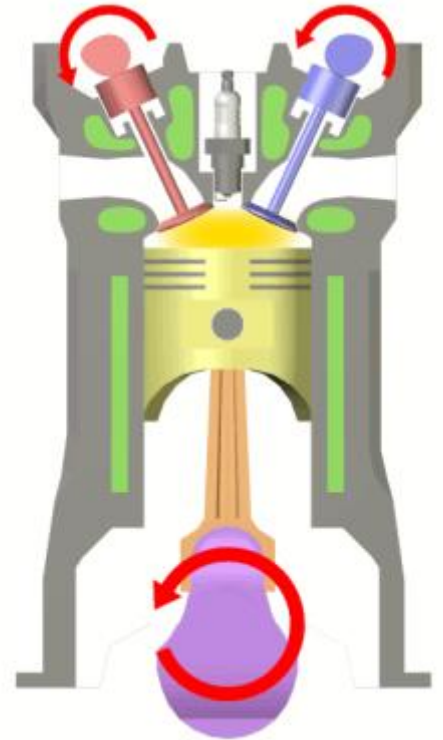
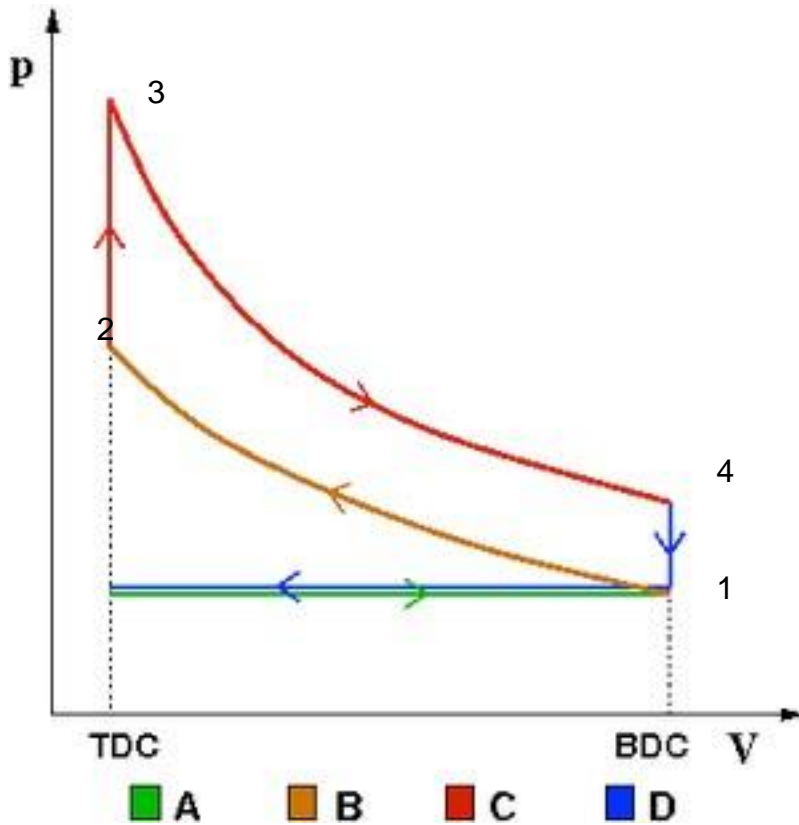


(Total 3 Problems)**Problem 1. Analysis of Otto cycle for an ideal gas.**

The so-called “Otto cycle” is a model for a gasoline engine. There are intake and exhaust steps, which go back and forth across the diagram at constant pressure. The other steps are as follows. From 1-2, is compression of the fuel mixture in the cylinder. From 2-3 is the very fast ignition of the fuel, while the cylinder is at its smallest volume position -- hence there is a rapid rise in pressure, from 3-4 is the power stroke as the pressure decreases while the piston retracts to its largest position and 4-1 is the exhausting and refilling step which just causes a small drop in pressure.

The picture on the right is the cylinder at 2-3 where it is at the smallest volume and the pressure is increasing because of combustion.

The goal of the problem is to understand some of the process steps and gain insight into the result for the efficiency:

$$\eta = 1 - r^{R/C_v}$$

The working fluid is an ideal gas with heat capacities, C_v and C_p . The compression ratio is $r = V_1/V_2 = V_4/V_3$.

- a. Consider first the compression step. The initial pressure and temperature are T_1 and P_1 . For a given compression ratio r , find a relation for T_2 and P_2 in terms of T_1 and P_1 .
- b. Find a relation for the amount of work that is required for this compression.
- c. Step 2-3 is combustion. Is there any work done during this step?
- d. For step 2-3, there is clearly a temperature rise. Relate the pressure change to the temperature rise.
- e. For step 2-3, what is "Q" in terms of T_2 and T_3 ?
- f. From examination of P-V diagram, describe the net work for this cycle.
- g. Give an argument for why the efficiency depends only on the properties of the gas and the compression ratio.

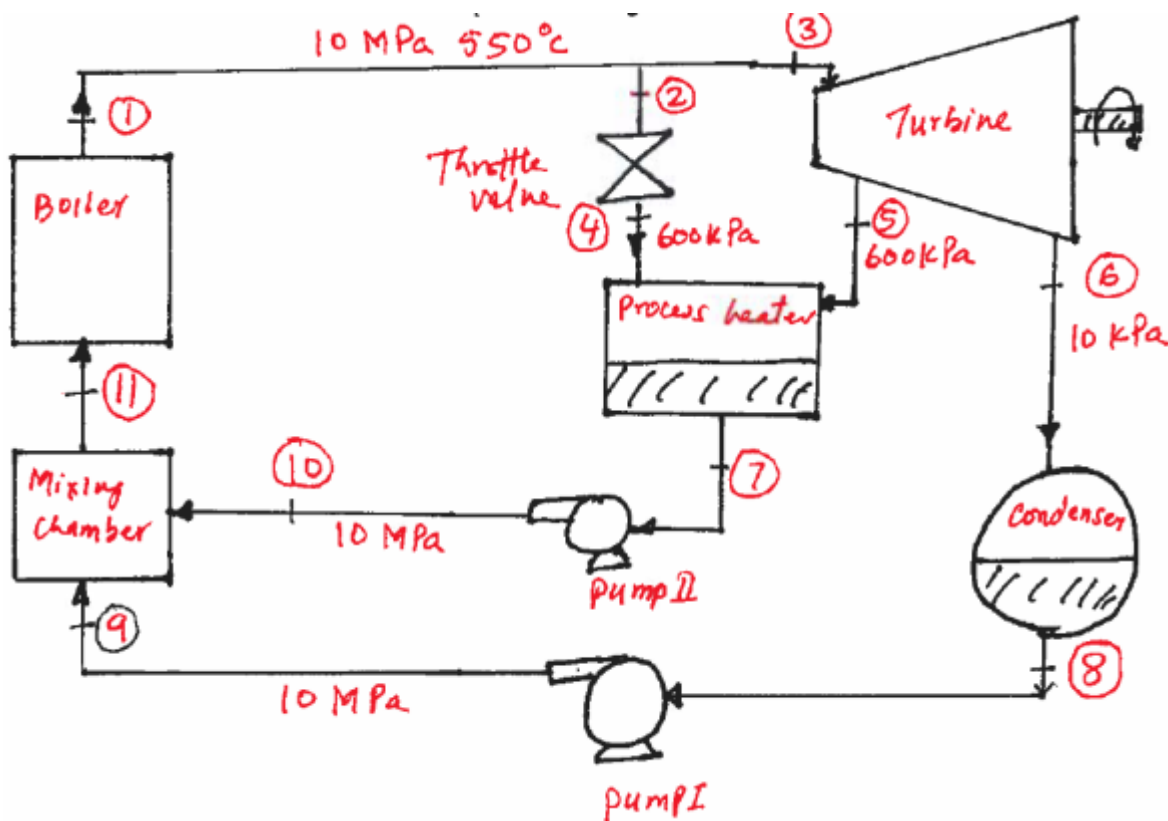
Problem 2. In a simple Rankine power cycle we lose significant amount of heat in the condenser. Since in a typical process plant there is often need for energy to heat process streams, this heat loss in the condenser can be utilized for process heating. This idea gave rise to co-generation plants where part or all of the steam generated in the boiler can be used for heating process streams or getting shaft work for power generation. The utilization factor (UF), another measure of efficiency, for these plants is defined as:

$$UF = (\dot{W}_{net} + \dot{Q}_p) / \dot{Q}_{in}$$

where \dot{W}_{net} , \dot{Q}_p , and \dot{Q}_{in} represent net work output, process heat delivered, and total heat input, respectively.

Consider the cogeneration plant shown in the figure below. Steam enters the turbine at 10 MPa and 550 deg. C. Some steam is extracted from the turbine at 600 kPa for process heating. The remaining steam continues to expand to 10 kPa. Steam is then condensed at constant pressure and pumped to the boiler pressure of 10 MPa. At times of high demand for process heat some steam leaving the boiler is throttled to 600 kPa and is routed to the process heater. The extracted fractions are adjusted so that steam leaves the process heater as a saturated liquid at 600 kPa. It is subsequently pumped to 10 MPa. The mass flow rate of steam through the boiler is 15 kg/s.

- Compute UF when 100% steam is diverted through the throttle valve for process heating.
- Compute UF (or thermal efficiency in this case) when no process steam is utilized for process heating.
- Compute UF when 10% of steam is extracted through the throttle valve and 70% of steam is extracted from the turbine at 600 kPa for process heating.

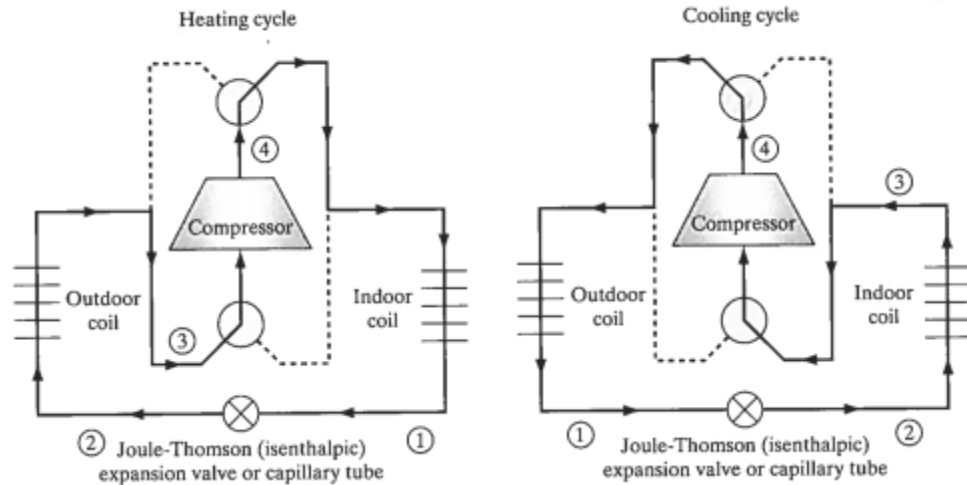


Problem 3. Heat Pump/air conditioner: Can we do better with an in- ground heat exchanger?

The latest model home air conditioners have COP's of 5.5 or so for cooling and only about 2.5 for heating. We would like to investigate this and determine if we should consider buying a "Water Furnace" that employs a long water loop that is several feet below ground. Such devices exchange heat at a constant temperature that is much better than the air temperature for the winter or summer.



Heat pump



First consider the cooling case of a heat pump. Your system is operating ideally, with a cooling load of 15 KW (15000 J/s). The cold side temperature is 5 C, the temperature of the refrigerant (R-410A) leaving the compressor is 70C and the fluid is a saturated liquid as it enters the "Joule-Thompson" valve and a saturated vapor as it enters the compressor.

- Draw the cycle on an P-H diagram showing each of the steps.
- Write down an energy balance for each step making all appropriate simplifications.
- What flow rate of cooling fluid is needed?
- What is the coefficient of performance for your cycle? Note that COP is the ratio of the cooling load, and the power input to the compressor.
- If your number differs from ~5.5, what could be changed in the cycle to move your COP closer to this value? A qualitative answer is fine.

Next consider running the system as a heat pump. In this case the refrigerant in the outside heat exchanger will be at -20C, the temperature of the "refrigerant" leaving the compressor is 80C. The fluid is a saturated liquid as it enters the "Joule-Thompson" valve and a saturated vapor as it enters the compressor. The necessary heat load is again 15 KW.

- Draw the cycle on a P-H diagram showing each of the steps.
- What flow rate of fluid is needed?

- h. What is the Coefficient of Performance for your cycle, if COP is the ratio of heat load divided by power to the compressor?
- i. If your number differs from 2.5, what could be changed to move your number in this direction?

The best "water furnace" claims a heating COP of 5 and a cooling COP of 7.

- j. For just the heating case, the outside temperature will now be 10C and you will need to compress to only 3MPa. What is the COP for your water furnace?