EVOLVE

Investigations on Capillary Cooling of the first wall

Preliminary results

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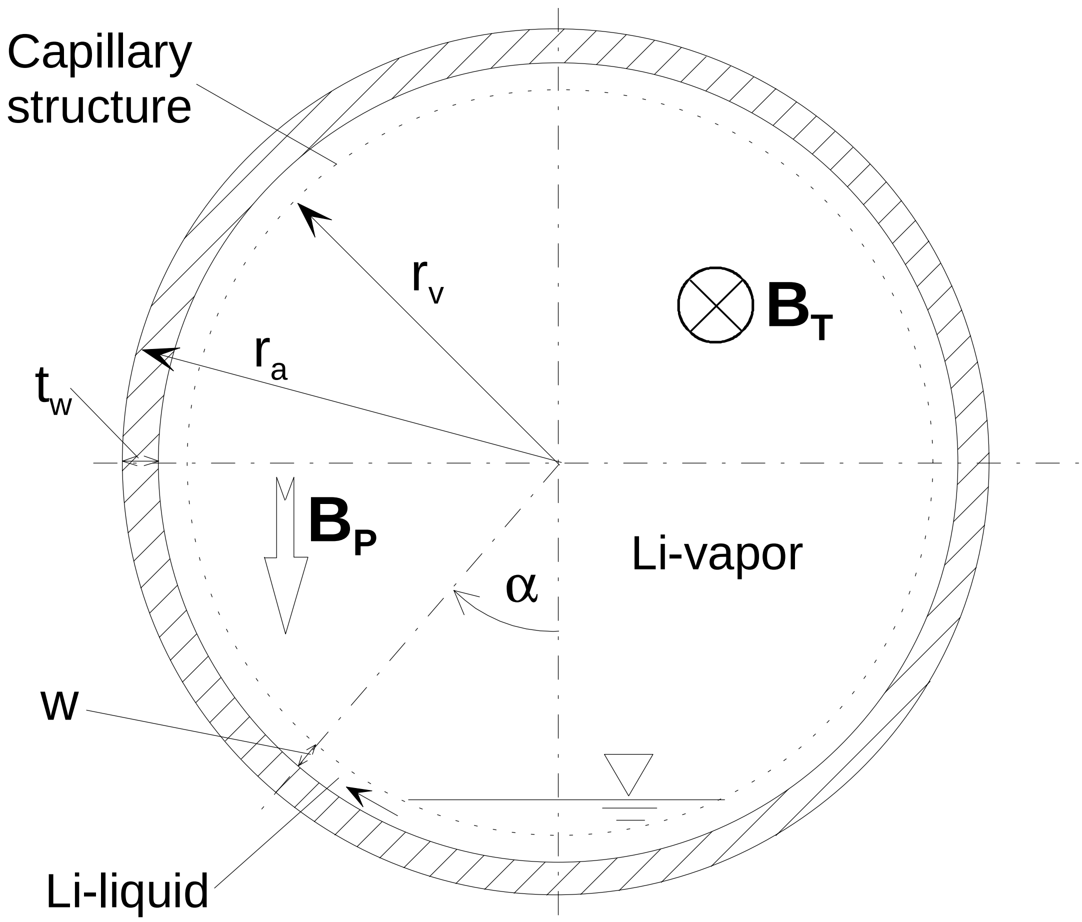
EVOLVE–Concept: Capillary Cooling

The model:

- Feeding the liquid lithium through an azimutal gap of the width w
- Evaporation and pumping of the liquid lithium in a capillary of the diameter d_C.



Simplifying assumptions and approximations:

- The toroidal field is exactly aligned with the tube (gap).
- The magnetic field perpendicular to the feeding gap $B_\perp = B_{P*} \cos\alpha$ where $B_P = 1/10\ B_T$.
- For pressure drop calculations $r_v = r_a$

Δp_C = Capillary pressure head

Δp_{H1} = Hydrostatic pressure head of the liquid

Δp_{H2} = Pressure drop of the liquid in the feeding gap

Δp_{H3} = Pressure drop of the liquid in the capillary

Δp_{M1} = MHD pressure drop in the feeding gap due to the poloidal field

Δp_{M2} = MHD pressure drop in the feeding gap due to the toroidal field

Δp_{M3} = MHD pressure drop in the capillary due to the toroidal field

Limiting operation condition:

$$\boldsymbol{\Delta p_C > \Delta p_{H1} + \Delta p_{H2} + \Delta p_{H3} + \Delta p_{M1} + \Delta p_{M2} + \Delta p_{M3}}$$

Choosen parameters:

Outer tube radius	r_a	= 0.03	m
Tube length	l_{ax}	= 3.00	m
Surface heat flux	q''_0	= 2.0E+6	W/m^2
Toroidal magnetic field strength	B_T	= 6.0	Tesla
Thickness of the capillary structure	t_c	= 0.5E-3	m
Area fraction of the capillaries	β	= 0.5	

Thermophysical data of lithium [Vargaftik] and tungsten at 1200°C:

Lithium:

Density			
Liquid	ρ_l	= 411	kg/m^3
Vapor	ρ_v	= 2.620E-2	kg/m^3
Viscosity			
Liquid	μ_l	= 0.169E-3	Ns/m^2
Vapor	μ_v	= 150E-7	Ns/m^2

Heat conductivity

Liquid λ_l = 62.1 W/m K (T = 1300K)

Heat of vaporization h = 19.757E+6 Ws/kg

Surface tension σ_c = 0.255 N/m

Electrical conductivity σ_l = 3.03E+6 A/Vm (T = 400°C)

Tungsten

Heat conductivity λ = 22.1 W/m K (T=1400K estim.)

Electrical conductivity σ_l = 2.00E+6 A/Vm (T = 1400°C)

Capillary pressure head:

$\Delta p_C = 2\sigma_c/r_c = 1.02/d_c$ N/m²

Hydrostatic pressure:

$\Rightarrow \Delta p_{H1} = \rho_l g 2 r_v = 217.72$ N/m²

Pressure drop of the liquid in the feeding gap:

$\Delta p_{H2}(\alpha) = C_1/w3(\alpha + \sin\alpha)$

For full hight ($\alpha = \Pi$) and

$C_1 = (12\mu_l q``_0 r_a^2)/(\rho_l h) = 4.4955E+10$

$\Delta p_{H2}(\Pi) = 1.4123E\text{-}9 / w^3$ N/m²

Pressure drop of the liquid in the capillary:

For $r_a \cong r_v$ and the length of the capillar $l_c \cong t_c$

$\Rightarrow \Delta p_{H3} = (64\, \mu_l q``_0 t_c)/ (\Pi\, d_c^2 \rho_l h \beta) = 8.480E\text{-}10 / d_c^2$

MHD pressure drop in the feeding gap due to the poloidal field:

$$\Delta p_{M1}(\alpha) = C_2 C_3(1/w) [(2r_a - r_v)((1/2)\alpha + (1/4) \sin 2\alpha) + r_v((1/12)\sin 3\alpha + (3/4)\sin\alpha)]$$

with $C_2 = C_w / (1+C_w)$ as a first approximation where

$C_w = (\sigma_w t_w) / (\sigma_l\, 0.5w)$ the corresponding wall conduction ratio

$C_w = (\sigma_w t_w) / (\sigma_l 0.5w) = 3.9604E\text{-}3/w$

$\Rightarrow$ $C_2 = 3.9604E\text{-}3 / (w (1 + 3.9604E\text{-}3/w))$

and $C_3 = (\sigma_l q``_0 r_v B_P^2) / (\rho_l h) = 7.254$

with $r_a \cong r_v$ and for full hight ($\alpha = \Pi$)

$\Delta p_{M1}(\Pi) = C_2 C_3 (1/w) r_a \Pi/2 = 1.354E\text{-}3 / (w^2 (1 + 3.9604E\text{-}3/w))$

MHD pressure drop in the feeding gap due to the toroidal field:

$\Delta p_{M2}(\alpha) = C_4 C_5 (1/w)[2r_a \alpha + r_v (\sin\alpha - \alpha)]$

with

where $C_{w,T} = (\sigma_{w,T} t_{w,T})/(0.5 b_T \sigma_l)$ $t_{w,T} = 0.5E+3$ m choosen

$C_{w,T} = 0.033$ $b_T = 20.0E+3$ m

$\Rightarrow$ $C_4 = 0.032$

and $C_5 = (\sigma_l q``_0 r_v B_T^2) / (\rho_l h) = 725.4$

with $r_a \cong r_v$ and for full hight ($\alpha = \Pi$):

$\Rightarrow$ $\Delta p_{M2}(\Pi) = C_4 C_5 (1/w) r_a \Pi = 2.321 / w$

MHD pressure drop in the capillary due to the toroidal field:

$\Delta p_{M3} = C_6 C_7$

where $C_6 = C_{w3} / (1 + C_{w3})$

$C_{w3} = (\sigma_w / \sigma_l) (t_w / r_c) = 0.66 = \text{const.}$

$C_7 = (\sigma_l q``_0 2r_a B_T^2 l_c) / (\Pi \beta r_v \rho_l h) = 19.00$

With $l_c \cong t_c$

$\Rightarrow$ $\Delta p_{M3} = C_6 C_7 = 12.54$ N/m^2

Maximal superheating of the lithium at the wall:

$T_{Li,w} = (q``_0 w_{eff}) / \lambda + T_s = 3.2206E+4\, w_{eff} + 1473$ K

Where $w_{eff} \cong w + f t_c$ d

$F = f(\lambda_l/\lambda_w) < 1.0$

Results:

Fig. 2 shows the dependance of the capillary pressure head from the capillary diameter d_C and the contributions of the different pressure drops to the total pressure drop of the liquid lithium needed to remove a heat flux of $q"_0$ = 2.0E+6 [W/m^2] from the first wall for the choosen parameters given on page 3 and 5 in dependance of the gap width w. The calculations of the MHD pressure drop are conducted neglecting three-dimensional effects which may happen due to the changing magnetic field size and/or mass flow through within the feeding gap along the flow direction.

As can be seen from Fig. 2 the MHD pressure drop in the feeding gap caused by the toroidal field represents a considerable contribution to the total pressure drop which can only be reduced by reducing the thickness $t_{w,T}$ of wall connecting the capillary structure with the first wall and by increasing the toroidal distance b_T of thes walls.

Fig. 3 shows the capillary pressure head and the total pressure drop as a function of the capillary diameter d_C and of the gap width w respectively. In the figure the dependance of the minimal needed gap width w from the capillary diameter is shown on an example.

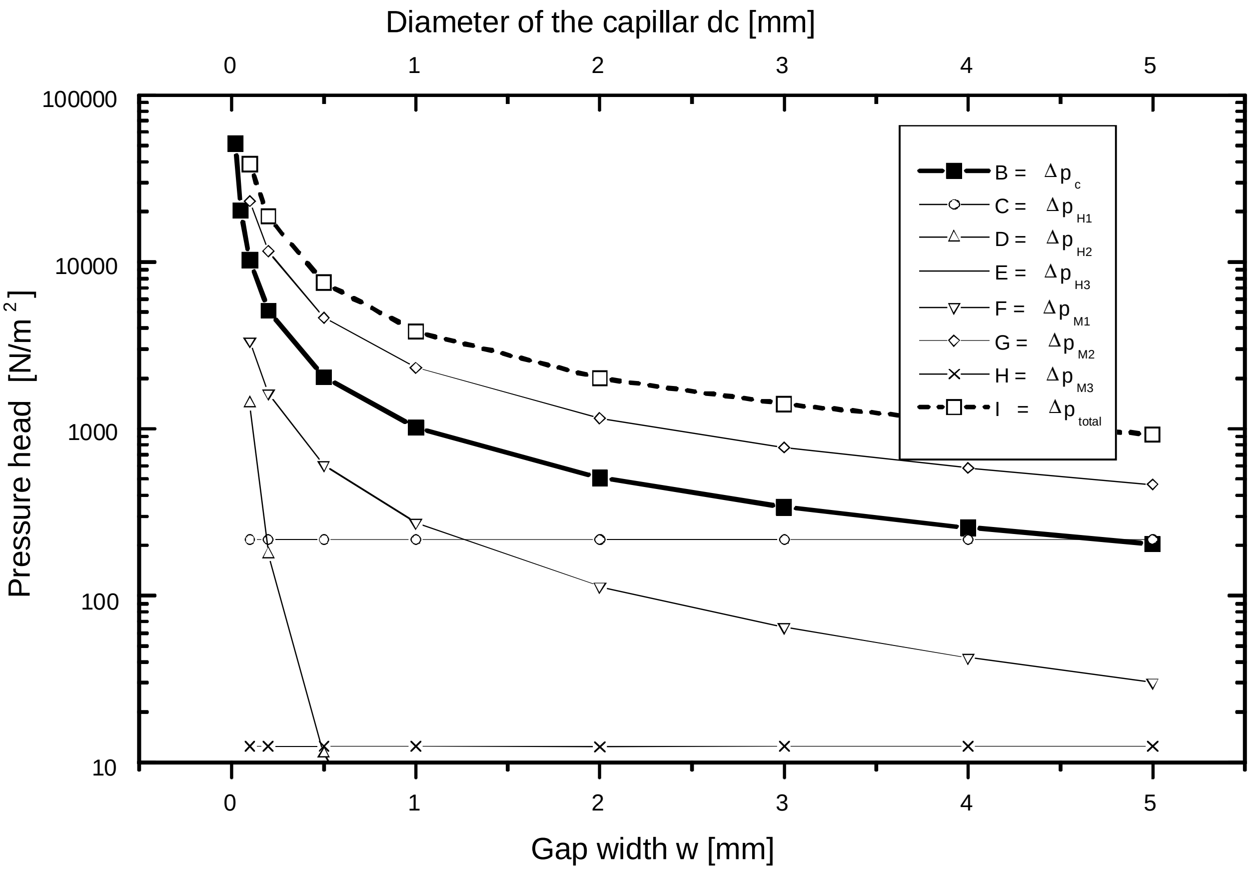


Fig. 2 Capillary pressure head, different pressure losses and the sum of the pressure losses in dependance of the capillary diameter d_C and of the gap width w respectively.

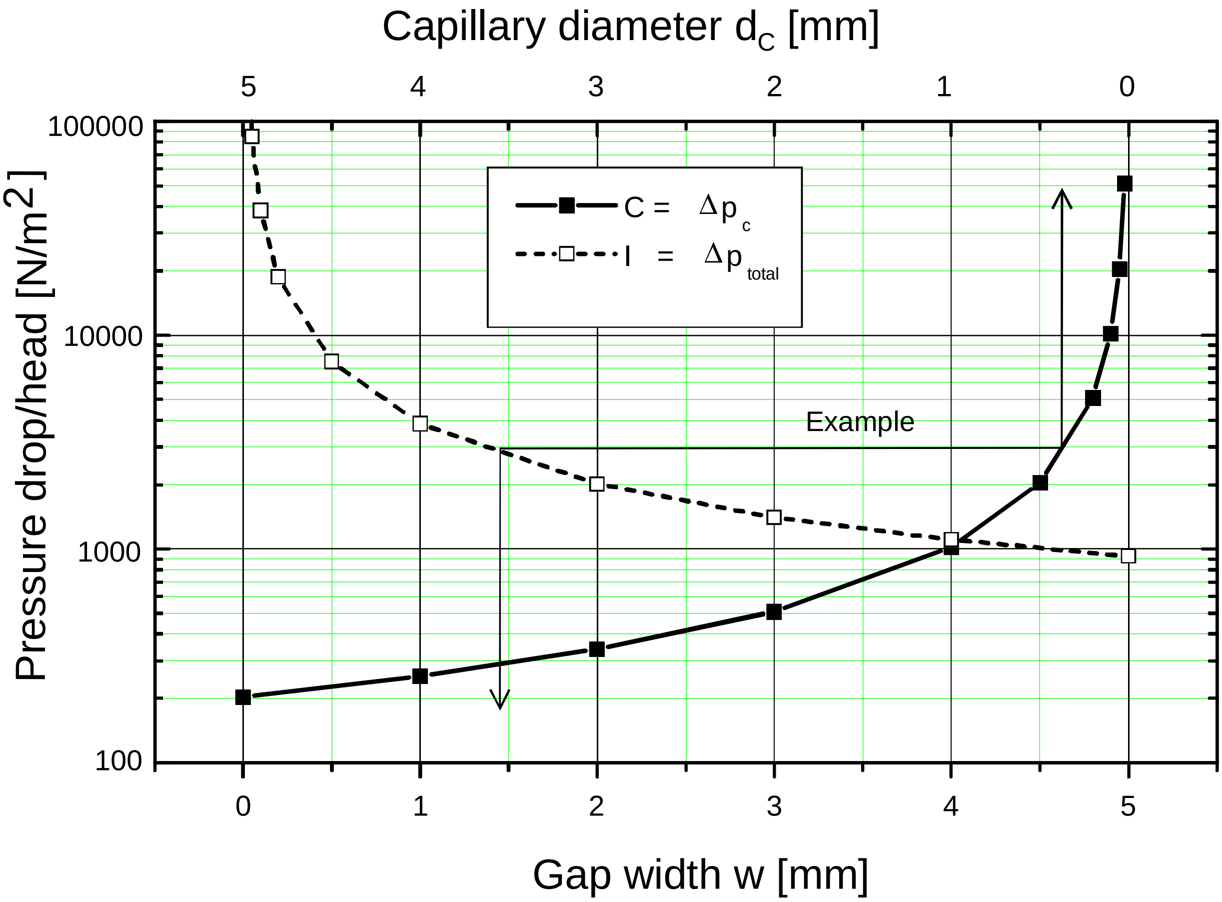


Fig. 3 Capillary pressure head and the total pressure drop in dependance of the capillar diameter d_C and of the gap width w respectively.