CFD Team Simulations for CAST

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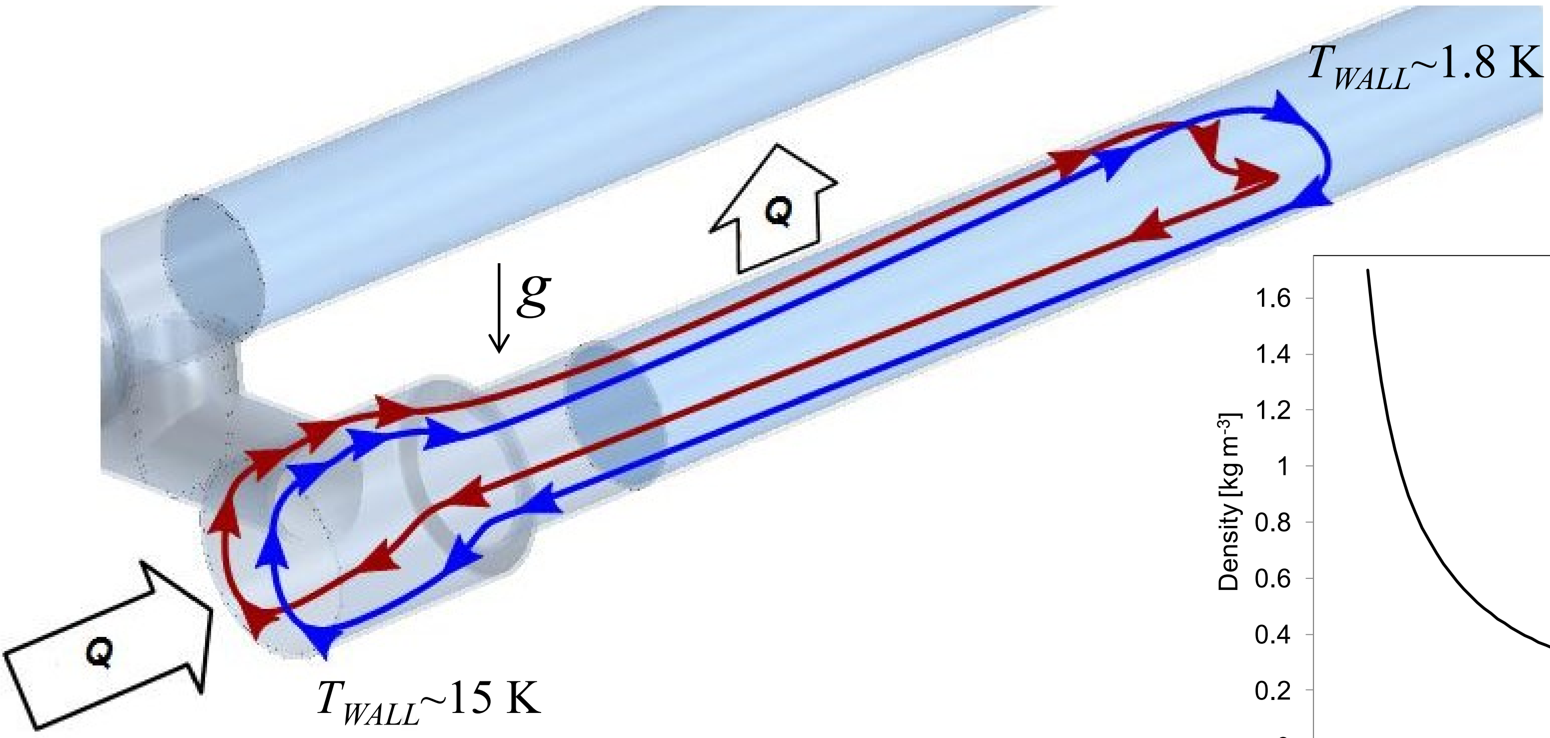
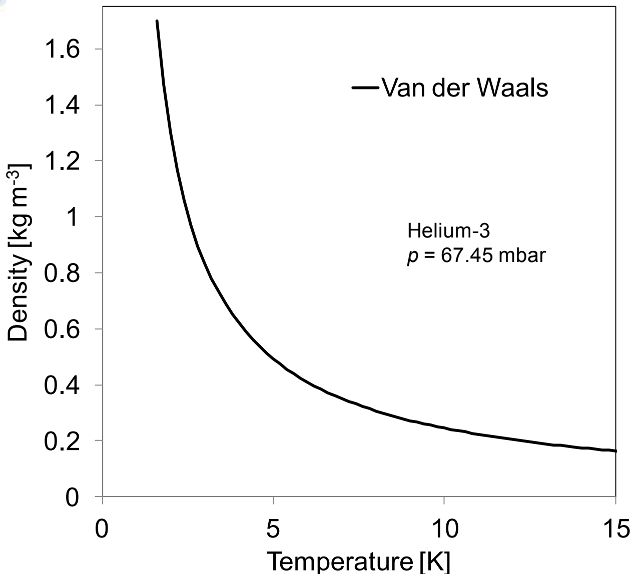
46th CAST Collaboration Meeting 26-28/09/2011

Summary

- What`s happening inside the magnet?
- Boundary conditions improvement:
    - A) Updates on thermal boundary conditions
    - B) Updates on helium-3 properties
- Test cases
- CFD model
- Validation
- Sample results
- Future work

What`s happening?





- ❑ Because of heat conduction from the outer environment through the solid parts, the temperature of the window wall is higher than the cryostat set point.
- ❑ Natural convection occurs at the window and helium-3 is heated up.
- ❑ Hot & light helium enters the cold bore, is cooled down, falls to the bottom of the cold bore and comes back to the window.
- ❑ The heat entering the fluid at the window is given back to the cryostat at the cold bore.
- ❑ The phenomenon is due to the huge dependence of density on temperature.

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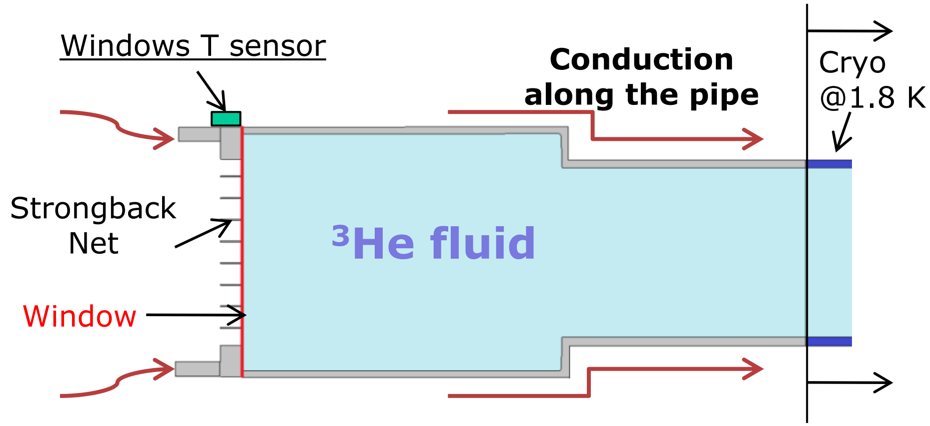
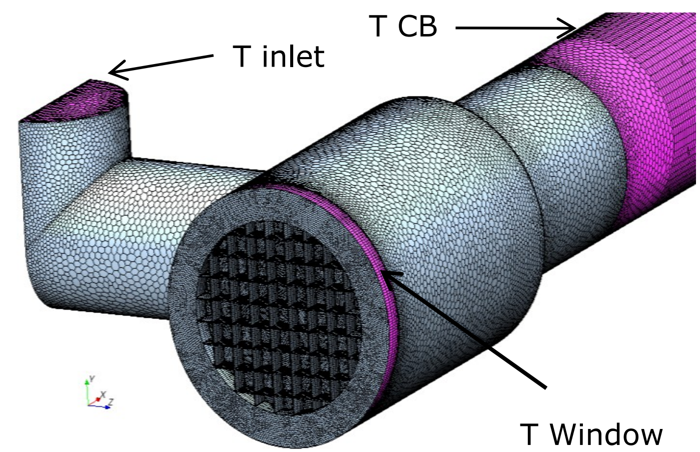
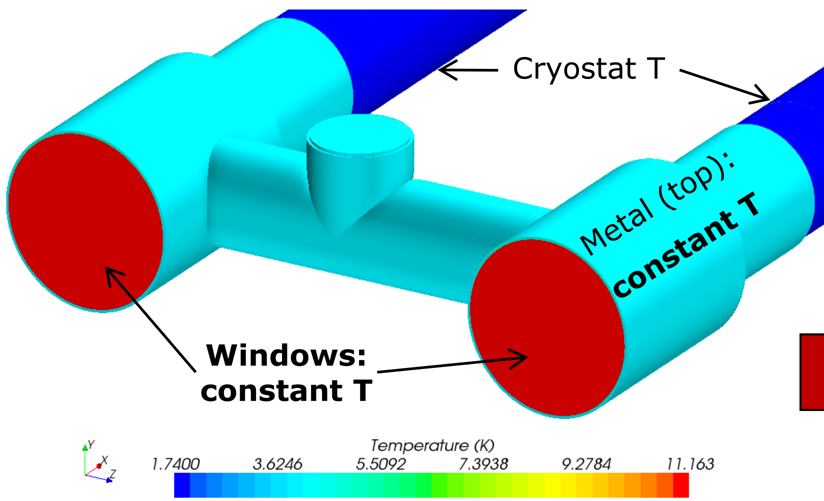
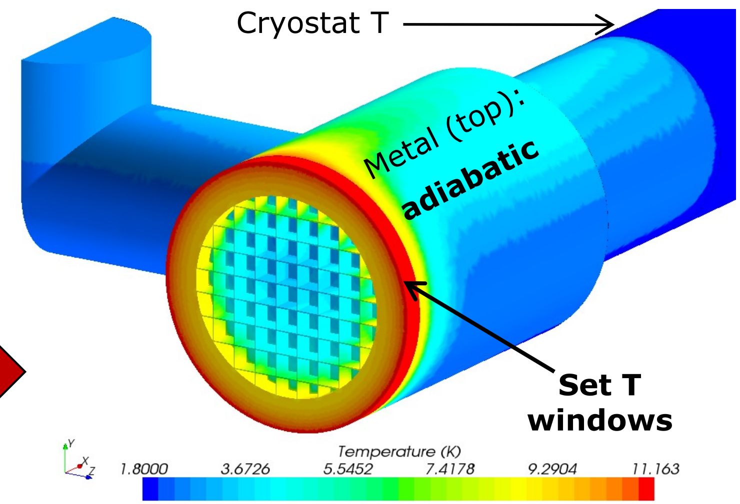
Updates on thermal boundary conditions





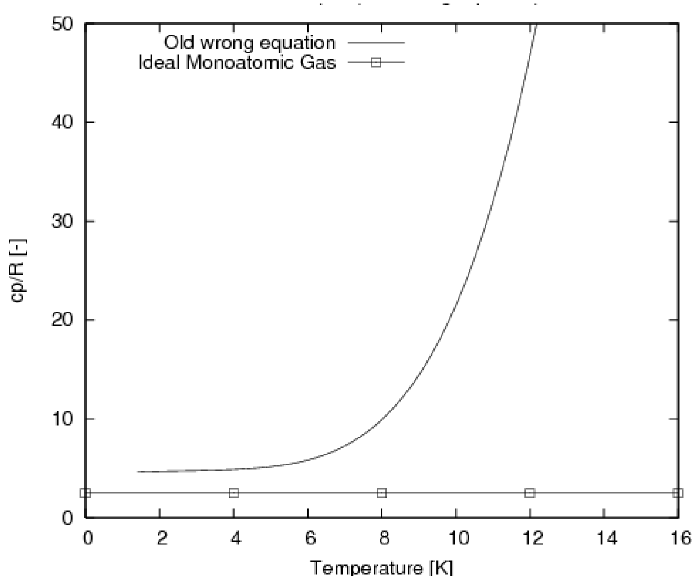


Old Boundary Conditions

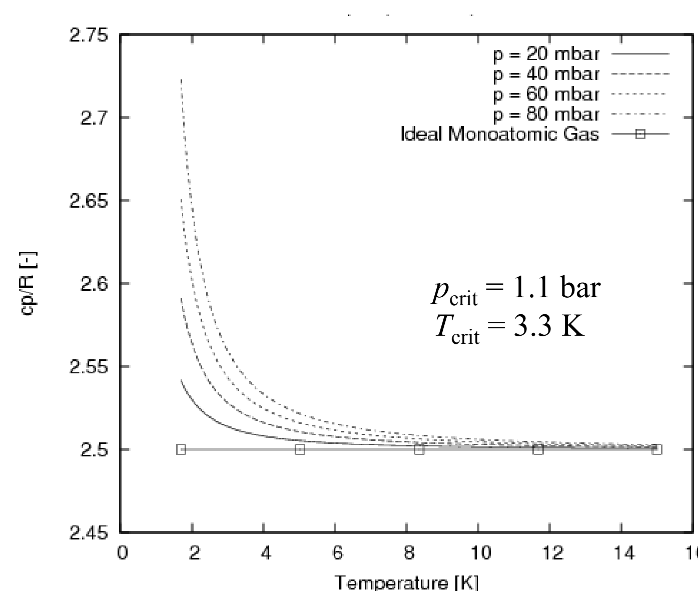


Revised Model

Updates on Helium-3 properties

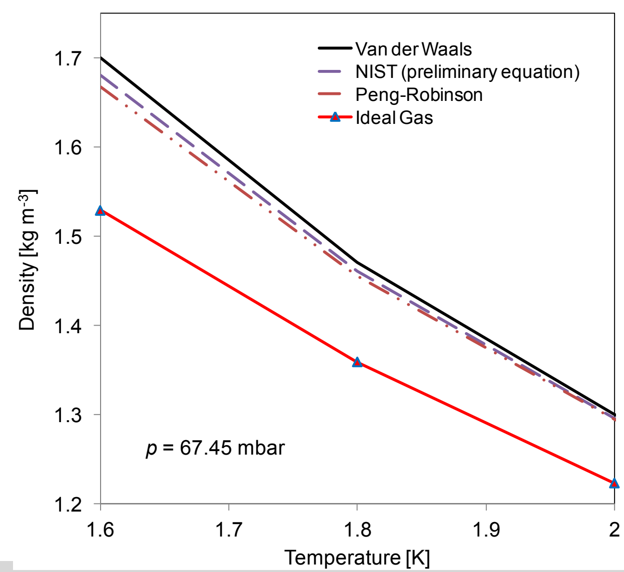


Old WRONG c_p



Revised c_p

- The c_p vs T correlation provided to the CFD Team was wrong (data reduced from Huang Y., Chen G., Arp V., Debye equation of state for fluid helium-3, Journal of Chemical Physics 125, 054505 (2006)).
- The revised c_p used in the CFD simulations is computed by means of a preliminary Helmholtz equation of state for Helium-3 of Lemmon E.W. (2002) [REFPROP NIST, Boulder, CO, USA].



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Test cases

- ❑ **Steady-state**
- ❑ **Horizontal position**

"Cold windows":

Pressure [mbar]	T_cold bore [K]	T_WF1 [K]	T_WF2 [K]	T_WR1 [K]
43.65	1.73	20.0	18.3	13.2
67.50	1.73	19.5	17.8	11.5
83.39	1.76	19.0	16.5	11.2
97.60	1.73	18.5	17.3	10.4

"Hot windows":

Pressure [mbar]	T_cold bore [K]	Tw_MFB1 [K]	Tw_MFB2 [K]	Tw_MRB1 [K]	Tw_MRB2 [K]
14.35	1.80	63.5	70.0	64.5	66.5
26.40	1.85	68.5	72.5	68.7	72.1
37.10	1.80	61.8	64.3	60.6	64.8

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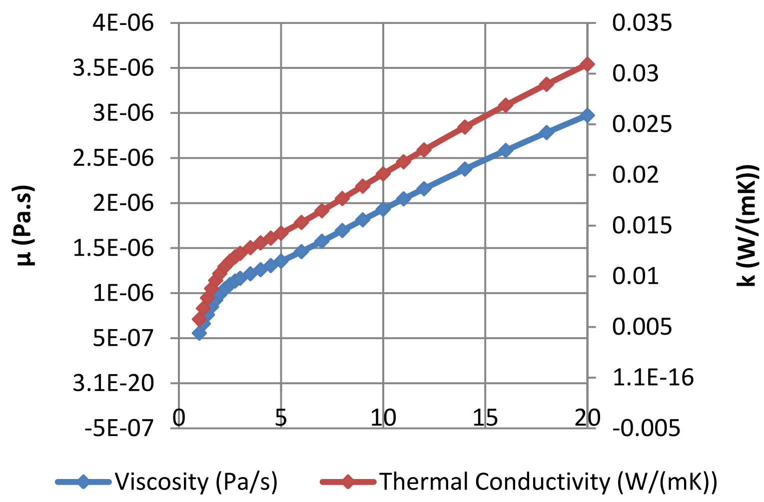
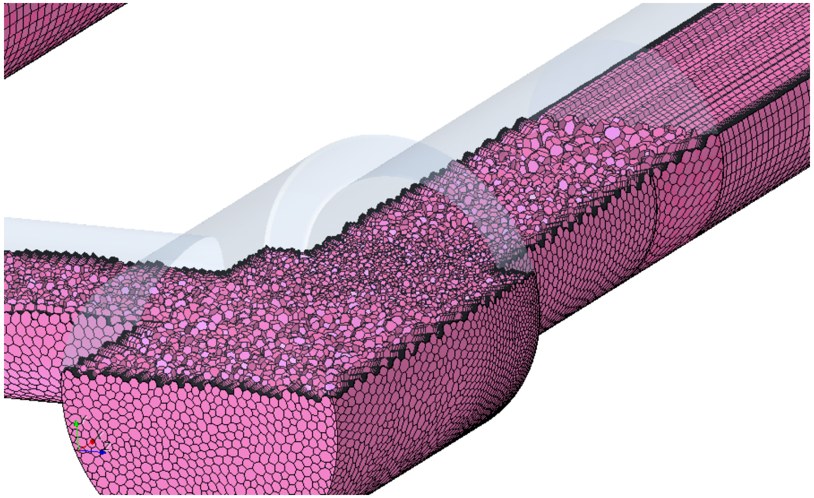
CFD Model

- ❑ Heat conduction occurs in the wall.
- ❑ Natural convection problem, strong coupling with energy equation.
- ❑ Turbulence must be taken into account.
- ❑ Strong dependence of density, viscosity, c_p and conductivity on temperature.
- ❑ High accuracy is required.



- ❑ Solid wall is solved together with fluid.
- ❑ Coupled solver (i.e. energy and Navier Stokes equations are solved together).
- ❑ Turbulence model: low-Re k-ω SST without wall function.
- ❑ Mesh size ~ 9 10^6 cells.



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Validation

“Cold windows”:

Pressure [mbar]	Experimental mass [mol]	CFD mass [mol]	Deviation [%]
43.65	9.49	9.54	0.5
67.50	15.18	15.28	0.6
83.39	18.89	18.91	0.1
97.60	23.11	23.19	0.3

“Hot windows”:

Pressure [mbar]	Experimental mass [mol]	CFD mass [mol]	Deviation [%]
14.35	2.78	2.81	0.9
26.40	4.98	5.04	1.3
37.10	7.37	7.33	-0.6

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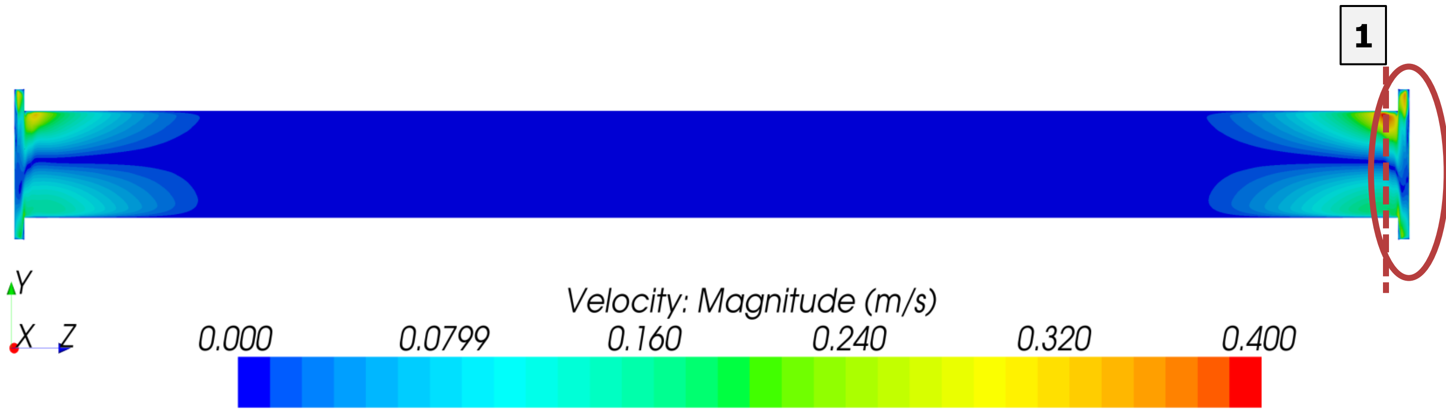
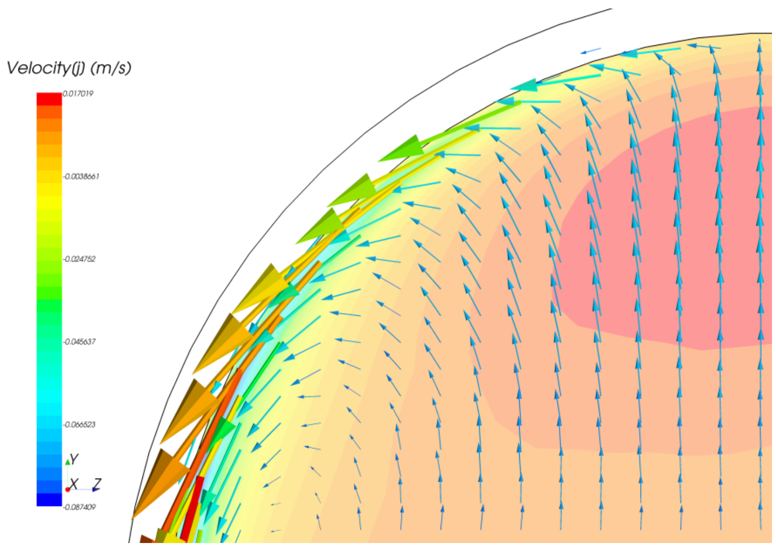
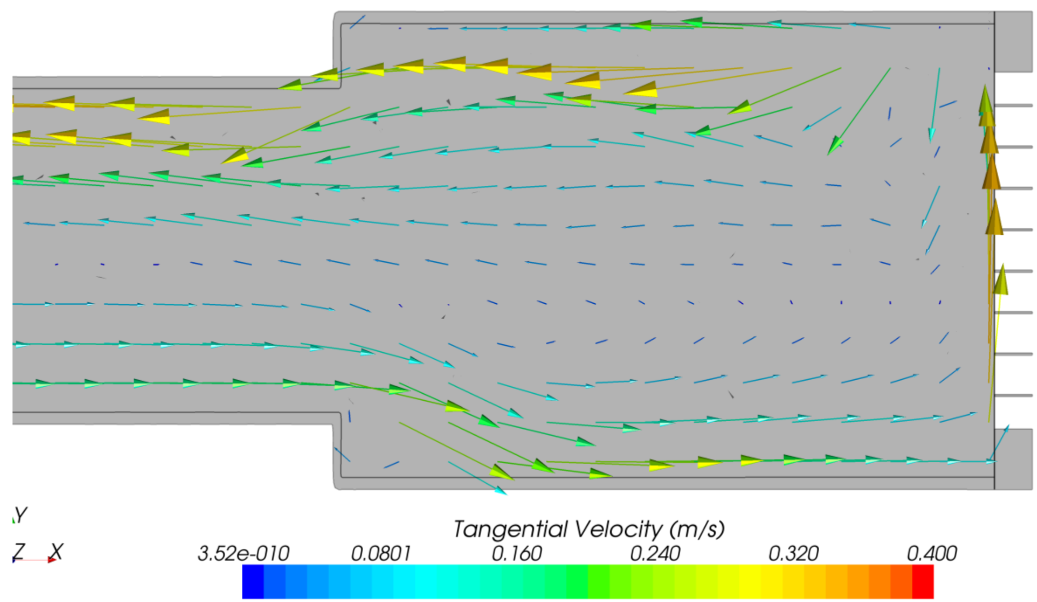
Velocity distribution (p = 43 mbar)



V (magnitude) in a Section along CB (scaled in axial direction)

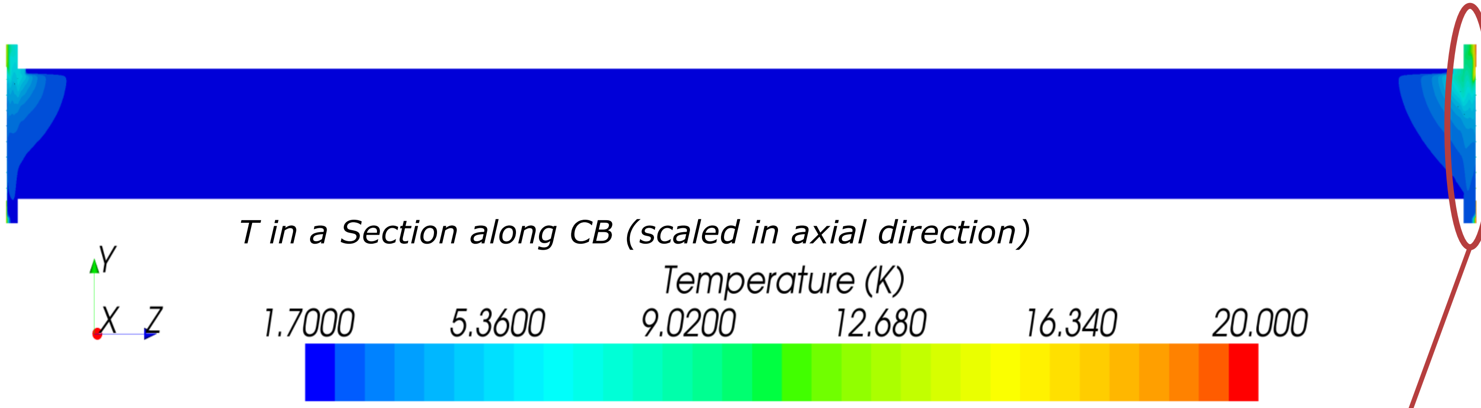


Velocity vectors in transversal CB pipe section (1) near MFB.

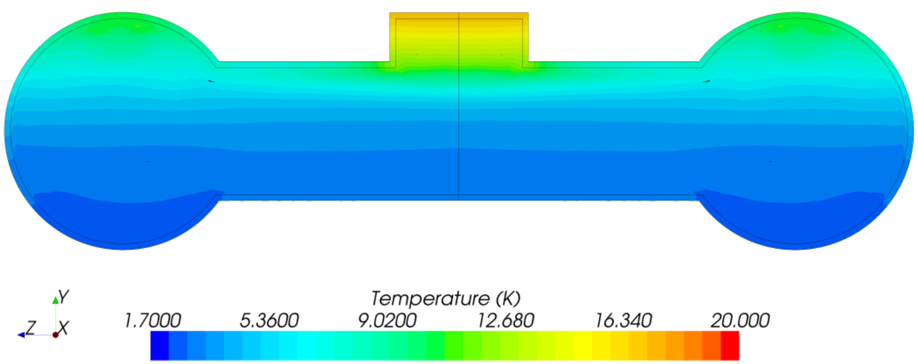


Velocity vectors magnitude. MFB detail.

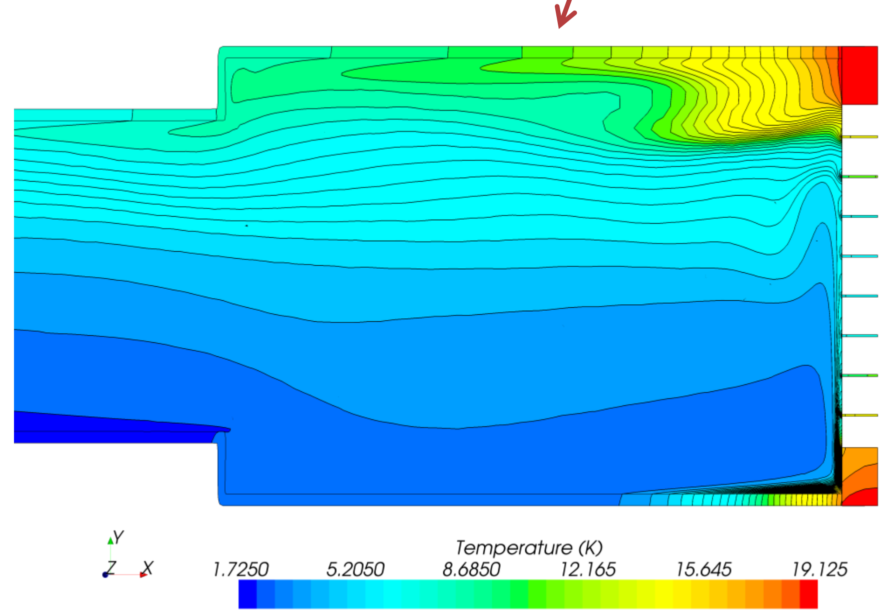
Temperature distribution (p = 43 mbar)



T in a Section along CB (scaled in axial direction)

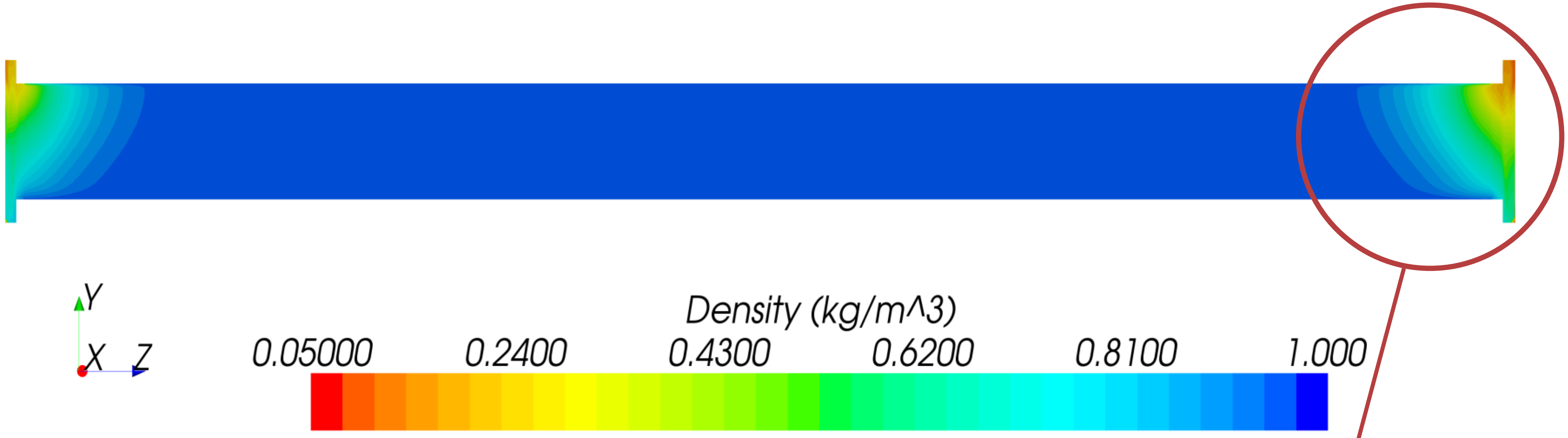


MRB temperature section.

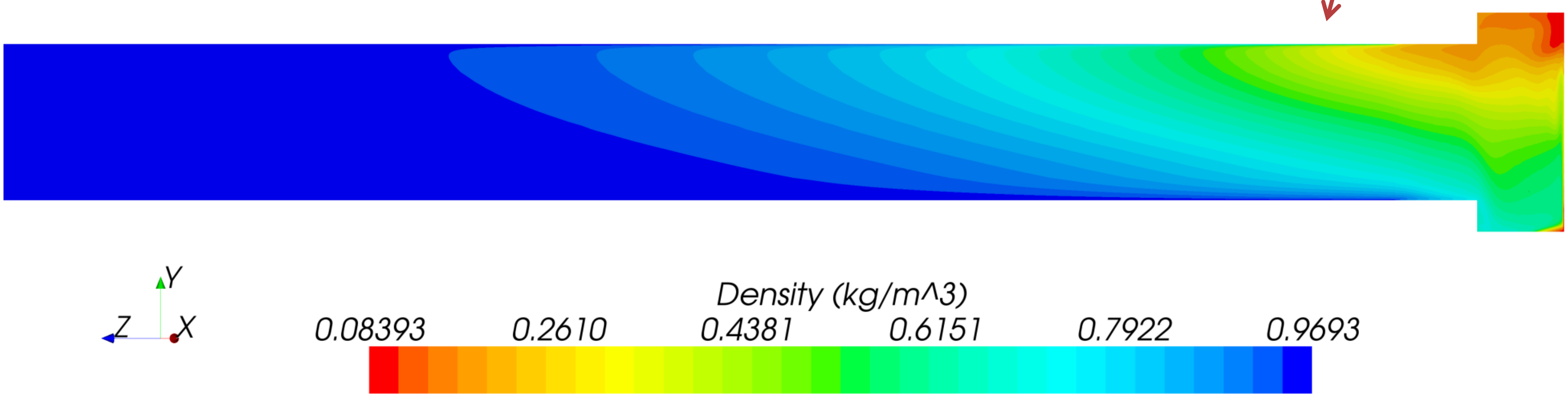


MFB temperature detail.

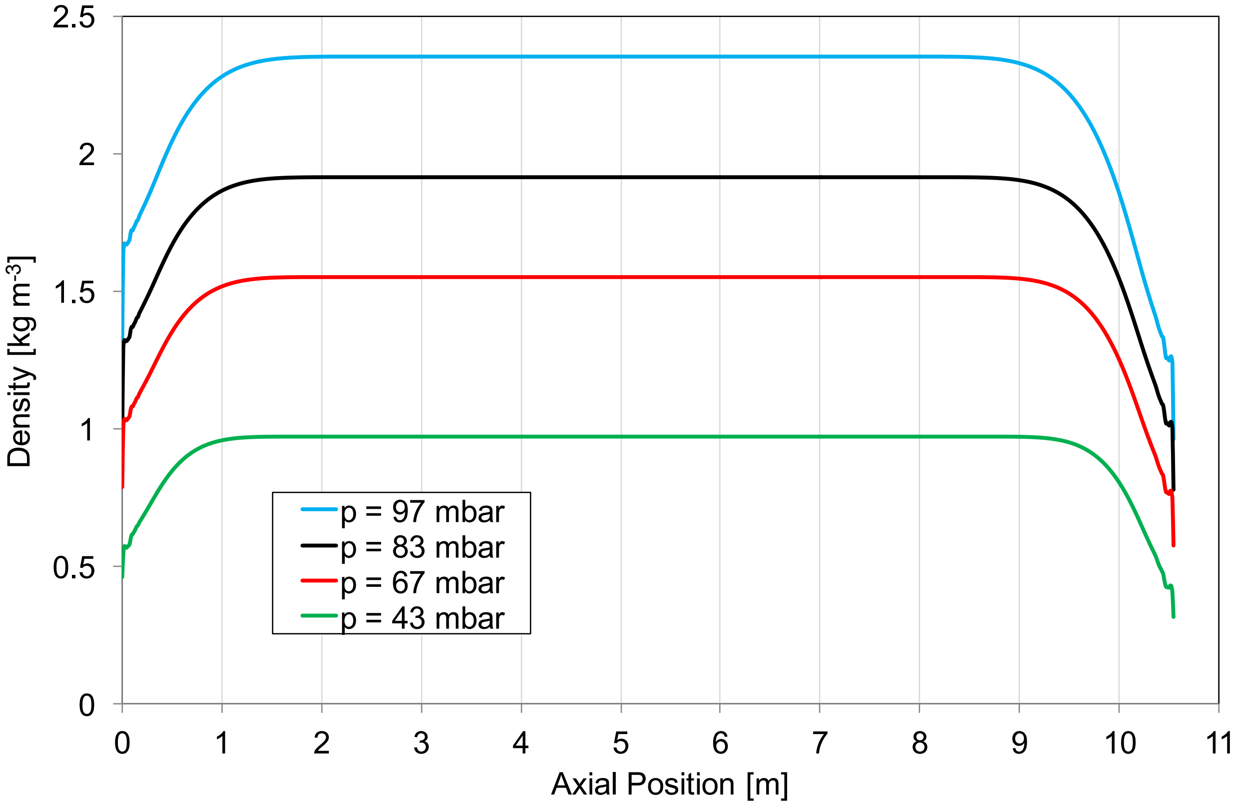
Density distribution (p = 43 mbar)

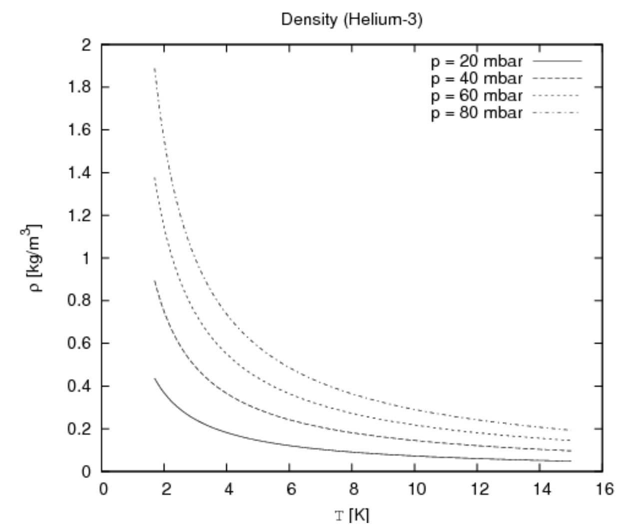


Section along CB (scaled in axial direction)



Influence of pressure





- ❑ Natural convection is due to the dependence of density on temperature.
- ❑ At higher pressure the density change is larger.

- ❑ At higher pressure the natural-convection phenomenon is stronger and the region with non-uniform density is wider.

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Future Work

- Transient simulations for the magnet tilting process are needed.
- The present computational approach is too demanding to perform a transient simulation for the tilting magnet case (1~2 weeks to get convergence for steady-state simulations).

- A "lighter" computational approach will be tested for the steady-state horizontal magnet case:

  -) segregated solver instead of coupled solver.

  -) lower number of cells.

- If possible, the "light model" will be used to solve the unsteady tilting case.

Thank you