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code_saturne documentation

**code_saturne version 7.0 tutorial:
full domain**

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Part I

Introduction

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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 7.0. It presents three simple test cases and guides the future code_saturne user step by step into the preparation and the computation of the cases.

The test case directories, containing the necessary meshes and data are available in the **examples** directory.

This tutorial focuses on the procedure and the preparation of the code_saturne computations. For more elements on the structure of the code and the definition of the different variables, it is highly recommended to refer to the user manual.

1.3 code_saturne copyright informations

code_saturne is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version. code_saturne is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

Part II

Full domain

1 Study description

1.1 Objective

The aim of this case is to tackle the merging of initially separate meshes into a single fluid domain. The questions of mesh joining and hanging nodes will be addressed. The test case will then be used to present more complex calculations, with time dependent variables and Fortran user routines.

1.2 Description of the configuration

The fluid domain is composed of three separate meshes, very roughly representing elements of a nuclear pressurized water reactor vessel:

- the downcomer
- the vessel's bottom
- the lower core plate and core

Figure II.1 represents the complete domain. The flow circulates from the top left horizontal junction to the right vertical outlet.

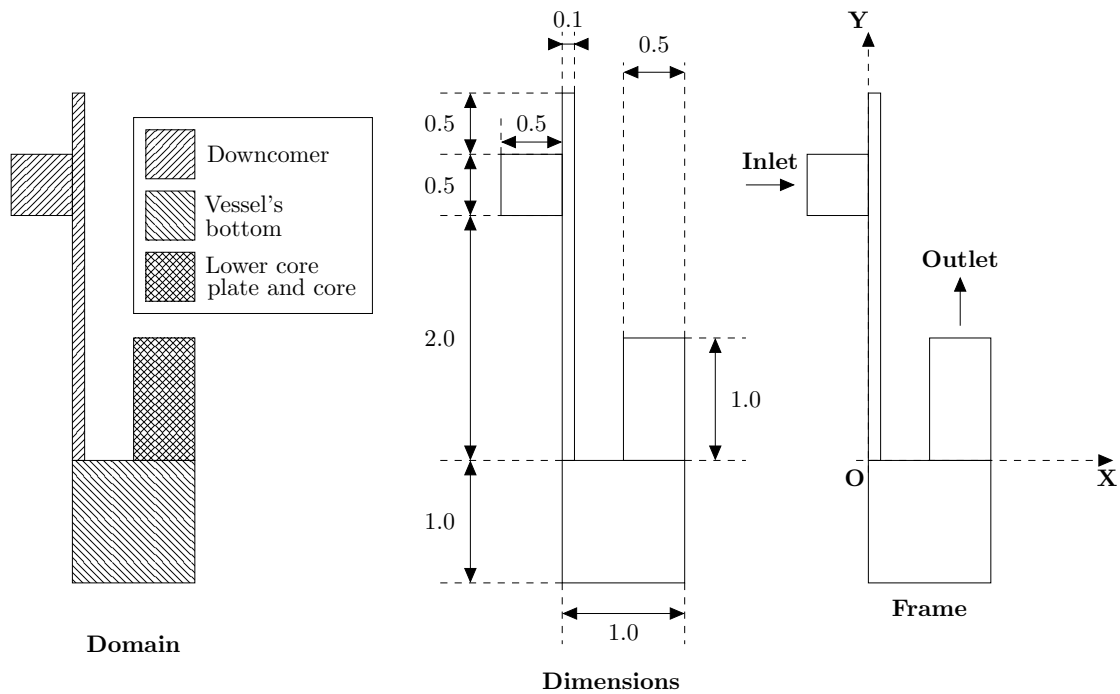


Figure II.1: Geometry of the complete domain

1.3 Characteristics

Characteristics of the geometry and the flow:

Height of downcomer	$H = 3.00 \text{ m}$
Thickness of downcomer	$E_d = 0.10 \text{ m}$
Diameter of the inlet cold branch	$D_b = 0.50 \text{ m}$
Height of vessel's bottom	$H_{fc} = 1.00 \text{ m}$
Width of vessel's bottom	$l_{fc} = 1.00 \text{ m}$
Height of core above the lower core plate	$H_{pic} = 1.00 \text{ m}$
Width of core above the lower core plate	$l_{pic} = 0.50 \text{ m}$
Inlet velocity of fluid	$V = 1 \text{ m.s}^{-1}$

Table II.1: Characteristics of the geometry and the flow

Physical characteristics of fluid:

The initial water temperature in the domain is equal to 20°C. The inlet temperature of water in the cold branch is 300°C. Water characteristics are considered constant¹ and their values taken at 300°C and $150 \times 10^5 \text{ Pa}$, except density which is considered variable in **case2** and **case3**:

- density: $\rho = 725.735 \text{ kg.m}^{-3}$
- dynamic viscosity: $\mu = 0.895 \times 10^{-4} \text{ kg.m}^{-1}.\text{s}^{-1} = 8.951 \times 10^{-5} \text{ Pa.s}$
- heat capacity: $C_p = 5483 \text{ J.kg}^{-1}.\text{°C}^{-1}$
- thermal conductivity = $0.02495 \text{ W.m}^{-1}.\text{K}^{-1}$

1.4 Mesh characteristics

Figure II.2 shows a global view of the mesh and some details of the joining zones, to show that code_saturne can deal with hanging nodes. This mesh is composed of 1 650 cells, which is very small compared to those used in real studies. This is a deliberate choice so that tutorial calculations run fast.

Type: block structured mesh

Coordinates system: cartesian, origin on the edge of the main pipe at the outlet level, on the nozzle side (figure II.2)

Mesh generator used: SIMAIL and mesh joining with the Preprocessor of code_saturne (in order to deal with hanging nodes)

Color definition: see figure II.3

1.5 Summary of the different calculations

Three cases will be studied with this geometry. The following table gives a summary of their different characteristics.

Remark: In this case, you must add three meshes which have to be joined. In order to join the three meshes, you must add a selection criteria in the box **Selection criteria** under the **Preprocessing** sub-folder. In this case, only faces of colors 5, 24 and 32 are liable to be joined (different colors can be entered on a single line, separated by comma).

You can verify the quality of your mesh by running a **Mesh quality criteria only** computation, which you can access through **Execution mode** in the **Mesh** heading.

¹Which makes temperature a passive scalar ... but it is only for simplification purposes.

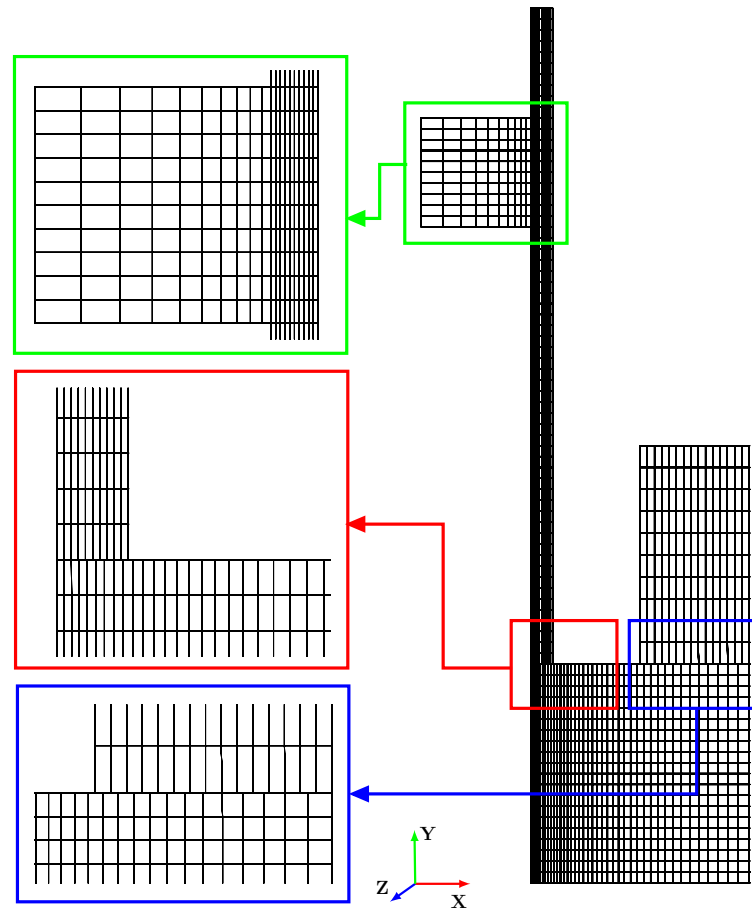


Figure II.2: View of the full domain mesh with zoom on the joining regions

CASE	Characteristics
CASE 1	Unsteady flow, additionnal passive scalar, output management
CASE 2	Same as case 1 with time dependent boundary conditions, fluid density depending on the temperature and calculation restart
CASE 3	Same as case 2 with head losses, parallelism and spatial average

Table II.2: Summary of the different calculations

2 CASE 1: Passive scalar with various boundary conditions and output management

2.1 Calculation options

Some options are similar to those of the `simple_junction` tutorial:

- Turbulence model: $k - \epsilon$
- Scalar(s): 1 - temperature
- Physical properties: uniform and constant

The new options are:

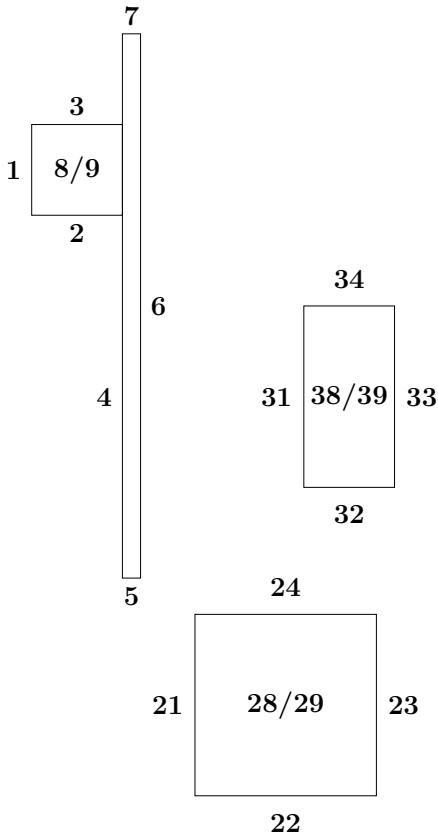


Figure II.3: Colors of the boundary faces

- Flow type: unsteady flow
- Time step: uniform and constant
- Scalar(s): 2 - passive scalar², with diffusion coefficient $8.55 (\times 10^{-5} \text{ m}^2.\text{s}^{-1})$
- Management of monitoring points

2.2 Initial and boundary conditions

- Initialization: 20°C for temperature
10 for the passive scalar

The boundary conditions are defined in the user interface and depend on the boundary zone.

- **Flow inlet:** Dirichlet condition, an inlet velocity of 1 m.s^{-1} , an inlet temperature of 300°C and an inlet value of 200 for the passive scalar are imposed
- **Outlet:** default value
- **Walls:** velocity, pressure and thermal scalar: default value
passive scalar: different conditions depending on the color and geometric parameters

In order to test the ability to specify boundary condition regions in the Graphical Interface, various conditions will be imposed for the passive scalar, as specified in the following table:

²It could correspond to a tracer concentration for instance.

Wall	Nature	Value
wall_1	Imposed value (Dirichlet)	0
wall_2	Imposed value (Dirichlet)	5
wall_3	Imposed value (Dirichlet)	0
wall_4	Imposed value (Dirichlet)	25
wall_5	Imposed value (Dirichlet)	320
wall_6	Imposed value (Dirichlet)	40

The [wall_1](#) to [wall_6](#) regions are defined as follows, through color references and geometric localization:

Label	Color and geometric parameters
wall_1	24 and $0.1 \leq x$ and $x \leq 0.5$
wall_2	2 or 3
wall_3	4 or 7 or 21 or 22 or 23
wall_4	6 and $y > 1$
wall_5	6 and $y \leq 1$
wall_6	31 or 33

Figure [II.3](#) shows the colors used for boundary conditions and table [II.3](#) defines the correspondance between the colors and the type of boundary condition to use.

Colors	Conditions
1	Inlet
34	Outlet
2 3 4 6 7 21 22 23 24 31 33	Wall
8 9 28 29 38 39	Symmetry

Table II.3: Boundary faces colors and associated references

2.3 Parameters and User routines

All parameters necessary to this study can be defined through the Graphical Interface without using any user Fortran files.

Calculation control parameters	
Pressure-Velocity coupling	SIMPLEC algorithm
Number of iterations	300
Reference time step	0.05
Output period for post-processing files	2

In order to join the separate meshes into a single domain, colors 5, 24 and 32 will have to be joined through the Graphical Interface.

2.4 Output management

In this case, different aspects of output management will be addressed.

By default, in the Graphical Interface, all variables are set to appear in the listing, the post-processing and the chronological records. This default choice can be modified by the user.

In this case, the **Pressure**, the **Turbulent energy** and the **Dissipation** will be removed from the listing file.

The **Courant number** (CFL) and **Fourier number** will be removed from the post-processing results³.

Eventually, probes will be defined for chronological records, following the data given in figure II.4. Then the **total pressure** will be deactivated for all probes.

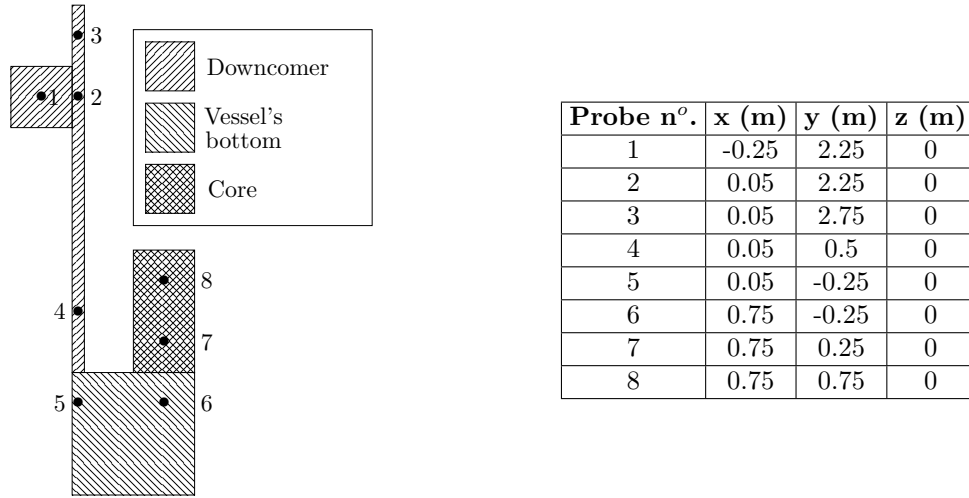


Figure II.4: Position and coordinates of probes in the full domain

In addition the domain boundary will be post-processed. This allows to check the boundary conditions, and especially that of the passive scalar.

2.5 Results

Figure II.5 shows the boundary domain colored by the passive scalar boundary conditions. The different regions of boundary conditions defined earlier can be checked.

Figure II.6 presents results obtained at different times of the calculation. They were plotted from the post-processing files, with ParaView.

³This can be very useful to save some disk space if some variables are of no interest, as post-processing files can be large.

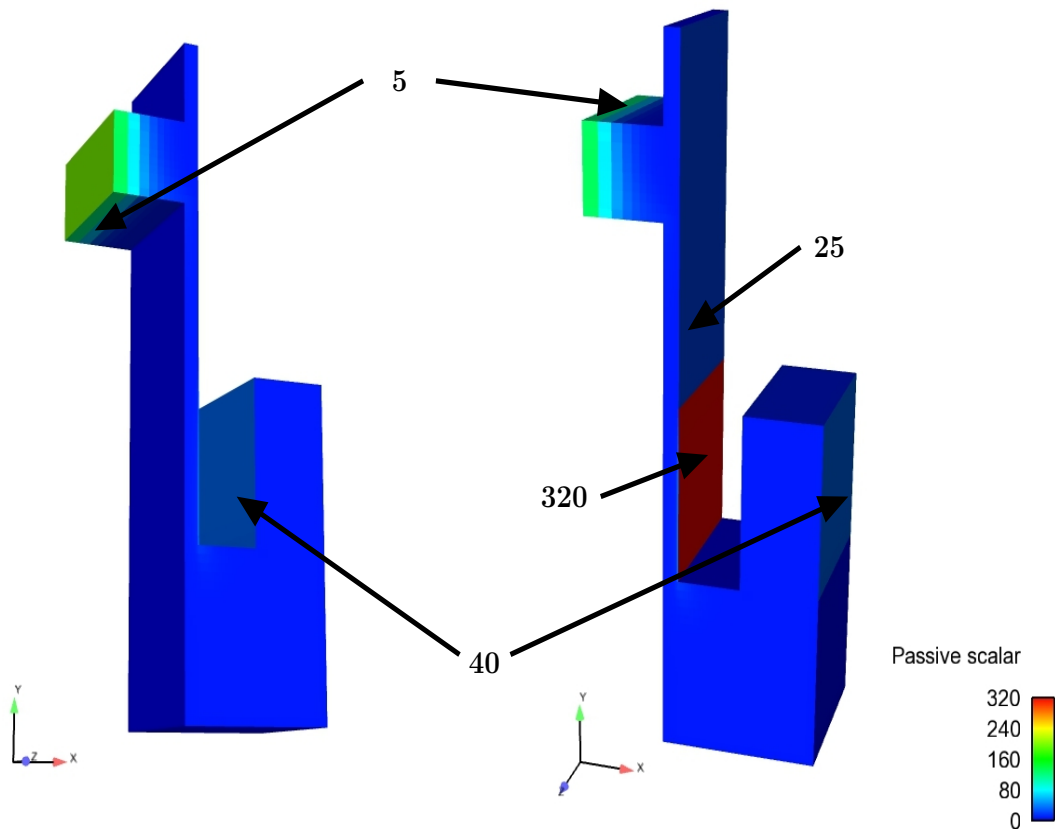


Figure II.5: View of the boundary domain colored by the scalar2 variable - Case 1

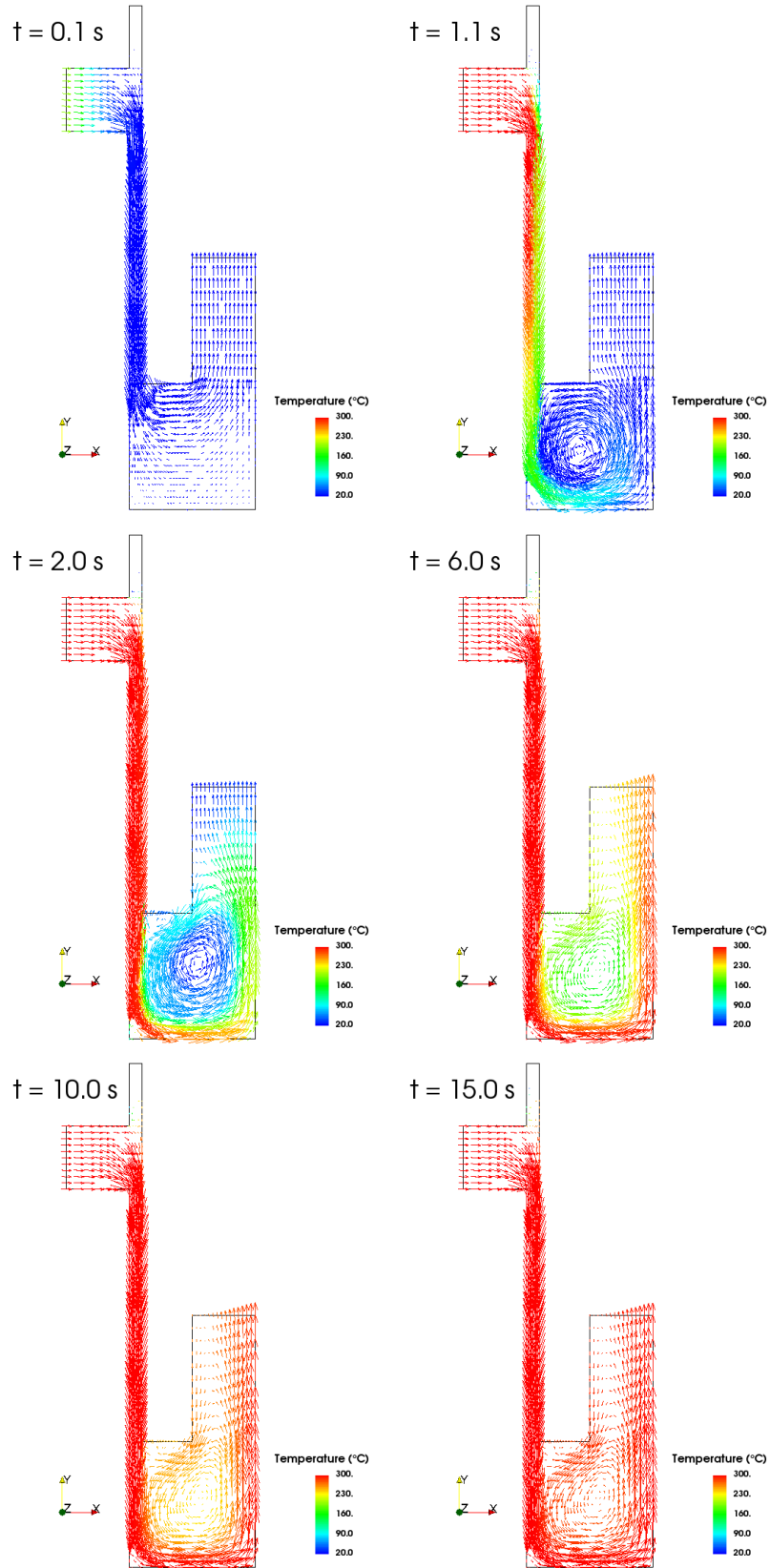


Figure II.6: Water velocity field colored by temperature at different time steps - Case 1

3 CASE 2: Time dependent boundary conditions and variable fluid density

In this case some boundary conditions will be time dependent and some physical characteristics of the fluid will be dependent on the temperature.

Remark: You can copy your `case1` in order to make the `case2`:

```
$ code_saturne create --copy-from case1 case2
```

3.1 Calculation options

The options for this case are the same as in `case1`, except for the variable fluid density:

- Flow type: unsteady flow
- Time step: uniform and constant
- Turbulence model: $k - \epsilon$
- Scalar(s): 1 - temperature
2 - passive scalar
- Physical properties: uniform and constant (except density)
- Management of monitoring points

3.2 Initial and boundary conditions

- Initialization: 20°C for temperature
10 for the passive scalar

The boundary conditions are defined in the user interface and depend on the boundary zone. The time dependence of the temperature boundary condition implies the use of a Fortran user routine (see below).

- **Flow inlet:** Dirichlet condition, an inlet velocity of 1 m.s^{-1} , a time dependent inlet temperature and a value of 200 for the passive scalar are imposed;
- **Outlet:** default value;
- **Walls:** velocity, pressure and thermal scalar: default value
passive scalar: different conditions depending on the color and geometric parameters.

The boundary conditions for the passive scalar are identical as those in `case1`, as specified in the following table:

Wall	Nature	Value
wall_1	Imposed value (Dirichlet)	0
wall_2	Imposed value (Dirichlet)	5
wall_3	Imposed value (Dirichlet)	0
wall_4	Imposed value (Dirichlet)	25
wall_5	Imposed value (Dirichlet)	320
wall_6	Imposed value (Dirichlet)	40

The `wall_1` to `wall_6` regions are defined as follows, through color references and geometric localization:

Figure II.3 shows the colors used for boundary conditions and table II.4 defines the correspondance between the colors and the type of boundary condition to use.

Label	Color and geometric parameters
wall_1	24 and $0.1 \leq x$ and $x \leq 0.5$
wall_2	2 or 3
wall_3	4 or 7 or 21 or 22 or 23
wall_4	6 and $y > 1$
wall_5	6 and $y \leq 1$
wall_6	31 or 33

Colors	Conditions
1	Inlet
34	Outlet
2 3 4 6 7 21 22 23 31 33	Wall
24 for $0.1 \leq x \leq 0.5$	Wall
8 9 28 29 38 39	Symmetry

Table II.4: Boundary faces colors and associated references

3.3 Variable Density

In this case the density is a function of the temperature. The variation law is defined in the Graphical User Interface, although it can also be defined in a Fortran user routine. The expression is:

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

where ρ is the density, T is the temperature, $A = -4.0668 \times 10^{-3}$, $B = -5.0754 \times 10^{-2}$ and $C = 1\,000.9$.

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

Remark:

The temperature is **temperature** in the user expression. Don't forget **;** at the end of the expression.

3.4 Parameters

The calculation parameters are identical as those in **case1**.

All the parameters necessary to this study can be defined through the Graphical Interface, except the time dependent boundary conditions that have to be specified in user routines.

In order to join the separate meshes into a single domain, colors 5, 24 and 32 will have to be joined through the Graphical Interface.

3.5 User routine

The routine `cs_user_boundary_conditions.f90` has to be copied from the folder `SRC/REFERENCE` into the folder `SRC` ⁴.

⁴Only when it appears in the `SRC` directory will it be taken into account by the code.

Parameters of calculation control	
Number of iterations	300
Reference time step	0.05
Output period for post-processing files	2

- **cs_user_boundary_conditions.f90**

This routine allows to define advanced boundary conditions on the boundary faces.

Even if `cs_user_boundary_conditions.f90` is used, all boundary conditions have to be defined in the Graphical User Interface (GUI). Only the conditions that differ from this first definition need to appear in `cs_user_boundary_conditions.f90`. The boundary conditions defined in `cs_user_boundary_conditions.f90` will replace those specified in the Graphical Interface.

In this case, the temperature at entry is supposed variable in time, following the law:

$$\begin{cases} T = 20 + 100t & \text{for } 0 \leq t \leq 3.8 \\ T = 400 & \text{for } t > 3.8 \end{cases} \quad (\text{II.2})$$

where T is the temperature in °C and t is the time in seconds (s).

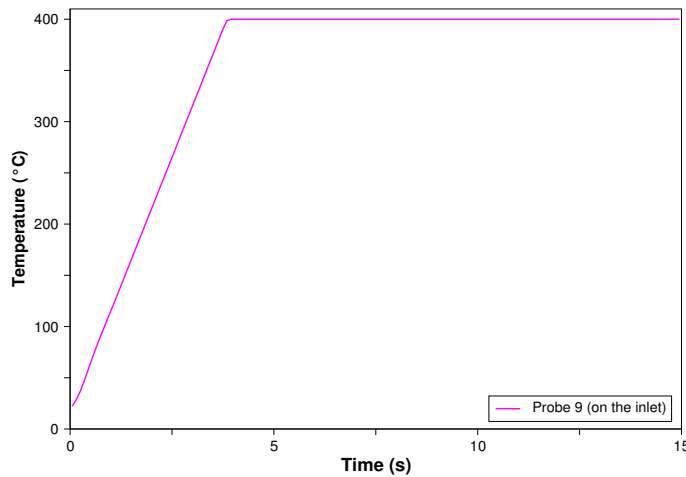


Figure II.7: Time evolution of the temperature at inlet.

Remark:

`ttcabs` is the current physical time. See the example file in the subdirectory `SRC/EXAMPLES` for the complete `cs_user_boundary_conditions.f90` file.

3.6 Output management

The output management is the same as in `case1`, except that a ninth monitoring point will be added, just at the entry, to monitor the temperature evolution at inlet.

In this case, the **Pressure**, the **Tubulent Energy** and the **Dissipation** will be removed from the listing file.

The **Courant number** (CFL) and **Fourier number** will be removed from the post-processing results⁵.

Eventually, probes will be defined for chronological records, following the data given in figure II.8. Then the **total_pressure** will be deactivated from all probes.

In addition the domain boundary will be post-processed. This allows to check the boundary conditions, and especially that of the temperature and passive scalar.

⁵This can be very useful to save some disk space if some variables are of no interest, as post-processing files can be large.

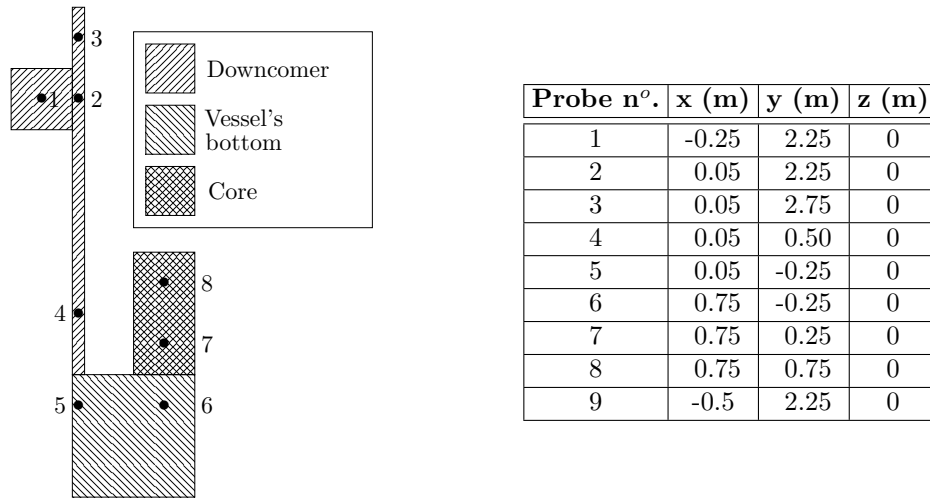


Figure II.8: Position and coordinates of probes in the full domain

3.7 Calculation restart

After the first run, the calculation will be continued for another 400 time steps. The calculation restart is managed through the Graphical Interface.

3.8 Results

Figure II.9 shows the time evolution of temperature recorded on each monitoring probe. Note that the .csv files obtained for each case, were concatenated to plot the evolution of temperature over the entire period.

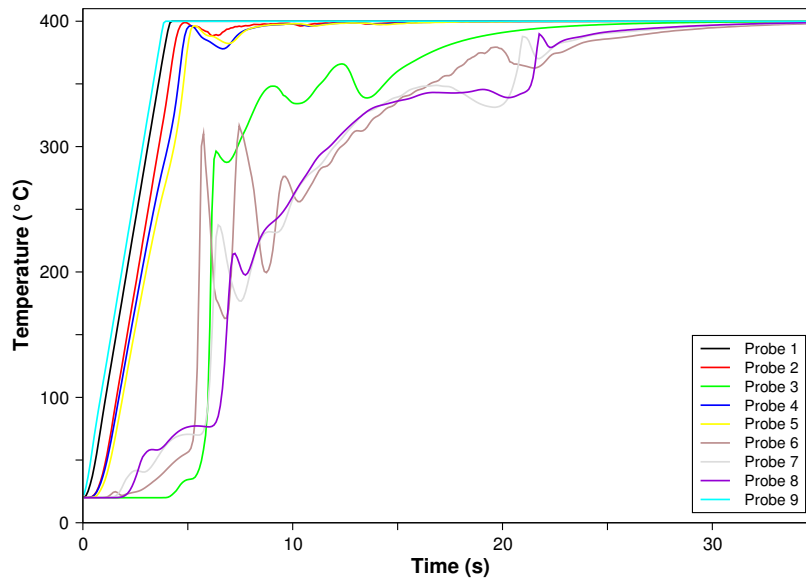


Figure II.9: Time evolution of temperature at monitoring probes - Case 2

Figure II.10 shows the velocity fields colored by temperature in the first run of calculation.

Figure II.11 shows the velocity fields in the second calculation (restart of the first one).

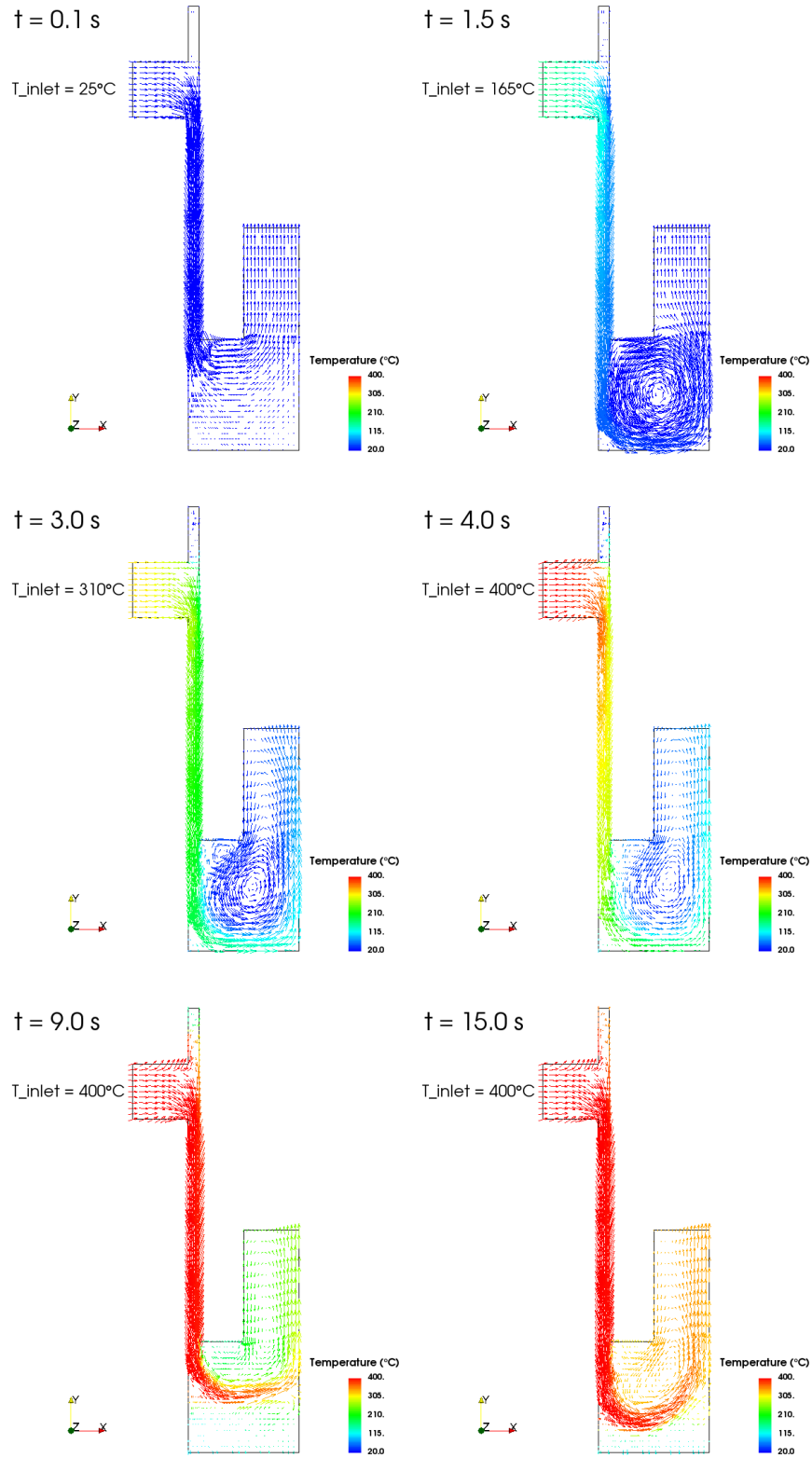


Figure II.10: Water velocity field colored by temperature and inlet temperature value at different time steps (first calculation) - Case 2

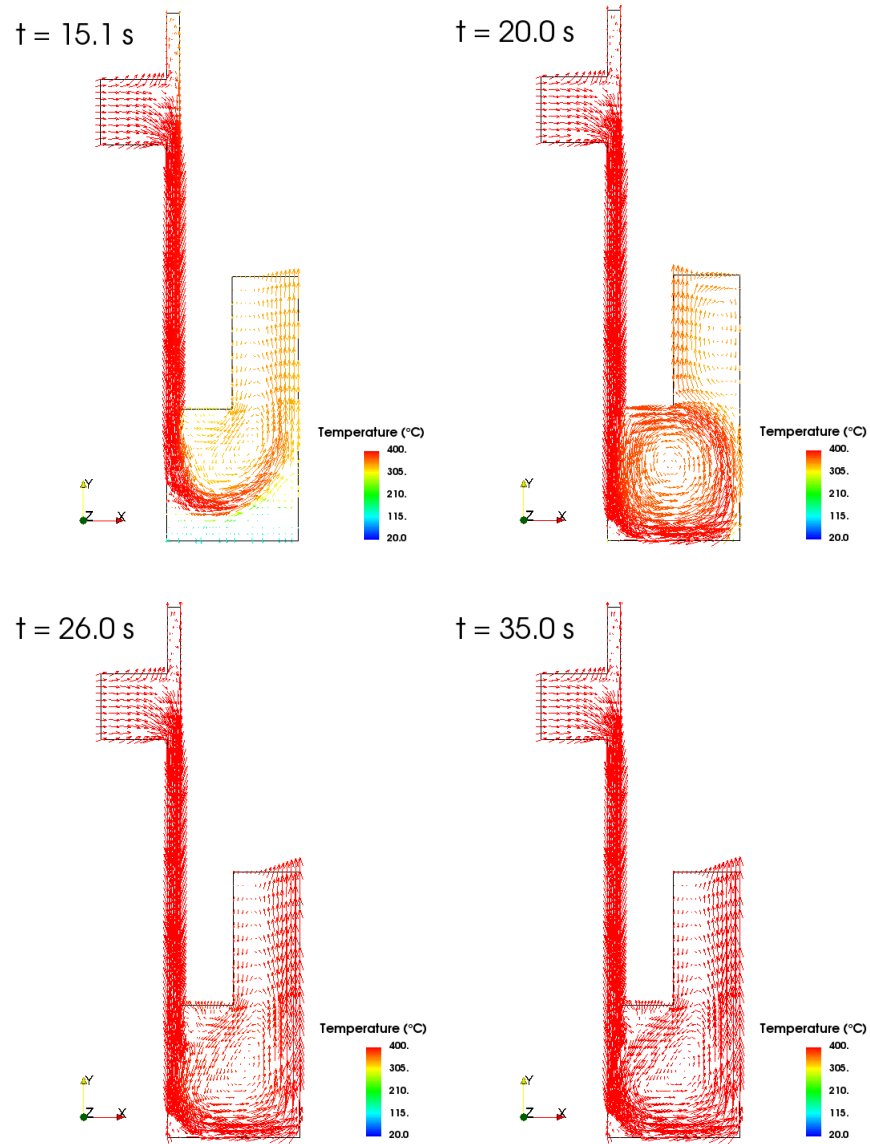


Figure II.11: Water velocity field colored by temperature at different time steps (second calculation)
- Case 2

4 CASE 3: Head losses, parallelism and spatial average

This case will be run in parallel on two processors. Head losses will be used to simulate the presence of an obstacle in the flow and the spatial average of the temperature will be calculated at each time step.

4.1 Calculation options

The options for this case are the same as in `case2`:

- Flow type: unsteady flow
- Time step: uniform and constant
- Turbulence model: $k - \epsilon$
- Scalar(s): 1 - temperature
2 - passive scalar, with diffusion coefficient $8.55 (\times 10^{-5} \text{ m}^2.s^{-1})$
- Physical properties: uniform and constant (except density)
- Management of monitoring points

4.2 Initial and boundary conditions

- Initialization: 20°C for temperature
10 for the passive scalar

The boundary conditions are defined in the user interface and depend on the boundary zone.

- **Flow inlet:** Dirichlet condition, an inlet velocity of 1 m.s^{-1} and a time dependent inlet temperature and a value of 200 for the passive scalar are imposed
- **Outlet:** default value
- **Walls:** velocity, pressure and thermal scalar: default value
passive scalar: different conditions depending on the color and geometric parameters

The boundary conditions for the passive scalar are identical as those in `case2`, as specified in the following table:

Wall	Nature	Value
wall_1	Imposed value (Dirichlet)	0
wall_2	Imposed value (Dirichlet)	5
wall_3	Imposed value (Dirichlet)	0
wall_4	Imposed value (Dirichlet)	25
wall_5	Imposed value (Dirichlet)	320
wall_6	Imposed value (Dirichlet)	40

The `wall_1` to `wall_6` regions are defined as follows, through color references and geometric localization:

Label	Color and geometric parameters
wall_1	24 and $0.1 \leq x$ and $x \leq 0.5$
wall_2	2 or 3
wall_3	4 or 7 or 21 or 22 or 23
wall_4	6 and $y > 1$
wall_5	6 and $y \leq 1$
wall_6	31 or 33

Figure II.3 shows the colors used for boundary conditions and table II.5 defines the correspondance between the colors and the type of boundary condition to use.

Colors	Conditions
1	Inlet
34	Outlet
2 3 4 6 7 21 22 23 31 33	Wall
24 for $0.1 \leq x \leq 0.5$	Wall
8 9 28 29 38 39	Symmetry

Table II.5: Boundary faces colors and associated references

4.3 Variable Density

The law for the variable density is identical as that in **case2**.

In this case the density is a function of temperature, the variation law is defined in the Graphical User Interface although it can also be defined in a Fortran user routine. The expression is:

$$\rho = T(AT + B) + C \quad (\text{II.3})$$

where ρ is the density, T is the temperature, $A = -4.0668 \times 10^{-3}$, $B = -5.0754 \times 10^{-2}$ and $C = 1\,000.9$.

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

4.4 Head losses

To simulate the presence of an obstacle 0.20 (m) large and 0.5 (m) high in the vessel, a zone of head losses will be created in the domain (fig II.12).

The head losses zone is located between the coordinates $x = 0.2$ (m) and $x = 0.4$ (m), and $y = -0.75$ (m) and $y = -0.25$ (m).

The head losses coefficient to apply is $K_{11} = K_{22} = K_{33} = 10^4 = \frac{1}{2} \alpha_{11} = \frac{1}{2} \alpha_{22} = \frac{1}{2} \alpha_{33}$ and is isotropic.

4.5 Parameters

All the parameters necessary to this study can be defined through the Graphical Interface. However, the calculation of the spatial average is defined by a user routine.

Parameters of calculation control	
Number of iterations	900
Reference time step	0.01
Output period for post-processing files	2
The calculation will be run in parallel	2 procs.

In order to join the separate meshes into a single domain, colors 5, 24 and 32 will have to be joined through the Graphical Interface.

Note that the time step has been reduced because of the head losses: the pressure step is more difficult to be solved in presence of head losses.

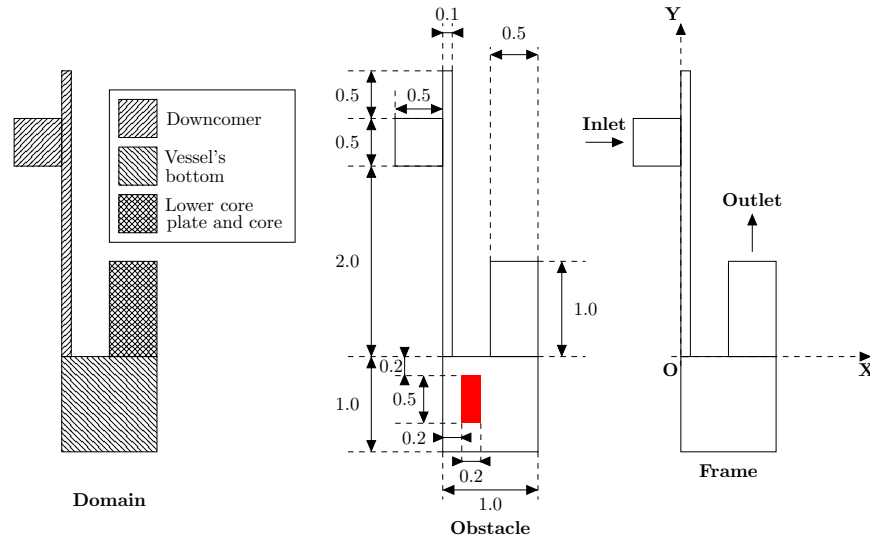


Figure II.12: Full domain geometry with the obstacle

4.6 User routines

The following routines have to be copied from the folder `SRC/REFERENCE/` into the folder `SRC/`⁶: `cs_user_boundary_conditions.f90` and `cs_user_extra_operations.f90`. We can find and copy some basic and specific boundary conditions examples in the folder `SRC/EXAMPLES/` to correctly impose the code_saturne boundary conditions.

- **cs_user_boundary_conditions.f90**

This routine allows to define advanced boundary conditions on the boundary faces.

Even if `cs_user_boundary_conditions.f90` is used, all boundary conditions have to be defined in the Graphical User Interface (GUI). Only the conditions that differ from this first definition need to appear in `cs_user_boundary_conditions.f90`. The boundary conditions defined in `cs_user_boundary_conditions.f90` will replace those specified in the Graphical Interface.

In this case, the temperature at entry is supposed variable in time, following the law:

$$\begin{cases} T = 20 + 100t & \text{for } 0 \leq t \leq 3.8 \\ T = 400 & \text{for } t > 3.8 \end{cases} \quad (\text{II.4})$$

where T is the temperature in °C and t is the time in seconds (s).

- **cs_user_extra_operations.c**

This routine is called at the end of each time step and has access to the whole set of variables of the code. It is therefore useful for many user-specific post-processing, including the calculation of a spatial average in the present case.

The spatial average of the temperature will be calculated at each time step and the result wrote in a file named `moy.dat`. The values are saved in order to draw the time evolution of the average temperature.

Beware when calculating the average. Since the calculation is running in parallel, computing the sum of the temperatures on **all the cells** will only yield for each processor to the sum on the cells managed by this processor. In order to obtain the full sum, the parallelism routine `cs_parallel_sum` must be used (see example in the `cs_user_extra_operations-scalar_balance.c` routine).

⁶Only when they appear in the SRC directory will they be taken into account by the code.

Remark: `cs_user_extra_operations-xxx.c` are different example routines present in the subdirectory `SRC/EXAMPLES`. They should be removed from the `SRC/` before running the case.

4.7 Output management

The output management is the same as in `case2`.

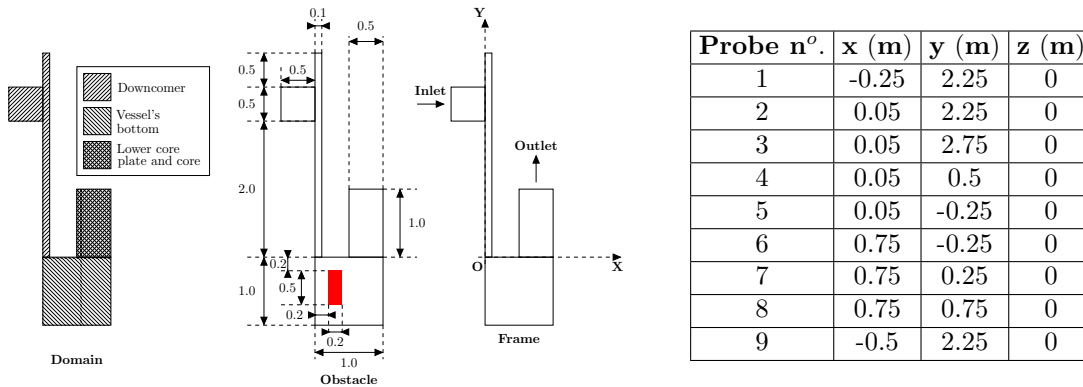


Figure II.13: Position and coordinates of probes in the full domain

In this case, the **Pressure**, the **Tubulent Energy** and the **Dissipation** will be removed from the listing file.

The **Courant number** (CFL) and **Fourier number** will be removed from the post-processing results⁷.

Eventually, probes will be defined for chronological records, following the data given in Figure II.4. Then the **total pressure** will be deactivated from all probes.

In addition the domain boundary will be post-processed. This allows to check the boundary conditions, and especially that of the temperature and passive scalar.

4.8 Results

Figure II.14 shows the evolution of the spatial average of the temperature.

Figure II.15 shows velocity fields colored by temperature. The effect of the head loss modeling the obstacle is clearly visible.

⁷This can be very useful to save some disk space if some variables are of no interest, as post-processing files can be large.

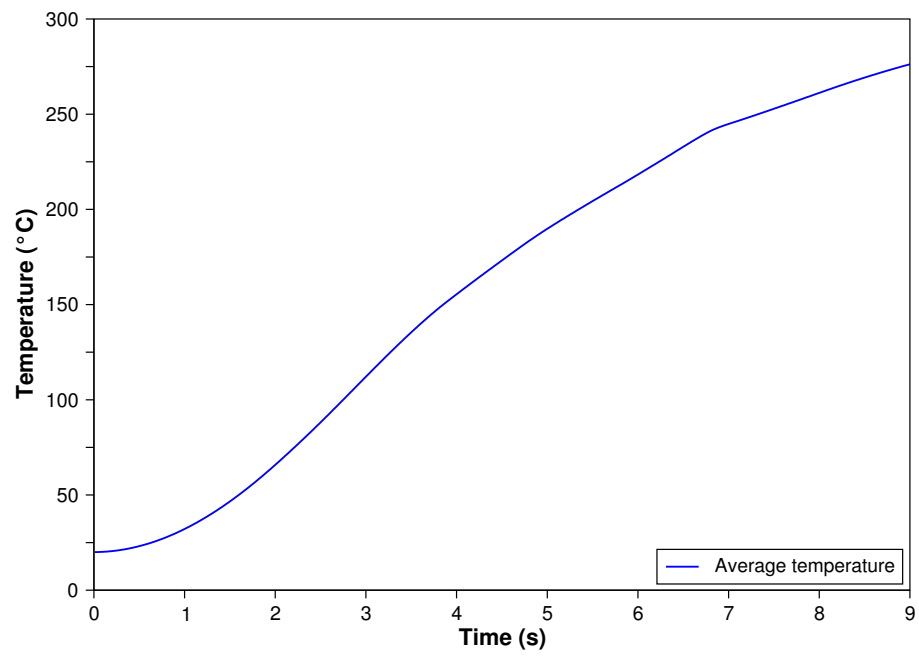


Figure II.14: Evolution of the spatial average of the temperature as a function of time - Case 3

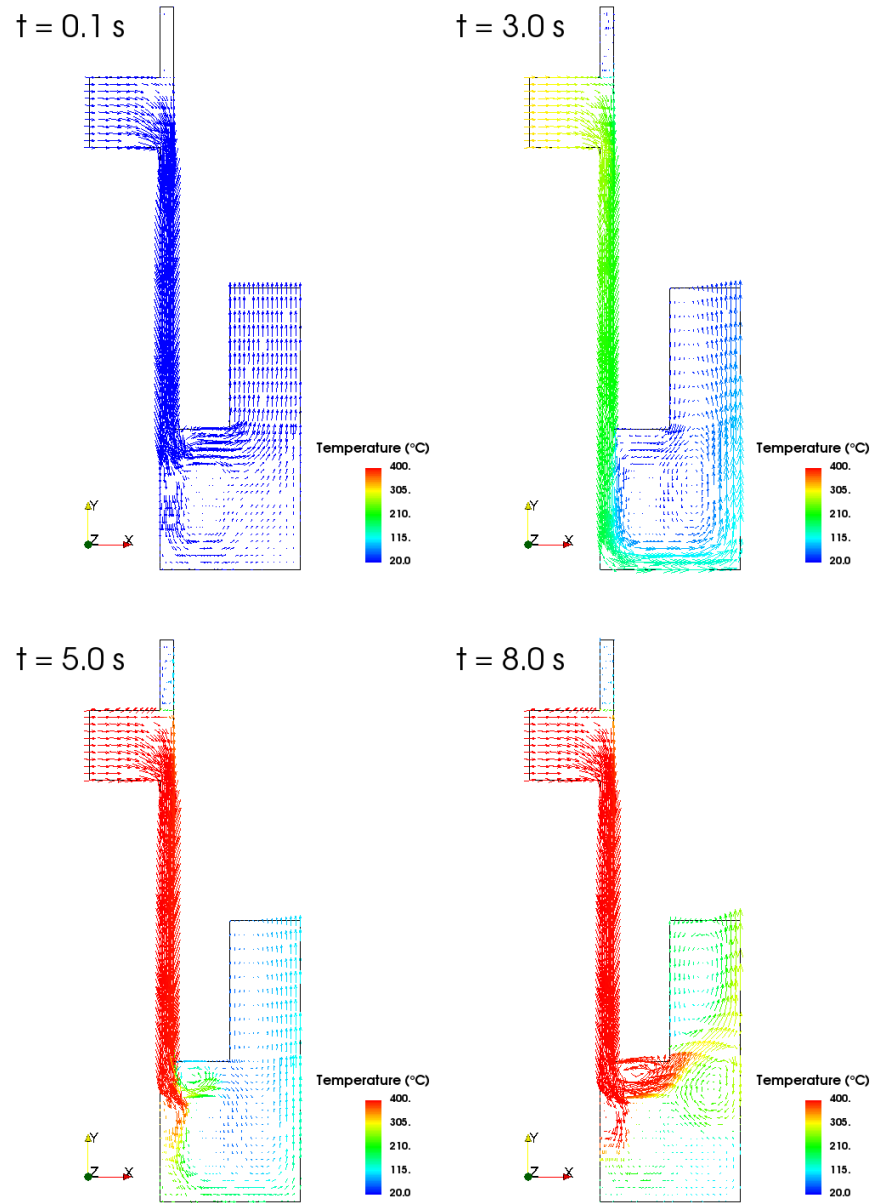


Figure II.15: Water velocity field colored by temperature - Case 3

Part III

Step by step solution

1 Solution for CASE1

1.1 Mesh tab

This case corresponds to a new study, in which there will be three calculation cases (cases 1, 2 and 3). We can create one case in a single `code_saturne create` command and additional cases can be added later. To test this functionality, first create the study directory, with case subdirectory `case1`, as below:

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

Go to the `DATA` directory in `case1`, open a new case and select the meshes to use.

Click on the heading **Mesh** then add three meshes which have to be joined as shown below.

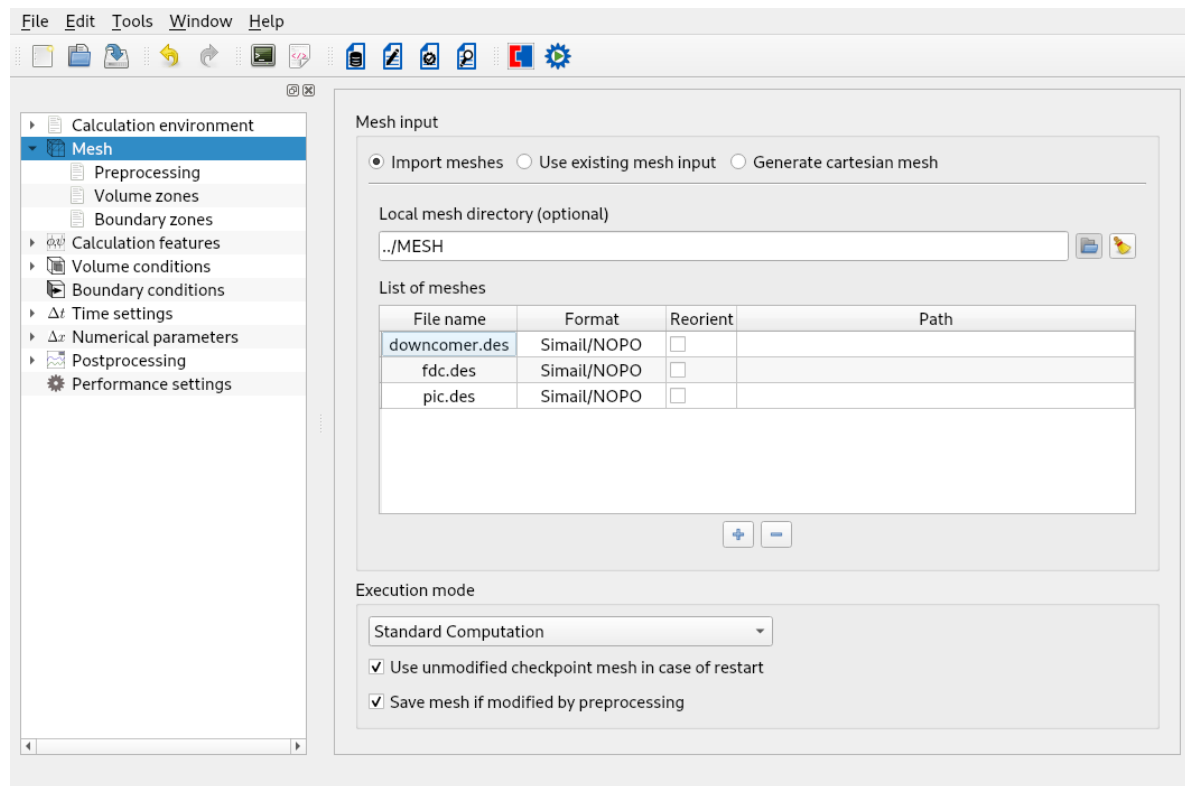



Figure III.1: Meshes: list of meshes

Preprocessing In order to join the three meshes, you must add a selection criteria in the box **Selection criteria** of the **Face joining (optional)** item under the **Preprocessing** sub-folder. In this case, only faces of colors 5, 24 and 32 can be joined (different colors can be entered on a single line, separated by comma).

Click on the  icon to enter the list of colors to be joined in the **Face joining (optional)** item.

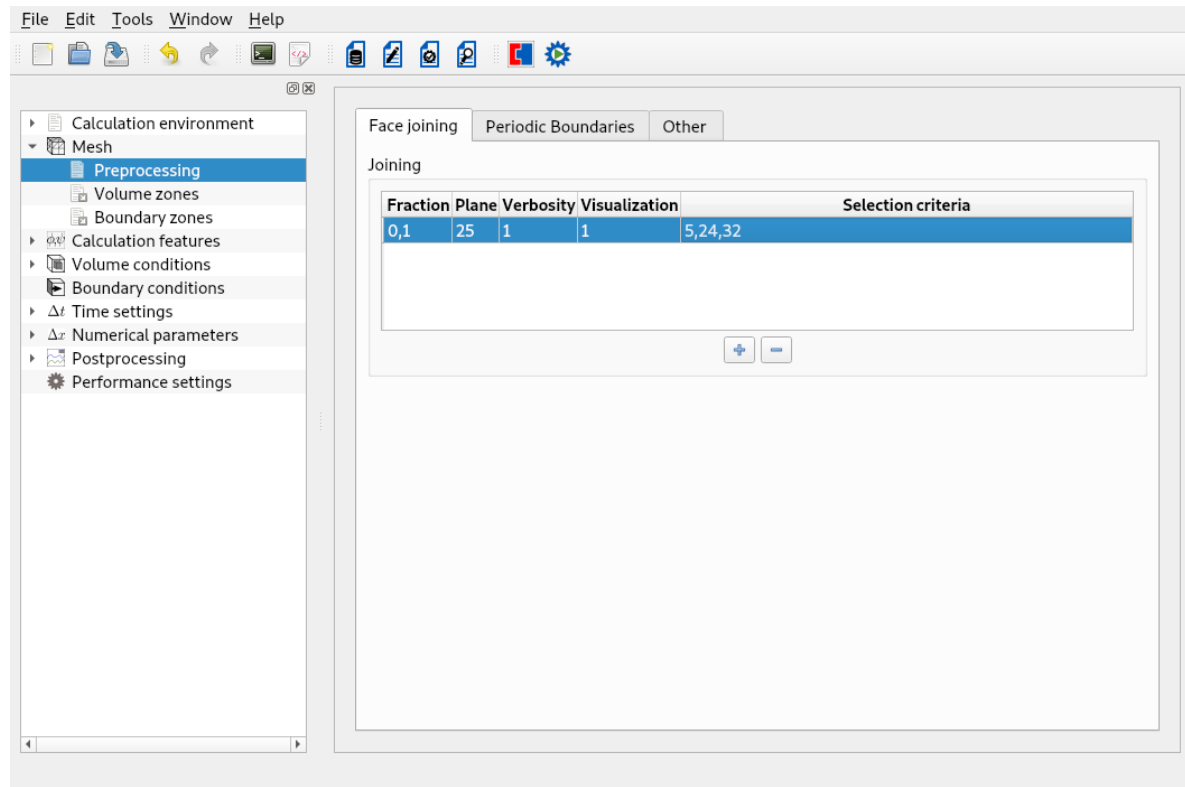


Figure III.2: Join a mesh

Boundary zones The procedure is the same as in `simple Junction`, but the colors are different. Note that colors 5 and 32 have completely disappeared in the joining process (they are now internal faces and are not considered as boundaries), while some boundary faces of color 24 remain.

Create the inlet, outlet and symmetry boundary zones with the following colors:

- Inlet : '1'
- Outlet : '34'
- Symmetry: '8 or 9 or 28 or 29 or 38 or 39'

In this case, different conditions are applied for the walls. Separate corresponding wall boundary regions must therefore be created, following the data in the following table.

Label	Zone	Nature	Selection criteria
Wall_1	4	Wall	24 and $0.1 \leq x$ and $x \leq 0.5$
Wall_2	5	Wall	2 or 3
Wall_3	6	Wall	4 or 7 or 21 or 22 or 23
Wall_4	7	Wall	6 and $y > 1$
Wall_5	8	Wall	6 and $y \leq 1$
Wall_6	9	Wall	31 or 33

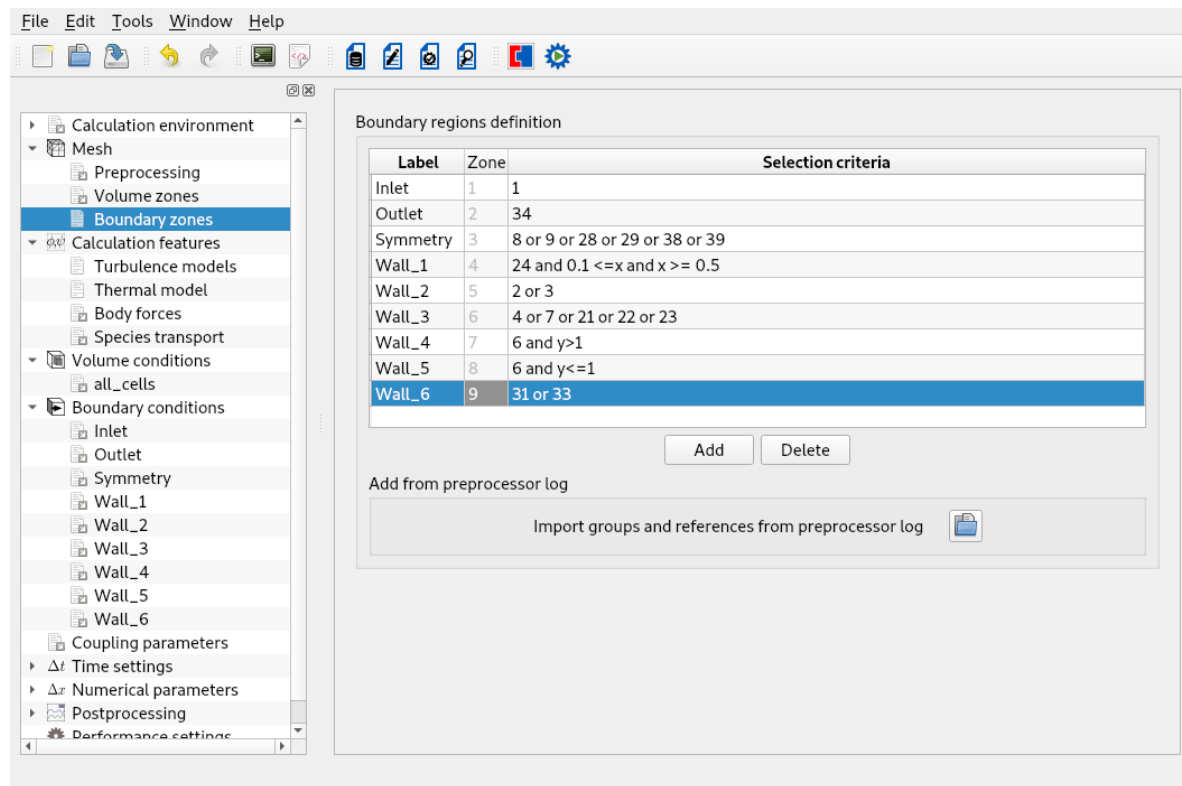


Figure III.3: Creation of the boundary zones

The **Wall_1** region combines color and geometrical criteria. The associated character string to enter in the **Selection criteria** box ¹ is as follows:

```
‘‘24 and 0.1 <= x and 0.5 >= x’’
```

Define the other wall boundary zones. The faces of color 6 have to be divided in two separate zones, based on a geometrical criterium on y .

¹Note that, due to the joining process, there are in fact no boundary faces of color 24 with x coordinate outside the $[0.1;0.5]$ interval. The geometrical criterium is therefore not necessary. It is presented here to show the capabilities of the face selection module.

Mesh quality verification You can now verify the quality of your mesh by running a **Mesh quality criteria only** Computation. To do so, go back to the heading **Mesh** and change the **Execution mode** to **Mesh quality criteria only**. calculation.

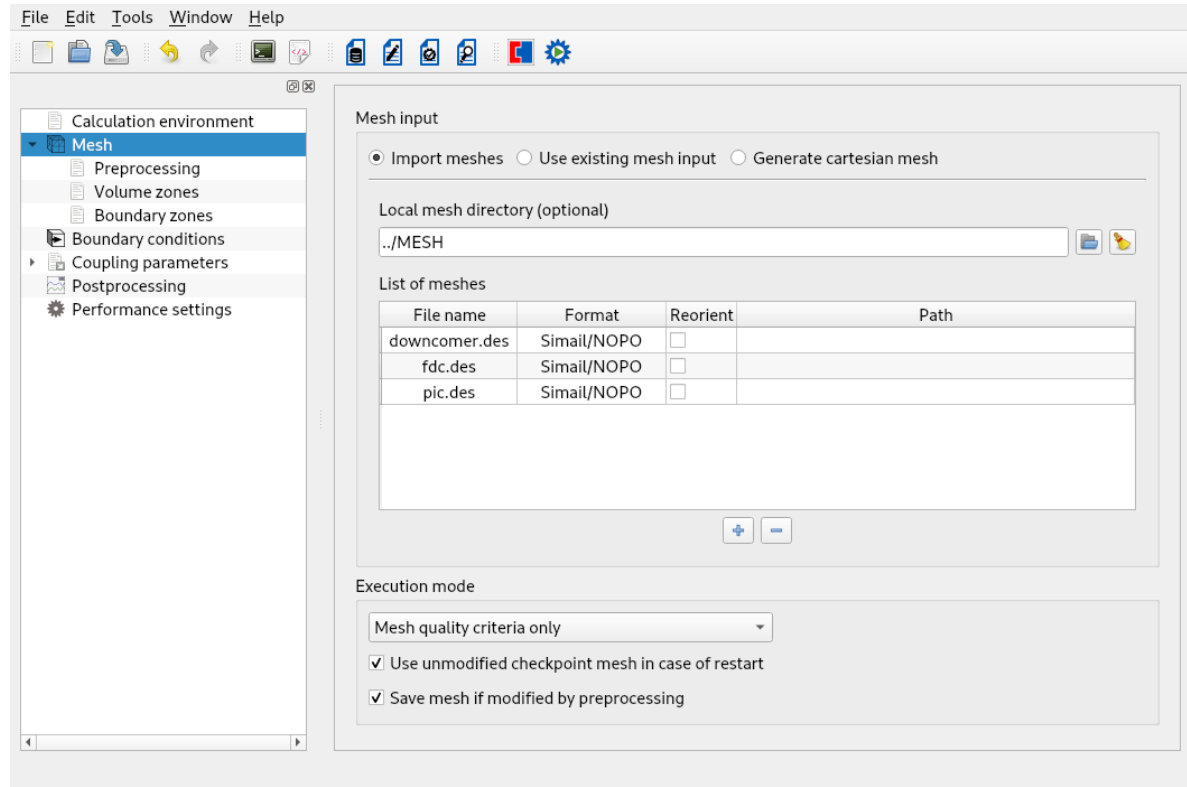



Figure III.4: Mesh quality criteria

Click on the  icon to run the mesh checking computation. Once this is done you can open the file entitled "listing" located in the fresh RESU sub-folder. You will find information related to the orthogonality, meshes types, etc.

1.2 Calculation features tab

Now, go back to the [Standard Computation](#) mode and click on the [Calculation features](#) heading. The heading [Calculation features](#) is identical to `simple_junction`.

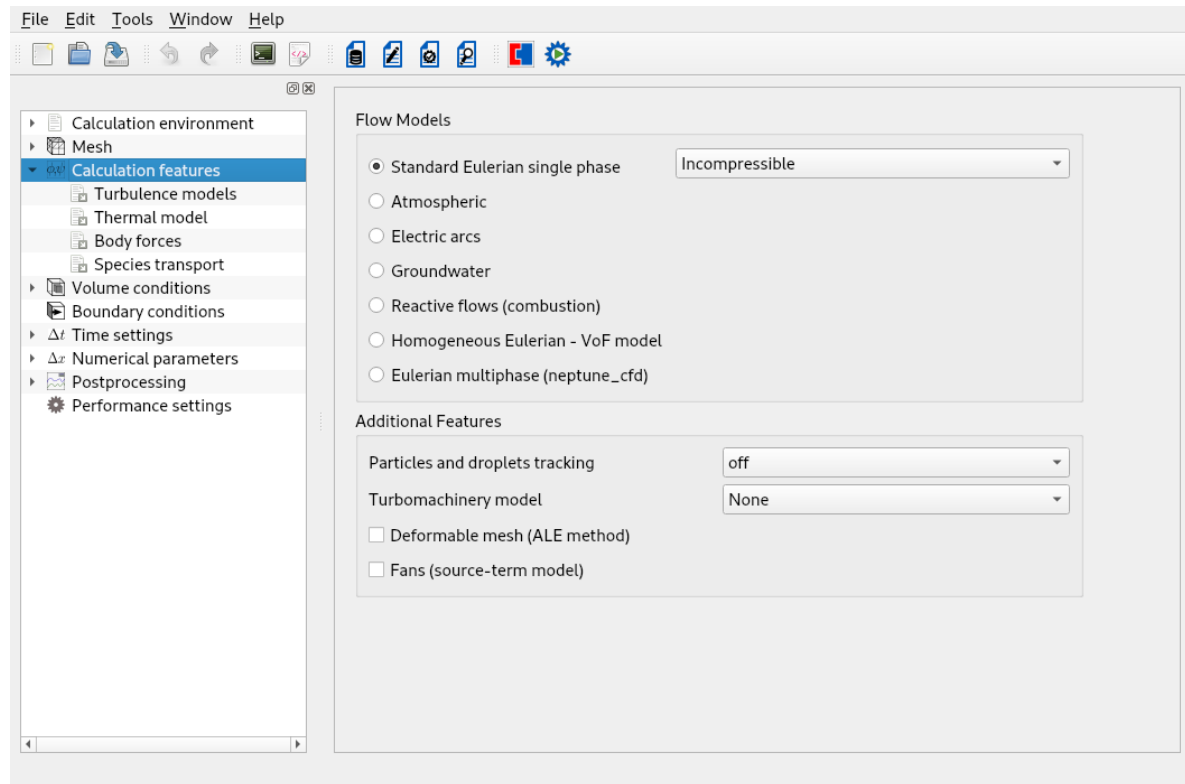


Figure III.5: Thermophysical models/Calculation features: unsteady flow

Turbulence models Set a $k-\varepsilon$ Production turbulence model with a velocity scale reference value of 1.0(m/s). See [III.6](#)

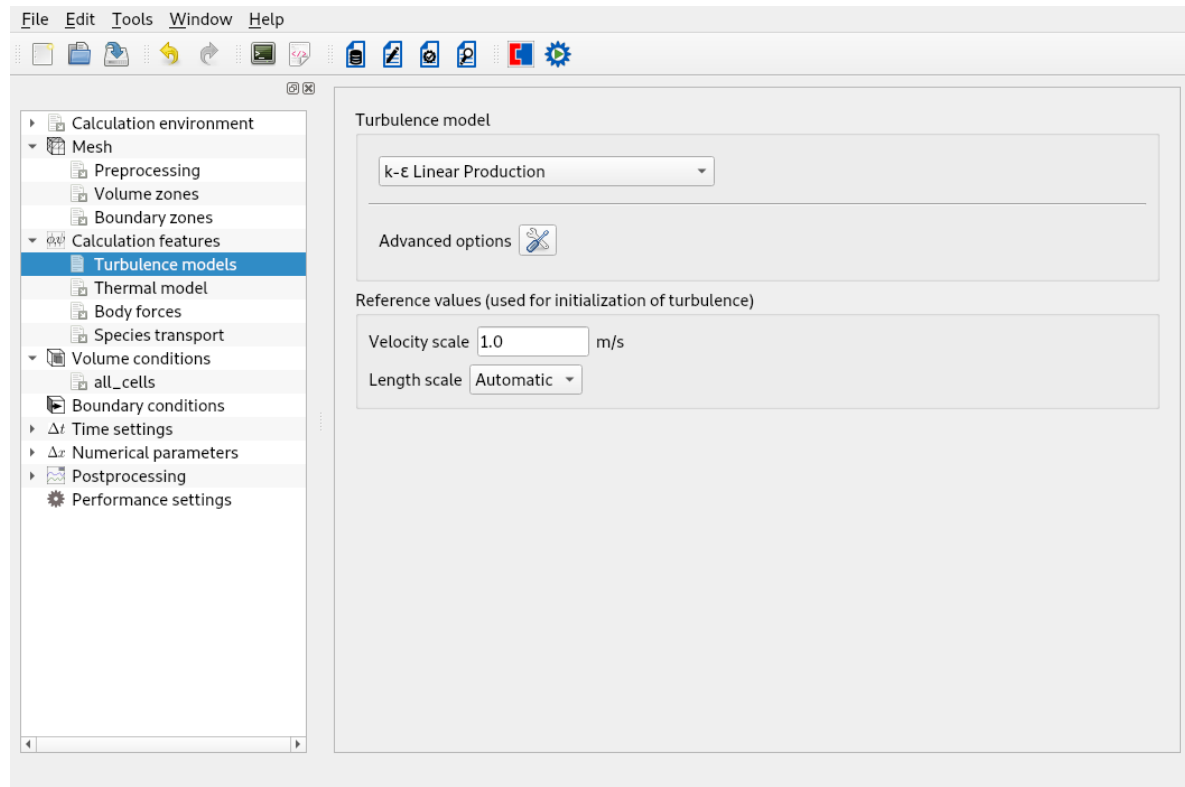



Figure III.6: Turbulence Model

Species transport To add an additional scalar, click on the  icon in the **Species transport** item under the **Calculation features** tab. You can rename the scalar by clicking on it. Here you can add : **scalar2**

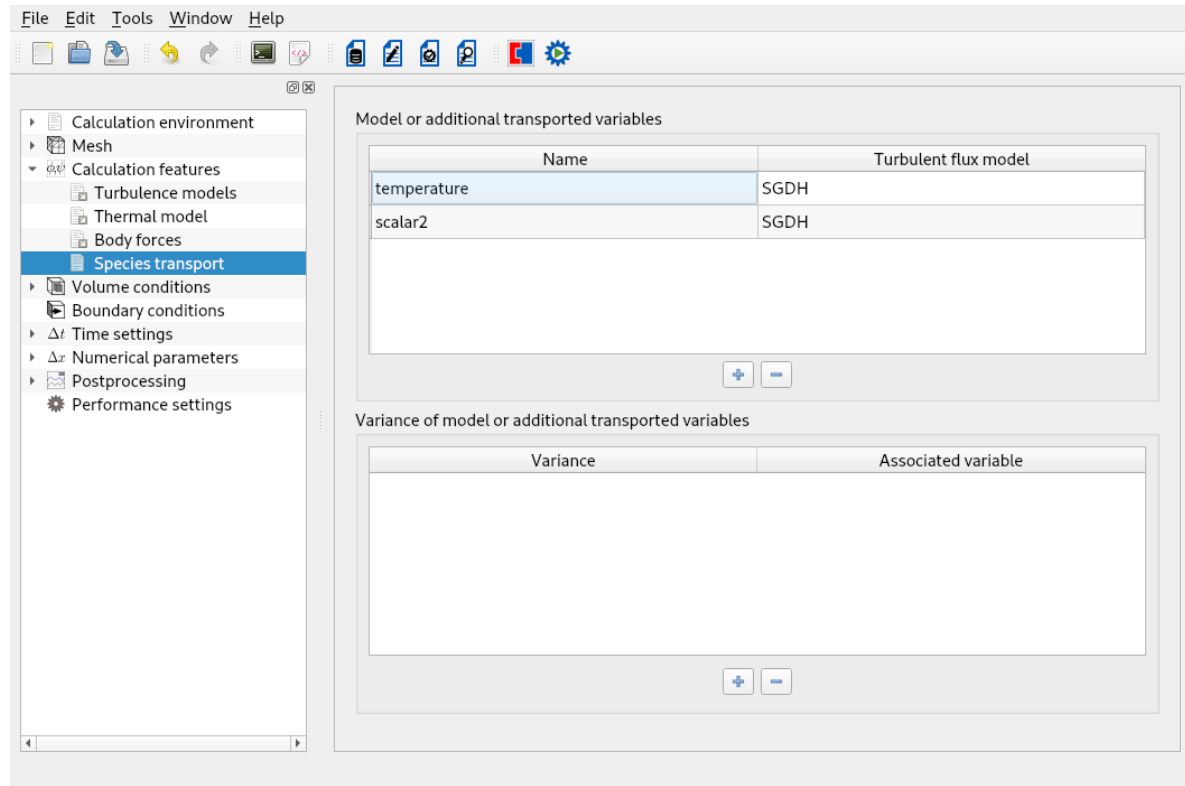


Figure III.7: Additional scalar

1.3 Volume conditions tab

Before setting fluid properties do not forget to tick all parameters you need otherwise you won't be able to see all tab options later. Tick : **Initialization** and **Physical properties**

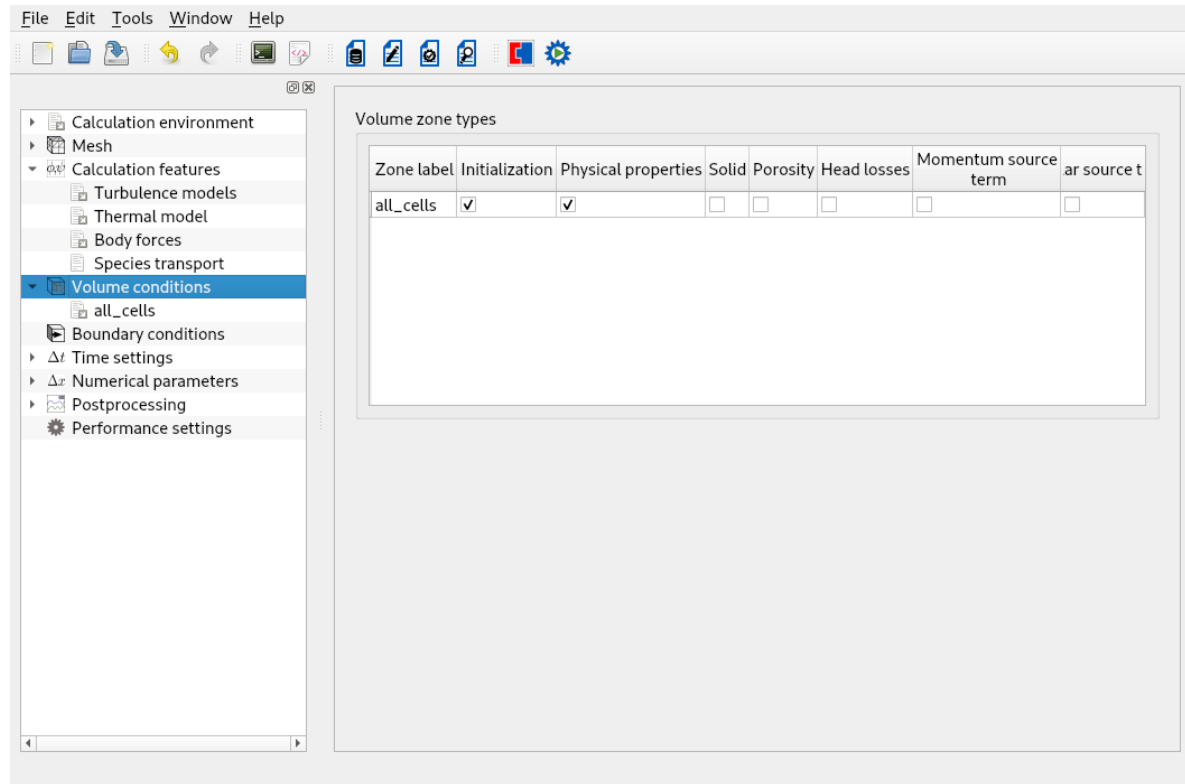


Figure III.8: Additional scalar

Physical properties The heading **Physical properties** is identical to `simple_junction`, except for the new scalar. Here, we can specify the diffusion coefficient of this new scalar.

- $\rho = 725.735 \text{ kg.m}^{-3}$
- $\mu = 0.895 \times 10^{-4} \text{ kg.m}^{-1}.s^{-1}$
- $C_p = 5483 \text{ J.kg}^{-1}.K^{-1}$
- $\lambda = 0.02495 \text{ W.m}^{-1}.K^{-1}$

Click on the scalar name to highlight it, then enter the value in the box. In this case, the species diffusion coefficient value is **8.55** ($\times 10^{-5} \text{ m}^2.s^{-1}$) for the **scalar2** to solve.

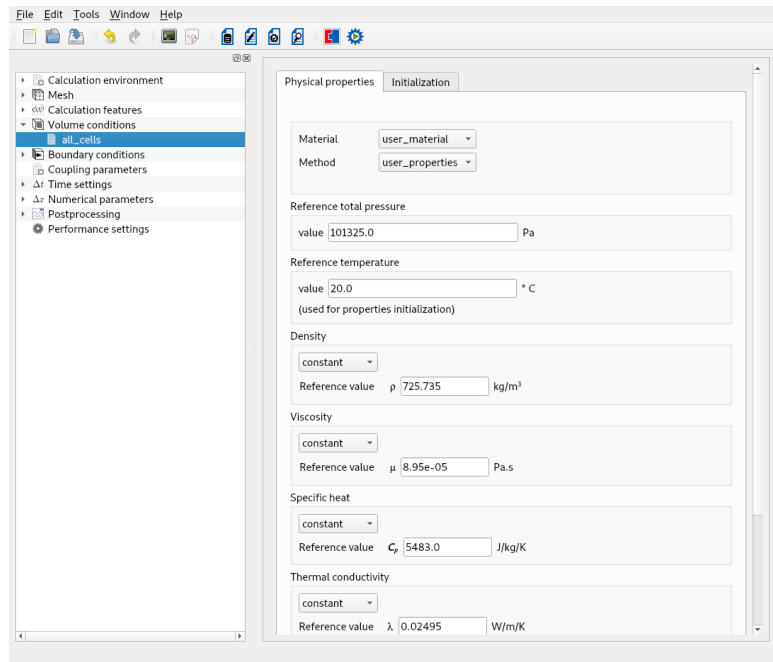


Figure III.9: Fluid properties : part1




Figure III.10: Fluid properties : part 2 - scalar2 settings

Initialization To initialize variables at the instant $t = 0$ s, go to the **Initialization** item under the heading **Volume conditions**.

Here the velocity, the thermal scalar and the turbulence can be initialized. In this case, the default values to be set are: zero velocity (default), an initial temperature of **20°C** and a turbulence level based on a reference velocity of **1** ($m.s^{-1}$) (default). You must also initialize the **scalar2** species at **10°C**.

Specific zones can be defined with different initializations. In this case, only the default **all_cells** is used.

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

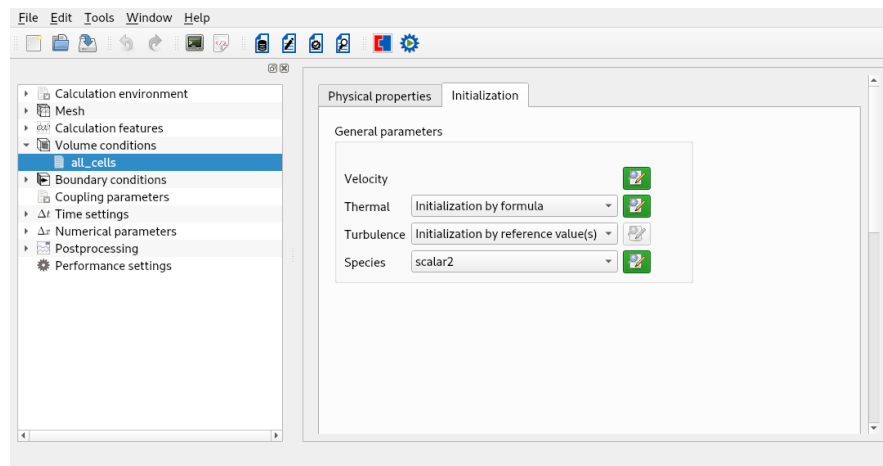


Figure III.11: Initialization

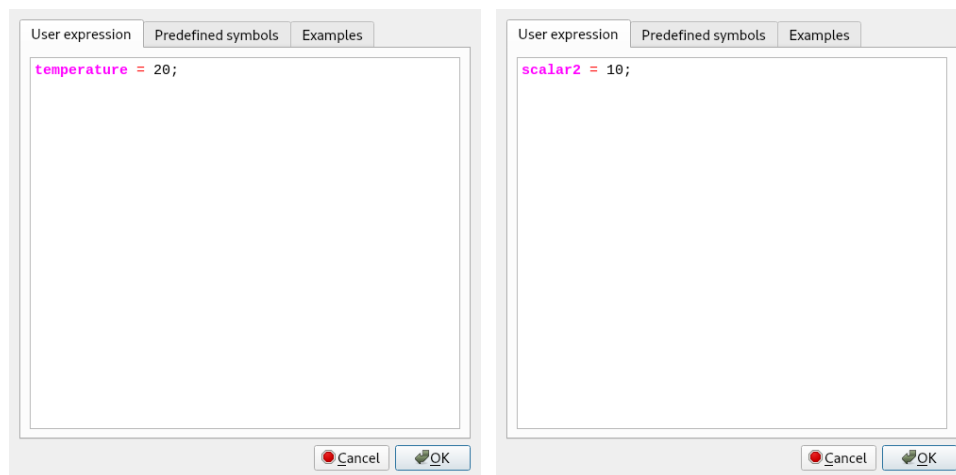


Figure III.12: Initialization: temperature and scalar2

1.4 Boundary conditions tab

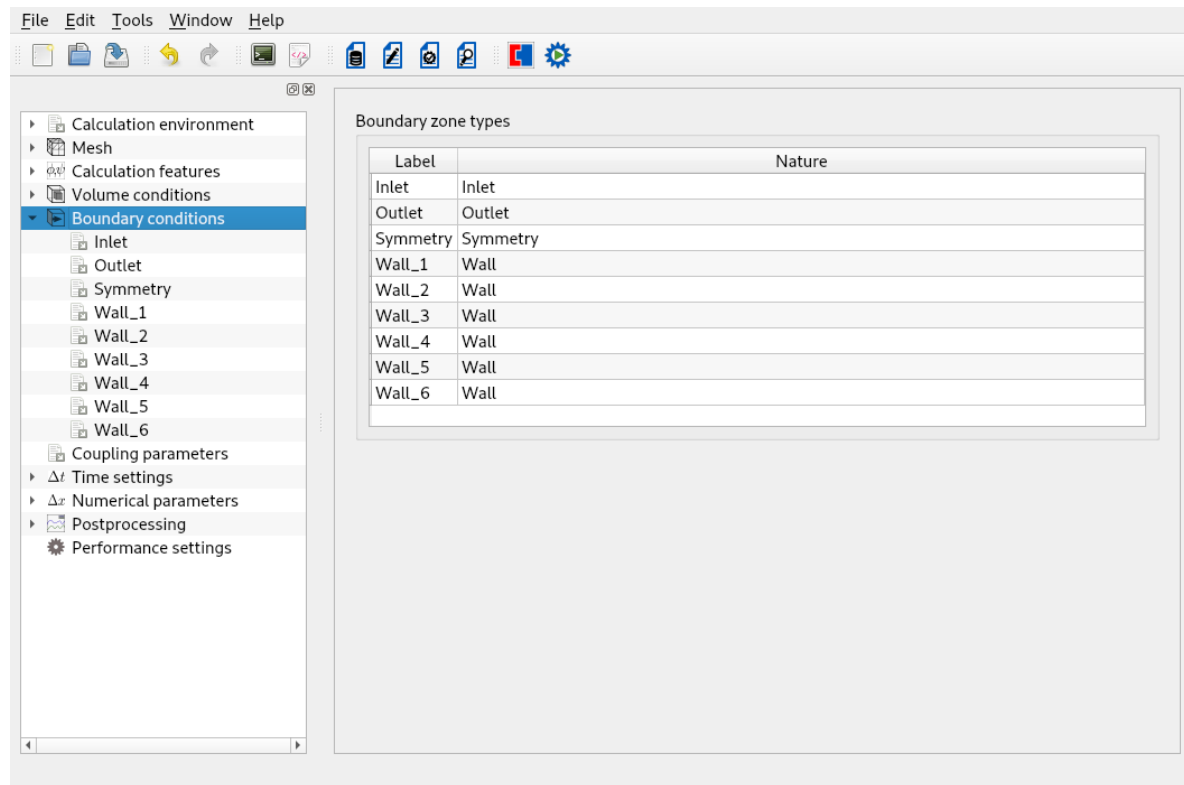


Figure III.13: Boundary conditions : nature

The dynamic boundary conditions are the same as in `simple_junction` for the inlet, and there are still no sliding walls.

- Inlet:

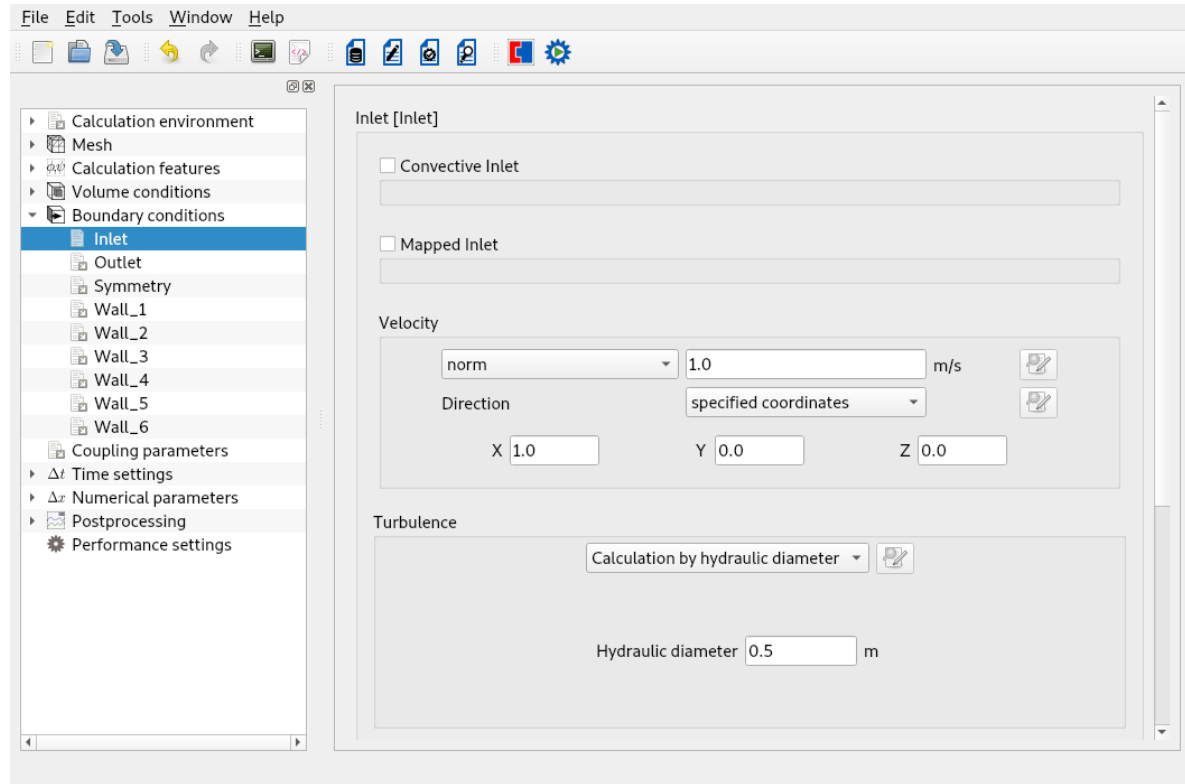


Figure III.14: Dynamic variables boundary: inlet - part1

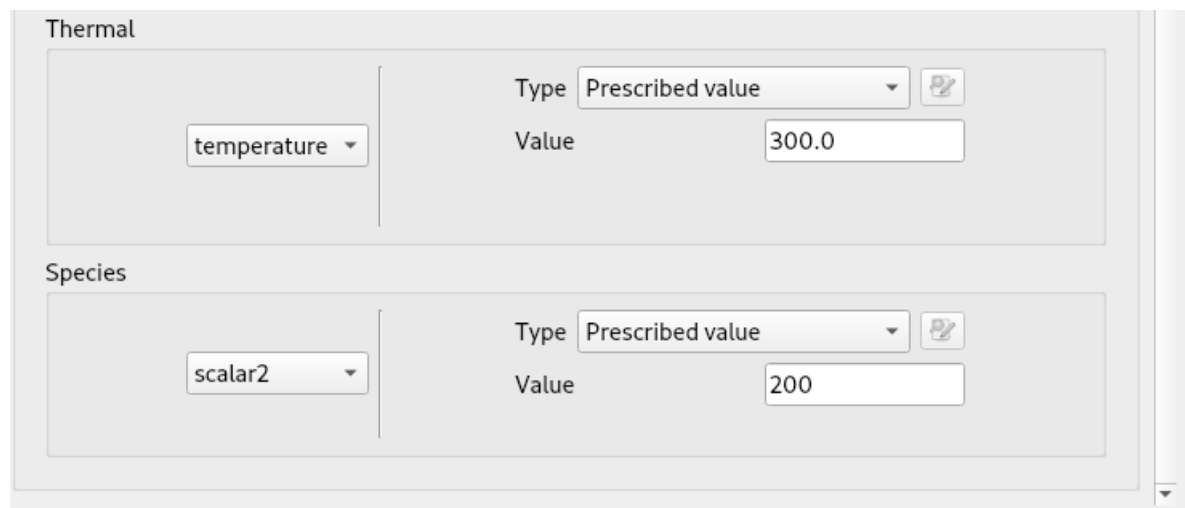


Figure III.15: Dynamic variables boundary: inlet - part2

- Outlet:

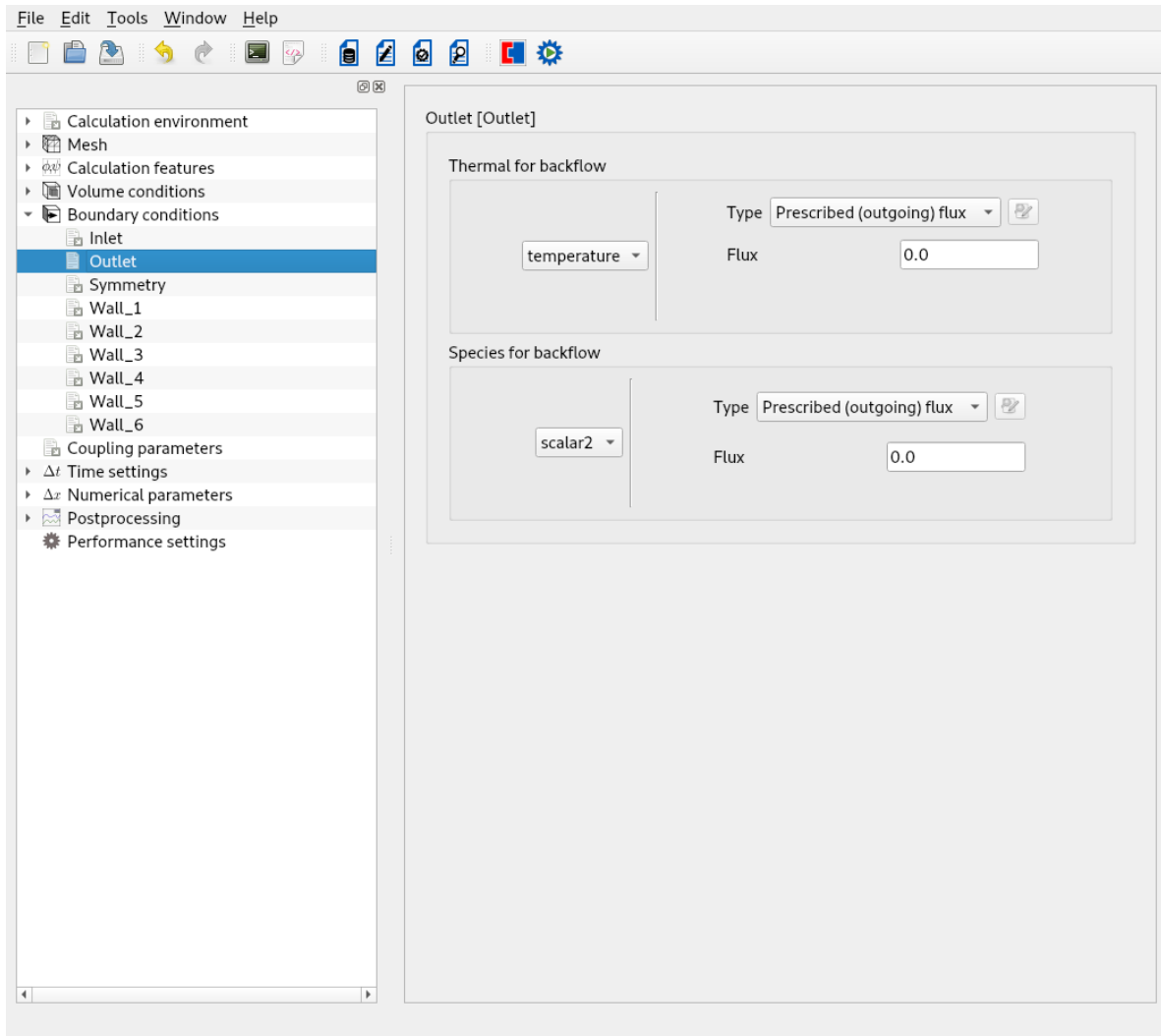


Figure III.16: Dynamic variables boundary: outlet

- Wall:

To configure the scalar boundary conditions on the walls, select individually each wall in the **Boundary conditions** item.

On all the walls, a default homogeneous **Prescribed flux** is set for temperature, and **Prescribed value** is specified for the passive scalar for each wall, named **scalar2**, according to the following table:

Wall	Nature	Scalar2 value
Wall_1	Prescribed value (Dirichlet)	0
Wall_2	Prescribed value (Dirichlet)	5
Wall_3	Prescribed value (Dirichlet)	0
Wall_4	Prescribed value (Dirichlet)	25
Wall_5	Prescribed value (Dirichlet)	320
Wall_6	Prescribed value (Dirichlet)	40

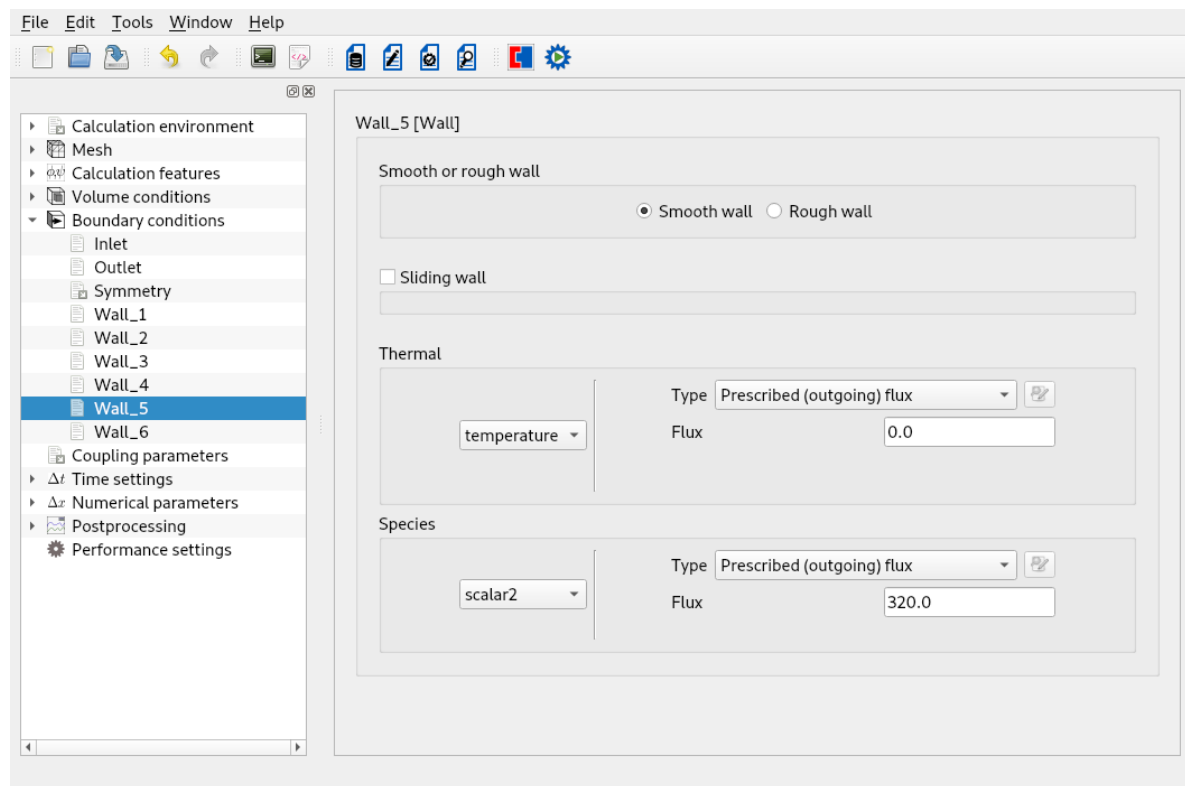


Figure III.17: Scalars boundaries: wall_5

1.5 Time settings tab

Some calculation parameters need to be defined now. Go to the [Time settings](#) heading. In our case the time step is [Constant](#) and the [Velocity-Pressure algorithm](#) is [SIMPLEC](#). Set the number of iterations to **300** and the reference time step to **0.05** (s).

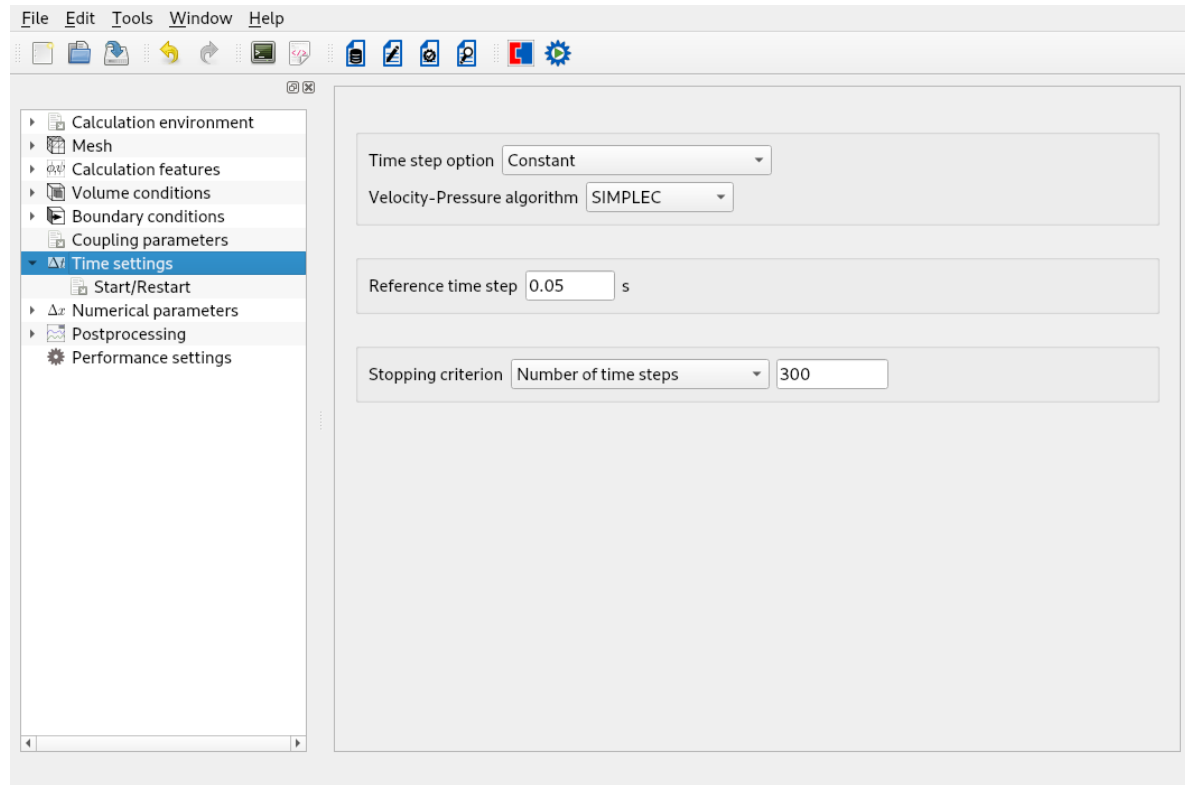


Figure III.18: Time step setting

Numerical parameters are the same as in simple_junction.

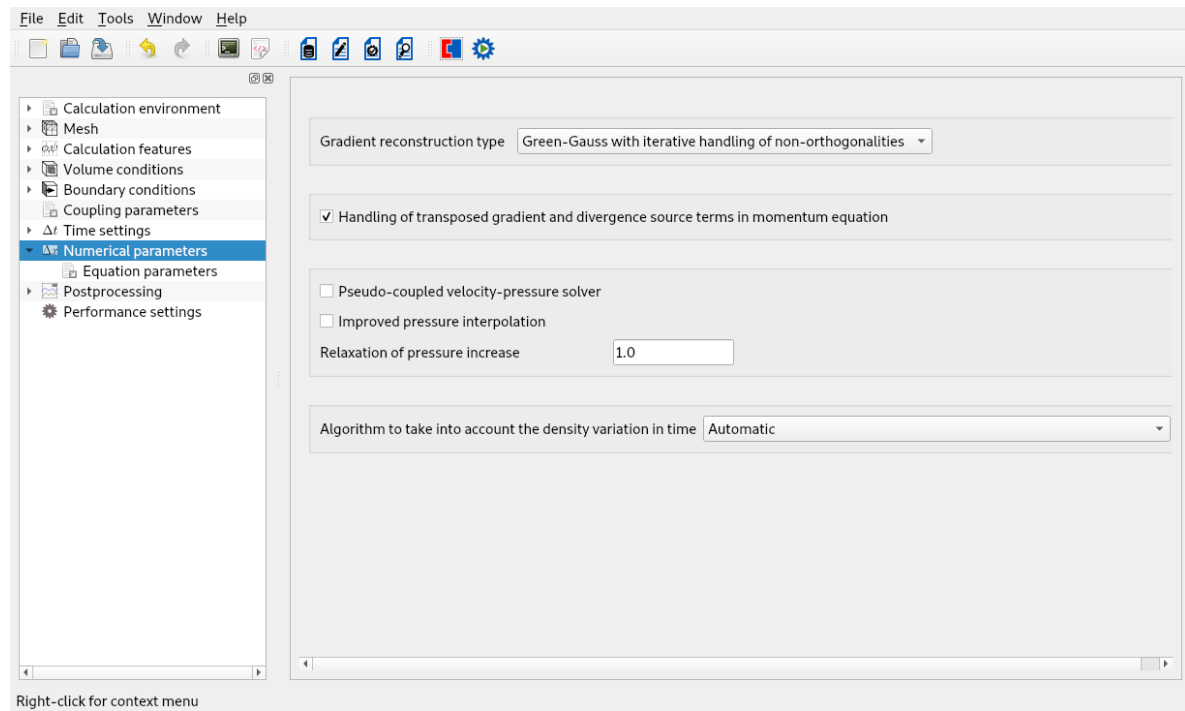


Figure III.19: Numerical parameters

1.6 Numerical Parameters tab

Go to the [Equation parameters](#) item under the heading [Numerical parameters](#). You can define the maximum and minimum value for the `temperature` and for the `scalar2` scalars.

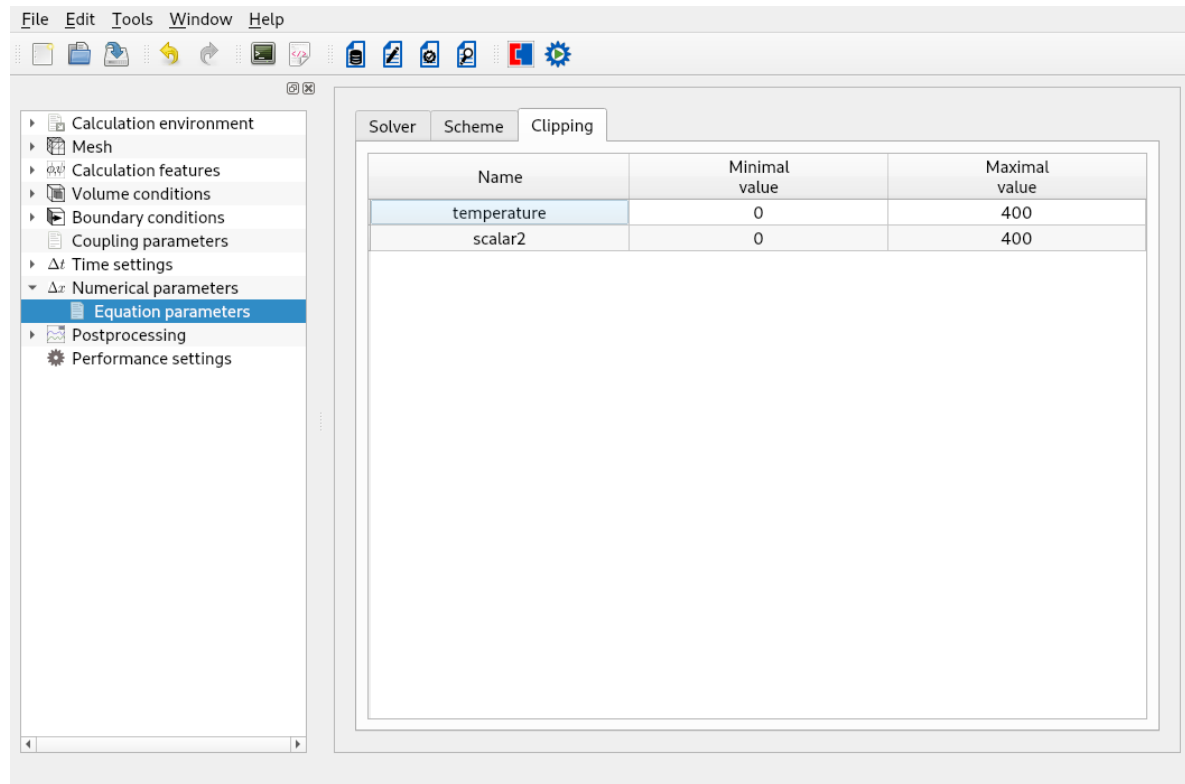


Figure III.20: Clipping

Go to the **Postprocessing** heading to set the output parameters. In the **Output Control** tab, keep the default value for the output listing frequency.

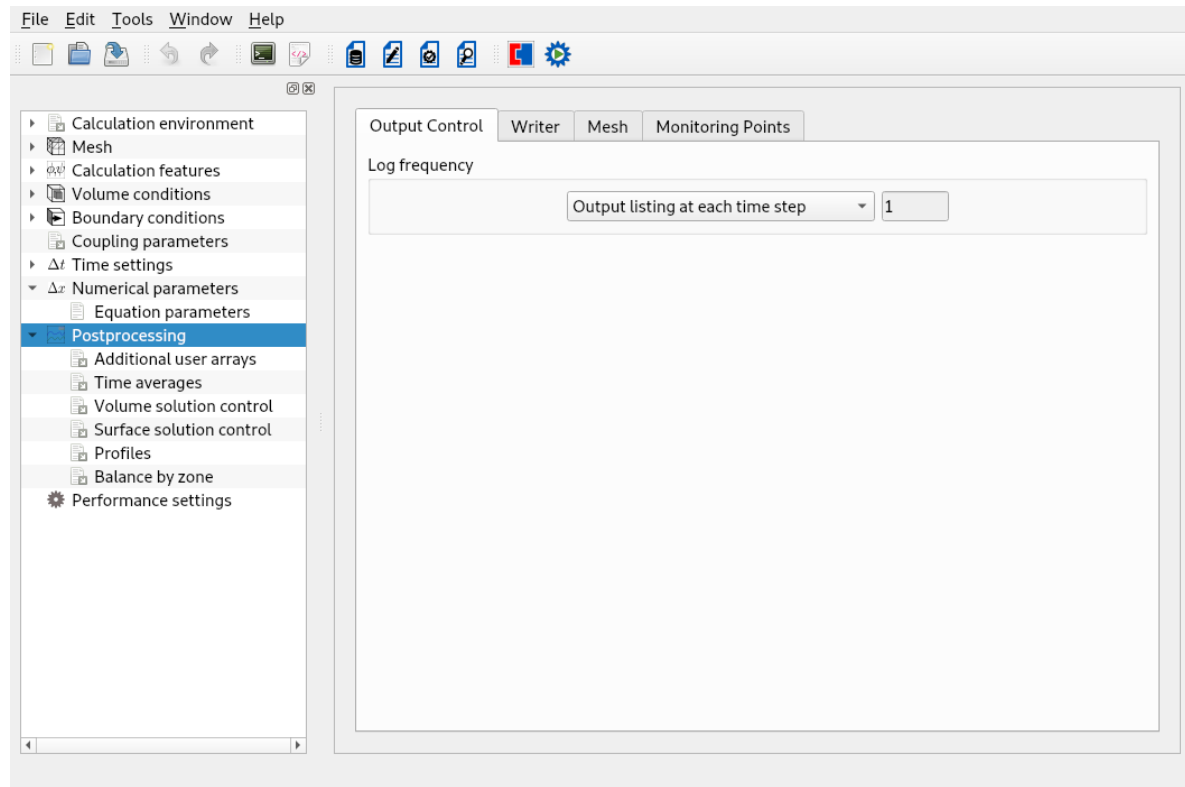


Figure III.21: Output control: log frequency

1.7 Postprocessing tab

For the post-processing, go to the [Writer](#) item and click on [results](#).

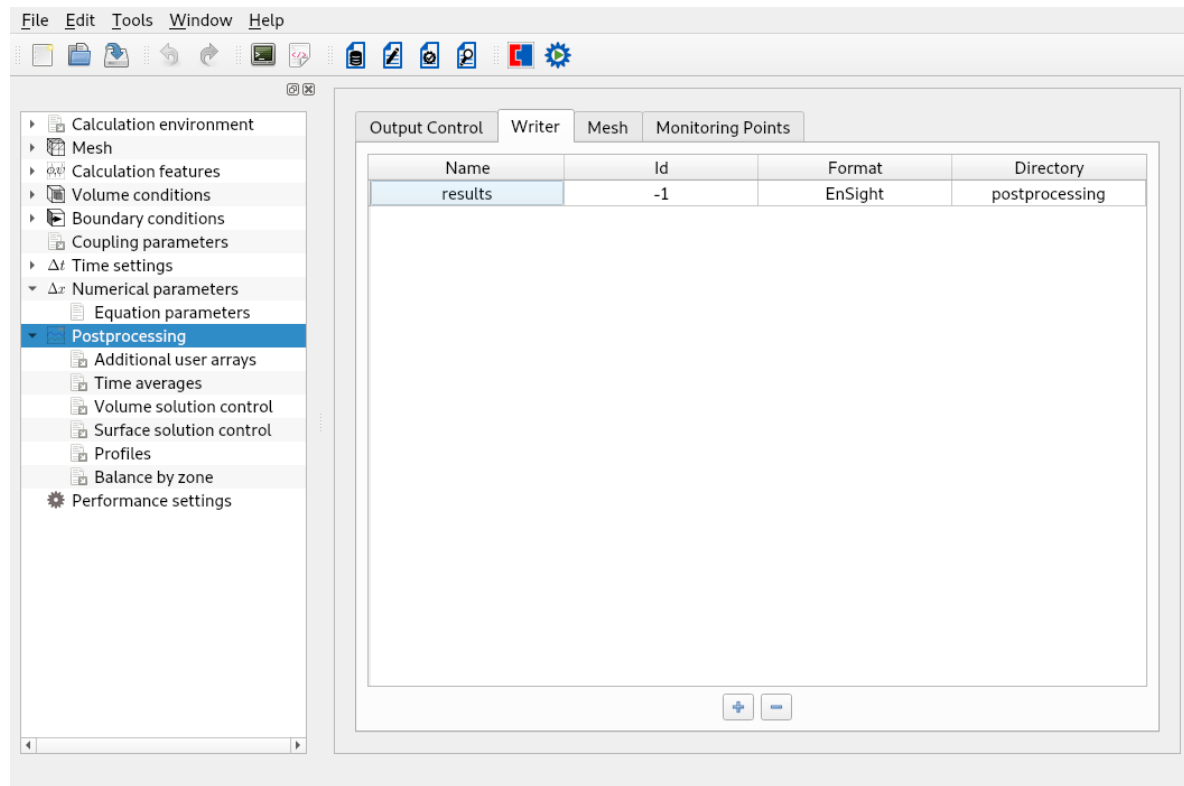


Figure III.22: Output control: writer

Now you can select the third option in the **Frequency** (output every 'n' time steps) item and set the value of **n** to 2.

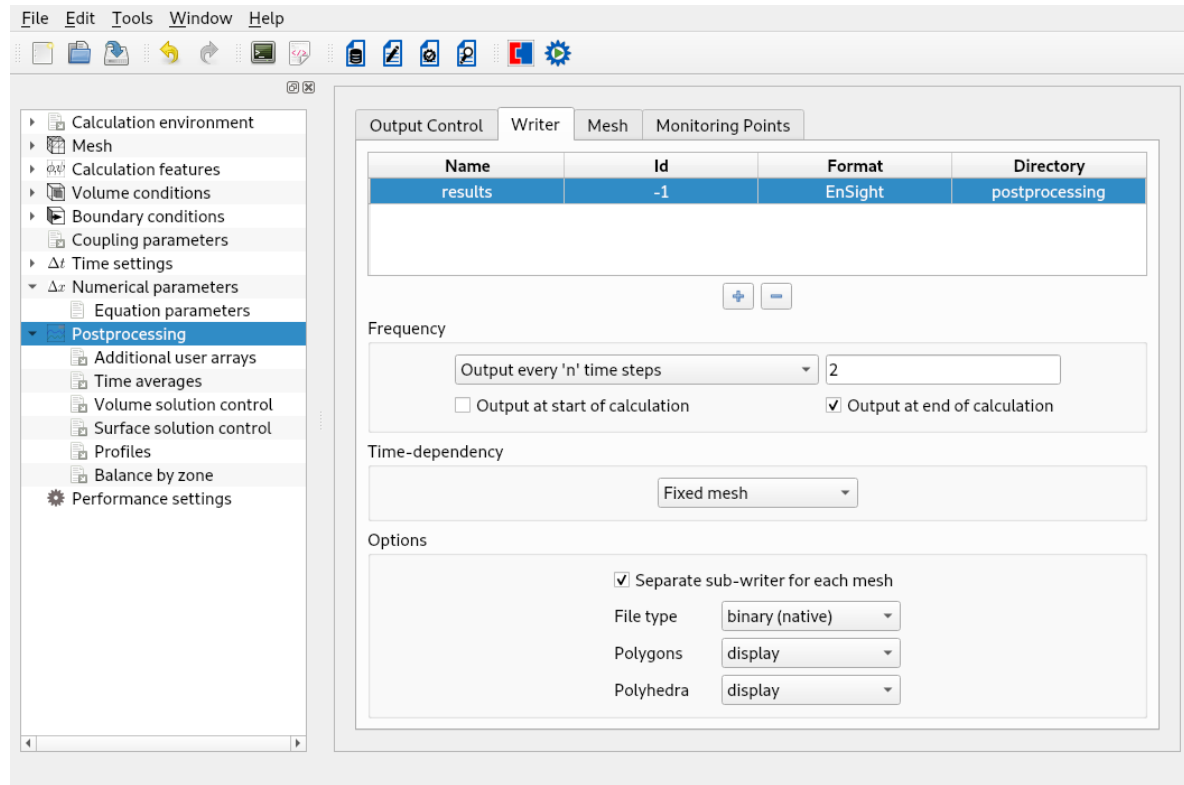



Figure III.23: Output control: results

You can also choose the format. In our case, we choose the EnSight format.

In this case, chronological records on specified monitoring probes are needed. To define the probes, click on the **Monitoring Points** tab. Click on  and enter the coordinates of the monitoring points you want to define.

Repeat the procedure for the other probes. The coordinates of the probes are indicated in the following table (the z coordinate is always 0):

Probe n°.	x (m)	y (m)	z (m)
1	-0.25	2.25	0.0
2	0.05	2.25	0.0
3	0.05	2.75	0.0
4	0.05	0.50	0.0
5	0.05	-0.25	0.0
6	0.75	-0.25	0.0
7	0.75	0.25	0.0
8	0.75	0.75	0.0

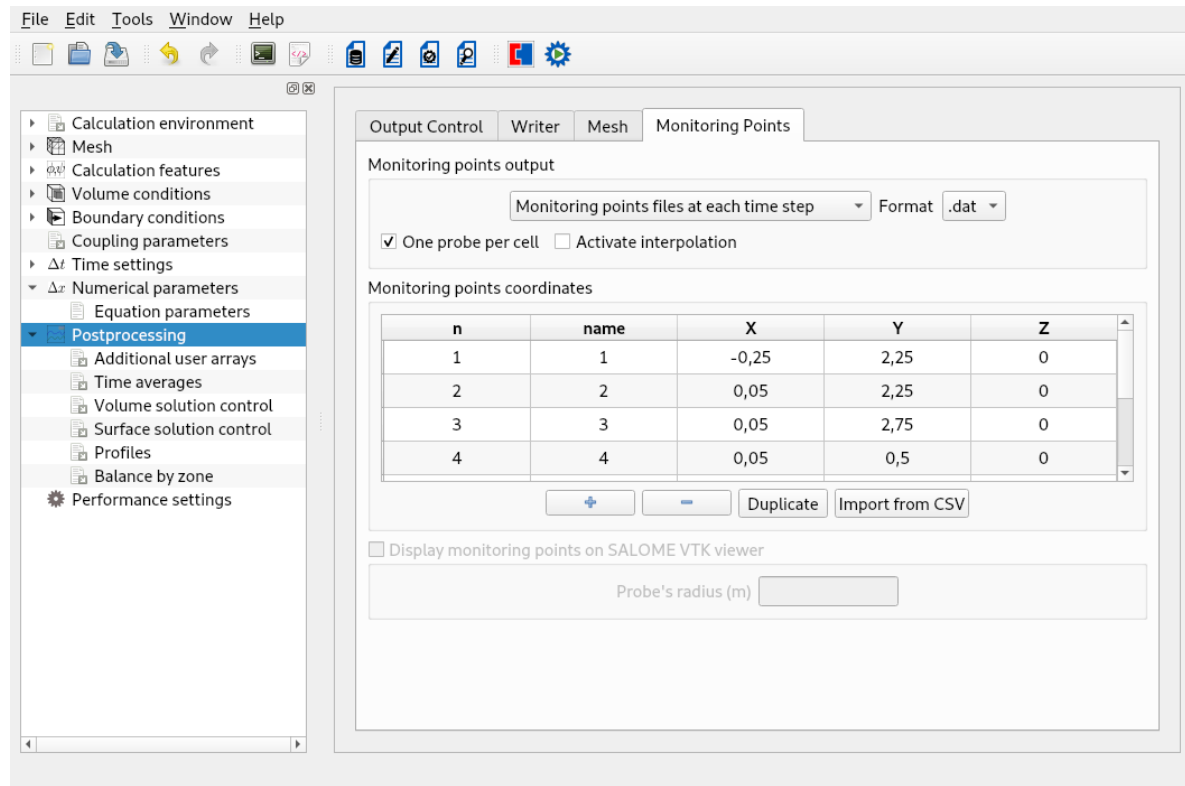


Figure III.24: Output control: monitoring points

Remember to save the **xml** file regularly.

Volume solution control Go to the **Volume solution control** item to define which variables will appear in the listing, the post-processing and the chronological records.

Uncheck the boxes in front of the **Pressure**, **k** and **epsilon** variables, in the **Print in listing** column. Information on these three variables will not appear in the output listing anymore.

Uncheck the boxes in front of the **CourantNb** and **FourierNb** variables in the **Post-processing** column. These variables will be removed from the post-processing results.

Uncheck the box in front of the **total_pressure** variable in the **Monitoring** column. No chronological record will be created for this variable.

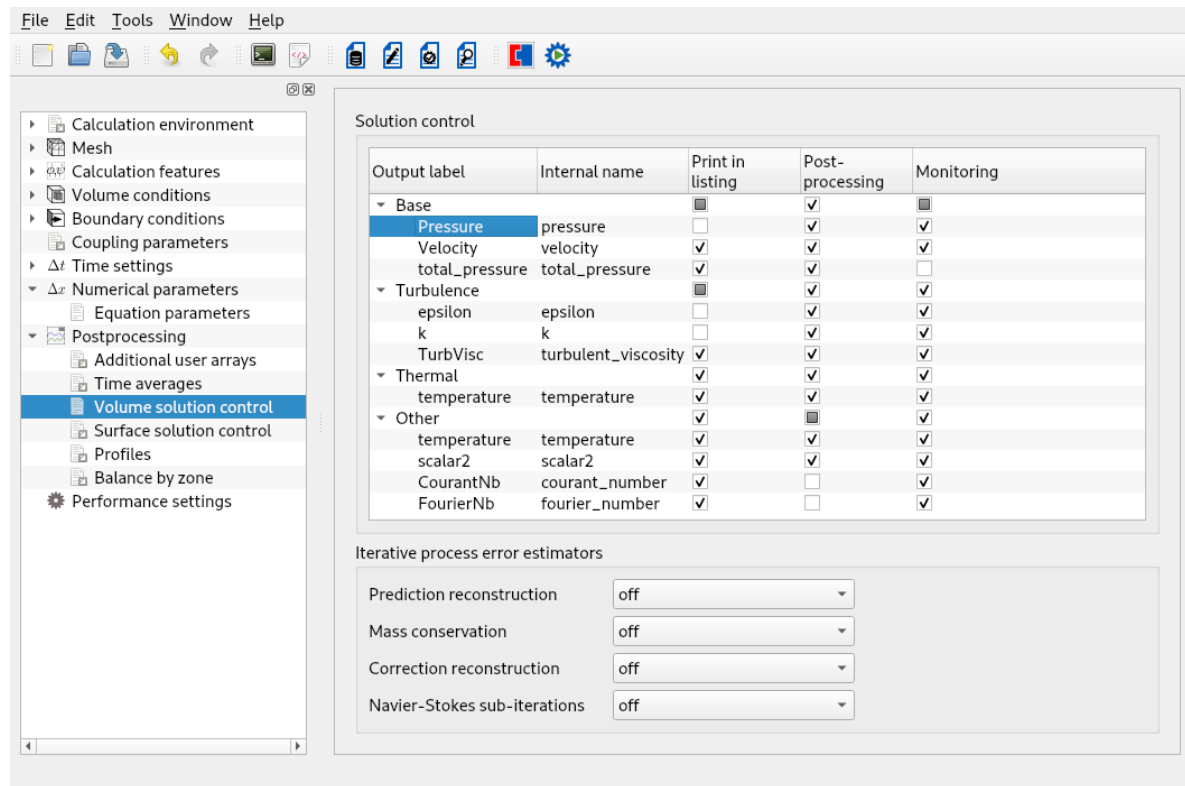


Figure III.25: Solution control: output configuration


After completing the interface, before running the calculation, some user routines need to be modified to post-process the additional transported scalars on the domain boundary (only boundary temperature post-processing can be dealt with in the GUI).

Go to the folder `SRC/REFERENCE` and copy `cs_user_parameters.c` in the `SRC` directory.

In this case `cs_user_parameters.c` is used to add boundary values for all scalars as follows :

```
void
cs_user_parameters(cs_domain_t *domain)
{
    /* Add boundary values for all scalars */
    {
        int n_fields = cs_field_n_fields();
        for (int f_id = 0; f_id < n_fields; f_id++) {
            cs_field_t *f = cs_field_by_id(f_id);
            if (f->type & CS_FIELD_VARIABLE)
                cs_parameters_add_boundary_values(f);
        }
    }
}
```

1.8 Run calculation

To prepare the launch script and, on certain architectures, launch the calculation, click on the  icon in the menu bar and a new window will appear as shown below:

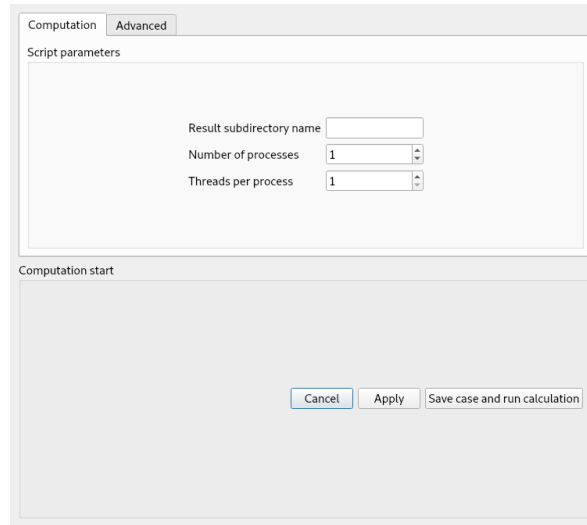


Figure III.26: Prepare batch calculation: computer selection

Run the calculation by clicking on the **Save case and run calculation** button:

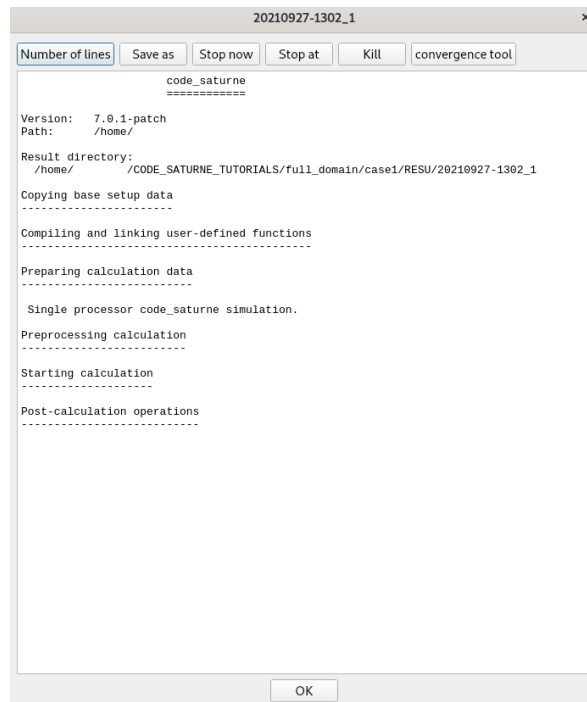


Figure III.27: Run

2 Solution for CASE2

Only a few elements are different from `case1`.

2.1 Volume tab

In this case the density becomes variable. Go to the **Fluid properties** heading and change the nature of the density from **constant** to **user law**.

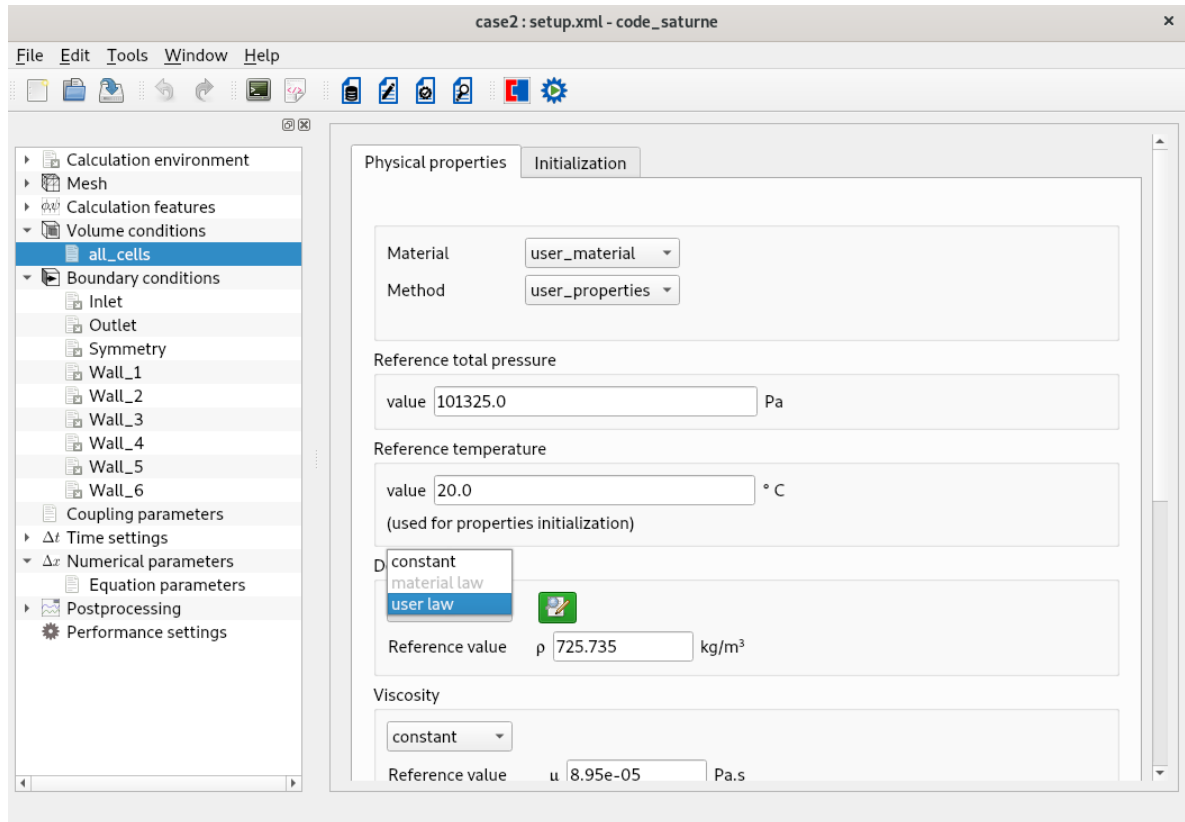


Figure III.28: Fluid properties: variable density

The user law of the density is defined as follows in the code_saturne (GUI):

```
density = temperature * ( -4.0668E-03*temperature - 5.0754E-02 ) + 1000.9;
```

Click on the highlighted icon and define the user law in the window that pops up. Follow the format used in the [Examples](#) tab.

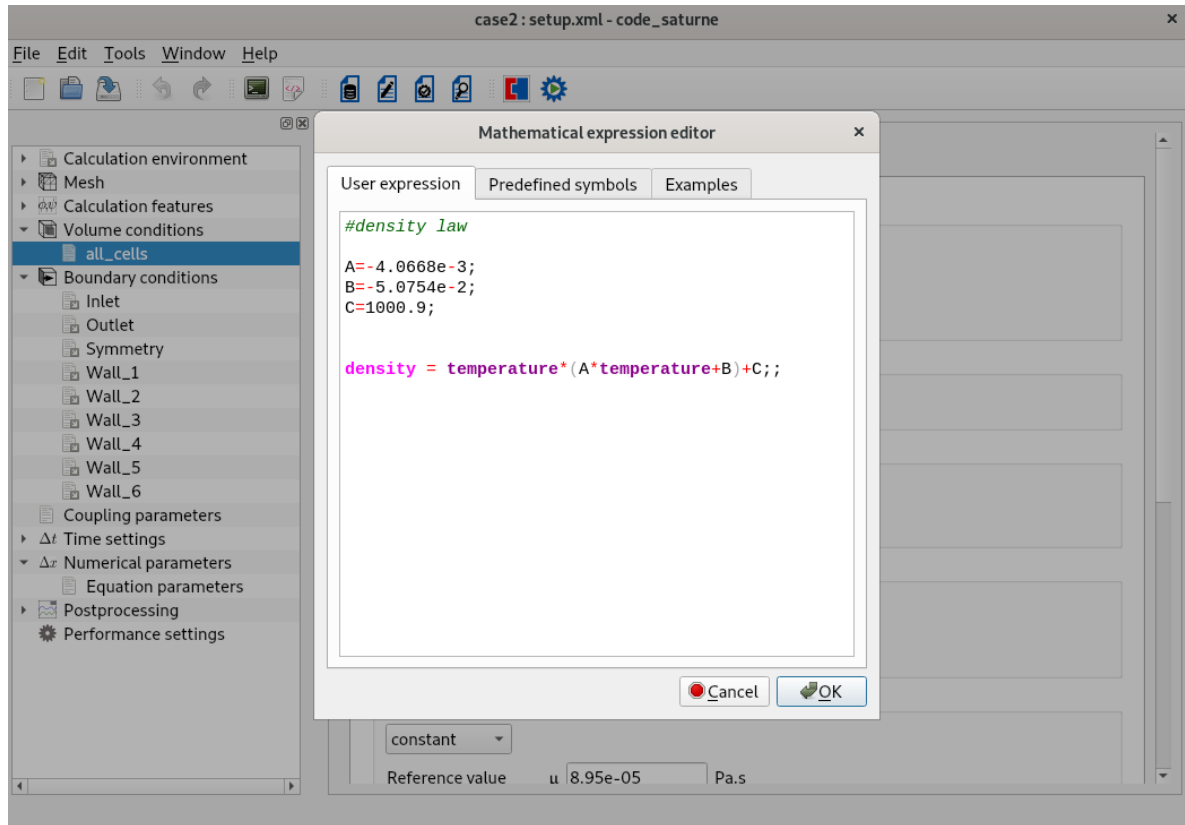


Figure III.29: Fluid properties/Variable density: user expression

Body forces As the density is variable, the influence of gravity has to be considered. Go to **Body forces** item under **Calculation features** heading and set the value of each component of the gravity vector.

$g_x = 0.0$ $g_y = -9.81$ $g_z = 0.0$

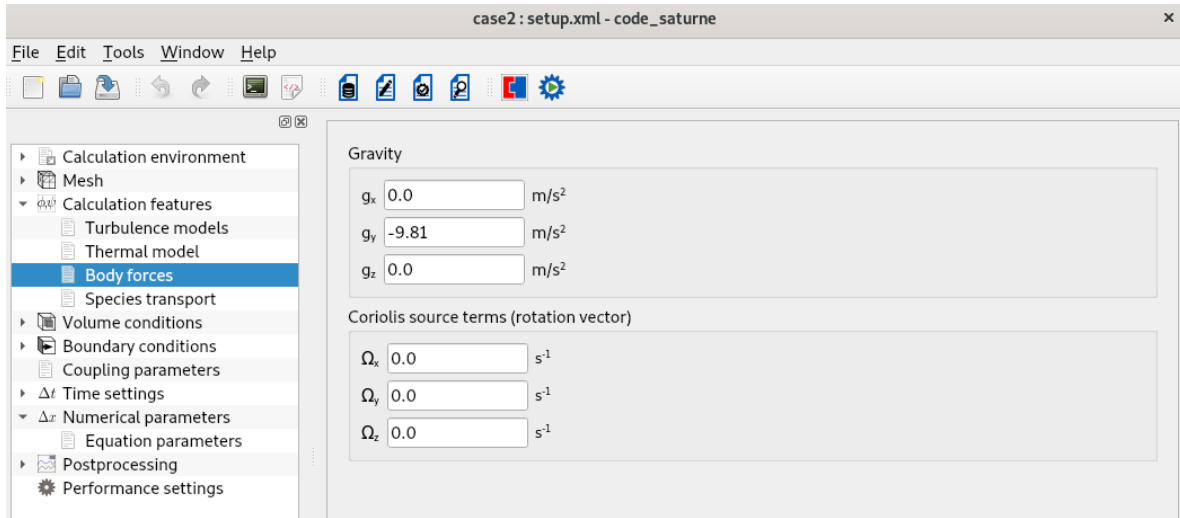


Figure III.30: Fluid properties: gravity

2.2 Postprocessing

Add a monitoring point close to the entry boundary condition in the **Monitoring Points** tab under the **Postprocessing** heading.

Probe	x (m)	y (m)	z (m)
9	-0.5	2.25	0.0

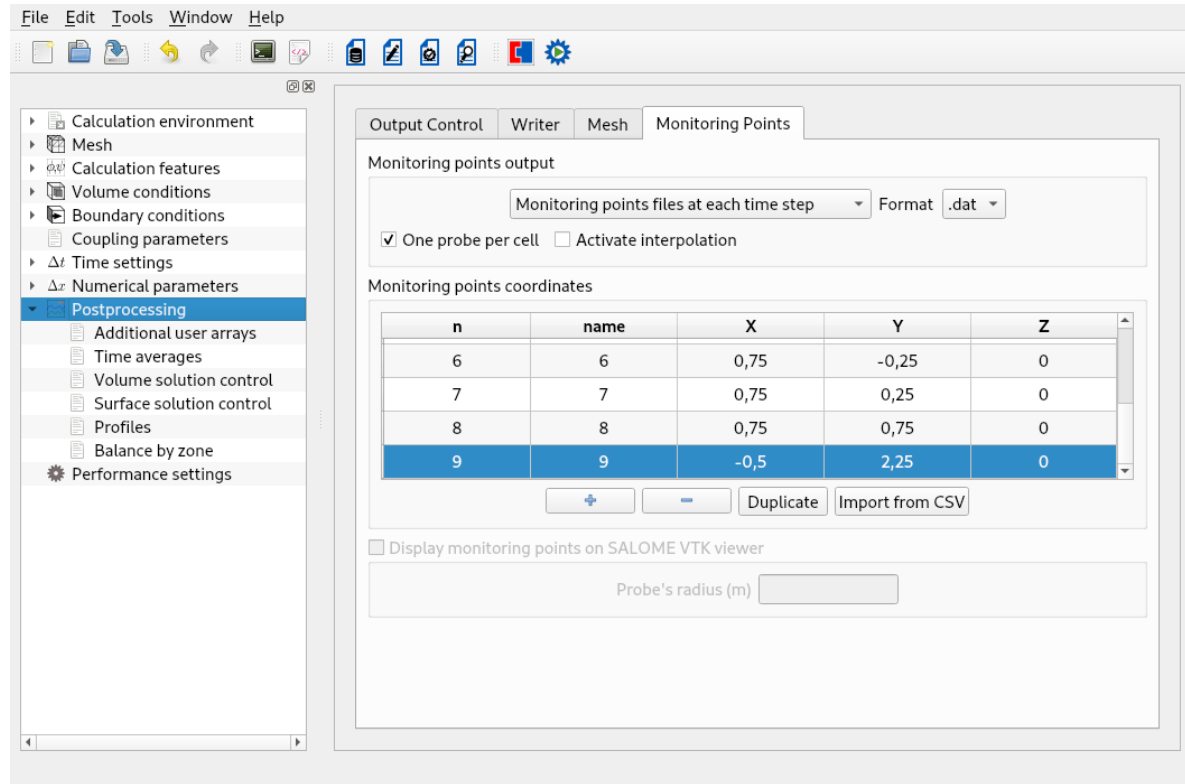




Figure III.31: New monitoring probe

2.3 Routines modifications

After completing the interface, before running the calculation, some Fortran user routines need to be modified.

Go to the folder  SRC/REFERENCE and copy `cs_user_boundary_conditions.f90` in the  SRC directory.

- **cs_user_boundary_conditions.f90:**

In this case, `cs_user_boundary_conditions.f90` is used to specify the time dependent boundary condition for the temperature. Refer to the comments in the routine or to the code_saturne user manual for more information on this routine.

In our case, you need to identify the boundary faces of color **1**.

The command

```
call getfbr('1',nlelt,lstelt)
```


will return an integer `nlelt`, corresponding to the number of boundary faces of color 1, and an integer array `lstelt` containing the list of the `nlelt` boundary faces of color 1.

Remark: Note that the string **1** can be more complex and combine different colors, group references or geometrical criteria, with the same syntax as in the Graphical Interface.

For each boundary face `ifac` in the list, the Dirichlet value is given in the multi-dimension array `rcodcl` as follows:

```
if (ttcabs.lt.3.8d0) then
  do ielt = 1, nlelt
    ifac = lstelt(ielt)
    rcodcl(ifac,isca(2),1) = 20.d0 + 100.d0*ttcabs
  enddo
else
  do ielt = 1, nlelt
    ifac = lstelt(ielt)
    rcodcl(ifac,isca(2),1) = 400.d0
  enddo
endif
```

`isca(2)` refers to the first scalar and `ttcabs` is the current physical time.

See the example `cs_user_boundary_conditions-base.f90` file in the subdirectory  SRC/EXAMPLES to complet correctly your boundary conditions for this **case2**.

Remark: Note that, although the inlet boundary conditions for temperature are specified in the `cs_user_boundary_conditions.f90` file, it is necessary to specify them also in the Graphical Interface.

The value given in the Interface can be anything, it will be overwritten by the Fortran routine.

After updating the Fortran file, run the calculation as explained in **case1**.

When a calculation is finished, code_saturne stores all the necessary elements to continue the computation in another execution, with total continuity. These elements are stored in several files, grouped in a `yyyyymmdd-hhmm/checkpoint` subdirectory, in the `RESU` directory.

2.4 Time settings

Start/Restart In this case, after the first calculation is finished, a second calculation will be run, starting from the results of the first one.

Go directly on the **Start/Restart** item under the heading **Time settings**. Activate the **Checkpoint/Restart** by clicking the **On** box.

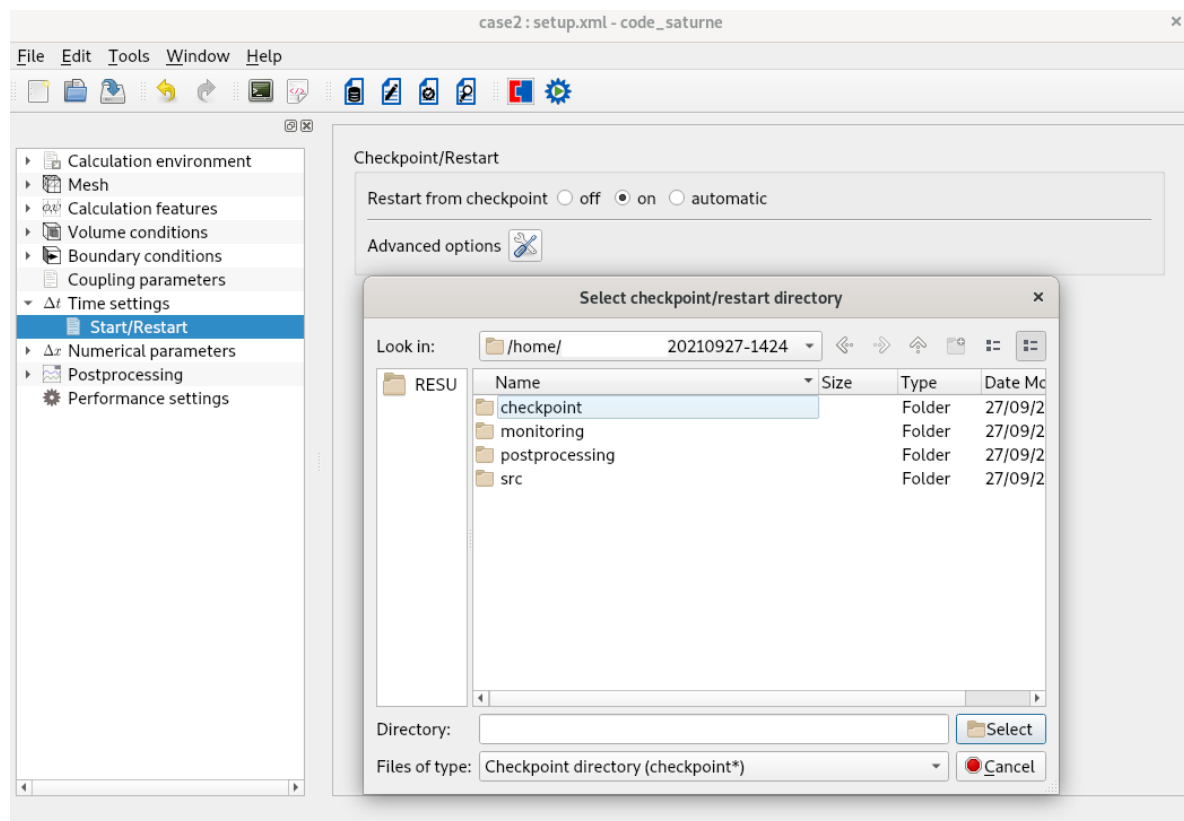


Figure III.32: Start / Restart

A window opens, with the architecture of the study sub-directories. In the **RESU** folder, click on the folder **yyyyymmdd-hhmm/checkpoint** (where yyyyymmdd-hhmm corresponds to the reference of the first calculation results). Then click on **Validate**.

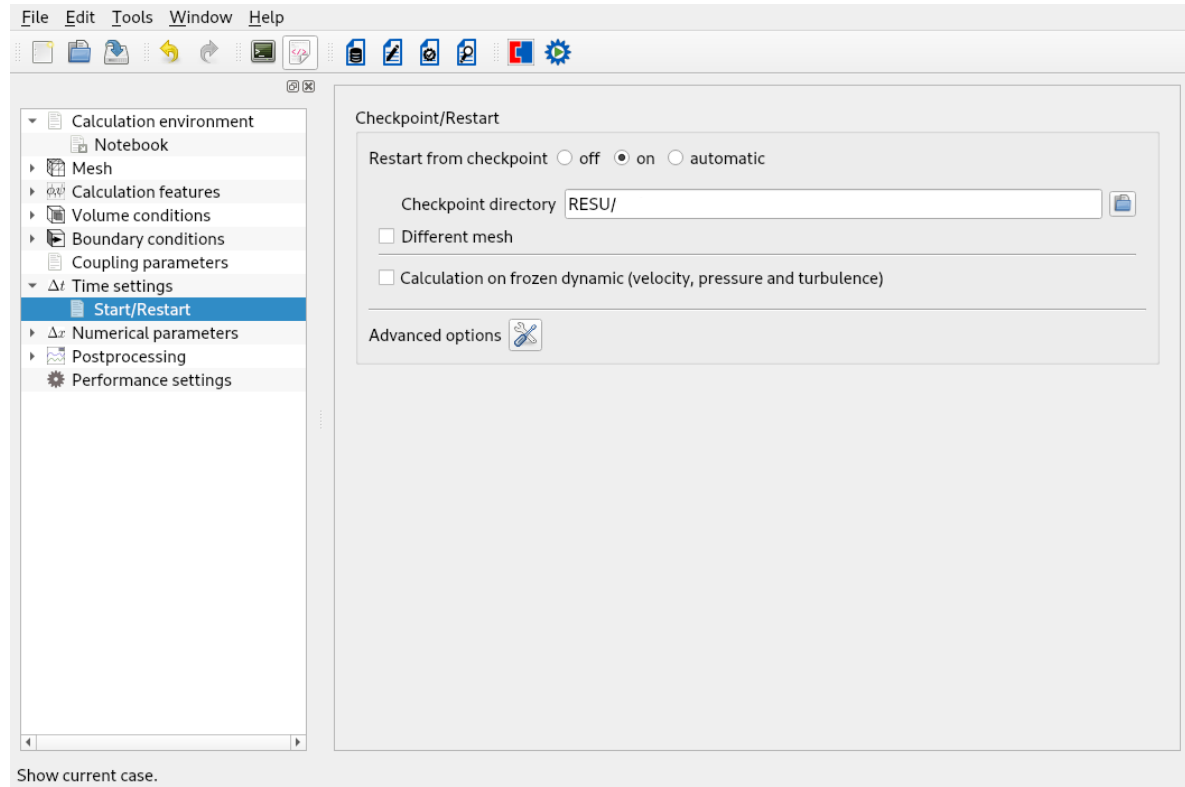


Figure III.33: Start/Restart: selection of the restart directory

Go to the **Time settings** heading and change the **Stopping criterion** from **Number of time steps** to **Additional time steps**. Set it to 400 which means another 400 iterations (the total number of iterations is 700 iterations).

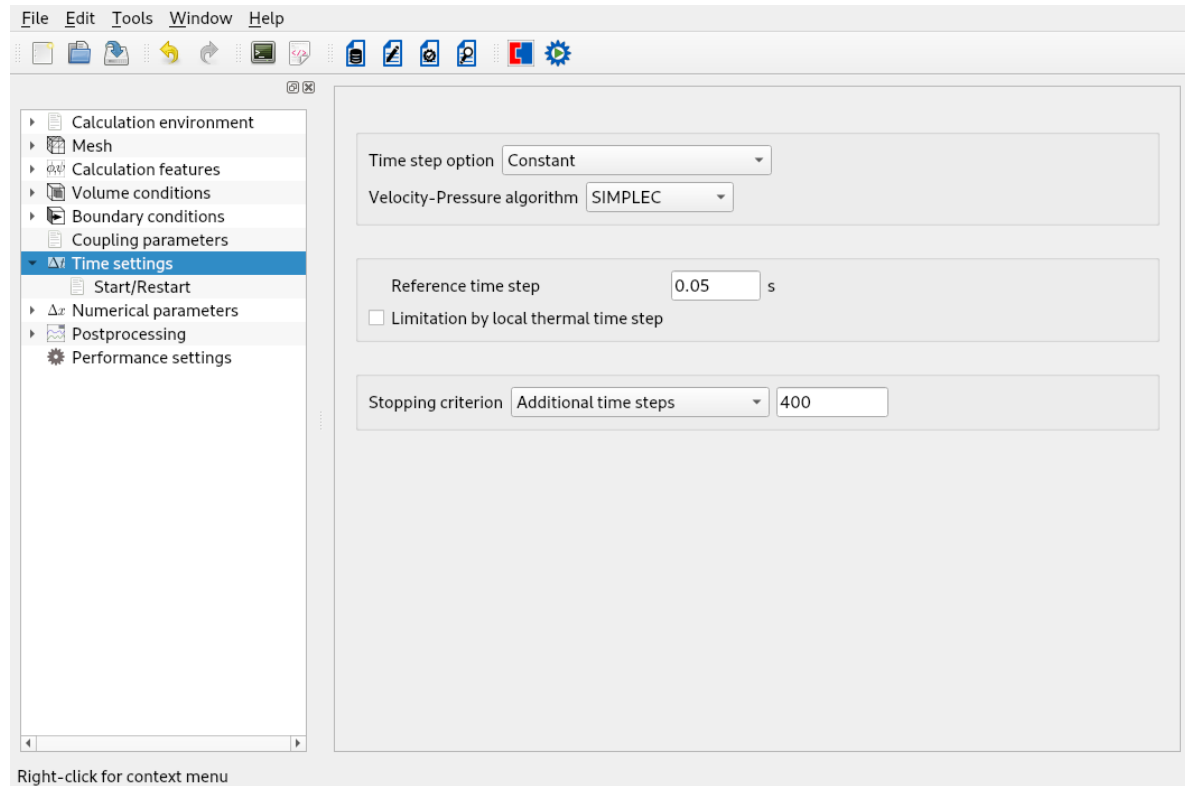


Figure III.34: Time step

Eventually, run the calculation.

3 Solution for CASE3

This case is similar to `case2`, with the following differences:

- **Step 1:** define head losses in the fluid domain,
 - **Step 2:** compute the spatial average of temperature scalar,
 - **Step 3:** update new Time settings,
 - **Step 4:** parallel computation on 2 processors,
 - **Step 5:** dealing with a user results file.
- **Step 1-1:** Define the head losses in the Graphical User Interface (GUI)

3.1 Mesh tab

Volume zones Go to **Volume zones** folder. Click on **Add** to create a new volume zone. You can renamed the **Label** as losses region.

Define the limits of the head losses region in **Selection criteria**. The associated character string to enter is as below:

```
'x >= 0.2 and x <= 0.4 and y >= -0.75 and y <= -0.25'
```

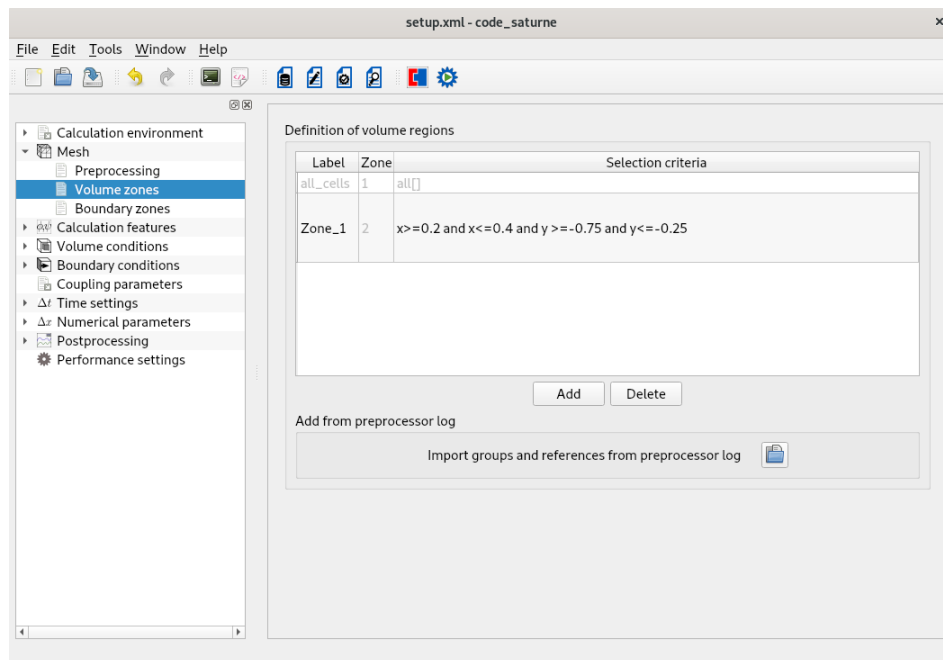


Figure III.35: Creation of the head losses region

3.2 Volume conditions tab

Head losses For this new volume you shall only tick **head losses** as follows. (see Figure III.36).

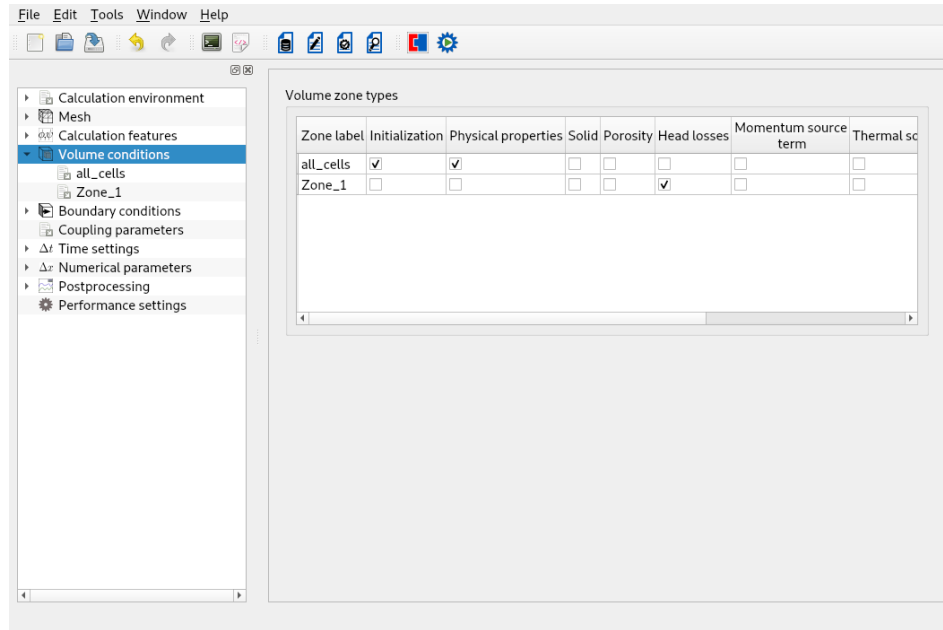


Figure III.36: Selection criteria of the head losses region

- **Step 1-2:** Specify the head losses coefficients α_{ii}

To specify the head losses coefficients go to the **Head losses** item and select the name of the head losses volume region. In this example, the coefficient is isotropic so that we use the same value for each α_{ii} . Please note that $\alpha_{ii} = 2 \times K_{ii}$, therefore if $K_{ii} = 10^4$, $\alpha_{ii} = 2 \times 10^4$.

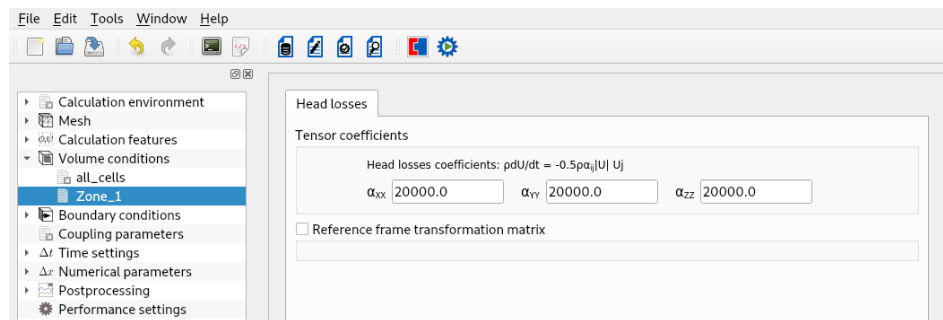


Figure III.37: Head losses coefficients

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- **Step 2:** Compute the spatial average of **temperature**

3.3 Routine update

The computation of the spatial average must be done in the `cs_user_extra_operations.c` routine.

The following code computes the spatial average temperature and writes it in a file called `moy.dat`.

```

/* Global declaration of the moy.dat file that will be filled with Tavg */
static FILE *file = NULL;

void
cs_user_extra_operations(cs_domain_t *domain)
{
    /* Variables declaration */
    /* Get pointers to the mesh and mesh quantities structures */
    const cs_mesh_t *m = cs_glob_mesh;
    const cs_mesh_quantities_t *fvq = cs_glob_mesh_quantities;

    /* Number of cells */
    const int n_cells = m->n_cells;

    /* Cell volumes */
    const cs_real_t *cell_vol = fvq->cell_vol;

    /* Get the temperature field */
    const cs_field_t *temp = cs_field_by_name_try("temperature");

    /* Cell volumes sum, Temp * volumes sum and Tavg */
    cs_real_t voltot = 0., temptot = 0., Tavg = 0.;

    /* Compute the sum of the cell volumes */
    for (int ii = 0 ; ii < n_cells ; ii++)
        voltot += cell_vol[ii];

    /* Compute the sum T*vol */
    for (int ii = 0 ; ii < n_cells ; ii++)
        temptot += temp->val[ii]*cell_vol[ii];

    /* Parallel sums */
    cs_parall_sum(1, CS_DOUBLE, &voltot);
    cs_parall_sum(1, CS_DOUBLE, &temptot);

    /* Compute Tavg */
    Tavg = temptot / voltot ;

    /* Open the file moy.dat at the first iteration
       and write the first comment line only on the
       first processor (0 in parallel, -1 in serial) */
    if (cs_glob_time_step->nt_cur == 1 && cs_glob_rank_id <= 0) {
        file = fopen("moy.dat", "a");
        fprintf(file, "#Time (s)    Average Temperature (C) \n");
    }

    /* Print the average temperature at the current time step
       on the first processor only */
    if (cs_glob_rank_id <= 0)
        fprintf(file, "%.6f %.6f\n", cs_glob_time_step->t_cur, Tavg);

    /* Close the file moy.dat at the last iteration
       on the first processor only */
    if (cs_glob_time_step->nt_cur == cs_glob_time_step->nt_max
        && cs_glob_rank_id <= 0)
        fclose(file);
}

```


- **Step 3:** Choose a computation with 2 processors

3.4 Time settings

This modification will be done in the [Calculation management](#) item.

To run the calculation on two processors, simply change the number of processors indicator to 2. The launch script will automatically deal with the rest.

Do not forget to set the right [Reference time step](#) and [Number of iterations](#) under the heading [Time settings](#) as mentioned

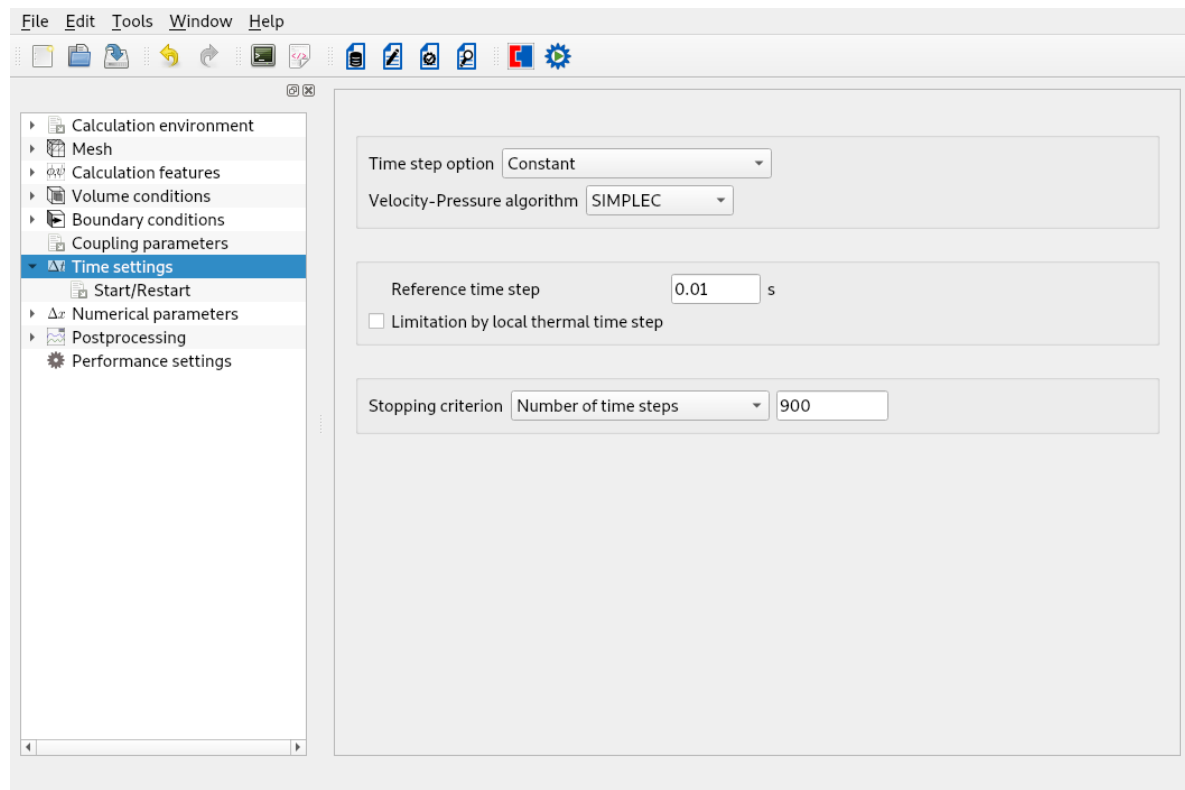


Figure III.38: Time settings

- **Step 4:** Choose a computation with 2 processors

3.5 Run calculation

Verify you hardware configuration. Depending on your hardware configuration you might select either 2 processes (or more) if you either 2 threads per process.

Computation **Advanced**

Script parameters

Result subdirectory name

Number of processes

Threads per process

Computation start

Figure III.39: Number of processors

- **Step 5:** Dealing with a user results file moy.dat

The new user file moy.dat created by cs_user_extra_operations.c will be written directly in the `yyyyymmdd-hhmm` results subdirectory created at the end of the computation in the `RESU` directory.

Remark 3.1 : We do not have to specify the name of the new user file in the Graphical User Interface (GUI), like in previous code_saturne versions. The name of the new user file had to be identified in the launch script in order to be automatically copied in the `RESU` directory; this is not requested anymore.

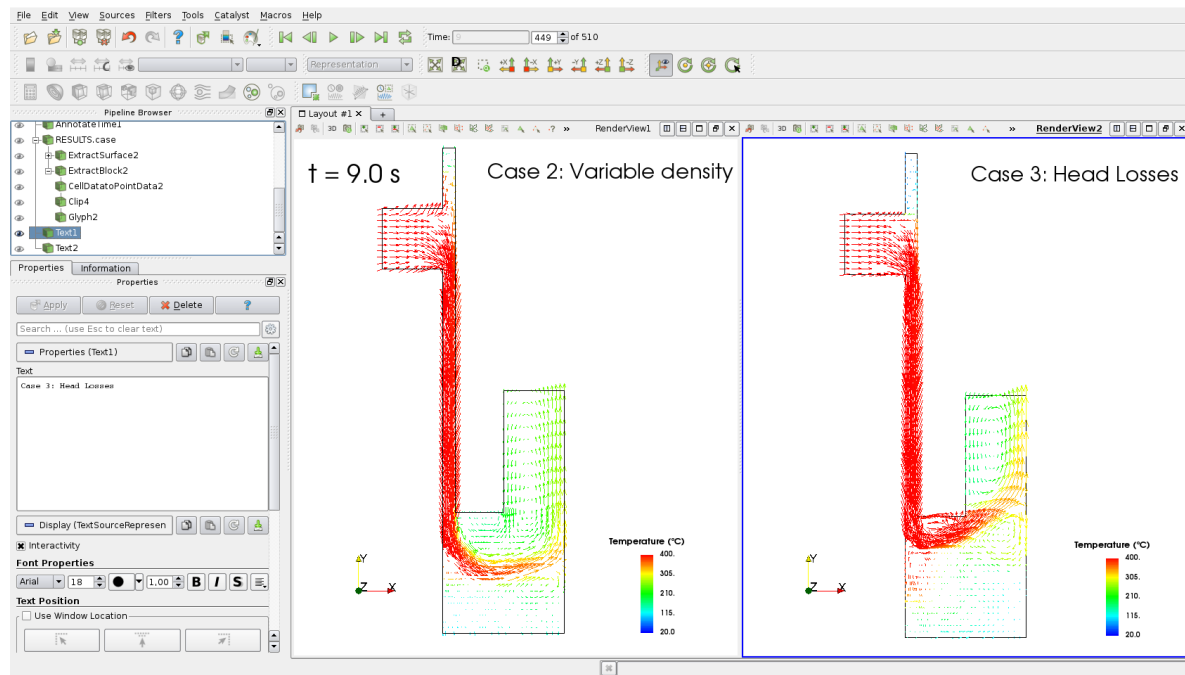


Figure III.40: User results files