22.312 **ENGINEERING OF NUCLEAR REACTORS**

Friday, December 16th, 2005, 1:30-4:30 pm

OPEN BOOK FINAL EXAM 3 HOURS

Problem 1 (50%) –Loss Of Flow Accident (LOFA) in a fast-spectrum BWR.

To achieve a fast neutron spectrum in a boiling water reactor, a nuclear engineer is analyzing a concept with short fuel assemblies and a tight fuel pin pitch. First consider the nominal operation of one of these fuel assemblies. The hydraulic diameter of the fuel assembly is 0.01 m, the flow area is 0.005 m^2 and the length is 2.5 m. The operating pressure is 6.4 MPa. The inlet temperature is 260°C, and the outlet equilibrium quality is 0.3. The fuel assembly power is 6 MW. The heat flux can be considered axially uniform.

Table 1. Properties of saturated water at 6.4 MPa

Parameter	Value
T_{sat}	279.8°C
ρ_f	751 kg/m^3
ρ_g	33 kg/m^3
h_f	1,236 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

i) Calculate the mass flow rate in the fuel assembly. (Assume constant specific heat in the subcooled region) (5%)

ii) Calculate the critical quality at the fuel assembly outlet. (Use the CISE-4 correlation; Assume L_b = distance from fuel assembly inlet; Assume D_e=D_h; P_c=22.12 MPa) (5%)

iii) Due to malfunction of one of the recirculation pumps, the flow in the fuel assembly suddenly drops and stabilizes at 50% of its nominal value, while the power, pressure and inlet temperature remain constant. Does the critical quality at the outlet increase or decrease and why? Does dryout occur? (20%)

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iv) Qualitatively describe the dominant heat transfer mechanisms at the fuel assembly **outlet** at the nominal conditions and at the reduced-flow conditions. Which correlation would you use to calculate the wall temperature in the two cases? (5%)

v) Consider each term of the momentum equation (i.e., acceleration, friction, form and gravity pressure drop) and describe the effect that could cause that term to increase or decrease as a result of the flow reduction. If there are two or more conflicting effects, list them and identify which one is likely to be dominant. Provide a qualitative answer. (10%)

vi) Is operation at reduced flow more or less susceptible to dynamic instabilities? Explain. (5%)

Problem 2 (15%) – Sizing the pressure vessel for a CO_2-cooled reactor

Japan Steel Works, the world's leading manufacturer of nuclear reactor pressure vessels, has established that components of weight up to 300 ton (300,000 kg) can be fabricated in its heavy workshop. You are to calculate the maximum allowable diameter of a cylindrical shell that is 4 m high and is made of carbon steel, to be used in a gas-reactor pressure vessel that will operate at 350°C and 20 MPa.

Assumptions:

- Use a thin-shell approximation to calculate the stresses.
- Assume that the external pressure is atmospheric.
- Use the ASME code primary general membrane stress requirements.
- The value of the maximum allowable stress intensity, S_m, for carbon steel at 350°C is 220 MPa.
- The density of carbon steel is 7,000 kg/m^3.

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Problem 3 (10%) – Thermodynamic analysis of a gas turbine

Is transformation 1→2, shown in Figure 1, thermodynamically possible for a gas turbine? If so, under what conditions? If not, why? (Assume steady-state)

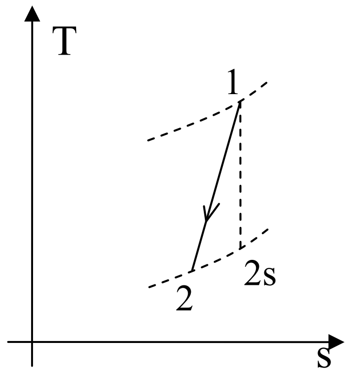

Figure 1. T-s diagram for transformation in the turbine.

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Problem 4 (25%) – Effect of geometry on single-phase heat transfer in straight tubes

Consider a smooth round tube (2 cm in diameter) and a smooth square tube (2cm×2cm), each 4m in length (shown in Figure 2). Each tube has a fluid flowing through it at the conditions given in Table 2.

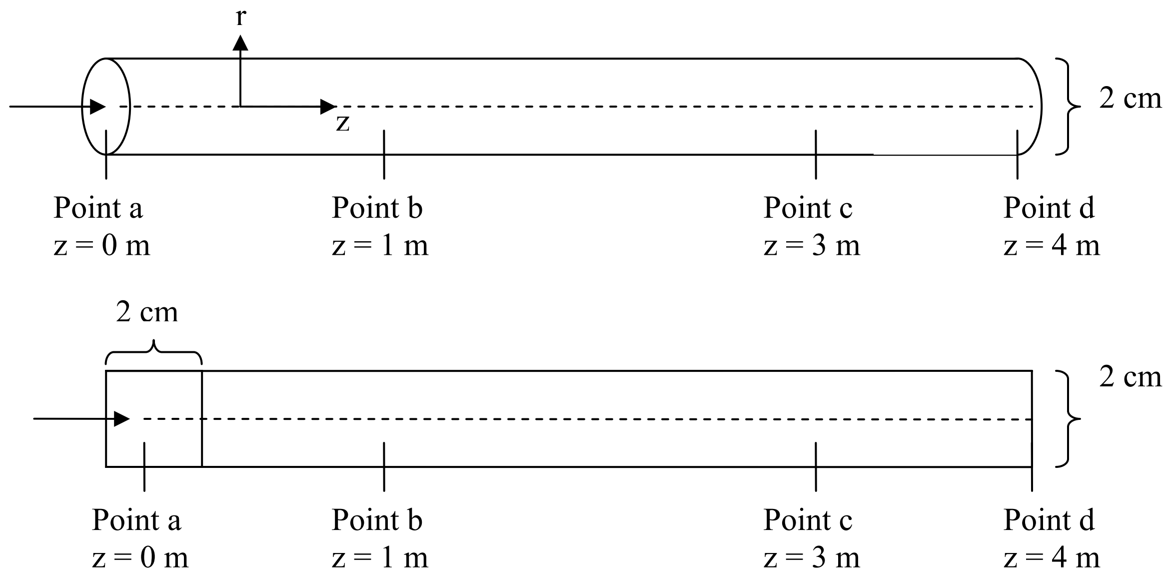

Figure 2. The round and square tubes (figure not to scale)

Table 2. Fluid conditions.

Parameter	Value
Density (ρ)	914 kg/m^3
Viscosity (μ)	9×10^{-5} Pa s
Specific heat (C_p)	5.8 kJ/(kg°C)
Thermal conductivity (k)	0.54 W/(m°C)
Mass flow rate ($\dot{m}$)	2.822×10^{-3} kg/sec
Wall temperature	Constant throughout the length of the tube

i) Determine if the flow is laminar or turbulent for both tubes. Justify your answer using calculations. (5%)

ii) Given a uniform velocity profile at Point a (shown below in Figure 3), sketch the velocity profiles at Points b and c for the **round** tube. Explain changes you see, if any, in the profiles at Points b and c. (5%)

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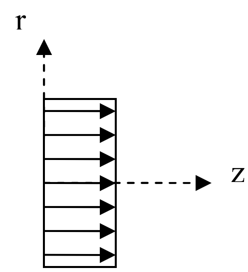

Figure 3. Velocity profile at Point a.

iii) Which tube has a higher heat transfer coefficient at Point c? Justify your answer using calculations. Give proper justification for the heat transfer correlation you choose. (10%)

iv) Suppose that the flow rate triples. Which tube has a higher heat transfer coefficient at Point c? (5%)

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