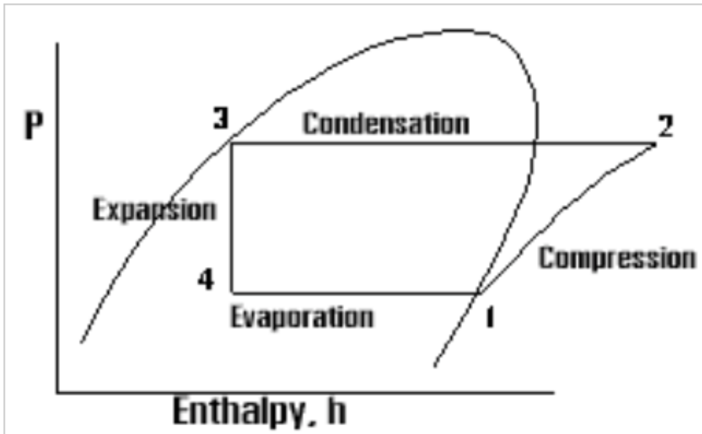
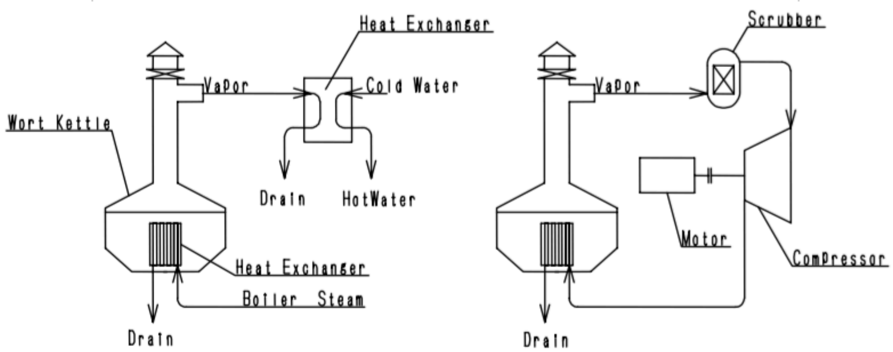
Quiz 5
Chemical Engineering Thermodynamics
February 9, 2017





Ordinary brewery plant　　　　VRC brewery plant

Fig.1 Ordinary Brewery plant and VRC Brewery plant

For a typical brewery the mashing process (heating of the mash, produced from water and grain to produce liquid wort) accounts for 20% of the energy consumption of the plant. Energy recovery from this process is a simple way to cut costs at a brewery. On the left of Fig. 1, above, is depicted the ordinary process of heat exchange for steam produced in the mashing process. To the right a vapor recompression (VRC) system is shown.

In the VRC system, the wort/mash boiler (called a mash tun) releases saturated steam at 120°C. After isothermal scrubbing, a mechanical vapor recompressor (MVR) produces superheated steam at 4.00 MPa and 700°C.

a) Calculate the work needed to run the compressor.
b) What is the efficiency of this compressor?
c) If this steam is then condensed to saturated liquid (2 to 3 in the pressure/enthalpy plot shown above) what heat can be added to the mash?
d) This arrangement of a compressor used to heat steam is often compared to a heat pump. Calculate the coefficient of performance for this process as a heat pump. What is the comparable coefficient of performance for a Sterling or Carnot heat pump? Explain the difference.

ANSWERS: Quiz 5
Chemical Engineering Thermodynamics
February 9, 2017

	State	**T°C**	**P MPa**	**S kJ/kg-K**	**H kJ/kg**
1	Sat. V	120	0.199	7.13	2710
2	SHS	700	4.00	7.62	3910
2'	SHS	514	4.00	7.13	3480 (isoentropic)
3	Sat. L	250	4.00	2.80	1090
4	L/V	120	0.199		1090 (isoenthalpic from P vs H plot)

a) **W_{EC} = 1200 kJ/kg** = 3910 kJ/kg - 2710 kJ/kg
b) Assume adiabatic so S_2'=7.13 kJ/kg-K. At P = 4.00 MPa
T_2' = 500°C+50°C*(7.13 kJ/kg-K -7.09 kJ/kg-K)/(7.23 kJ/kg-K -7.09 kJ/kg-K)
= 500°C + 50°C * 0.286 = 514°C
H2' = 3450 kJ/kg + 0.286*(3560 kJ/kg -3450 kJ/kg) = 3480 kJ/kg
W_{EC} = 3480 kJ/kg – 2710 kJ/kg = **770 kJ/kg**

η_θ = 770 kJ/kg /1200 kJ/kg = **0.642**
c) Q_H = 1090 kJ/kg - 3910 kJ/kg = **-2820 kJ/kg**
d) Calculate the coefficient of performance for this as a heat pump.
Q_C = ΔH = 2710 kJ/kg -1090 kJ/kg = 1620 kJ/kg
COP = Q_H/W = 2820 kJ/kg / 1200 kJ/kg = 2.35
COP Carnot/Sterling Heat Pump = (700°C+273°K)/(700°C - 120°C) = 1.69
Carnot heat pump should have the maximum COP. It doesn't because the heat Q_H includes the heat of vaporization (condensation) of the original steam. That is, this is not a full cycle. The water would have to be boiled to return to the original saturated steam at 120°C. $\Delta H_{v,120°C}$ = 2,200 kJ/kg from the steam table. The actual COP for a cyclic process is,
$COP_{cyclic\ process}$ = (2820 kJ/kg - 2200kJ/kg)/ 1200 kJ/kg = 0.517
This is the "free heat" that we are taking advantage of in the VCR system, almost half of the heat returned to the "mash tun".