22.312 ENGINEERING OF NUCLEAR REACTORS

Thursday, November 13th, 2014, 1:00 – 2:30 p.m.

OPEN BOOK QUIZ 2 1.5 HOURS

Problem 1 (50%) – Gas lift pump for a lead-cooled reactor

You are designing a lift pump for a small test fast reactor, cooled by molten lead. A lift pump consists in injection of an inert gas (such as helium) in the lead coolant, to create buoyancy. The region in which the lead/helium two-phase mixture is created is called the chimney. Helium naturally separates at the top of the chimney, while lead circulates back to the core via a downcomer, thus effectively realizing a flow loop. The situation is shown in the figure below.

The desired mass flow rate of liquid lead coolant in the core is 2,500 kg/s.

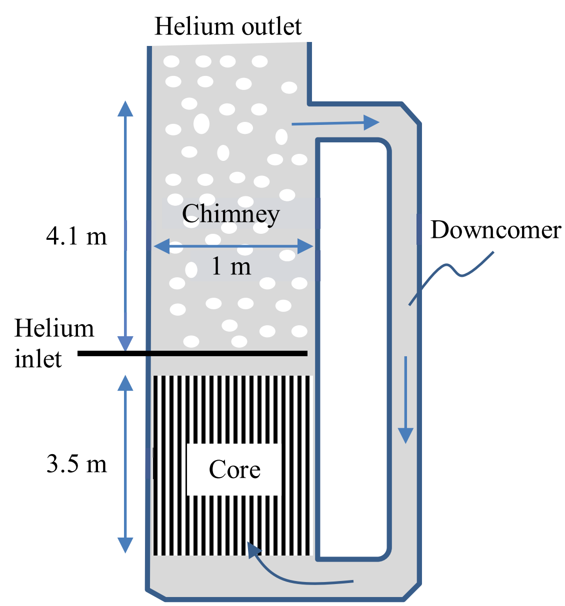
i) Find the void fraction required in the chimney to achieve the desired lead mass flow rate in the core. In solving this problem you may neglect all pressure changes due to friction, form and acceleration in the loop, except the friction pressure loss in the core. In calculating the friction factor in the core, you may neglect entrance effects. The core has a total flow area of 0.25 m^2, an equivalent diameter of 4.7 mm, and a length of 3.5 m. The chimney length is 4.1 m and its diameter is 1 m. (30%)

ii) For the value of void fraction found in Part 'i', calculate the mass flow rate of helium needed in the chimney. In solving this problem you may assume a slip ratio equal to 1.5. (10%)

iii) What is the likely flow regime in the chimney? Justify your answer. (10%)

The properties of helium and liquid lead are reported below and can be considered independent of both temperature and pressure:

Fluid	ρ (kg/m^3)	μ (Pa·s)
Molten Lead	10,400	1.9×10^{-3}
Helium	0.3	3.5×10^{-5}



Problem 2 (50%) – Lowering the temperature of the fuel in a PWR

The core of a PWR has a power rating of 4500 MW, 241 fuel assemblies and 264 fuel pins in each assembly. The fuel pins have the following dimensions: pin outer diameter 9.5 mm; cladding thickness 0.6 mm; gap thickness 0.1 mm; heated length 4.2 m. The cladding is made of Zircaloy-4. The power peaking factors are $P_{rad} = 1.40$, $P_{loc} = 1.18$ and $P_{ax}=1.50$.

i) Calculate the maximum linear power in the core. (5%)

A nuclear fuel vendor wishes to reduce the operating temperature in the fuel, without changing the total core power. This would increase the safety margin for undercooling accidents, without hurting the economics of the plant. Three *alternative* options are explored:

a) Change fuel pellet material, from UO_2 to U-Zr alloy.

b) Fill the gap with an inert liquid metal, such as molten tin.

c) Change the radial distribution of the enrichment in the pellet to get a non-uniform volumetric heat generation rate distribution, $q'''(r) = q_0'''[1+(r/R_f)]$, where q_0''' is the volumetric heat generation rate at the pellet centerline, r is the radial coordinate within the pellet, R_f is the radius of the pellet.

Please answer the following questions:

ii) For each of the three options listed above, calculate the *average* temperature in the fuel pellet at the location of maximum linear power. (40%)

iii) Which option would you choose? In your answer please consider the results in Part 'ii', but also other aspects of fuel design that you deem appropriate. (5%)

Properties of materials (assumed constant):

Material	ρ (kg/m^3)	k (W/m°C)	c (J/kg°C)
UO_2	10,300	2.8	250
U-Zr	16,000	25	130
Molten Tin	7,300	65	220
Zircaloy-4	6,500	20	330

Assumptions:

- Steady-state analysis
- At the location of interest in the core, the coolant has a bulk temperature of 310°C and a heat transfer coefficient of 38 kW/m^2°C.
- Gap conductance is 10 kW/m^2°C for options (a) and (c)
- Develop an appropriate gap conductance model for option (b) assuming the molten tin in the gap is stagnant

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Fall 2015