22.312 ENGINEERING OF NUCLEAR REACTORS

Tuesday, October 9th, 2014, 1:00 – 2:30 p.m.

OPEN BOOK	QUIZ 1	1.5 HOURS

Problem 1 (50%) – Loss of condensate pump transient in a LWR condenser

Consider the condenser of a large Light Water Reactor (LWR), which uses seawater as the heat sink (Figure 1). Wet steam (mass flow rate = 1,231 kg/s; enthalpy = 1,840 kJ/kg) enters the condenser and is condensed to saturated liquid water, which is drawn away by a condensate pump (not shown in the figure). At steady-state the condenser operating pressure and temperature are 0.03 bar (3.3 kPa) and 25°C, respectively. The seawater mass flow rate, inlet and outlet temperatures are 51,000 kg/s, 10°C and 20°C, respectively.

i) Find the heat transfer rate to seawater at steady conditions. (10%).

Now assume that the condensate pump stops working, and as a result no more condensate is drawn from the bottom of the condenser. During the ensuing transient the mass flow rate and enthalpy of the wet steam entering the condenser can be assumed constant and equal to their steady-state values stated above. The heat transfer rate to seawater can be assumed to be 90% of the value calculated in Part 'i'.

ii) After the condensate pump stops working, do the temperature and pressure in the condenser increase, decrease or stay the same? Answer qualitatively. (5%)

iii) Write a complete set of equations that would allow you to find the pressure and temperature in the condenser 30 seconds after the condensate pump stops working. (35%)

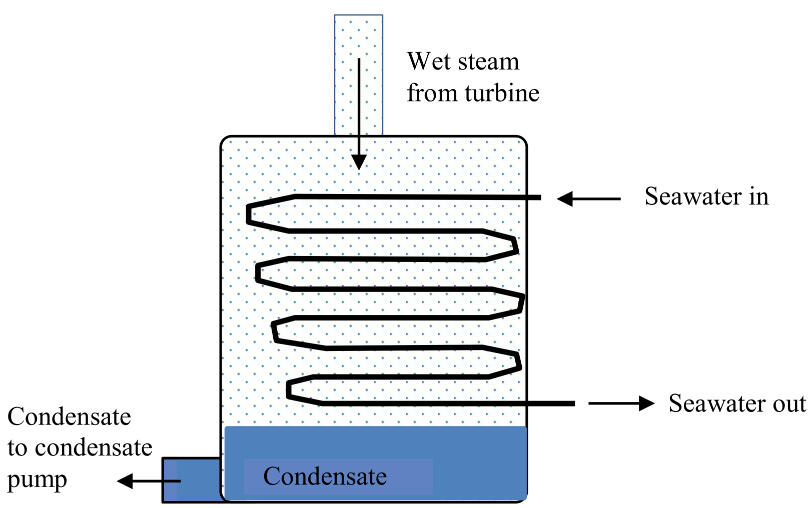

Figure 1. Schematic of the condenser.

Assumptions:

- Neglect kinetic and gravitational energy terms in the analysis
- Seawater heating in the condenser is isobaric
- Treat seawater as an incompressible fluid

Data:

Initial volume of condensate in the condenser: 86 m^3
Initial volume of steam in the condenser: 778 m^3

Properties of seawater: $c_w = 4190$ J/kg-K, $\rho_w = 1020$ kg/m^3

Properties of saturated water

T (°C)	P (kPa)	v_f (m^3/kg)	v_g (m^3/kg)	u_f (kJ/kg)	u_g (kJ/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg·K)	s_g (kJ/kg·K)
20	2.3	1.00×10^{-3}	57.8	83.9	2403	83.9	2538	0.297	8.667
25	3.3	1.00×10^{-3}	45.4	104.8	2410	104.8	2547	0.367	8.560
30	4.2	1.00×10^{-3}	32.9	125.7	2416	125.7	2556	0.437	8.453
35	5.8	1.00×10^{-3}	26.2	146.6	2423	146.6	2565	0.505	8.355
40	7.4	1.00×10^{-3}	19.5	167.5	2430	167.5	2574	0.572	8.257

Problem 2 (50%) – Thermal parameters in the core of a helium-cooled fast reactor

Figure 2 shows the power of each fuel pin in the hot fuel assembly of a small helium-cooled fast reactor. Assume the axial power profile within the pins follows a chopped-cosine function:

$$q'(z) = q'_{\max} \cos(\frac{\pi z}{L_e})$$

where z is the axial coordinate ($z = 0$ at core midplane), $L_e = 1.5 \cdot L$ is the extrapolated length, and $L = 1.2$ m is the heated length of the fuel pin.

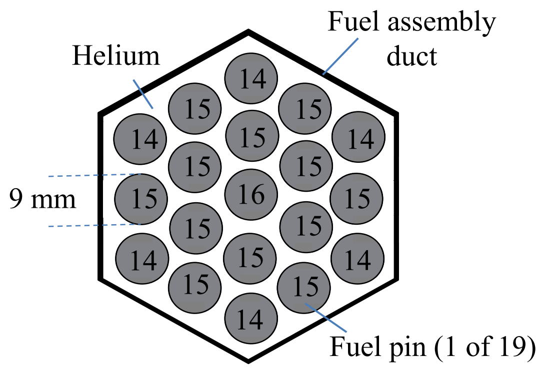

Figure 2. Cross sectional view of the hot fuel assembly. Values of fuel pin power are in kW.

i) Calculate the local power peaking factor (15%)

ii) Assuming the fuel pin diameter is 9 mm, calculate the maximum heat flux (on the outer surface of the cladding) in the assembly (15%)

In the same reactor the following conditions are observed for the helium coolant at steady state:
Core inlet: 5.0 MPa, 350°C, 38 m/s
Core outlet: 4.7 MPa, 700°C

The total core flow area is 0.75 m^2. Helium is an ideal gas ($c_v = 3116$ J/kg-K, $R = 2077$ J/kg-K). Calculate the following quantities:

iii) The coolant mass flow rate (10%)

iv) The coolant velocity at the outlet of the core. (5%)

v) The reactor power. (5%)