22.312 **ENGINEERING OF NUCLEAR REACTORS**

Tuesday, October 16th, 2007, 2:30 – 4:00 p.m.

OPEN BOOK QUIZ 1 1.5 HOURS

Problem 1 (55%) - Nuclear cogeneration plant

A High-Temperature Gas Reactor (HTGR) is being considered for cogeneration of electricity and heat for residential heating. This HTGR uses the direct Brayton cycle shown in Figure 1, which comprises a turbine, a regenerator, a cogeneration heat exchanger ($3\rightarrow4$) and a compressor. The cogeneration heat exchanger is used to generate steam, which is then sent to the residential area served by the plant. The helium temperature and pressure at the turbine inlet are 1000 K and 9 MPa, respectively. The minimum temperature in the cycle is 373 K. The cycle operates with a compression ratio equal to 2. The isentropic efficiency for the turbo-machines (turbine and compressor) is 0.9. Assume negligible pressure losses throughout the cycle.

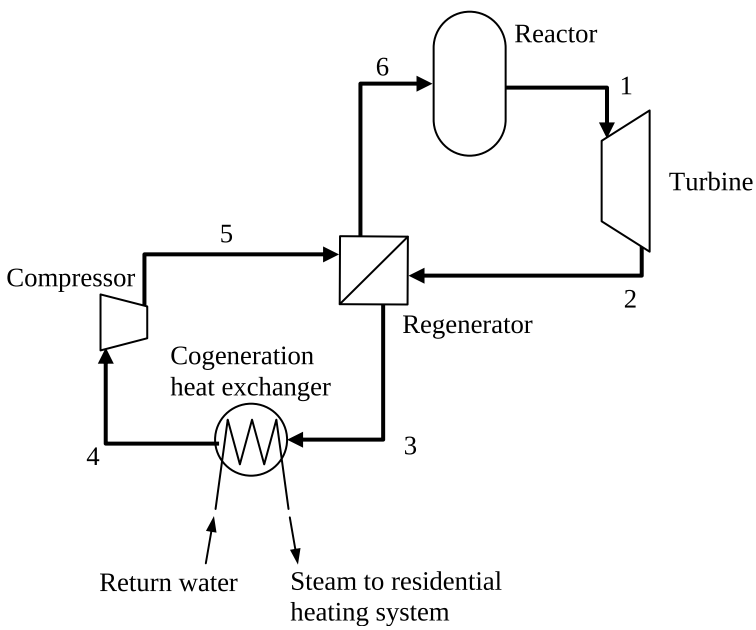

Figure 1. Schematic of the nuclear cogeneration plant.

i) Sketch the T-s diagram for the cycle. (5%)

ii) An important parameter to select is the cogeneration temperature T_3. If T_3 is too high, regeneration is minimal and the cycle thermal efficiency becomes too low. If T_3 is too low, the amount of heat delivered to the residential heating system may be too low. Find the value of T_3 that will give a cycle thermal efficiency equal to 30%. (30%)

iii) What is the energy utilization factor (EUF) of this cycle? The EUF is defined as the ratio of the energy utilized (net work + cogeneration heat) to the heat input (reactor heat). (5%)

iv) What is the reactor thermal power if the plant is to produce 100 kg/s of saturated steam at 0.5 MPa from the return water at 80°C? (10%)

v) Nuclear cogeneration for residential heating has been rarely done. What are in your opinion the drawbacks of this approach? (5%)

Useful properties

Helium: Treat as an ideal gas with c_p= 5193 J/kg-K, R=2077 J/kg-K, γ=1.667.
Water at 0.5 MPa (T_{sat}=152°C): specific heat = 4.24 kJ/kg-K, enthalpy of vaporization = 2109 kJ/kg

Problem 2 (45%) – Pressure rise in a BWR suppression pool during a LOCA

In a BWR containment the steam discharged from the reactor during a Loss of Coolant Accident (LOCA) is directed to and condensed in a large suppression pool (Figure 2). The free volume above the water in the pool (i.e., the so-called 'wet well') is sealed tight and filled with nitrogen gas. The wet well is equipped with a safety/relief valve that opens at 0.68 MPa.

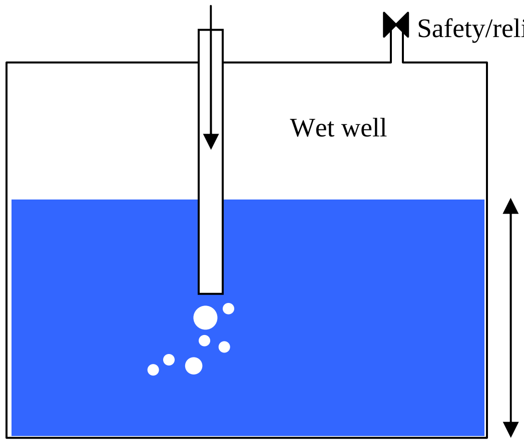

Figure 2. The BWR suppression pool.

i) Assuming that during a large LOCA the rate of steam discharge to the pool is 1000 kg/s (constant in time), write a complete set of equations that would allow you to calculate the time at which the safety/relief valve opens. (35%)

ii) Does the liquid level (i.e., height of water) in the pool increase, decrease or stay the same during the LOCA (prior to the safety/relief valve opening)? To get full credit for this question, it is sufficient to list the effects that tend to increase the level and those that tend to decrease the level, and take a guess based on your engineering judgment of the relative importance of such effects. (10%)

Data

Initial liquid water volume in the pool: 240 m^3
Initial volume of nitrogen: 200 m^3
Initial relative humidity of nitrogen: 100%
Initial temperature of the pool: 30°C
Initial pressure of the pool: 0.101 MPa (atmospheric)
Nitrogen specific heat at constant volume: 742 J/kg-K
Nitrogen gas constant: 297 J/kg-K
Enthalpy of the steam discharged into the pool: 2600 kJ/kg

Assumptions

- Steam tables are available
- Treat nitrogen as a perfect gas
- Thermodynamic equilibrium exists in the suppression pool throughout the accident
- Neglect kinetic and gravitational terms
- Neglect heat transfer between the pool and the surrounding structures