Boundary conditions Tab

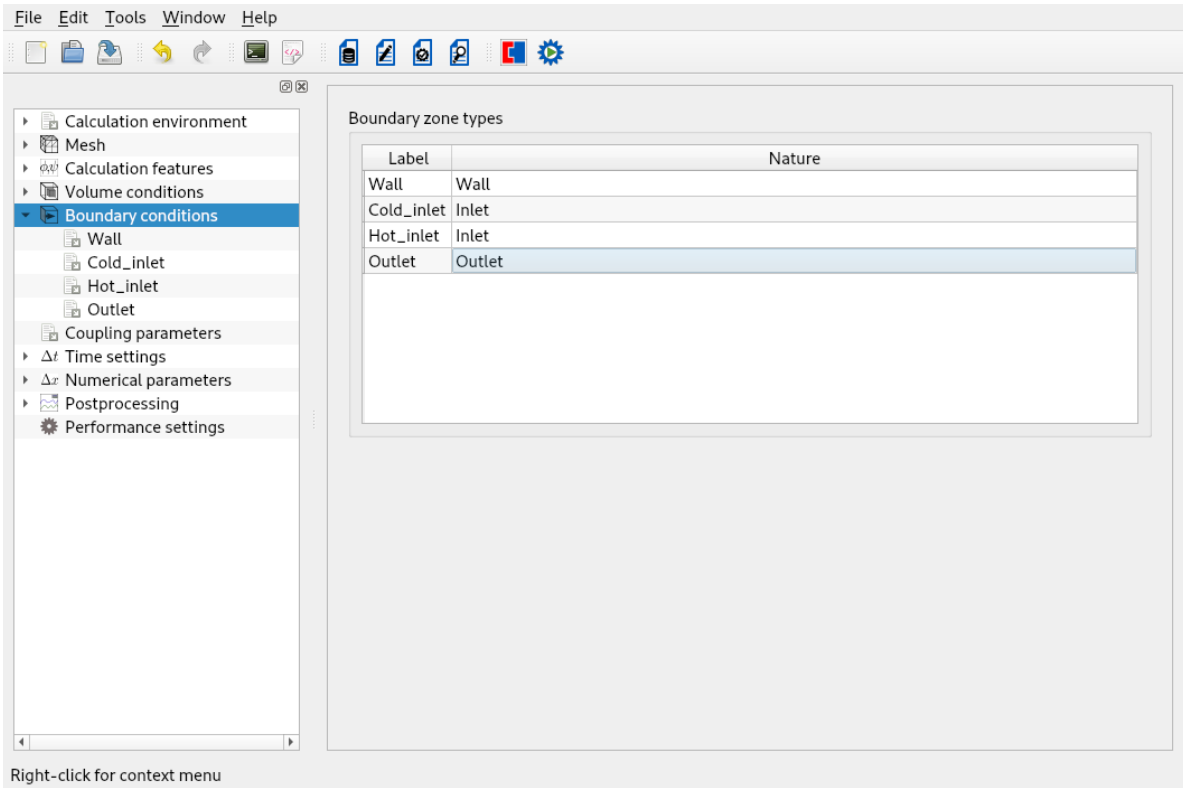


Figure III.15: Boundary conditions - Boundary nature definition

For the inlet boundary conditions, the velocity is 0.03183 $m.s^{-1}$ in the z direction and the hydraulic diameter is 0.4 m for both inlets. For the thermal conditions, the cold inlet and the hot inlet temperatures are 18.6°C and 38.5°Crespectively.

– Cold inlet:

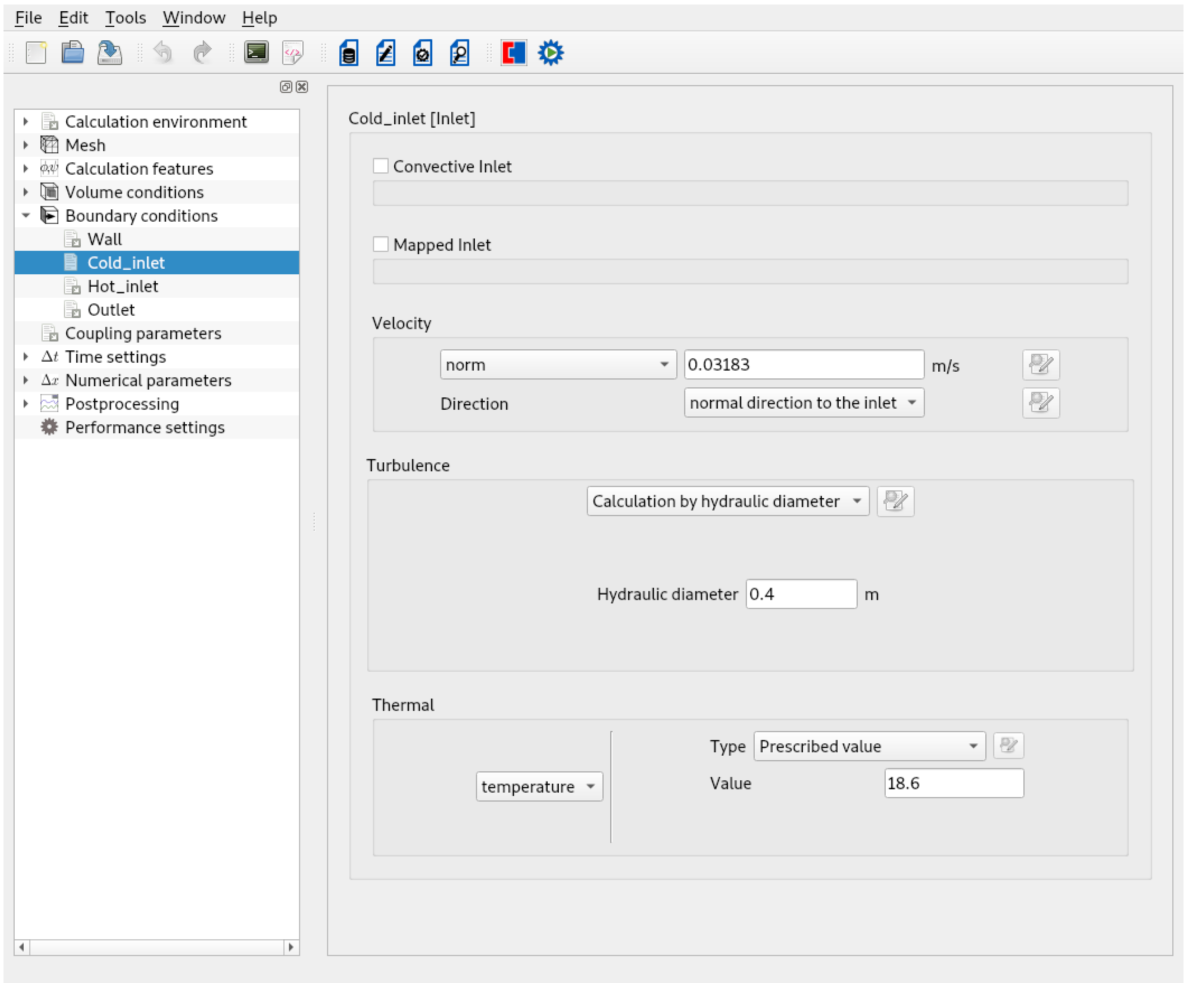


Figure III.16: Cold inlet boundary condition

– Hot inlet:

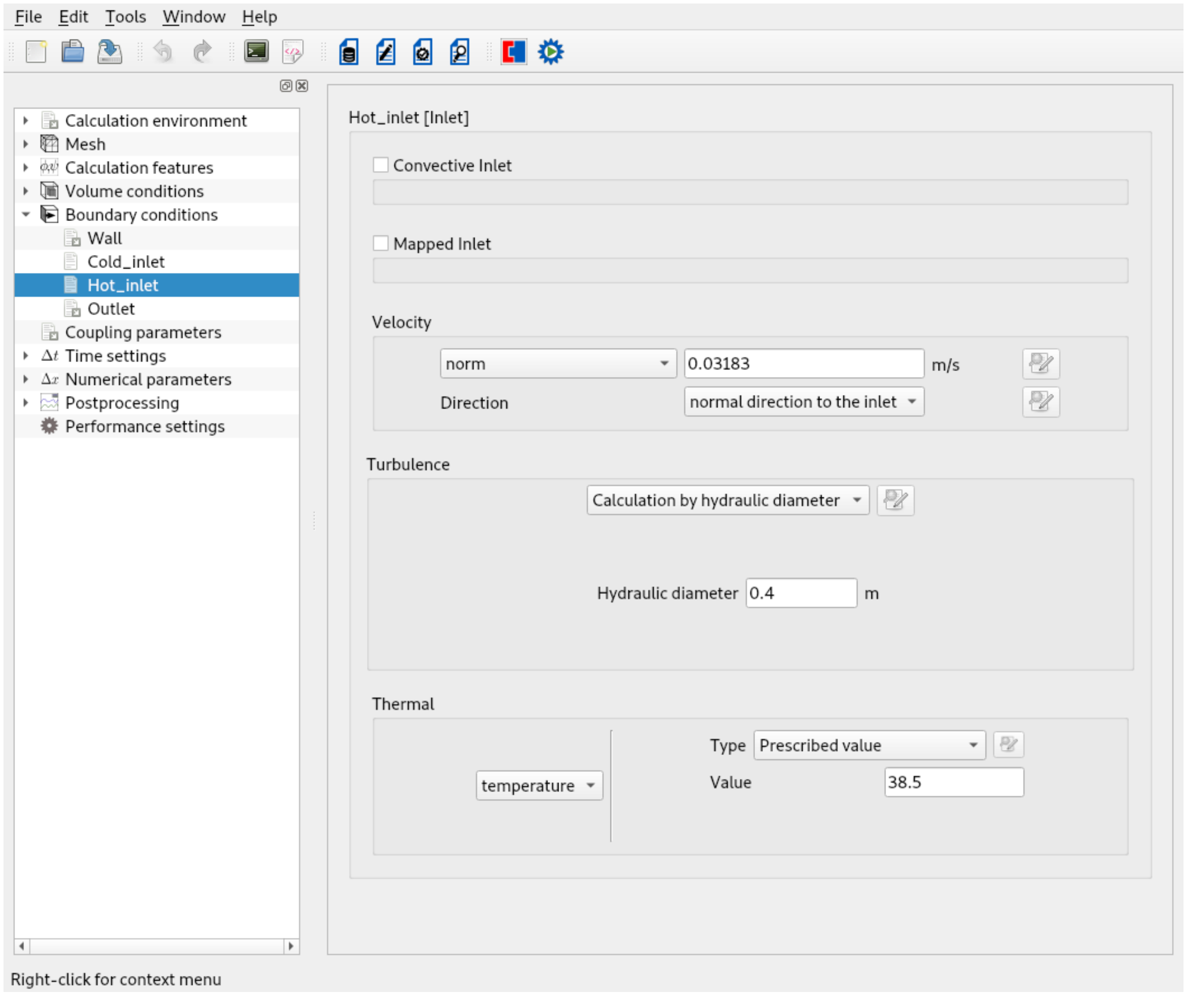


Figure III.17: Hot inlet boundary condition

– Walls and Outlet:

Wall and outlet boundary conditions remain with their default values.

1.8 Time settings Tab

Under **Time settings** tab, tick the appropriate box for the time step to be variable in time and uniform in space. In the boxes below, enter the following parameters:

Parameters of calculation control	
Number of time steps	100
Reference time step	0.1 s
Maximal CFL number	20
Maximal Fourier number	60
Minimal time step factor	0.01
Maximal time step factor	70.0
Time step maximal variation	0.1

Then, activate the option **Limitation by local thermal time step**

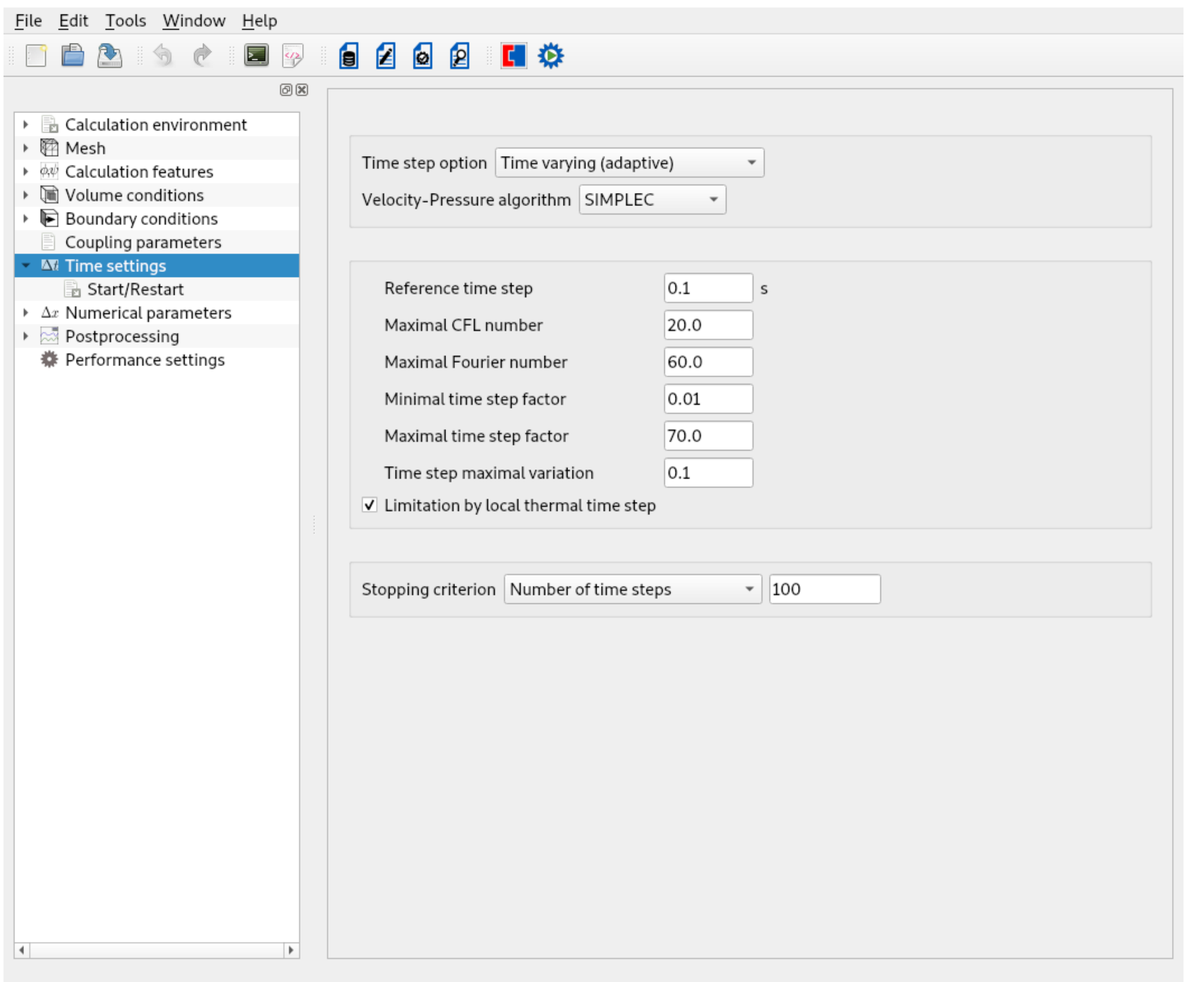


Figure III.18: Time step

1.9 Numerical parameters Tab

Under **Numerical parameters** tab, tick the option *Improved pressure interpolation*.

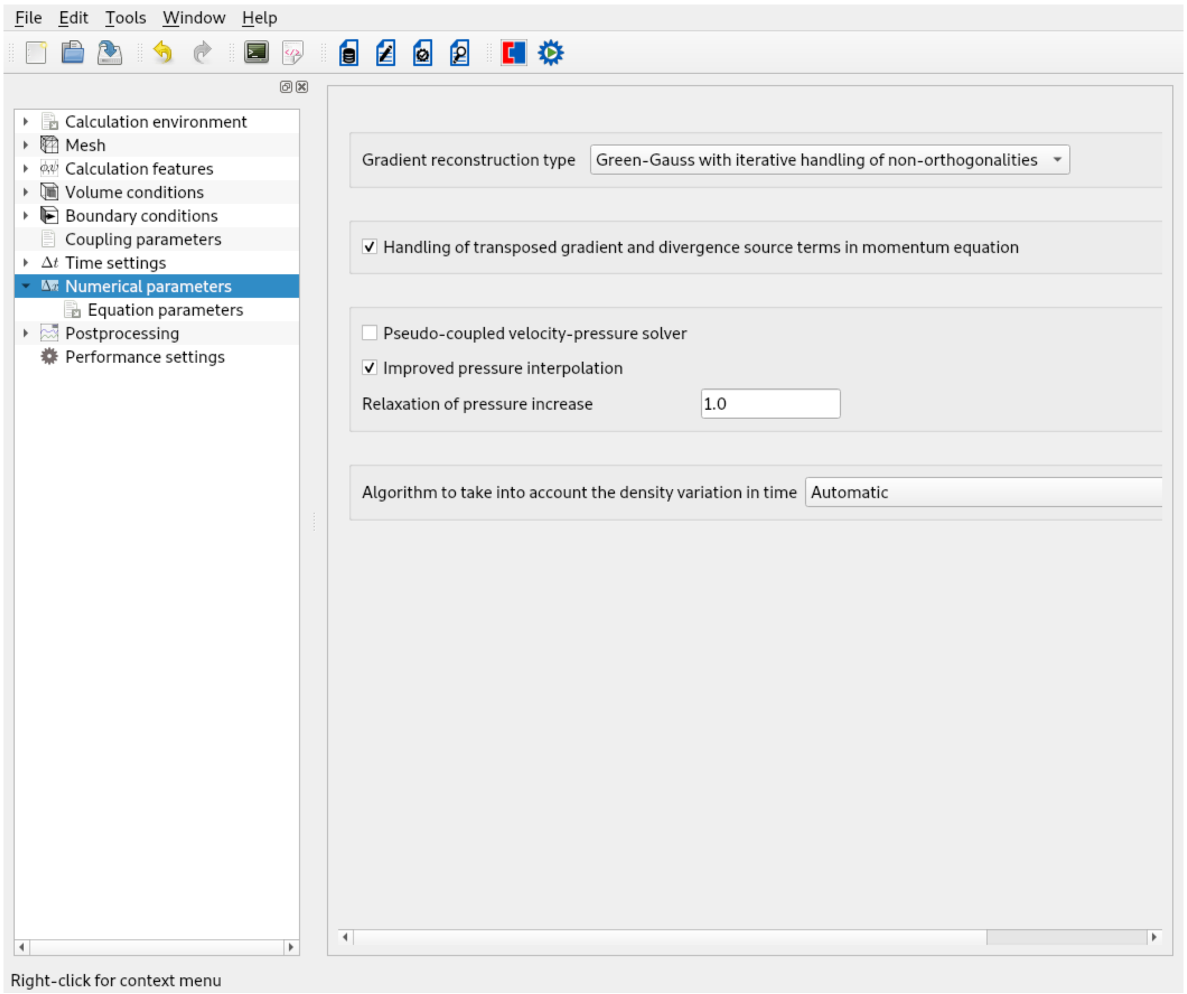


Figure III.19: Numerical parameters

Equation parameters - Clipping Still under the same tab, go to the item **Equation parameters**, and open the *Clipping* tab to specify the minimal and maximal values for the temperature: 18.6°C and 38.5°C. Note that the initial value of 38.5°C set earlier is properly taken into account.

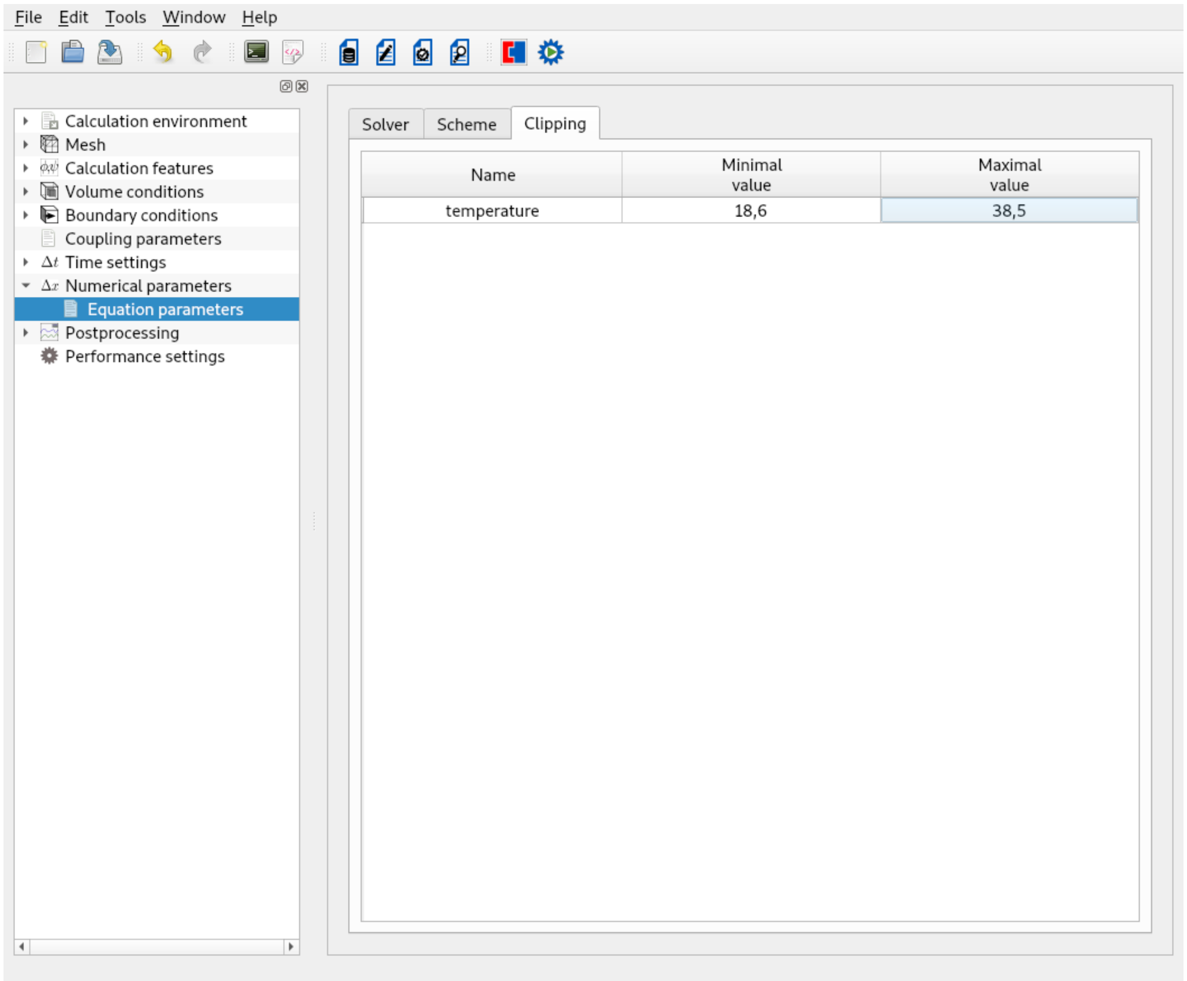


Figure III.20: Scalar clipping

1.10 Postprocessing Tab

Writer Under **Postprocessing** tab, go to the *Writer* tab and set the frequency of post-processing for the main writer `results` to 10 (time steps).

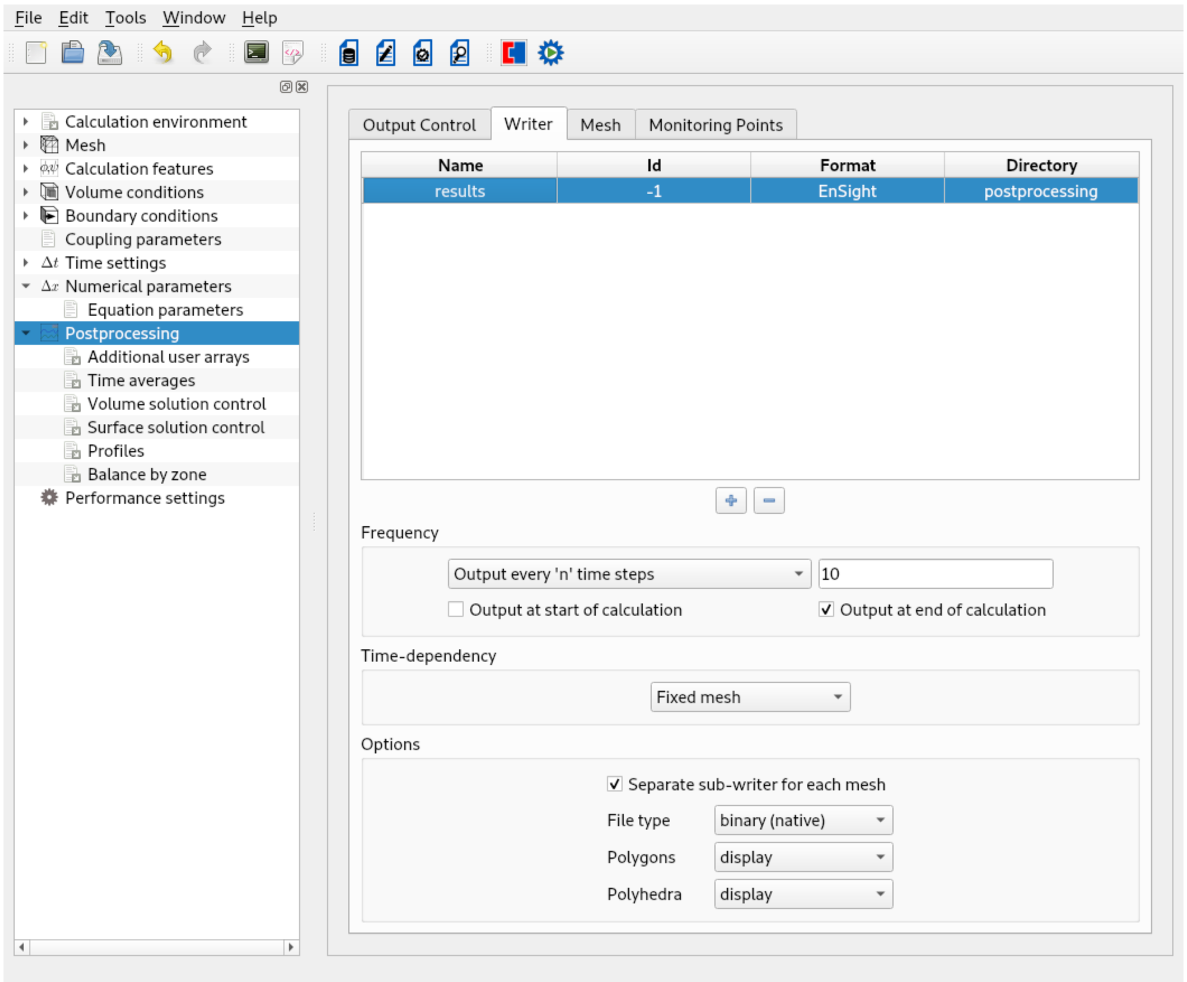


Figure III.21: Output management

Monitoring Points Switch to the *Monitoring Points* tab and create four monitoring probes at the following coordinates:

Probes	x(m)	y(m)	z(m)
1	0.010025	0.01534	-0.011765
2	1.625	0.01534	-0.031652
3	3.225	0.01534	-0.031652
4	3.8726	0.047481	0.725

Note: If you do work on SALOME, the monitoring points can be directly displayed in SALOME viewer by ticking the box *Display monitoring points on SALOME viewer*.

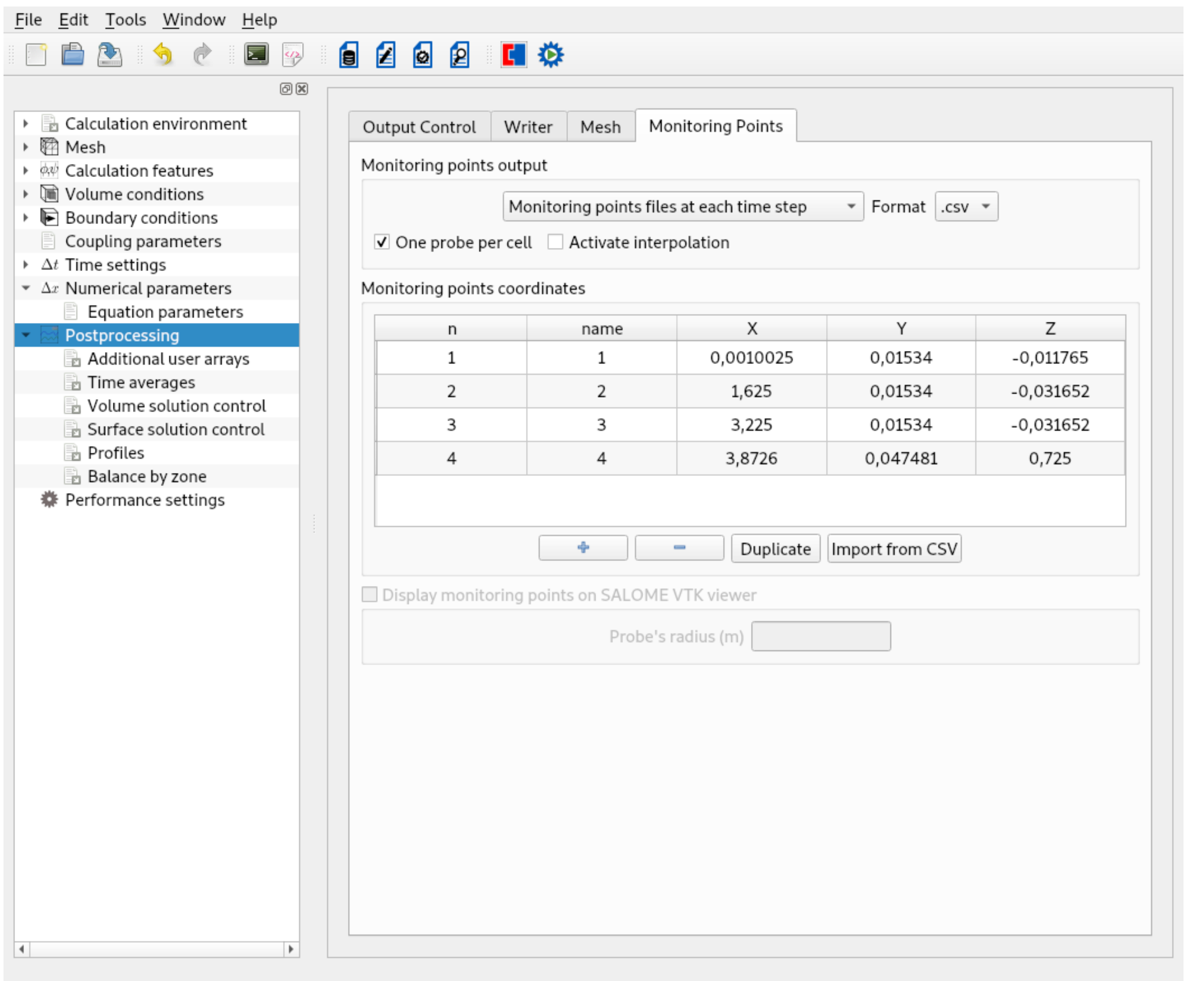


Figure III.22: Monitoring points

Profils Still under **Postprocessing** tab, select **Profiles** item and create two vertical profiles at the following locations with an output frequency of 10.

Note: To set user expressions you need to click on the green icon  next to the selected field.

Profile	x(m)	y(m)	z(m)
`profil16`	1.6	0	$-0.2 \leqslant z \leqslant 0.2$
`profil32`	3.2	0	$-0.2 \leqslant z \leqslant 0.2$

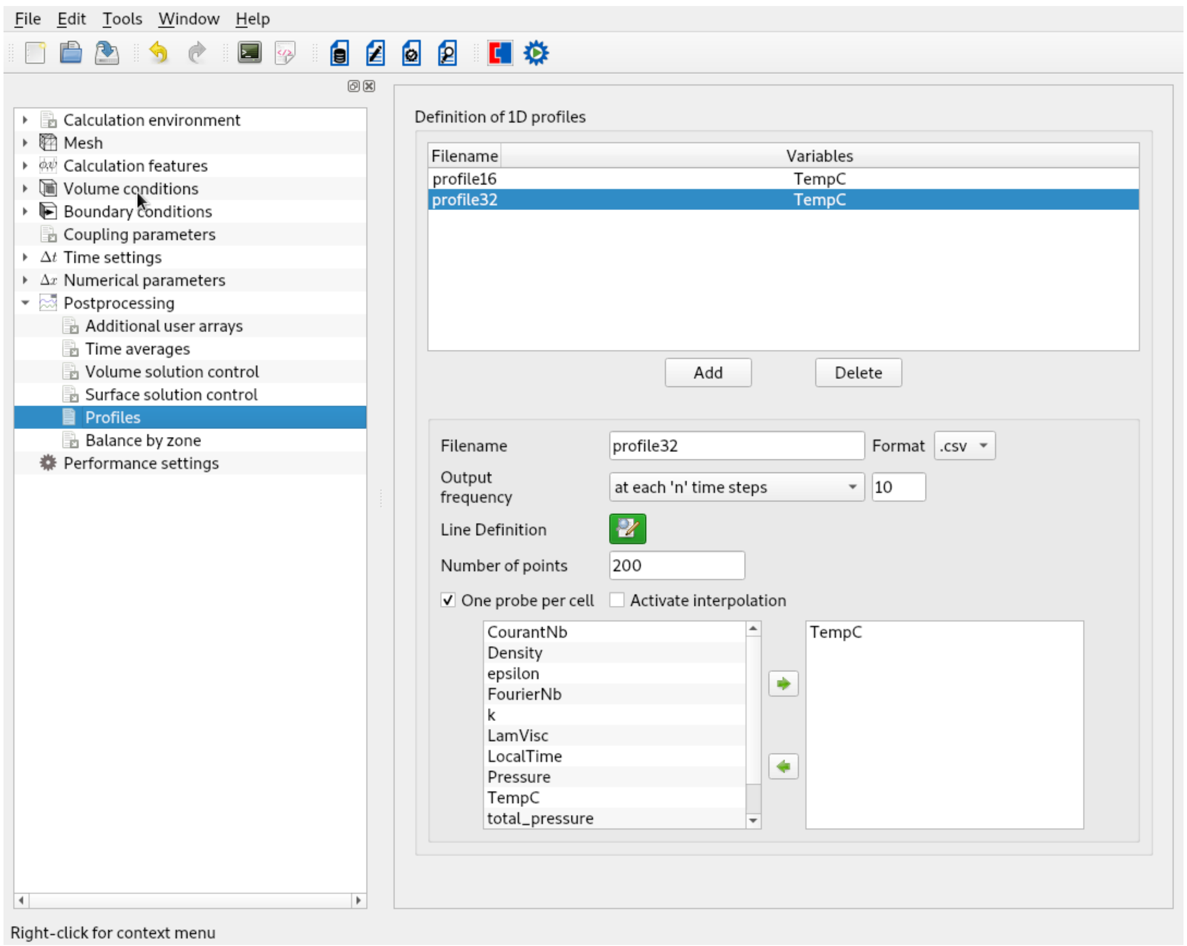


Figure III.23: Vertical profiles

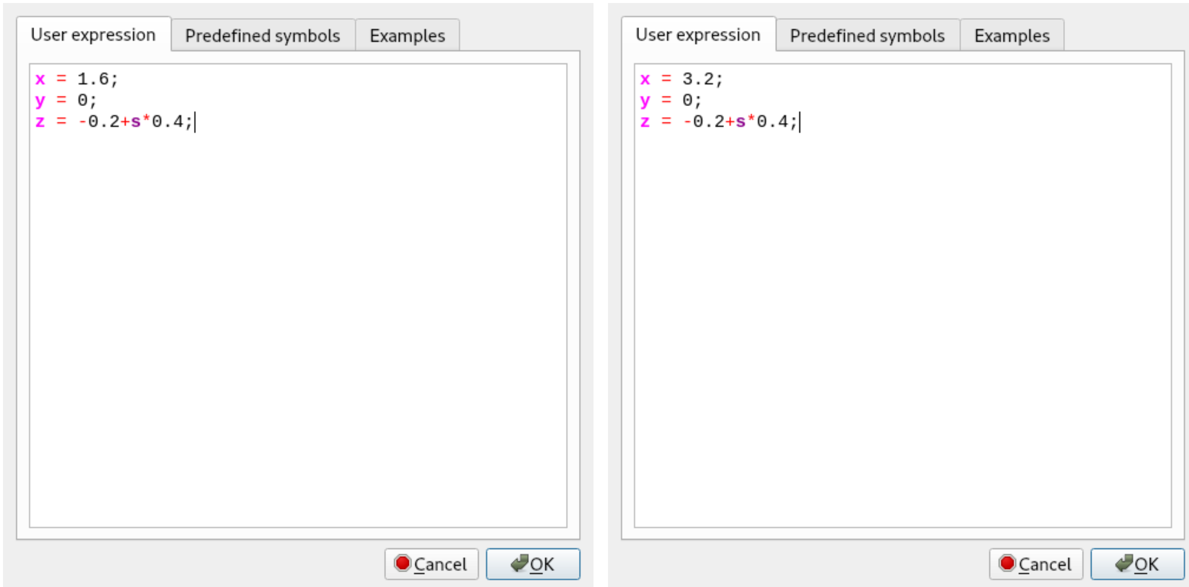


Figure III.24: Vertical profiles : Line definition - Profil16 and Profil32

1.11 Postprocessing Routines modifications

For the advanced post-processing features, copy into the SRC directory the file `cs_user_postprocess.c` from the directory SRC/REFERENCE. The general content of this routine is described in the user manual and some examples are available in the directory SRC/EXAMPLES Only the main elements are mentioned here :

- **cs_user_postprocess_meshes** (in `cs_user_postprocess.c`):
  This is called only once, at the beginning of the calculation. It allows to define the different writers and parts.
- **cs_user_postprocess_values** (in `cs_user_postprocess.c`):
  This routine is called at each time step. It allows to specify which variable will be written on which part.