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ME 3322A: Thermodynamics: Fall 2014
Homework Set # 2
Due Date: Sept. 4, 2014

	Problem # in Textbook		Answer
	7th Ed.	**8th Ed.**	
1	2.56	2.59	a) 4 kJ; b) -2 kJ
2	2.64	2.67	b) -50.4 kJ; c) -10.4 kJ/kg
3	2.70	2.73	Q=2.031 kJ
4	2.73	2.76	a) W_{12}=16 kJ, W_{23}=-8kJ; c) 19.5%
5	2.74	2.77	a) Q31=22 kJ, U_3=540 kJ; b) no, because W_{net}<0

PROBLEM 2.56

KNOWN: A gas contained in a piston-cylinder assembly undergoes a constant-pressure expansion while being slowly heated. State data are provided.

FIND: For the gas, evaluate work and heat transfer. For the piston, evaluate work and change in potential energy.

SCHEMATIC & GIVEN DATA:

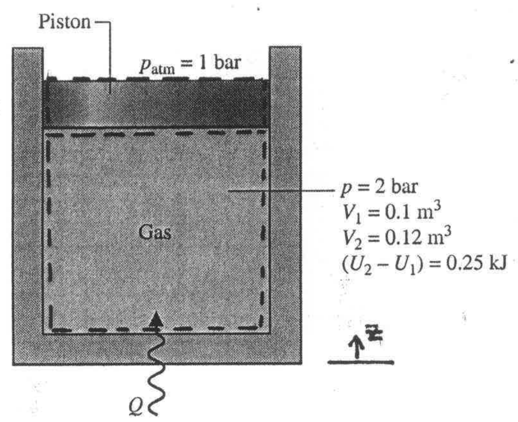


Fig. P2.56

ENGINEERING MODEL:

1. As shown in the schematic, two closed systems are considered: the gas and the piston.
2. The gas undergoes a constant-pressure process.
3. For the gas there is no change in potential energy (see Example 2.3) and no overall change in kinetic energy.
4. For the piston, there is no heat transfer. Also, there is no change in internal energy, no overall change in kinetic energy, and no friction.

ANALYSIS: (a) Taking the gas as the system, the work is obtained from Eq. 2.17:

$$W = \int_1^2 p\,dV = p[V_2 - V_1] = \left(2\times10^5 \frac{N}{m^2}\right)(0.12 - 0.1)\,m^3 \left|\frac{1\,kJ}{10^3\,N\cdot m}\right| = 4\,kJ \longleftarrow$$

Reducing an energy balance, $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q - W \Rightarrow Q = W + \Delta U$

$$\Rightarrow Q = 4\,kJ + 0.25\,kJ = 4.25\,kJ \longleftarrow$$

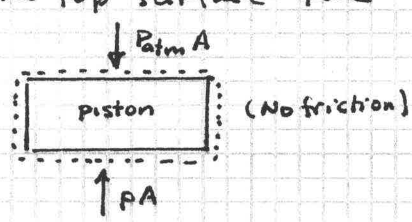
(b) Taking the piston as the system, an energy transfer by work occurs on the bottom surface from the gas. At the top surface the piston does work on the atmosphere:

$$W_{piston} = \int F\,dz = (p_{atm}A - pA)\Delta z = (p_{atm} - p)(A\Delta z)$$

$$= (p_{atm} - p)\underbrace{\Delta V}_{gas}$$

$$= (1-2)\left(10^5 \frac{N}{m^2}\right)(0.12 - 0.1)\,m^3 \left|\frac{1\,kJ}{10^3\,N\cdot m}\right|$$

$$= -2\,kJ \longleftarrow$$



An energy balance for the piston reduces as follows:

$$[\cancel{\Delta U} + \cancel{\Delta KE} + \Delta PE]_{piston} = \cancel{Q}_{piston} - W_{piston}$$

$$\Rightarrow \Delta PE]_{piston} = -W_{piston}$$

① $$= +2\,kJ \longleftarrow$$

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1. Overall energy "balance sheet" in terms of magnitudes:

<u>Input:</u> $Q = 4.25\,kJ$

<u>Disposition of the energy input:</u>

⊙ Stored as ΔU in the gas:	0.25 kJ
⊙ Stored as ΔPE in the piston:	2.00 kJ
⊙ Transfer by work to the atmosphere	2.00 kJ
	4.25 kJ

PROBLEM 2.64

Known: Carbon monoxide (CO) is contained in a rigid tank with a paddle wheel that transfers energy to the air at a constant rate of 14 W for 1 h. During the process, the specific internal energy of the carbon monoxide increases.

Find: Determine the specific volume at the final state, in m^3/kg; the energy transfer by work, in kJ; and the energy transfer by heat transfer, in kJ, with direction.

Schematic and Given Data:

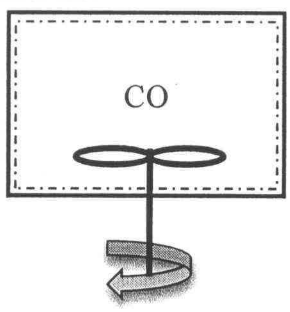
$V = 1\ m^3$

$m = 4\ kg$

$\Delta u = 10\ kJ/kg$

$\dot{W} = -14\ W$

$\Delta t = 1\ h$



Engineering Model:

(1) The carbon monoxide within the tank is the closed system.

(2) The tank is rigid, therefore $V_1 = V_2$.

(3) The system experiences no change in potential and kinetic energy.

Analysis:

(a) The mass and volume remain constant in the process due to assumptions (1) and (2), therefore

$$v = \frac{V}{m} = \frac{1\ m^3}{4\ kg} = 0.25 \frac{m^3}{kg} \quad \longleftarrow$$

(b) To evaluate W, in kJ, integrate the following

$$\int_0^{1\,h} \dot{W} dt = \int_0^{1\,h} (-14\ W) dt = (-14\ W)(1\ h) \left| \frac{3600\ s}{1\ h} \right| \left| \frac{1 \frac{J}{s}}{1\ W} \right| \left| \frac{1\ kJ}{1000\ J} \right| = -50.4\ kJ \quad \longleftarrow$$

The minus sign for W indicates that energy is added to the system by work, as expected.

(c) To evaluate Q, in kJ, use the closed system energy balance

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

$$Q = \Delta U + W = m\Delta u + W = (4\ kg)\left(10 \frac{kJ}{kg}\right) + (-50.4\ kJ) = -10.4\ kJ \quad \longleftarrow$$

Energy is removed from the system through heat transfer. ⟵

PROBLEM 2.70

KNOWN: A gas contained in a piston-cylinder assembly is slowly heated. State data and operating data are provided.

FIND: Determine the work done by the shaft mounted on the top of the piston and work done in displacing the atmosphere, each in kJ. Also, determine the heat tranfer to the gas, in kJ, and develop an accounting of the heat transfer.

SCHEMATIC & GIVEN DATA:

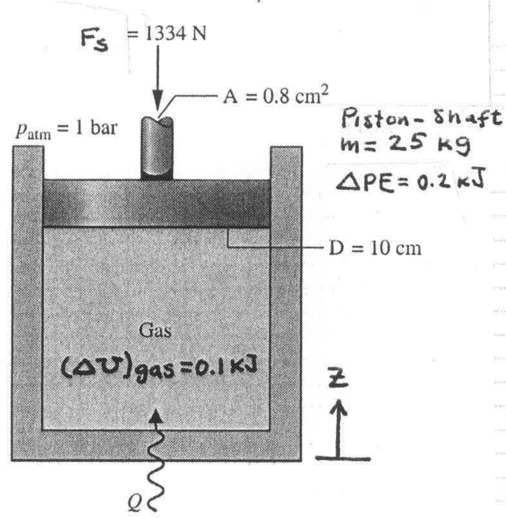


Fig. P2.70

ENGINEERING MODEL:

1. The closed system is the gas plus the piston and attached shaft.
2. There is no overall change in kinetic energy. For the piston-shaft, $\Delta U = 0$. For the gas, $\Delta PE = 0$.
3. $g = 9.81\ m/s^2$

ANALYSIS:

The work can be evaluated using $F\Delta Z$, where ΔZ is the change in elevation of the piston-shaft found as follows:

$$\Delta PE = m g \Delta Z$$

$$\Rightarrow \Delta Z = \frac{\Delta PE}{mg} = \frac{0.2\ kJ}{(25 kg)(9.81 m/s^2)}\left|\frac{10^3 N\cdot m}{1 kJ}\right|\left|\frac{1 kg\cdot m/s^2}{1 N}\right|$$

$$= 0.82\ m$$

Thus, the work done by the shaft is

$$W_s = F_s \Delta Z = (1334\ N)(0.82\ m)\left|\frac{1\ kJ}{10^3 N\cdot m}\right| = 1.094\ kJ$$

The work done in displacing the atmosphere is $W_{atm} = (P_{atm} A_{net})\Delta Z$, where A_{net} is the net area: Area of piston face less area of the shaft. That is,

$$A_{net} = \left[\frac{\pi D^2}{4} - A\right] = \left[\frac{\pi (10 cm)^2}{4} - 0.8 cm^2\right] = 77.74\ cm^2.$$ Thus

$$W_{atm} = \left(10^5 \frac{N}{m^2}\right)(77.74\ cm^2)\left|\frac{1 m}{100 cm}\right|^2 \left|\frac{1\ kJ}{10^3 N\cdot m}\right|(0.82 m) = 0.637\ kJ$$

An energy balance for the system reads

$$\left\{\left[\cancel{\Delta KE} + \Delta PE + \cancel{\Delta U}\right]_{\text{piston-shaft}} + \left[\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U\right]_{gas}\right\} = Q - W$$

$$\Rightarrow Q = (\Delta PE)_{\text{piston-shaft}} + (\Delta U)_{gas} + W$$

$$= (0.2\ kJ) + (0.1\ kJ) + [1.094\ kJ + 0.637\ kJ] = 2.031\ kJ$$

ENERGY "balance sheet":

ENERGY IN:

Q = 2.031 kJ

DISPOSITION OF THE ENERGY IN:

ENERGY STORED: (ΔU)gas	0.10 kJ	(4.92%)
ENERGY STORED: (ΔPE) piston-shaft	0.20 kJ	(9.85%)
ENERGY OUT BY WORK:		
✓ SHAFT	1.094 kJ	(53.87%)
✓ ATM	0.637 kJ	(31.36%)
	2.031 kJ	

PROBLEM 2.73

KNOWN: Data are provided for a power cycle executed by a gas in a piston-cylinder assembly.

FIND: For each process evaluate W. Find Q for processes 1-2, 2-3. Evaluate the thermal efficiency.

SCHEMATIC & GIVEN DATA:

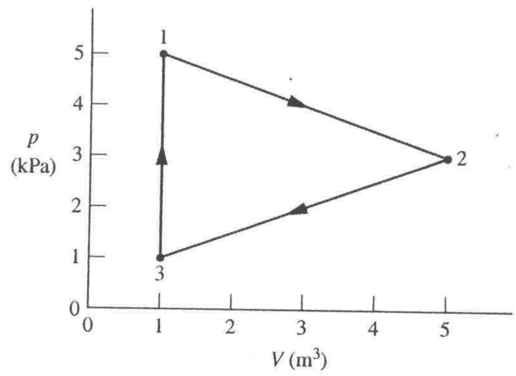
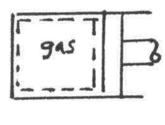


Fig. P2.73



$U_2 - U_1 = 15\,kJ$
$Q_{31} = 10\,kJ$

ENGR. MODEL

1. The gas is the closed system.
2. Volume change is the only work mode.
3. For each process, $\Delta KE = \Delta PE = 0$.

ANALYSIS: (a) The work can be evaluated from Eq. 2.17. For Process 3-1, the piston does not move (volume is constant). Thus, $W_{31} = 0$. ← W_{31}

For Processes 1-2 and 2-3, the work can be evaluated geometrically. That is,

$$W_{12} = P_{ave}[V_2 - V_1] = \left(\frac{P_1+P_2}{2}\right)(V_2 - V_1) = \left[\left(\frac{5+3}{2}\right)kPa\right]\left[5-1\right]m^3 \left|\frac{10^3\,N/m^2}{1\,kPa}\right|\left|\frac{1\,kJ}{10^3\,N\cdot m}\right| \quad \leftarrow W_{12}$$
$$= 16\,kJ$$

$$W_{23} = P_{ave}[V_3 - V_2] = \left(\frac{P_3+P_2}{2}\right)(V_3 - V_2) = \left[\left(\frac{3+1}{2}\right)kPa\right]\left[1-5\right]m^3 \left|\frac{10^3\,N/m^2}{1\,kPa}\right|\left|\frac{1\,kJ}{10^3\,N\cdot m}\right| \quad \leftarrow W_{23}$$
$$= -8\,kJ$$

(b) Q_{31} is given. For Process 1-2, $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q_{12} - W_{12}$

$$\Rightarrow Q_{12} = \Delta U + W_{12} = 15\,kJ + 16\,kJ = 31\,kJ \quad \leftarrow Q_{12}$$

For Process 2-3, $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q_{23} - W_{23}$

$$\Rightarrow Q_{23} = (U_3 - U_2) + W_{23}$$

To find $(U_3 - U_2)$, note that since internal energy is a property

$$(U_2 - U_1) + (U_3 - U_2) + (U_1 - U_3) = 0$$

$$\Rightarrow (U_3 - U_2) = -\underbrace{(U_2 - U_1)}_{15\,kJ} - (U_1 - U_3)$$

Energy balance for Process 3-1:
$$(U_1 - U_3) = Q_{31} - \cancel{W_{31}}^{\,0}$$
$$= 10\,kJ$$

$$\therefore (U_3 - U_2) = -15\,kJ - 10\,kJ = -25\,kJ$$

(1) $$\therefore Q_{23} = -25\,kJ + (-8\,kJ) = -33\,kJ \quad \leftarrow Q_{23}$$

(c) For any power cycle, the thermal efficiency is $\eta = \frac{W_{cycle}}{Q_{in}}$

Here, $W_{cycle} = W_{12} + W_{23} + W_{31} = 16 - 8 + 0 = 8\,kJ$

$Q_{in} = Q_{12} + Q_{31} = 31 + 10 = 41\,kJ$

$$\therefore \eta = \frac{8\,kJ}{41\,kJ} = 0.195\ (19.5\%) \leftarrow \eta$$

1. Also, note that for any cycle, $W_{cycle} = Q_{cycle}$ (Eq. 2.40). Thus $W_{12} + W_{23} + W_{31} = Q_{12} + Q_{23} + Q_{31} \Rightarrow Q_{23} = W_{12} + W_{23} + W_{31} - Q_{12} - Q_{31}$, or $Q_{23} = 16 + (-8) + 0 - 31 - 10 = -33\,kJ$.

PROBLEM 2.74

KNOWN: A gas within a piston–cylinder assembly undergoes a thermodynamic cycle consisting of three processes in series.

FIND: Determine Q_{12}, Q_{31}, U_3. Determine if the cycle can be a power cycle.

SCHEMATIC & GIVEN DATA:

Process 1–2: Compression with $pV = constant$, $W_{12} = -104$ kJ, $U_1 = 512$ kJ, $U_2 = 690$ kJ.
Process 2–3: $W_{23} = 0$, $Q_{23} = -150$ kJ.
Process 3–1: $W_{31} = +50$ kJ.

ENGR. MODEL:

1. The gas is the closed system.
2. Volume change is the only work mode.
3. For each process, $\Delta KE = \Delta PE = 0$.

ANALYSIS: (a) Process 1-2, $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q_{12} - W_{12} \Rightarrow$

$$Q_{12} = [U_2 - U_1] + W_{12} = (690 - 512)\text{kJ} + (-104\text{kJ}) = +74\text{kJ} \quad \leftarrow Q_{12}$$

For any cycle, $W_{cycle} = Q_{cycle}$ (Eq. 2.40). Thus

$$W_{12} + W_{23} + W_{31} = Q_{12} + Q_{23} + Q_{31}$$

$$\Rightarrow \quad Q_{31} = W_{12} + W_{23} + W_{31} - Q_{12} - Q_{23}$$
$$= (-104) + 0 + 50 - 74 - (-150) = +22\text{ kJ} \quad \leftarrow Q_{31}$$

Process 3-1: $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q_{31} - W_{31} \Rightarrow U_1 - U_3 = Q_{31} - W_{31}$ $\quad \leftarrow U_3$

(1) $\Rightarrow \quad U_3 = U_1 - Q_{31} + W_{31} = 512 - 22 + 50 = 540\text{kJ}$

(b) A power cycle is one for which $W_{cycle} > 0$. For the current cycle,

$$W_{cycle} = W_{12} + W_{23} + W_{31}$$
$$= +(-104) + (0) + (50) = -54\text{kJ}$$

*

No. This cycle cannot be a power cycle. $\leftarrow$

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1. As checks on these calculations, note that

Process 2-3: $(U_3 - U_2) = Q_{23} - W_{23}$
$= (-150\text{kJ}) - 0 \Rightarrow U_3 - U_2 = -150\text{kJ}$
$\Rightarrow U_3 = 690 - 150 = 540\text{kJ}$

Since U is a property,

$$(U_2 - U_1) + (U_3 - U_2) + (U_1 - U_3) = 0$$
$$(690 - 512) + (U_3 - 690) + (512 - U_3) = 0$$

540 540

$$178 + (-150) + (-28) = 0 \checkmark$$