MECH 310 Thermodynamics I, Sections 1,2 ,3 December 10, 2011
American University of Beirut, Fall 2011
Professors: R. Slim, M. Al Hindi

Quiz 2 (100 minutes)

Problem 1

At steady state, an adiabatic air compressor is to be powered by a direct-coupled adiabatic steam turbine that is also driving an electrical generator. Steam enters the turbine at 12.5 MPa and 500°C at a rate of 25 kg/s and exits at 10 kPa and a quality of 0.92. Air enters the compressor at 98 kPa and 22°C at a rate of 520 m^3/min and exits at 1 MPa and 347°C. Determine the net power delivered to the electrical generator by the turbine.

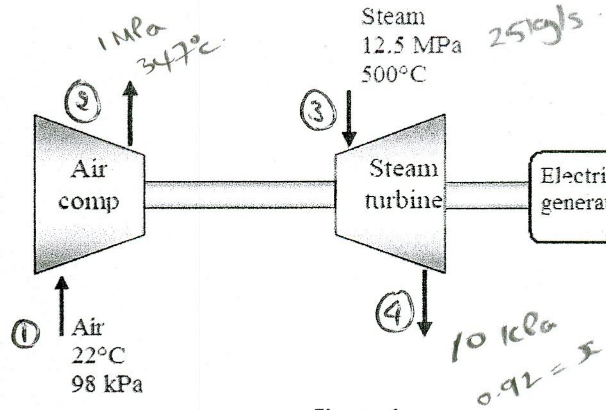


Figure 1

Steam tables:

(3) $P_3 = 12.5\,MPa$, $T_3 = 500°C$ } interpolation B1.3 $\Rightarrow h_3 = 3341.08$ kJ/kg

(4) $P_4 = 10\,kPa$, $x_4 = 0.92$ } Table B1.2 $\Rightarrow h_4 = h_f(10\,kPa) + x \times h_{fg}(10\,kPa)$

$\Rightarrow h_4 = 191.81 + 0.92 \times 2392.82 = 2393.204$ kJ/kg

Air table (A7)

$T_1 = 22 + 273 = 295K \Rightarrow h_1 = 295.45$ kJ/kg

$T_2 = 347 + 273 = 620K \Rightarrow h_2 = 628.38$ kJ/kg

$$\dot{m}_{air} = \frac{(AV)_{air}}{v_{air}} = \frac{(AV)_1}{v_1} = \frac{520}{60} \times \left(\frac{RT_1}{P_1}\right)^{-1} = \frac{520}{60} \times \left(\frac{0.287 \times 295}{98}\right)^{-1} = 10.03\ kg/s \quad (\sim 10\ kg/s)$$

C.V. air compressor

Energy rate balance @ steady state. $\dot{W}_{comp,in} = \dot{m}_{air}(h_2 - h_1) = 3329.3$ kW

C.V. steam turbine

Energy rate balance @ steady state $\dot{W}_{Turb,out} = \dot{m}_{steam}(h_3 - h_4) = 23721.9$ kW

$\dot{W}_{net,out} = \dot{W}_{Turb,out} - \dot{W}_{comp,in} = 23721.9 - 3329.3 = 20392.6$ kW

or **20.393 MW**

Problem 2

A 0.12-m^3 rigid tank contains saturated refrigerant-134a at 800 kPa. Initially, 25 % of the volume is occupied by liquid and the rest by vapor. A valve at the bottom of the tank is now opened, and liquid is withdrawn from the tank. Heat is transferred to the refrigerant such that the pressure inside the tank remains constant. The valve is closed when no liquid is left in the tank. For this process, find:

a. the amount of refrigerant that exited the tank and
b. the total heat transfer for this process.

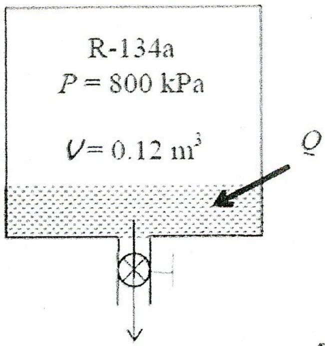


Figure 2

① $P_1 = 800\,kPa$
Table B.5.1 (interpolating)
$\Rightarrow v_f = 0.0008465\ m^3/kg$; $u_f = 242.93\ kJ/kg$
$v_g = 0.02571\ m^3/kg$. ; $u_g = 395.15\ kJ/kg$.

) $P_2 = 800\,kPa$
only sat vap $\Rightarrow v_2 = v_g(800\,kPa) = 0.02571\ m^3/kg$.
$u_2 = u_g(800\,kPa) =$ 395.15 kJ/kg

) At the exit : $P_e = 800\,kPa$
$h_e = h_f(800\,kPa) = 243.6\ kJ/kg$.

For C.V R134a: $(\Delta KE = \Delta PE = 0)$

$m_2u_2 - m_1u_1 = Q_{cv} - W_{cv} + m_i h_i - m_e h_e$ (W = 0, rigid tank; m_i = 0)

$\Rightarrow Q_{cv} = m_2u_2 - m_1u_1 + m_e h_e$.

$m_2 = \frac{V_2}{v_2} = \frac{0.12}{0.02571} = 4.667\ kg$.

$m_1 = \frac{V_1}{v_1} = m_g + m_f = \frac{0.25V_1}{v_f} + \frac{0.75V_1}{v_g} = \frac{0.25 \times 0.12}{0.0008465} + \frac{0.75 \times 0.12}{0.02571}$

$\simeq 35.44 + 3.5 = 38.94\ kg$. $\Rightarrow x_1 = \frac{3.5}{38.94} = 0.089$

$\Rightarrow m_e = m_1 - m_2 = 38.94 - 4.667 = \boxed{34.27\ kg = m_e}$

$Q_{cv} = 4.667 \times 395.15 - 38.94(242.93 + 0.089(395.15 - 242.93)) + 34.27 \times 243.$

$\boxed{Q_{cv} = 205.1\ kJ}$.

Problem 3

A simple steam power plant operates at steady state with water circulating through its components. The net power output of the power plant is 45 MW. Steam enters the turbine at 7 MPa and 500°C and exits with a quality of 82%. Water is then cooled in the condenser at a pressure of 10 kPa by running cooling water from a lake through the tubes of the condenser at a rate of 2000 kg/s. The working fluid leaves the condenser as saturated liquid. The enthalpy of water at the exit of the pump is of 200 kJ/kg. Figure 3 shows additional data at key points in the cycle.

Effects of kinetic and potential energy changes at all points of the cycle are negligible. Water experiences no pressure drop in the steam generator and the condenser of the plant. If the heat losses to the atmosphere of the cycle components are negligible, find:

a. the thermal efficiency,
b. the mass flow rate of the steam,
c. the temperature rise of the cooling water.

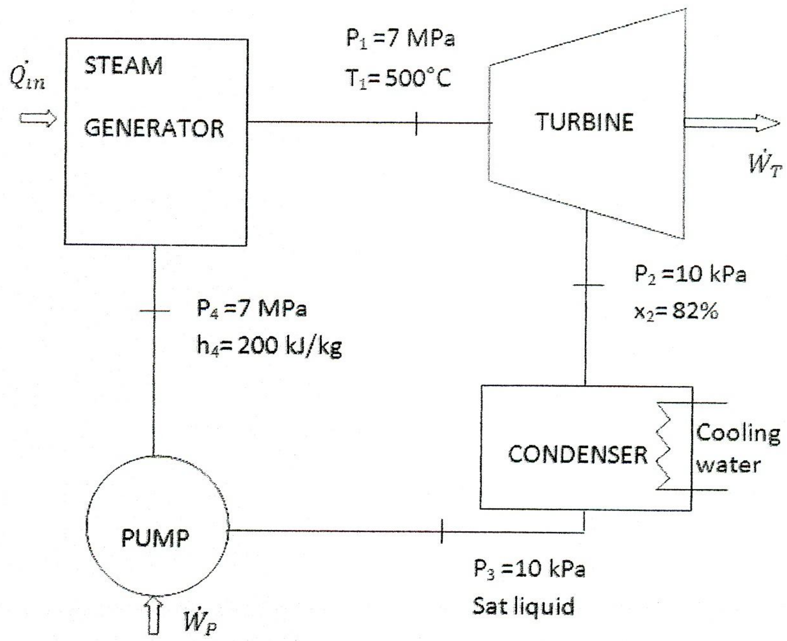


Figure 3

State ①:
$P_1 = 7 MPa$
$T_1 = 500°C$
interpolate in B1.3.
} $\Rightarrow h_1 = 3410.195$ KJ/Kg

State ②
$P_2 = 10 kPa$
$x_2 = 0.82$
B1.2
} $\Rightarrow h_2 = h_f(10 kPa) + x_2 h_{fg}(10 kPa) = 191.81 + 0.82(2392.82)$
$\Rightarrow h_2 = 2153.93$ KJ/Kg.

State ③
$P_3 = P_2 = 10 kPa$
sat liq
} $\Rightarrow h_3 = h_f(10) = 191.81$ KJ/Kg.

State ④
$P_4 = P_1 = 7 MPa$
$h_4 = 200$ KJ/Kg

a) $\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{\dot{W}_T - \dot{W}_P}{\dot{Q}_{in}} = \frac{\dot{m}(h_1 - h_2) - \dot{m}(h_4 - h_3)}{\dot{m}(h_1 - h_4)} = 1 - \frac{(h_2 - h_3)}{(h_1 - h_4)}$

$\Rightarrow \eta_{th} = 1 - \frac{2153.93 - 191.81}{3410.95 - 200} = 0.3889$ ✓ $\boxed{39\%}$

b) $\dot{W}_{net} = 45 \times 10^3 \text{ KW} = \dot{m}\left[(h_1 - h_2) - (h_4 - h_3)\right]$

$\Rightarrow \dot{m} = \frac{45 \times 10^3}{(3410.95 - 2153.93 - 200 + 191.81)}$

$\Rightarrow \boxed{\dot{m} = 36.03 \text{ Kg/s}}$

c) Heat rejection $\dot{Q}_{out} = \dot{m}(h_2 - h_3) = \dot{m}_{cw}(C \cdot \Delta T)$

(C: Table A4)

$\Rightarrow \Delta T = \frac{\dot{Q}_{out}}{\dot{m}_{cw} \cdot C} = \frac{36.03(2153.93 - 191.81)}{2000 \times 4.18} = \boxed{8.46°C}$

Bonus (5 points)

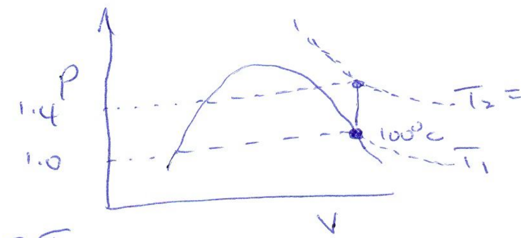
A well-insulated rigid tank having a volume of 3 m^3 contains saturated water vapor at 100°C. The water is rapidly stirred until the pressure is 1.4 Bar. Determine the temperature at the final state, and the work during the process.

State 1 :- Saturated Water Vapour, 100°c = T_1

From Table B.1.1

$u_1 = 2,506.1$ kJ/kg $P_1 = 1.0$ Bar. $v_1 = 1.672$ m³/kg

Mass $= \frac{3}{1.672} = 1.79$ kg.



State 2: Super heated Vapour, Pressure = 1.4 Bar.

Double interpolation to determine Temp, T_2 + u_2

From Table B.1.3, at 100 kPa + 200 kPa.

Temp = 229 °c.

u_2 = 2,722.8 kJ/kg.

⇒ W = 1.79 (2,722.8 − 2,506.1)

= 387.9 kJ