BNEN NTH pressure drop exam challenge

- Academic year 2025-2026
- v1.0
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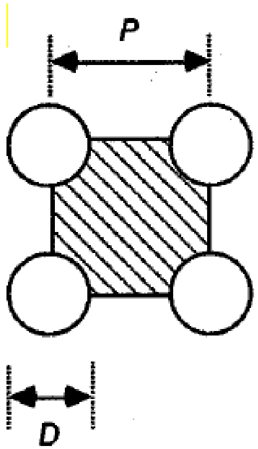
BNEN NTH pressure drop exam challenge

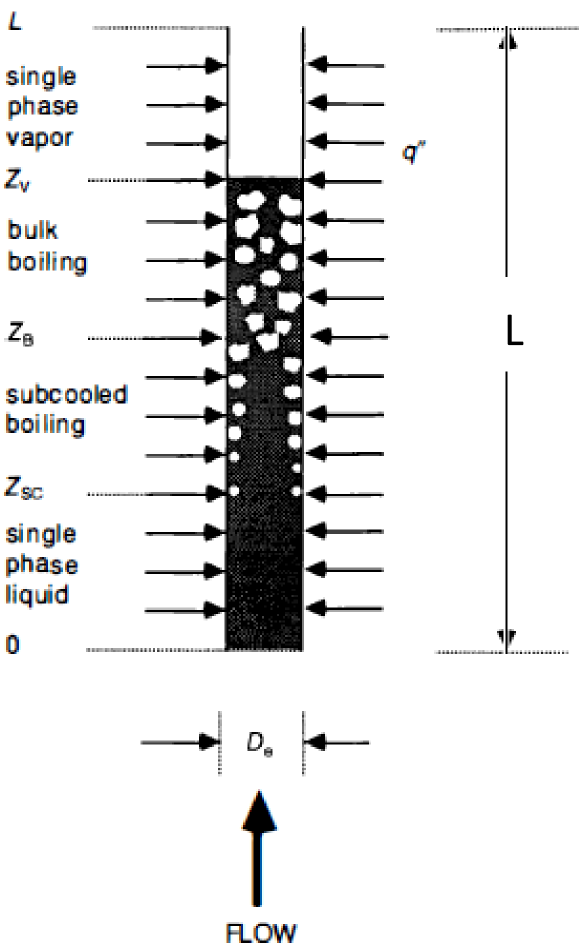
- A typical subchannel in a BWR reactor operates under the following conditions:
  - Up-flow of water
  - Inlet tempeature= $T_{sat}(p_{in}) - 40°C$
  - Inlet pressure = 5500 kPa
  - Heated length
    - $L = 3.1\ m\ thus\ from\ \frac{L}{2} = -1.55\ m\ to\ \frac{L}{2} = 1.55\ m$
  - Rod diameter = 10.3 mm and Pitch = 21.2 mm
  - Relative wall roughness (λ/D_e) = 0.001
  - Average heat flux for one pin = 2.4 MW/m^2
  - Axial heat flux distribution = cosine



- Plot the total pressure drop and its individual components in function of the mass flow rate through the subchannel

BNEN NTH pressure drop exam challenge

SINGLE HEATED CHANNEL: STEADY-STATE ANALYSIS 607



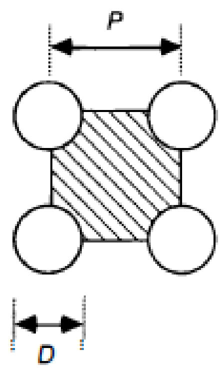


Figure 13-13 Subchannel flow region (left) and cross section (right).

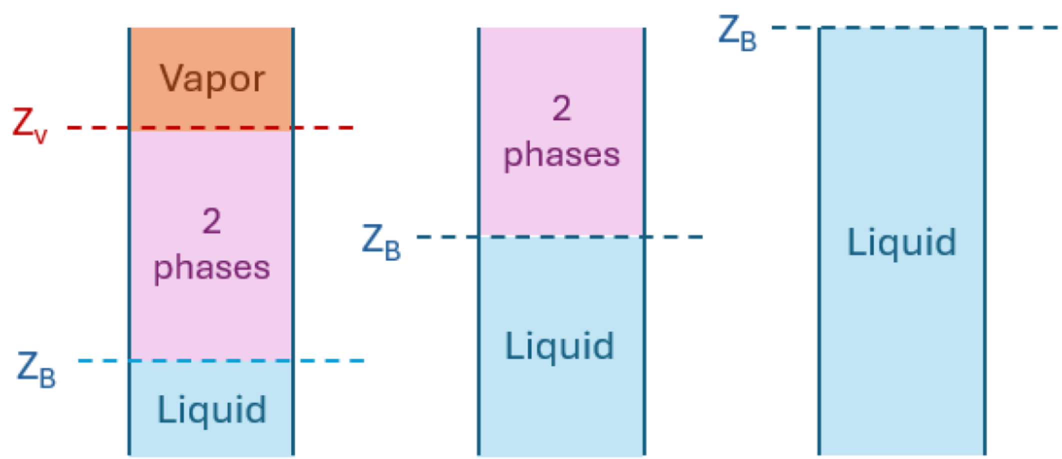


Figure adopted from Brieux and Wlodarski 2024

BNEN NTH pressure drop exam challenge

- Day 3-5: Exam challenge
  - Plot the total pressure drop through the subchannel and its individual components in function of the mass flow rate
    - For the range [0-2.5 kg/s]
    - Use McAdams correlation for the two phase pressure drop and Coolebrook for the monophase pressure drop
    - Assume constant material properties and use the inlet pressure to calculate those for the subcooled region
    - E.g. Four graphs (liquid, two phase, vapour, total) with each three components (acceleration, gravity and friction) - see example 13-4 of Todreas and Kazimi volume 1 old edition
  - Extra
    - Plot z_B and z_V in terms of mass flow
    - Plot equilibrium and flow quality in terms of height for a mass flow of 0,1 kg/s
    - Which parameter can you change in order to (not) have an 'S' curve as shape? Explain why.
    - Use Jones' correlation as alternative for the two phase friction pressure drop (see p. 503 & 611 Todreas and Kazimi vol. 1 old ed.)
  - Report requirements
    - Only report total pressure drop and its individual components in function of the mass flow rate through the subchannel
      - Reporting on extra's = bonus points
      - No reporting of exercises done on day 1-2
    - Focus
      - Assumptions that have been made and where e.g. formulas have been found
      - Explanation on the graph and formulas
      - Correctness of output
      - Lay-out is of minor importance
    - Maximum two students for one report

BNEN NTH pressure drop exam challenge

- Day 1-2: guided exercises as support for the exam challenge
- Day 1: for a mass flow range [0 -> 2.5] kg/s
  - Calculate friction monophase pressure drop through the channel without heating
    - A First do this for a pipe diameter $D = 0.02\ m$ and with McAdams
    - B Then do it for the actual BWR subchannel and with McAdams
    - C Finally, do the same for the actual BWR subchannel and with Coolebrooke
  - Calculate two phase pressure drop through the channel
    - D First assume the inlet equilibrium quality is 0.15 and the channel is adiabatic (no heating)
    - E Then assume the inlet and outlet equilibrium quality are 0 and 0.15 respectively. Thus instead of using a heat flux as input it is assumed that the quality evolves linearly from inlet to outlet.
- Day 2: for a mass flow of 0.1 kg/s
  - A Find axial position where the equilibrium quality is zero:
    - This bulk boiling point (z_B)
    - Assume cosine axial heat distribution neglecting pressure drop for material properties
  - B Find axial position where the flow (dynamic quality) is one
    - This is were we have saturated vapour (z_V)
  - C Extra
    - Find axial position where the flow (dynamic quality) is zero: bubble detachment (z_D)
    - Plot the thermodynamic and flow quality at different heights (-L/2 to L/2) and use Levy's correlation
    - Find the position of maximum wall temperature

Day 1 – guidance for solution

- Numerical modeling
  - Discretization over height versus functions ?
  - Will you use AI ?
- Material properties
  - See next slides

Day 1 – guidance for solution

- Matlab Xsteam (also see example script)

```
%inlet properties

rho_in_L=XSteam('rho_pT',p_in_bar,T_in); %kg/m^3
mu_in_L=XSteam('my_pT',p_in_bar,T_in); %absolute/dynamic Pa s of kg/m/s
Cp_in_L=XSteam('Cp_pT',p_in_bar,T_in)*10^3; %J.kg°C


h_in=XSteam('h_pT',p_in_bar,T_in)*10^3;

% properties at saturation at inlet

rho_satG_in=XSteam('rhoV_p',p_in_bar); %( kg/ m3)
rho_satL_in=XSteam('rhoL_p',p_in_bar); %( kg/ m3)
```

!!

- What is inlet temperature?

Day 1 – guidance for solution

Python IAPWS97

[MPa]

```
from iapws import IAPWS97 # requires pip install iapws numpy matplotlib
Tsat_in = IAPWS97(P=Pin_MPa, x=0).T  # saturation temperature at inlet pressure
```

```
# fluid properties at inlet
fluid = IAPWS97(P=P, T=Tin+273.15)
rho = fluid.rho
h = fluid.h
```

[K]

[kJ/kg] !!

Python XSteam

```
from pyXSteam.XSteam import XSteam
steamTable  = XSteam(XSteam.UNIT_SYSTEM_MKS) # m/kg/sec/°C/bar/W
```

```
Xsteam Install run the following in the console of for instance spyder
'python3 setup.py install'
OR
'pip install XSteamPython'
```

Day 1 – guidance for solution

- Python XSteam

```
rho=steamTable.rho_pt(p_bar,T_C)        #( kg/ m3)
mu=steamTable.my_pt(p_bar,T_C)          # absolute/dynamic Pa.s
Cp=steamTable.Cp_pt(p_bar,T_C)*1000     # % J/(kg*K)
k=steamTable.tc_pt(p_bar,T_C)           # W/mK
```

!!

```
h      =steamTable.h_pt(p_bar,T_C)*1000      # J/kg

perties at saturation
Tsat_C  =steamTable.tsat_p(p_bar)   # °C
st_w    =steamTable.st_p(p_bar)     # N/m
rho_G   =steamTable.rhoV_p(p_bar)   # ( kg/ m3)
rho_L   =steamTable.rhoL_p(p_bar)    # ( kg/ m3)
h_sat_L =steamTable.hL_p(p_bar)*1000 # J/kg
h_sat_G =steamTable.hV_p(p_bar)*1000 # J/kg
```

Approach to get viscosity of saturated liquid

```
mu_satL    =steamTable.my_pt(p_bar,self.Tsat_C*.99)   # absolute/dynamic Pa s of kg/m/s
muV=XSteam('my_pT',pLibbar,TsatLib*.101); %absolute/dynamic
k_satL     =steamTable.tcL_p(p_bar)                # W/(m °C)
Cp_satL    =steamTable.CpL_t(p_bar)*1000          # J/(kg*K)
```

Day 1A – guidance for solution

- Example code
  - Friction factor in terms of Re
  - Mass flow range in vector
  - Pressure drop vector for each discrete mass flow point
  - Put in figure together with other vectors

```
McAdams_f=@(Re) 0.184*Re^(-0.2);

% delP=rho K V^2/2+ rho f L/D *V^2/2
% mass flow
M_F=[0.01:0.01:2.5]; %kg/s
for i=1:1:length(M_F)
    Vpipe=M_F(i)/Aflow/rho_in_L;
    Repipe=rho_in_L*Vpipe*Dh/mu_in_L;
    if Repipe<2100
        % laminar
        fpipe=64/Repipe;
    else
        % turbulent via McAdams
        fpipe=McAdams_f(Repipe);
    end

    DEL_P_mono_pipe(i)=rho_in_L* fpipe*L/Dh*Vpipe^2/2;

end
```

```
figure
axes('FontSize',14)
hold on
box on
grid on
plot(M_F,DEL_P_mono_pipe/10^5,'LineWidth',3)
plot(M_F,DEL_P_mono_BWR_Mc/10^5,':','color',[0 0.5 0],'LineWidth',3)
plot(M_F,DEL_P_mono_BWR_Co/10^5,'--','LineWidth',3)

xlabel(['Mass Flow [kg/s]'])
ylabel(['Pressure drop [bar]'])
legend('pipe McAdams','BWR McAdams','BWR Coole')
```

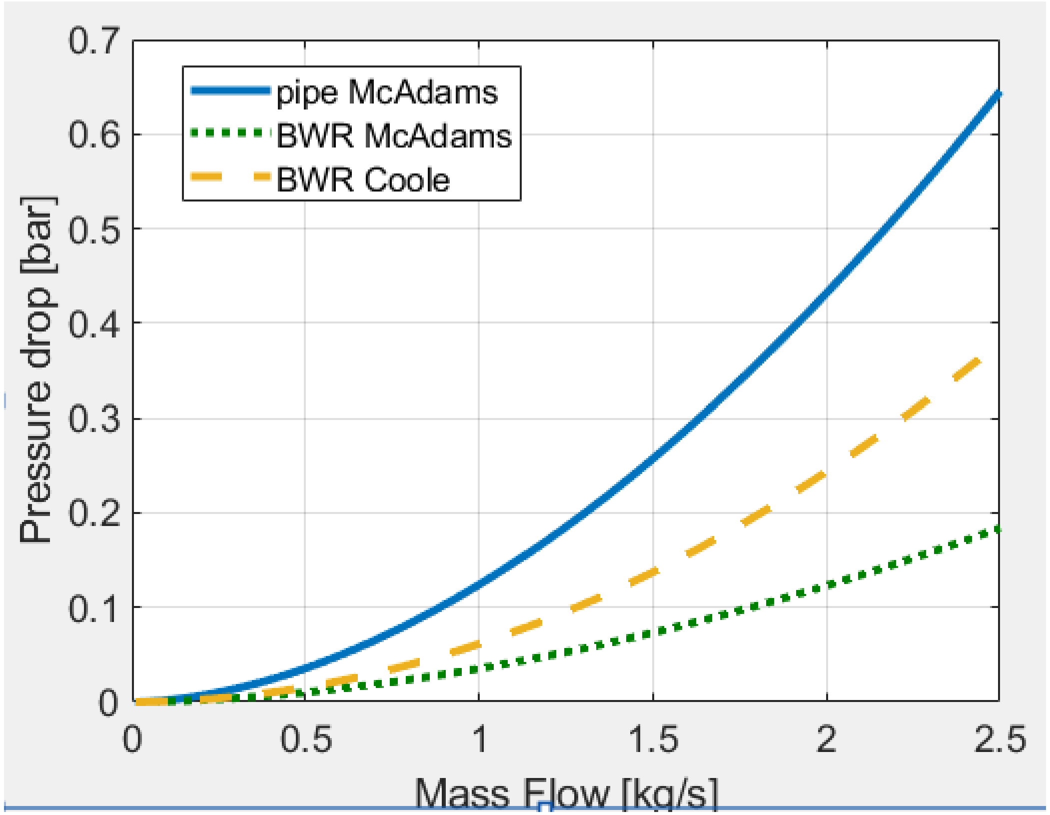
Day 1ABC – guidance for solution

- Summary graph – mono phase pressure drop
  - BWR subchannel

D_h	45.3	mm
A_{flow}	366.1	mm^2

Q: laminar use 64/Re for BWR with Dh is this OK?

Q: what to do with transition region?



Day 1D – guidance for solution

- Steady state pressure drop 1D axial vertical channel

$$\frac{d}{dz}\left(\frac{G_m^2}{\rho_m^+}\right) = -\frac{dp}{dz} - f\,\frac{G_m|G_m|}{2D_e\rho_m} - \rho_m g \quad (13\text{-}10)$$

- Integrated over channel length and assuming HEM

$$\Delta p = \Delta p_{acc} + \Delta p_{gravity} + \Delta p_{fric} + \Delta p_{form} \quad (13\text{-}44)$$

$$\Delta p = p_{in} - p_{out} \quad (13\text{-}45a)$$

$$\Delta p_{acc} = \left(\frac{G_m^2}{\rho_m^+}\right)_{out} - \left(\frac{G_m^2}{\rho_m^+}\right)_{in} \quad (13\text{-}45b)$$

$$\Delta p_{gravity} = \int_{Z_{in}}^{Z_B} \rho_\ell g dz + \int_{Z_B}^{Z_{out}} \rho_m g dz \quad (13\text{-}45c)$$

$$\Delta p_{fric} = [(Z_B - Z_{in}) + \overline{\phi_{\ell o}^2}(Z_{out} - Z_B)]\,\frac{f_{\ell o}G_m|G_m|}{2D_e\rho_\ell} \quad (13\text{-}45d)$$

$$\Delta p_{form} = \sum_i \left(\phi_{\ell o}^2\, K\,\frac{G_m|G_m|}{2\rho_\ell}\right)_i \quad (13\text{-}45e)$$

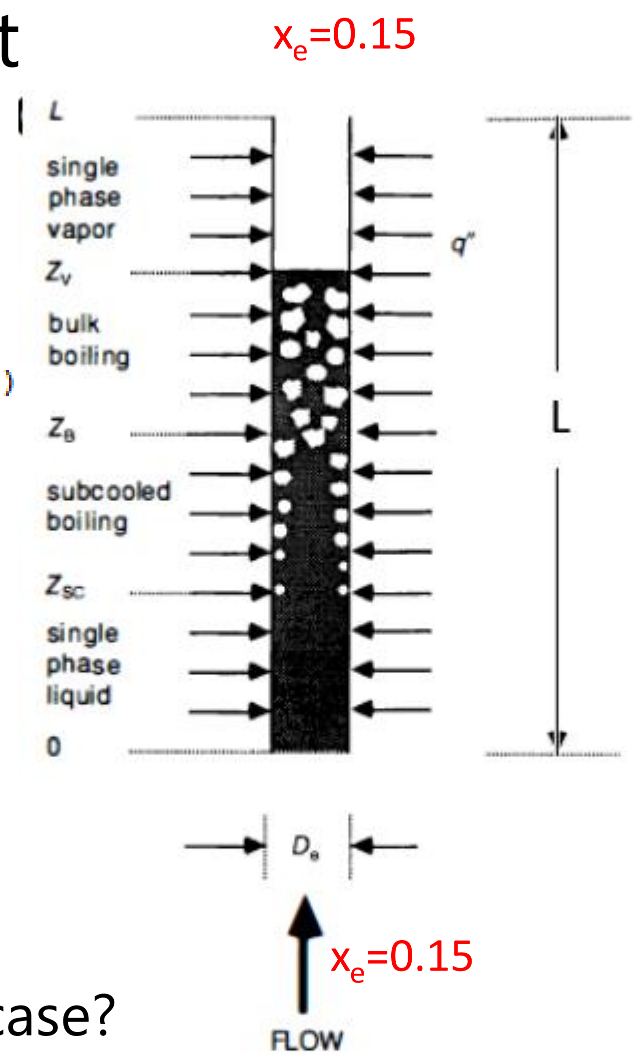
- Q: For Ex. 1D what will we do with
  - Acceleration term?
  - Gravity term?
  - Friction pressure drop?
  - Form losses?

Day 1D – guidance for solution

- q'' =0 (adiabatic) -> x_e=constant
- Write void fraction in terms of quality

```
alpha_itx=@(x,rho_L,rho_G) 1./(1+ (1-x)./x *(rho_G./rho_L))
```

- Q: is quality in this formulation
  - Mass dynamic/flow quality,
  - Mass static quality, or,
  - Equilibrium quality
- Assume HEM
  - Q: Which quality will you use in that case?



Day 1D – guidance for solution

Need approach for two phase friction factor or multiplier

- Friction pressure drop $$\Delta p_{TP} = f_{TP} \frac{L}{D} \frac{G_m^2}{2\rho_m^+} = \Delta p_{LO} \Phi_{LO}^2 = f_{LO} \frac{L}{D} \frac{G_{m=LO}^2}{2\rho_L} \Phi_{LO}^2$$
  - HEM $\rho_m^+ = \rho_\mathrm{m}$ assume TP and LO have same dependence on Re
  - Different options ?
    - A HEM and $f_{TP} = f_{LO}$
    - B HEM and $\Delta p_{TP} = \Delta p_{LO} \Phi_{LO}^2$

$$\Phi_{LO}^2 = \frac{f_{TP}}{f_{LO}} \frac{\rho_L}{\rho_m^+} = \left[1 + x \left(\frac{\rho_L}{\rho_G} - 1 \right) \right]$$

Valid for Therm. Eq. with f_{TP}=f_{LO} see TK1 Eq. 11-82

    - C HEM and $f_{TP} = f_{LO} \left(\frac{\mu_{TP}}{\mu_L} \right)^n$ → $\left(\frac{\mu_{TP}}{\mu_L} \right)^n$: see next slide
    - D HEM and $\Delta p_{TP} = \Delta p_{LO} \Phi_{LO}^2$

$$\Phi_{LO}^2 = \frac{f_{TP}}{f_{LO}} \frac{\rho_L}{\rho_m^+} = \left[1 + x \left(\frac{\rho_L}{\rho_G} - 1 \right) \right] \left[1 + x \left(\frac{\mu_L}{\mu_G} \right) - 1 \right]^{-n}$$

    - Lockhart-Martinelli
      - Air water atmospheric pressure
      - Thermal equilibrium and $S \neq 1$
    - Martinelli Nelson
      - Steam water
      - $\rho_G = cte$, $dx/dz = cte$ and velocity profile radially uniform
    - Jones TK1 page 503
  - For this exercise: use option C with McAdams

Day 1D – guidance for solution

- Friction pressure drop

$$\Delta p_{TP} = \begin{cases} \Delta p_{LO}\Phi^2_{LO} \\ f_{LO}\dfrac{L}{D}\dfrac{G^2_{m=LO}}{2\rho_L}\Phi^2_{LO} \\ f_{TP}\dfrac{L}{D}\dfrac{G^2_m}{2\rho^+_m} \end{cases}$$

$$\Phi^2_{LO} = \frac{f_{TP}}{f_{LO}}\frac{\rho_L}{\rho^+_m} = \frac{f_{TP}}{f_{LO}}\left[1 + x\left(\frac{\rho_L}{\rho_G} - 1\right)\right]$$

$$\frac{\rho_L}{\rho^+_m} = \left[1 + x\left(\frac{\rho_L}{\rho_G} - 1\right)\right]$$

- Different options ?
  - A HEM and $f_{TP} = f_{LO}$
  - B HEM and $\Delta p_{TP} = \Delta p_{LO}\Phi^2_{LO}$

$$\Phi^2_{LO} = \frac{f_{TP}}{f_{LO}}\frac{\rho_L}{\rho^+_m} = \left[1 + x\left(\frac{\rho_L}{\rho_G} - 1\right)\right]$$

Valid for Therm. Eq. with f_{TP}=f_{LO} see TK1 Eq. 11-82

  - C HEM and $f_{TP} = f_{LO}\left(\frac{\mu_{TP}}{\mu_L}\right)^n$ → $\left(\frac{\mu_{TP}}{\mu_L}\right)^n$: see next slide
  - D HEM and $\Delta p_{TP} = \Delta p_{LO}\Phi^2_{LO}$

$$\Phi^2_{LO} = \frac{f_{TP}}{f_{LO}}\frac{\rho_L}{\rho^+_m} = \left[1 + x\left(\frac{\rho_L}{\rho_G} - 1\right)\right]\left[1 + x\left(\frac{\mu_L}{\mu_G}\right) - 1\right]^{-n}$$

  - Q: Difference A, B, C and D?

Day 1D – guidance for solution

HEM model pressure drop

- Friction gradient: $\left(\dfrac{dp}{dz}\right)_{fric} = \dfrac{f_{TP}}{D_e}\left(\dfrac{G_m^2}{2\rho_m}\right)$
- Various ways to estimate f_{TP} : $f_{TP} = f_{Lo}$
- Or $\dfrac{f_{TP}}{f_{Lo}} = \dfrac{C_1/\mathrm{Re}_{TP}^n}{C_1/\mathrm{Re}_{Lo}^n} = \left(\dfrac{\mu_{TP}}{\mu_L}\right)^n$

McAdams

With C_1=0.3164 and n = 0.25, or C_1=0.184 and n = 0.2. (turbulent)

McAdams et al: $\dfrac{\mu_{TP}}{\mu_L} = \left[1 + x\left(\dfrac{\mu_L}{\mu_G} - 1\right)\right]^{-1}$

Not very accurate

Only at high or low quality

Cichitti et al. $\dfrac{\mu_{TP}}{\mu_L} = \left[1 + x\left(\dfrac{\mu_G}{\mu_L} - 1\right)\right]$

At saturation

Dukler et al. $\dfrac{\mu_{TP}}{\mu_L} = \left[1 + \beta\left(\dfrac{\mu_G}{\mu_L} - 1\right)\right]$

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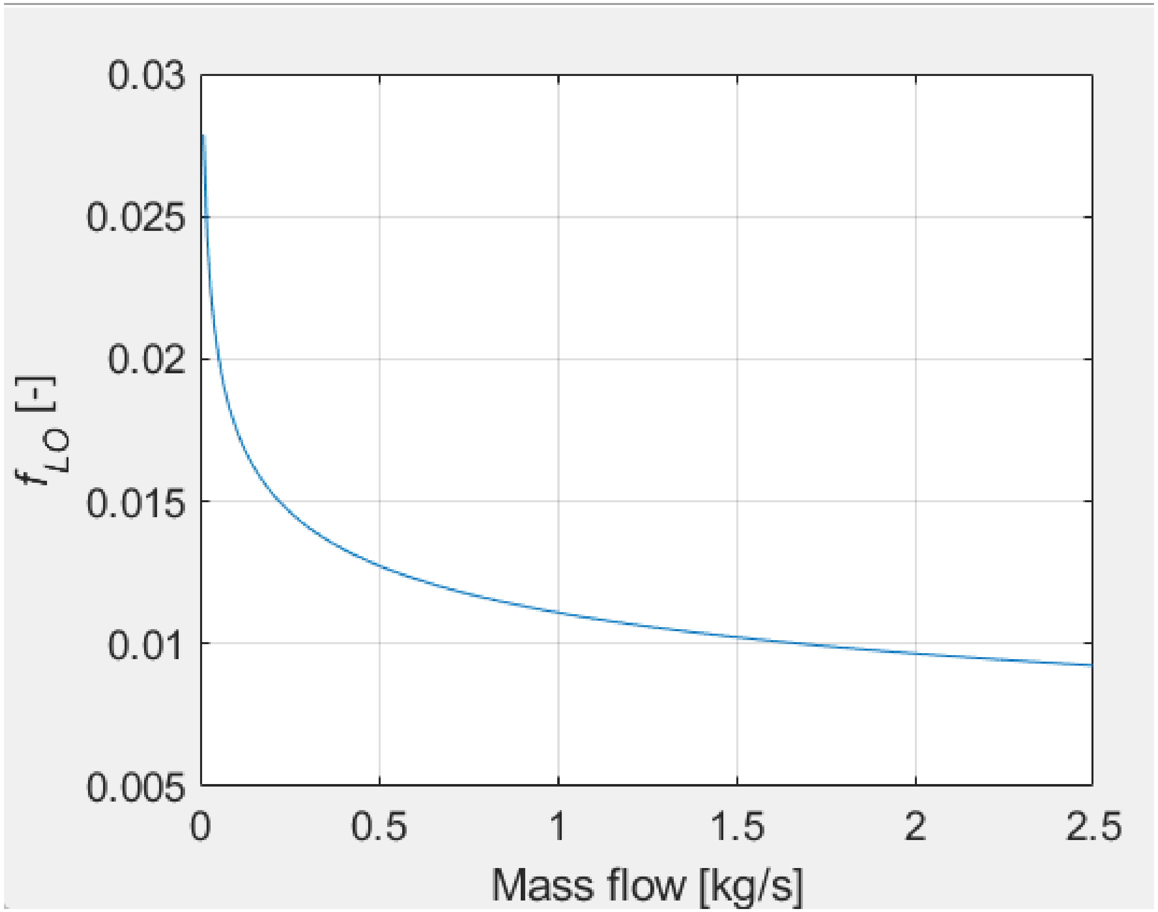
! XSteam does not give viscositites at saturation; possible 'trick'

```
mu_inG_sat=XSteam('my_pT',p_in_bar,T_sat_in_C/.99);
mu_inL_sat=XSteam('my_pT',p_in_bar,T_sat_in_C*.99);
```

Alternative 'trick' -> use enthalpy of liquid/gas at saturation and pressure to get viscosity

Day 1D – guidance for solution

- f_{LO} in terms of mass flow (kg/s)



Day 1E – guidance for solution

- q" not given but a certain heating results in the fact that x_e evolves linearly from 0 to 0.15 from inlet to outlet
- Possible approach
  - Write x in terms of height

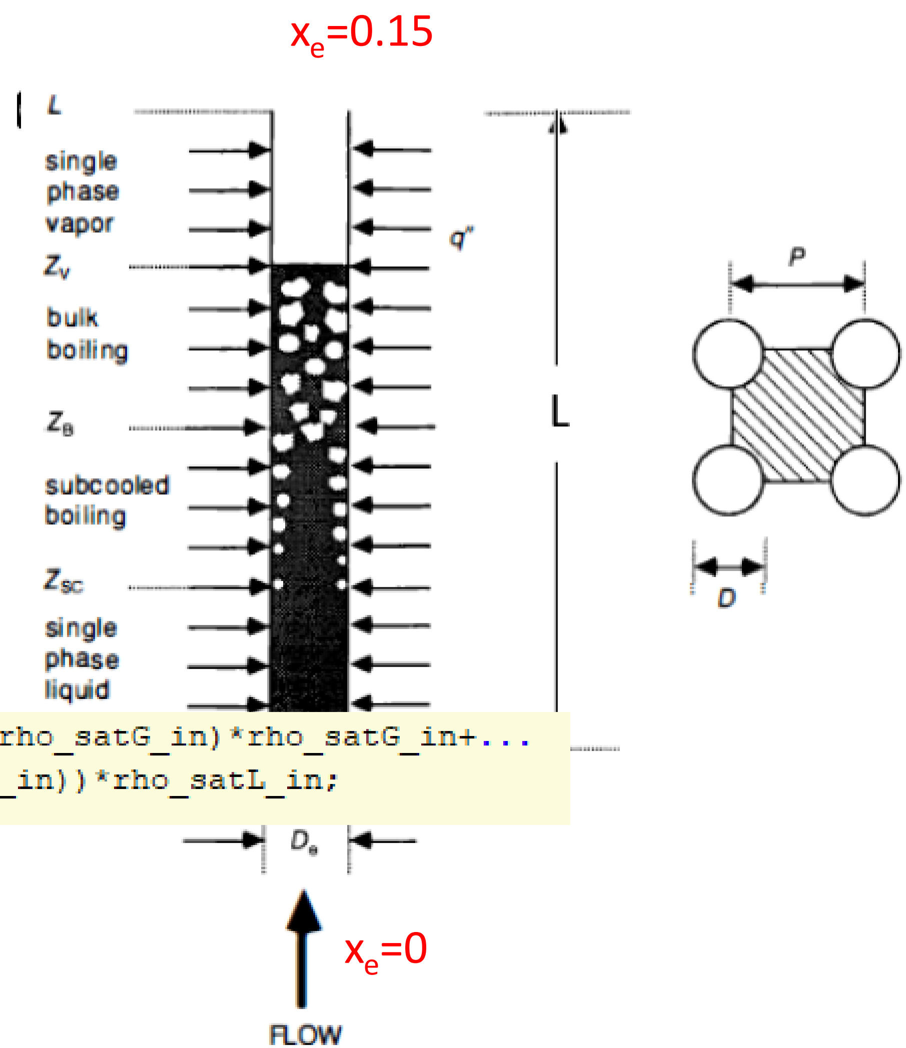
```
xfun=@(z) 0+0.15*z/L;
```

  - This allows to write mixture density in terms of height

```
rho_m_fun=@(z) alpha_itx(xfun(z),rho_satL_in,rho_satG_in)*rho_satG_in+...
    (1-alpha_itx(xfun(z),rho_satL_in,rho_satG_in))*rho_satL_in;
```

  - Example of integral for gravity term

```
delPgrav=g*quad(@(z) rho_m_fun(z),0,L);
```



Day 1DE – guidance for solution

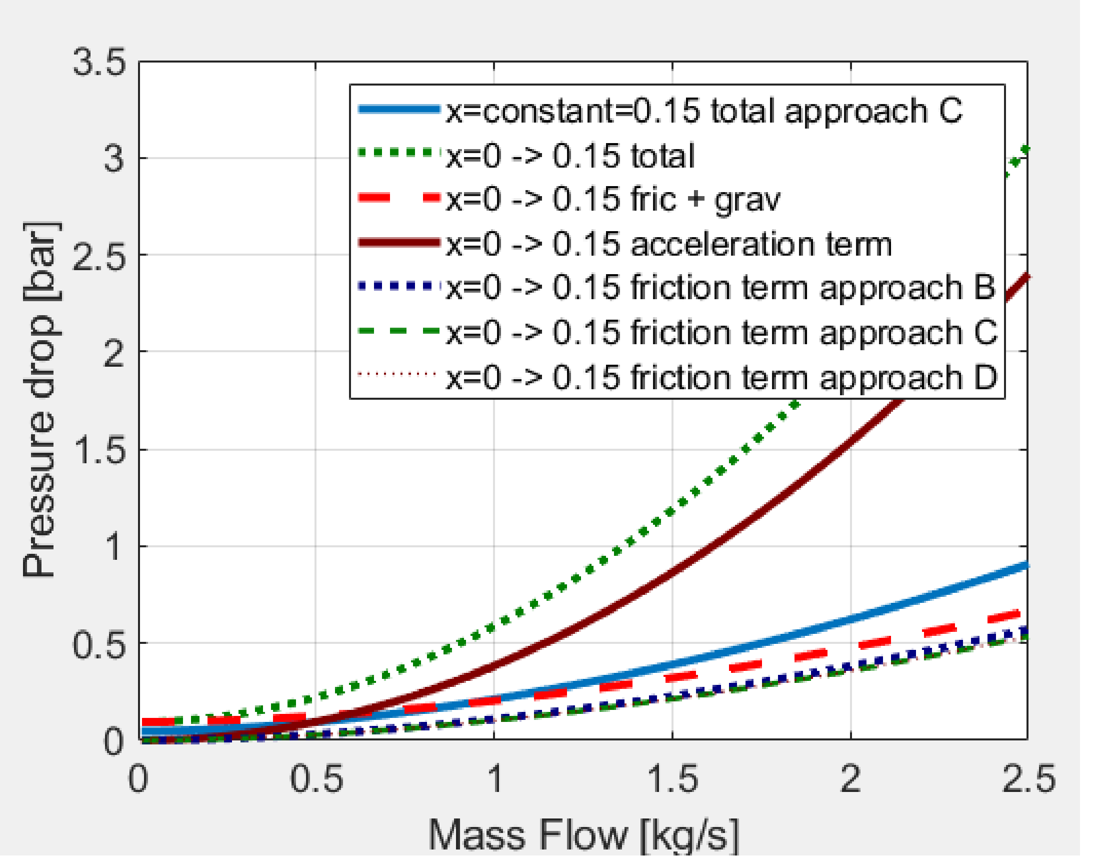
Graph with numerical output

- 1D = blue solid line

α	0.83	-
ρ_m	155	kg/m^3
ΔP_{grav}	0.047	bar

- 1E = other curves

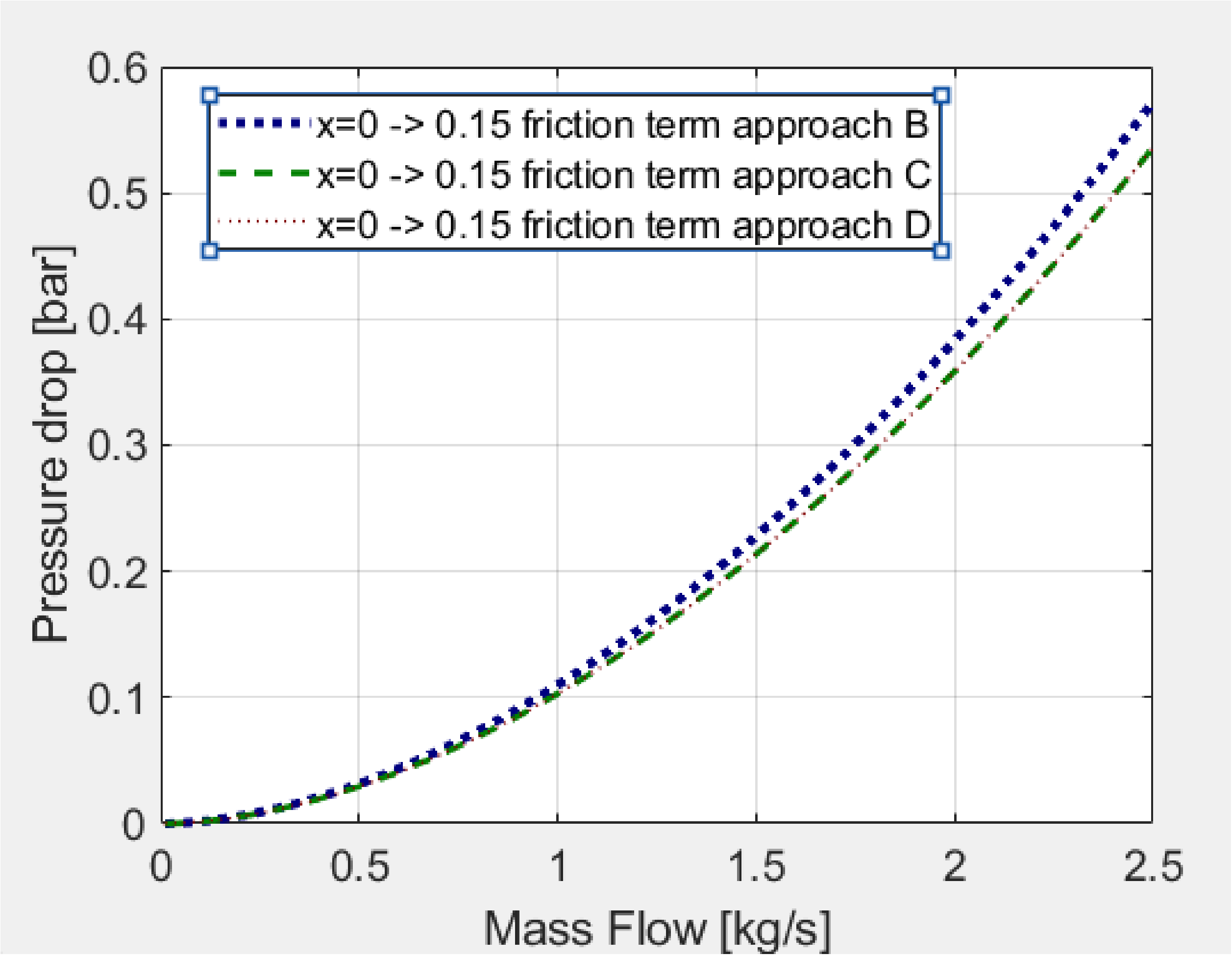
ΔP_{grav}	0.0945	bar



Q: why gravity for 1E larger than for 1D?

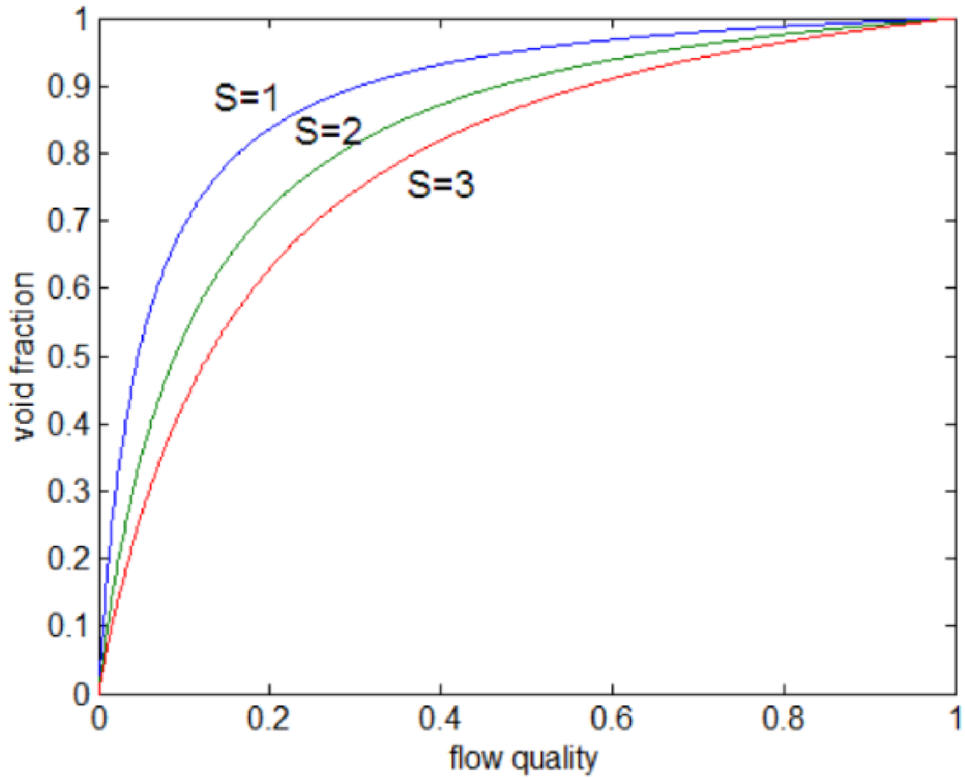
Day 1DE – guidance for solution

- Graph of numerical output – friction only for question 1E



Day 1E – guidance for solution

$$\alpha = \frac{1}{1 + \frac{1-x}{x} \cdot \frac{\rho_G}{\rho_L} \cdot S}, \qquad x = \frac{1}{1 + \frac{1-\alpha}{\alpha} \cdot \frac{\rho_L}{\rho_G} \cdot \frac{1}{S}}, \qquad S = \frac{1-\alpha}{\alpha} \cdot \frac{x}{1-x} \cdot \frac{\rho_L}{\rho_G}$$



Effect of S on α vs x for water at 7 MPa. Source: Buongiorno Jacopo, MIT Department of Nuclear Science and Engineering, NOTES ON TWO-PHASE FLOW

http://www.nuclear-power.net/nuclear-engineering/fluid-dynamics/two-phase-fluid-flow/void-fraction-two-phase-flow

Day 2A – guidance for solution

- Fluid saturated: look for elevation where
  - $T = Tsat$
  - $h = h_{L,\ sat} = h_L$ (subscript 'sat' omitted)
  - x_e=0
  - Q: Which one is easiest in use?
- Hint
  - Write enthalpy and equilibrium quality in terms of height, mass flux and heating

Day 2B – guidance for solution

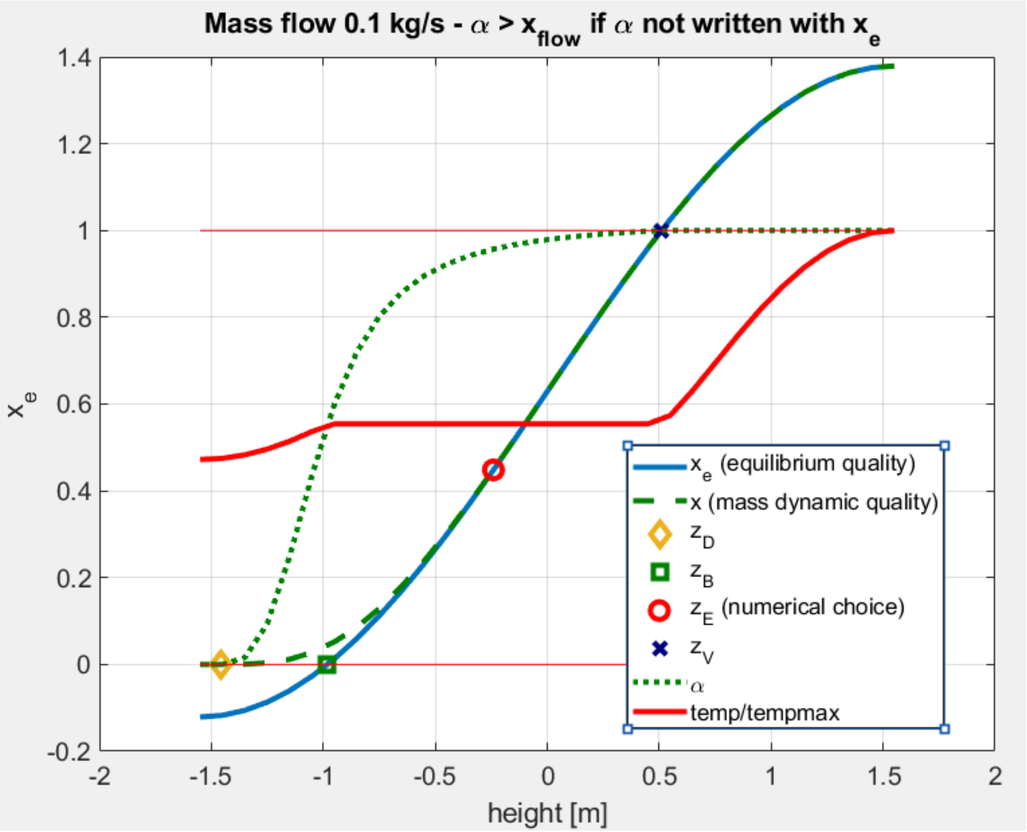
Point	Possible strategy	x	x_e
z_{ONB}	Bergles Roshenhow	0	<0
$z_{SC}=z_D$	Saha – Zuber	0 ->	<0
$z_{OSB}=z_B$	$x_e=0$	>0	0
z_E	Levy	x_e	x
z_V	$x_e=1$	1	1

- Levy correlation for relationship between
  - x=flow dynamic quality
  - x_e=equilibrium quality

- Hints
  - See TK2 pages 852-854 (or TK1 pages 606 and further)
  - Calculate temperature in terms of height (via enthalpy/quality in terms of height)
  - Look for elevation, z, where $T(z)=T_{Saha\text{-}Zuber}(z)$
    - Graphically or with fsolve function in matlab or own script
    - Alterantive: Look for Stanton number = 0,0065 for Pe>70 000 (! TK1 page 535)
    - Q: which heat flux is used to make the calculation representative for the cosine heat flux in this exercise?
- z_{ONB}: nucleate boiling starts
  - Q: Does this influence friction factor?
  - Q: Should you model this?
- z_D: bubbles leave wall + some collapse in bulk of coolant
  - Q: Does this influence friction factor?
  - Q: Should you model this?

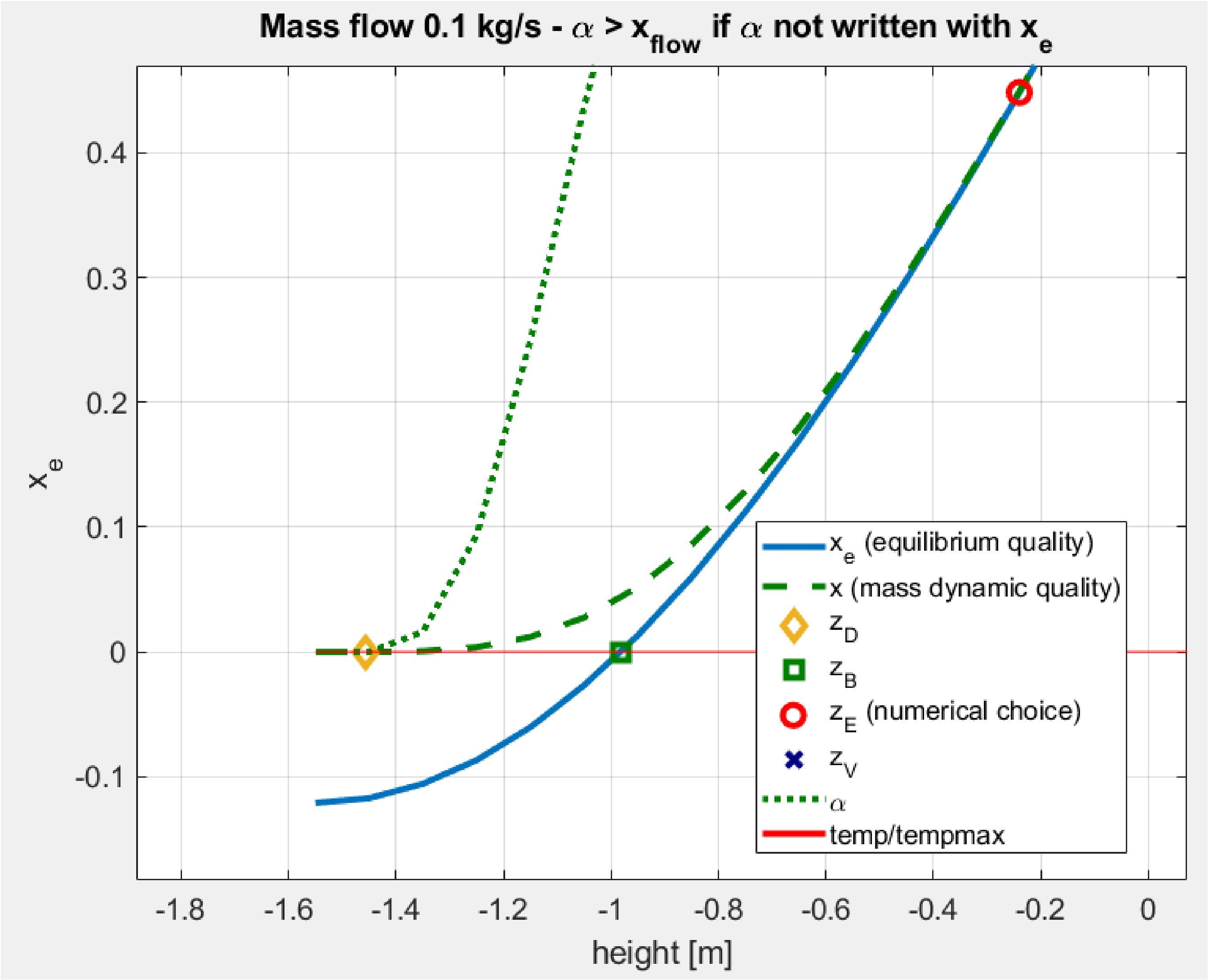
Day 2ABC – numerical answers

m_f= 0.1 kg/s cos heating –L/2 to L/2	[m]	x	x_e
z_{ONB}	Not calculated here	0	<0
$z_{SC}=z_D$	-1.4572	0	<0
$z_{OSB}=z_B$	-0.98145	>0	0
z_E	-0.24 =f(numerical choice)	x_e	x
z_V	0.51056	1	1



Q1: is T/T_{max} in °C or K ?
Q2: can x_{flow} be higher than 1 ?
Q3: will you use x_E or x_{flow} for determination of mixture density and friction factors?

Day 2ABC – numerical answers



Day 3 – guidance

- Friction pressure drop considerations

$$\Delta p_{\text{fric}} = \frac{G_m^2 f_{\ell o}}{2\rho_f\, D_e} \int_{z_B}^{z_V} (\phi_{\ell o}^2)\, dz \qquad (13\text{-}77)$$

  - Q4: do you think it is appropriate to integrate from z_D=z_{SC} to z_V as alternative?
  - Q5: for which mass flow rate z_D>L/2 ?
    - At this point no bubble detachment in the channel
    - Discontinuity because of Saha Zuber correlation
      - Numerical challenge which is not required if z_B is used
      - Also see Q&A

Q&A

- *"In the pressure drop challenge the Relative wall roughness (lambda/D_e) = 0.001 is given. I suppose this D_e is the equivalent diameter (hydraulic diameter) which in the slides of the prof is named D_h. correct?"*
  - Yes
- *"I noticed a bug with XSteam: It is important to use*
  - *rho_in = Steam('rho_pT',p_in_bar,T_in); and not rho_in = Steam("rho_pT",p_in_bar,T_in);"*
- *"For Question 1D you need viscosity of liquid at saturation which is not possible via Xsteam?"*
  - f_LO is calclulated via Re_LO with assumption that G_LO = G_m; so as if liquid flows through system at flow rate of mixture.
  - To calculate viscosity of liquid/gas at saturation with Xsteam following trick can be used
  - mu_inG_sat=XSteam('my_pT',p_in_bar,T_sat_in_C/.99);
  - mu_inL_sat=XSteam('my_pT',p_in_bar,T_sat_in_C*.99);

Q&A

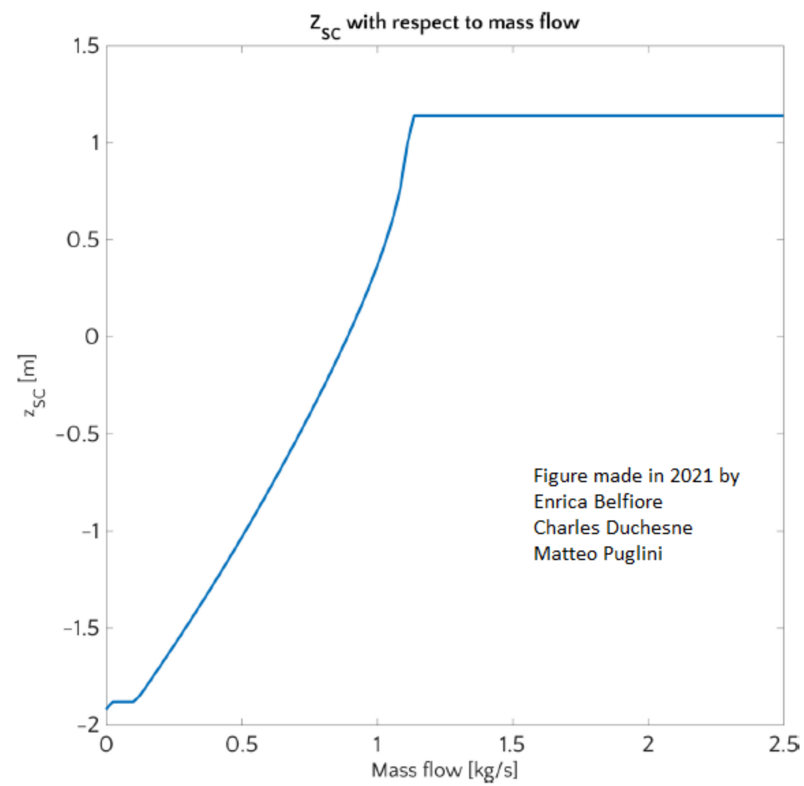
- *"In the exercise 1D and 1E, it is asked to calculate f_TP with the following equation. But it is dependent on x, which is variable in ex 1E. So f_TP is also dependent on the distance in the channel. I am wondering how to calculate this"*

$$\frac{\mu_{TP}}{\mu_L} = \left[1 + x\left(\frac{\mu_L}{\mu_G} - 1\right)\right]^{-1}$$

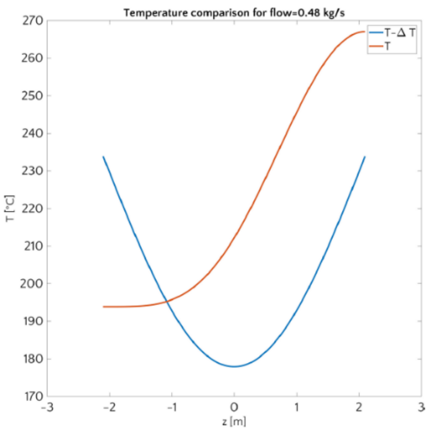
  - you have to integrate f_TP(z) /rho_m(z) from L=0 -> L=L. f_TP is fuction of quality x and x is function of height (linear evoluation from 0 to 0.15)
- *"trapz versus quad/integral in matlab"*
  - see samplefunctions of matlab. One is for function other is for vector (discrete points)
- *"In table it is seen that at Z_ONB x=0. This should also be the case off course in the single phase liquid region as in a single phase (SP) the quality is 0 or 1. But if I take the Levy correlation I don't end up with x=0 in the SP liquid region and also not at Z_ONB. In boh cases x<0 but off course very close to 0. The same story for the single phase vapor region. There x>1. Is this just because x is being calculated with a correlation that is only valid in the 2-phase region between ZD and ZV and should not be applied outside this interval?"*
  - Be careful in your explanation that you always clarify that you talk about mass/flow and equilibrium quality. Levy is made to calculate x_flow from the point z_D to the point Z_V. For the other points in a practical calculation you would force x_flow to zero respectively one
- *"The Levy's correlation that we use for x_flow leads to x_flow > 1. Is it a good way to just limit the maximum value of x to 1?"*
  - The easiest numerical approach is to limit is to 1. This gives a discontinuity and is just an approximation of the actual physics. It is good enough as an approach for this project.

Q&A

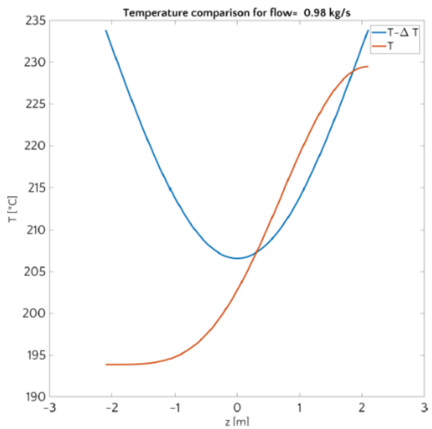
- *"if we calcualte the point z_sc=z_D for different mass flows; from a certain mass flow, z_D is constant? "*
  - Indeed, at high mass flow rate there only is liquid in the channel. In the mass flow range region where there is a transition from subcooled to bubbles leaving the wall, the correlation of Saha and Zuber cannot be used anymore. From numerical/calculation point of view this means that ther is not crossing of the actual temperature (z) curve (fluid temperature) and the temperature (z) curve given by the correlation. This can also give an issue if you make integral calculations from the point z_D to e.g. z_B or Z_V for different mass flow. At a certain mass flow rate the Z_D will not change anymore. Therefore, a possible numerical solution is to make an interpolation between the max of z_SC and z=L/2. In matlab working with fzero instead of fsolve also changes the numerical influence
  - See pictures on next slide



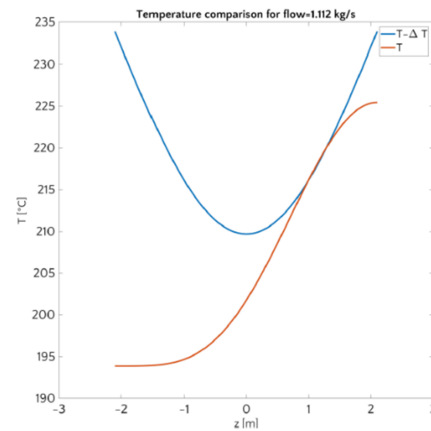
Q&A



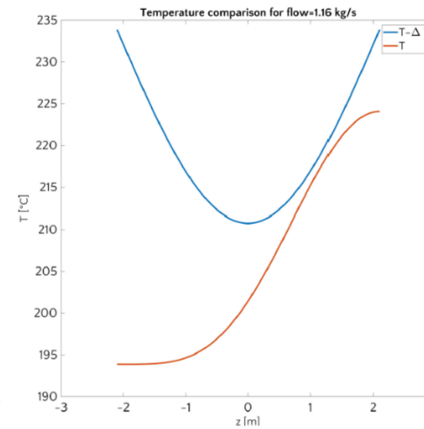
z_{SC}=1.08 m



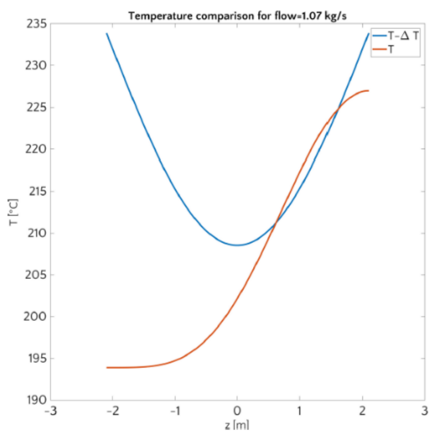
z_{SC}=0.31 m



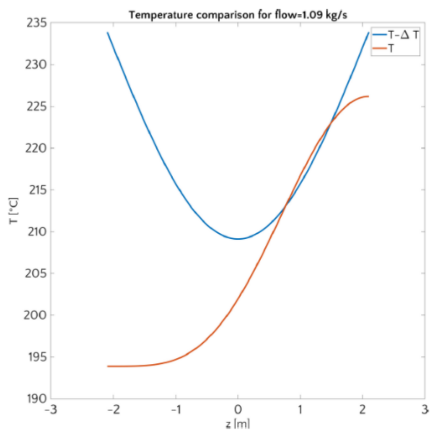
z_{SC}=0.99 m



z_{SC}=1.14 m



z_{SC}=0.62 m



z_{SC}=0.76 m

Figures made in 2021 bu
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