22.312 ENGINEERING OF NUCLEAR REACTORS

Due November 17, 2006 by 12:00 pm

TAKE HOME QUIZ 2

Problem 1 (60%) – Hydraulic Analysis of the Emergency Core Spray System in a BWR

The emergency spray system of a BWR delivers cold water to the core after a large-break loss of coolant accident has emptied the reactor vessel. The system comprises a large water pool, a pump, a spray nozzle and connecting pipes (Figure 1). All pipes are smooth round tubes made of stainless steel with 10 cm internal diameter and 5 mm thickness. The pipe lengths are shown in Figure 1. Two sharp 90° elbows connect the vertical pipe to the horizontal pipe and the horizontal pipe to the spray nozzle. Each elbow has a form loss coefficient of 0.9. The spray nozzle has a total flow area of 26 cm^2 and a form loss coefficient of 15. The suction pipe in the pool has a sharp edged entrance with a form loss coefficient of 0.5.

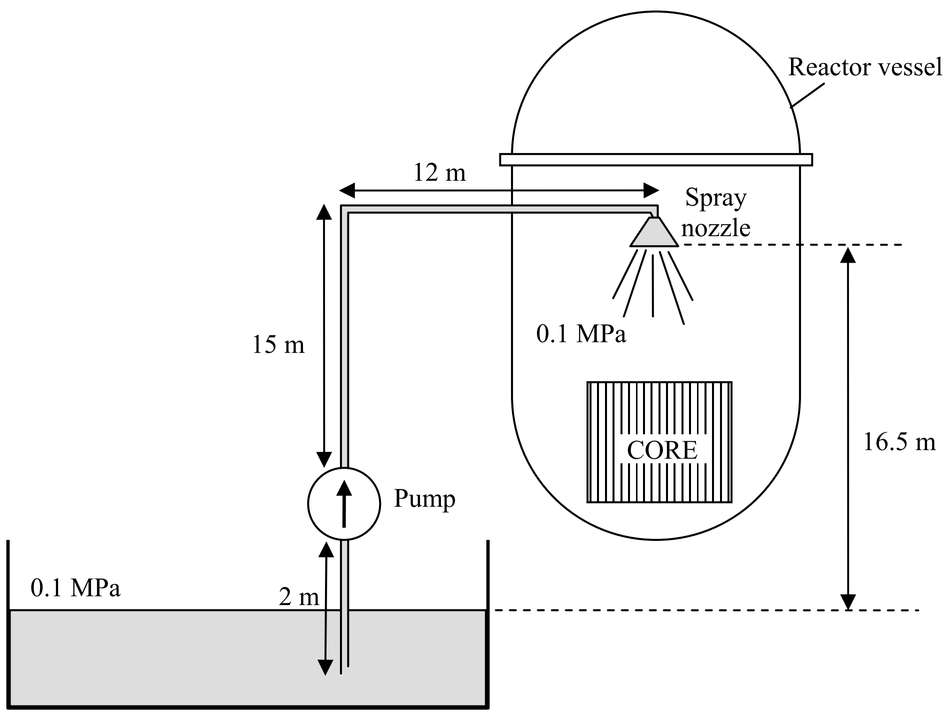

Figure 1. The emergency spray system.

i) Calculate the pumping power required to deliver 50 kg/s of cold water to the core. (Assume steady-state and constant water properties. Do not neglect the acceleration terms in the momentum equation. Neglect entry region effects in calculating the friction factor. To calculate the irreversible term of the spray nozzle form loss, use the value of the mass flux in the pipe. Neglect the vertical dimension of the pump. The isentropic efficiency of the pump is 80%.) (40%)

ii) The horizontal pipe leading to the spray nozzle is exposed to superheated steam at 200°C and 0.1 MPa. The length of the exposed section is 5 m. Estimate the heat transfer rate from the steam to the water inside the pipe. (Assume that the heat transfer coefficient on the outer surface of the pipe is 5000 W/m^2K. Neglect entry region effects in calculating the heat transfer coefficient within the pipe.) (15%)

iii) In light of the results in 'ii' judge the accuracy of the constant property assumption made in calculating the pumping power in 'i'. (5%)

Properties of water at room temperature (25°C)

Property	*Value*
Density	997 kg/m^3
Viscosity	9×10^{-4} Pa·s
Thermal conductivity	0.61 W/m·K
Specific heat	4.2 kJ/kg·K

Properties of steam at 200°C and 0.1 MPa

Property	*Value*
Density	0.46 kg/m^3
Viscosity	2×10^{-5} Pa·s
Thermal conductivity	0.03 W/m·K
Specific heat	2.0 kJ/kg·K

Properties of stainless steel

Property	*Value*
Density	8000 kg/m^3
Thermal conductivity	14 W/m·K
Specific heat	0.47 kJ/kg·K

Problem 2 (40%) – Radial and Axial Temperature Distribution in a Restructured Fuel Pin

You are to analyze the temperature distribution in a PWR fuel pin that has undergone restructuring.

Fuel Pin Geometry and Density

The fuel pin is composed of a clad, a gap and a UO_2 fuel pellet (Figure 2). Assume two zone fuel restructuring.

R_{co}	4.75 mm
R_{ci}	4.18 mm
R_{fo}	4.10 mm
Active fuel length, L	4.0 m
Density of the as-manufactured fuel pellet	95 %TD
Density of restructured fuel region (T≥1600°C)	97 %TD

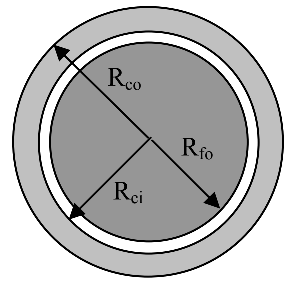

Figure 2. The as-manufactured fuel pin.

Thermo-physical Properties

Coolant specific heat, c_p	6.1 kJ/kg·K
Heat transfer coefficient (coolant/clad), h	25 kW/m^{2}K
Clad conductivity, k_c	13 W/m·K
Gap conductance, h_g	5 kW/m^{2}K
Fuel conductivity, k_f (at 95 %TD)	3 W/m·K (independent of temperature. Use Biancharia's correlation to account for the effect of porosity)

Operating Conditions

Coolant entry temperature	285°C
Mass flow rate in peak channel	0.38 kg/s
Peak linear power	40 kW/m
Axial power shape	Cosine
Operating pressure	15.5 MPa

i) Find the first axial location where restructuring occurs. (15%)

ii) What is the maximum fuel temperature at the pin midplane, i.e., 2 m from the inlet? (15%)

iii) Provide a *qualitative* plot of the fuel pellet void radius (R_v) as a function of the axial coordinate z. (10%)

Useful trigonometry formula to be used in solving Part 'i':

$$a \cdot \sin x - b \cdot \cos x = 1 \quad \Rightarrow \quad x = 2 \cdot \mathrm{atan}\left[\frac{a - \sqrt{a^2 + b^2 - 1}}{1 - b}\right]$$