Thermodynamics
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Lecture 13
Tutorial Problem on 'Work' – Part 3

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Figure 1

Solution of the problem in Fig. 1:

Initial state: $p_1 = 300\ kPa, \quad V_1 = 0.4\ m^3$

The piston requires 150 kPa to lift.

The system consists of the mass of nitrogen. Initially, it is restricted to tank A. Finally, at the end of the process, the nitrogen occupies volumes in both tanks. The mass is constant.

The provision of the valve in the setup allows the process to be quasi-static. The valve can be opened slowly so that the system is never far away from the equilibrium. Without a valve, the process would not be quasi-static.

Assumptions:

1. The pipe is very small and the mass of nitrogen there is negligibly small. 2. There are no heat losses. 3. The process is quasi-static. 4. There are no losses because of the valve.

We open the valve slowly. The piston in tank B doesn't lift up until the pressure reaches 150 kPa. Once it reaches 150 kPa, the piston starts moving up, and this process is at constant pressure of 150 kPa. The upward movement of the piston stops when the pressure below it equals 150 kPa.

Hence, the final pressure is 150 kPa.

The initial and final states are related through pV = constant.

Hence, $p_1V_1 = p_2V_2$

$$V_2 = \frac{p_1V_1}{p_2} = \frac{300 \times 0.4}{150} = 0.8 \, m^3$$

It is a constant pressure process for nitrogen. Hence, the work interaction for nitrogen,

$$W_{nitrogen} = \int_1^2 pdV = p \int_1^2 dV = 150 \, kPa \times (V_2 - V_1) = 150 \, kPa \times (0.8 - 0.4)m^3$$
$$= 60 \, kJ$$

How would you calculate the work interaction for atmosphere in this process if the atmospheric pressure is 100 kPa?

It is a constant pressure process for the atmosphere.

$W_{atmosphere} = p \int_1^2 dV = 100 \, kPa \times (-0.4) \, m^3 = -40 \, kJ$ (the change in volume is negative for the atmosphere)

In the above problem, the sum of work interactions for the nitrogen, the piston and the atmosphere should be zero.

$$W_{nitrogen} + W_{piston} + W_{atmosphere} = 0$$

$W_{piston} = -20 \, kJ$ (work is done on the piston)

At Initial and final states

$$pV = C$$

$$p_1 V_1 = p_2 V_2$$

$$300 \, kPa \times 0.4 \, m^3 = 150 \, kPa \times V_2$$

$$V_2 = 0.8 \, m^3$$

$$W_2 = \int_1^2 p \, dV = \int_1^2 k \, dV = k \int_1^2 dV$$

$$= 150 \, (V_2 - V_1)$$

$$W_{N_2} = 150 \times (0.8 - 0.4) = \frac{150 \times 0.4}{kPa \; m^3} = 60 \, kJ$$

$$kPa \qquad m^3 \quad m^3$$

$$p_a = 100 \, kPa$$

$$W_{atm} = \int_1^2 p \, dV = p_{atm} \int_1^2 dV \qquad 0.4 \, m^3$$

$$= -100 \, kPa \times (V_2 - V_1)$$

$$= -40 \, kJ$$

$$\Sigma W = 0 \qquad W_{N_2} + W_{atm} + W_{piston} = 0 \qquad W_{piston} = -20 \, kJ = -mgh$$
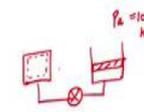
Q3) Tank A and a piston-cylinder arrangement B are connected through pipes as shown. The piston is frictionless. Tank A contains Nitrogen at 300 kPa and its volume is 0.4 m3 . It requires 150 kPa to lift the piston. As the connecting valve opens, Nitrogen flows into the piston-cylinder arrangement B and attains a steady state after some time. What is the final pressure and work interaction for Nitrogen if the initial and final states are related by pV = C, where p and V represent pressure and volume of the gas and C represents a constant.

System analysis N_2

$$p_1 = 300 \, kPa \qquad p_2 = 150 \, kPa \qquad p_1 = 300 \, kPa$$

$$V_1 = 0.4 \, m^3 \qquad \text{const. } p \text{. process} \qquad V_1 = 0.4 \, m^3$$

$$p_{150}$$