ENGR 251 Thermodynamics
Assignment 3: Chapter 4

2-19C Energy can cross the boundaries of a closed system in two forms: heat and work.

2-20C The form of energy that crosses the boundary of a closed system because of a temperature difference is heat; all other forms are work.

2-21C An adiabatic process is a process during which there is no heat transfer. A system that does not exchange any heat with its surroundings is an adiabatic system.

2-22C Point functions depend on the state only whereas the path functions depend on the path followed during a process. Properties of substances are point functions, heat and work are path functions.

4-1C It represents the boundary work for quasi-equilibrium processes.

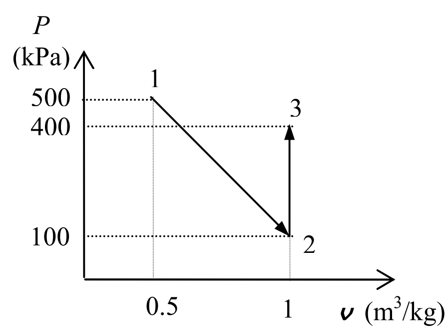
4-2C Yes.

4-3C The area under the process curve, and thus the boundary work done, is greater in the constant pressure case.

4-6 The boundary work done during the process shown in the figure is to be determined.

Assumptions The process is quasi-equilibrium.

Analysis No work is done during the process 2-3 since the area under process line is zero. Then the work done is equal to the area under the process line 1-2:



$$W_{b,\text{out}} = \text{Area} = \frac{P_1 + P_2}{2} m(v_2 - v_1)$$
$$= \frac{(100+500)\text{kPa}}{2}(2\text{ kg})(1.0-0.5)\text{m}^3/\text{kg}\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right)$$
$$= \mathbf{300\ kJ}$$

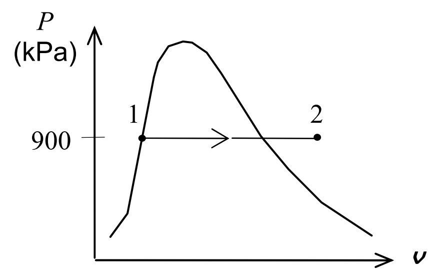
4-12 Refrigerant-134a in a cylinder is heated at constant pressure until its temperature rises to a specified value. The boundary work done during this process is to be determined.

Assumptions The process is quasi-equilibrium.

Properties Noting that the pressure remains constant during this process, the specific volumes at the initial and the final states are (Table A-11 through A-13)

$$\left.\begin{array}{l} P_1 = 900 \text{ kPa} \\ \text{Sat. liquid} \end{array}\right\} v_1 = v_{f@900 \text{ kPa}} = 0.0008580 \text{ m}^3/\text{kg}$$

$$\left.\begin{array}{l} P_2 = 900 \text{ kPa} \\ T_2 = 70°\text{C} \end{array}\right\} v_2 = 0.027413 \text{ m}^3/\text{kg}$$



Analysis The boundary work is determined from its definition to be

$$m = \frac{V_1}{v_1} = \frac{0.2 \text{ m}^3}{0.0008580 \text{ m}^3/\text{kg}} = 233.1 \text{ kg}$$

and

$$W_{b,\text{out}} = \int_1^2 P\,dV = P(V_2 - V_1) = mP(v_2 - v_1)$$

$$= (233.1 \text{ kg})(900 \text{ kPa})(0.027413 - 0.0008580)\text{m}^3/\text{kg}\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)$$

$$= \mathbf{5571\ kJ}$$

Discussion The positive sign indicates that work is done by the system (work output).

4-19 Nitrogen gas in a cylinder is compressed polytropically until the temperature rises to a specified value. The boundary work done during this process is to be determined.

Assumptions **1** The process is quasi-equilibrium. **2** Nitrogen is an ideal gas.

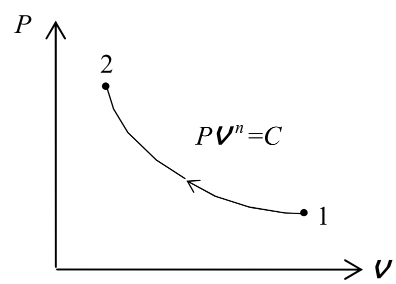
Properties The gas constant for nitrogen is R = 0.2968 kJ/kg.K (Table A-2a)

Analysis The boundary work for this polytropic process can be determined from

$$W_{b,\text{out}} = \int_1^2 P\,dV = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$$

$$= \frac{(2 \text{ kg})(0.2968 \text{ kJ/kg}\cdot\text{K})(360-300)\text{K}}{1-1.4}$$

$$= \mathbf{-89.0\ kJ}$$

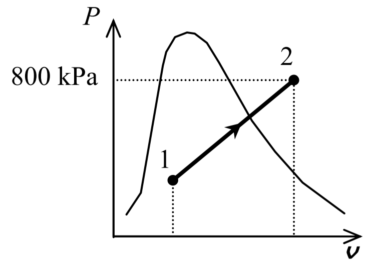


Discussion The negative sign indicates that work is done on the system (work input).

4-26 A saturated water mixture contained in a spring-loaded piston-cylinder device is heated until the pressure and temperature rises to specified values. The work done during this process is to be determined.

Assumptions The process is quasi-equilibrium.

Analysis The initial state is saturated mixture at 90°C. The pressure and the specific volume at this state are (Table A-4),



$$P_1 = 70.183 \text{ kPa}$$
$$\begin{aligned} \boldsymbol{v}_1 &= \boldsymbol{v}_f + x\boldsymbol{v}_{fg} \\ &= 0.001036 + (0.10)(2.3593 - 0.001036) \\ &= 0.23686 \text{ m}^3/\text{kg} \end{aligned}$$

The final specific volume at 800 kPa and 250°C is (Table A-6)

$$\boldsymbol{v}_2 = 0.29321 \text{ m}^3/\text{kg}$$

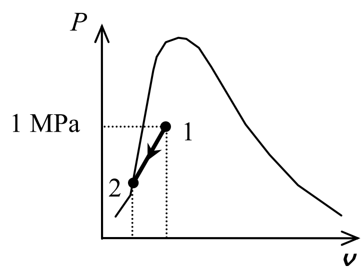
Since this is a linear process, the work done is equal to the area under the process line 1-2:

$$\begin{aligned} W_{b,\text{out}} &= \text{Area} = \frac{P_1 + P_2}{2} m(\boldsymbol{v}_2 - \boldsymbol{v}_1) \\ &= \frac{(70.183 + 800)\text{kPa}}{2}(1 \text{ kg})(0.29321 - 0.23686)\text{m}^3 \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right) \\ &= \mathbf{24.52 \text{ kJ}} \end{aligned}$$

4-27 A saturated water mixture contained in a spring-loaded piston-cylinder device is cooled until it is saturated liquid at a specified temperature. The work done during this process is to be determined.

Assumptions The process is quasi-equilibrium.

Analysis The initial state is saturated mixture at 1 MPa. The specific volume at this state is (Table A-5),



$$\begin{aligned} \boldsymbol{v}_1 &= \boldsymbol{v}_f + x\boldsymbol{v}_{fg} \\ &= 0.001127 + (0.10)(0.19436 - 0.001127) \\ &= 0.020450 \text{ m}^3/\text{kg} \end{aligned}$$

The final state is saturated liquid at 100°C (Table A-4)

$$P_2 = 101.42 \text{ kPa}$$
$$\boldsymbol{v}_2 = \boldsymbol{v}_f = 0.001043 \text{ m}^3/\text{kg}$$

Since this is a linear process, the work done is equal to the area under the process line 1-2:

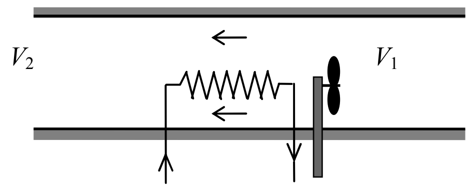
$$\begin{aligned} W_{b,\text{out}} &= \text{Area} = \frac{P_1 + P_2}{2} m(\boldsymbol{v}_2 - \boldsymbol{v}_1) \\ &= \frac{(1000 + 101.42)\text{kPa}}{2}(0.5 \text{ kg})(0.001043 - 0.020450)\text{m}^3 \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right) \\ &= \mathbf{-5.34 \text{ kJ}} \end{aligned}$$

The negative sign shows that the work is done on the system in the amount of 5.34 kJ.

5-10 Air is expanded and is accelerated as it is heated by a hair dryer of constant diameter. The percent increase in the velocity of air as it flows through the drier is to be determined.

Assumptions Flow through the nozzle is steady.

Properties The density of air is given to be 1.20 kg/m^3 at the inlet, and 1.05 kg/m^3 at the exit.



Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Then,

$$\dot{m}_1 = \dot{m}_2$$

$$\rho_1 A V_1 = \rho_2 A V_2$$

$$\frac{V_2}{V_1} = \frac{\rho_1}{\rho_2} = \frac{1.20 \text{ kg/m}^3}{1.05 \text{ kg/m}^3} = 1.14 \quad \text{(or, and increase of } \mathbf{14\%}\text{)}$$

Therefore, the air velocity increases 14% as it flows through the hair drier.

5-15 Air flows through an aircraft engine. The volume flow rate at the inlet and the mass flow rate at the exit are to be determined.

Assumptions **1** Air is an ideal gas. **2** The flow is steady.

Properties The gas constant of air is R = 0.287 kPa·m^3/kg·K (Table A-1).

Analysis The inlet volume flow rate is

$$\dot{\boldsymbol{V}}_1 = A_1 V_1 = (1 \text{ m}^2)(180 \text{ m/s}) = \mathbf{180 \ m^3/s}$$

The specific volume at the inlet is

$$\boldsymbol{v}_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(20 + 273 \text{ K})}{100 \text{ kPa}} = 0.8409 \text{ m}^3/\text{kg}$$

Since the flow is steady, the mass flow rate remains constant during the flow. Then,

$$\dot{m} = \frac{\dot{\boldsymbol{V}}_1}{\boldsymbol{v}_1} = \frac{180 \text{ m}^3/\text{s}}{0.8409 \text{ m}^3/\text{kg}} = \mathbf{214.1 \ kg/s}$$