

**ME 18b, Midterm Exam**  
**Due by 5 pm, Tuesday May 5, 2009**

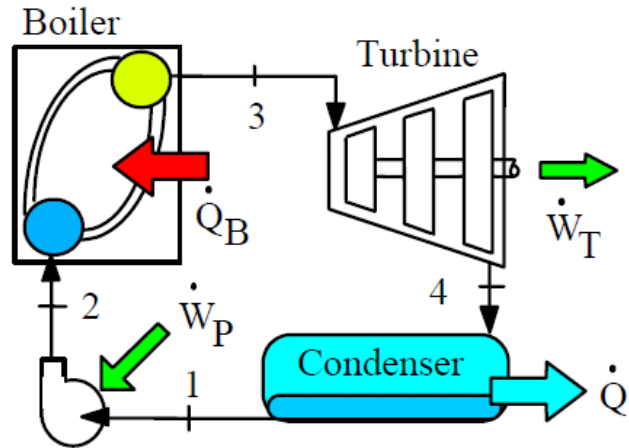
ME 18b Midterm Exam Spring 2009

1. Consider a simple ideal Rankine cycle with fixed turbine inlet conditions. What is the effect of lowering the condenser pressure on the following processes? Circle your responses.

|                                  |           |           |                   |
|----------------------------------|-----------|-----------|-------------------|
| Pump work input                  | Increases | Decreases | Remains unchanged |
| Turbine work output              | Increases | Decreases | Remains unchanged |
| Heat Supplied                    | Increases | Decreases | Remains unchanged |
| Heat Rejected                    | Increases | Decreases | Remains unchanged |
| Cycle efficiency                 | Increases | Decreases | Remains unchanged |
| Moisture Content at turbine exit | Increases | Decreases | Remains unchanged |

2. A steam power plant operates on the cycle shown below. If the adiabatic efficiency of the turbine is 87% and the pump is 85% determine the thermal efficiency of the cycle and the quality of the steam exiting the turbine.

| State | Temp, C | Pressure |
|-------|---------|----------|
| 1     | 40 C    | 7.5 kPa  |
| 2     | 40 C    | 15 MPa   |
| 3     | 600 C   | 15 MPa   |
| 4     |         | 10 kPa   |



Solution:

$$w_{\text{pump}} = v(P_2 - P_1)/\eta_p = 0.001(15\,000 - 7.5)/0.85 = 18 \text{ kJ/kg}$$

$$q_H = h_3 - h_2 = 3582 - 181 = 3401 \text{ kJ/kg}$$

$$w_{\text{turb}} = \eta_t(h_3 - h_{4s}) = (h_3 - h_{4a})$$

need to find steam quality at turbine exit first.  $s_3 = s_4 = 6.6775$

$$6.6775 = 0.6492 + x_{4s} * 7.5010, \quad x_{4s} = 0.804 \text{ (isentropic turbine quality)}$$

$$h_{4s} = 192 + x_{4s} * 2393 = 2115 \text{ kJ/kg} \quad \text{from steam table}$$

$$w_{\text{turb}} = 0.87(3582 - 2115) = 1276 \text{ kJ/kg}$$

$$h_{4a} = (h_3 - w_{\text{turb}}) = 3582 - 1276 = 2307 \text{ kJ/kg}$$

$$x_{4a} = (2307 - 192)/2393 = \mathbf{0.88}$$

$$\eta_{\text{th}} = (1275 - 18)/3401 = \mathbf{37\%}$$

3. Consider two vapor-compression refrigeration cycles. The refrigerant enters the throttling valves as a saturated liquid at  $30^{\circ}\text{C}$  in one cycle and as a subcooled liquid at  $30^{\circ}\text{C}$  in the other one. The evaporator pressure for both cycles is the same. Which cycle do you think will have a higher COP? Why?

The sat. liq. case will have the higher COP. The condenser pressure in the subcooled case will be higher than that of the sat. liq. case. Since the enthalpy of liquids doesn't change very much with small pressure changes the amount of heat rejection capacity doesn't change very much between the two cases. However, a small change in pressure can result in a large change in compressor work. Since the condenser in the sub cooled case must operate with a higher condenser pressure, it has a larger compressor work. This means it has a lower COP than the sat. liq. case.

4. Determine the coefficient of performance for an ideal refrigerator using R-134a as the fluid. The evaporator temperature is 5°C and the condenser exit temperature is at 40°C. Sketch the process on a T-s diagram.

Solution:

$$\beta_r = -q_{41}/w_{12}$$

$$q_{41} = h_1 - h_4$$

$$w_{12} = h_1 - h_2$$

State 1:

$$\text{sat. vapor at } 5^\circ\text{C:} \quad h_1 = 401 \text{ kJ/kg} \quad s_1 = s_2 = 1.724 \text{ kJ/kgK}, \quad P_1 = 351 \text{ kPa}$$

State 3:

$$\text{sat. liquid at } 40^\circ\text{C:} \quad h_3 = h_4 = 257 \text{ kJ/kg} \quad P_3 = P_2 = 1017 \text{ kPa}$$

State 2:

Superheated vapor at ~ 1000 kPa, need to interpolate for  $h_2$ .

$$X = (1.724 - 1.715)/(1.749 - 1.715); \quad X = 0.265$$

$$h_2 = 0.265(431 - 420) + 420 = 423 \text{ kJ/kg}$$

$$q_{41} = 401 - 257 = 144 \text{ kJ/kg}$$

$$w_{12} = 401 - 423 = -22 \text{ kJ/kg}$$

$$\beta_r = 144/22 = 6.5$$

5. An ideal Brayton cycle has a pressure ratio of 10.38 and a heat input during combustion of 750 kJ/kg. If the inlet conditions are 27°C and 101 kPa, find the temperature and pressure at the beginning and end of the combustion process

Solution:

First assuming variable specific heat:

At 300K,  $Pr_1 = 1.115$

$Pr_2 = (P_2/P_1)Pr_1 = 10.38(1.115) = 11.568$ , so  $T_2 = 580\text{K}$  or  $307^\circ\text{C}$

$P_2 = P_3 = 10.38(101 \text{ kPa}) = \mathbf{1.05 \text{ MPa}}$

$h_2 = 586 \text{ kJ/kg}$

$q_{23} = h_3 - h_2$ , so  $h_3 = 750 + 586 = 1336 \text{ kJ/kg}$  and  $T_3 = \mathbf{1250\text{K}}$  or  $977^\circ\text{C}$

Assuming constant specific heat (cold air std)

$T_2 = T_1(P_2/P_1)^{(k-1)/k} = 300(10.38)^{0.4/1.4} = 585\text{K}$  or  $312^\circ\text{C}$

$q_{23} = C_p(T_3 - T_2)$ , so  $T_3 = q_{23}/C_p + T_2 = 750/1 + 585 = \mathbf{1335\text{K}}$  or  $1062^\circ\text{C}$

The specific heat increases with temperature, using  $C_p$  at average process temperature of 915K would give a more accurate value than the cold air standard method.

6. Somebody claims that at very high pressure ratios, the use of regeneration in a Brayton cycle actually decreases the thermal efficiency of a gas-turbine engine. Is there any truth in this claim? Explain.

Yes it's true, as the pressure ratio ( $P_2/P_1$ ) of a Brayton cycle with regeneration increases, the efficiency of the cycle decreases. This is shown by observing the efficiency relationship for regenerative Brayton cycles:

$$\eta_{th} = 1 - (T_1/T_3)(P_2/P_1)^{(k-1)/k}$$

This contrasts with the efficiency of a regular Brayton cycle where the efficiency increases with the pressure ratio as seen in this relationship:

$$\eta_{th} = 1 - (P_1/P_2)^{(k-1)/k}$$