FERMILAB
Accelerator Division Cryogenic Department
PARTI Student Meeting
The Final Report

Thermal analysis of a sub-atmospheric bayonet

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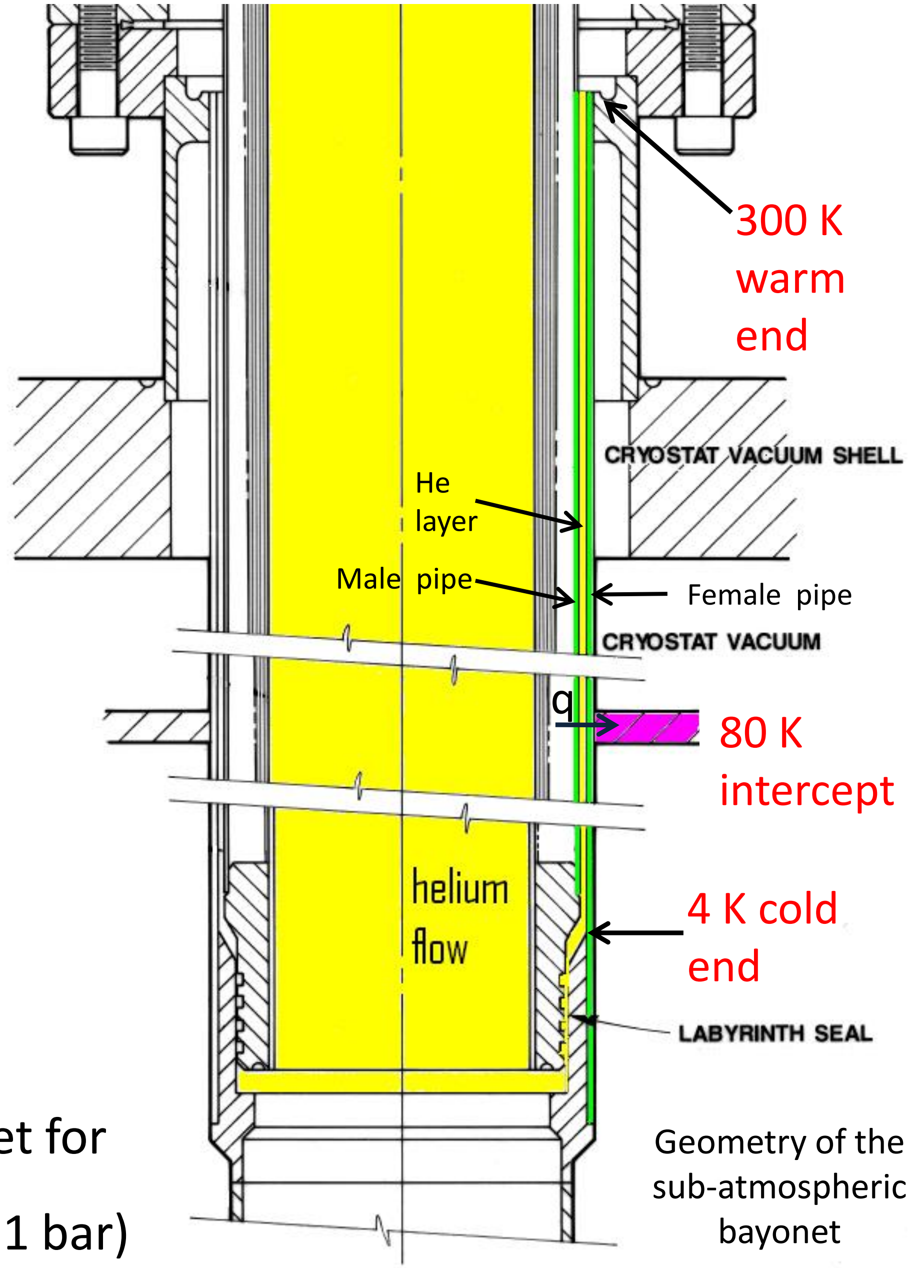
Problem

Other system(CEBAF and SNS) have identified that the sub-atmospheric bayonet has significant thermal inefficiencies due to ineffective thermal intercepts.

They suggested that it is the poor intercepting of the male bayonet due to poor helium thermal conductivity
between the female and male bayonets.

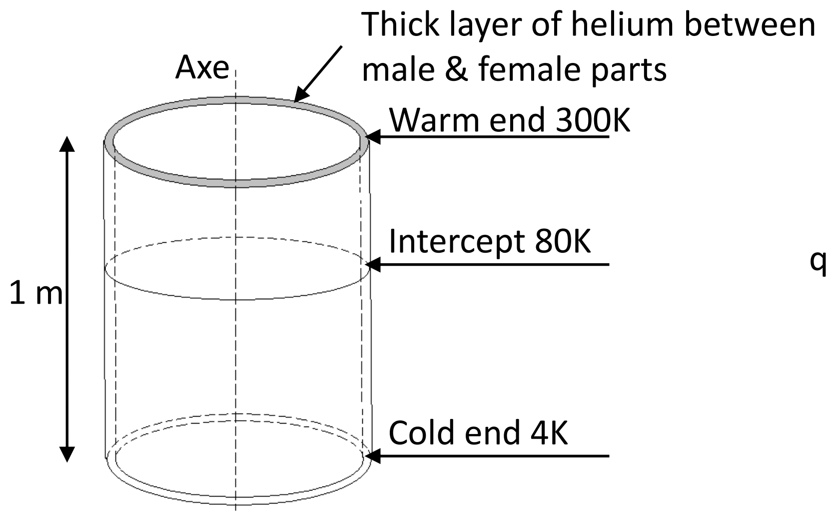
My task is:

•Thermal analysis of cryogenic bayonet for two different pressures (P=1 and 0.031 bar)



Geometry of the sub-atmospheric bayonet

Model description



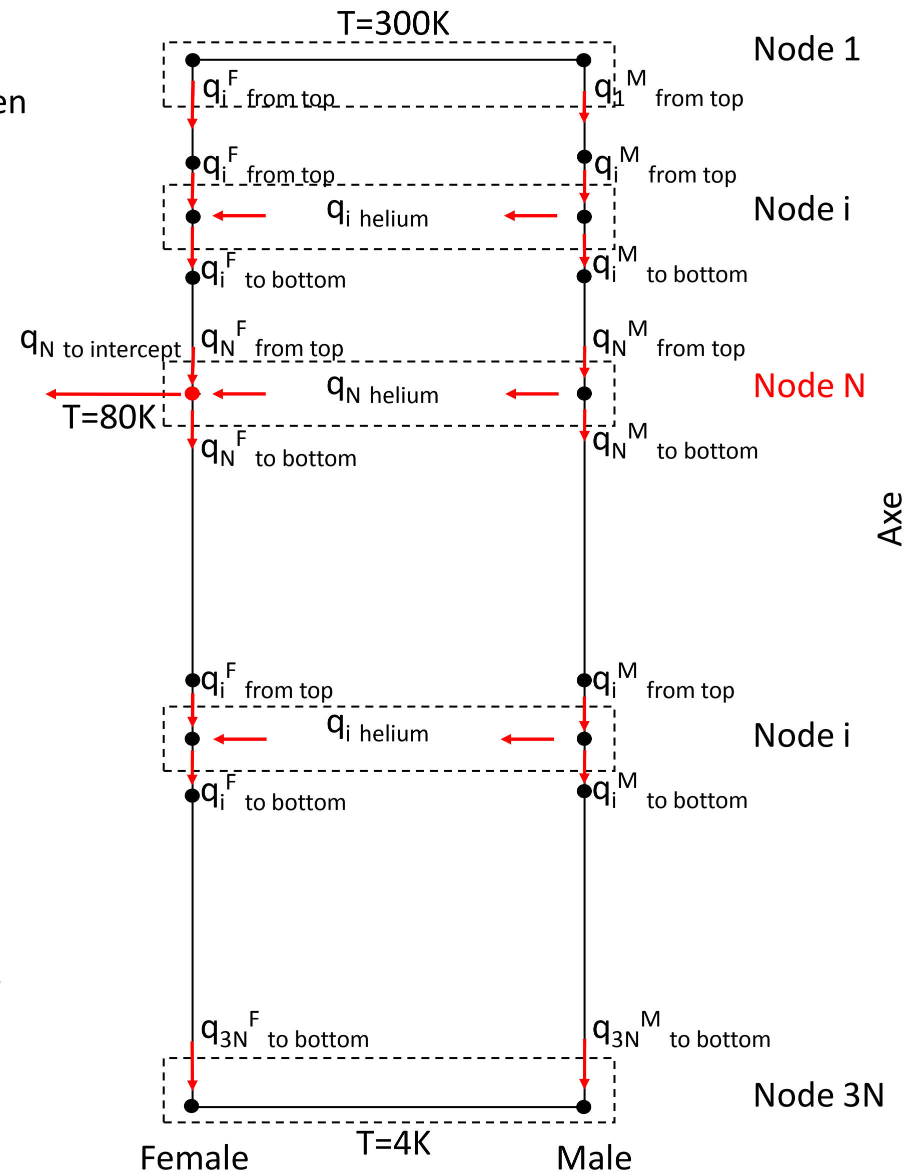
Geometry of the bayonet model

We consider only gas conductive mechanism of heat transfer between bayonet's walls using Fourier's law:

$$\dot{q} = -k\frac{\partial T}{\partial x}$$

where is the heat flux in the x-direction and k is the thermal conductivity of the stagnant gas.

System of linear equations were solved in EES (Engineering Equation Solver)*



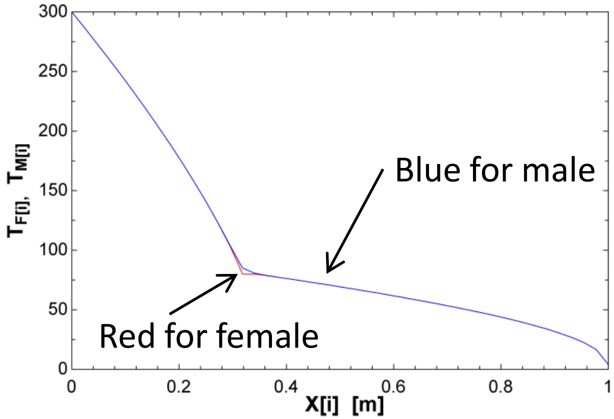
Calculating scheme

* Commercial software package http://www.fchart.com/ees/

Models results: temperature profile of male(blue) and female (red)

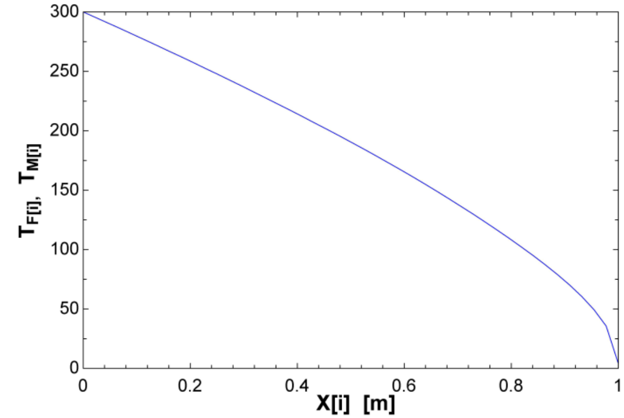
Sub-atmospheric bayonet: P_{He}=0.031 bar

With intercept



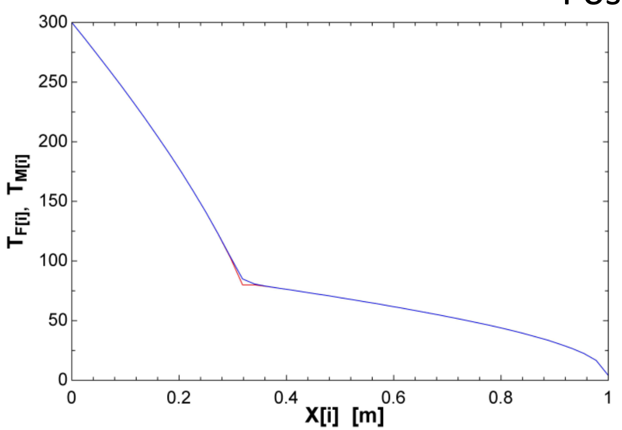
q_bayonet = 0.33 [W]

Unintercepted

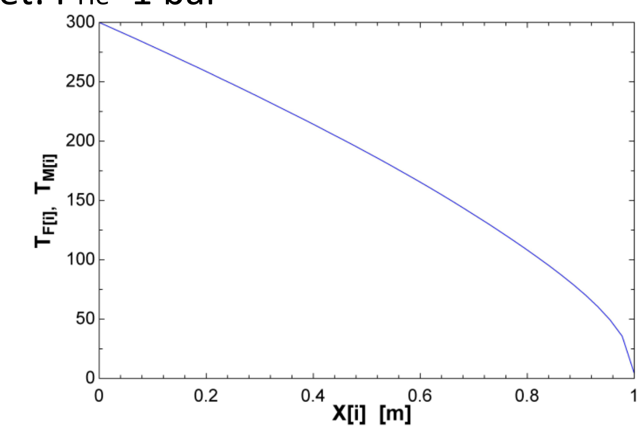


q_bayonet=1.88[W]

Positive pressure bayonet: P_{He}=1 bar

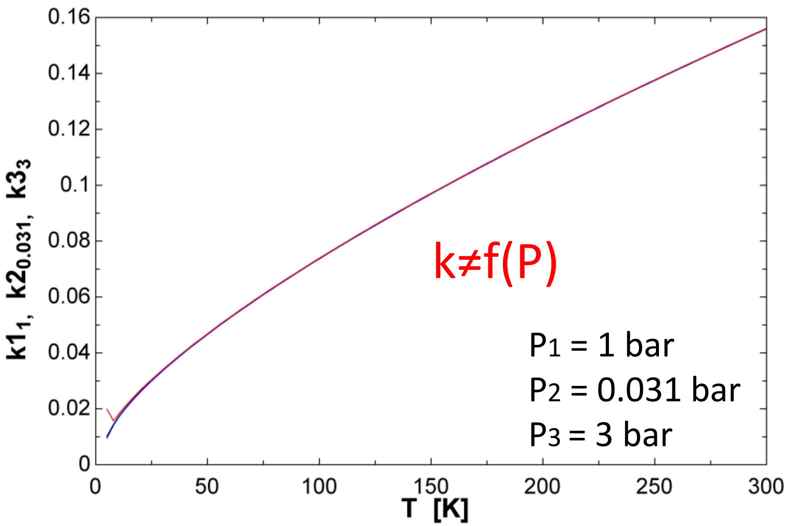


q_bayonet = 0.33 [W]



q_bayonet=1.88[W]

Thermal He conductivity



Thermal conductivity as function of temperature for different pressures

It correctly predicts that the thermal conductivity of an ideal gas is independent of pressure.

Increasing the pressure both increases the number density of the gas and decreases the mean free path.

The ratio of the length between energy carrier interactions to the length scale that characterizes the problem is referred to as the Knudsen number (Kn).

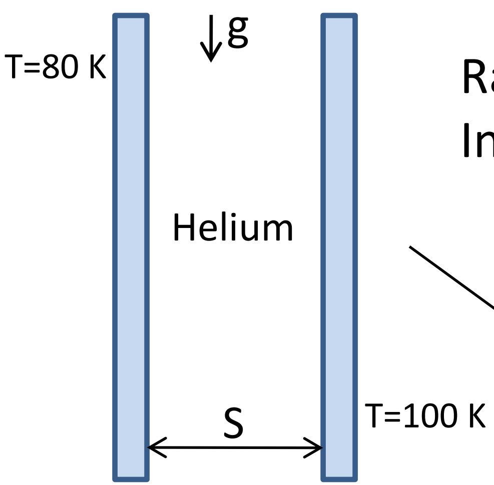
This mean free path is calculated for two value of pressure: $\lambda = \dfrac{k_b T}{\sqrt{2}\pi d^2 P}$ $\quad \lambda_{P=1\text{bar}} \cong 10^{-9}$ $\quad \lambda_{P=0.031\text{bar}} \cong 10^{-7}$

$L \cong 10^{-3}$-distance between male and female

$$\mathrm{Kn} = \frac{\lambda}{\mathrm{L}} = 10^{-4} \div 10^{-6} \ll 1$$

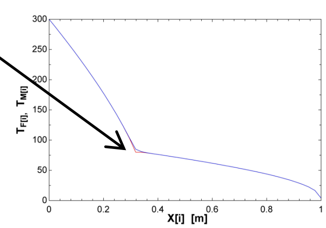
The Knudsen number reports us to have a good condition to use conductive theory.

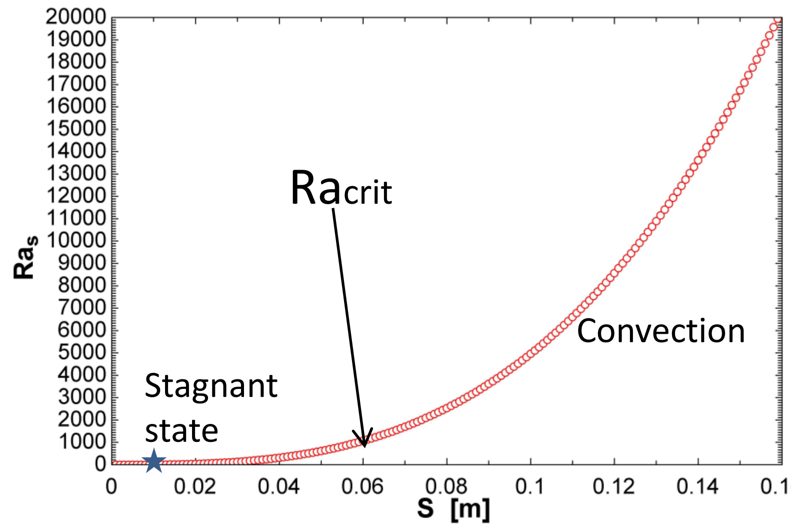
Natural convection



Scheme of convection challenge near intercept

Ra_{crit}





Ra as function of S-distance between plate

The Rayleigh number is defined as the product of the Grasshof number and the Prandtl number*:

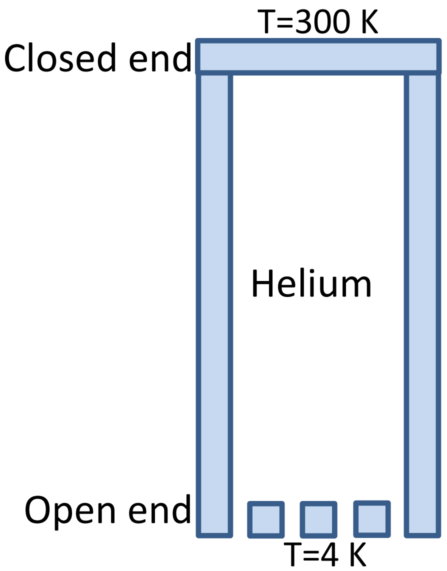
$$Ra_L = Gr_L Re = \frac{gL^3\beta(T_s - T_\infty)}{\nu\alpha}$$

Result demonstrates that convection doesn't exist in our case where $S \cong 0.001m$

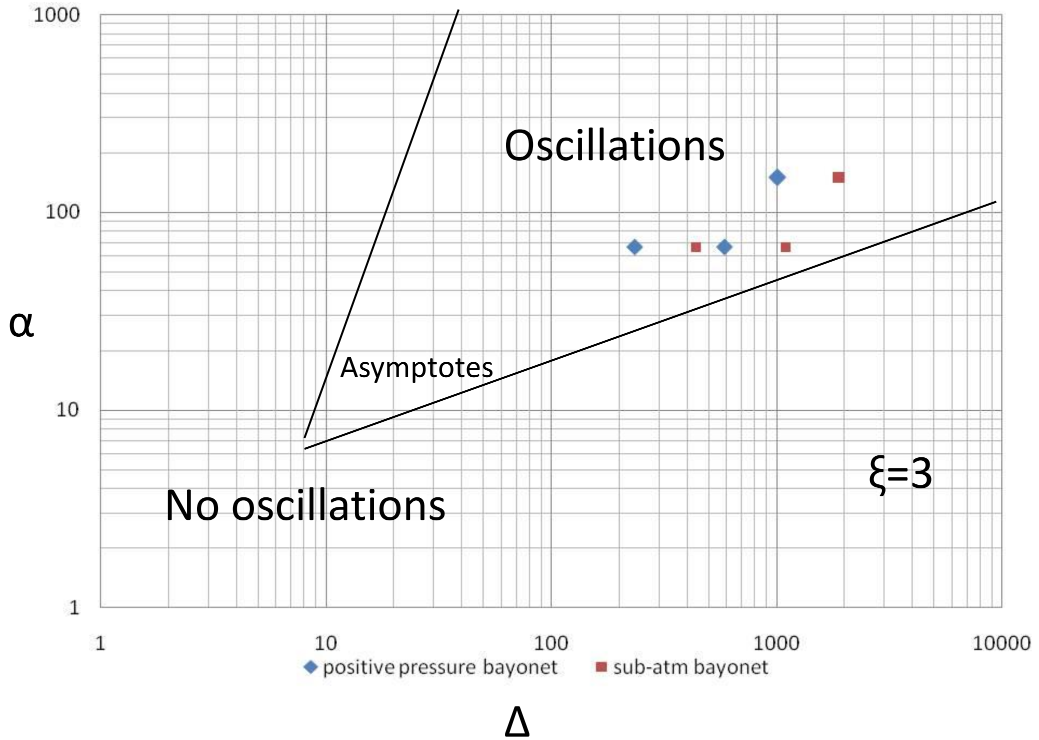
Helium is stagnant

* Heat Transfer by G. Nellis & S. Klein

Thermoacoustic oscillations (TAO)



Scheme of TAO's challenge



Stability area

N. Rott's theory*: a stability curve within which oscillations are predicted.

Three parameters are used: $\xi = \frac{L_c}{L_n}$ $\Delta = \left(\frac{d_0}{2}\right)\left(\frac{a_c}{\nu_c L_c}\right)^{(1/2)}$ $\alpha = \frac{T_n}{T_c}$

* Rott, N., Thermally driven acoustic oscillations, Zamp 24:54 (1973)

We have TAO in our case and it could be cause of the problem. However, labyrinth seals are used at the cold end to help prevent TAO.

Conclusions

- Thermal analysis of sub-atmospheric bayonet showed the same results as a positive pressure bayonet, no poor helium conductivity and intercept works great.
- It is related to the fact that helium conductivity is not dependent on pressure. Helium is ideal gas in our conditions.
- Different possible mechanisms for lose of heat are checked (natural convection and thermoacoustic oscillations)
- One possible reason of a problem with lose a heat may be no effective labyrinth seal

Thanks for everything!