22.312 ENGINEERING OF NUCLEAR REACTORS

Tuesday, October 17th, 2006, 2:30 – 4:00 p.m.

OPEN BOOK	QUIZ 1	1.5 HOURS

Problem 1 (45%) – Assessment of a steam cycle with moisture separation and vapor compression

Consider the Carnot cycle in Figure 1, which uses water as the working fluid. It is well known that such cycle could not be realized in practice mainly due to the difficulties of designing and operating a two-phase mixture pump ($1 \rightarrow 2$). A bright MIT student thinks he can solve this problem by separating the liquid from the vapor at Point 1, separately compressing the liquid and vapor in a pump and compressor, respectively, and finally mixing the compressed liquid and vapor in an open feedwater heater. A schematic layout of the modified cycle is shown in Figure 2.

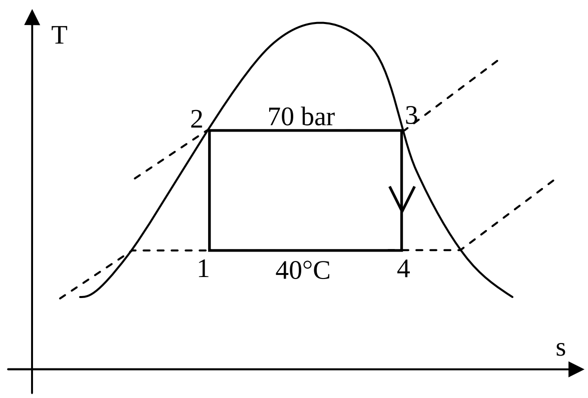

Figure 1. T-s diagram for the Carnot cycle.

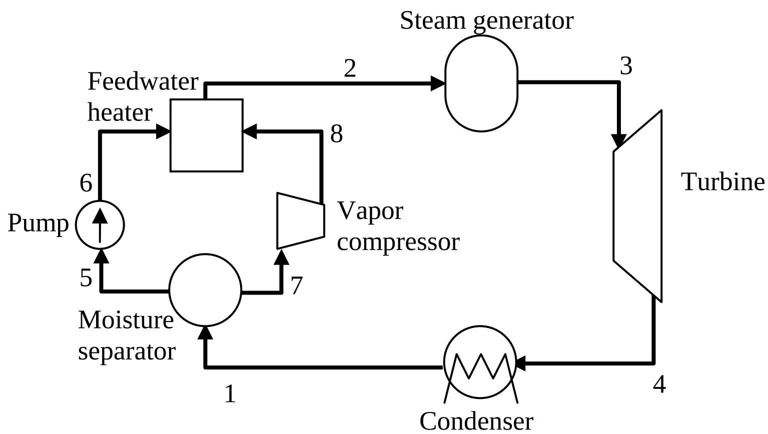

Figure 2. The modified cycle with moisture separation and vapor compression.

i) Sketch the T-s diagram for the modified cycle assuming the pump, compressor and turbine are ideal machines. (5%)

ii) Find the thermal efficiency of the modified cycle. (35%)

iii) Find the thermal efficiency of the Carnot cycle and compare it with the answer in ‘ii’. Does the student idea have merit? Why? (5%)

Data for 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	0.0737	1.01×10^{-3}	19.54	167	2574	0.572	8.257
285.7	70	1.35×10^{-3}	0.0275	1267	2772	3.119	5.815

Data for superheated vapor at 70 bar:

T (°C)	h (kJ/kg)	s (kJ/kg·K)
950	4497	7.905
1060	4775	8.122
1132	4957	8.257
1300	5403	8.555

Problem 2 (55%) – Analysis of a transient overpower in the PWR steam generator

The steam generator of a large PWR delivers dry saturated steam at 5.7 MPa to the turbine. Consider the steam generator secondary side, which has a volume of 100 m^3 and receives a thermal power $\dot{Q}$ from the primary coolant flowing in the U-tubes (Figure 3). At steady state the operating conditions for the secondary coolant are as follows:

- Inlet mass flow rate $\dot{m}_i$ = 456 kg/s
- Inlet temperature T_i = 267°C (h_i = 1170 kJ/kg)
- Mass of steam 880 kg
- Mass of liquid 54000 kg

i) Calculate $\dot{Q}$. (10%)

At one point in time the operator maneuvers the reactor so that the thermal power supplied to the secondary coolant increases to $1.2\dot{Q}$. Assume that the secondary coolant pressure, **inlet** mass flow rate and inlet temperature do not change during the transient.

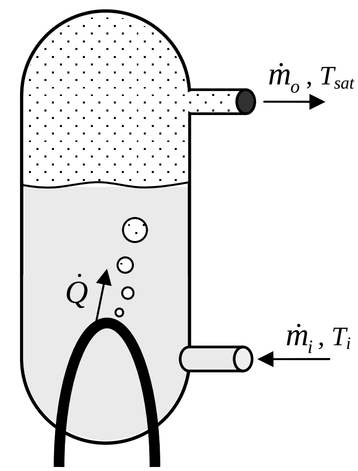

Figure 3. Schematic of the steam generator.

ii) Write a complete set of equations that would allow you to find how the secondary coolant mass ($M_{SC}(t)$) in the steam generator changes during the transient. Clearly identify all known and unknown parameters in the equations. You may neglect kinetic and gravitational terms. State all your assumptions. (30%)

iii) Does the secondary coolant **outlet** mass flow rate increase, decrease or stay the same during the transient? (5%)

iv) Now imagine that after 2 minutes both the secondary coolant inlet and outlet are suddenly and simultaneously closed shut, while the thermal power remains at $1.2\dot{Q}$. Does the secondary coolant pressure increase or decrease during this transient? Write a complete set of equations that would allow you to find the pressure change in the secondary coolant during this transient. (10%)

Properties of saturated water at 5.7 MPa.

Parameter	**Value**
T_{sat}	272°C
v_f	1.3×10^{-3} m^3/kg
v_g	0.034 m^3/kg
h_f	1196 kJ/kg
h_g	2788 kJ/kg
$C_{p,f}$	5.2 kJ/(kg°C)
$C_{p,g}$	4.7 kJ/(kg°C)
u_f	1189 kJ/kg
u_g	2592 kJ/kg