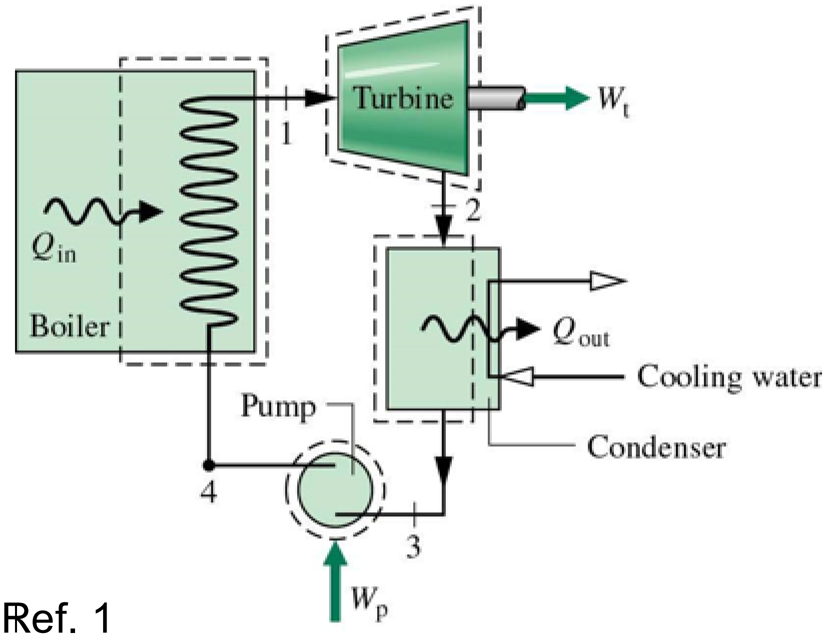
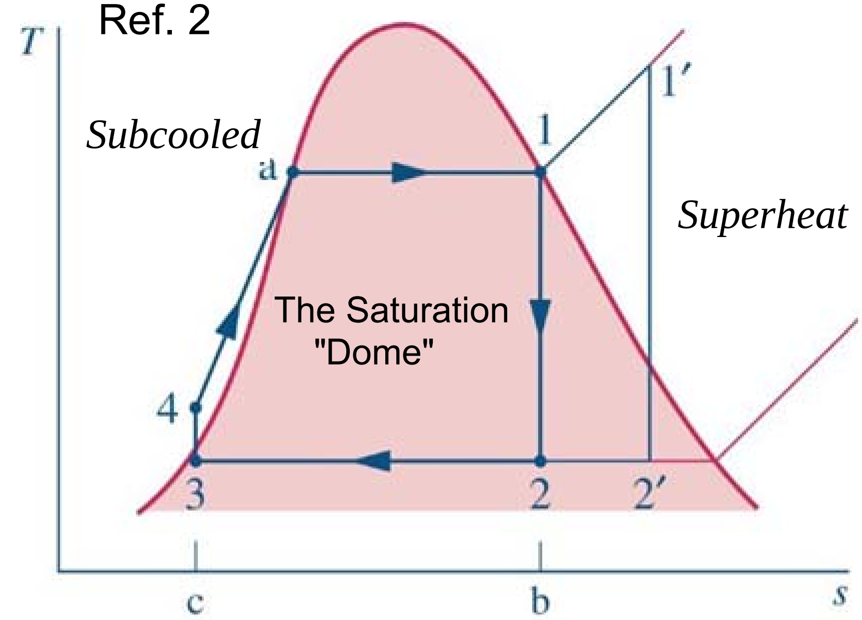
The Ideal Rankine Cycle



Ref. 1

The T-S (temperature-entropy) Diagram for the Ideal Rankine Cycle.

Ref. 2



Thermodynamic Process States

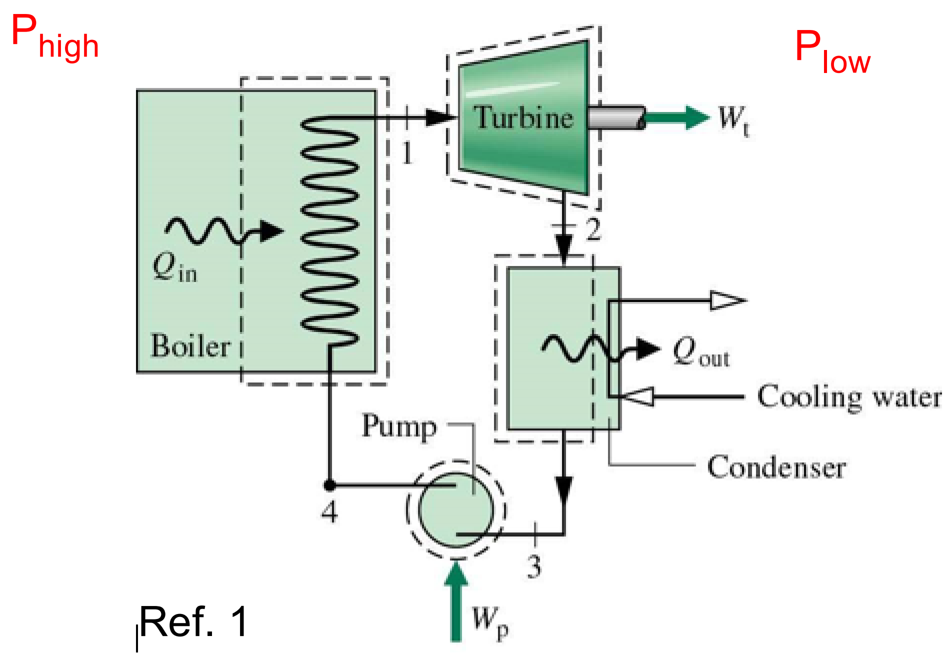
1) boiler exit, turbint inlet
2) turbine exit, condenserinlet
3) condenser exit, pump inlet
4) pump exit, boiler inlet
4a) an intermediate state inside the boiler, where actual boiling begins

Thermodynamic Properties

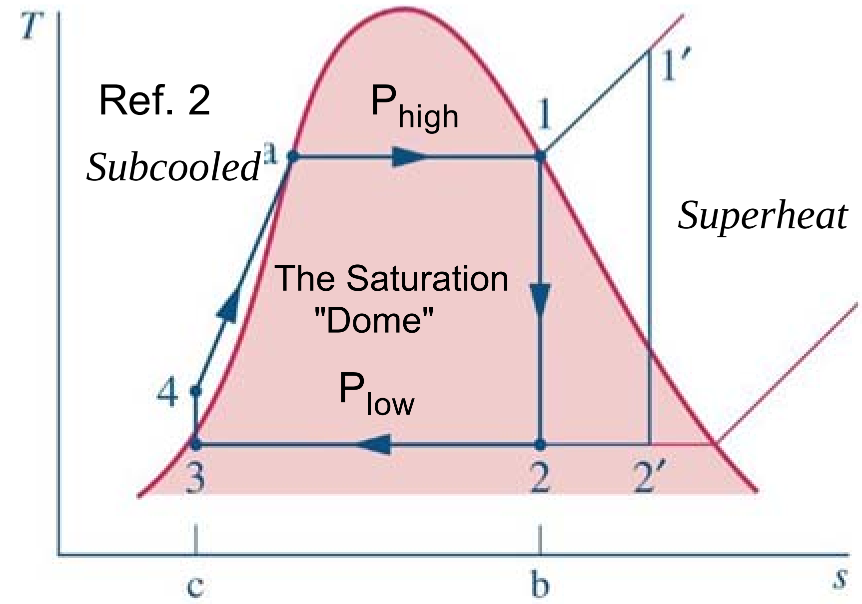
T - temperature (degrees C or K)
P - pressure (Pascal, bar, ...
x - quality (%) in saturation region
v - specific volume (m^3/kg)
h - enthalpy (kJ/kg)
s - entropy (kJ/kg-K)

Property data is usually obtained from Thermodynamic Property Tables, and interpolation is required.

Thermodynamic Processes



The T-S (temperature-entropy) Diagram for the Ideal Rankine Cycle.



Process 1-2) Isentropic (constant entropy) expansion through the turbine from P_{high} to P_{low}. Turbine produces work.

Process 2-3) Condensation in the saturation region, at constant pressure and temperature. Quality (x) is reduced to near zero. Heat is removed from the system

Process 3-4) Isentropic increase in pressure through the pump from P_{low} to P_{high} . Work is required.

Process 4-4a) Boiler increases the temperature of high pressure liquid to the saturation termerature.

Precess 4a-1) Boiler increases the quality (x) to 100% (pure vapor) at constant temperature and pressure. Heat is added to the system. Note: The boiler might continue to add heat, and bring the fluid into the superheated region (1')

Initial Problem Statement: Give P_{low} and P_{high}, determine all unknown properties at each state, using the defined characteristics of the processes.

given: $p_{high} = 8000 \quad kPa \qquad p_{low} = 8 \quad kPa$

Truncated Saturated Steam Table

degC	Pressure, bar	hf, kJ/kg	hg, kJ/kg	sf, kJ/(kg K)	sg, kJ/(kg K)	vf, m^3/kg	vg,
40	0.0738442749	167.5410472587	2573.542416808	0.5724296025	8.2556689123	0.0010078784	19.5
45	0.0959438884	188.437174006	2582.4526465914	0.6386242256	8.1634367692	0.001009914	15.2
290	74.4164254362	1289.7957210967	2766.6326458614	3.1607744802	5.7832318823	0.0013662912	0.02
300	85.8770832956	1344.7713390197	2749.573742544	3.2547405505	5.7057636168	0.001404223	0.02

State 1 - Turbine Inlet:

Known: $p1 = p_{high} = 8000 \quad kPa \qquad x = 1$

Lookup: $t1 = 290 + (300 - 290)\cdot\frac{80 - 74.416}{85.877 - 74.416} = 294.872$ (saturation temperature at p_{high})

$s1 = 5.7832 + (5.7057 - 5.7832)\cdot\frac{80 - 74.416}{85.877 - 74.416} = 5.745$ (entropy of saturated gas, s_g at p_{high})

$h1 = 2766.6 + (2749.6 - 2766.6)\cdot\frac{80 - 74.416}{85.877 - 74.416} = 2758.317$ (entalpy of saturated gas, h_g at p_{high})

Process 1-2) Isentropic (constant entropy) expansion through the turbine from P_{high} to P_{low}. Turbine produces work.

State 2 - Turbine Exit

Known: $s2 = s1 = 5.745$ (Constant entropy expansion)

$p2 = p_{low} = 8$ (... expand to the low pressure state)

Lookup:

$$sf = .572429 + (.638624 - .572429)\cdot\frac{0.08 - 0.07384}{0.09594 - 0.07384} = 0.59088$$

sf, kJ/(kg K)	sg, kJ/(kg K)
0.5724296025	8.2556689123
0.6386242256	8.1634367692

$$sg = 8.25567 + (8.16343 - 8.25567)\cdot\frac{0.08 - 0.07384}{0.09594 - 0.07384} = 8.22996$$

$$x2 = \frac{5.745 - 0.59088}{8.22996 - 0.59088} = 0.675$$ (quality using s2, sf and sg at state 2)

$$hf = 167.54 + (188.44 - 167.54)\cdot\frac{0.08 - 0.07384}{0.09594 - 0.07384} = 173.36552$$

hf, kJ/kg	hg, kJ/kg
167.5410472587	2573.542416808
188.437174006	2582.4526465914

$$hg = 2573.5 + (2583.5 - 2573.5)\cdot\frac{0.08 - 0.07384}{0.09594 - 0.07384} = 2576.29$$

$$h2 = hf + x2\cdot(hg - hf) = 1794.63$$

State 3 - Condenser Exit

Known: $p3 = p_{low} = 8$ (... still at the low pressure state)

$x3 = 0$ (... fully condensed)

Lookup: $h3 = 173.36$ (entalpy of saturated liquid, h_f at p_{low})

$v3 = 0.001008$ (specific volume of saturated liquid, v_f at p_{low})

State 4 - Pump Exit

Known: $p4 = p_{high} = 8000$ (... back to the high pressure state)

Calculate $h4 = h3 + v3\cdot(p4 - p3) = 181.416$ (entalpy of sub-cooled liquid)

$$Turbine\_work = h1 - h2 = 963.69$$

$$Pump\_work = h4 - h3 = 8.056$$

$$Heat\_added = h1 - h4 = 2576.9$$

$$efficiency = \frac{Turbine\_work - Pump\_work}{Heat\_added}\cdot 100 = 37.085$$

Ref. 1) http://www.mae.wvu.edu/~smirnov/mae320/figs/F8-2.jpg
Ref. 2) http://s3.amazonaws.com/answer-board-image/208e96fb-e66d-456d-8674-ae66cf3c935b.png