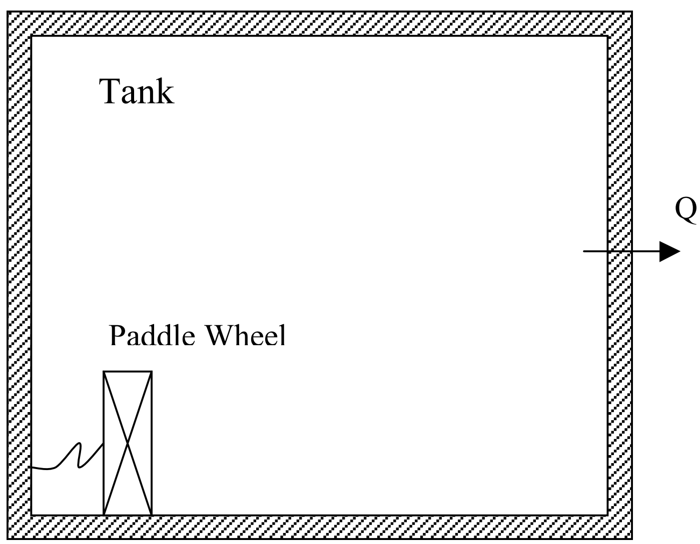
Tutorial #3

First Law of Thermodynamics: Closed Systems

Problem 3-73 A 0.3-m^3 tank contains oxygen initially at 100kPa and 27°C. A paddle wheel within the tank is rotated until the pressure inside rise to 150kPa. During the process 2KJ of heat is lost to the surroundings. Determine the paddle-wheel work done. Neglect the energy stored in the paddle wheel.

Solution:

Step 1: Draw a schematic diagram to represent the system



Step 2: What to determine?

The work done by paddle-wheel work, W_e

Step 3: The information given in the problem statement.

- Volume of the tank, $V = 0.3\,\text{m}^3$, and Volume remains constant during the whole process: $V_2 = V_1 = V$.
- Initial condition of the Oxygen in the tank: $P_1 = 100$ kPa, $T_1 = 27\,°\text{C}$;
- Final condition of the Oxygen in the tank: $P_2 = 150$ kPa;
- Heat loss to the surroundings, $Q = -2$ KJ.

Step 4: Table of all known values and properties

Oxygen	Pressure (kPa)	Volume (m^3)	Temperature (K)	Heat loss (KJ)
Initial condition 1	100	0.3	300	-2
Final condition 2	150	0.3		

Step 5: Assumptions

- It's a closed system and no mass loss in the whole process;
- Consider the Oxygen as ideal gas for given conditions;
- Neglect the energy stored in the paddle wheel;
- Change in kinetic and potential energy is negligible.

Step 6: Solve

1. According the ideal gas equation,

$$PV = mRT$$

From the initial condition, the mass of the Oxygen is determined by

$$m = \frac{P_1V_1}{RT_1} = \frac{(100kPa)\times(0.3m^3)}{(0.2598kPa\cdot m^3/kg\cdot K)(300K)} = 0.3849(kg)$$

2. The final temperature of the Oxygen can be determined from

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

So,

$$T_2 = \frac{P_2V_2}{P_1V_1}T_1 = \frac{(150kPa)\times(0.3m^3)}{(100kPa)\times(0.3m^3)}\times(300K) = 450(K)$$

3. The energy conservation equation of this closed system can be described as:

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

where, ΔKE and ΔPE are both zero according to the assumptions. As for the work,

$$W = W_e + W_b + W_{other}$$

Due to the volume remains constant, the boundary work is zero and there is no other works indicated in the problem. Thus the above energy conservation equation became,

$$Q - W_e = \Delta U$$

Because it's a constant-volume process, the above equation can be concluded,

$$Q - W_e = m(u_2 - u_1) = C_v m(T_2 - T_1)$$

Here, the specific heat of Oxygen at the average temperature of

$T_{avg} = (300 + 450)/2 = 375(K)$ is, $C_{v,avg} = 0.6745KJ/(kg \cdot K)$ (from the Table A-2b).

So, rearrange the above equation and substitute the values,

$$\begin{aligned} W_e &= Q - C_v m(T_2 - T_1) \\ &= (-2KJ) - (0.6745KJ/kg \cdot K)\times(0.3849kg)\times(450K - 300K) \\ &= -40.94KJ \end{aligned}$$

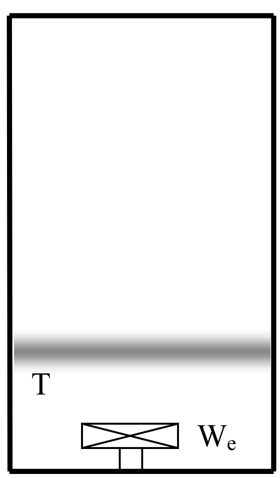
Step 7: Conclusion statement

The work done by the paddle-wheel is **-40.94KJ**.

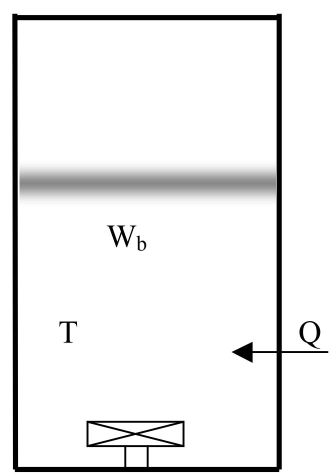
Problem 3-83 A piston-cylinder device contains 5kg of argon at 400kPa and 30°C. During a quasi-equilibrium, isothermal expansion process, 15KJ of boundary work is done by the system, and 3KJ of paddle-wheel work is done on the system. Determine the heat transfer for this process.

Solution:

Step 1: Draw a schematic diagram to represent the problem



Initial Condition



Final Condition

Step 2: What to determine?

The heat transfer between the system and the surroundings, Q

Step 3: The information given in the problem statement.

1. Argon in the cylinder: m=5kg, P=400kPa and T=30V;
2. A boundary work done by the system, W_b=15KJ;
3. The paddle-wheel work done on the system, W_e=-3KJ

Step 4: Assumptions

1. It's a quasi-equilibrium, isothermal expansion process, which means that the temperature remains constant in the whole process;
2. For the argon in the piston-cylinder system, it's a closed system, no mass enters or leaves.
3. Change in kinetic and potential energy is negligible.

Step 6: Solve

We take the argon in the piston-cylinder system as our system, and the energy conservation equation of this closed system can be described as:

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

where, ΔKE and ΔPE are both zero according to the assumptions. It's a quasi-equilibrium, isothermal expansion process. The temperature remains constant, so is the total internal energy. The change of the total internal energy is zero during the whole process, which give us

$$\Delta U = 0$$

So,

$$Q - W = 0$$

Substituting the works,

$$Q = W = W_e + W_b = (-3KJ) + (15KJ) = 12KJ$$

The sign is positive, which means that heat transfers from the surroundings to the system.

Step 7: Conclusion statement

In this process, the argon in the piston-cylinder device will absorb heat with an amount of **12KJ** from the surroundings.