2–48 The basic barometer can be used to measure the height of a building. If the barometric readings at the top and at the bottom of a building are 730 and 755 mm Hg, respectively, determine the height of the building. Take the densities of air and mercury to be 1.18 kg/m^3 and 13,600 kg/m^3, respectively.

Atmospheric pressures at the top and at the bottom of the building are

$$\begin{aligned} P_{top} &= (\rho g h)_{top} \\ &= (13{,}600 kg/m^3)(9.807 m/s^2)(0.730 m)\left(\frac{1N}{1kg\cdot m/s^2}\right)\left(\frac{1kPa}{1000N/m^2}\right) \\ &= 97.36 kPa \end{aligned}$$

$$\begin{aligned} P_{bottom} &= (\rho g h)_{bottom} \\ &= (13{,}600 kg/m^3)(9.807 m/s^2)(0.755 m)\left(\frac{1N}{1kg\cdot m/s^2}\right)\left(\frac{1kPa}{1000N/m^2}\right) \\ &= 100.70 kPa \end{aligned}$$

Taking an air column between the top and the bottom of the building and writing a force balance per unit base area, we obtain

$$W_{air}/A = P_{bottom} - P_{top}$$

$$(\rho g h)_{air} = P_{bottom} - P_{top}$$

$$(1.18 kg/m^3)(9.807 m/s^2)(h)\left(\frac{1N}{1kg\cdot m/s^2}\right)\left(\frac{1kPa}{1000N/m^2}\right) = (100.70 - 97.36) kPa$$

It yields h = **288.6 m**

which is also the height of the building.

2–51 A gas is contained in a vertical, frictionless piston–cylinder device. The piston has a mass of 4 kg and a cross-sectional area of 35 cm^2. A compressed spring above the piston exerts a force of 60 N on the piston. If the atmospheric pressure is 95 kPa, determine the pressure inside the cylinder. *Answer: 123.4 kPa*

Drawing the free body diagram of the piston and balancing the vertical forces yield

$$\mathrm{PA} = \mathrm{P_{atm}A} + \mathrm{W} + \mathrm{F_{spring}}$$

Thus,

$$P = P_{atm} + \frac{mg + F_{spring}}{A}$$

$$= (95 kPa) + \frac{(4kg)(9.807 m/s^2) + 60N}{35 \times 10^{-4} m^2}\left(\frac{1 kPa}{1000 N/m^2}\right)$$

$$= \mathbf{123.4 kPa}$$

2–53 Both a gage and a manometer are attached to a gas tank to measure its pressure. If the reading on the pressure gage is 80 kPa, determine the distance between the two fluid levels of the manometer if the fluid is (*a*) mercury (ρ = 13,600 kg/m^3) or (*b*) water (ρ = 1000 kg/m^3).

The gage pressure is related to the vertical distance h between the two fluid levels by

$$\mathrm{P_{gage}} = \rho \mathrm{gh} \quad \longrightarrow \quad \mathrm{h} = \frac{\mathrm{P_{gage}}}{\rho \mathrm{g}}$$

(a) For mercury,

$$h = \frac{P_{gage}}{\rho_{Hg} g} = \frac{80 kPa}{(13600 kg/m^3)(9.807 m/s^2)}\left(\frac{1000 kg/m \cdot s^2}{1 kPa}\right) = \mathbf{0.60m}$$

(b) For water,

$$h = \frac{P_{gage}}{\rho_{H_2O} g} = \frac{80 kPa}{(1000 kg/m^3)(9.807 m/s^2)}\left(\frac{1000 kg/m \cdot s^2}{1 kPa}\right) = \mathbf{8.16m}$$

2–85 Balloons are often filled with helium gas because it weighs only about one-seventh of what air weighs under identical conditions. The buoyancy force, which can be expressed as $F_b = \rho_{air} g V_{balloon}$, will push the balloon upward. If the balloon has a diameter of 10 m and carries two people, 70 kg each, determine the acceleration of the balloon when it is first released. Assume the density of air is $\rho = 1.16\ kg/m^3$, and neglect the weight of the ropes and the cage. *Answer: 16.5 m/s²*

The buoyancy force acting on the balloon is

$$V_{balloon} = 4\pi r^3/3 = 4\pi(5m)^3/3 = 523.6m^3$$

$$\begin{aligned} F_B &= \rho_{air} g V_{balloon} \\ &= (1.16kg/m^3)(9.807m/s^2)(523.6m^3)\left(\frac{1N}{1kg\cdot m/s^2}\right) = 5956.5N \end{aligned}$$

The total mass is

$$m_{He} = \rho_{He} V = \left(\frac{1.16}{7} kg/m^3\right)(523.6m^3) = 86.8kg$$

$$m_{total} = m_{He} + m_{people} = 86.8 + 2\times 70 = 226.8kg$$

The total weight is

$$W = m_{total} g = (226.8kg)(9.807m/s^2)\left(\frac{1N}{1kg\cdot m/s^2}\right) = 2224.2N$$

Thus the net force acting on the balloon is

$$F_{net} = F_B - W = 5956.5 - 2224.2 = 3732.3\ N$$

Then the acceleration becomes

$$a = \frac{F_{net}}{m_{total}} = \frac{3732.2N}{226.8kg}\left(\frac{1kg\cdot m/s^2}{1N}\right) = \mathbf{16.5 m/s^2}$$

2–89 The lower half of a 10-m-high cylindrical container is filled with water (ρ = 1000 kg/m^3) and the upper half with oil that has a specific gravity of 0.85. Determine the pressure difference between the top and bottom of the cylinder. *Answer:* 90.7 kPa

The density of the oil is obtained by multiplying its specific gravity by the density of water which is given to be 1000 kg/m^3,

$$\rho = (\rho_s)(\rho_{H_2O}) = (0.85)(1000\,\mathrm{kg/m^3}) = 850\,\mathrm{kg/m^3}$$

The pressure difference between the top and the bottom of the cylinder is the sum of the pressure differences across the two fluids,

$$\begin{aligned}\Delta P_{total} &= \Delta P_{oil} + \Delta P_{water} = (\rho g h)_{oil} + (\rho g h)_{water} \\ &= \left[(850 kg/m^3)(9.807 m/s^2)(5m) + (1000 kg/m^3)(9.807 m/s^2)(5m)\right]\left(\frac{1 kPa}{1000 N/m^2}\right) \\ &= \mathbf{90.7 kPa}\end{aligned}$$

2–91 A pressure cooker cooks a lot faster than an ordinary pan by maintaining a higher pressure and temperature inside. The lid of a pressure cooker is well sealed, and steam can escape only through an opening in the middle of the lid. A separate metal piece, the petcock, sits on top of this opening and prevents steam from escaping until the pressure force overcomes the weight of the petcock. The periodic escape of the steam in this manner prevents any potentially dangerous pressure buildup and keeps the pressure inside at a constant value. Determine the mass of the petcock of a pressure cooker whose operation pressure is 100 kPa gage and has an opening cross-sectional area of 4 mm^2. Assume an atmospheric pressure of 101 kPa, and draw the free-body diagram of the petcock. *Answer:* 40.8 g

FIGURE P2–91

Atmospheric pressure is acting on all surfaces of the petcock, which balances itself out. Therefore, it can be disregarded in calculations if we use the gage pressure as the cooker pressure. A force balance on the petcock ($\mathbb{S}F_y = 0$) yields

$$W = P_{gage} A$$

$$m = \frac{P_{gage} A}{g} = \frac{(100 kPa)(4 \times 10^{-6} m^2)}{9.807 m/s^2}\left(\frac{1000 kg/m \cdot s^2}{1 kPa}\right)$$

$$= \mathbf{0.0408 kg}$$

3–17 A river flowing steadily at a rate of 240 m^3/s is considered for hydroelectric power generation. It is determined that a dam can be built to collect water and release it from an elevation difference of 50 m to generate power. Determine how much power can be generated from this river water after the dam is filled.

$$E_{mek} = 240 \times 1000\,(9.81 \times 50)\,\frac{1}{1000}$$

$$= 122625\ kW$$

3–28 A small electrical motor produces 10 W of mechanical power. What is this power in (*a*) N, m, and s units; and (*b*) kg, m, and s units? *Answers:* (*a*) 10 N · m/s, (*b*) 10 kg · m^2/s^3

$$W_e = 10\ W$$

$$W = \frac{J}{s} \qquad J = N.m \qquad W = \frac{Nm}{s}$$

$$N = kg\,\frac{m}{s^2} \qquad W = \frac{kgm}{s^2}\,\frac{m}{s} = \frac{kg\,m^2}{s^3}$$

3–31 Determine the energy required to accelerate an 800-kg car from rest to 100 km/h on a level road. *Answer:* 309 kJ

$$E_{mek} = 800\left[\left(\frac{100/1000}{3600}\right)^2 \frac{1}{2} - \frac{0^2}{2}\right]\frac{1}{1000}$$

$$= 309\ kJ$$

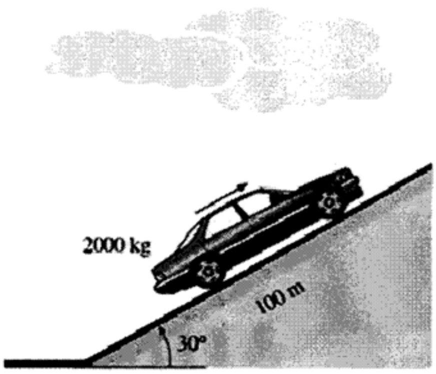
3–33 A man whose mass is 100 kg pushes a cart whose mass, including its contents, is 100 kg up a ramp that is inclined at an angle of 20° from the horizontal. The local gravitational acceleration is 9.8 m/s^2. Determine the work, in kJ, needed to move along this ramp a distance of 100 m considering (*a*) the man and (*b*) the cart and its contents as the system.

$\sin 20 = \dfrac{\Delta z}{100} \qquad \Delta z = 34.20\,m$

a) $W_g = mg\Delta z = 200 \times 9.81 \times \dfrac{34.20}{1000} = 67.1\,kJ$

b) $W_g = 100 \times 9.81 \times 34.20 / 1000 = 33.6\,kJ$

3–40 Determine the power required for a 2000-kg car to climb a 100-m-long uphill road with a slope of 30° (from horizontal) in 10 s (*a*) at a constant velocity, (*b*) from rest to a final velocity of 30 m/s, and (*c*) from 35 m/s to a final velocity of 5 m/s. Disregard friction, air drag, and rolling resistance. *Answers:* (*a*) 98.1 kW, (*b*) 188 kW, (*c*) −21.9 kW



a) $\dot{W}_g = 2000 \times 9.81 \times \dfrac{\sin 30 \times 100}{10} \dfrac{1}{1000}$

$= 98.1\,kW$

b) $W_a = 2000 \dfrac{30^2}{2} \dfrac{1}{1000} = 900\,kJ$

$\dot{W}_a = \dfrac{900}{10} = 90\,kW \qquad \dot{W}_g + \dot{W}_a = 188.1\,kW$

c) $W_a = \dfrac{2000}{2} (5^2 - 35^2) = -1200\,kJ$

$\dot{W}_g + \dot{W}_a = -\dfrac{1200}{10s} + 98.1 = -21.9\,kW$

3–50 A classroom that normally contains 40 people is to be air-conditioned with window air-conditioning units of 5-kW cooling capacity. A person at rest may be assumed to dissipate heat at a rate of about 360 kJ/h. There are 10 lightbulbs in the room, each with a rating of 100 W. The rate of heat transfer to the classroom through the walls and the windows is estimated to be 15,000 kJ/h. If the room air is to be maintained at a constant temperature of 21°C, determine the number of window air-conditioning units required.

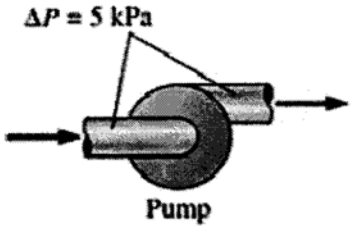
$40 \times 360 = 14400\ kJ/h = 4\ kW$

$10 \times 100 = 1000\ W = 1.0\ kW$

$\frac{15000}{3600} = 4.16\ kW$

$4 + 1 + 4.16 = 9.16\ kW$ 2 units

3–56 The driving force for fluid flow is the pressure difference, and a pump operates by raising the pressure of a fluid (by converting the mechanical shaft work to flow energy). A gasoline pump is measured to consume 5.2 kW of electric power when operating. If the pressure differential between the outlet and inlet of the pump is measured to be 5 kPa and the changes in velocity and elevation are negligible, determine the maximum possible volume flow rate of gasoline.



$\dot{W}_e = 5.2\ kW \qquad \Delta P = 5\ kPa$

$\Delta \dot{E}_{mek} = \dot{m}\left(\frac{\Delta P}{\rho}\right) = \dot{W}_e = 5.2\ kW$

$\frac{\dot{m}}{\rho} = \frac{5.2}{\Delta P} = 1.04\ m^3/s$

8

3–62 Consider a 3-kW hooded electric open burner in an area where the unit costs of electricity and natural gas are \$0.07/kWh and \$1.20/therm (1 therm = 105,500 kJ), respectively. The efficiency of open burners can be taken to be 73 percent for electric burners and 38 percent for gas burners. Determine the rate of energy consumption and the unit cost of utilized energy for both electric and gas burners.

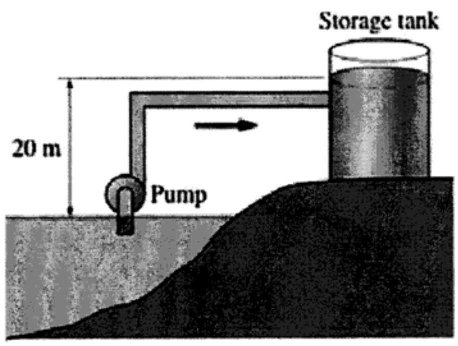
$\dot{Q} = 3\times 0.73 = 2.19\,kW$ kullanılabilir enerji

K. Enerjinin maliyeti: $\frac{\$0.07/kWh}{0.73} = \$0.096/kWh$

$\dot{Q}_{gaz} = \frac{2.19}{0.38} = 5.76\,kW$ $\quad 2.19\times 0.09 = \$0.1971$

1 therm = 29.3 kWh $\quad \frac{1.20/29.3}{0.38} = \$0.108/kWh$

3–75 Water is pumped from a lake to a storage tank 20 m above at a rate of 70 L/s while consuming 20.4 kW of electric power. Disregarding any frictional losses in the pipes and any changes in kinetic energy, determine (*a*) the overall efficiency of the pump–motor unit and (*b*) the pressure difference between the inlet and the exit of the pump.



$$\Delta\dot{E}_{mek,fluid} = \dot{m}gh = 9.81\times 20\times 70\times 10^{-3}\times 1000$$
$$= 13.734\,kW$$

$$\eta_{overall} = \eta_{pump-motor} = \frac{\Delta\dot{E}_{mek,fluid}}{\dot{W}_{elec,in}} = \frac{13.734}{20.4} = 0.67$$

$$\Delta\dot{E}_{mek,fluid} = \dot{m}\left(\frac{P}{\rho}\right)$$
$$= 70\times 10^{-3}\,\Delta P;\quad \Delta P = 196.2\,kPa$$

3–91 A typical car driven 20,000 km a year emits to the atmosphere about 11 kg per year of NO_x (nitrogen oxides), which cause smog in major population areas. Natural gas burned in the furnace emits about 4.3 g of NO_x per therm (1 therm = 105,500 kJ), and the electric power plants emit about 7.1 g of NO_x per kWh of electricity produced. Consider a household that has two cars and consumes 9000 kWh of electricity and 1200 therms of natural gas. Determine the amount of NO_x emission to the atmosphere per year for which this household is responsible.

2×11 kg Nox/yıl = 22 kg Nox/yıl (araba)

9000 kWh/yıl × 7.1 g Nox/kWh = 63900 g Nox/yıl (elektrik)

1200 therm/yıl × 4.3 g/therm = 5160 g Nox/yıl (Gaz)

22 + 63.9 + 5.16 = 91.06 kg Nox/yıl

10

4–23 Complete this table for H_2O:

T, °C	P, kPa	v, m^3/kg	Phase description
50		4.16	
	200		Saturated vapor
250	400		
110	600		

Tablo A4, A5, A6 yardımı ile

T, °C	**P, kPa**	***v*, m^3 / kg**	**Phase description**
50	***12.352***	4.16	***Doymuş sıvı buhar karışımı***
120.21	200	***0.88578***	Doymuş buhar
250	400	***0.59520***	***Kızgın buhar***
110	600	***0.001052***	***Sıkıştırılmış sıvı***

Su için aşağıdaki tabloyu tamamlayınız.

T, °C	**P, kPa**	***h*, kJ / kg**	***x***	**Phase description**
	325		0.4	
160		1682		
	950		0.0	
80	500			
	800	3161.7		

Tablo A4, A5, A6 yardımı ile

T, °C	**P, kPa**	***h*, kJ / kg**	***x***	**Phase description**
136.27	325	***1435.35***	0.4	***Doymuş sıvı buhar karışımı***
160	***618.23***	1682	***0.483***	***Doymuş sıvı buhar karışımı***
177.66	950	***752.74***	0.0	***Doymuş sıvı***
80	500	***335.02***	**- - -**	***Sıkıştırılmış sıvı***
350	800	3162.2	**- - -**	***Kızgın buhar***

R 134a için aşağıdaki tabloyu tamamlayınız.

T, °C	P, kPa	*h*, kJ / kg	*x*	Faz açıklaması
	240	81		
4			0.27	
-20	500			
	1400	362		
20			1.0	

Tablo A11, A12, A13 yardımı ile

T, °C	P, kPa	*h*, kJ / kg	*x*	Faz açıklaması
-5.38	240	81	***0.179***	***Doymuş sıvı buhar karışımı***
4	***337.90***	***110.03***	0.27	***Doymuş sıvı buhar karışımı***
-20	500	***25.49***	**- - -**	***Sıkıştırılmış sıvı***
130	1400	363.02	**- - -**	***Kızgın buhar***
20	***572.07***	***261.59***	1.0	***Doymuş buhar***

4–49 Water in a 5-cm-deep pan is observed to boil at 98°C. At what temperature will the water in a 40-cm-deep pan boil? Assume both pans are full of water.

The pressure at the bottom of the 5-cm pan is the saturation pressure corresponding to the boiling temperature of 98°C:

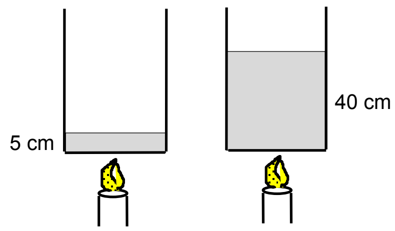
$$P = P_{sat@98^\circ C} = 94.63\,\text{kPa}$$

The pressure difference between the bottoms of two pans is

$$\Delta P = \rho g h = (1000 kg/m^3)(9.8 m/s^2)(0.35 m)\left(\frac{1 kPa}{1000 kg/m \cdot s^2}\right) = 3.43 kPa$$

Then the pressure at the bottom of the 40-cm deep pan is

P = 94.63 + 3.43 = 98.06 kPa



Then the boiling temperature becomes

$$T_{boiling} = T_{sat@98.06\,kPa} = \mathbf{99.0^\circ C}$$

4–53 A 0.5-m^3 vessel contains 10 kg of refrigerant-134a at −20°C. Determine (*a*) the pressure, (*b*) the total internal energy, and (*c*) the volume occupied by the liquid phase. *Answers:* (*a*) 132.82 kPa, (*b*) 904.2 kJ, (*c*) 0.00489 m^3

The specific volume of the water is

$$v = \frac{V}{m} = \frac{0.5\ \mathrm{m}^3}{10\ \mathrm{kg}} = 0.05\ \mathrm{m}^3/\mathrm{kg}$$

At -20°C, $v_f = 0.0007362$ m^3/kg and $v_g = 0.14729$ m^3/kg. Thus the tank contains saturated liquid-vapor mixture since $v_f < v < v_g$, and the pressure must be the saturation pressure at the specified temperature,

$$P = P_{sat@-20^\circ C} = \mathbf{132.82kPa}$$

(b) The quality of the refrigerant-134a and its total internal energy are determined from

$$x = \frac{\mathbf{v} - \mathbf{v}_f}{\mathbf{v}_{fg}} = \frac{0.05 - 0.0007362}{0.14729 - 0.0007362} = 0.336$$

$$u = u_f + xu_{fg} = 25.39 + 0.336 \times (218.84 - 25.39) = 90.39 kJ/kg$$

$$U = mu = (10kg)(90.39kJ/kg) = 903.9\mathbf{kJ}$$

R-134a
10 kg
-20°C

(c) The mass of the liquid phase and its volume are determined from

$$m_f = (1-x)m_t = (1 - 0.336) \times 10 = \mathbf{6.64kg}$$

$$V_f = m_f \mathbf{v}_f = (6.64kg)(0.0007362 m^3/kg) = \mathbf{0.00489m^3}$$

4–54 A piston–cylinder device contains 0.1 m^3 of liquid water and 0.9 m^3 of water vapor in equilibrium at 800 kPa. Heat is transferred at constant pressure until the temperature reaches 350°C.

(*a*) What is the initial temperature of the water?
(*b*) Determine the total mass of the water.
(*c*) Calculate the final volume.
(*d*) Show the process on a *P*-*v* diagram with respect to saturation lines.

(a) Initially two phases coexist in equilibrium, thus we have a saturated liquid-vapor mixture. Then the temperature in the tank must be the saturation temperature at the specified pressure,

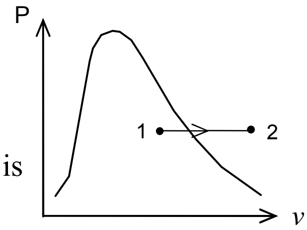
$$\mathrm{T} = \mathrm{T}_{\mathrm{sat\,@\,800\,kPa}} = \mathbf{170.43\ ^\circ C} \qquad \text{(Table A-5)}$$

(b) The total mass in this case can easily be determined by adding the mass of each phase,

$$m_f = \frac{V_f}{v_f} = \frac{0.1\,m^3}{0.001115\,m^3/kg} = 89.69\,kg$$

$$m_g = \frac{V_g}{v_g} = \frac{0.9\,m^3}{0.2404\,m^3/kg} = 3.74\,kg$$

$$m_t = m_f + m_g = 89.69 + 3.74 = \mathbf{93.43\,kg}$$



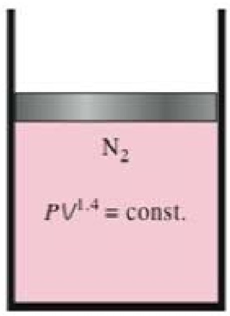
(c) At the final state water is superheated vapor, and its specific volume is

$$\left.\begin{array}{l} P_2 = 800 kPa \\ T_2 = 350\,^\circ C \end{array}\right\} v_2 = 0.3544 m^3/kg \quad \text{(Table A-6)}$$

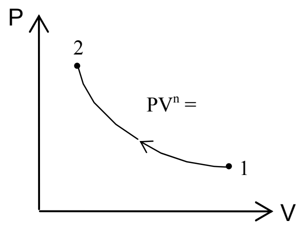
Then,

$$V_2 = m_t v_2 = (93.43\,kg)(0.3544\,m^3/kg) = \mathbf{33.1\,m^3}$$

5–19 A frictionless piston–cylinder device contains 2 kg of nitrogen at 100 kPa and 300 K. Nitrogen is now compressed slowly according to the relation $PV^{1.4}$ = constant until it reaches a final temperature of 360 K. Calculate the work input during this process. *Answer: 89 kJ*



Nitrogen at specified conditions can be treated as an ideal gas. Then the boundary work for this polytropic process can be determined from Eq. 3-12,

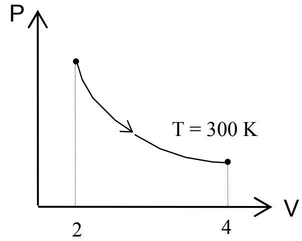


$$W_b = \int_1^2 P dV = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$$

$$= \frac{(2kg)(0.2968 kJ/kg\cdot K)(360-300)K}{1-1.4} = \mathbf{-89.0kJ}$$

5–20 The equation of state of a gas is given as $\bar{v}(P + 10/\bar{v}^2) = R_u T$, where the units of $\bar{v}$ and P are m^3/kmol and kPa, respectively. Now 0.5 kmol of this gas is expanded in a quasi-equilibrium manner from 2 to 4 m^3 at a constant temperature of 300 K. Determine (*a*) the unit of the quantity 10 in the equation and (*b*) the work done during this isothermal expansion process.

(a) The term $10/\bar{v}^2$ must have pressure units since it is added to P.
Thus the quantity 10 must have the unit kPa·m^6/kmol^2.



(b) The boundary work for this process can be determined from

$$P = \frac{R_u T}{\bar{v}} - \frac{10}{\bar{v}^2} = \frac{R_u T}{V/N} - \frac{10}{(V/N)^2} = \frac{N R_u T}{V} - \frac{10 N^2}{V^2}$$

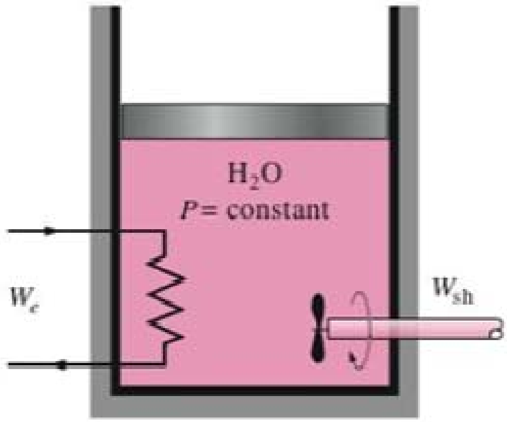
and

$$W_b = \int_1^2 P dV = \int_1^2 \left(\frac{N R_u T}{V} - \frac{10 N^2}{V^2} \right) dV = N R_u T \ln \frac{V_2}{V_1} + 10 N^2 \left(\frac{1}{V_2} - \frac{1}{V_1} \right)$$

$$= (0.5 kmol)(8.314 kJ / kmol \cdot K)(300K) \ln \frac{4m^3}{2m^3} + (10 kPa \cdot m^6 / kmol^2)(0.5 kmol)^2 \left(\frac{1}{4m^3} - \frac{1}{2m^3} \right) \left(\frac{1 kJ}{1 kPa \cdot m^3} \right)$$

$= \mathbf{863.8 kJ}$

5–39 An insulated piston–cylinder device contains 5 L of saturated liquid water at a constant pressure of **150** kPa. Water is stirred by a paddle wheel while a current of 8 A flows for 45 min through a resistor placed in the water. If one-half of the liquid is evaporated during this constant-pressure process and the paddle-wheel work amounts to 400 kJ, determine the voltage of the source. Also, show the process on a *P-v* diagram with respect to saturation lines. *Answer: 224 V*



We take the water in the piston-cylinder device as our system. This is a closed system since no mass enters or leaves. The conservation of energy equation for this case reduces to

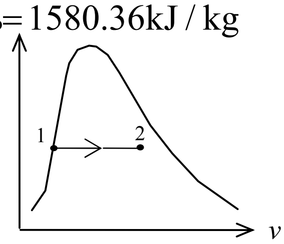
$$Q^{\nearrow 0} + W_{other} - W_b = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$
$$-W_e - W_b = m(h_2 - h_1)$$
$$-(-VI\Delta t) - W_b = m(h_2 - h_1)$$

since P = constant and $\Delta U + W_b = \Delta H$ for constant pressure quasi-equilibrium processes.

$$\left.\begin{array}{l} P_1 = 150\text{kPa} \\ \text{sat.liquid} \end{array}\right\} \begin{array}{l} h_1 = h_{f@150\text{kPa}} = 467.11\text{kJ/kg} \\ v_1 = v_{f@150\text{kPa}} = 0.0010528\text{m}^3/\text{kg} \end{array}$$

$$\left.\begin{array}{l} P_1 = 150\text{kPa} \\ x_2 = 0.5 \end{array}\right\} h_2 = h_f + x_2 h_{fg} = 467.11 + (0.5 \times 2226.5) = 1580.36\text{kJ/kg}$$

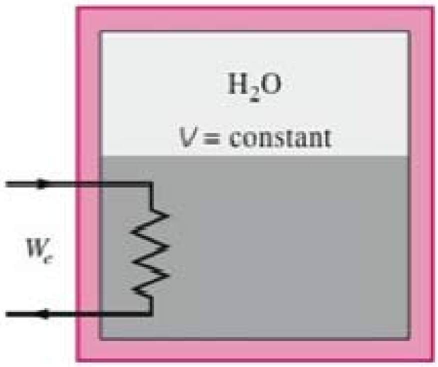
$$m = \frac{V_1}{v_1} = \frac{0.005\text{m}^3}{0.0010528\text{m}^3/\text{kg}} = 4.75\text{kg}$$



Substituting,

$$\text{VI}\Delta\text{t} - (-300\text{kJ}) = (4.75\text{kg})(1580.36 - 467.11)\text{kJ/kg}$$
$$\text{VI}\Delta\text{t} = 4988\text{kJ}$$
$$\text{V} = \frac{4988\text{kJ}}{(8\text{A})(45 \times 60\text{s})}\left(\frac{1000\text{VA}}{1\text{kJ/s}}\right) = 230.9\text{V}$$

5–35 A well-insulated rigid tank contains 5 kg of a saturated liquid–vapor mixture of water at 100 kPa. Initially, three-quarters of the mass is in the liquid phase. An electric resistor placed in the tank is connected to a 110-V source, and a current of 8 A flows through the resistor when the switch is turned on. Determine how long it will take to vaporize all the liquid in the tank. Also, show the process on a *T-v* diagram with respect to saturation lines.

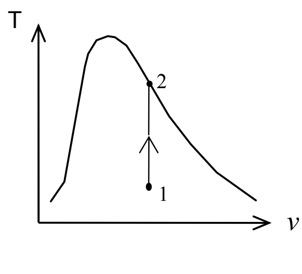


We take the water in the tank as our system. This is a closed system since no mass enters or leaves.

$$\left.\begin{array}{l} P_1 = 100kPa \\ x_1 = 0.25 \end{array}\right\} \begin{array}{ll} v_f = 0.001043, & v_g = 1.6940m^3/kg \\ u_f = 417.36, & u_{fg} = 2088.7kJ/kg \end{array}$$

$$v_1 = v_f + x_1 v_{fg} = 0.001043 + [0.25 \times (1.6940 - 0.001043)] = 0.42428m^3/kg$$
$$u_1 = u_f + x_1 u_{fg} = 417.36 + (0.25 \times 2088.7) = 939.5kJ/kg$$

$$\left.\begin{array}{l} v_2 = v_1 = 0.42428m^3/kg \\ sat.vapor \end{array}\right\} u_2 = u_{g@0.42428m^3/kg} = 2556.7kJ/kg$$



The conservation of energy equation for this case reduces to

$$Q^{\nearrow 0} - W_e - W_b^{\nearrow 0} = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$
$$-W_e = m(u_2 - u_1)$$
$$-(-VI\Delta t) = m(u_2 - u_1)$$

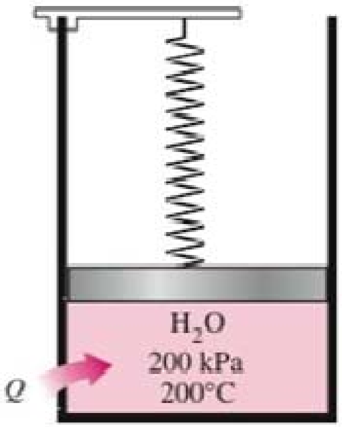
Substituting,

$$(110V)(8A)\Delta t = (5kg)(2556.7 - 939.5)kJ/kg\left(\frac{1000VA}{1kJ/s}\right)$$

$$\Delta t = 9189s$$

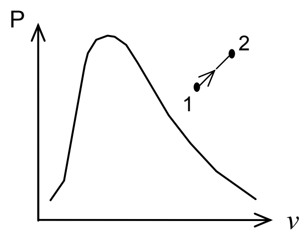
$$\cong \mathbf{153.2min}$$

5–40 A piston–cylinder device initially contains steam at 200 kPa, 200°C, and 0.5 m³. At this state, a linear spring ($F \propto x$) is touching the piston but exerts no force on it. Heat is now slowly transferred to the steam, causing the pressure and the volume to rise to 500 kPa and 0.6 m³, respectively. Show the process on a *P-v* diagram with respect to saturation lines and determine (*a*) the final temperature, (*b*) the work done by the steam, and (*c*) the total heat transferred. *Answers:* (*a*) 1132°C, (*b*) 35 kJ, (*c*) 808 kJ



(a) We take the steam in the piston-cylinder device as our system. This is a closed system since no mass enters or leaves.

$$\left.\begin{array}{l} P_1 = 200kPa \\ T_1 = 200\,^\circ C \end{array}\right\} \begin{array}{l} v_1 = 1.0803m^3/kg \\ u_1 = 2654.4kJ/kg \end{array}$$



$$m = \frac{V_1}{v_1} = \frac{0.5m^3}{1.0803m^3/kg} = 0.463kg$$

$$v_2 = \frac{V_2}{m} = \frac{0.6m^3}{0.463kg} = 1.296m^3/kg$$

$$\left.\begin{array}{l} P_2 = 500kPa \\ v_2 = 1.296m^3/kg \end{array}\right\} \begin{array}{l} T_2 = \mathbf{1131\,^\circ C} \\ u_2 = 4321.9kJ/kg \end{array}$$

(b) The pressure of the gas changes linearly with the gas, and thus the process curve on a P-V diagram will be a straight line. The boundary work during this process is simply the area under the process curve, which is a
trapezoidal. Thus,

$$W_b = Area = \frac{P_1 + P_2}{2}\left(V_2 - V_1\right) = \frac{(200+500)kPa}{2}(0.6-0.5)m^3\left(\frac{1kJ}{1kPa\cdot m^3}\right) = \mathbf{35kJ}$$

(c) The conservation of energy equation for this case reduces to

$$Q - W_b = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$
$$Q = m(u_2 - u_1) + W_b$$

Substituting,

Q = (0.463 kg)(4321.9 - 2654.4)kJ/kg + 35 kJ = **807 kJ**

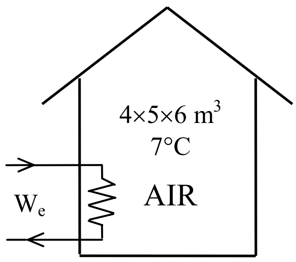
5–66 A 4-m × 5-m × 6-m room is to be heated by a baseboard resistance heater. It is desired that the resistance heater be able to raise the air temperature in the room from 7 to 23°C within 15 min. Assuming no heat losses from the room and an atmospheric pressure of 100 kPa, determine the required power of the resistance heater. Assume constant specific heats at room temperature. *Answer:* 1.91 kW

At specified conditions air can be treated as an ideal gas. We take the air in the room as our system. Assuming the room is well-sealed and no air leaks out, we have a constant volume closed system. The conservation of energy equation for this case reduces to

$$Q^{\nearrow 0} - W_e = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$
$$-W_e = m(u_2 - u_1) = mC_{v,\,ave}(T_2 - T_1)$$

or,

$$-\dot{W}_e \Delta t = mC_{v,\,ave}(T_2 - T_1)$$



The mass of air is

$$V = 4\times5\times6 = 120\ m^3$$
$$m = \frac{P_1V}{RT_1} = \frac{(100\ kPa)(120\ m^3)}{(0.287\ kPa\cdot m^3/kg\cdot K)(280\ K)} = 149.3\ kg$$

Using C_v value at room temperature from Table A-2a ,

$$-\dot{W}_e(15\times60\ s) = (149.3\ kg)(0.718\ kJ/kg\cdot^\circ C)(23-7)^\circ C = \mathbf{-1.91\ kW}$$

The negative sign indicates electrical work is done on the system.

5–67 A student living in a 4-m × 6-m × 6-m dormitory room turns on her 150-W fan before she leaves the room on a summer day, hoping that the room will be cooler when she comes back in the evening. Assuming all the doors and windows are tightly closed and disregarding any heat transfer through the walls and the windows, determine the temperature in the room when she comes back 10 h later. Use specific heat values at room temperature, and assume the

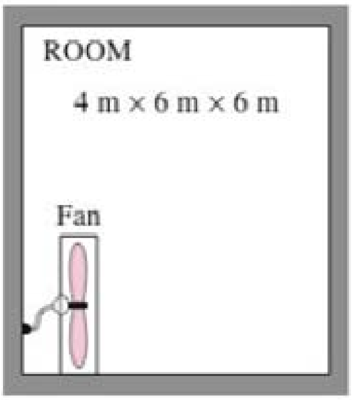
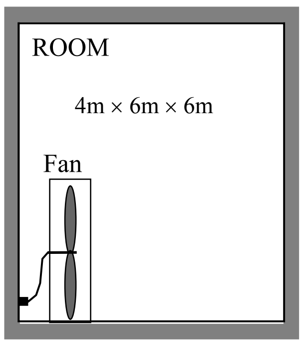


FIGURE P5–67

room to be at 100 kPa and 15°C in the morning when she leaves. *Answer:* 58.2°C

At specified conditions air can be treated as an ideal gas. We take the air in the room as our system. Assuming the room is well-sealed and no air leaks out, we have a constant volume closed system. The conservation of energy equation for this case reduces to

$$Q^{\nearrow 0} - W_e - W_b^{\nearrow 0} = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$
$$-W_e = m(u_2 - u_1) = mC_{v,\,ave}(T_2 - T_1)$$



The mass of air is

$$V = 4 \times 6 \times 6 = 144\ m^3$$
$$m = \frac{P_1 V}{RT_1} = \frac{(100\ kPa)(144\ m^3)}{(0.287\ kPa\cdot m^3/kg\cdot K)(288\ K)} = 174.2\ kg$$

The electrical work done by the fan is

$$W_e = \dot{W}_e \Delta t = (0.15\ kJ/s)(10 \times 3600\ s) = 5400\ kJ$$

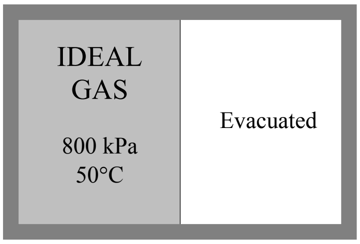
Substituting and using C_v value at room temperature from Table A-2a,

$$-(-5400\text{ kJ}) = (174.2\text{ kg})(0.718\text{ kJ/kg°C})(T_2 - 15)\text{°C}$$

$$T_2 = \mathbf{58.2°C}$$

4–61 An insulated rigid tank is divided into two equal parts by a partition. Initially, one part contains 4 kg of an ideal gas at 800 kPa and 50°C, and the other part is evacuated. The partition is now removed, and the gas expands into the entire tank. Determine the final temperature and pressure in the tank.

We take the entire tank as our system. This is a constant volume closed system since no mass enters or leaves the system. The conservation of energy equation for this ideal gas reduces to



$$Q^{\nearrow 0} - W^{\nearrow 0} = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$

$$0 = m(u_2 - u_1) = mC_{v,ave}(T_2 - T_1)$$

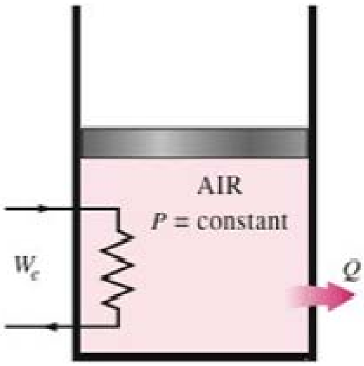
Thus,

$T_2 = T_1 =$ **50°C**

and

$$\frac{P_1V_1}{T_1} = \frac{P_2V_1}{T_2} \longrightarrow P_2 = \frac{V_2}{V_1}P_1 = \frac{1}{2}(800\ kPa) = \mathbf{400\ kPa}$$

5–79 A mass of 15 kg of air in a piston–cylinder device is heated from 25 to 77°C by passing current through a resistance heater inside the cylinder. The pressure inside the cylinder is held constant at 300 kPa during the process, and a heat loss of 60 kJ occurs. Determine the electric energy supplied, in kWh. *Answer:* 0.235 kWh



At specified conditions air can be treated as an ideal gas. We take the air in the piston-cylinder device as our system. This is a closed system since no mass enters or leaves. The conservation of energy equation for this case reduces to

$$Q - W_e - W_b = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$

$$Q - W_e = m(h_2 - h_1)$$

or

$$W_e = -m(h_2 - h_1) + Q$$

since $\Delta U + W_b = \Delta H$ for constant pressure quasi-equilibrium expansion or compression processes. From Table A-18,

$$h_1 = h_{@\,298\,K} = 298.18\ kJ/kg$$
$$h_2 = h_{@\,350\,K} = 350.49\ kJ/kg$$

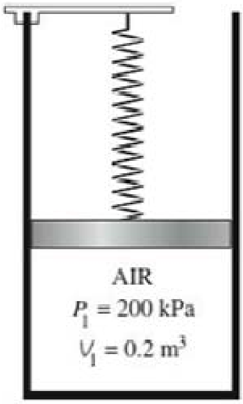
Substituting,

$$W_e = -(15\text{ kg})(350.49 - 298.18)\text{kJ/kg} + (-60\text{ kJ}) = -844.7\text{ kJ}$$

or,

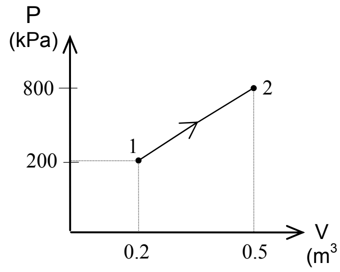
$$W_e = (-844.7\text{kJ})\left(\frac{1\text{kWh}}{3600\text{kJ}}\right) = \mathbf{-0.235kWh}$$

5–104 A frictionless piston–cylinder device initially contains air at 200 kPa and 0.2 m³. At this state, a linear spring ($F \propto x$) is touching the piston but exerts no force on it. The air is now heated to a final state of 0.5 m³ and 800 kPa. Determine (*a*) the total work done by the air and (*b*) the work done against the spring. Also, show the process on a *P*-*v* diagram. *Answers:* (*a*) 150 kJ, (*b*) 90 kJ



(a) The pressure of the gas changes linearly with volume during this process, and thus the process curve on a P-V diagram will be a straight line. Then the boundary work during this process is simply the area under the process curve, which is a trapezoidal. Thus,

$$\begin{aligned} W_b &= \text{Area} = \frac{P_1 + P_2}{2}(V_2 - V_1) \\ &= \frac{(200+800)\text{kPa}}{2}(0.5-0.2)\text{m}^3\left(\frac{1\text{kJ}}{1\text{kPa}\cdot\text{m}^3}\right) \\ &= \mathbf{150kJ} \end{aligned}$$



(b) If there were no spring, we would have a constant pressure process at P = 200 kPa. The work done during this process is

$$W_{b,\text{nospring}} = \int_1^2 PdV = P(V_2 - V_1) = (200\text{kPa})(0.5-0.2)\text{m}^3/\text{kg}\left(\frac{1\text{kJ}}{1\text{kPa}\cdot\text{m}^3}\right) = 60\text{kJ}$$

$$W_{spring} = W_b - W_{b,\,no\,spring} = 150 - 60 = \mathbf{90\ kJ}$$

5–110 A piston–cylinder device contains helium gas initially at 150 kPa, 20°C, and 0.5 m^3. The helium is now compressed in a polytropic process (PV^n = constant) to 400 kPa and 140°C. Determine the heat loss or gain during this process. *Answer: 11.2 kJ loss*

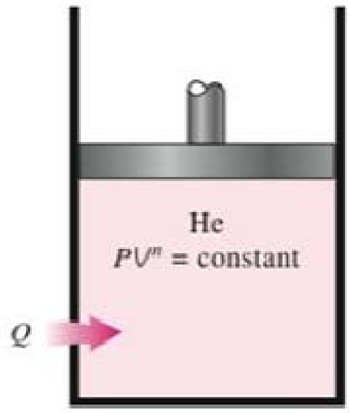


FIGURE P5–110

Helium at specified conditions can be treated as an ideal gas. The mass of helium and the exponent *n* are determined from

$$m = \frac{P_1 V_1}{RT_1} = \frac{(150\text{kPa})(0.5\text{m}^3)}{(2.0769\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\text{K})} = 0.123\text{kg}$$

$$\frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{RT_2} \longrightarrow V_2 = \frac{T_2 P_1}{T_1 P_2} V_1 = \frac{413\text{K}}{293\text{K}} \times \frac{150\text{kPa}}{400\text{kPa}} \times 0.5\text{m}^3 = 0.264\text{m}^3$$

$$P_2 V_2^n = P_1 V_1^n \longrightarrow \left(\frac{P_2}{P_1}\right) = \left(\frac{V_1}{V_2}\right)^n \longrightarrow \frac{400}{150} = \left(\frac{0.5}{0.264}\right)^n \longrightarrow n = 1.536$$

Then the boundary work for this polytropic process can be determined from

$$W_b = \int_1^2 P\,dV = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$$

$$= \frac{(0.123\text{kg})(2.0769\text{kJ/kg}\cdot\text{K})(413-293)\text{K}}{1-1.536} = \mathbf{-57.2kJ}$$

We take the helium in the piston-cylinder device as our system. This is a closed system since no mass enters or leaves. The conservation of energy equation for this closed system reduces to

$$Q - W_b = \Delta U + \Delta KE^{\nearrow 0} + \Delta PE^{\nearrow 0}$$

$$Q = m(u_2 - u_1) + W_b$$

or ,

$$Q = mC_v(T_2 - T_1) + W_b$$

Using C_v value from Table A-2a,

Q = (0.123 kg)(3.1156 kJ/kg·K)(413 - 293)K + (-57.2 kJ) = **-11.2 kJ**