KMU 501 Advanced Chemical Engineering Thermodynamics

Fall 2009, Homework V

Instructor: Selis Önel, PhD

Question 1: One of the many cyclic processes that do not operate on a Carnot cycle is the Otto cycle of a gasoline engine. The Otto cycle is subject to similar analysis as the Carnot cycle. The work done is the area enclosed by the curve in the plane. The expansion and compression stokes are adiabatic, so heat enters and leaves only during the constant volume phases.

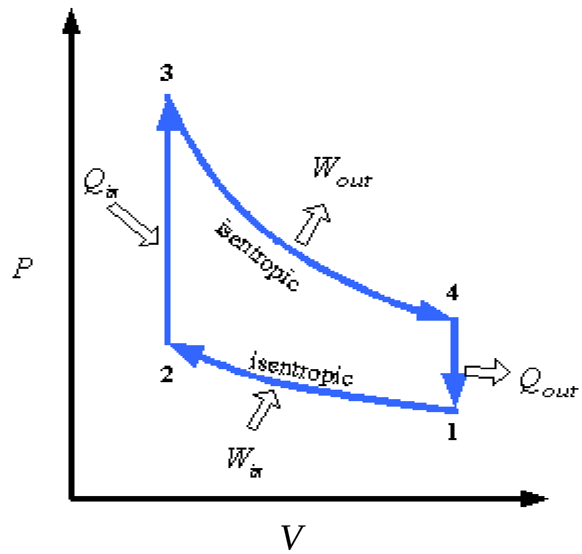
At 1, induction stroke takes place. Although in theory the pressure should be the same as atmospheric, in practice it's rather lower. The amount of petrol air mixture taken in can be increased by use of a supercharger.

1→2 is the compression stroke. Valves are closed. The compression is adiabatic, and no heat enters or leaves the cylinder.

At 3, ignition occurs. The gases resulting from the ignition expand adiabatically, leading to the power stroke.

4→1 is when the gas is cooled instantaneously.

At 1, the exhaust stroke occurs and the the gases are removed at constant pressure to the atmosphere.



Develop an expression for the thermal efficiency of a reversible heat engine operating on the Otto cycle with an ideal gas of constant heat capacity as the working medium.

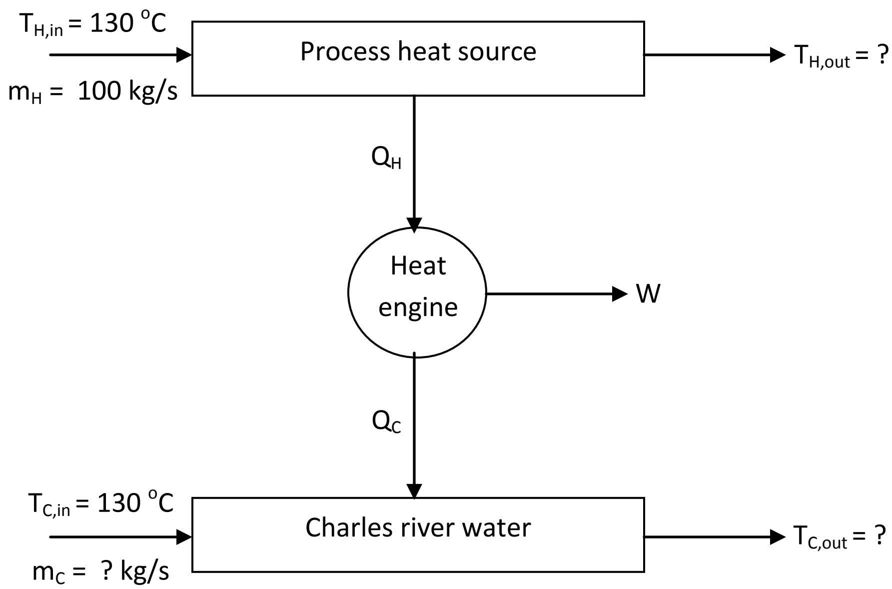
a) First obtain the efficiency as a function of temperature,
b) Then, write it as a function of volume,
c) Finally, write it as a function of the compression ratio $r = V_1/V_2$

Question 2: A Massachusetts industrial company has come up with a novel idea to conserve the wasted thermal energy in chemical plants. The concept involves using a set of state-of-the-art heat engine. The aim is to generate electric power by converting waste heat that would normally be released in cooling towers.

The company claims that 1 MW of electric power can be generated from a 100 kg/s flow of hot process water available at 130 ^oC and 2 bars. Water is also available from the Charles river basin with a seasonal average temperature of 17 ^oC.

Assuming steady state flow of water with specific heat eqaul to 4200 J/kgK and density 1000 kg/m3, describe what you think of the process. Analyze the system using a combination of the first and second laws of thermodynamics. Does the proposed process with a 1 MW output violate any thermodynamic laws?

Hint: Assume that $m_C >> m_H$ = 100 kg/s (i.e. $m_C \sim\infty$) and $T_{H,out} = T_{C,\ out}$ = 17 °C



Question 3: In class we derived the relations for the work obtainable from a heat engine between two reservoirs, one hot and the other cold. Considering the engine and the heat reservoirs as our system, we showed that $\Delta S_{total} = \Delta S_H + \Delta S_C + \Delta S_{engine}$. Since the engine remains unchanged, the last term becomes zero to give $\Delta S_{total} = \frac{Q_H}{T_H} + \frac{Q_C}{T_C}$ and finally we obtain $\frac{W}{-Q_H} = 1 - \frac{T_C}{T_H}$.

Deduce a similar expression for a work-producing device which again exchanges heat with cold and hot reservoirs, but whose properties show a net change during the process, i.e. engine does not remain unchanged.

Question 4: 1 kmol of an ideal gas is compressed isothermally at 400 K from 100 kPa to 1000 kPa in a piston-cylinder system. Calculate the entropy change of the gas, surroundings, and the total entropy change if

a) The process is mechanically reversible and the surroundings consist of a heat reservoir at 400 K
b) The process is mechanically reversible and the surroundings consist of a heat reservoir at 300 K
c) The process is mechanically irreversible requiring 20% more work than the mechanically reversible compression, and the surroundings consist of a heat reservoir at 300 K