

22.313J, 2.59J, 10.536J THERMAL-HYDRAULICS IN POWER TECHNOLOGY

Homework Set 1

Question 1 – Basic Parameters in Two-phase Flow

- 1.1 Prove that the volumetric flow fraction, β , is related to the flow quality, x , by the following expression:

$$\beta = \frac{1}{1 + \frac{\rho_v}{\rho_\ell} \cdot \frac{1-x}{x}}$$

- 1.2 Prove that for homogeneous flow (i.e., $v_\ell = v_v$), the following equations are valid:

- a) $\alpha = \beta$
- b) $\rho_m^+ = \rho_m$
- c) $h_m^+ = h_m$

Question 2 – Conservation Equations for Two-phase Flow

The boiler of a coal-fired power plant consists of a tube bundle surrounding the combustion chamber. The tubes are vertical (10-m length) and round (2-cm inner diameter). The operating conditions for the boiler are as follows:

- Pressure: 10 MPa (corresponding to a saturation temperature of 311°C)
- Water inlet temperature: 300°C
- Water mass flow rate (per tube): 0.57 kg/s
- Wall heat flux: 300 kW/m² (axially and circumferentially constant)

- 2.1 Write the steady-state mixture mass, momentum and energy conservation equations for a boiler tube.
- 2.2 Using the mass equation, find the mass flux (G) at the tube inlet, middle axial position and outlet.
- 2.3 Calculate the equilibrium quality (x_e) at the inlet. Using the energy equation, find also the equilibrium quality at the outlet. Is it reasonable to assume that $x = x_e$ at the inlet? At the outlet?
- 2.4 Assuming a slip ratio of 1.9, calculate the void fraction, and the vapor and liquid velocities at the outlet.

Table 1. Properties of saturated water at 10 MPa.

Parameter	Value
ρ_f	667 kg/m ³
ρ_g	55 kg/m ³
h_f	1,407 kJ/kg
h_g	2,724 kJ/kg
$C_{p,f}$	6.2 kJ/(kg°C)
$C_{p,g}$	7.1 kJ/(kg°C)
μ_f	9×10^{-5} Pa·s
μ_g	2×10^{-5} Pa·s
k_f	0.52 W/(m°C)
k_g	0.08 W/(m°C)
σ	0.012 N/m

Question 3 – Two-phase Flow Map

Consider two-phase flow of water at 6.4 MPa, corresponding to a saturation temperature of 280°C (properties in Table 2). The BWR nominal channel (Figure 1) operates at this pressure.

3.1 Generate a flow map for this system, making use of the following assumptions:

- Use j_v and j_ℓ as the map parameters.
- Treat the BWR channel as a round tube of equivalent diameter.
- Demonstrate that bubbly flow cannot exist in such small diameter channel.
- Then consider only the dispersed bubbly, intermittent and annular flow patterns.
- In calculating the transition line from dispersed bubbly-to-intermittent use $S=1$.

3.2 The coolant mass flux in the BWR channel is 1,800 kg/m²s. Assuming that the coolant enters the BWR channel as saturated liquid, and leaves it as a steam/water mixture of 14% quality, sketch the coolant “trajectory” (i.e., the j_v - j_ℓ line described by the coolant as it flows from the inlet to the outlet) on the flow map.

3.3 Assuming that the channel is 3.5-m long and the heat flux is axially constant, at what distance from the inlet does the transition to annular flow occur?

Table 2. Properties of saturated water at 6.4 MPa.

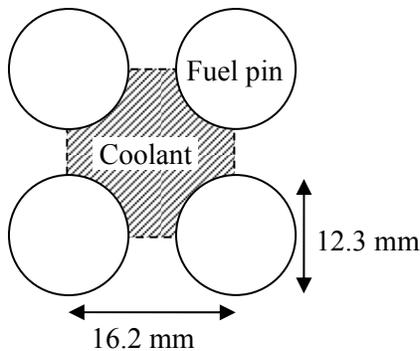


Figure 1. Cross-sectional view of the BWR nominal channel

Parameter	Value
ρ_f	769 kg/m ³
ρ_g	33 kg/m ³
h_f	1,237 kJ/kg
h_g	2,780 kJ/kg
$C_{p,f}$	5.3 kJ/(kg°C)
$C_{p,g}$	5.0 kJ/(kg°C)
μ_f	9.8×10^{-5} Pa·s
μ_g	1.9×10^{-5} Pa·s
k_f	0.574 W/(m°C)
k_g	0.061 W/(m°C)
σ	0.019 N/m