Problem 1

Consider an air-standard Diesel cycle with the following information:

Compression ratio: 12

P_1 = 100 kPa

T_1 = 290 K

V_1 = 350 cm^3

T_3 = 2000 K

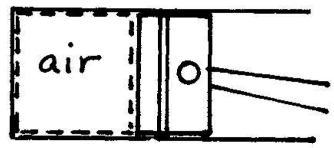
T_o = 293 K

P_o = 100 kPa

Source temperature: 1250 K

Boundary temperature: 450 K

k = 1.4, C_v = 0.718 kJ/kgK and C_p = 1.005 kJ/kgK



Calculate the following by using the ideal gas equations:

a) heat addition, b) net work output, c) thermal (energy) efficiency, d) mean effective pressure, e) exergy efficiency, f) write all mass, energy, entropy and exergy balance equations, find g) entropy generation for isobaric (constant-pressure) heat addition process and exergy destruction for isochoric (constant-volume) heat rejection, and h) show the cycle on a P-v diagram.

Problem 2

Consider an air standard cycle as presented in the figure with the pressure ratio, minimum and maximum temperatures and compressor and turbine isentropic efficiencies given.

Take C_v = 0.718 kJ/kgK, C_p = 1.005 kJ/kgK and k =1.4; use ideal gas equations

T_o = 293 K

Source temperature: 1400 K

Boundary temperature: 400 K

Calculate the following for a unit mass flow rate:

a) heat addition and rejection,

b) net work output,

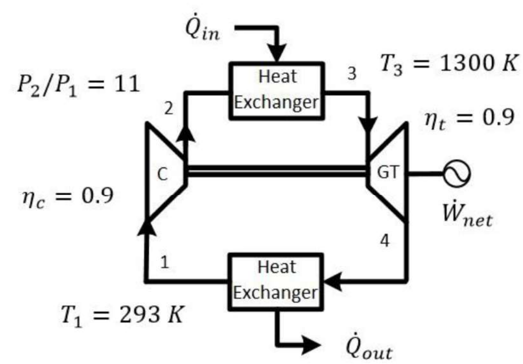
c) thermal (energy) efficiency,

d) exergy efficiency,

e) write all mass, energy, entropy and exergy balance equations, find;

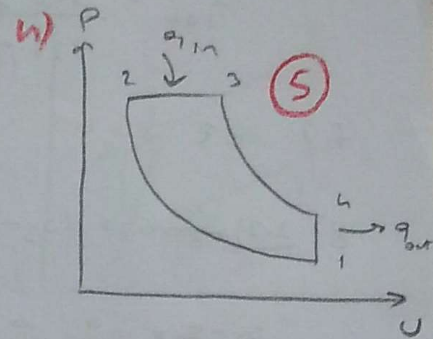
f) entropy generation for isobaric heat addition process and exergy destruction for isobaric heat rejection, and

g) show the cycle on a T-s diagram



Thermodynamics II : 1st Exam 10/04/2018

Problem (1)

e) 

(5)

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} \Rightarrow T_2 = 290 \cdot 12^{0.4} = 783.56\,K$$

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \Rightarrow \frac{v_3}{v_2} = \frac{2000\,K}{783.56} = 2.55$$

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{k-1} \Rightarrow \frac{v_3}{v_4} = \frac{v_3}{v_2} \cdot \frac{v_2}{v_4} = 2.55 \cdot \frac{1}{12} \Rightarrow T_4 = 2000\,K \cdot \left(\frac{2.55}{12}\right)^{0.4} = 1076.4\,K$$

($v_4 = v_1$)

f) **1-2**

mBE: $m_1 = m_2 = m$

EBE: $m_1 u_1 + W_{in} = m_2 u_2$

EnBE: $m_1 s_1 + S_{gen} = m_2 s_2$

ExBE: $m_1 ex_1 + W_{in} = m_2 ex_2 + Ex_D$

(15)

2-3

mBE: $m_2 = m_3 = m$

EBE: $m_2 u_2 + Q_{in} + W_{b_2} = m_3 u_3 + W_{b_3}$

$m_2 h_2 + Q_{in} = m_3 h_3$

EnBE: $m_2 s_2 + Q_{in}/T_s + S_{gen} = m_3 s_3$

ExBE: $m_2 ex_2 + Ex^{Q_{in}} = m_3 ex_3 + Ex_D$

3-4

mBE: $m_3 = m_4 = m$

EBE: $m_3 u_3 = m_4 u_4 + W_{out}$

EnBE: $m_3 s_3 + S_{gen} = m_4 s_4$

ExBE: $m_3 ex_3 = m_4 ex_4 + W_{out} + Ex_D$

4-1

mBE: $m_4 = m_1 = m$

EBE: $m_4 u_4 = m_1 u_1 + Q_{out}$

EnBE: $m_4 s_4 + S_{gen} = m_1 s_1 + Q_{out}/T_b$

ExBE: $m_4 ex_4 = m_1 ex_1 + Ex^{Q_{out}} + Ex_D$

a) $q_{in} = h_3 - h_2 = c_p \cdot (T_3 - T_2) = 1222.53\ kJ/kg$ (5)

b) $q_{out} = u_4 - u_1 = c_v \cdot (T_4 - T_1) = 560.6\ kJ/kg$

$w_{net} = 661.93\ kJ/kg$ (5)

c) $\eta_{th} = \frac{w_{net}}{q_{in}} = 0.54\ (54\%)$ (5)

$P_1 v_1 = R \cdot T_1 \Rightarrow v_1 = \frac{0.287 \cdot 290}{100} = 0.83\ m^3/kg$

d) $MEP = \frac{w_{net}}{v_1 - v_2} \Rightarrow \frac{661.93}{v_1\left(1 - \frac{v_2}{v_1}\right)} = 870.04\ kPa$ (5)

e) $Ex^{q_{in}} = \left(1 - \frac{290}{1250}\right) \cdot 1222.53 = 938.9$ kJ/kg

$\eta_{ex} = \frac{661.93}{938.9} = 0.705$ (70.5%) (5)

f) BE 15 ✓

g) 2-3) $S_{gen} = (s_3 - s_2) - \frac{q_{in}}{T_s}$

$s_3 - s_2 = s_3^o - s_2^o - R \cdot \ln\left(\frac{P_3}{P_2}\right) = 3.7994 - 2.6954 = 1.104$ kJ/kgK

$S_{gen} = 1.104 - \frac{1222.53}{1250} = 0.126$ kJ/kgK ✓ (heat addition)

4-1) $S_{gen} = (s_1 - s_4) + \frac{q_{out}}{T_b}$

$\frac{P_4 v_4}{T_4} = \frac{P_1 v_1}{T_1} \Rightarrow \frac{P_4}{P_1} = \frac{T_4}{T_1} = \frac{959.4}{290} = 3.308$

$s_4 - s_1 = s_4^o - s_1^o - R \cdot \ln\left(\frac{P_4}{P_1}\right)$ (5)

$= 2.3212 - 1.668 - 0.287 \cdot \ln 3.308$

$= 0.909$

$S_{gen} = \frac{560.6}{450} - 0.909 = 0.337$ kJ/kgK (heat rejection)

$Ex_D = 290 \cdot 0.337 = 97.66$ kJ/kg (heat rejection)

h) P-v diagram 5 ✓

Thermodynamics II 1st Exam 10/04/2018

Problem (2)

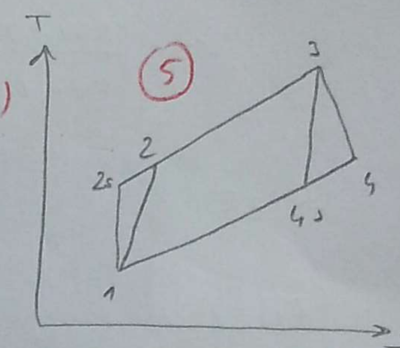
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} \Rightarrow T_{2s} = 293K \cdot 11^{0.4/1.4} = 581.31K$$

$$\eta_c = \frac{T_{2s}-T_1}{T_2-T_1} \Rightarrow T_2 = 613.35$$

$$\frac{T_{4s}}{T_3} = \left(\frac{P_4}{P_3}\right)^{(k-1)/k} \Rightarrow T_{4s} = 1300K \cdot \left(\frac{1}{11}\right)^{0.4/1.4} = 655.24K$$

$$\eta_T = \frac{T_3-T_4}{T_3-T_{4s}} \Rightarrow T_4 = 719.7K$$

g) (5)



e) 1-2

MBE $\dot m_1 = \dot m_2 = \dot m$

EBE $\dot m_1 h_1 + \dot W_{in} = \dot m_2 h_2$

EnBE $\dot m_1 s_1 + S_{gen} = \dot m_2 s_2$

ExBE $\dot m_1 ex_1 + \dot W_{in} = \dot m_2 ex_2 + \dot E_{xD}$

(15)

2-3

MBE $\dot m_2 = \dot m_3 = \dot m$

EBE $\dot m_2 h_2 + \dot Q_{in} = \dot m_3 h_3$

EnBE $\dot m_2 s_2 + \frac{\dot Q_{in}}{T_3} + S_{gen} = \dot m_3 s_3$

ExBE $\dot m_2 ex_2 + \dot E_x^{Q_{in}} = \dot m_3 ex_3 + \dot E_{xD}$

3-4

MBE $\dot m_3 = \dot m_4 = \dot m$

EBE $\dot m_3 h_3 = \dot m_4 h_4 + \dot W_{out}$

EnBE $\dot m_3 s_3 + S_{gen} = \dot m_4 s_4$

ExBE $\dot m_3 ex_3 = \dot m_4 ex_4 + \dot W_{out} + \dot E_{xD}$

4-1

MBE $\dot m_4 = \dot m_1 = \dot m$

EBE $\dot m_4 h_4 = \dot m_1 h_1 + \dot Q_{out}$

EnBE $\dot m_4 s_4 + S_{gen} = \dot m_1 s_1 + \frac{\dot Q_{out}}{T_L}$

ExBE $\dot m_4 ex_4 = \dot m_1 ex_1 + \dot E_x^{Q_{out}} + \dot E_{xD}$

a) $q_{in} = h_3 - h_2 = c_p \cdot (T_3 - T_2) = 1.005 \cdot (1300 - 613.35)$

$= 690.08$ kJ/kg

$q_{out} = h_4 - h_1 = c_p (T_4 - T_1) = 1.005 (719.7 - 293) =$

$= 428.85$ kJ/kg (5)

b) $w_{net} = 261.23$ kJ/kg (5)

c) $\eta_{th} = \frac{261.23}{690.08} = 0.38$ (38%) (5)

d) $Ex^{Qin} = \left(1 - \frac{290}{1400}\right) \cdot 690.08 = 547.135$ kJ/kg

$\eta_{ex} = \frac{261.23}{547.135} = 0.48$ (48%) ⑤

e) BE 15 ✓

f) 2-3) $S_{gen} = s_3 - s_2 - \frac{q_{in}}{T_s}$

$s_3 - s_2 = s_3^o - s_2^o - R\ln\left(\frac{P_3}{P_2}\right) = 3.274 - 2.431$

$= 0.843$ kJ/kgK

⑤ $S_{gen} = 0.843 - \frac{690.08}{1400} = 0.35$ kJ/kgK (heat addition)

4-1) $S_{gen} = s_1 - s_4 + \frac{q_{out}}{T_L}$

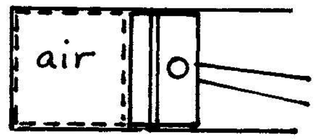
$s_4 - s_1 = s_4^o - s_1^o - R.\ln\left(\frac{P_4}{P_1}\right) = 2.603 - 1.67 = 0.933$ kJ/kgK

$S_{gen} = \frac{428.85}{400} - 0.933 = 0.139$ kJ/kgK

⑤ $Ex_D = 0.139 \cdot 293 = 40.76$ kJ/kg (heat rejection)

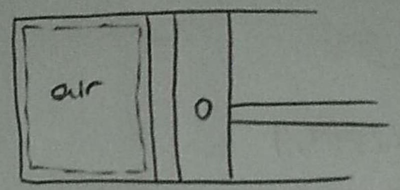
g) T-s diagram 5 ✓

Consider an air-standard Otto cycle with the following information:
Compression ratio: 8
P_1 = 100 kPa
T_1 = 290 K
V_1 = 400 cm3
T_3 = 2200 K
To = 290 K
Po = 100 kPa
Source temperature: 1300 K
k = 1.4 and Cv = 1.0035 kJ/kgK



Calculate the following by using the ideal gas equations:
a) heat addition, b) net work output, c) thermal (energy) efficiency, d) mean effective pressure, e) exergy efficiency, f) write all mass, energy, entropy and exergy balance equations, find g) entropy generation for isochoric (constant-volume) heat addition process and exergy destruction for isochoric (constant-volume) heat rejection, and h) show the cycle on a P-v diagram.

(1)



$P_1 = 100 kPa$ $\quad T_3 = 2200 K$ $\quad T_0 = 290 K$

$T_1 = 290 K$ $\quad P_0 = 100 kPa$

$V_1 = 400 cm^3$

$k = 1.4$

$c_v = 0.718 \, kJ/kgK$

$c_p = 1.005 \, kJ/kgK$

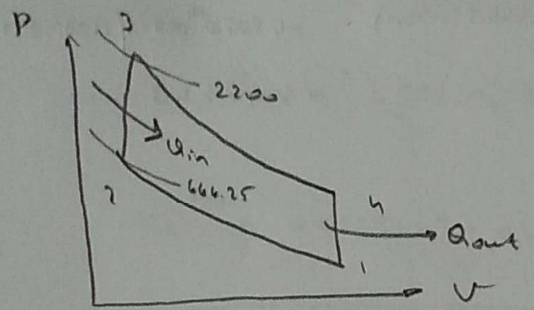
$P_1 \cdot v_1^k = P_2 \cdot v_2^k$

$$\frac{P_1 v_1 = R T_1}{P_2 v_2 = R T_2} \qquad \frac{P_1}{P_2} = \frac{T_1}{T_2} \cdot \frac{v_2}{v_1}$$

$$\frac{P_1}{P_2} = \left(\frac{v_2}{v_1}\right)^k \Rightarrow \frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1} \Rightarrow \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{k-1}$$

$$\frac{290K}{T_2} = \left(\frac{1}{8}\right)^{0.4}$$

$$\boxed{T_2 = 666.25 K}$$



$$\frac{T_4}{T_3} = \left(\frac{V_4}{V_3}\right)^{k-1}$$

$$\frac{T_4}{2200K} = \left(\frac{1}{8}\right)^{0.4} \qquad \boxed{T_4 = 957.6 K}$$

$$P_1 V_1 = m_1 R T_1 \Rightarrow m_1 = \frac{100 kPa \cdot 400 cm^3}{0.278 \frac{kJ}{kgK} \cdot 290K} = 4.806 \cdot 10^{-4} \, kg$$

1-2)

mBE $\quad m_1 = m_2 = m$

EBE $\quad mu_1 + W_{in} = mu_2$

EnBE $\quad ms_1 + S_{gen} = ms_2$

ExBE $\quad mex_1 + W_{in} = mex_2 + Ex_D$

2-3)

mBE $\quad m_2 = m_3 = m$

EBE $\quad mu_2 + Q_{in} = mu_3$

EnBE $\quad ms_2 + \frac{Q_{in}}{T_{source}} + S_{gen} = ms_3$

ExBE $\quad mex_2 + Ex^{Q_{in}} = mex_3 + Ex_D$

3-4)

mBE $\quad m_3 = m_4 = m$

EBE $\quad mu_3 = mu_4 + W_{out}$

EnBE $\quad ms_3 + S_{gen} = ms_4$

ExBE $\quad mex_3 = mex_4 + W_{out} + Ex_D$

4-1)

mBE $\quad m_4 = m_1 = m$

EBE $\quad mu_4 = mu_1 + Q_{out}$

EnBE $\quad ms_4 + S_{gen} = ms_1 + \frac{Q_{out}}{T_{boundary}}$

ExBE $\quad mex_4 = mex_1 + e_x^{Q_{out}} + Ex_D$

heat addition

$mu_2 + Q_{in} = mu_3 \Rightarrow Q_{in} = m(u_3 - u_2) = m \cdot c_v \cdot (T_3 - T_2)$

$= 4.806 \cdot 10^{-4} \cdot 0.718 \cdot (2200 - 666,25)$

$= \underline{0.529 \text{ kJ}}$

net work output

$W_{net} = W_{out} - W_{in}$

$mu_1 + W_{in} = mu_2$

$W_{in} = m \cdot c_v \cdot (T_2 - T_1)$

$= 4.806 \cdot 10^{-4} \cdot 0.718 \cdot (666.25 - 290)$

$= 0.13 \text{ kJ}$

$mu_3 = mu_4 + W_{out}$

$W_{out} = m \cdot c_v \cdot (T_3 - T_4)$

$= 4.806 \cdot 10^{-4} \cdot 0.718 (2200 - 357.6)$

$= 0.429 \text{ kJ}$

$\boxed{W_{net} = 0.298 \text{ kJ}}$

thermal efficiency

$\eta = \dfrac{W_{net}}{Q_{in}} = \dfrac{0.298}{0.529 \text{ kJ}} = 0.563 \quad (56.3\%)$

mean effective pressure

$mep = \dfrac{W_{net}}{V_1 - V_2} = \dfrac{W_{net}}{V_1\left(1 - \frac{V_2}{V_1}\right)} = \dfrac{0.298 \text{ kJ}}{400 cm^3\left(1 - \frac{1}{8}\right)} \cdot \dfrac{kNm}{kJ} \cdot \dfrac{1 bar}{10^5 N/m^2} \cdot \dfrac{10^6 cm^3}{1 m^3} = \underline{8.54 \text{ bar}}$

exergy efficiency

$\eta_{ex} = \dfrac{W_{net}}{E_x^{Q_{in}}}$

$ms_2 + \dfrac{Q_{in}}{T_{source}} + S_{gen} = ms_3$

$s_3 - s_2 = c_p \cdot \ln\left(\dfrac{T_3}{T_2}\right) - R \cdot \ln\left(\dfrac{P_3}{P_2}\right)$

$v_3 = v_2 \Rightarrow \dfrac{P_3}{P_2} = \dfrac{T_3}{T_2}$

$= 1.005 \ln\left(\dfrac{2200}{666.25}\right) - 0.278 \ln\left(\dfrac{2200}{666.25}\right)$

$= 0,868 \text{ kJ/kgK}$ or $c_v \cdot \ln\left(\dfrac{T_3}{T_2}\right) + R \cdot \ln\left(\dfrac{V_3}{V_2}\right)$

$= 0.718 \cdot \ln\left(\dfrac{2200}{666.25}\right)$ ✓

from 2-3 EnBE

$$S_{gen} = 4.806 \cdot 10^{-4} \cdot 0{,}868 - \frac{0{,}529\,kJ}{1300\,K}$$

$$S_{gen} = 0.00001\ kJ/K$$ entropy generation for heat adding

$$Ex_D = T_0 \cdot S_{gen} = \underline{0{,}00297\ kJ}$$

from 2-3 ExBE

$$Ex^{Q_{in}} = Ex_D + m.(ex_3 - ex_2)$$

$$ex_3 - ex_2 = \underbrace{(u_3 - u_2)}_{c_v.(T_3-T_2)} - T_0\,\underbrace{(s_3 - s_2)}_{0.868} = 0.718\,(2200-666.25) - 290 \cdot 0.868 = 849.5\ \frac{kJ}{kg}$$

$$m(ex_3 - ex_2) = 4.806 \cdot 10^{-4}\,kg \cdot 849.5 \frac{kJ}{kg} = 0.408\ kJ$$

$$Ex^{Q_{in}} = 0.00297\,kJ + 0.408\,kJ = 0.411\ kJ$$

or

$$Ex^{Q_{in}} = \left(1 - \frac{T_0}{T_{source}}\right) \cdot Q_{in} = \left(1 - \frac{290}{1300}\right) \cdot 0{,}529 = \underline{0{,}411\ kJ}$$

$$\boxed{\eta_{ex} = \frac{0.298\,kJ}{0.411\,kJ} = 0.725\ (72.5\%)}$$

exergy destruction for heat rejection

$$ms_4 + S_{gen} = ms_1 + \frac{Q_{out}}{T_{boundary}} \qquad S_{gen} = m(s_1 - s_4) + \frac{Q_{out}}{T_{boundary}}$$

$$T_b = \frac{T_1 + T_4}{2} = \frac{290 + 957.6}{2} = 623.8\,K$$

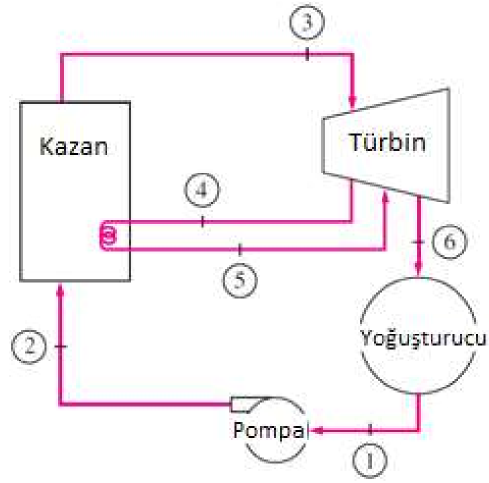
$$Q_{out} = m(u_4 - u_1) = m.0.718.(957.6 - 290)$$

$$S_{gen} = 4.806 \cdot 10^{-4} \cdot \left[1.005 \cdot \ln\left(\frac{2200}{666.25}\right) - 0.278 \cdot \ln\left(\frac{2200}{666.25}\right)\right] + \frac{0.23\,kJ}{623\,K}$$

$$= 0.000417\ kJ/K$$

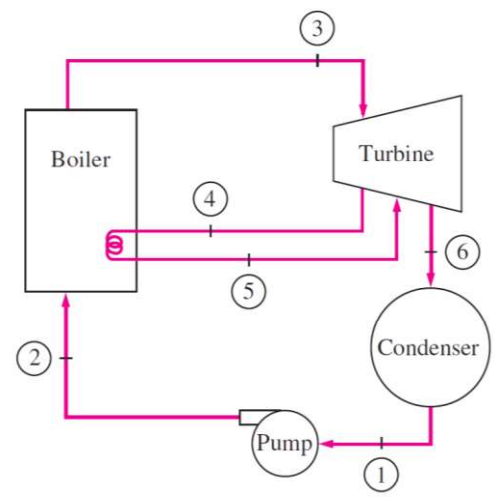
$$Ex_D = T_0\,S_{gen} = 290 \cdot 0.000417 = \underline{0.121\ kJ}$$

İdeal ara ısıtmalı Rankine çevrimine göre çalışan bir buharlı güç santralinde, su buharı yüksek basınç türbinine 6MPa basınç ve 500 °C sıcaklıkta girmekte, doymuş buhar olarak çıkmaktadır. Buhar daha sonra 450 °C sıcaklığa ısıtılmakta ve alçak basınç türbininde 7.5 kPa basınca genişletilmektedir. Kazanda buhara verilen ısı gücü 60 MW'dır. Yoğuşturucuda buharın soğutulması, yakınlardaki bir akarsudan yararlanılarak gerçekleştirilmekte ve soğutma suyu yoğuşturucuya 7 °C sıcaklıkta girmektedir.



a) Çevrimi doymuş sıvı ve doymuş buhar eğrilerinin de yer aldığı T-s diyagramında gösteriniz.
b) Tüm kütle, enerji, entropi ve ekserji denge eşitliklerini yazarak,
c) Ara ısıtmanın yapıldığı basıncı,
d) Çevrimin net gücünü ve ısıl verimini,
e) Gerekli en az soğutma suyu debisini hesaplayınız
f) Kaynak sıcaklığını 1600 K, kuyu sıcaklığını 285 K alarak, çevrime ısı girişinin olduğu hal değişimiyle ilgili ekserji yok oluşunu hesaplayınız.
g) Kazan çıkışındaki buharın ekserjisini de belirleyiniz. (P_0=100kPa)

Steam enters the high-pressure turbine of a steam power plant that operates on the ideal reheat Rankine cycle at 6 MPa and 500°C and leaves as saturated vapor. Steam is then reheated to 450°C before it expands to a pressure of 7.5 kPa. Heat is transferred to the steam in the boiler at a rate of 60 MW. Steam is cooled in the condenser by the cooling water from a nearby river, which enters the condenser at 7°C.



a) Show the cycle on a *T-s* diagram with respect to saturation lines, and determine
b) write all mass, energy, entropy and exergy balance equations,
c) find the pressure at which reheating takes place,
d) net power output and thermal efficiency,
e) the minimum mass flow rate of the cooling water required.
f) Determine the exergy destruction associated with the heat addition process. Assume a source temperature of 1600 K and a sink temperature of 285 K.
g) Also, determine the exergy of the steam at the boiler exit. (P_0=100kPa)

10-35 A steam power plant that operates on the ideal reheat Rankine cycle is considered. The pressure at which reheating takes place, the net power output, the thermal efficiency, and the minimum mass flow rate of the cooling water required are to be determined.

Assumptions 1 Steady operating conditions exist. 2 Kinetic and potential energy changes are negligible.

Analysis (*a*) From the steam tables (Tables A-4, A-5, and A-6)

$$h_1 = h_{\text{sat liq @ 7.5 kPa}} = 168.75 \text{ kJ/kg}$$

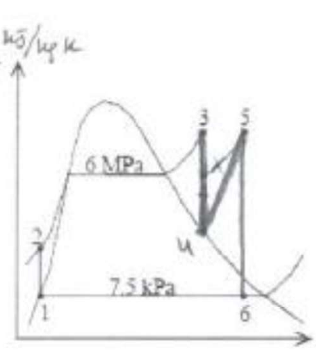
$s_1 = s_f = 0,5763$ kJ/kg K

$$v_1 = v_{\text{sat liq @ 7.5kPa}} = 0.001008 \text{ m}^3/\text{kg}$$

$$T_1 = T_{\text{sat @ 7.5 kPa}} = 40.29°\text{C}$$

$$w_{p,\text{in}} = v_1(P_2 - P_1) = (0.001008 \text{ m}^3/\text{kg})(6000 - 7.5 \text{ kPa})\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right) = 6.04 \text{ kJ/kg}$$

$$h_2 = h_1 + w_{p,\text{in}} = 168.75 + 6.04 = 174.79 \text{ kJ/kg}$$



$$\left.\begin{array}{l} P_3 = 6 \text{ MPa} \\ T_3 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3423.1 \text{ kJ/kg} \\ s_3 = 6.8826 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} s_4 = s_3 \\ \text{(sat.vapor)} \end{array}\right\} \begin{array}{l} h_4 = h_{g @ s_4 = s_4} = 2739.8 \text{ kJ/kg} \\ P_4 = P_{\text{sat @ } s_g = s_4} = \mathbf{416 \text{ kPa}} \quad \text{(the reheat pressure)} \end{array}$$

$$\left.\begin{array}{l} P_5 = 416 \text{ kPa} \\ T_5 = 450°\text{C} \end{array}\right\} \begin{array}{l} h_5 = 3378.8 \text{ kJ/kg} \\ s_5 = 8.0329 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_6 = 7.5 \text{ kPa} \\ s_6 = s_5 \end{array}\right\} \begin{array}{l} x_6 = \dfrac{s_6 - s_f}{s_{fg}} = \dfrac{8.0329 - 0.5763}{17.6738} = 0.9717 \\ h_6 = h_f + x_6 h_{fg} = 168.75 + (0.9717)(2405.3) = 2505.9 \text{ kJ/kg} \end{array}$$

(*b*)

$$q_{\text{in}} = (h_3 - h_2) + (h_5 - h_4) = 3423.1 - 174.79 + 3378.8 - 2739.8 = 3887.3 \text{ kJ/kg}$$

$$q_{\text{out}} = h_6 - h_1 = 2505.9 - 168.75 = 2337.2 \text{ kJ/kg}$$

Thus,

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{2337.2 \text{ kJ/kg}}{3887.3 \text{ kJ/kg}} = 0.399 = \mathbf{39.9\%}$$

(*c*) The mass flow rate of the cooling water will be a minimum when it is heated to the temperature of the steam in the condenser, which is 40.29°C,

$$\dot{Q}_{\text{out}} = \dot{Q}_{\text{in}} - \dot{W}_{\text{net}} = (1 - \eta_{\text{th}})\dot{Q}_{\text{in}} = (1 - 0.399)(60{,}000 \text{ kW}) = 36{,}074 \text{ kW}$$

$$\dot{m}_{\text{cool}} = \frac{\dot{Q}_{\text{out}}}{c\Delta T} = \frac{36{,}074 \text{ kW}}{(4.18 \text{ kJ/kg}\cdot°\text{C})(40.29 - 7)°\text{C}} = 259.2 \text{ kg/s}$$

$T_0 = 285$ K

$P_0 = 100$ kPa

$T_K = 1600$ K

$h_0 \cong h_f = 50{,}51$ kJ/kg

$s_0 \cong s_{f, 285 K} = 0{,}1806$ kJ/kg K

$$x_{\text{destroyed, heating}} = T_0 \left[(s_3 - s_2) + (s_5 - s_4) + \frac{q_{in}}{T_K}\right]$$

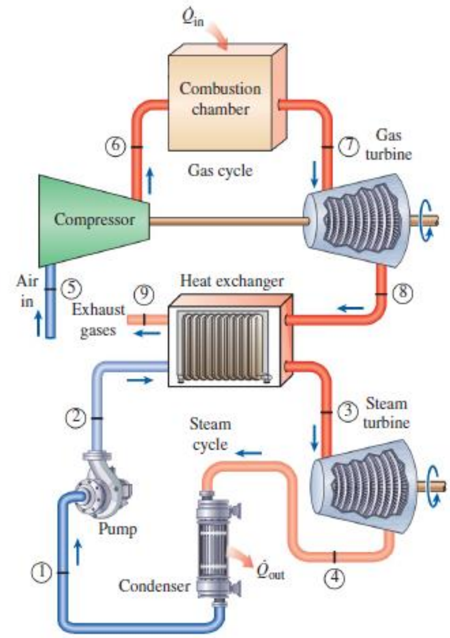
$$= 285 \cdot \left[(6{,}88 - 0{,}57) + (8{,}03 - 6{,}88) + \frac{-3887{,}3 \text{ kJ/kg}}{1600 \text{ K}}\right]$$

$$= 1433{,}835 \frac{\text{kJ}}{\text{K}}$$

$$\psi_3 = (h_3 - h_0) - T_0(s_3 - s_0) + \frac{V_3^2}{2} + gz_3$$

$$= (3423 - 50{,}51)\frac{\text{kJ}}{} - 285 \cdot (6{,}88 - 0{,}1806)$$

The gas-turbine portion of a combined gas-steam power plant has a pressure ratio of 16. Air enters the compressor at 300 K at a rate of 14 kg/s and is heated to 1500 K in the combustion chamber. The combustion gases leaving the gas turbine are used to heat the steam to 400 ºC at 10 MPa in a heat exchanger. The combustion gases leave the heat exchanger at 420 K. The steam leaving the turbine is condensed at 15 kPa. Assume all the compression and expansion processes to be isentropic. $(T_0 = 293\ K, T_{boundary} = 300\ K\ and\ T_{source} = 2200\ K)$. For air, assume constant specific heats at room temperature (c_p=1.005 kJ/kg·K and k=1.4).



For water and steam;

$h_{f\ @\ P=15\ kPa} = 225.94\ kJ/kg$

$v_{f\ @\ P=15\ kPa} = 0.001014\ m^3/kg$

$h_{@\ P=10\ MPa\ and\ T=400°C} = 3097.0\ kJ/kg$

$s_{@\ P=10\ MPa\ and\ T=400°C} = 6.2141\ kJ/kg \cdot K$

$s_{f\ @\ P=15\ kPa} = 0.7549\ kJ/kg \cdot K$

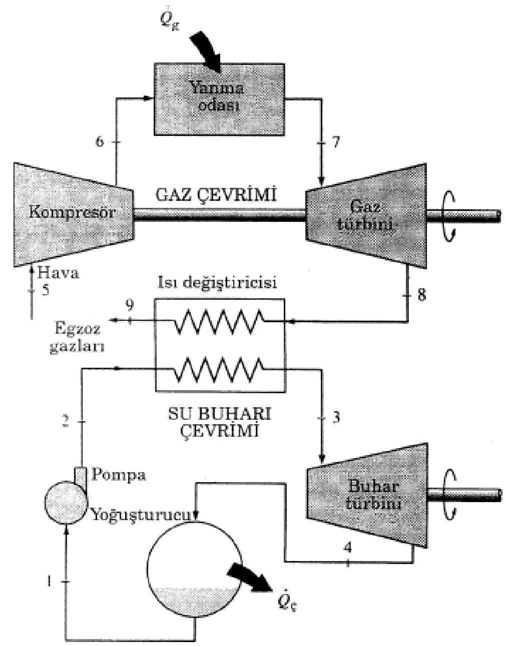
$s_{fg\ @\ P=15\ kPa} = 7.2522\ kJ/kg \cdot K$

$h_{f\ @\ P=15\ kPa} = 225.94\ kJ/kg$

$h_{fg\ @\ P=15\ kPa} = 2372.3\ kJ/kg$

a) Draw the cycle T-s diagram.
b) Write all mass, energy, entropy and exergy balance equations for each device.
c) Determine the mass flow rate of the steam,
d) Determine the net power output,
e) Find the energy and exergy efficiencies of the combined cycle.

Bir birleşik gaz-buhar santralinde gaz türbininin basınç oranı 16 olup, hava kompresöre 300 K sıcaklıkta, 14 kg/s debiyle girmektedir. Yanma odasından 1500 K sıcaklıkta çıkan gazlar, türbinde genişledikten sonra atık ısı kazanına girmekte ve buradan 420 K sıcaklıkta çıkmaktadır. Yanma sonu gazlarının verdiği ısı ile atık ısı kazanında 10 MPa basınç ve 400 °C sıcaklıkta buhar üretilmektedir. Üretilen buhar bir türbinde 15 kPa basınca kadar genişlemektedir. Tüm sıkıştırma ve genişlemelerin izantropik olduğunu kabul ediniz. $(T_0 = 293\ K,\ T_{sınır} = 300\ K\ ve\ T_{kaynak} = 2200\ K)$. Hava için oda sıcaklığında sabit özgül ısılar kabul ediniz (c_p=1,005 kJ/kg·K ve k=1,4).



Hava ve buhar için;

$h_{f\ @\ P=15\ kPa} = 225{,}94\ kJ/kg$

$v_{f\ @\ P=15\ kPa} = 0{,}001014\ m^3/kg$

$h_{@\ P=10\ MPa\ ve\ T=400°C} = 3097{,}0\ kJ/kg$

$s_{@\ P=10\ MPa\ ve\ T=400°C} = 6{,}2141\ kJ/kg \cdot K$

$s_{f\ @\ P=15\ kPa} = 0{,}7549\ kJ/kg \cdot K$

$s_{fg\ @\ P=15\ \mathrm{kPa}} = 7{,}2522\ kJ/kg \cdot K$

$h_{f\ @\ P=15\ kPa} = 225{,}94\ kJ/kg$

$h_{fg\ @\ P=15\ \mathrm{kPa}} = 2372{,}3\ kJ/kg$

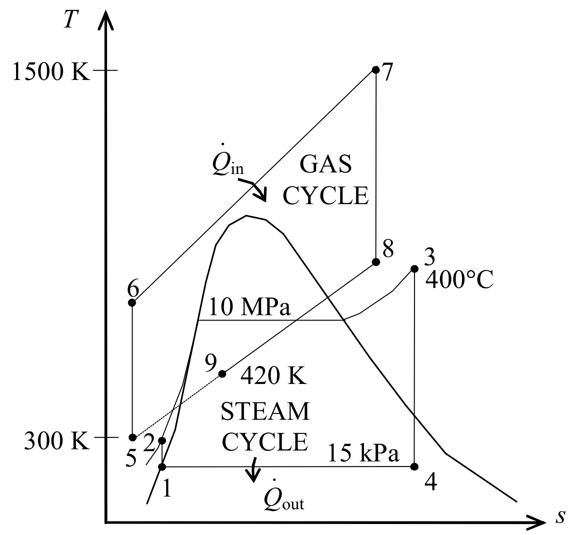
a) Çevrime ait T-s diyagramını çiziniz.
b) Tüm kütle, enerji, entropi ve ekserji denge denklemlerini her bir bileşen için yazınız.
c) Buharın kütle debisini bulunuz.
d) Santralin net gücünü bulunuz.
e) Birleşik gaz-buhar çevriminin enerji ve ekserji verimlerini hesaplayınız.

10-77 A combined gas-steam power cycle is considered. The topping cycle is a gas-turbine cycle and the bottoming cycle is a simple ideal Rankine cycle. The mass flow rate of the steam, the net power output, and the thermal efficiency of the combined cycle are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with constant specific heats.

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K and k = 1.4 (Table A-2).

Analysis (*a*) The analysis of gas cycle yields



$$T_6 = T_5\left(\frac{P_6}{P_5}\right)^{(k-1)/k} = (300\text{ K})(16)^{0.4/1.4} = 662.5\text{ K}$$

$$\dot{Q}_{in} = \dot{m}_{air}(h_7 - h_6) = \dot{m}_{air}c_p(T_7 - T_6)$$
$$= (14\text{ kg/s})(1.005\text{ kJ/kg}\cdot\text{K})(1500 - 662.5)\text{ K} = 11{,}784\text{ kW}$$

$$\dot{W}_{C,gas} = \dot{m}_{air}(h_6 - h_5) = \dot{m}_{air}c_p(T_6 - T_5)$$
$$= (14\text{ kg/s})(1.005\text{ kJ/kg}\cdot\text{K})(662.5 - 300)\text{ K} = 5100\text{ kW}$$

$$T_8 = T_7\left(\frac{P_8}{P_7}\right)^{(k-1)/k} = (1500\text{K})\left(\frac{1}{16}\right)^{0.4/1.4} = 679.3\text{ K}$$

$$\dot{W}_{T,gas} = \dot{m}_{air}(h_7 - h_8) = \dot{m}_{air}c_p(T_7 - T_8)$$
$$= (14\text{ kg/s})(1.005\text{ kJ/kg}\cdot\text{K})(1500 - 679.3)\text{ K} = 11{,}547\text{ kW}$$

$$\dot{W}_{net,gas} = \dot{W}_{T,gas} - \dot{W}_{C,gas} = 11{,}547 - 5{,}100 = 6447\text{ kW}$$

From the steam tables (Tables A-4, A-5, and A-6),

$$h_1 = h_{f\,@\,15\text{ kPa}} = 225.94\text{ kJ/kg}$$
$$v_1 = v_{f\,@\,15\text{ kPa}} = 0.001014\text{ m}^3\text{/kg}$$

$$w_{pI,in} = v_1(P_2 - P_1) = (0.001014\text{ m}^3\text{/kg})(10{,}000 - 15\text{ kPa})\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) = 10.12\text{ kJ/kg}$$

$$h_2 = h_1 + w_{pI,in} = 225.94 + 10.13 = 236.06\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 10\text{ MPa} \\ T_3 = 400°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3097.0\text{ kJ/kg} \\ s_3 = 6.2141\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 15\text{ kPa} \\ s_4 = s_3 \end{array}\right\} \begin{array}{l} x_4 = \dfrac{s_4 - s_f}{s_{fg}} = \dfrac{6.2141 - 0.7549}{7.2522} = 0.7528 \\ h_4 = h_f + x_4 h_{fg} = 225.94 + (0.7528)(2372.3) = 2011.8\text{ kJ/kg} \end{array}$$

Noting that $\dot{Q} \cong \dot{W} \cong \Delta\text{ke} \cong \Delta\text{pe} \cong 0$ for the heat exchanger, the steady-flow energy balance equation yields

$$\dot{E}_{in} - \dot{E}_{out} = \Delta\dot{E}_{system}^{\;\nearrow 0\text{ (steady)}} = 0 \longrightarrow \dot{E}_{in} = \dot{E}_{out}$$

$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_s(h_3 - h_2) = \dot{m}_{air}(h_8 - h_9)$$

$$\dot{m}_s = \frac{h_8 - h_9}{h_3 - h_2}\dot{m}_{air} = \frac{c_p(T_8 - T_9)}{h_3 - h_2}\dot{m}_{air} = \frac{(1.005\text{ kJ/kg}\cdot\text{K})(679.3 - 420)\text{ K}}{(3097.0 - 236.06)\text{ kJ/kg}}(14\text{ kg/s}) = \mathbf{1.275\ kg/s}$$

(*b*)
$$\dot{W}_{T,steam} = \dot{m}_s(h_3 - h_4) = (1.275\text{ kg/s})(3097.0 - 2011.5)\text{ kJ/kg} = 1384\text{ kW}$$
$$\dot{W}_{p,steam} = \dot{m}_s w_p = (1.275\text{ kg/s})(10.12\text{ kJ/kg}) = 12.9\text{ kW}$$
$$\dot{W}_{net,steam} = \dot{W}_{T,steam} - \dot{W}_{p,steam} = 1384 - 12.9 = 1371\text{ kW}$$

and
$$\dot{W}_{net} = \dot{W}_{net,steam} + \dot{W}_{net,gas} = 1371 + 6448 = \mathbf{7819\,kW}$$

(*c*)
$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{7819\text{ kW}}{11{,}784\text{ kW}} = \mathbf{66.4\%}$$

→ Entropy generation in combustion chamber;
($T_{source} = 2200K$)

$$\dot{m}_{air} \cdot s_6 + S_{gen} + \frac{\dot{Q}_{in}}{T_{source}} = \dot{m}_{air} \cdot s_7$$

$$s_7 - s_6 = c_{p,av.} \left(\frac{T_7}{T_6}\right) - R \ln \left(\frac{P_7}{P_6}\right)$$

0

$$s_7 - s_6 = 1.005 \left(\frac{1500}{662.5}\right) = 2.276 \ kJ/kgK$$

$$S_{gen} = 14 \frac{kg}{s} \cdot 2.276 \frac{kJ}{kgK} - \frac{11784 \ kW}{2200k}$$

$$= 31.864 - 5.356 = 26.508 \ kW/K$$

→ Exergy destruction in condenser.

$T_{boundary} = 300K$ $\quad T_0 = 293K$

$$\dot{m}_4 \cdot s_4 + S_{gen} = \dot{m}_1 \cdot s_1 + \frac{\dot{Q}_{out}}{T_{boundary}}$$

$s_4 = s_3 = 6.2141 \ kJ/kgK$ $\quad \dot{Q}_{out} = \dot{m}(h_4 - h_1)$

$= 1.275 \cdot (2011.8 - 225.9)$

$=$

$s_1 = s_{f@15kPa} = 0.7549$

$$S_{gen} = 1.275 \frac{kg}{s} \left(0.7549 - 6.2141\right) \frac{kJ}{kgK} + \frac{2277.023 \ kW}{300 \ K}$$

$S_{gen} = 0.63 \frac{kW}{K}$ $\quad \dot{E}x_D = T_0 \cdot S_{gen} = 293 \cdot 0.63 = \underline{184.6 \ kW}$

exergy efficiency ;

$$\eta_{ex} = \frac{\dot{W}_{GT} + \dot{W}_{ST}}{\dot{E}_x^{Qin}}$$

$$\dot{E}_x^{Qin} = \left(1 - \frac{T_0}{T_S}\right) \cdot \dot{Q}_{in} = \left(1 - \frac{293}{2200}\right) \cdot 11784$$

$$= 10\,214 \text{ kW}$$

$$\eta_{ex} = \frac{7819 \text{ kW}}{10\,214 \text{ kW}} = 76.55\,\%$$