22.312 **ENGINEERING OF NUCLEAR REACTORS**

Tuesday, October 27th, 2009, 1:00 – 2:30 p.m.

OPEN BOOK QUIZ 1 1.5 HOURS

Problem 1 (60%) – Nuclear power plant for night-time desalination of seawater

A nuclear power plant located on the seashore of an arid country sells electricity to the grid during the day (from 6 am to 10 pm) and heat and electricity to a seawater desalination plant at night. In the day-time mode, the plant employs a simple Rankine cycle with saturated steam at 70 bar at the turbine inlet, and a condenser temperature of 40°C. In the night-time mode, the expansion in the turbine is terminated at 1 bar, followed by complete condensation at that pressure. During the night, the latent heat of condensation is used by the desalination plant, and the condensate is then pumped back to 70 bar. The reactor thermal power is 300 MW, constant day and night.

Assumptions:

- Electricity is sold at 8 ¢/kW-hour during the day, and 2 ¢/kW-hour at night. Heat to the desalination plant is 0.2 ¢/MJ.
- The isentropic efficiencies of the turbine and feedwater pump are 0.90 and 0.85, respectively.

Questions:

i) Sketch the cycle T-s diagram for the day-time and night-time modes of operation. (5%)

ii) Calculate the total revenues ($$) generated by the plant in one full day (24-hour). (35%)

iii) Would the plant owner be better off selling only electricity to the grid during the night? (5%)

iv) What is the 24-hour-averaged energy utilization factor (EUF) of the plant? The EUF is defined as the ratio of the energy utilized (net work + desalination heat) to the heat input (reactor heat). (10%)

v) What would the EUF be, if the plant operated in the electricity-production mode all the time? (5%)

Properties of saturated water

T (°C)	P (bar)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg·K)	s_g (kJ/kg·K)
40	0.074	1.01×10^{-3}	19.54	167	2574	0.572	8.257
100	1	1.04×10^{-3}	1.67	419	2676	1.307	7.354
285.7	70	1.35×10^{-3}	0.0275	1267	2772	3.119	5.815

Problem 2 (40%) – Nuclear energy storage in molten-salt pool

The heat produced by a High Temperature Gas Reactor (HTGR), rated at 500 MW_t, is transferred to and stored in a large pool of molten salt. The molten-salt pool has a cover gas (nitrogen), as shown in the figure below. During a transient lasting 3 minutes, 500 kg/s of molten salt are extracted from the bottom of the pool, while heat addition from the reactor continues at a steady 500 MW_t.

i) Write a complete set of equations that would allow you to find the pressure and temperature of the system at the end of the transient. (35%)

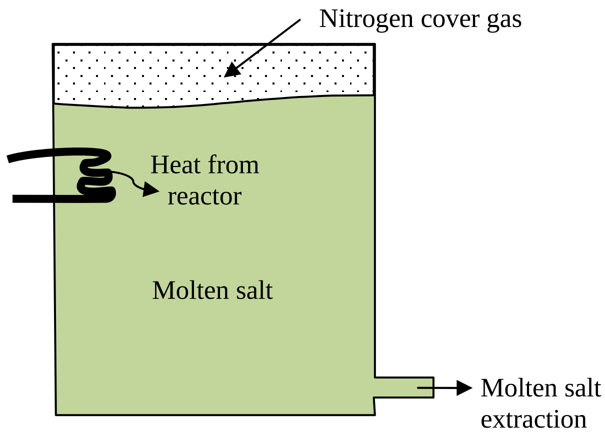

Figure 1. Schematic of the energy storage pool.

ii) If the cover gas were helium, how would the temperature and pressure at the end of the transient change with respect to the nitrogen case? A qualitative answer is acceptable. (5%)

Assumptions:

- The molten salt can be treated as an incompressible fluid (ρ = 1600 kg/m^3, c_p = 1200 J/kg-K) with zero vapor pressure.
- Nitrogen can be treated as a perfect gas (c_v = 742 J/kg-K, R = 297 J/kg-K).
- The enthalpy of the molten salt drawn from the bottom of the pool can be assumed to be constant during the transient.
- The pool is well insulated, so heat losses to the environment can be neglected.
- Neglect kinetic and gravitational energy terms in the analysis.
- Helium can be treated as a perfect gas (c_v = 3116 J/kg-K, R = 2077 J/kg-K).

Data:

Initial volume of molten salt in the pool: 1600 m^3

Initial volume of nitrogen: 160 m^3

Initial pressure of nitrogen and molten salt: 200 kPa

Initial temperature of nitrogen and molten salt: 600°C