

Chapter 4

- 1st Law of Thermodynamics in the Closed System

$$\Delta Q \equiv \Delta E + \Delta W$$

$$(\delta Q = dE + \delta W)$$

Perfect differential
완전미분

Non-perfect differential
불완전 미분 (Path dependent)

- In general, total energy E,
 $E = U$ (internal energy) + KE + PE

$$KE = \frac{1}{2}mv^2$$

$$PE = mg(z_2 - z_1)$$

- If the system is static,
 $KE = PE = 0$

$$\Delta Q = \Delta U + \Delta W$$

- Conservation of Energy
(1) For a cycle process,

$$\oint \delta Q = \oint \overset{0}{dU} + \int \delta W$$

$$\oint \delta Q = \oint \delta W$$

“한 Cycle 동안 System에 주어진 Net Heat는 System이 행한 Net Work와 같다.”

$$Q_1 - Q_2 = W_{net}$$

Q_1 = Cycle 과정 중 System으로 준 열량.

Q_2 = Cycle 과정 중 System으로부터 방출된 열량.

W_{net} = System이 행한 Net Work.

(2) Energy conservation in Isolated (고립) System.

→ 주위와 열이나 일을 교환하지 않는 밀폐 system

$$Q_{12} = 0, W_{12} = 0$$

$$\rightarrow E_2 - E_1 = 0$$

If static, $U_2 - U_1 = 0$

(3) Internal energy

Extensive property:

That is, it depends on the mass of the system.

(4) Enthalpy: thermodynamic property

Defined $H = U + pV$ total enthalpy

Or, per unit mass

$$h = u + pv \quad \text{specific enthalpy}$$

One reason for introducing enthalpy at this time is that although the steam tables list values for internal energy, many other tables and charts of thermodynamic properties give values for enthalpy but not for the internal energy.

For saturated steam, we know that

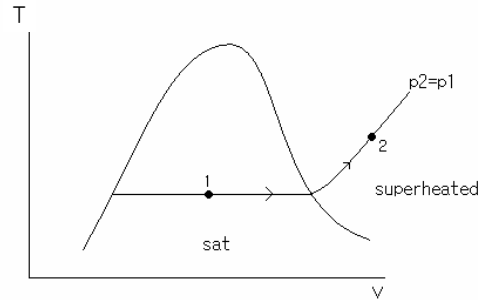
$$\begin{aligned} v &= (1-x)v_f + xv_g && \text{specific volume} \\ u &= (1-x)u_f + xu_g && \text{specific internal energy} \\ h &= (1-x)h_f + xh_g && \text{specific enthalpy} \end{aligned}$$

Look up of steam table

• Example 1

A cylinder fitted with a piston has a volume of 0.1m³ and contains 0.5 kg of steam at 0.4 Mpa. Heat is transferred to the system until the temperature is 300°C, while the pressure remains constant.

Find $\Delta Q = \Delta U + \Delta W$



$$\Delta W_{12} = \int_1^2 p \, dV = p \int_1^2 dV = p(V_2 - V_1) = m(p_2 v_2 - p_1 v_1)$$

(Method 1) Consider the First Law,

$$\begin{aligned} \Delta Q_{12} &= m(u_2 - u_1) + \Delta W_{12} && \text{Since } p = \text{constant} \\ &= m(u_2 - u_1) + m(p_2 v_2 - p_1 v_1) \\ &= m(h_2 - h_1) && \text{Steam table look up, enthalpy} \end{aligned}$$

(Method 2)

From steam table, internal energy

$$\begin{aligned} u_1 &= u_f + x_1 u_{fg} \\ u_2 &= 2804.8 \end{aligned}$$

$$\begin{aligned} \Delta Q_{12} &= U_2 - U_1 + \Delta W_{12} \\ &= m(u_2 - u_1) + 91.0 = 771.1 \text{ kJ} \end{aligned}$$

From last time...

- Recall the 1st Law of Thermodynamics from last time,

$$\begin{aligned} \delta Q &= dU + \delta W \\ &= dU + p \, dV \end{aligned} \quad \text{Neglect KE, PE change}$$

With assumptions:

a simple compressible substance & quasi-equilibrium process.

We find that this expression can be evaluated for two separate cases.

(1) Constant Volume

The specific heat \equiv The amount of heat required per unit mass to raise the temperature by 1 degree.

$$c_v = \frac{1}{m} \left(\frac{\delta Q}{\delta T} \right)_v = \frac{1}{m} \left(\frac{\partial U}{\partial T} \right)_v = \left(\frac{\partial u}{\partial T} \right)_v$$

(2) Constant Pressure, $\delta Q = dH$ ($H = U + pV$) for constant p.

$$c_p = \frac{1}{m} \left(\frac{\delta Q}{\delta T} \right)_p = \frac{1}{m} \left(\frac{\partial H}{\partial T} \right)_p = \left(\frac{\partial h}{\partial T} \right)_p$$

- Some comments about Internal energy, Enthalpy and specific heat of ideal gas.

$$p v = RT \quad \text{For an ideal gas}$$

For an ideal gas, the internal energy is:

$$u = f(T) \quad \longrightarrow \quad \text{We will explain this later}$$

We had

$$c_v = \left(\frac{\partial u}{\partial T} \right)_v \quad \text{But since "u" depends only on T}$$

$$c_v = \frac{du}{dT}$$

or $du = c_v \, dT \quad \dots\dots\dots(1)$

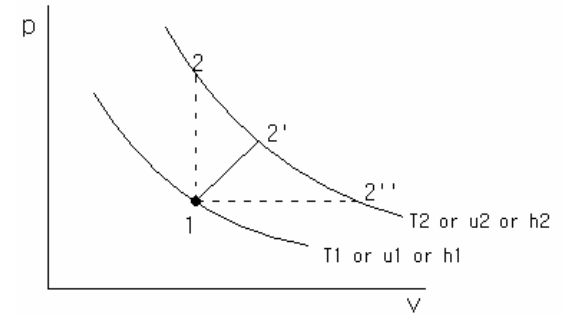
From the definition of enthalpy,

$$h = f(T) \quad \text{for an ideal gas}$$

Now, from $c_p = \left(\frac{\partial h}{\partial T}\right)_p$, we can also write

$$c_p = \frac{dh}{dT}$$

Or $dh = c_p dT$ -----(2)



Pressure-Volume (p-v) diagram for ideal gas

Since $u(T)$ and $h(T)$, these are also lines of constant u or h or T .
 For all processes $1 \rightarrow 2$, $1 \rightarrow 2'$, $1 \rightarrow 2''$,
 The changes in internal energy and enthalpy are the same.

• Further, $c_v = f(T)$, $c_p = f(T)$ for ideal gas

$$dh = du + RdT$$

→ $c_p dT = c_v dT + R dT$

$$c_p - c_v = R$$

→ $c_v = \frac{1}{\gamma - 1} R$ Using $\gamma = \frac{c_p}{c_v}$

$$c_p = \frac{\gamma}{\gamma - 1} R$$

This says, the difference between the constant pressure and constant volume specific heats of an ideal gas is always constant.

		C_v	C_p	$\gamma = C_p/C_v$
Monatomic gas (He, Ar, etc)		3/2 R	5/2 R	5/3=1.67
Diatomic gas (N ₂ , O ₂ , CO, etc)				
	극저온	3/2 R	5/2 R	5/3=1.67
General	상온	5/2 R	7/2 R	7/5=1.4
	극고온	7/2 R	9/2 R	9/7=1.29

• **Adiabatic System**

$$\delta Q = 0$$

$$0 = dU + pdV$$

Where $du = c_v dT$ (ideal gas), $p = \frac{RT}{v}$

or $0 = du + pdv$

so

$$c_v dT + \frac{RT}{v} dv = 0$$

$$\frac{dT}{T} + \frac{R}{v c_v} dv = 0 \quad ; \quad c_v = \frac{1}{\gamma - 1} R$$

Take the integral,

$$\ln T + \frac{R}{c_v} \ln v = C$$

or $\ln T + (\gamma - 1) \ln v = C$

Then for adiabatic ($\delta Q = 0$) process, we find

$$TV^{\gamma-1} = C_1 \quad ; \quad p = \frac{RT}{v}$$

or $\frac{pV}{R} v^{\gamma-1} = C_1 \quad ; \quad pv^\gamma = C_2$

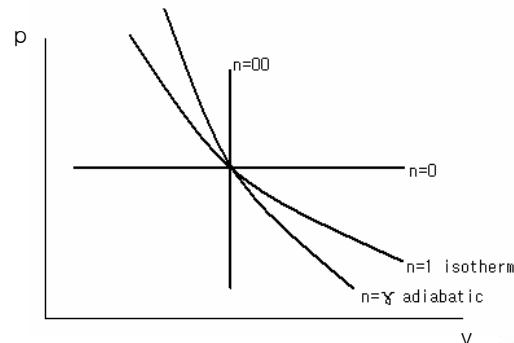
or $Tp^{\frac{\gamma-1}{\gamma}} = C_3$

$$\left. \begin{aligned} \frac{T_2}{T_1} &= \left(\frac{v_2}{v_1}\right)^{1-\gamma} \\ \frac{p_2}{p_1} &= \left(\frac{v_1}{v_2}\right)^\gamma \\ \frac{T_2}{T_1} &= \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \end{aligned} \right\} \text{For ideal gas in Adiabatic System}$$

• In general, for polytropic gas (i.e. $pv^n = c$)

Consider $pv^n = c$

$n=0$: Isobaric Process (등압 과정)
$n = \pm \infty$: Isochoric Process (등적 과정)
$\gamma > 1$ $n = \gamma$: Adiabatic process (단열 과정)
$n=1$: Isothermal process (등온 과정)



$$W_{12} = \int_1^2 pdV = m \int_1^2 pdv$$

$$= m \int_1^2 \left(\frac{c}{v^n}\right) dv$$

$$= cm \int_1^2 \frac{dv}{v^n}$$

$$= cm \frac{(v_2^{1-n} - v_1^{1-n})}{(1-n)}$$

$$= m \frac{(p_2 v_2 - p_1 v_1)}{1-n} = \frac{p_2 V_2 - p_1 V_1}{1-n}$$

Note, $\begin{cases} pv^n = c \\ p_1 v_1^n = p_2 v_2^n = c \end{cases}$

If ideal gas,

$$W_{12} = \frac{mR(T_2 - T_1)}{1-n}$$

- Homework Set #3
- due 3/30

- 4-1, 4-3, 4-6, 4-13, 4-20, 4-23, 4-26, 4-28