3 Thermofluids Lecture 3: First law of thermodynamics (Part 2) (27/04/2020)

3.1 Quick recap of previous lecture

The first law of thermodynamics is for a closed system is:

$$\Delta KE + \Delta PE + \Delta U = Q - W \tag{1}$$

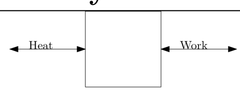
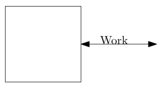
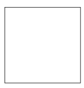
Where $\Delta KE + \Delta PE + \Delta U = \Delta E$, Q is energy transfer by heat ($Q > 0$ is transfer <u>to</u> the system and $Q < 0$ is transfer <u>from</u> the system.) and W is energy transfer by work ($W > 0$ is work done <u>by</u> the system and $W < 0$ is work done <u>on</u> the system.). The first law can also differently be denoted by any of the following expression:

- Delta form: $\Delta E = \int_1^2 \delta Q - \int_1^2 \delta W = Q_{12} - W_{12}$
- Differential form: $dE = \delta Q - \delta W$
- Differential form per unit mass: $de = \delta q - \delta w$
- Differential form per unit time: $\frac{dE}{dt} = \dot{Q} - \dot{W}$

3.2 The general procedure for solving thermodynamics problems

1. Sketch the system to be analyzed
2. Indicate the system boundary
3. List the made assumptions
4. Indentify the reference fram (or datum, basicly the 0 reference point)
5. Define the forces acting on the system
6. Indicate the energy transfer by heat
7. Indentify if the system is on a time interval or rate of change

Table 1: Internal energies for closed systems

	System	ΔU
diabatic		$\Delta U = Q - W$
adiabatic		$\Delta U = \cancelto{0}{Q} - W$
isolated		$\Delta U = \cancelto{0}{Q} - \cancelto{0}{W}$

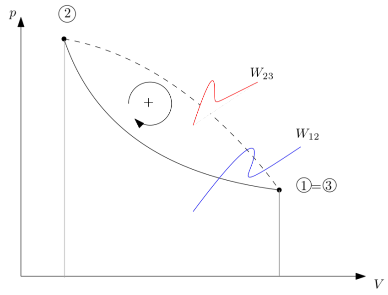


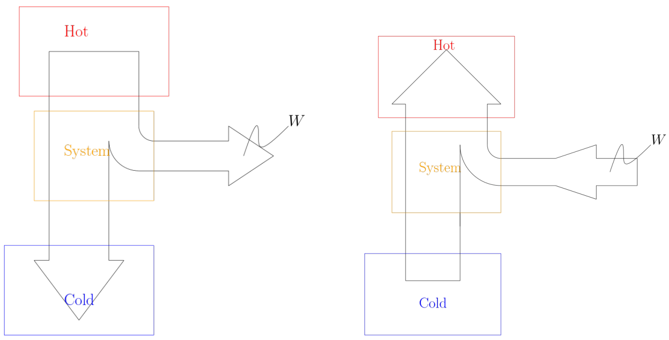
Figure 1: An example of a p, V-diagram for a power cycle

3.3 thermodynamic cylcles

A thermodynamic cylce is a process which begins and ends at the same state. Examples of cycles are power cycles (developing a net energy transfer by work) and heat pump/refrigeration cycles (developing a net heat transfer of energy by inputting work.). An example of a thermodynamic power cycle is shown below:

$$\text{process } 1 \to 2 : U_2 - U_1 = Q_{12} - W_{12} \tag{2}$$
$$\text{process } 2 \to 3 : U_3 - U_2 = Q_{23} - W_{23} \tag{3}$$
$$\text{process } 1 \to 3 : U_2 - U_1 + U_3 - U_2 = (Q_{12} + Q_{23}) - (W_{12} + W_{23}) \tag{4}$$
$$U_1 = U_3 \Rightarrow Q_{12} + Q_{23} = W_{12} + W_{23} \tag{5}$$
$$Q_{cycle} = W_{cycle} \tag{6}$$

Since for this process $W_{12} < 0$ and $W_{23} > 0$ there is a net gain in work (Also note that $|W_{12}| < |W_{23}|$). Because of this, this process is a power cycle. The flow of energy for thermodynamic cylces is show in the figures 2 (a) and (b).



(a) Power cycle (b) Cooling/Heating cycle

Figure 2: A visualization of cycle processes.

3.4 Thermal efficiency and the COP

Thermal efficiency and the COP are a way of mathematically expressing the amount of required input to get a desired output. It can thus be thought of as the "losses" in a given system. Note that these are not actual losses of energy, but rather energy being transformed or transfered in undesirable ways for a given output (e.g. creation of heat through friction when moving an object). Efficiency denoted as η is defined as follows:

$$\eta = \frac{\text{Desired output}}{\text{Required input}} \tag{7}$$

Using this equation and figure 2 (a) we can express the thermal efficiency of a power cycle as:

$$\eta_{th} = \frac{W_{cycle}}{Q_{net}} \tag{8}$$

When describing the efficiency of a cooling or heating cycle we instead talk about a coefficient of performance. Much like efficiency, this is the ratio between the desired output and required output, where the output in the net heating or cooling. Note that for cooling the letter β is used and for heating the letter γ.

$$\beta = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}} \tag{9}$$

$$\gamma = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{net,in}} \tag{10}$$

3.5 Example problem of a cyclical process

A gas undergoes a thermodynamic cycle consisting of the following processes:

- process $1 \to 2$: $p(V) = p$, $p = 1.4\,bar$, $V = 0.028\,m^3$, $W_{12} = 10.5\,kJ$
- process $2 \to 3$: Compression with $p(V) = \frac{k}{V}$, $U_3 = U_2$
- process $3 \to 1$: $V =$ constant, $U_1 - U_3 = -26.4\,kJ$

There are no significant changes in potential and kinetic energy. The p, V-diagram for the process is show in figure 3. From here we can create tables for the state and process variables:

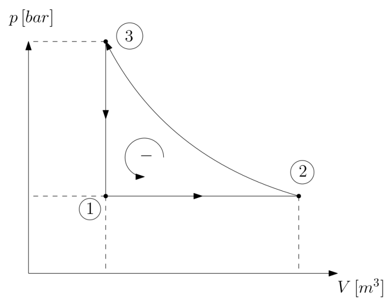


Figure 3: The p, V-diagram of the process described

Table 2: A table for the process variables (Computations below)

Process	Q $[kJ]$	W $[kJ]$
$1 \to 2$	36.9	10.5
$2 \to 3$	-18.78	-18.78
$3 \to 1$	-26.4	0

process $1 \to 2$:

$$W_{12} = \int_1^2 p\,dV = p \cdot \int_1^2 dV = p(V_2 - V_1) \tag{11}$$

$$V_2 = \frac{W_{12}}{p} + V_1 = 0.103\,m^3 \tag{12}$$

Table 3: A table for the state variables (Computations below)

State	p [bar]	V $[m^3]$
1	1.4	0.028
2	1.4	0.103
3	-	0.028

process $2 \to 3$:

$$W_{23} = \int_2^3 p\,dV = k \cdot \int_1^2 \frac{1}{V} dV = k \cdot \ln\left(\frac{V_3}{V_2}\right) = -18.78\,kJ \tag{13}$$

$$\cancelto{0}{\Delta U} = Q_{23} - W_{23} \Rightarrow Q_{23} = W_{23} = -18.78\,kJ \tag{14}$$

process $3 \to 1$:

$$\Delta U = Q_{31} - \cancelto{0}{W_{31}} \tag{15}$$

$$U_1 - U_3 = Q_{31} = -26.4\,kJ \tag{16}$$