

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

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**Homework Set 2**

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**Annular and Bubbly Flow in the Riser of a High-Pressure Two-Phase Loop**

An engineer at the Electric Power Research Institute (EPRI) is studying the two-phase flow behavior of water at 6.4 MPa (properties in Table 1). His data will be used to improve the design of nuclear and conventional steam generators. The experimental apparatus is a natural circulation loop comprising an electric heater of variable power, a riser and a downcomer. The riser is a vertical pipe of hexagonal cross-section, 5.68-cm wide (flat-to-flat) and 6-m long. You are to analyze the characteristics of the two-phase flow in the riser, at two different power levels of the electric heater.

*Full Power*

At full power, the riser receives a two-phase mixture with 2.52 kg/s mass flow rate at 15% quality.

- i) Verify that the two-phase flow pattern in the riser is annular.
- ii) Verify the condition for the onset of liquid entrainment.
- iii) Calculate the equilibrium entrained-liquid fraction with the Ishii-Mishima correlation.
- iv) Calculate the void fraction in the riser using the EPRI correlation.
- v) Calculate the vapor velocity.
- vi) Estimate the maximum diameter of the entrained droplets. (Hint: use a value of 10 for the critical Weber number)
- vii) Calculate the average value of the droplet/steam relative velocity. (Hint: equate weight and drag forces to find the droplet/steam relative velocity as a function of the droplet diameter. Then use a flat droplet diameter distribution to compute the average relative velocity)
- viii) How would the result in 'vii' change if a more realistic droplet diameter distribution (i.e., the upper-limit lognormal distribution) were used instead of a flat distribution? (Provide only a qualitative answer)
- ix) Calculate the velocity of the liquid film on the riser wall. (Hint: assume that the average liquid velocity in the riser can be expressed as the weighed sum of the film velocity and the entrained-droplet velocity, with the entrained liquid fraction as the weight. Then solve for the film velocity)

*Reduced Power*

At reduced power, the mass flow rate and quality in the riser are 1.5 kg/s and 1%, respectively, and the flow pattern is bubbly.

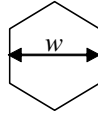
- x) The bubbles have an equivalent diameter of 1 cm. What is the bubble shape? What is the bubble velocity relative to the liquid? (Hint: use a Re-Eo-M diagram)
- xi) Using the drift-flux model and the relative velocity calculated in 'x', estimate the void fraction. (Hint: assume  $C_0=1.2$ )
- xii) Calculate the acceleration and gravity pressure drop in the riser.
- xiii) Calculate the friction pressure drop using the following correlations:
- Friedel
  - HEM with  $f_{TP}=f_{fo}$
  - Martinelli-Nelson
  - Baroczy

Assumptions:

- Adiabatic, fully-developed upflow
- Treat the riser as a round tube of equivalent diameter

**Hexagon area:**  $A = \frac{\sqrt{3}}{2} w^2$

**Hexagon perimeter:**  $p = 2\sqrt{3}w$



**Table 1. Properties of saturated water at 6.4 MPa.**

Parameter	Value
$\rho_f$	769 kg/m <sup>3</sup>
$\rho_g$	33 kg/m <sup>3</sup>
$h_f$	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)
$\mu_f$	$9.8 \times 10^{-5}$ Pa·s
$\mu_g$	$1.9 \times 10^{-5}$ Pa·s
$k_f$	0.574 W/(m°C)
$k_g$	0.061 W/(m°C)
$\sigma$	0.019 N/m