Chapter 4
KAPALI SİSTEMLERDE ENERJİ ANALİZİ

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Objectives

- Özellikle otomobil motoru ve kompresör gibi pistonlu makinelerde yaygın olarak karşılaşılan hareketli sınır işi veya P*dV* işi olmak üzere değişik iş biçimlerinin incelenmesi.
- Kapalı sistemler (Sabit kütleli) için Termodinamiğin birinci yasasının enerjinin korunumu ifadesi olduğunun tanıtılması.
- Kapalı sistemler için genel enerji dengesi bağıntısının geliştirilmesi.
- Sabit hacimde veya sabit basınçta özgül ısıların tanımlanması.
- İdeal gazların iç enerji ve entalpi değişimlerinin hesaplanmasını özgül ısılar ile ilişkilendirmek.
- Katı ve sıvı gibi sıkıştırılamayan maddelerin tanımlanması ve bu maddelerin iç enerji ve entalpi değişimlerinin belirlenmesi.
- Saf maddeler, mükemmel gazlar ve sıkıştırılamayan maddeler için iş ve ısı etkileşimleri içeren kapalı sistemlerin (sabit kütleli) enerji dengesi problemlerinin çözülmesi.

HAREKETLİ SINIR İŞİ

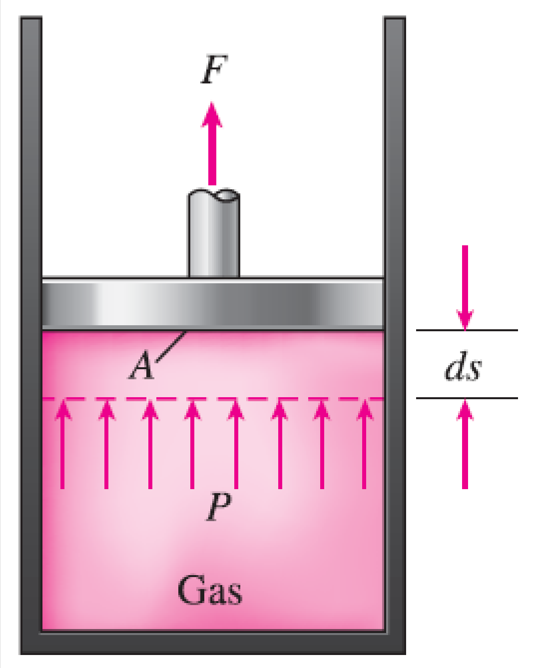
Moving boundary work (*P dV* work): Bir gazın piston-silindir düzeneğinde genişlemesi veya sıkıştırılması sırasında gerçekleşir.

$$\delta W_b = F\,ds = PA\,ds = P\,dV$$

$$W_b = \int_1^2 P\,dV \qquad (\mathrm{kJ})$$

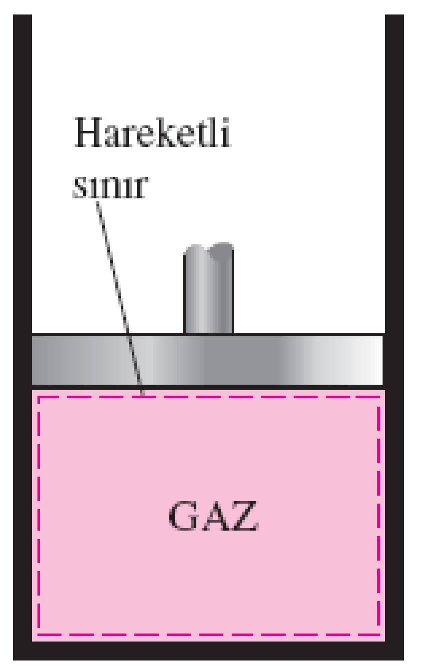
Sanki dengede durumu sistemin her an dengede olduğu.

W_s is positive → for expansion
W_s is negative → for compression



Gaz pistonu iterek *ds diferansiyel* miktarında hareket ettirirken δW_s miktarında iş yapar.

Hareketli sınırla ilişkili iş *sınır işi* diye adlandırılır.



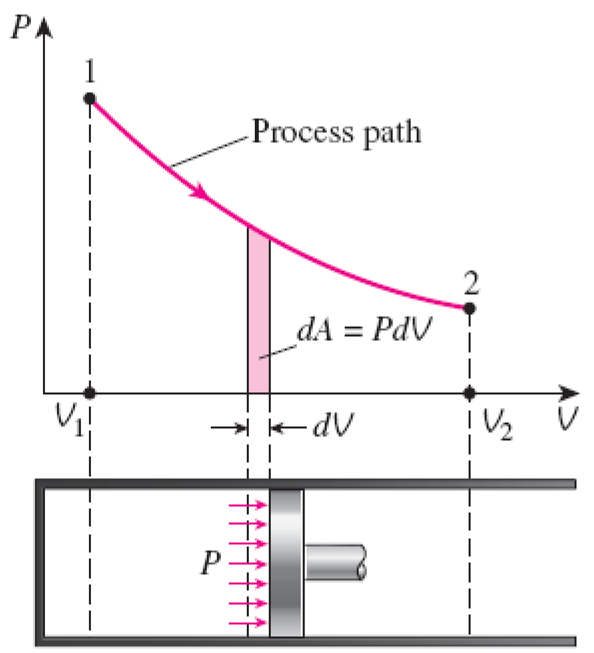


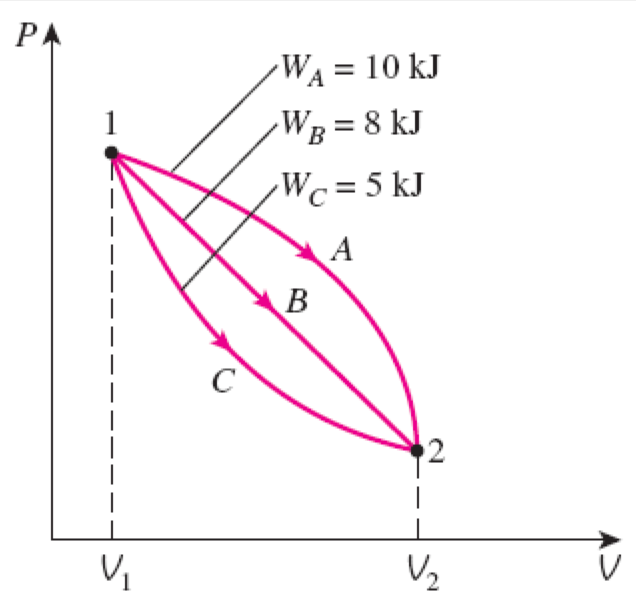
FIGURE 4–3

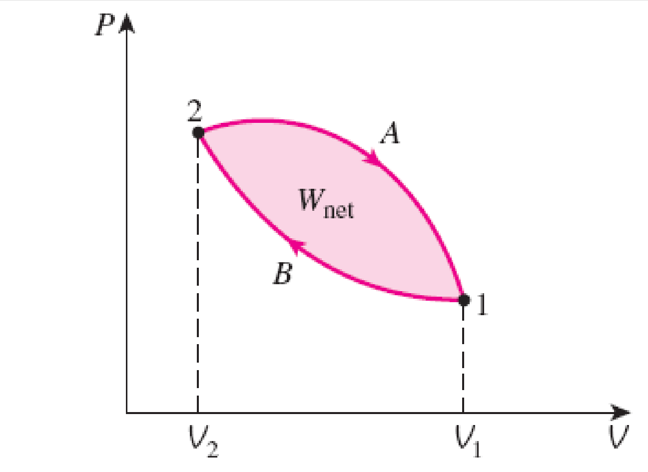
The area under the process curve on a P-V diagram represents the boundary work.

$$\text{Area} = A = \int_1^2 dA = \int_1^2 P\,dV$$

The area under the process curve on a P-V diagram is equal, in magnitude, to the work done during a quasi-equilibrium expansion or compression process of a closed system.

Bir hal değişimi sırasında yapılan sınır işi, ilk ve son hallerle hal değişiminin yoluna bağlıdır.





Bir çevrim sırasında yapılan net iş, sistem tarafından yapılan işle sistem üzerinde yapılan iş arasındaki farktır.

Politropik, İzotermal ve İzobarik hal değişimi

$P = CV^{-n}$ Politropik hal değişimi: *C*, *n* sabittir.

$$W_b = \int_1^2 P\,dV = \int_1^2 CV^{-n}\,dV = C\frac{V_2^{-n+1} - V_1^{-n+1}}{-n+1} = \frac{P_2V_2 - P_1V_1}{1-n}$$

Polytropic process

$$W_b = \frac{mR(T_2 - T_1)}{1-n}$$

Polytropic and for ideal gas

$$W_b = \int_1^2 P\,dV = \int_1^2 CV^{-1}\,dV = PV\ln\left(\frac{V_2}{V_1}\right)$$

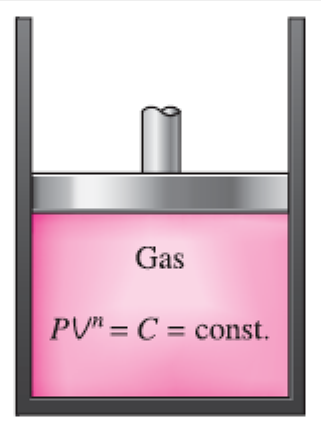
When *n* = 1 (isothermal process)

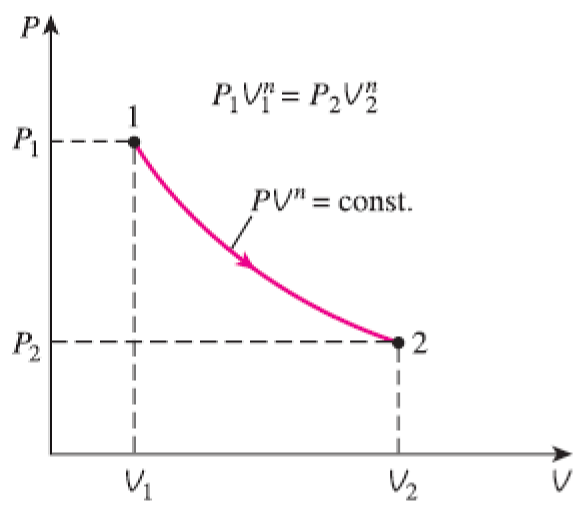
$$W_b = \int_1^2 P\,dV = P_0\int_1^2 dV = P_0(V_2 - V_1)$$

Constant pressure process

What is the boundary work for a constant-volume process?

Politropik hal değişiminin *P-V* diyagramı.





EXAMPLE 4–1 **Boundary Work for a Constant-Volume Process**

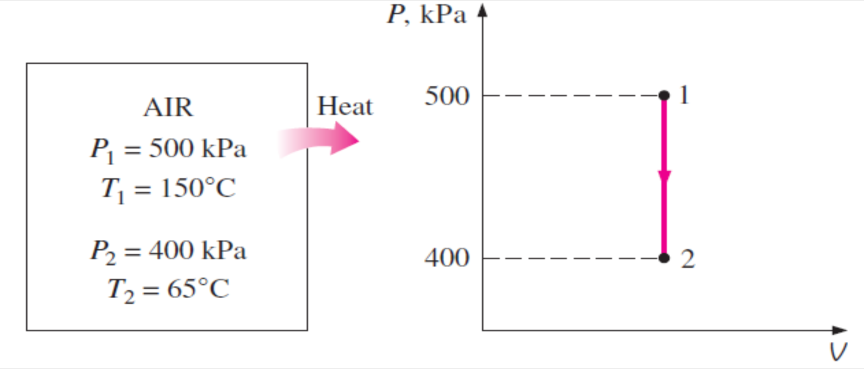
A rigid tank contains air at 500 kPa and 150°C. As a result of heat transfer to the surroundings, the temperature and pressure inside the tank drop to 65°C and 400 kPa, respectively. Determine the boundary work done during this process.

Solution Air in a rigid tank is cooled, and both the pressure and temperature drop. The boundary work done is to be determined.

Analysis A sketch of the system and the P-V diagram of the process are shown in Fig. 4–6. The boundary work can be determined from Eq. 4–2 to be

$$W_b = \int_1^2 P\, \overset{0}{\cancel{dV}} = \mathbf{0}$$

Discussion This is expected since a rigid tank has a constant volume and $dV = 0$ in this equation. Therefore, there is no boundary work done during this process. That is, the boundary work done during a constant-volume process is always zero. This is also evident from the P-V diagram of the process (the area under the process curve is zero).



EXAMPLE 4–2 **Boundary Work for a Constant-Pressure Process**

A frictionless piston–cylinder device contains 10 lbm of steam at 60 psia and 320°F. Heat is now transferred to the steam until the temperature reaches 400°F. If the piston is not attached to a shaft and its mass is constant, determine the work done by the steam during this process.

Solution Steam in a piston cylinder device is heated and the temperature rises at constant pressure. The boundary work done is to be determined.

Analysis A sketch of the system and the P-v diagram of the process are shown in Fig. 4–7.

Assumption The expansion process is quasi-equilibrium.

Analysis Even though it is not explicitly stated, the pressure of the steam within the cylinder remains constant during this process since both the atmospheric pressure and the weight of the piston remain constant. Therefore, this is a constant-pressure process, and, from Eq. 4–2

$$W_b = \int_1^2 P\,dV = P_0 \int_1^2 dV = P_0(V_2 - V_1) \qquad \textbf{(4–6)}$$

or

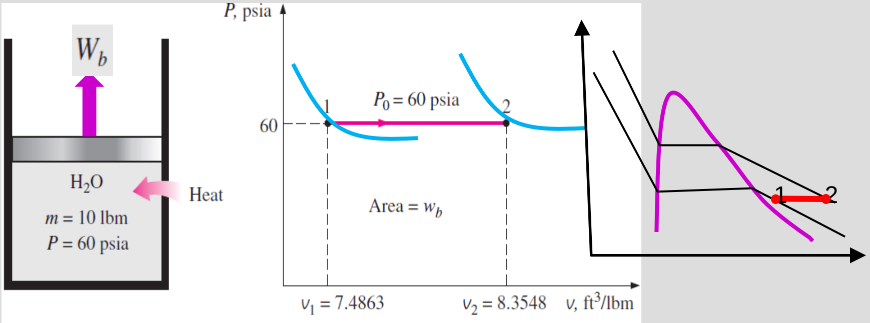
$$W_b = mP_0(v_2 - v_1)$$

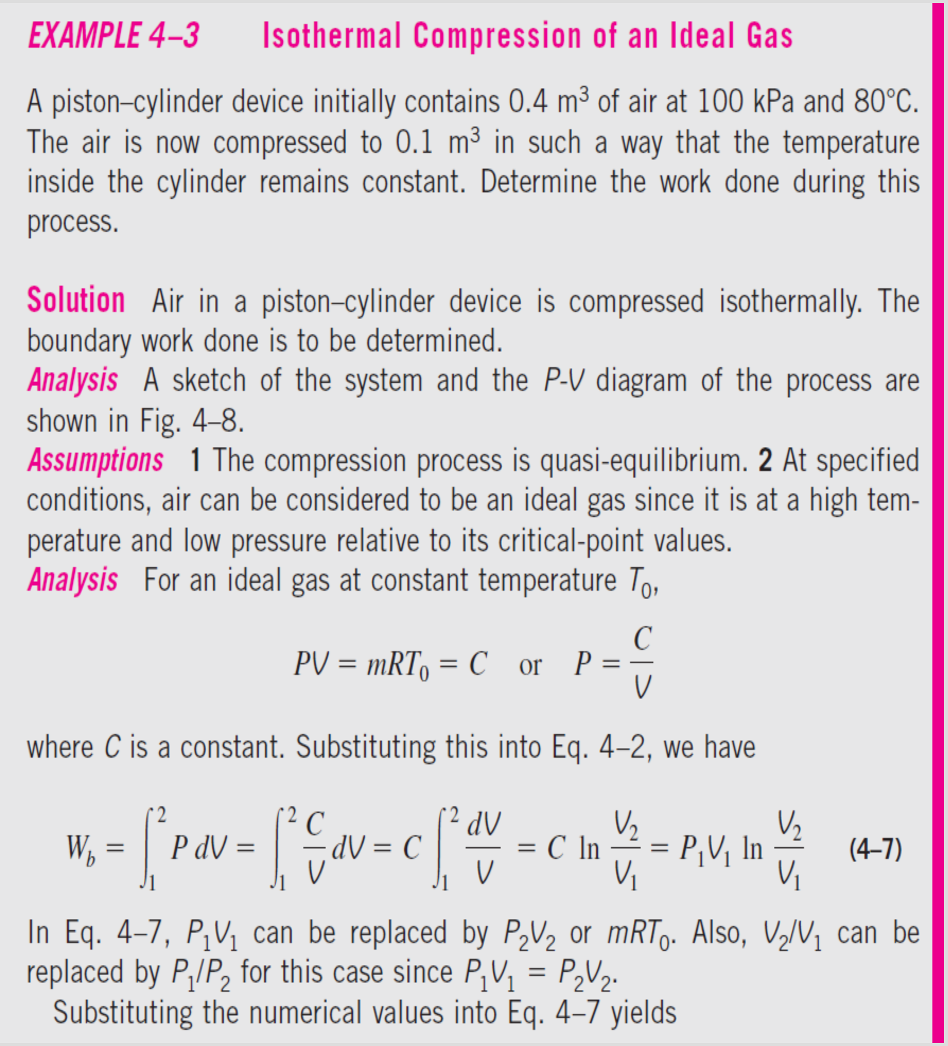
since $V = mv$. From the superheated vapor table (Table A–6E), the specific volumes are determined to be $v_1 = 7.4863$ ft³/lbm at state 1 (60 psia, 320°F) and $v_2 = 8.3548$ ft³/lbm at state 2 (60 psia, 400°F). Substituting these values yields

$$W_b = (10\text{ lbm})(60\text{ psia})[(8.3548 - 7.4863)\text{ ft}^3/\text{lbm}]\left(\frac{1\text{ Btu}}{5.404\text{ psia}\cdot\text{ft}^3}\right)$$

$$= \mathbf{96.4\ Btu}$$

Discussion The positive sign indicates that the work is done by the system. That is, the steam used 96.4 Btu of its energy to do this work. The magnitude of this work could also be determined by calculating the area under the process curve on the P-V diagram, which is simply $P_0\,\Delta V$ for this case.





EXAMPLE 4–3 Isothermal Compression of an Ideal Gas

A piston–cylinder device initially contains 0.4 m^3 of air at 100 kPa and 80°C. The air is now compressed to 0.1 m^3 in such a way that the temperature inside the cylinder remains constant. Determine the work done during this process.

Solution Air in a piston–cylinder device is compressed isothermally. The boundary work done is to be determined.

Analysis A sketch of the system and the *P-V* diagram of the process are shown in Fig. 4–8.

Assumptions **1** The compression process is quasi-equilibrium. **2** At specified conditions, air can be considered to be an ideal gas since it is at a high temperature and low pressure relative to its critical-point values.

Analysis For an ideal gas at constant temperature T_0,

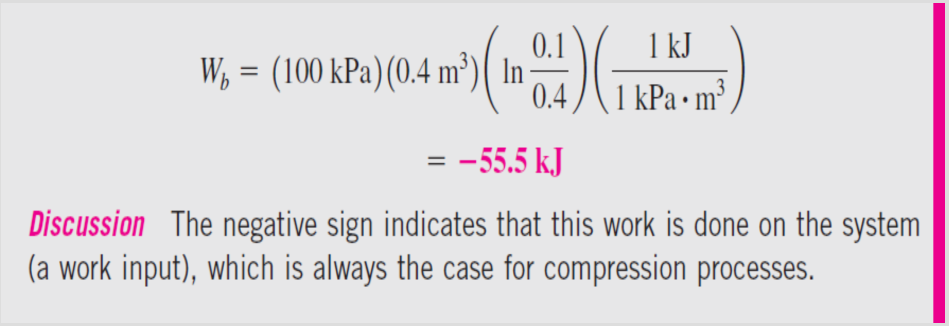
$$PV = mRT_0 = C \quad \text{or} \quad P = \frac{C}{V}$$

where *C* is a constant. Substituting this into Eq. 4–2, we have

$$W_b = \int_1^2 P\,dV = \int_1^2 \frac{C}{V}\,dV = C\int_1^2 \frac{dV}{V} = C\ \ln\frac{V_2}{V_1} = P_1V_1\ \ln\frac{V_2}{V_1} \tag{4–7}$$

In Eq. 4–7, P_1V_1 can be replaced by P_2V_2 or mRT_0. Also, V_2/V_1 can be replaced by P_1/P_2 for this case since $P_1V_1 = P_2V_2$.

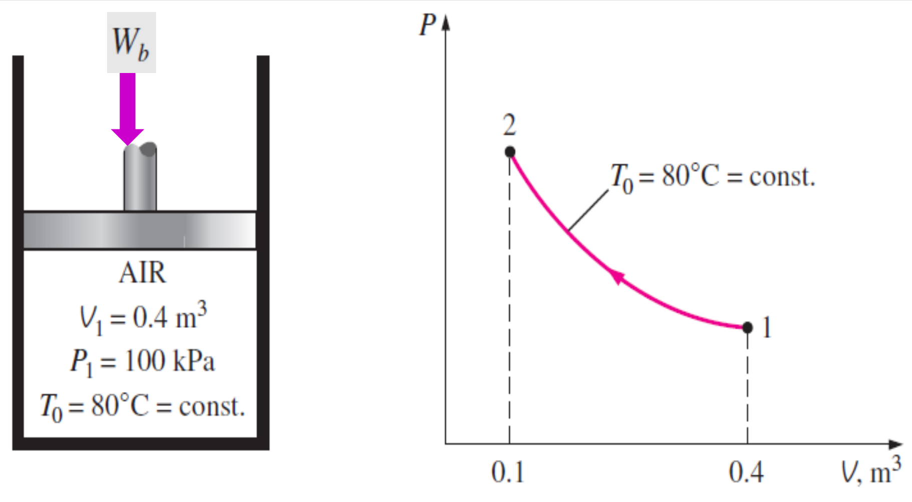
Substituting the numerical values into Eq. 4–7 yields



$$W_b = (100\ \text{kPa})(0.4\ \text{m}^3)\left(\ln\frac{0.1}{0.4}\right)\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right)$$

$$= -55.5\ \text{kJ}$$

Discussion The negative sign indicates that this work is done on the system (a work input), which is always the case for compression processes.



EXAMPLE 4–4 Expansion of a Gas against a Spring

A piston–cylinder device contains 0.05 m^3 of a gas initially at 200 kPa. At this state, a linear spring that has a spring constant of 150 kN/m is touching the piston but exerting no force on it. Now heat is transferred to the gas, causing the piston to rise and to compress the spring until the volume inside the cylinder doubles. If the cross-sectional area of the piston is 0.25 m^2, determine (*a*) the final pressure inside the cylinder, (*b*) the total work done by the gas, and (*c*) the fraction of this work done against the spring to compress it.

Solution A gas in a piston–cylinder device equipped with a linear spring expands as a result of heating. The final gas pressure, the total work done, and the fraction of the work done to compress the spring are to be determined.

Assumptions **1** The expansion process is quasi-equilibrium. **2** The spring is linear in the range of interest.

Analysis A sketch of the system and the *P*-*V* diagram of the process are shown in Fig. 4–10.

(*a*) The enclosed volume at the final state is

$$V_2 = 2V_1 = (2)(0.05\ \text{m}^3) = 0.1\ \text{m}^3$$

Then the displacement of the piston (and of the spring) becomes

$$x = \frac{\Delta V}{A} = \frac{(0.1 - 0.05)\ \text{m}^3}{0.25\ \text{m}^2} = 0.2\ \text{m}$$

The force applied by the linear spring at the final state is

$$F = kx = (150\ \text{kN/m})(0.2\ \text{m}) = 30\ \text{kN}$$

The additional pressure applied by the spring on the gas at this state is

$$P = \frac{F}{A} = \frac{30\ \text{kN}}{0.25\ \text{m}^2} = 120\ \text{kPa}$$

Without the spring, the pressure of the gas would remain constant at 200 kPa while the piston is rising. But under the effect of the spring, the pressure rises linearly from 200 kPa to

$$200 + 120 = \mathbf{320\ kPa}$$

at the final state.

(*b*) An easy way of finding the work done is to plot the process on a *P*-*V* diagram and find the area under the process curve. From Fig. 4–10 the area under the process curve (a trapezoid) is determined to be

$$W = \text{area} = \frac{(200 + 320)\ \text{kPa}}{2}\left[(0.1 - 0.05)\ \text{m}^3\right]\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = \mathbf{13\ kJ}$$

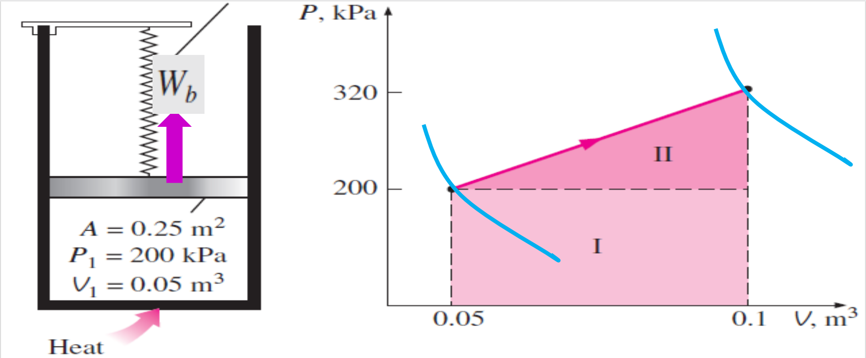
Note that the work is done by the system.

(*c*) The work represented by the rectangular area (region I) is done against the piston and the atmosphere, and the work represented by the triangular area (region II) is done against the spring. Thus,

$$W_{\text{spring}} = \tfrac{1}{2}\left[(320 - 200)\ \text{kPa}\right](0.05\ \text{m}^3)\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = \mathbf{3\ kJ}$$

Discussion This result could also be obtained from

$$W_{\text{spring}} = \tfrac{1}{2}k(x_2^2 - x_1^2) = \tfrac{1}{2}(150\ \text{kN/m})\left[(0.2\ \text{m})^2 - 0^2\right]\left(\frac{1\ \text{kJ}}{1\ \text{kN}\cdot\text{m}}\right) = 3\ \text{kJ}$$



KAPALI SİSTEMLER İÇİN ENERJİ DENGESİ

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}} \qquad (\text{kJ})$$

Hal değişimi gerçekleştiren herhangi bir sistem için enerji dengesi

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}}/dt}_{\substack{\text{Rate of change in internal,}\\ \text{kinetic, potential, etc., energies}}} \qquad (\text{kW})$$

birim zaman için

Zamana göre değişim oranı sabit olduğu durumlarda

$$Q = \dot{Q}\,\Delta t, \quad W = \dot{W}\,\Delta t, \quad \text{and} \quad \Delta E = (dE/dt)\,\Delta t \qquad (\text{kJ})$$

$$e_{\text{giren}} - e_{\text{çıkan}} = \Delta e_{\text{sistem}} \qquad (\text{kJ/kg})$$

Birim kütle için enerji dengesi

$$\delta E_{\text{giren}} - \delta E_{\text{çıkan}} = dE_{\text{sistem}} \quad \text{veya} \quad \delta e_{\text{giren}} - \delta e_{\text{çıkan}} = de_{\text{sistem}}$$

Enerji dengesinin diferansiyel formu

$$W_{\text{net,çıkan}} = Q_{\text{net,giren}} \quad \text{veya} \quad \dot{W}_{\text{net,çıkan}} = \dot{Q}_{\text{net,giren}}$$

Çevrim için enerji denklemi

$$Q_{\text{net,giren}} - W_{\text{net,çıkan}} = \Delta E_{\text{sistem}} \quad \text{veya} \quad Q - W = \Delta E$$

$$Q = Q_{\text{net, giren}} = Q_{\text{giren}} - Q_{\text{çıkan}}$$

$$W_{\text{net; çıkan}} = W_{\text{çıkan}} - W_{\text{giren}}$$

Energy balance when sign convention is used: (i.e., heat input and work output are positive; heat output and work input are negative).

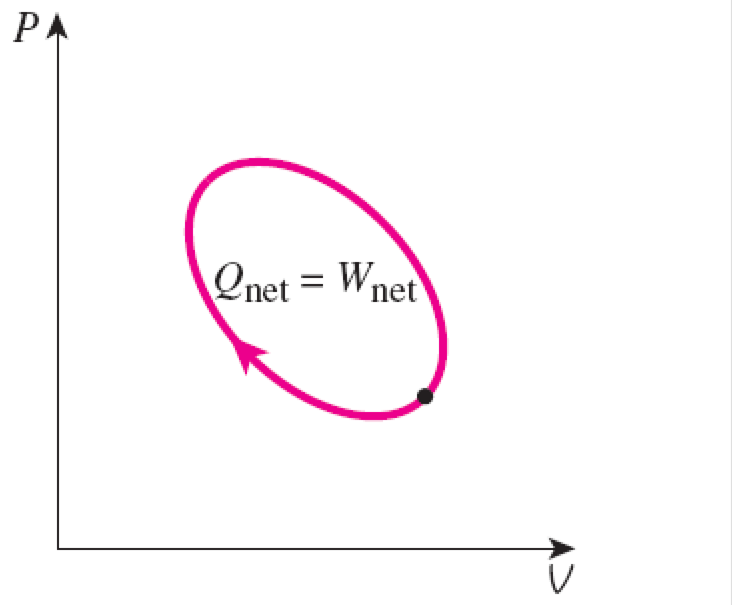
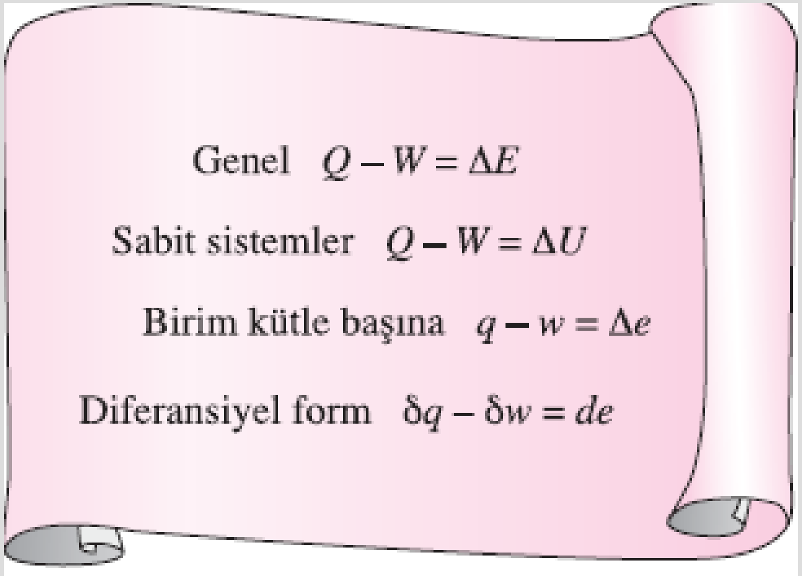


FIGURE 4–11

Bir çevrim için $\Delta E = 0$, böylece $Q = W$



Genel $Q - W = \Delta E$

Sabit sistemler $Q - W = \Delta U$

Birim kütle başına $q - w = \Delta e$

Diferansiyel form $\delta q - \delta w = de$

Kapalı sistemler için birinci yasanın değişik yazılış biçimleri.

Birinci yasayı matematiksel olarak kanıtlamak olanaksızdır, fakat doğada birinci yasaya aykırı herhangi bir hal değişimi bilinmemektedir, bu da yeterli kanıt sayılmalıdır.

Sabit basınçlı bir genişleme ve sıkıştırma işlemi için enerji denkliği

Sabit basınçta sanki dengeli hal değişiminden geçen kapalı bir sistem için genel analizde ısı geçiş yönü *Q* *sisteme doğru* ve *W* iş ise *sistem tarafından yapıldığı* kabul edilir.

Sabit basınçta sıkıştırma ve genişleme işlemi için:

$$\Delta U + W_s = \Delta H$$

$$\underbrace{E_{\text{giren}} - E_{\text{çıkan}}}_{\substack{\text{Isı, iş ve kütle ile} \\ \text{transfer edilen net enerji}}} = \underbrace{\Delta E_{\text{sistem}}}_{\substack{\text{İç enerji, kinetik ve} \\ \text{potansiyel enerjilerdeki değişim}}}$$

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

$$Q - W_{\text{diğer}} - W_s = U_2 - U_1$$

$$Q - W_{\text{diğer}} - P_0(V_2 - V_1) = U_2 - U_1$$

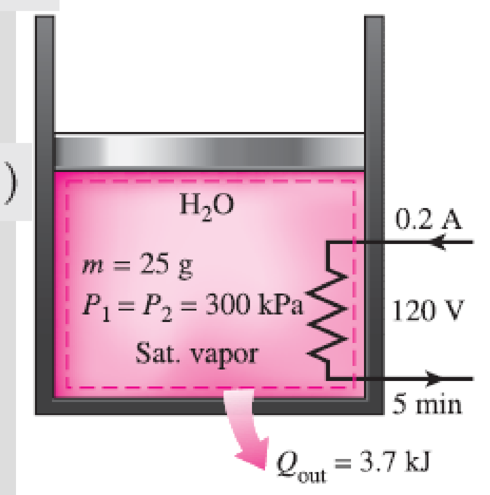
$$Q - W_{\text{diğer}} = (U_2 + P_2V_2) - (U_1 + P_1V_1)$$

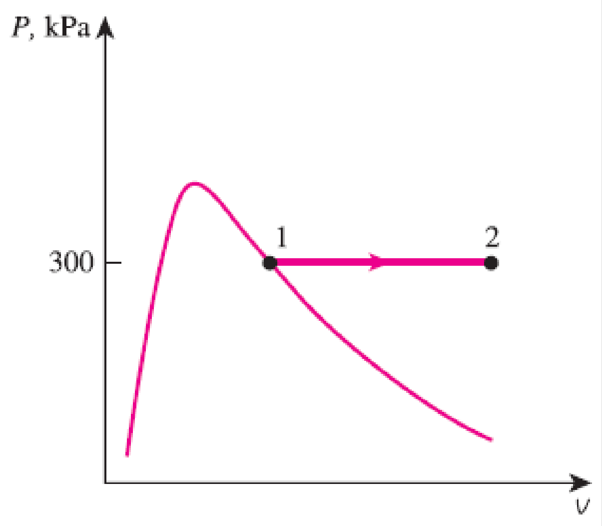
$$Q - W_{\text{diğer}} = H_2 - H_1 \qquad \text{(kJ)}$$

Sabit basınçta hal değişim örneği

$$W_{e,\text{in}} - Q_{\text{out}} - W_b = \Delta U$$

$$W_{e,\text{in}} - Q_{\text{out}} = \Delta H = m(h_2 - h_1)$$





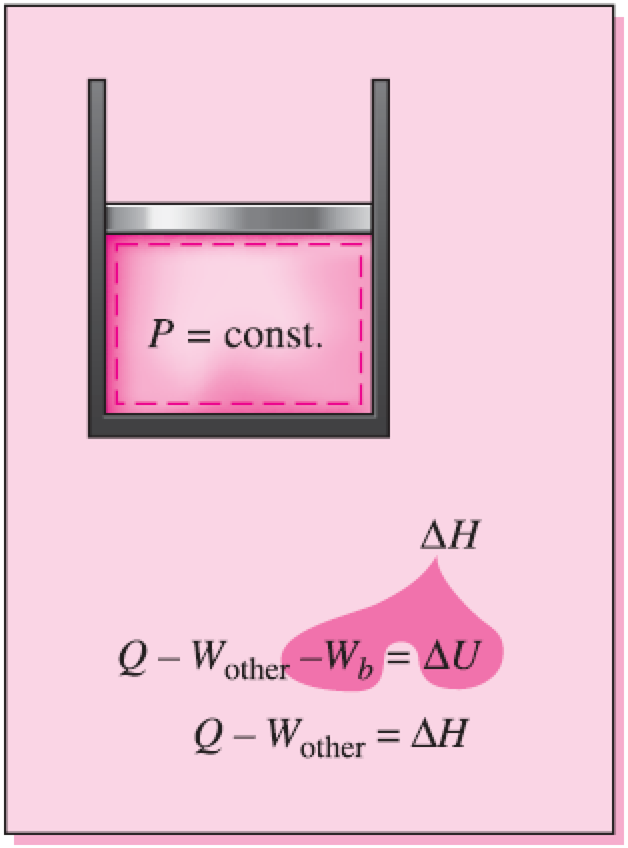


FIGURE 4–14

For a closed system undergoing a quasi-equilibrium, P = constant process, $\Delta U + W_b = \Delta H$. Note that this relation is NOT valid for closed systems processes during which pressure DOES NOT remain constant.

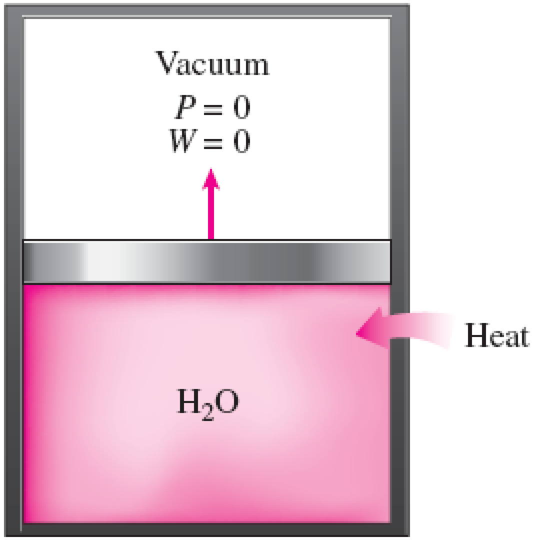
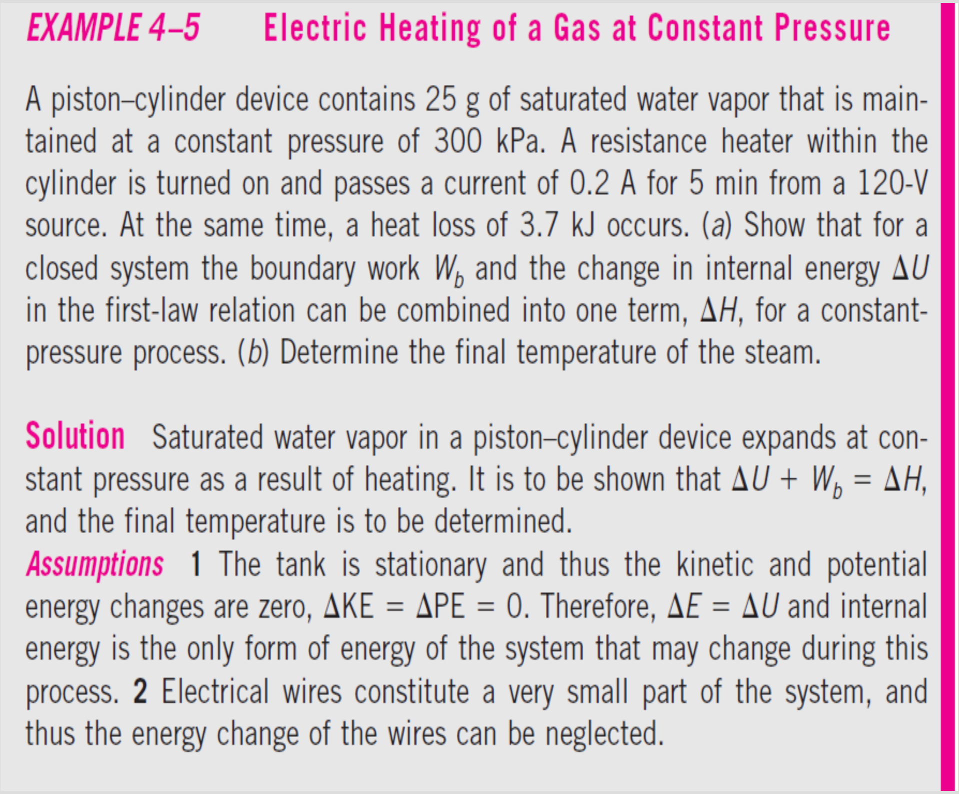


FIGURE 4–16

Expansion against a vacuum involves no work and thus no energy transfer.

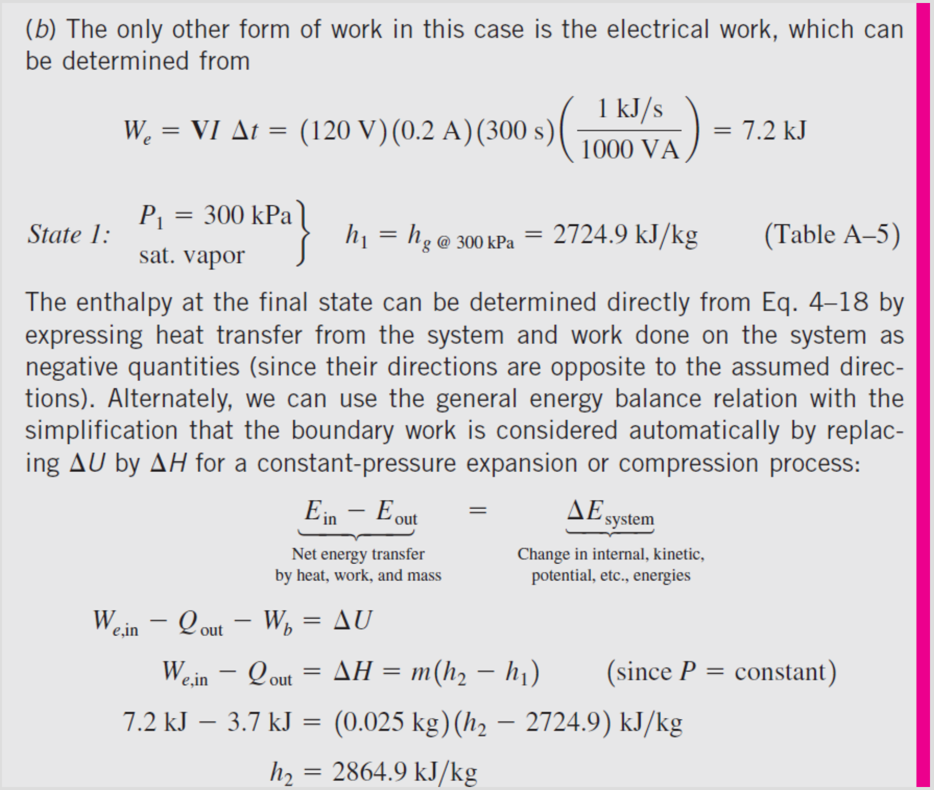


EXAMPLE 4–5 Electric Heating of a Gas at Constant Pressure

A piston–cylinder device contains 25 g of saturated water vapor that is maintained at a constant pressure of 300 kPa. A resistance heater within the cylinder is turned on and passes a current of 0.2 A for 5 min from a 120-V source. At the same time, a heat loss of 3.7 kJ occurs. (*a*) Show that for a closed system the boundary work W_b and the change in internal energy ΔU in the first-law relation can be combined into one term, ΔH, for a constant-pressure process. (*b*) Determine the final temperature of the steam.

Solution Saturated water vapor in a piston–cylinder device expands at constant pressure as a result of heating. It is to be shown that $\Delta U + W_b = \Delta H$, and the final temperature is to be determined.

Assumptions **1** The tank is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE = \Delta PE = 0$. Therefore, $\Delta E = \Delta U$ and internal energy is the only form of energy of the system that may change during this process. **2** Electrical wires constitute a very small part of the system, and thus the energy change of the wires can be neglected.



(*b*) The only other form of work in this case is the electrical work, which can be determined from

$$W_e = \mathbf{V}I\,\Delta t = (120\text{ V})(0.2\text{ A})(300\text{ s})\left(\frac{1\text{ kJ/s}}{1000\text{ VA}}\right) = 7.2\text{ kJ}$$

$$\textit{State 1:}\quad \left.\begin{array}{l} P_1 = 300\text{ kPa} \\ \text{sat. vapor} \end{array}\right\} \quad h_1 = h_{g\,@\,300\text{ kPa}} = 2724.9\text{ kJ/kg} \qquad \text{(Table A–5)}$$

The enthalpy at the final state can be determined directly from Eq. 4–18 by expressing heat transfer from the system and work done on the system as negative quantities (since their directions are opposite to the assumed directions). Alternately, we can use the general energy balance relation with the simplification that the boundary work is considered automatically by replacing ΔU by ΔH for a constant-pressure expansion or compression process:

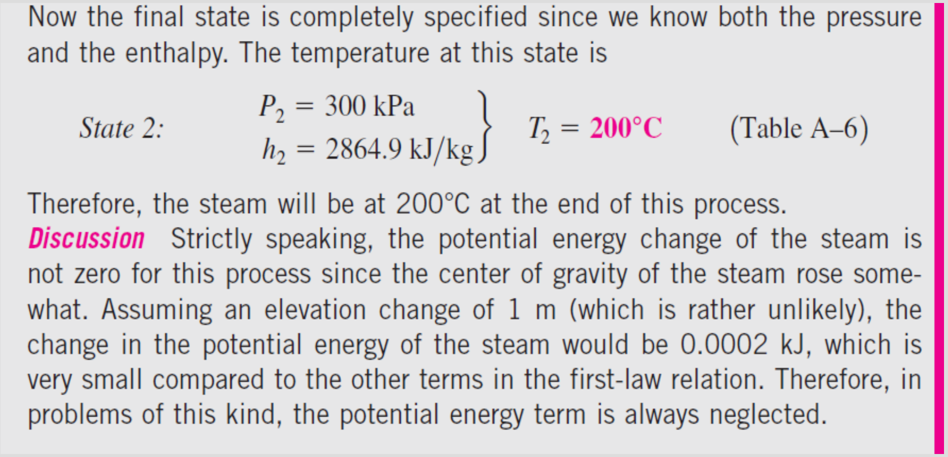
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}}$$

$$W_{e,\text{in}} - Q_{\text{out}} - W_b = \Delta U$$

$$W_{e,\text{in}} - Q_{\text{out}} = \Delta H = m(h_2 - h_1) \qquad (\text{since } P = \text{constant})$$

$$7.2\text{ kJ} - 3.7\text{ kJ} = (0.025\text{ kg})(h_2 - 2724.9)\text{ kJ/kg}$$

$$h_2 = 2864.9\text{ kJ/kg}$$

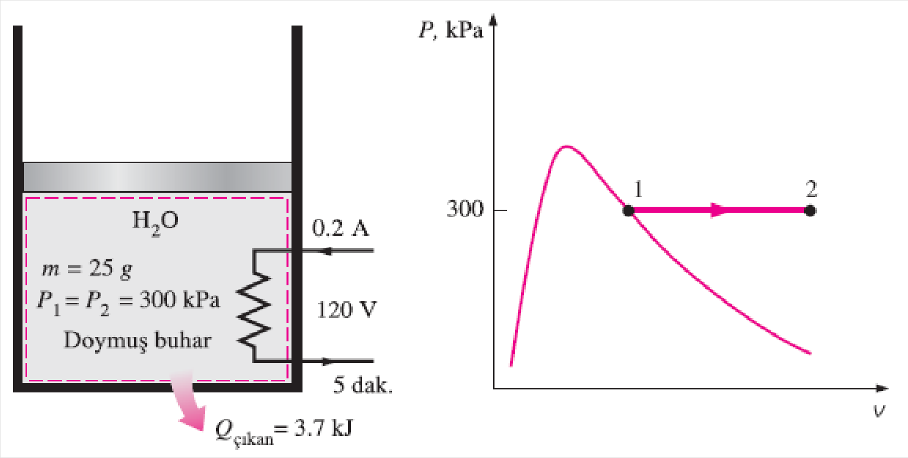


Now the final state is completely specified since we know both the pressure and the enthalpy. The temperature at this state is

$$\textit{State 2:}\quad \left.\begin{array}{l} P_2 = 300\text{ kPa} \\ h_2 = 2864.9\text{ kJ/kg} \end{array}\right\} \quad T_2 = \mathbf{200°C} \qquad \text{(Table A–6)}$$

Therefore, the steam will be at 200°C at the end of this process.

Discussion Strictly speaking, the potential energy change of the steam is not zero for this process since the center of gravity of the steam rose somewhat. Assuming an elevation change of 1 m (which is rather unlikely), the change in the potential energy of the steam would be 0.0002 kJ, which is very small compared to the other terms in the first-law relation. Therefore, in problems of this kind, the potential energy term is always neglected.



EXAMPLE 4–6 Unrestrained Expansion of Water

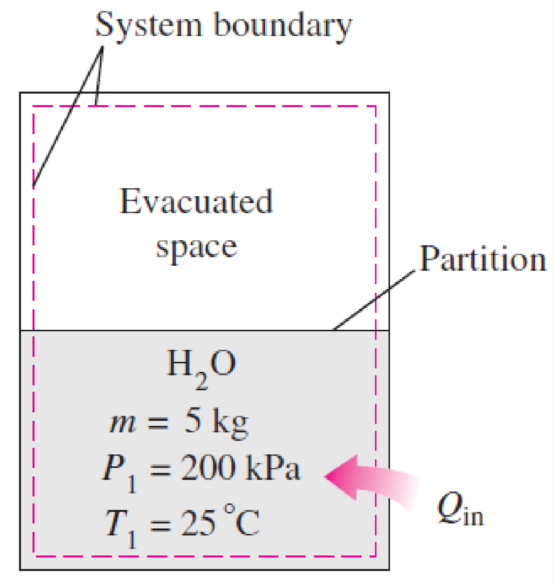
A rigid tank is divided into two equal parts by a partition. Initially, one side of the tank contains 5 kg of water at 200 kPa and 25°C, and the other side is evacuated. The partition is then removed, and the water expands into the entire tank. The water is allowed to exchange heat with its surroundings until the temperature in the tank returns to the initial value of 25°C. Determine (*a*) the volume of the tank, (*b*) the final pressure, and (*c*) the heat transfer for this process.

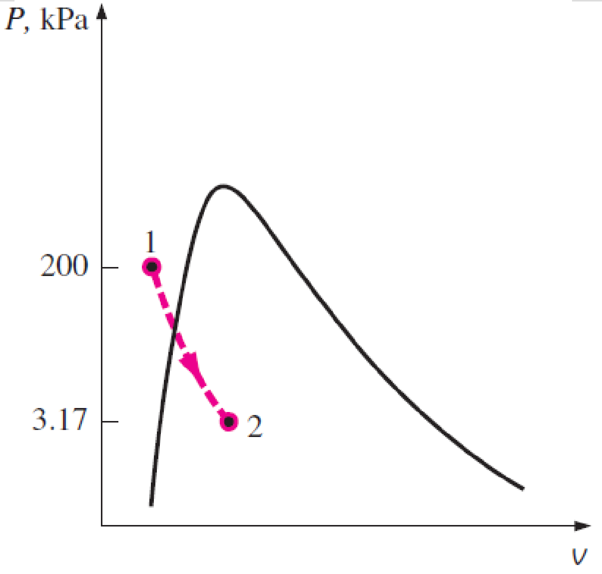
Solution One half of a rigid tank is filled with liquid water while the other side is evacuated. The partition between the two parts is removed and water is allowed to expand and fill the entire tank while the temperature is maintained constant. The volume of tank, the final pressure, and the heat transfer are to be to determined.

Assumptions **1** The system is stationary and thus the kinetic and potential energy changes are zero, ΔKE = ΔPE = 0 and Δ*E* = Δ*U*. **2** The direction of heat transfer is to the system (heat gain, Q_{in}). A negative result for Q_{in} indicates the assumed direction is wrong and thus it is a heat loss. **3** The volume of the rigid tank is constant, and thus there is no energy transfer as boundary work. **4** The water temperature remains constant during the process. **5** There is no electrical, shaft, or any other kind of work involved.

Analysis We take the contents of the tank, including the evacuated space, as the *system* (Fig. 4–15). This is a *closed system* since no mass crosses the system boundary during the process. We observe that the water fills the entire tank when the partition is removed (possibly as a liquid–vapor mixture).

(*a*) Initially the water in the tank exists as a compressed liquid since its pressure (200 kPa) is greater than the saturation pressure at 25°C (3.1698 kPa). Approximating the compressed liquid as a saturated liquid at the given temperature, we find





$$v_1 \cong v_{f\,@\,25^\circ\mathrm{C}} = 0.001003\ \mathrm{m^3/kg} \cong 0.001\ \mathrm{m^3/kg} \qquad \text{(Table A–4)}$$

Then the initial volume of the water is

$$V_1 = mv_1 = (5\ \mathrm{kg})(0.001\ \mathrm{m^3/kg}) = 0.005\ \mathrm{m^3}$$

The total volume of the tank is twice this amount:

$$V_{\mathrm{tank}} = (2)(0.005\ \mathrm{m^3}) = \mathbf{0.01\ m^3}$$

(*b*) At the final state, the specific volume of the water is

$$v_2 = \frac{V_2}{m} = \frac{0.01\ \mathrm{m^3}}{5\ \mathrm{kg}} = 0.002\ \mathrm{m^3/kg}$$

which is twice the initial value of the specific volume. This result is expected since the volume doubles while the amount of mass remains constant.

$$\text{At } 25^\circ\mathrm{C}:\quad v_f = 0.001003\ \mathrm{m^3/kg} \quad \text{and} \quad v_g = 43.340\ \mathrm{m^3/kg} \qquad \text{(Table A–4)}$$

Since $v_f < v_2 < v_g$, the water is a saturated liquid–vapor mixture at the final state, and thus the pressure is the saturation pressure at 25°C:

$$P_2 = P_{\mathrm{sat}\,@\,25^\circ\mathrm{C}} = \mathbf{3.1698\ kPa} \qquad \text{(Table A–4)}$$

(*c*) Under stated assumptions and observations, the energy balance on the system can be expressed as

$$\underbrace{E_{\mathrm{in}} - E_{\mathrm{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\mathrm{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}}$$

$$Q_{\mathrm{in}} = \Delta U = m(u_2 - u_1)$$

Notice that even though the water is expanding during this process, the system chosen involves fixed boundaries only (the dashed lines) and therefore the moving boundary work is zero (Fig. 4–16). Then $W = 0$ since the system does not involve any other forms of work. (Can you reach the same conclusion by choosing the water as our system?) Initially,

$$u_1 \cong u_{f\,@\,25^\circ\mathrm{C}} = 104.83\ \mathrm{kJ/kg}$$

The quality at the final state is determined from the specific volume information:

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.002 - 0.001}{43.34 - 0.001} = 2.3 \times 10^{-5}$$

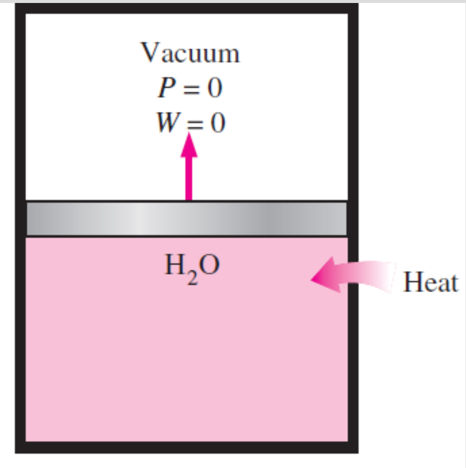
Then

$$\begin{aligned} u_2 &= u_f + x_2 u_{fg} \\ &= 104.83\ \mathrm{kJ/kg} + (2.3 \times 10^{-5})(2304.3\ \mathrm{kJ/kg}) \\ &= 104.88\ \mathrm{kJ/kg} \end{aligned}$$

Substituting yields

$$Q_{\mathrm{in}} = (5\ \mathrm{kg})[(104.88 - 104.83)\ \mathrm{kJkg}] = \mathbf{0.25\ kJ}$$

Discussion The positive sign indicates that the assumed direction is correct, and heat is transferred to the water.



ÖZGÜL ISILAR

Specific heat at constant volume, c_v:
Maddenin birim kütlesinin sıcaklığını sabit hacimde bir derece yükseltmek için gerekli enerji.

Specific heat at constant pressure, c_p:
Maddenin birim kütlesinin sıcaklığını sabit basınçta bir derece yükseltmek için gerekli enerji.

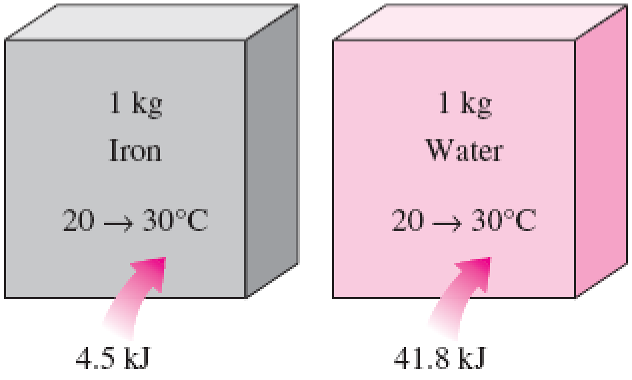


FIGURE 4–17
It takes different amounts of energy to raise the temperature of different substances by the same amount.

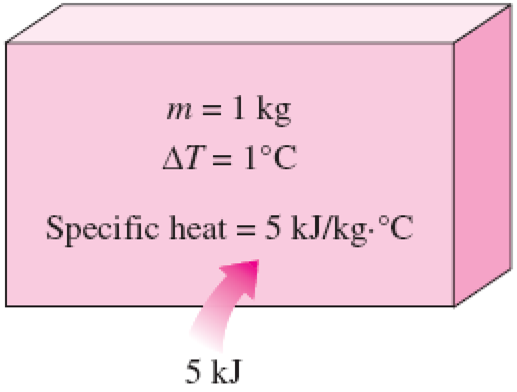
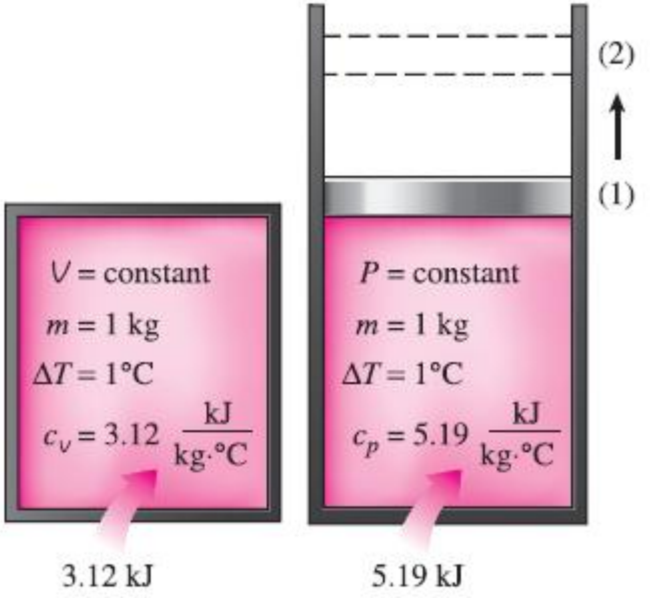


FIGURE 4–18
Özgül ısı, maddenin birim kütlesinin sıcaklığını bir derece artırmak için gerekli enerjidir.

Sabit hacimde ve sabit basınçta özgül ısılar c_v *ve* c_p *(verilen* değerler helyum gazı içindir).



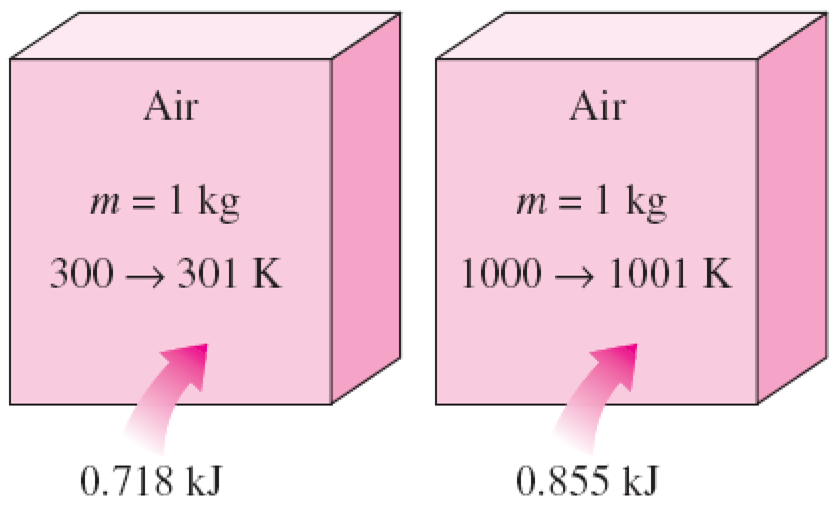
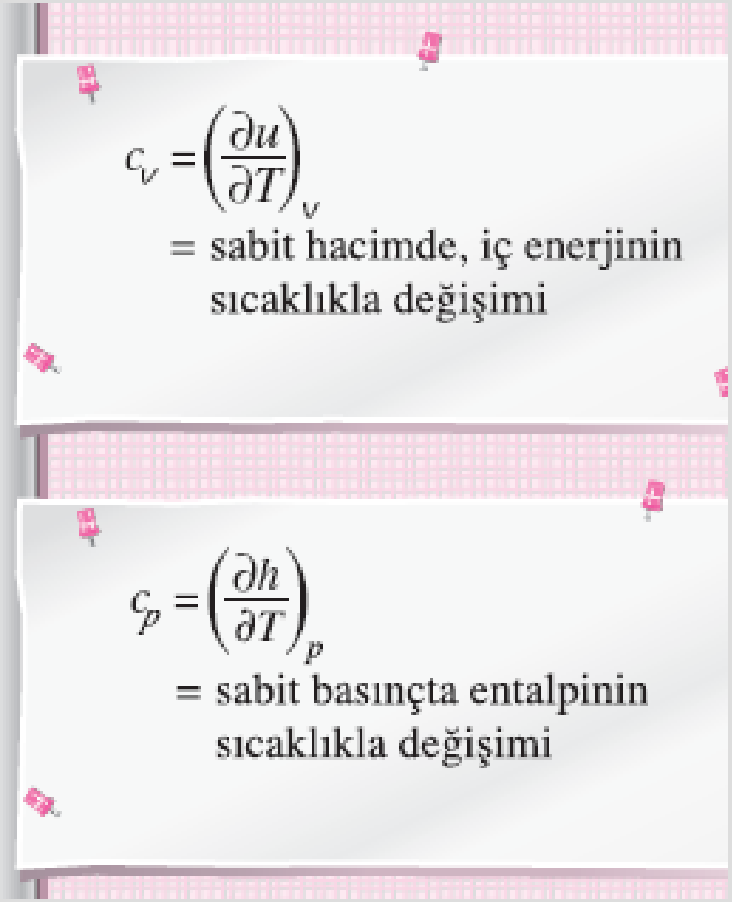


FIGURE 4–21

Bir maddenin özgül ısısı sıcaklıkla değişir.

Doğru mu yanlış mı?
c_p daima c_v. den büyüktür.

- The equations in the figure are valid for *any* substance undergoing *any* process.
- c_v and c_p are properties.
- c_v is related to the changes in *internal energy* and c_p to the changes in *enthalpy*.
- A common unit for specific heats is kJ/kg·°C or kJ/kg·K. **Are these units identical?**



$$c_v = \left(\frac{\partial u}{\partial T}\right)_v$$

= sabit hacimde, iç enerjinin sıcaklıkla değişimi

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

= sabit basınçta entalpinin sıcaklıkla değişimi

Formal definitions of c_v and c_p.

MÜKEMMEL GAZLARIN İÇ ENERJİ, ENTALPİ VE ÖZGÜL ISILARI

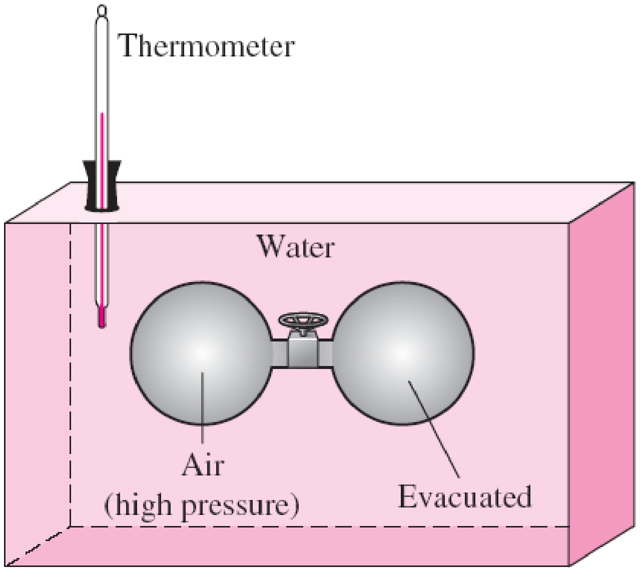


FIGURE 4–22

Joule'ün deney düzeneğinin genel çizimi.

$$\left.\begin{aligned} h &= u + Pv \\ Pv &= RT \end{aligned}\right\} \quad h = u + RT$$

$$u = u(T) \qquad h = h(T)$$

$$du = c_v(T)\,dT \qquad dh = c_p(T)\,dT$$

$$\Delta u = u_2 - u_1 = \int_1^2 c_v(T)\,dT$$

$$\Delta h = h_2 - h_1 = \int_1^2 c_p(T)\,dT$$

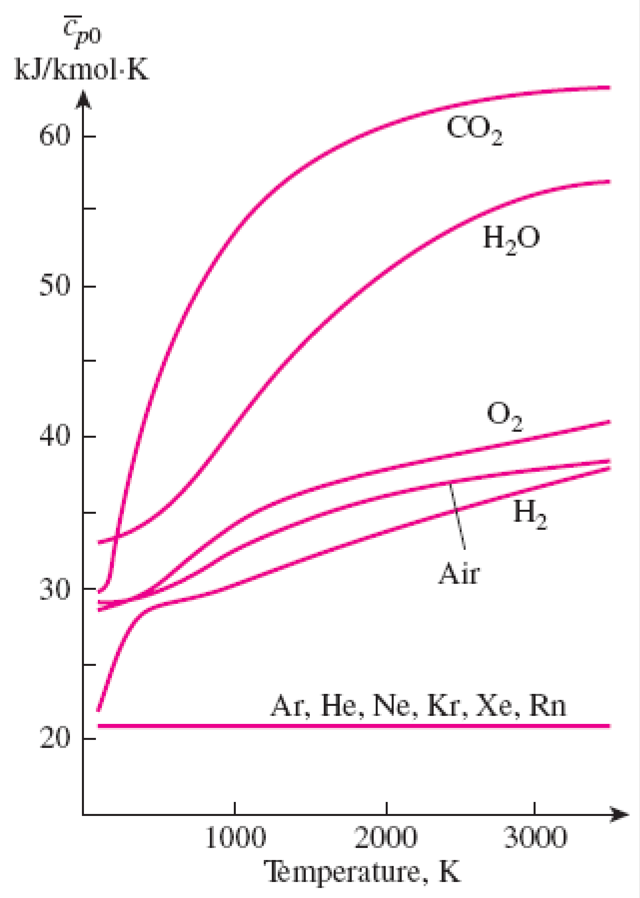
mükemmel gazın iç enerji ve entalpi değişimleri

Joule showed using this experimental apparatus that $u=u(T)$

$$\begin{aligned} u &= u(T) \\ h &= h(T) \\ c_v &= c_v(T) \\ c_p &= c_p(T) \end{aligned}$$

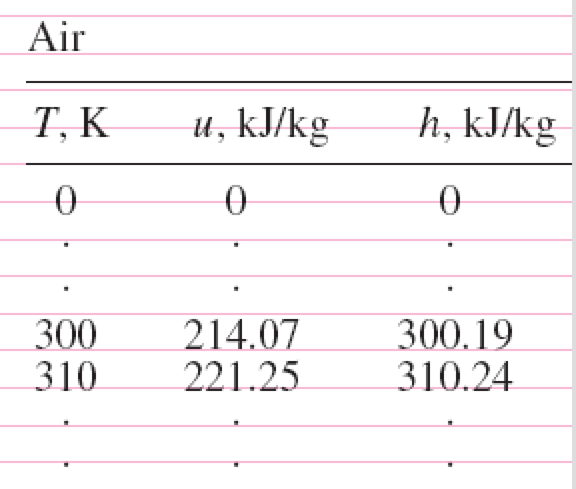
Mükemmel gazlar için, u, h, c_v, and c_p vary sadece sıcaklıkla değişir.

- Düşük basınçlarda, tüm gerçek gazlar mükemmel gaz davranışına yaklaşırlar, bu nedenle özgül ısıları sadece sıcaklığın fonksiyonu olur.
- Gerçek gazların düşük basınçlarda özgül ısıları mükemmel-gaz veya sıfır basınç özgül ısısı diye adlandırılır c_{p0} and c_{v0} ile gösterilir.



Bazı gazların mükemmel gaz özgül Isıları (see Table A–2*c* for c_p equations).

- bazı gazlara ilişkin *u* ve *h* değerleri, küçük sıcaklık aralıklarında hesaplanarak tablolarla verilmiştir.
- Bu tablolar belirli bir referans noktası seçip bunu 1 hali olarak saptadıktan sonra 4-25 ve 4-26 numaralı denklemlerdeki integraller alınarak hazırlanmışlardır.



Air

T, K	*u*, kJ/kg	*h*, kJ/kg
0	0	0
.	.	.
.	.	.
300	214.07	300.19
310	221.25	310.24
.	.	.
.	.	.

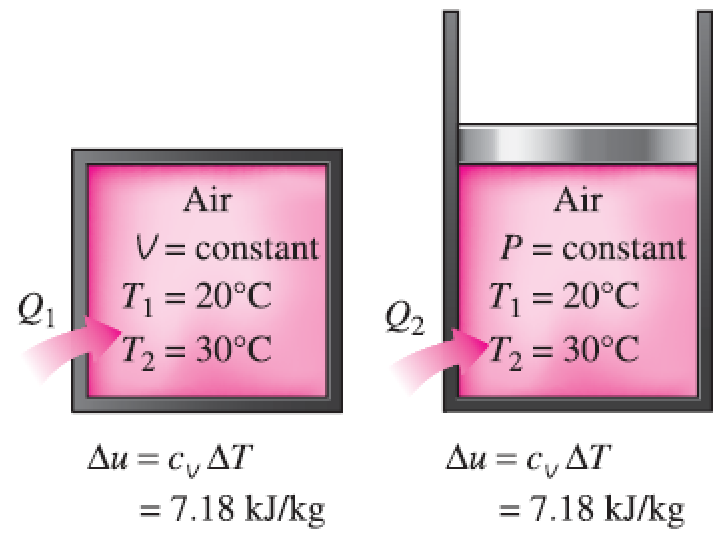
Mükemmel gaz tabloları hazırlanırken, 0 K referans sıcaklığı olarak seçilir.

İç enerji ve enthalpy, özgül ısının, ortalama bir değerde sabit alındığı zaman değişir

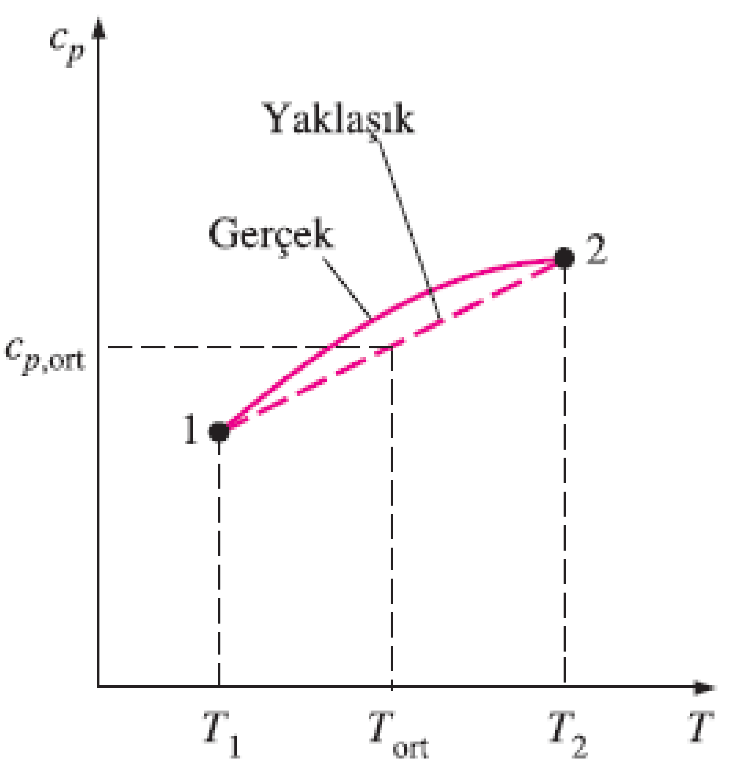
$$u_2 - u_1 = c_{v,\mathrm{avg}}(T_2 - T_1)$$

$$h_2 - h_1 = c_{p,\mathrm{avg}}(T_2 - T_1)$$

(kJ/kg)



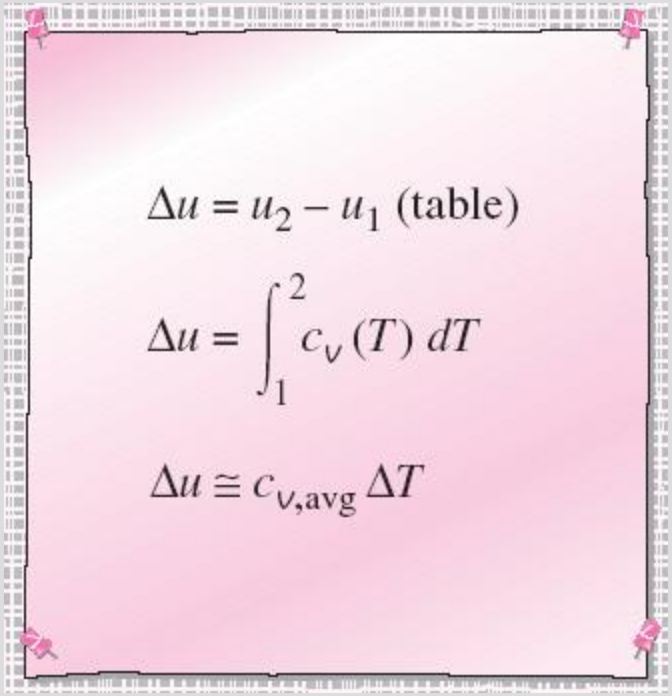
$\Delta u = c_v \Delta T$ bağıntısı, sabit hacimde olsun veya olmasın tüm hal değişimleri için geçerlidir.



Küçük sıcaklık aralıklarında özgül ısıların sıcaklıkla doğrusal olarak değiştiği kabul edilebilir.

Three ways of calculating Δu and Δh

1. Tablolarla verilmiş *u* ve *h* değerleri kullanılabilir. Tablolar bulunabiliyorsa **en hassas ve en kolay yol** budur.
2. c_v ve c_p değerlerini sıcaklığın fonksiyonu olarak veren bağıntıları kullanarak integral alınabilir (Table A-2c). El hesapları için bu yol zaman alıcıdır, ancak bilgisayarda yapılan hesaplar için çok elverişlidir. Elde edilen **sonuçlar çok hassastır**.
3. Ortalama özgül ısı değerleri kullanılabilir. Bu yol kolayca uygulanabilir ve özelik tabloları bulunamadığı zaman çok uygundur. Sıcaklık aralığı çok büyük olmadığı sürece sonuçlar oldukça hassastır.



$$\Delta u = u_2 - u_1 \text{ (table)}$$

$$\Delta u = \int_1^2 c_v(T)\, dT$$

$$\Delta u \cong c_{v,\text{avg}} \Delta T$$

Three ways of calculating Δu.

Mükemmel Gazlar İçin Özgül Isı Bağıntıları

$$\left.\begin{aligned} h &= u + RT \\ dh &= du + R\,dT \\ dh = c_p dT \;\; &\text{and} \;\; du = c_v dT \end{aligned}\right\} \longrightarrow$$

c_p, c_v ve R arasındaki bağlantı

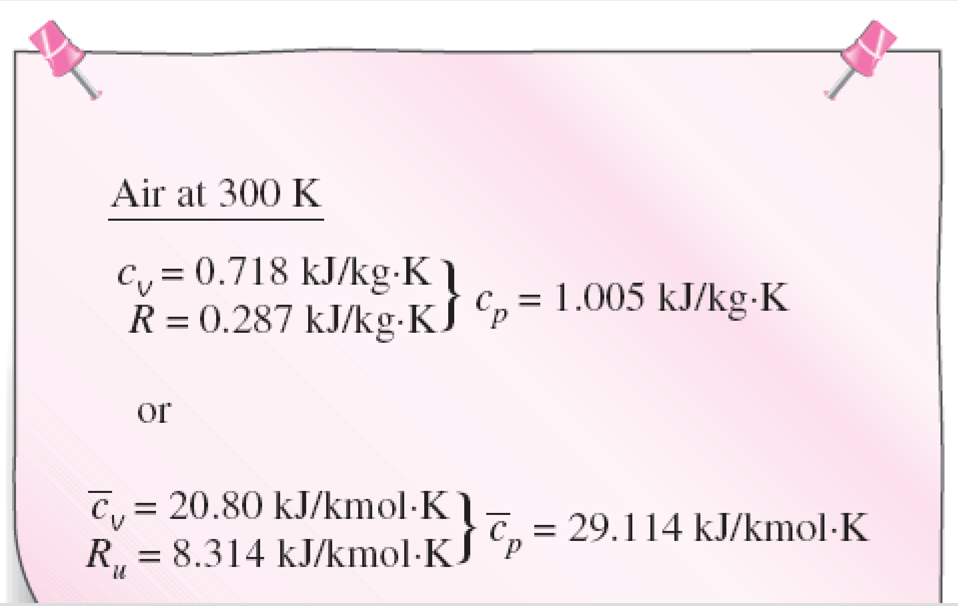
$$c_p = c_v + R \qquad (\mathrm{kJ/kg\cdot K})$$

Mol esasına göre

$$\bar{c}_p = \bar{c}_v + R_u \qquad (\mathrm{kJ/kmol\cdot K})$$

$$k = \frac{c_p}{c_v}$$

Özgül ısı oranı



Air at 300 K

$$\left.\begin{aligned} c_v &= 0.718\ \mathrm{kJ/kg\cdot K} \\ R &= 0.287\ \mathrm{kJ/kg\cdot K} \end{aligned}\right\} c_p = 1.005\ \mathrm{kJ/kg\cdot K}$$

or

$$\left.\begin{aligned} \bar{c}_v &= 20.80\ \mathrm{kJ/kmol\cdot K} \\ R_u &= 8.314\ \mathrm{kJ/kmol\cdot K} \end{aligned}\right\} \bar{c}_p = 29.114\ \mathrm{kJ/kmol\cdot K}$$

Mükemmel bir gazın c_p değeri c_v ve R biliniyorsa hesaplanabilir. Δu hesaplanmasının üç yolu.

- Özgül ısıların oranı da sıcaklığın fonksiyonudur. Fakat özgül ısıların oranının sıcaklıkla değişimi çok belirgin değildir.
- Tek atomlu gazlar için *k sabit* olup 1.667 değerindedir.
- Hava ve iki atomlu gazların birçoğu için oda sıcaklığında özgül ısıların oranı yaklaşık 1.4 değerindedir.

KATI VE SIVILARIN İÇ ENERJİ, ENTALPİ VE ÖZGÜL ISILARI

Incompressible substance: Özgül hacmi veya yoğunluğu sabit olan maddedir. Solids and liquids özgül hacimleri bir hal değişimi sırasında hemen hemen sabit kalır.

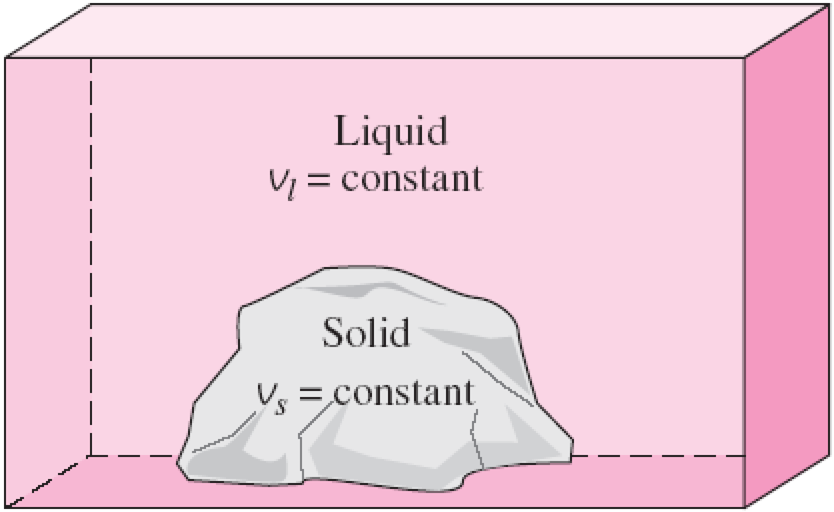


FIGURE 4–33

Sıkıştırılamayan maddelerin özgül hacimleri bir hal değişimi sırasında sabit kalır.

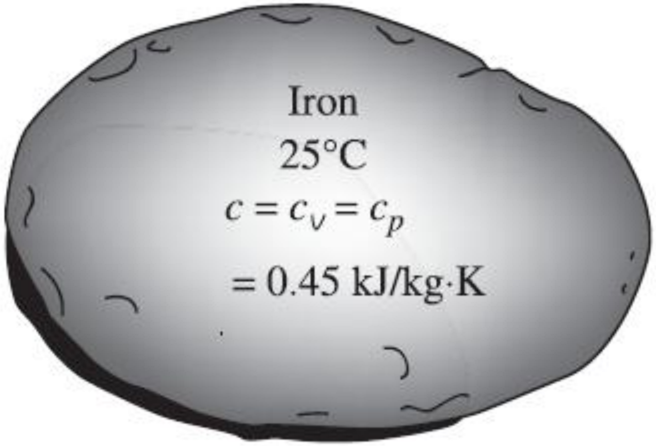


FIGURE 4–34

Sıkıştırılamayan maddelerin c_v *ve* c_p *değerleri* eşittir ve *c ile gösterilir.*

İç Enerji Değişimleri

$$du = c_v \, dT = c(T)\, dT$$

$$\Delta u = u_2 - u_1 = \int_1^2 c(T)\, dT \qquad (\text{kJ/kg})$$

$$\Delta u \cong c_{\text{avg}}(T_2 - T_1) \qquad (\text{kJ/kg})$$

Entalpi Değişimi

$$h = u + Pv$$

$$dh = du + v\, dP + \cancelto{0}{P\, dv} = du + v\, dP$$

$$\Delta h = \Delta u + v\, \Delta P \cong c_{\text{avg}}\, \Delta T + v\, \Delta P \qquad (\text{kJ/kg})$$

Katılar için, $v\,\Delta P$ terimi ihmal edilebilecek kadar küçüktür, bu nedenle $\Delta h = \Delta u \cong c_{\text{ort}}\Delta T$. Sıvılar için iki özel durumla karşılaşılabilir:

1. *Sabit basınçta hal değişimi*, ısıtıcılarda ; $(\Delta P = 0)$: $\Delta h = \Delta u \cong c_{\text{ort}}\Delta T$
2. *Sabit sıcaklıkta hal değişimi*, pompalarda ; $(\Delta T = 0)$: $\Delta h = v\,\Delta P$

$$h_{@P,T} \cong h_{f\,@\,T} + v_{f\,@\,T}(P - P_{\text{sat}\,@\,T})$$ Sıkıştırılmış sıvı entalpisi

son terimin etkisi genellikle çok küçüktür ve ihmal edilebilir $h_{@\,P,T} \cong h_{f\,@\,T}$

Summary

- Moving boundary work
  - ✓ W_b for an isothermal process
  - ✓ W_b for a constant-pressure process
  - ✓ W_b for a polytropic process
- Energy balance for closed systems
  - ✓ Energy balance for a constant-pressure expansion or compression process
- Specific heats
  - ✓ Constant-pressure specific heat, c_p
  - ✓ Constant-volume specific heat, c_v
- Internal energy, enthalpy, and specific heats of ideal gases
  - ✓ Specific heat relations of ideal gases
- Internal energy, enthalpy, and specific heats of incompressible substances (solids and liquids)