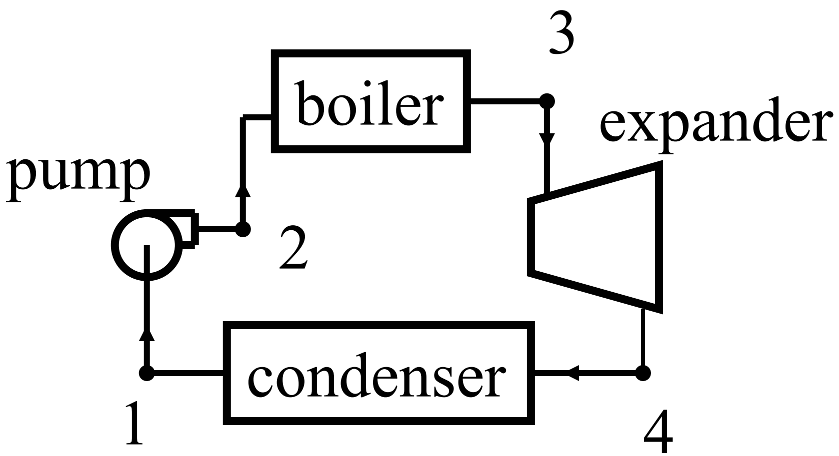
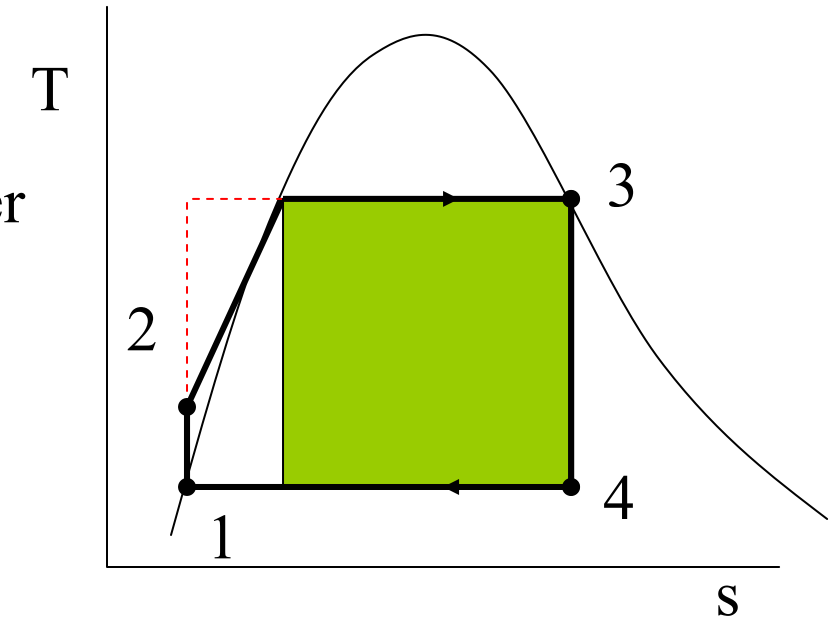
SIMPLE RANKINE CYCLE





Steady Flow, Open System - region in space

Steady Flow Energy Equation for Processes

$$Q = m \times \Delta\left(u + pv + \frac{V^2}{2} + \rho g h\right) + W_{shaft}$$

Pump Process, $1 \Rightarrow 2$, $Q = 0$, $W_{in} = m\left(h_2 - h_1\right)$

Boiler Process, $2 \Rightarrow 3$, $W = 0$, $Q_{in} = m\left(h_3 - h_2\right)$

Expansion Process, $3 \Rightarrow 4$, $Q = 0$, $W_{out} = m\left(h_3 - h_4\right)$

Condenser Process, $4 \Rightarrow 1$, $W = 0$, $Q_{out} = m\left(h_4 - h_1\right)$

First Law for Cycles

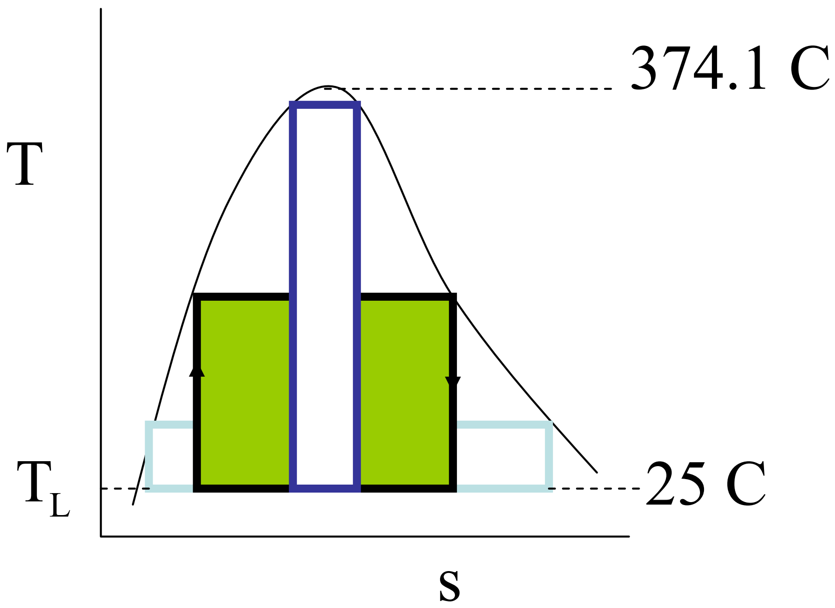
$$\oint_{cycle} \delta Q = \oint_{cycle} \delta W$$

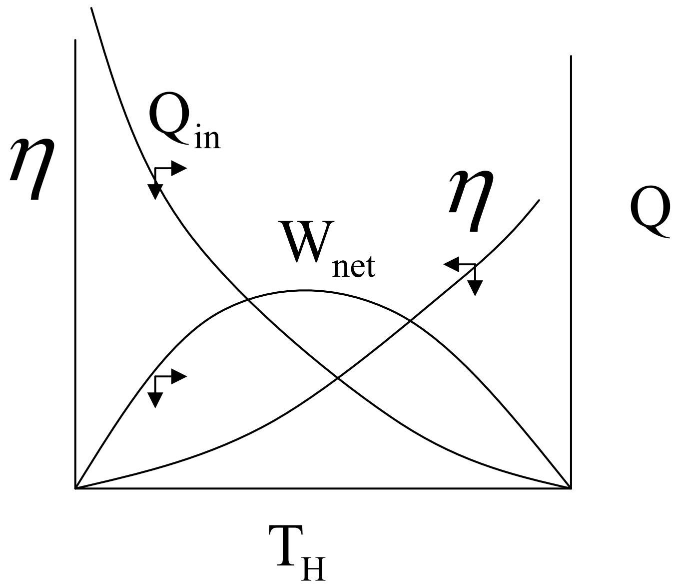
$$\sum_{cycle} Q = \sum_{cycle} W$$

$$\eta_{cycle} = \frac{W_{net}}{Q_{in}} = \frac{\sum_{cycle} W}{Q_{in}}$$

$$FIRSTLAW$$
$$ClosedSystem Q = \Delta E + W$$
$$OpenSystem Q = m\Delta(u + pv + \frac{V^2}{2} + gz) + W$$
$$Unsteadu_2 ySystem$$
$$Q = m_2 u_2 - m_1 u_1 - (m_2 m_1) h_o + W_{boundary}$$
$$PROPERTIES$$
$$IdealGasModel$$
$$pv = RT$$
$$pVmRT$$
$$isentropicprocess$$
$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)$$

CARNOT CYCLE WITH WATER





$$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$$

$$Q_{in} = T_H \Delta S$$

$$W_{net} = \eta \times Q_{in}$$

W_{net} maximum at:

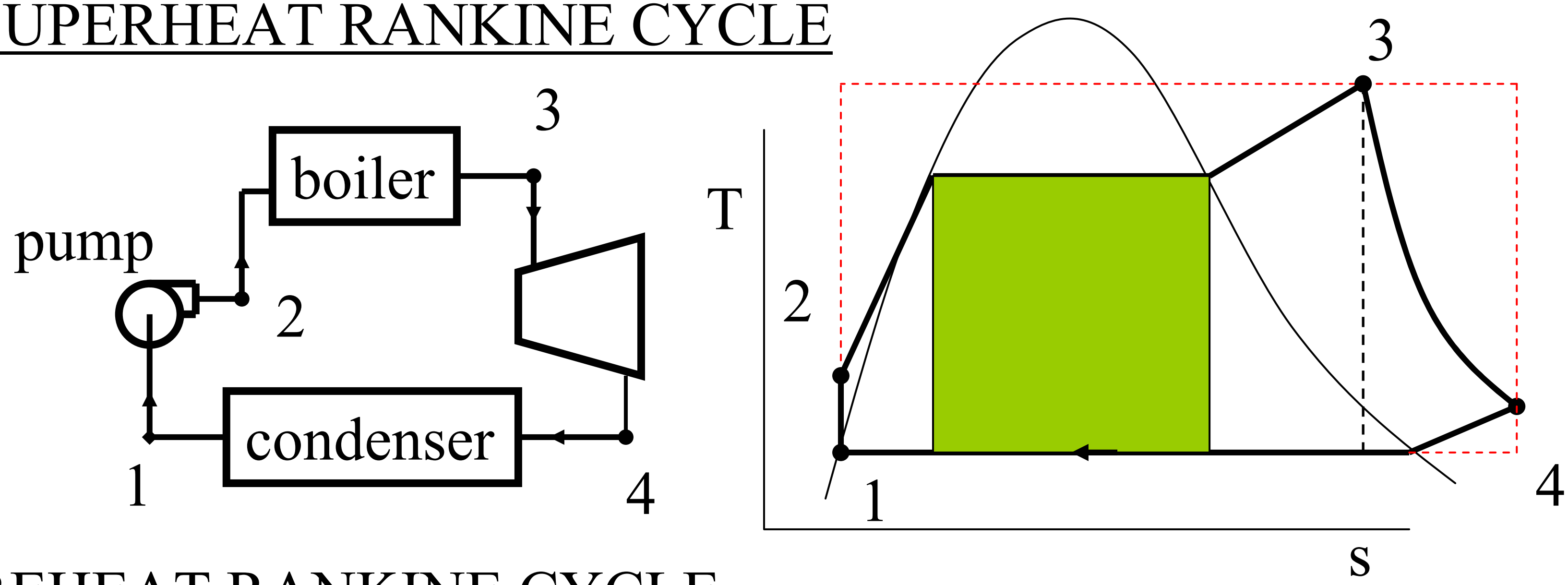
$T = 240$ C

$\eta_{Carnot} = 41.9\ \%$

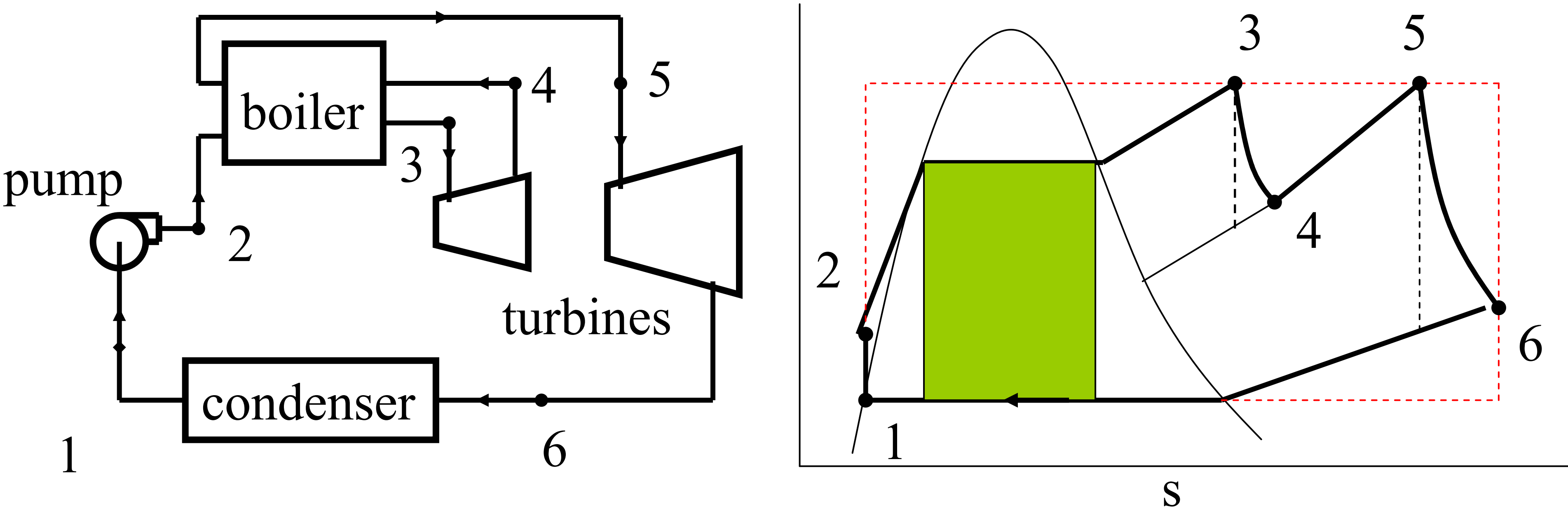
$W_{net} = 740.$ kJ/kg

maximum area

SUPERHEAT RANKINE CYCLE



REHEAT RANKINE CYCLE



$$Q = \Delta U + W \quad \text{First Law}$$

$$dq = du + dw$$

$$dq = Tds \quad \text{Second Law}$$

$$dw = pdv \quad \text{Boundary Work}$$

subsitiuting for dq and dw,

$$Tds = (du) + (pdv)$$

$$h = u + pv \quad \text{h property definition,}$$

h is an exact differential

$$dh = du + pdv + vdp$$

subsitiuting for du,

$$Tds = (dh - pdv - vdp) + (pdv)$$

$$Tds = dh - vdp$$

for an adiabatic process, $Q = Tds = 0$

$$dh = vdp$$

$$h = \int vdp$$

Example: water pumped from 15 psia to 30 psia

$$w = h_2 - h_1 = v(p_2 - p_1)$$

$$w = \frac{(30\text{psia} - 15\text{psia}) \times 144\text{psi/psf}}{62.4\text{lb/ft}^3}$$

$$w = \frac{2160 \frac{lb_f}{ft^2}}{62.4 \frac{lb_m}{ft^2} \frac{1}{ft}} = 34.6 \frac{ft\ lb_f}{lb_m}, \text{ (ft of fluid)}$$

$$w = 34.6 \frac{ft\ \ lb_f}{lb_m} \times \frac{1\ BTU}{778\ ft\ lb_f} = .044\ BTU/lb_m$$

Example: water pumped from 100 kPa to 300 kPa

$$w = v(p_2 - p_1)$$

$$w = .0010432\ m^3/kg \times (300\ kPa - 100\ kPa)$$

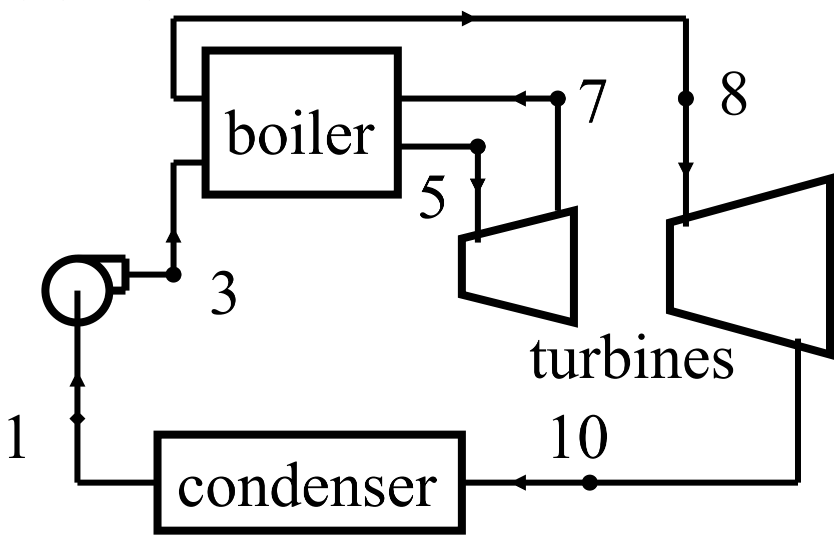
$$w = .2086\ \frac{m^3}{kg} kPa, \quad kJ/kg$$

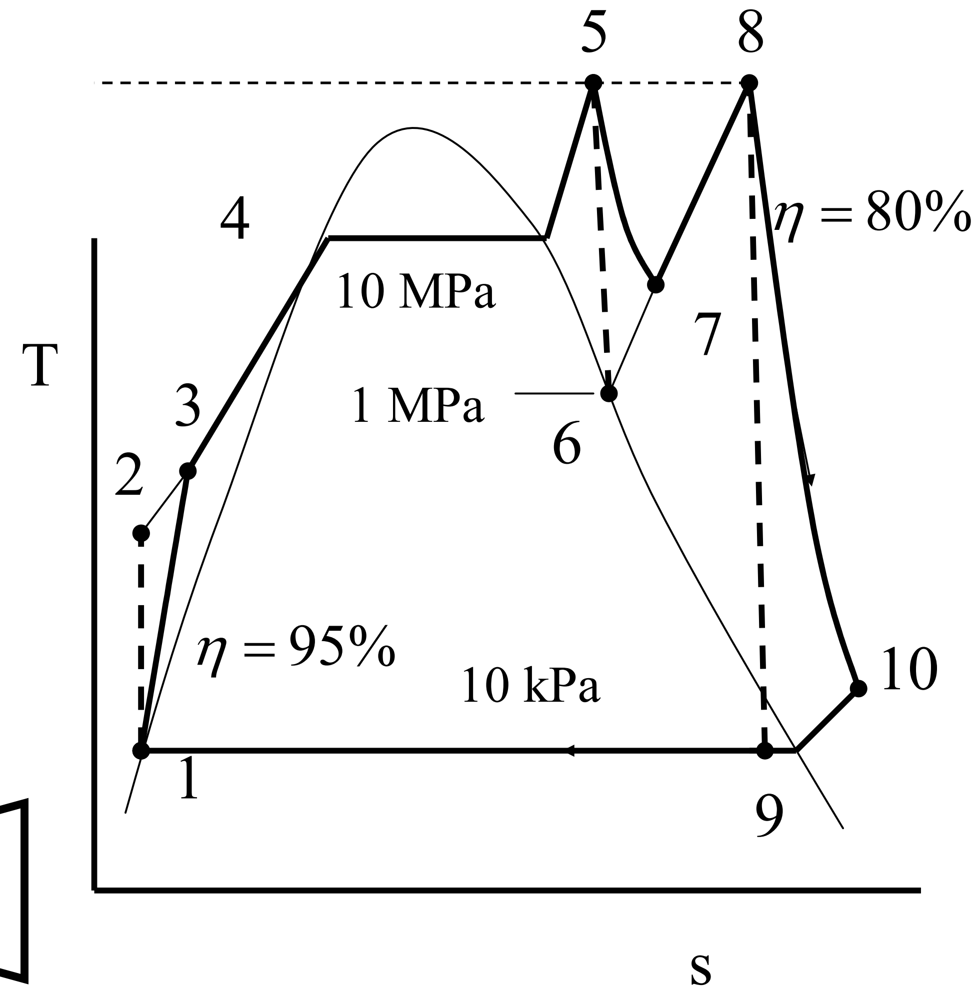
A steam power plant runs on a reheat cycle and produces 80 MW. The turbine inlet conditions are 10 MPA , 500 C and 1 MPA, 500 C. The condenser operates at 10 kPa. The efficiency of the turbines is 80%. The efficiency of the pump is 95%. Determine:

a) the turbine exit conditions

b) the cycle efficiency and

c) the mass flow rate of the steam.





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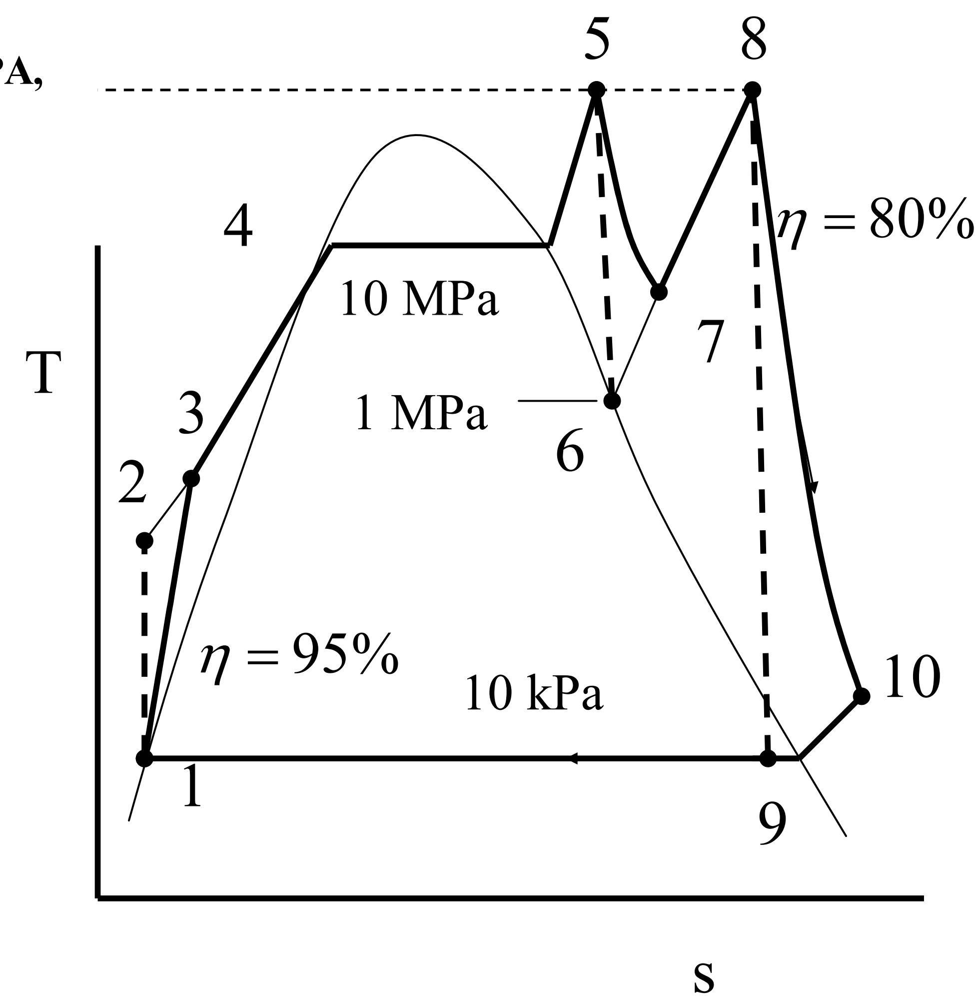

Pt	T	p	h	s	v
1	45.81	10 kPa	191.81	.6492	.001010
2		10 MPa		.6492	
3		10 MPa			
4		10 MPa			
5	500	10 MPa	3375.1	6.5995	
6		1 MPa		6.5995	
7		1 MPa			
8	500	1 MPa	3479.1	7.7642	
9		10 kPa		7.7642	
10		10 kPa			

compressed liquid water, Table A-7, $p_2 = 10\text{MPa}$

T	h	s
60	259.43	.8260
	$s_2 = s_1 = .6492$	
40	176.37	.5685

$$h_2 = 202.39 \text{ kJ/kg}$$

$$W_{pump\ actual} = \frac{W_{pump\ ideal}}{.95} = \frac{h_2 - h_1}{.95}$$

$$W_{pump\ actual} = \frac{202.39 - 191.81}{.95} = 11.14 \text{ kJ/kg}$$

$$h_3 = h_1 + W_{pumpactural} = 191.81 + 11.14$$

$$h_3 = 203.95 \text{ kJ/kg}$$

$$W_{pump} = \frac{v \times \Delta p}{\eta} = \frac{.001010 \times (10{,}000 - 10)}{.95}$$

$$W_{pump} = 10.71 \text{ kJ/kg}$$

@1 MPa, $s_6 = s_5$

T	h	s
200	2828.3	6.6956
	$s_6 = s_5 = 6.5995$	
179.88	2777.1	6.5850

$$h_6 = 2784.11 \text{ J/kg}$$

$$\eta = \frac{h_5 - h_7}{h_5 - h_6}$$

$$h_7 = h_5 - .8 \times (h_5 - h_6)$$

$$h_7 = 3373.7 - .8 \times (3373.7 - 2784.11)$$

$$h_7 = 2902.03 \text{ kJ/kg}$$

@10 kPa, $s_9 = s_8$

$$x = \frac{s_8 - s_f}{s_{fg}} = \frac{7.7642 - .6492}{7.4996} = .9487$$

$$h_9 = 191.81 + x \times 2392.8 = 2460.86 \text{ kJ/kg}$$

$$\eta = \frac{h_8 - h_{10}}{h_8 - h_9} = .8$$

$$h_{10} = h_8 - .8 \times (h_8 - h_9)$$

$$h_{10} = 3479.1 - .8 \times (3479.1 - 2460.86)$$

$$h_{10} = 2664.51 \text{ kJ/kg} \qquad (h_{sat} = 2519.8, \approx 90^{O}\text{C})$$

$$Q_{in} = \left(h_8 - h_7\right) + \left(h_5 - h_3\right)$$
$$Q_{in} = \left(3479.1 - 2902.03\right) + \left(3375.1 - 203.95\right)$$
$$Q_{in} = 3748.22 \text{ kJ/kg}$$
$$Q_{out} = \left(h_{10} - h_1\right) = \left(2664.51 - 191.81\right) = 2472.7 \text{ kJ/kg}$$
$$W = \left(h_5 - h_7\right) + \left(h_8 - h_{10}\right) - W_{pump}$$
$$W = \left(3375.1 - 2902.03\right) + \left(3479.1 - 2664.51\right) - 11.28$$
$$W = 472.74 + 814.11 - 11.28 = 1276.38 \text{ kJ/kg}$$
$$\oint dQ = \oint dW$$
$$Q_{in} - Q_{out} = W_{net}$$
$$3748.22 - 2472.7 = 1275.52$$
$$\eta_{cycle} = \frac{W_{net}}{Q_{in}} = \frac{1276.38}{3748.22} = 34.05\%$$
$$m = \frac{\text{Total Work}}{\text{Specific Work}} = \frac{80{,}000 \text{kJ/sec}}{1275.527} = 62.72 \text{ kg/sec}$$

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File Edit Search Options Calculate Tables Plots Windows Help Examples

EES Model

```
p1= 10
p2=10000
effp=.95
efft1=.80
efft2=.8
T5=500
p5=p2
p6=1000
p8=p6
p9=p1
p10=p9
T8=500

h1=enthalpy(STEAM, p=p1, x=0)
s1=entropy(STEAM, p=p1, x=0)
h2=enthalpy(STEAM,p=p2,s=s1)
      h3=h1+(h2-h1)/effp
h5=enthalpy(STEAM,T=T5,p=p5)
s5=entropy(STEAM, T=T5,p=p5)
h6=enthalpy(STEAM, p=p6,s=s5)
      h7=h5-(h5-h6)*efft1
h8=enthalpy(STEAM,p=p8,T=T8)
s8=entropy(STEAM,p=p8,T=T8)
h9=enthalpy(STEAM, p=p9,s=s8)
      h10=h8-(h8-h9)*efft2
T10=temperature(STEAM, p=p10, h=h10)
     Qin=(h5-h3)+(h8-h7)
    Qout=(h10-h1)
   Effc=1-(Qout/Qin)
    wnet=Qin-Qout
   m=80000/wnet
```

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Solution

Main

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

Effc = 0.3406	effp = 0.95	efft1 = 0.8	efft2 = 0.8	h1 = 191.7	h10 = 2664	h2 = 201.8	h3 = 202.3	h5 = 3374
h6 = 2783	h7 = 2901	h8 = 3479	h9 = 2460	m = 62.65	p1 = 10	p10 = 10	p2 = 10000	p5 = 10000
p6 = 1000	p8 = 1000	p9 = 10	Qin = 3749	Qout = 2472	s1 = 0.6489	s5 = 6.597	s8 = 7.762	T10 = 87.97
T5 = 500	T8 = 500	wnet = 1277						

10 potential unit problems were detected. Check Units

Calculation time = .0 sec

Rankine

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Q and W dependent on path

$$W = \int pdv$$

FIRST LAW

$$\oint \delta Q = \oint \delta W \qquad \text{Cycle}$$

CLOSED SYSTEM quantity of mass

$$Q = \Delta E + W \qquad \text{Process}$$

$$\delta q = du + pdv$$

Processes

Q and W for $p = c$, $v = c$, $T = c$, adiabatic, polytropic

OPEN SYSTEM region in space

$$Q = m\Delta(u + pv + \frac{V^2}{2} + gz) + W$$

Processes

compression, expansion, heat exchanger, throttling, diffuser, nozzle

UNSTEADY SYSTEM unequal mass flow

$$Q = m_2u_2 - m_1u_1 - (m_2 - m_1)h_o + W_{boundary}$$

First Law is an Energy Balance

PROPERTIES

Idealal Gas Model

$pv = RT + \text{room temperature } c_p \text{ and } c_v$

$$R = \frac{\text{universal gas constant}}{\text{molecular weight}} (8.314\text{metric}, 1545.25\text{English})$$

$R = c_p - c_v$ in the same units

Isentropic process $pv^k = \text{constant}, Q = 0, \Delta s = 0$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

$$\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right)$$

$$\Delta s = c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{v_2}{v_1}\right)$$

Ideal Gas with Temperature dependent c_p and c_v

Table A – 17

$$\left(\frac{Pr_1}{Pr_2}\right)_{TableA-17} = \left(\frac{p_1}{p_2}\right)_{problem}$$

Real Gases – Steam, R – 134a TABLES

$$x = \frac{\text{mass gas}}{\text{mass mixture}}$$

$$v = v_f = x \times v_{fg} \quad (\text{also } u, h, s)$$

$$x = \frac{v - v_f}{v_{fg}} \quad (\text{also } u, h, s)$$

$$v_{\text{sub cooled}} = v_f @ T$$

SECOND LAW

$$Q_{in} \neq W \Rightarrow \text{Heat Engine}$$

$$\eta = \frac{\text{benefit}}{\text{effort}} = \frac{\text{Work}}{Q_{in}}$$

by First Law $\eta = \dfrac{Q_{in} - Q_{out}}{Q_{in}}$

$$\eta = \text{function}\,(T_{H,} T_L)$$

$$\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$$

$$\oint \frac{\delta Q}{T} \text{ independent of path} \Rightarrow \text{property ?}$$

$$\Delta s = \int \frac{\delta Q}{T}$$

$\Delta s = 0$ for reversible processes

$\Delta s > 0$ for irreversible processes

$\Delta S = m \times \Delta s > 0$ isolated systems, irreversible processes

$$\eta_{\substack{\text{CARNOT}\\ \text{reversible}}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = \frac{T_H - T_L}{T_H} = \frac{W}{Q_{in}}$$

$$COP_{\text{refrigerator}} = \frac{Q_{in}}{Q_{in} - Q_{out}} = \frac{T_L}{T_H - T_L} = \frac{Q_{in}}{W}$$

$$COP_{\substack{\text{heat}\\ \text{pump}}} = \frac{Q_{out}}{Q_{in} - Q_{out}} = \frac{T_H}{T_H - T_L} = \frac{Q_{out}}{W}$$

PROCESS EFFICIENCY

$$\eta_{\substack{\text{expansion}\\ \text{process}}} = \frac{h_1 - h_2}{h_1 - h_{\text{issentropic}}} = \frac{W_{\text{actual}}}{W_{\text{ideal}}}$$

$$\eta_{\substack{\text{compression}\\ \text{process}}} = \frac{h_1 - h_{\text{issentropic}}}{h_1 - h_2} = \frac{W_{\text{ideal}}}{W_{\text{actual}}}$$

CYCLE EFFICIENCY

$$\eta_{\text{CYCLE}} = \frac{W}{Q_{in}}$$

FIRST AND SECOND LAWS COMBINED

$$Tds = du + pdv$$

Thermodynamic Problem Solving Technique

Concepts

System

Properties

State Point

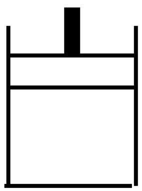
Process

Cycle

1. Problem Statement

Carbon dioxide is contained in a cylinder with a piston. The carbon dioxide is compressed with heat removal from T1,p1 to T2,p2. The gas is then heated from T2, p2 to T3, p3 at constant volume and then expanded without heat transfer to the original state point.

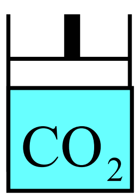
2. Schematic



3. Select Thermodynamic System

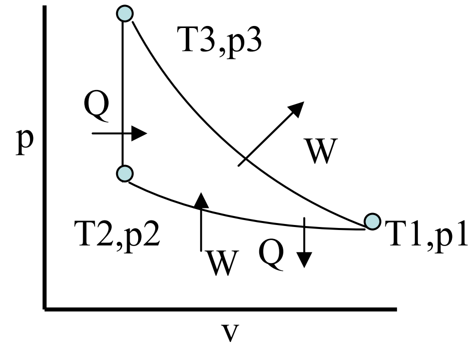
open - closed - control volume

a closed thermodynamic system composed to the mass of carbon dioxide in the cylinder

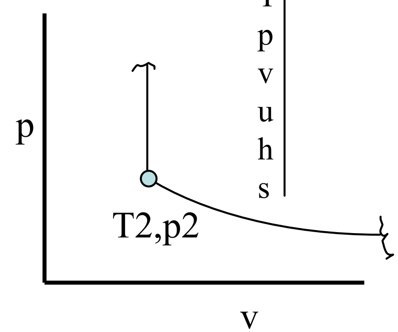


4. Property Diagram

state points - processes - cycle



5. Property Determination



	1	2	3
T			
p			
v			
u			
h			
s			

6. Laws of Thermodynamics

Q=? W=? E=? material flows=?