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ME 354 THERMODYNAMICS - II

Final Examination

- This is a 3-hour, closed-book examination.
- There are 4 questions. Read them very carefully.
- It is your responsibility to write clearly and legibly.
- Put your name and ID number on this page and return it with your examination booklet.
- My best wishes for the future.

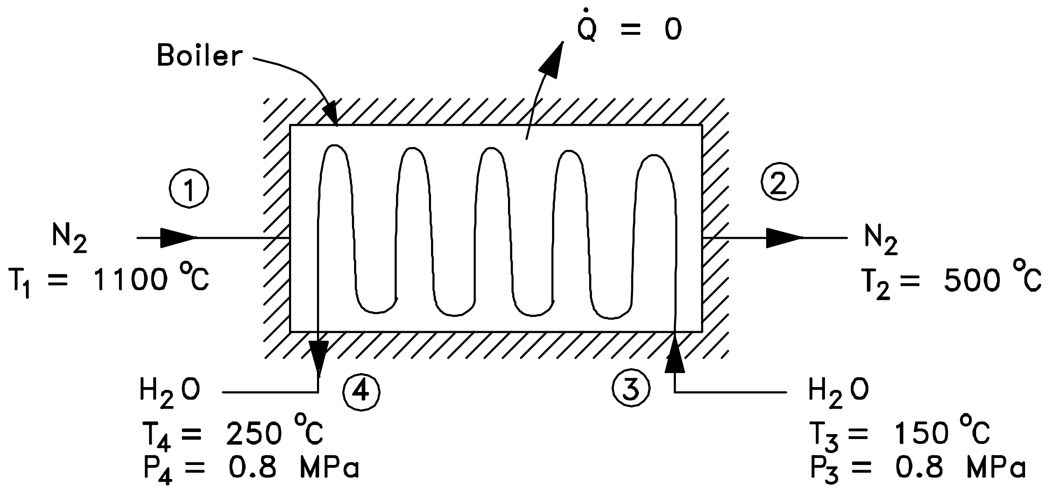
Question 1 (25%)

In the boiler of a typical power plant, H_20 flows inside the tubes lining the walls of the combustion chamber. Consider a case in which H_20 is brought from 0.8 MPa, 150^{o}C to 250^{o}C at essentially constant pressure while the combustion gases passing over the tubes cool from 1100^{o}C to 500^{o}C at essentially constant pressure. The combustion gases can be modeled as nitrogen (is this a reasonable assumption?). There is no significant heat transfer from the combustion chamber to the surroundings. See the sketch below.

a) Calculate the required mass flow rate of combustion gases per kg of H_20 flowing inside the tubes.

b) Calculate the rate of exergy destruction per kg of H_2O. Explain what exergy is and what caused its destruction in this particular process.

c) Develop a meaningful second law efficiency based on exergy for this heat exchanger.



Question 2 (25%)

Consider a steady ideal-gas compression process involving two compressors and an intercooler as shown below. The purpose of the intercooler is to have $T_3 = T_1$. Neglecting kinetic and potential energy effects, and assuming that each compression process is reversible and adiabatic, and that there is no pressure drop in the intercooler, answer the following:

a) What is the motivation for using an intercooler and two compressors instead of a single compressor to achieve state 4? To answer this, consider a single compressor and show that:

$$\frac{\dot{W}}{\dot{m}} = \int_1^2 v \, dP$$

b) Show the process on a P-v diagram. On this diagram, fix state 1 and then show the process path to state 4.

c) Show the process on a T-s diagram.

d) Show that the total compressor work requirement is:

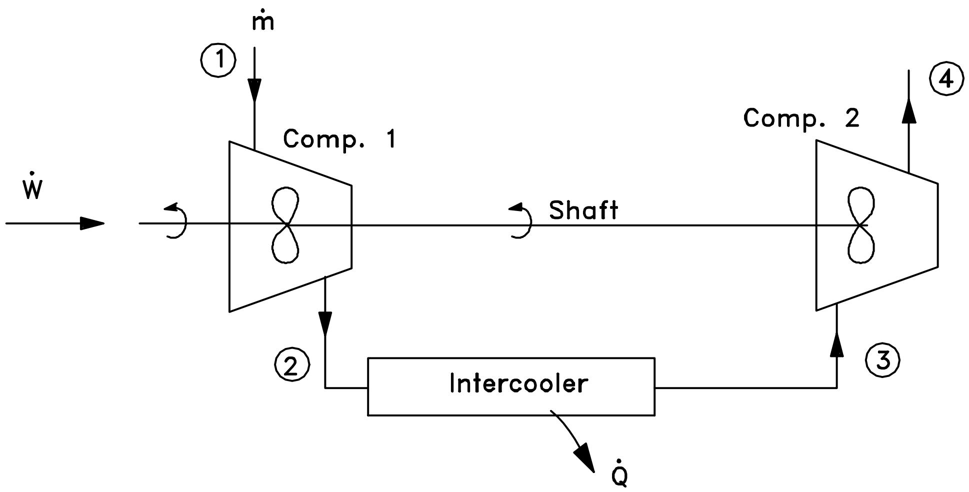
$$\dot{W} = \dot{m} c_p T_1 \left[\left(\frac{P_2}{P_1} \right)^a + \left(\frac{P_4}{P_3} \right)^a - 2 \right]$$

where $a = (k-1)/k$ and $k = c_p/c_v$ = constant.

e) Show that the minimum work requirement corresponds to:

$$\frac{P_2}{P_1} = \frac{P_4}{P_3}$$

that is, the pressure ratio is the same across each stage of the compression process.



Question 3 (25%)

The figure below shows a water desalination plant. Air is circulated between the evaporator and the condenser by means of a blower which is not shown in the figure. The basic principle in this design is that saturated air "holds" more water vapour as its temperature is increased. All relevant information is given in the figure. For a fresh water requirement of $\dot{m}_7 = 1200\ kg/hr$, calculate :

a) $\dot{m}_1$ = sea water pumping requirement

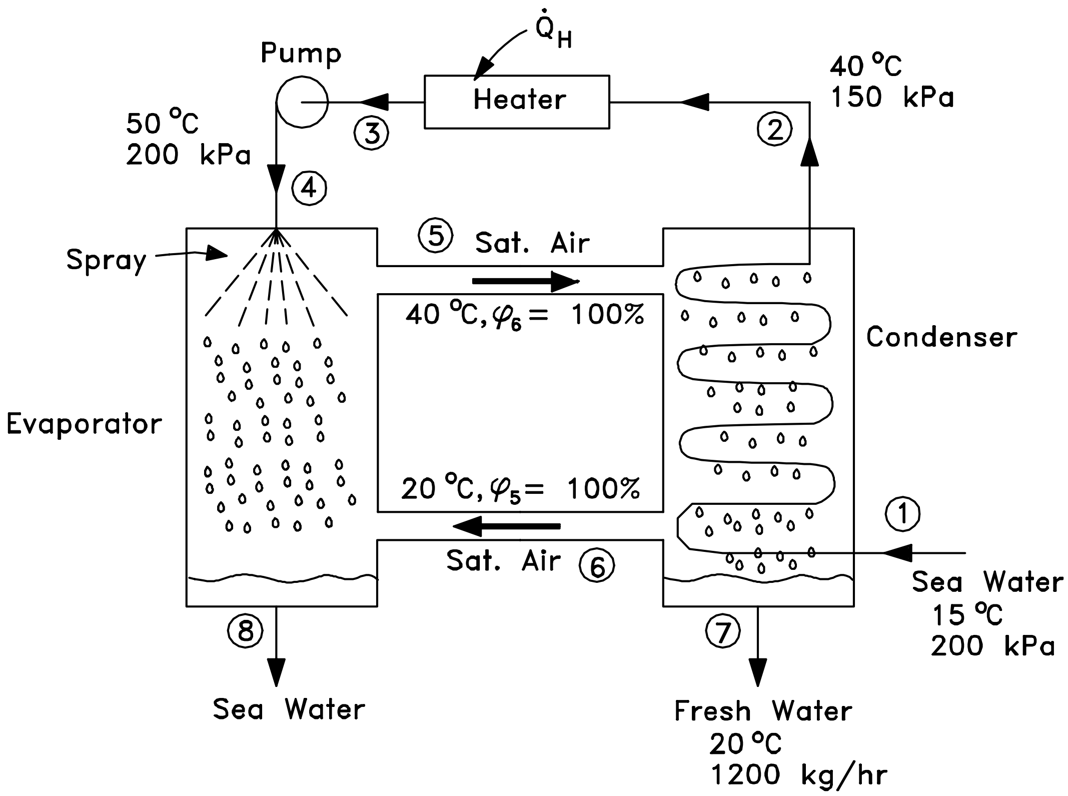
b) $\dot{m}_{a,6}$ = air circulation requirement

c) T_8 = sea water discharge temperature

d) $\dot{Q}_H$ = heat transfer requirement

Formulas: $$\phi \equiv \frac{P_w(T)}{P_{sat}(T)} \quad ; \quad \omega \equiv \frac{m_w}{m_a}$$

where w =water and a = air



Question 4 (25%)

The gas turbine shown below burns natural gas (essentially methane, CH_4 with 20% excess air. The air is provided by a compressor which has an isentropic efficiency ($\eta_c = \dot{W}_{isentropic}/\dot{W}_{actual}$) of 0.77. The compressor is driven by a turbine which has an isentropic efficiency ($\eta_t = \dot{W}_{actual}/\dot{W}_{isentropic}$) of 0.92. All other relevant information is given in the figure.

a) Calculate T_2.

b) Give a complete set of equations to obtain T_3. Do not substitute numbers.

c) Assuming $T_3 = 2073\ K$, calculate T_4.

d) Determine the thermal efficiency (η = benefit/penalty) of this gas turbine.