

Thermodynamics: An Engineering Approach, 6<sup>th</sup> Edition  
Yunus A. Cengel, Michael A. Boles  
McGraw-Hill, 2008

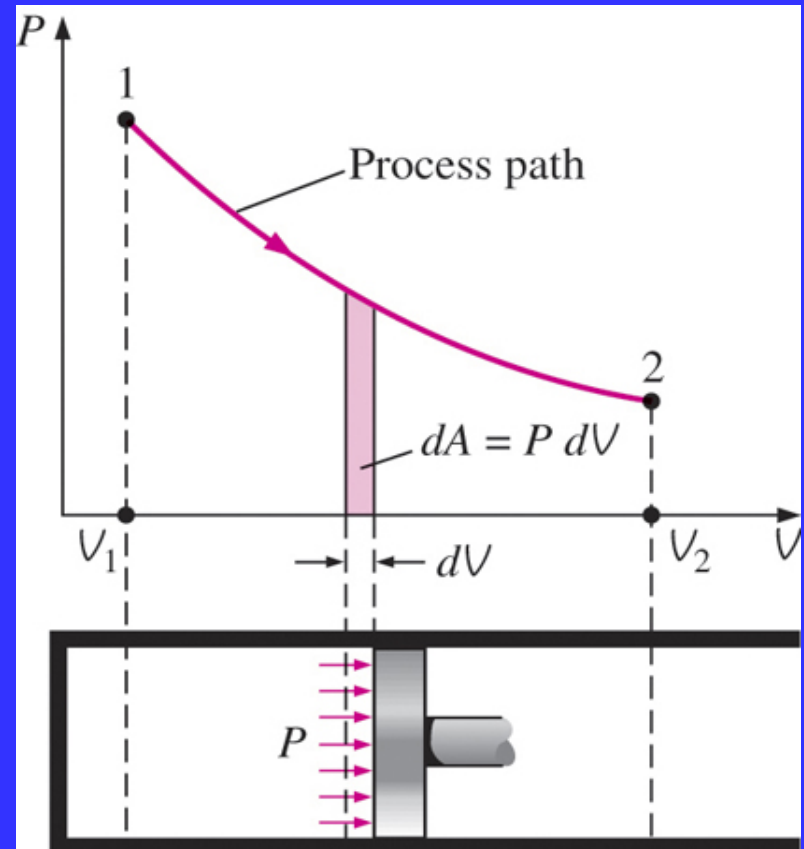
# Chapter (4)

## ENERGY ANALYSIS OF CLOSED SYSTEMS

# SUMMARY

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

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



# SUMMARY

## MOVING BOUNDARY WORK EQUATIONS

Polytropic process

$$W_b = \int_1^2 P dV = \int_1^2 C V^{-n} dV = C \frac{V_2^{-n+1} - V_1^{-n+1}}{-n + 1} = \frac{P_2 V_2 - P_1 V_1}{1 - n}$$

Polytropic for ideal gas

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

When  $n = 1$  (isothermal process)

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

Isothermal process for ideal gas

$$W_b = mRT_0 \ln \frac{V_2}{V_1}$$

Constant pressure process

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

12/9/2010

**(Isobaric)**

Dr. MUNZ

# ENERGY BALANCE FOR CLOSED SYSTEMS

## Energy balance per unit mass basis

$$e_{\text{in}} - e_{\text{out}} = \Delta e_{\text{system}} \quad (\text{kJ/kg})$$

## Energy balance in differential form

$$\delta E_{\text{in}} - \delta E_{\text{out}} = dE_{\text{system}} \quad \text{or} \quad \delta e_{\text{in}} - \delta e_{\text{out}} = de_{\text{system}}$$

## Energy balance for a cycle

$$W_{\text{net,out}} = Q_{\text{net,in}} \quad \text{or} \quad \dot{W}_{\text{net,out}} = \dot{Q}_{\text{net,in}}$$

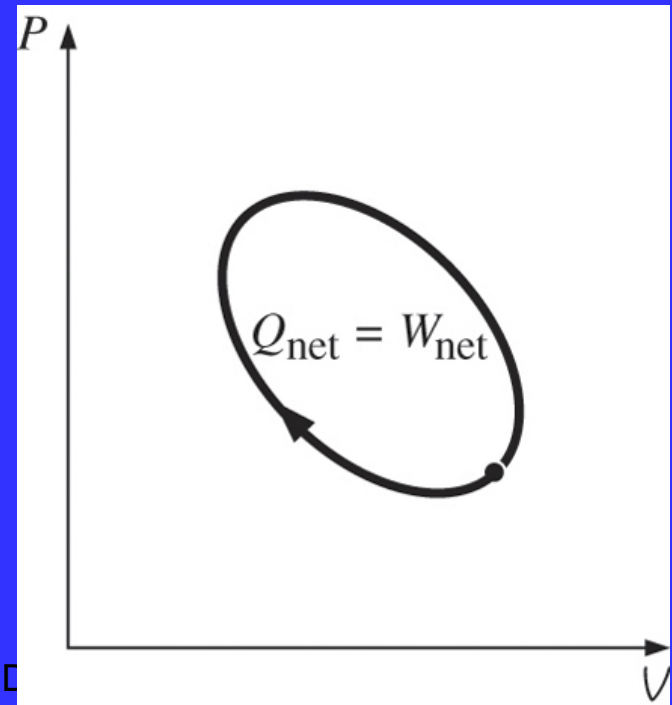
$$Q_{\text{net,in}} - W_{\text{net,out}} = \Delta E_{\text{system}} \quad \text{or} \quad Q - W = \Delta E$$

$$Q = Q_{\text{net,in}} = Q_{\text{in}} - Q_{\text{out}}$$

$$W = W_{\text{net,out}} = W_{\text{out}} - W_{\text{in}}$$

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

For a cycle  $\Delta E = 0$ , thus  $Q = W$ .



## Energy balance in the rate form

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}} = \underbrace{dE_{system}/dt} \quad (\text{kW})$$

Rate of net energy transfer  
by heat, work, and mass

Rate of change in internal,  
kinetic, potential, etc., energies

$$\dot{E}_{in} - \dot{E}_{out} = \Delta U + \Delta K.E + \Delta P.E$$

$$\Delta U = m(u_2 - u_1) \quad \Delta K.E = \frac{1}{2}m(v_2^2 - v_1^2) \quad \Delta P.E = mg(z_2 - z_1)$$

For a constant-pressure expansion or compression process:

$$\Delta U + W_b = \Delta H$$

# Energy balance for a **constant-pressure** expansion or compression process

General analysis for a closed system undergoing a quasi-equilibrium constant-pressure process.  $Q$  is *to* the system and  $W$  is *from* the system.

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

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

$$Q - W_{\text{other}} - W_b = U_2 - U_1$$

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

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

$$H = U + PV$$

$$Q - W_{\text{other}} = H_2 - H_1$$

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

= the change in internal energy with temperature at constant volume

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

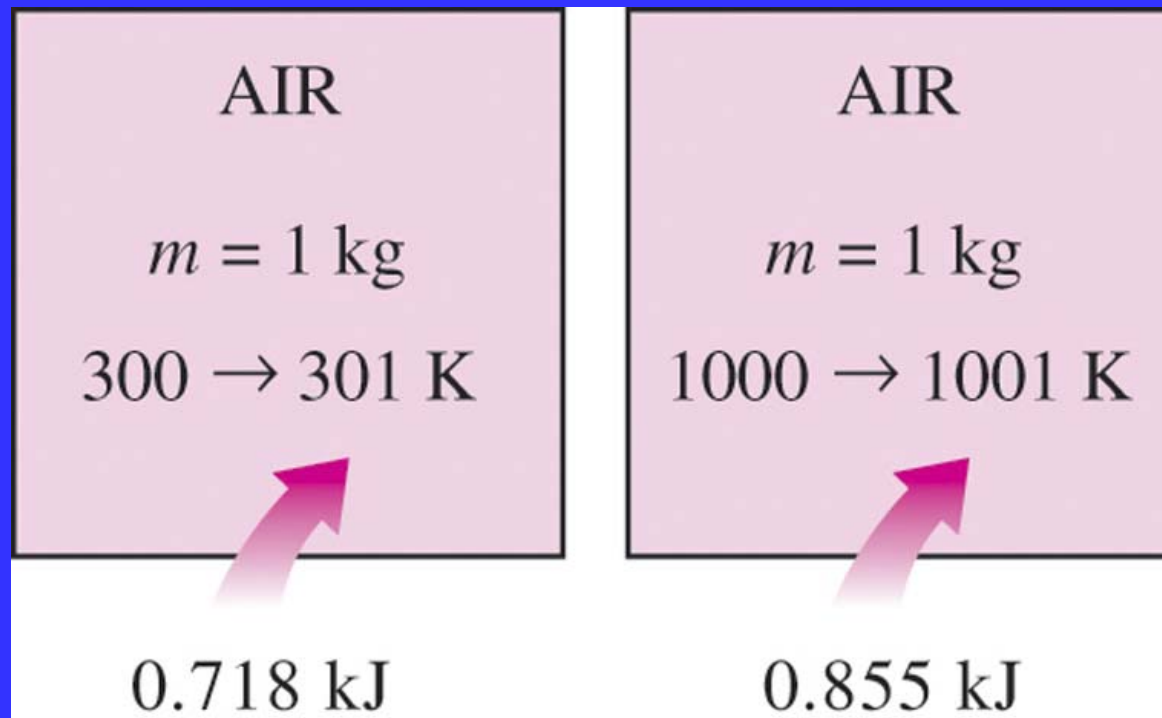
= the change in enthalpy with temperature at constant pressure

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

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



- $c_v$  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  $\text{kJ/kg} \cdot ^\circ\text{C}$  or  $\text{kJ/kg} \cdot \text{K}$ .



1. By using the tabulated  $u$  and  $h$  data. This is the easiest and **most accurate** way when tables are readily available.
2. By using the  $c_v$  or  $c_p$  relations (Table A-2c) as a function of temperature and performing the integrations. The results obtained are **very accurate**.
3. By using average specific heats. This is very simple and certainly very convenient when property tables are not available. The results obtained are **reasonably accurate** if the temperature interval is not very large.

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

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

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

# Specific Heat Relations of Ideal Gases

$$h = u + RT$$

$$dh = du + R dT$$

$$dh = c_p dT \text{ and } du = c_v dT$$

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

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

AIR at 300 K

$$\left. \begin{array}{l} c_v = 0.718 \text{ kJ/kg} \cdot \text{K} \\ R = 0.287 \text{ kJ/kg} \cdot \text{K} \end{array} \right\} c_p = 1.005 \text{ kJ/kg} \cdot \text{K}$$

or

$$\left. \begin{array}{l} \bar{c}_v = 20.80 \text{ kJ/kmol} \cdot \text{K} \\ R_u = 8.314 \text{ kJ/kmol} \cdot \text{K} \end{array} \right\} \bar{c}_p = 29.114 \text{ kJ/kmol} \cdot \text{K}$$

The relationship between  $c_p$ ,  $c_v$  and  $R$

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

Specific heat ratio

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

**Incompressible substance:** Solids and liquids are incompressible substances.

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

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

For *solids*, the term  $v \Delta P$  is insignificant and thus  $\Delta h = \Delta u \cong c_{\text{avg}} \Delta T$ . For *liquids*, two special cases are commonly encountered:

1. *Constant-pressure processes*, as in heaters ( $\Delta P = 0$ ):  $\Delta h = \Delta u \cong c_{\text{avg}} \Delta T$
2. *Constant-temperature processes*, as in pumps ( $\Delta T = 0$ ):  $\Delta h = v \Delta P$

**THE END**