CBE 20260
Spring 2012
Test #2
2/16/2011

1. Treatment of process steam (35 points)

Process steam is generally available in different pressures and temperatures (e.g., as shown in this diagram) both because there are different needs for different uses and because it is always desirable to operate a boiler system in the most energy efficient way possible. This figure is an example of a system, which is using some of the steam in turbines for generation of electricity (the "Ts") or for driving a specific large process device, like a compressor. Note that it does not show a common case where some of streams are may be re-fed into the boiler and the possibility that a stream is extracted at temperature and pressure much below the "VHP" steam which is a 10 MPa and 660C.

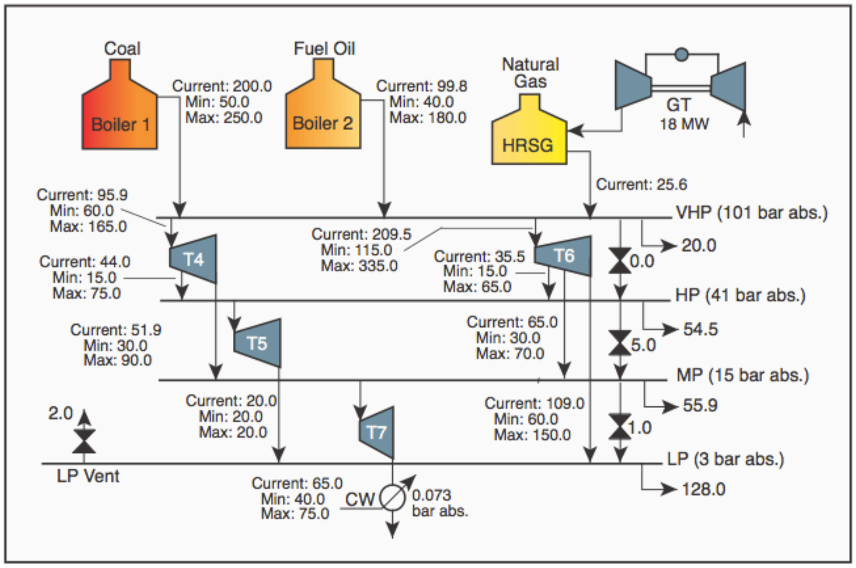


Figure 1. A typical site utility system for a CPI facility.

This problem will address some applications of process steam.

a. Suppose you tap the "LP" stream which is at 3 bar (.3 MPa) and 250 C. This stream is used for a radiant heater that has a steady inflow of .1 kg/s of the steam and an outflow of saturated water at this same pressure. How many Watts is the heater producing?

b. The safety people at your plant decide that your design is unsafe because of the high temperature and pressure of the steam in a large heater. They tell you to feed it with saturated steam at .2 MPa. So you design a "pre-conditioner" that has a steam inlet, a water inlet and a single steam outlet. For this same flowrate of LP steam, 0.1 kg/s, what flow rate of water at 25 C must be added so that the steam comes out as a saturated vapor at .2 MPa.

c. Using the output steam stream from the part b configuration, how many Watts could your heater produce if the exit stream is saturated water at .2 MPa?

d. On the figure, "T5" takes HP steam (4 MPa) and 500 C and expanded it through a turbine to produce MP steam at (say) 1.6 MPa and 350 (to make the numbers easy to get). If the flow rate of steam is 10 kg/s, what is the power output of the turbine?

e. It appears from the figure that there is constricting valve that allows some flow of HP (4 MPa, 500 C) steam down to the MP steam at (say) 1.6 MPa. Note that the pressure must match, but not temperature. This is a bleed stream that might be needed to control pressure or balance a flow for a particular situation. Explain how you would get the temperature of this stream.

f. What is the approximate temperature of this stream?

g. Explain this value in comparison with steam that has gone through the turbine from HP down to MP (1.6 MPa and 350C)

2. How ideal is 134a refrigerant? (45 points)

F_3C-CH_2F Ideal gas or 134a

For this problem, we will consider a piston and cylinder arrangement that contains ideal gas or 134a refrigerant. We are interested in the degree that 134a differs from ideal gas behavior at some specific conditions and for some specific process steps.

The ideal gas has a $C_p = 7/2R$ and $C_v = 5/2R$. The refrigerant has the properties specified on the P-H diagram. Unfortunately the data are in terms of mass on the diagram. The molecular mass of 134a is 102 g/mol.

a. Derive the appropriate form of the energy balance for this problem from the “General Equation” in either table 3.1-2 or 3.1-2 (which ever is best) in the appendix. State the assumptions (restrictions) necessary to eliminate the terms you cross out.

Consider volumetric properties for the two gases

b. Consider ideal gas at 10 MPa and 100C. Calculate the volume of 1 mole of ideal gas at these conditions.
c. Switch to 134a at 10 MPa and 100C. Determine the volume of .102kg of 134a at these conditions.

Now consider isobaric heating.

d. Find/write down a general expression for the change in internal energy of an ideal gas that is heated from T_1, to T_2 at pressure P_1.
e. Find/write down a general expression for the change in enthalpy of an ideal gas that is heated from T_1, to T_2 at pressure P_1.
f. Calculate the change in enthalpy of a mole of ideal gas at 1 MPa as it is heated from 120C to 230 C
g. Calculate the change in enthalpy of .102 kg of 134a at 1 MPa as it is heated from 120C to 230 C.
h. Find the work done for the part g step.

Now consider isothermal compression

i. Find a general expression for the work done when an ideal gas that is compressed from P_1 to P_2 at temp = T_1.
j. Calculate the change in enthalpy when 1 mole of ideal gas is compressed from .1 MPa to 10 MPa at 200C.
k. Calculate the change in enthalpy when .102 kg of 134a at 200C is compressed from .1MPa to 10 MPa
l. For what conditions is this behavior becoming more non-ideal?

Now consider adiabatic compression. On the P-H diagram, the lines of constant entropy are also called “adiabats” meaning that they are lines of change that involve no Q

m. Find the enthalpy change when 0.102 kg of 134a at 160 C is adiabatically compressed from .1 MPa to 1 MPa.
n. Find the temperature change for this process.
o. Find the work done for this compression.

p. The result of adiabatic compression for an ideal gas is

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/C_{\boldsymbol{P}}^*}$$

Find the expected temperature change for an ideal gas.

3. Steam train: 300 PSI, 650 F (25 points)

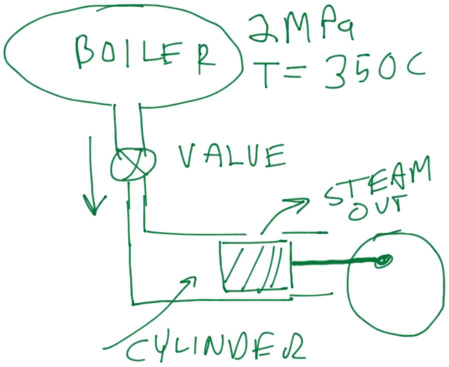
The Union Pacific Railroad has always been known for having some of the biggest, heaviest and most powerful locomotives. This was the case during the steam era and for a while during the diesel era until diesel electric locomotives became completely standardized.

One of most powerful late era steam locomotives was the Union Pacific 9000 series (and the longest rigid frame, non-articulated locomotive ever built). These could provide a tractive force of more than 96,000 lb. (430,000) Newtons. This force, at low speed, is comparable to modern diesel-electric locomotives.

The 9000 had 3 driving pistons. One on each side and one under the middle of the locomotive. These had dimensions 27 in. (diameter) and 32 in. stroke. The pressure in the boiler was about 220 PSI. The thermal efficiency of these could have been something close to 10%, (compared to a modern diesel electric which is about 30%).

We would like to analyze these to see if we can get some idea how they work and where the 10% comes from.

A diagram of the steam drive looks like this.



a. Derive the energy balance equation for the continuous flow of steam through the valve.
b. If the train is operating such that the boiler pressure is 2 MPa and the temperature is 350C, what is the value of the enthalpy of the steam entering the cylinder?
c. Derive the appropriate energy balance to analyze the processes associated with the piston in terms of a mass flow rate of steam and work being done by the piston.
d. The cylinder has an area of 0.36m and a travel distance of 0.81 m. If the steam pressure entering the cylinder is 1 MPa, the force is about 360,000 N on the piston. For these conditions, what flow rate of steam is necessary to produce 1000 kW, which, on a per-cylinder basis, is a reasonable fraction of the rated output.
e. Provide some insight into where the (roughly) 10% efficiency could be coming from.