BNEN NTH pressure drop exam challenge

- Academic year 2025-2026
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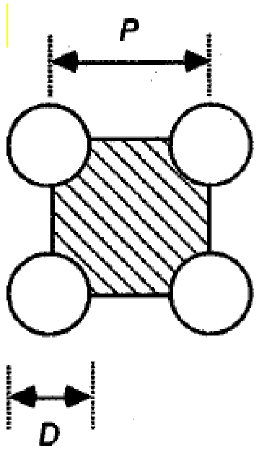
BNEN NTH pressure drop exam challenge

- 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

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SINGLE HEATED CHANNEL: STEADY-STATE ANALYSIS 607

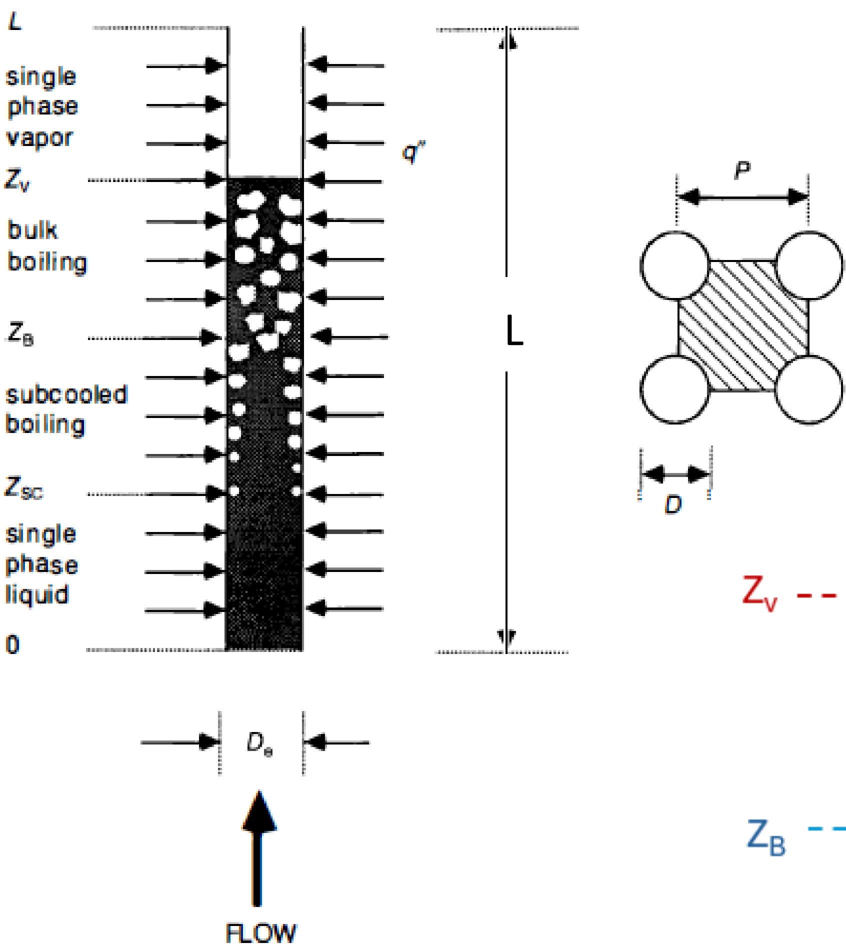

Figure 13-13 Subchannel flow region (left) and cross section (right).

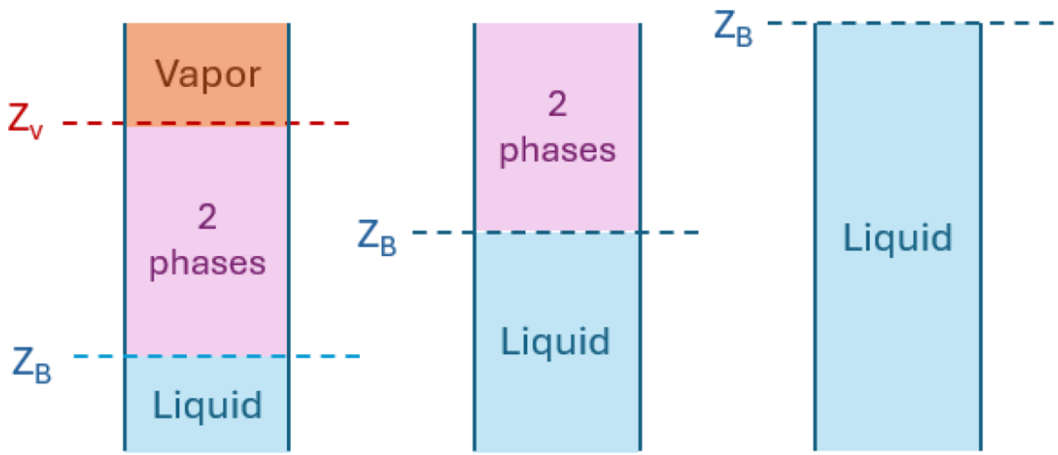

Figure adopted from Brieux and Wlodarski 2024

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- 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

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- 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)
```