Tutorial for the supercritical pressure pipe with STAR-CCM+

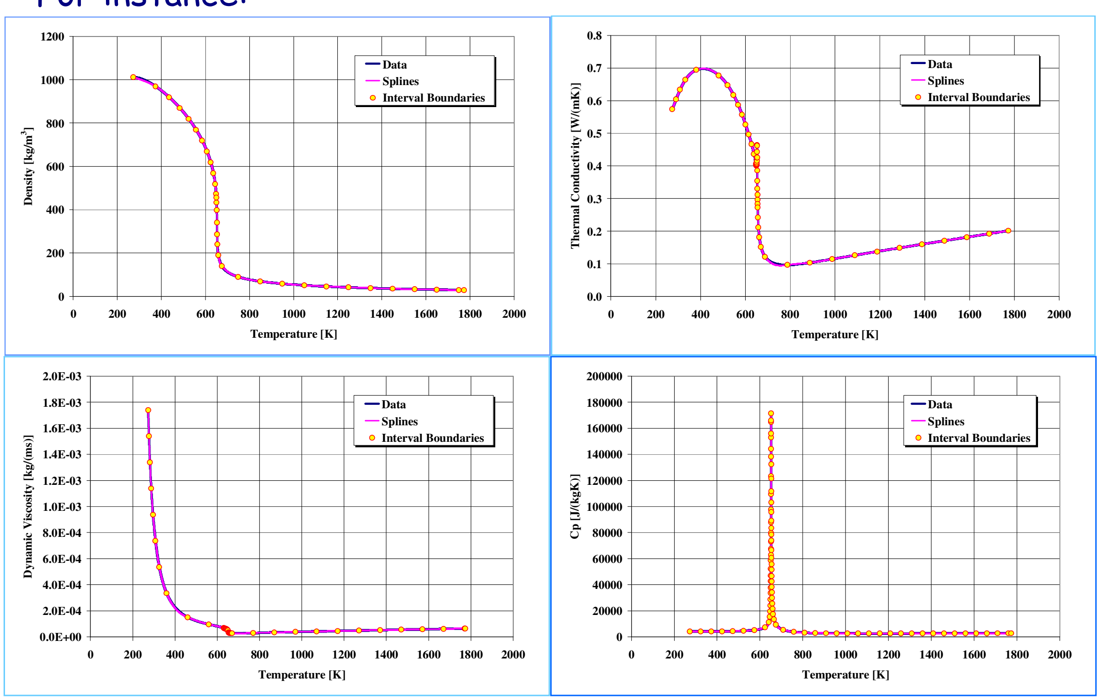
For performing this tutorial, it is necessary to have already studied the tutorial on the upward bend. In fact, after getting abilities with that case, many concepts will turn out relatively straightforward.

Problem definition

A circular pipe having an heated length of 0.6 m with imposed heat flux, preceded by an unheated section of 0.4 m. The inner pipe diameter is 6.26 mm.

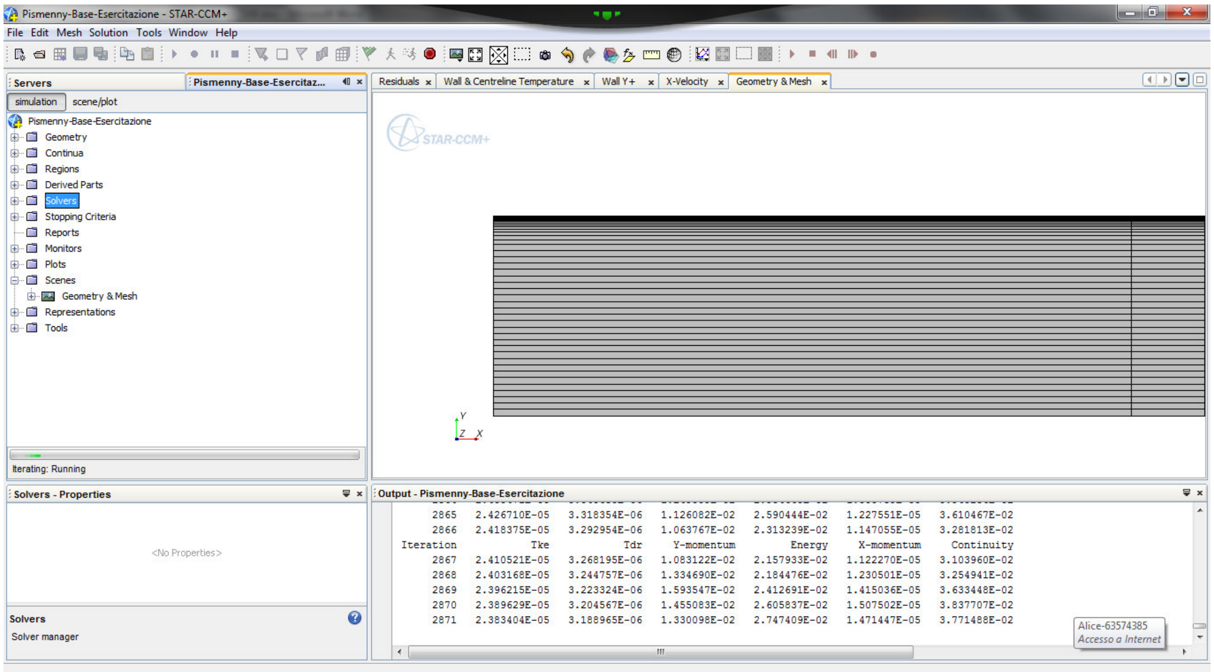
The contained fluid is water at the supercritical pressure of 23.5 MPa (the critical pressure for water is 22.06 MPa). The inlet temperature and the heating power are such that the "pseudo-critical temperature" is reached at the wall. The pseudo-critical temperature is defined as the temperature at which a supercritical fluid at a constant pressure has a maximum in the specific heat. Around this temperature, the properties of the fluid change drastically, showing a transition from *liquid-like* to *gas-like* conditions.

For instance:

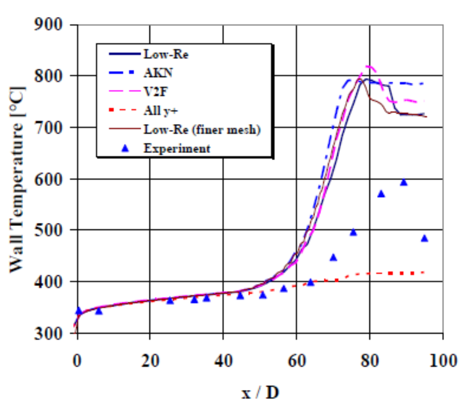


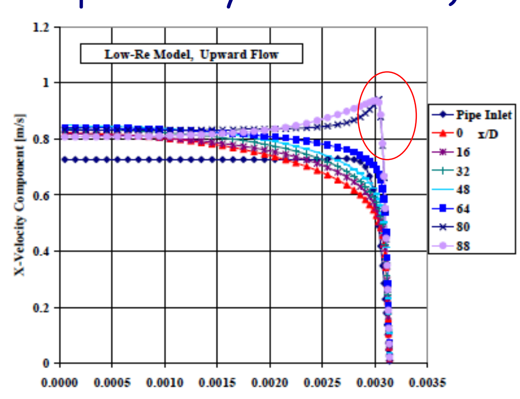
In this problem, it was chosen to use “a low-Reynolds number model”, requiring a very fine discretisation close to the wall. The resulting radial discretisation is much larger than the axial one.

Expand the related “Scene” to understand how the mesh looks like. Make use of the mouse for displacing the geometry in the view.



Though the present is only a didactic exercise, it is necessary to recognise that the comparison of wall temperature with experimental data by Pis’menny (Ucraine) is only qualitatively accurate for upward flow. This is the present state-of-the-art for k-ε models when they describe “deterioration” of heat transfer (to be explained by the teacher)

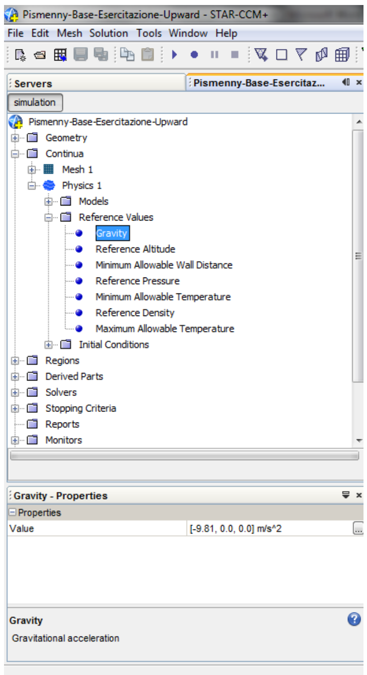


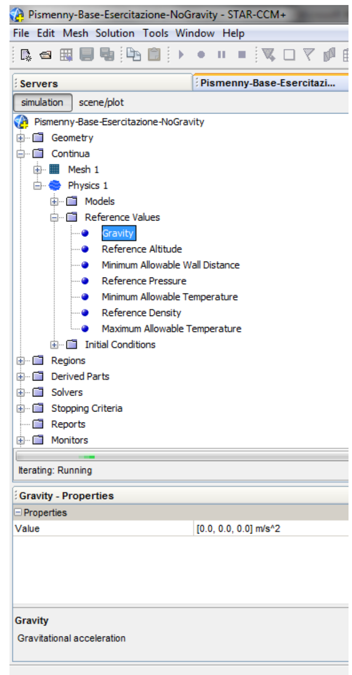


We will anyway consider two variants of the exercise:

1. no gravity flow, showing a typical forced flow behaviour;
2. upward flow with gravity, showing the effects of mixed convection (the one whose results are reported in the above figures).

The difference between the two cases is just in the value of the gravity parameter that has the first component (the x one) equal to 0.0 or -9.81.





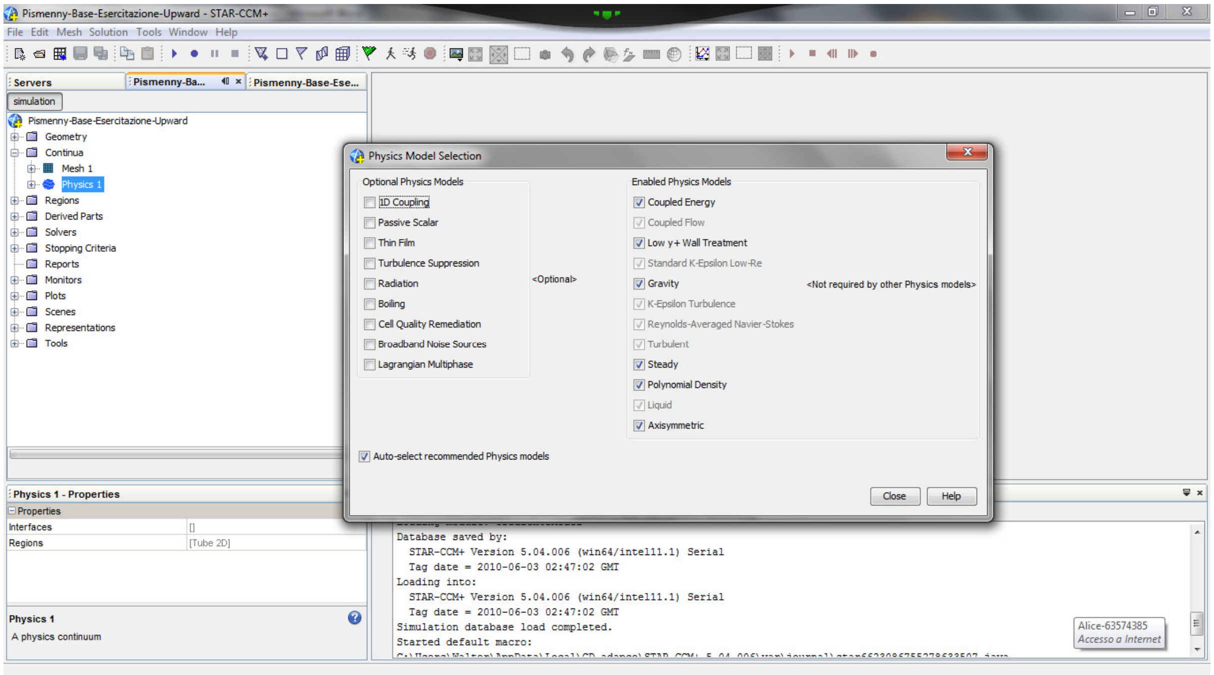
In the following, suggestions are given to revise the different sections of the tree structure.

<u>Continua</u>

Try understanding which models have been selected for this case. Open the related node in the tree structure by right-clicking to obtain the result shown in the figure of the following page.

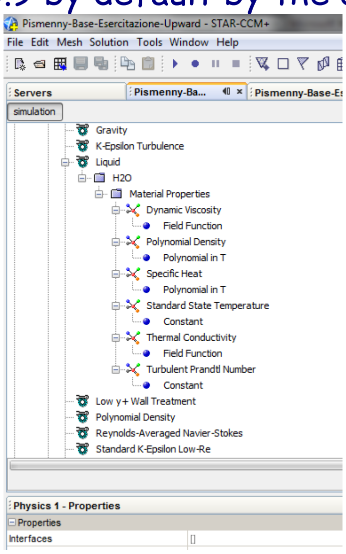
Take notes hereafter. Some hints are given:

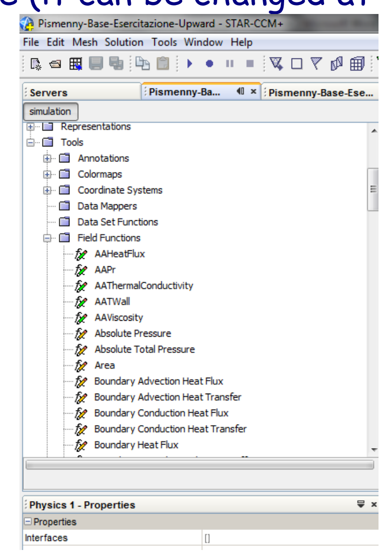
- *the standard low-Re k-ε model with <u>a low-y+ treatment</u> is used*
- ____
- ____
- ____
- ____
- ____



The properties are assigned by cubic splines implemented in piecewise form as polynomials in T also assigned as "field functions" defined by the user.

In particular, consider the value of the turbulent Prandtl number assigned to 0.9 by default by the code (it can be changed at ease!.. try!)

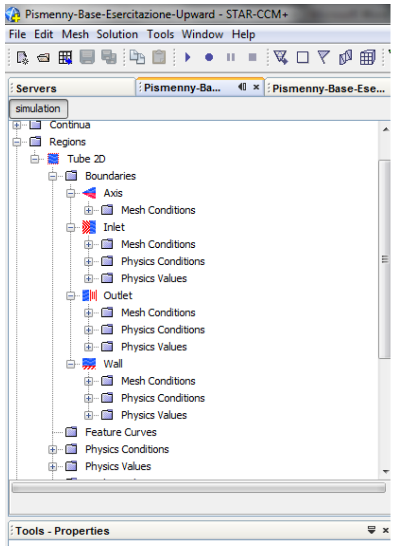


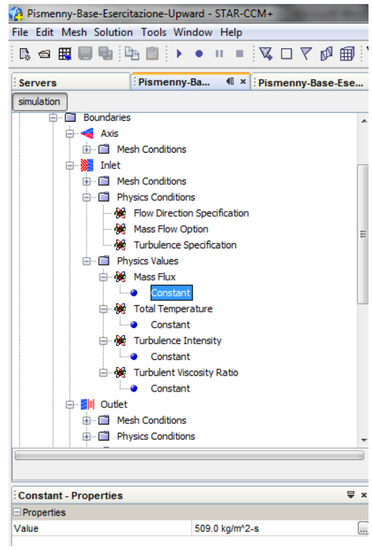


Regions

Try understanding the nature of the boundary conditions applied to the four different boundaries.

In particular, look at the Physics Conditions and the Physics Values. E.g., the mass flux at the "Inlet" is 509.0 kg/(m^2s).



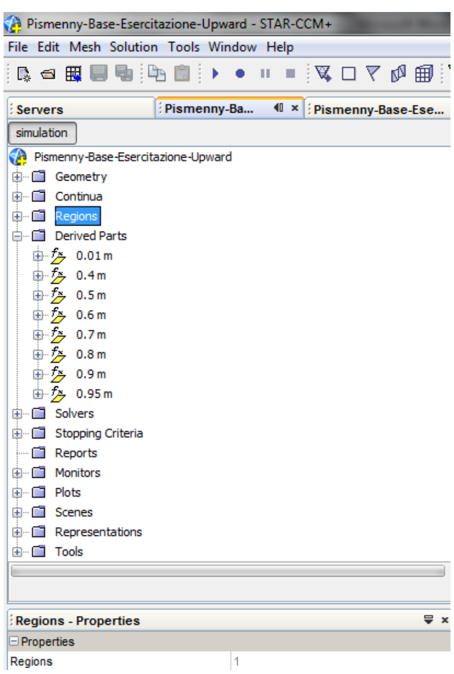


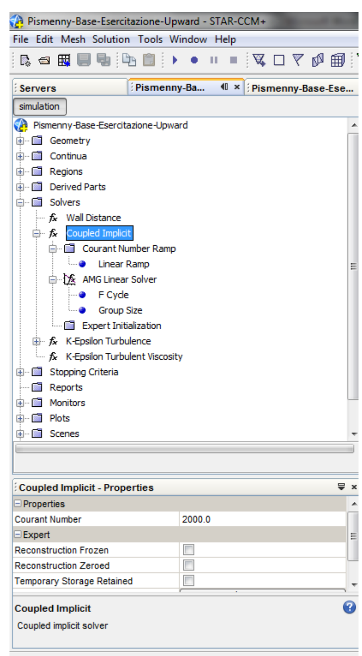
Derived parts

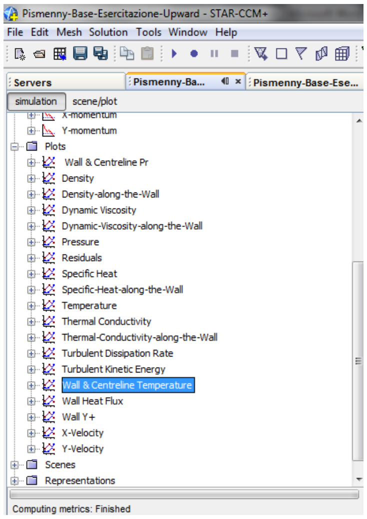
They have been introduced as "sections" to be used in setting up plots of radial distributions at different distances along the pipe.

Solvers

In this case a "Coupled" flow and energy numerical scheme (as opposed to the "segregated" one) was used. This option is preferable in cases in which the flow is affected by strong buoyancy forces. A ramp of Courant number is assigned in a pseudo-transient iteration scheme (to be explained by the teacher).





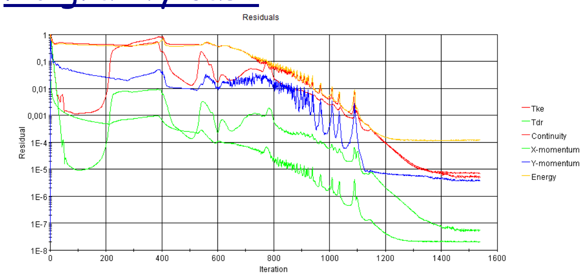


Plots

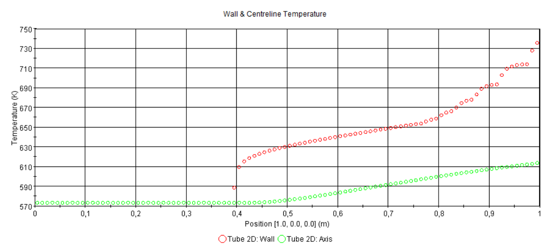
In this case several 2D plots have been defined in order to monitor axial and radial distributions of different quantities

Some of them are presented hereafter for the two cases, starting with the no-gravity flow.

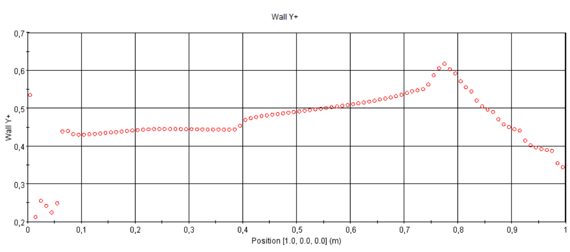
No gravity case



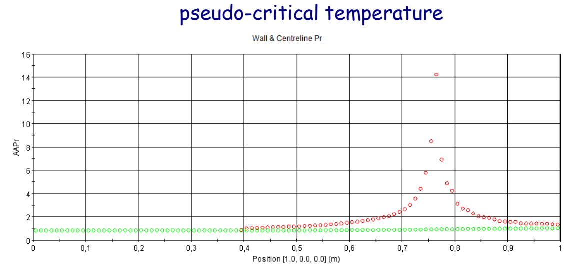
The residuals decrease and stabilise



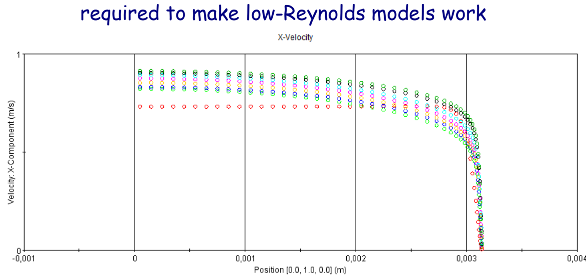
The wall temperature increases smoothly also beyond the pseudo-critical temperature



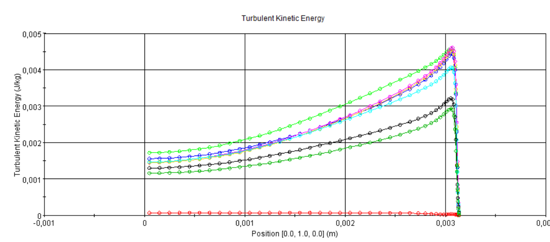
The y+ at the centroid of the first node is less than unity, as required to make low-Reynolds models work



The molecular Prandtl number at the wall reaches a sharp peak at the pseudo-critical temperature

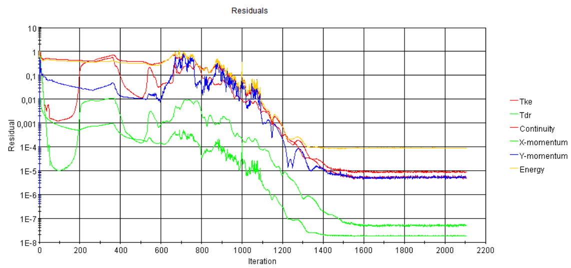


The radial velocity profiles at different locations are typical of a flow that is not affected by buoyancy forces (i.e., it is of the power law type)

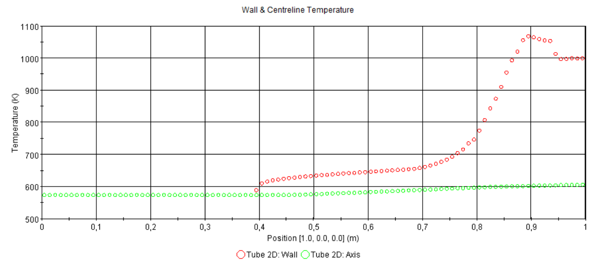


The turbulent kinetic energy has the classical sharp peak close to the wall. Note the large number of nodes needed to describe the near wall region with a reasonable detail in the boundary layer

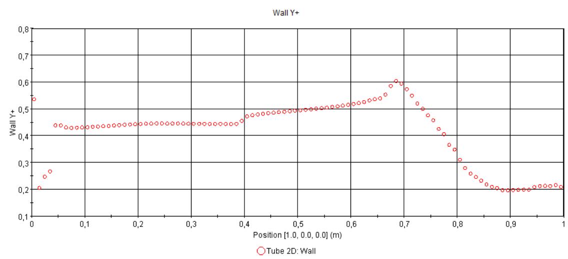
Upward flow case



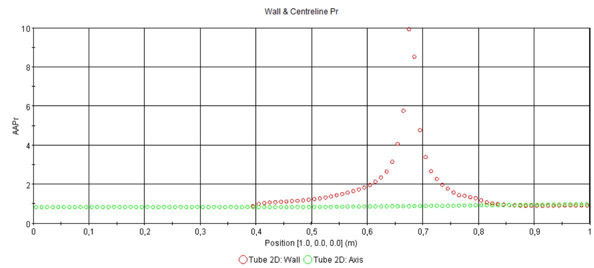
The residuals decrease and stabilise



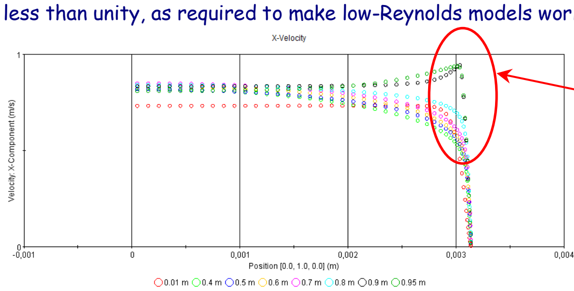
It is remarkable noting that with "aided" mixed convection, the heat transfer efficiency is decreased. This is the effect, named "heat transfer deterioration", that can be explained with a decrease of turbulence intensity close to the wall.



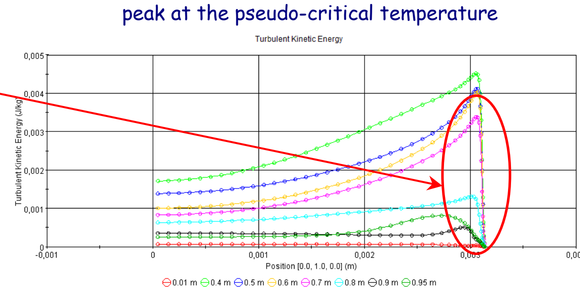
Also in this case, the y+ at the centroid of the first node is less than unity, as required to make low-Reynolds models work



The molecular Prandtl number at the wall reaches a sharp peak at the pseudo-critical temperature



The radial velocity profiles at different locations are typical of a flow that <u>is affected</u> by buoyancy forces; an M-shaped profile is clearly noted due to acceleration close to the wall



In the region where the velocity gradient at the wall decreases (from 0.7 m), the turbulent kinetic energy at the wall progressively decreases, because the shear stress (proportional to the velocity gradient) decreases and so the production of turbulence decreases: this explains the occurrence of "heat transfer deterioration"

Suggestions to make exercises.

Run the code after making a change (e.g., inlet flow rate, different turbulent Prandtl number). You will see the residuals jumping (the equations are no more satisfied with the new parameter value) and then, hopefully, decrease while a new steady-state is approached.

AGAIN, GOOD LUCK !