열전달(Heat Transfer)

2012년도 1학기(제 3주)

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제2장 정상 열전도(1)

(Heat Conduction on the Steady State Condition)

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◈ 학습목표

o 정상상태에서의 열전도에 대한 개념 이해
o 열저항 개념 도입에 의한 평면벽에서의 열전도 문제 해석 방법
o 접촉 열저항 발생 문제에 대한 열전도 문제 해석 방법
o 열저항 회로의 일반화 방법

◈ 학습성과

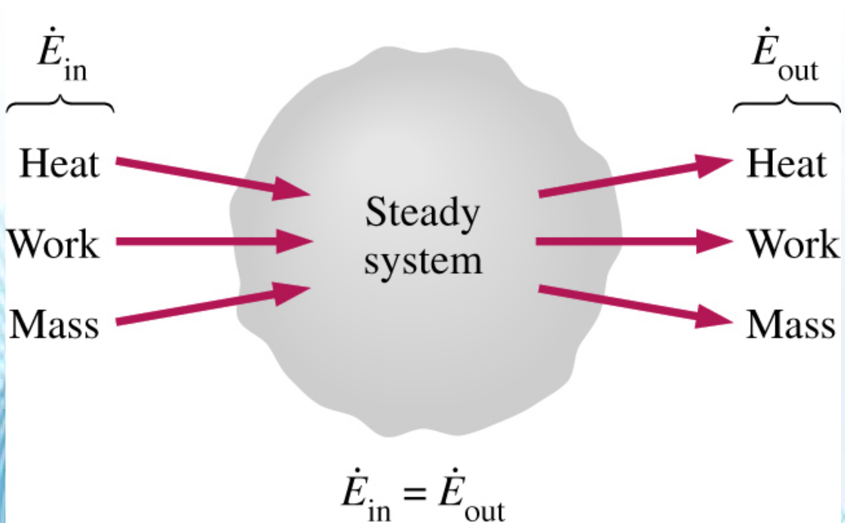
o 정상상태의 평면벽 및 접촉면에서의 열저항 개념을 적용한 실제 공학적 문제를 해결할 수 있어야 함.
o 다층(직열 및 병렬 연결)구조에서의 열저항 회로를 구성하고 열전달 문제를 해결할 수 있어야 함.

강의 내용 및 순서

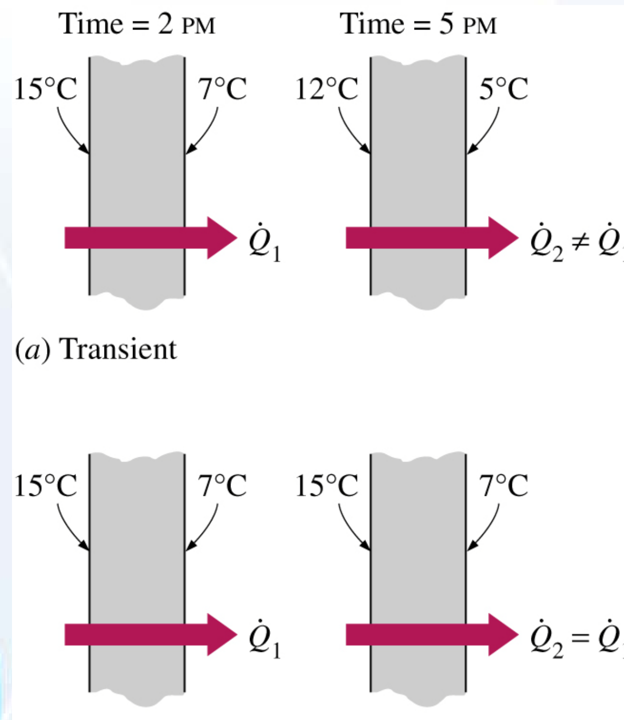
- 평면 벽에서의 정상 열전도
- 열접촉 저항
- 열저항 회로의 일반화
- 종합요약

■ 평면벽에서의 정상 열전도

▣ 정상상태(定常狀態, steady state condition)란?

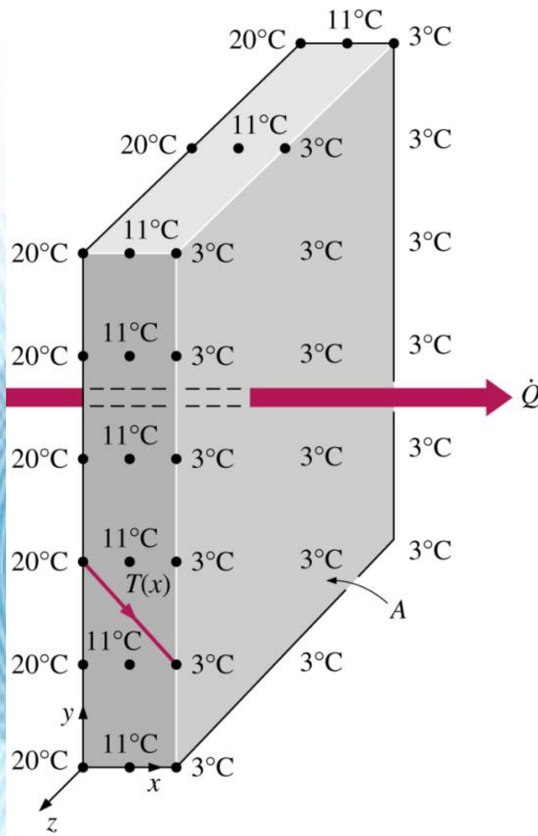


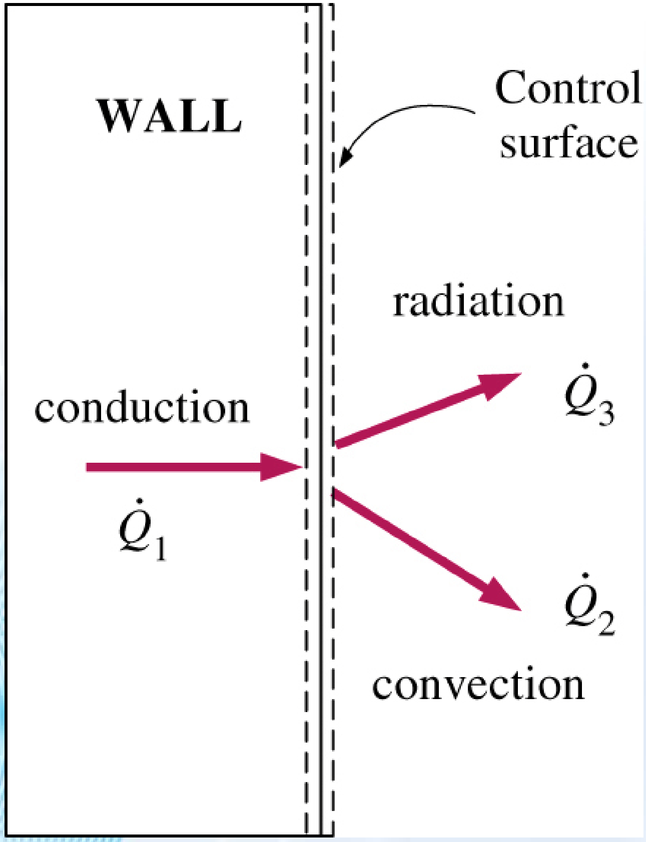
$$\dot{Q}_i - \dot{Q}_o = \frac{dE_{wall}}{dt} \qquad (2-1)$$



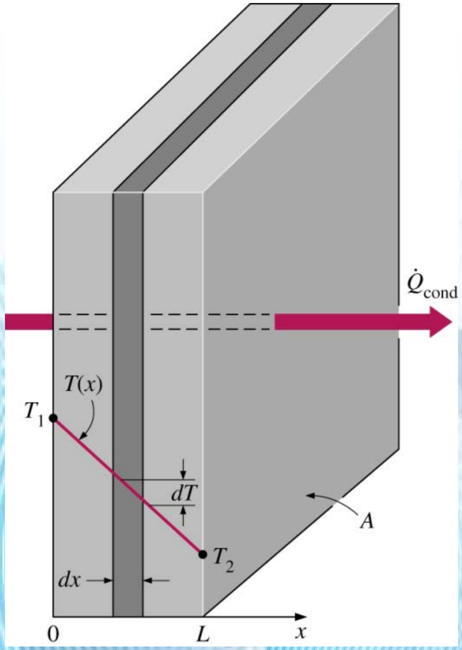
(*a*) Transient
(*b*) Steady-state

■ 평면벽에서의 정상 열전도





■ 평면벽에서의 정상 열전도



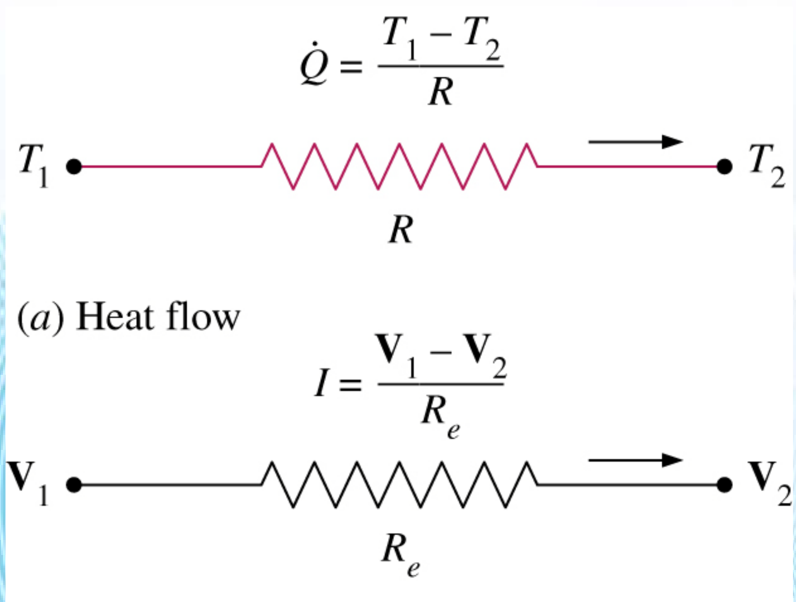
$$\dot{Q}_{cd,wall} = -kA\frac{dT}{dx} \qquad (2-2)$$

$$\int_{x=0}^{L} \dot{Q}_{cd,wall}\,dx = -\int_{T=T_1}^{T_2} kA\,dT$$

$$\dot{Q}_{cd,wall} = kA\frac{T_1 - T_2}{L} \qquad (2-3)$$

■ 평면벽에서의 정상 열전도

▣ 열저항 개념



(a) Heat flow

(b) Electric current flow

$$\dot{Q}_{cd,wall} = \frac{T_1 - T_2}{R_{cd}} \qquad (2-4)$$

R_{cd} : 전도저항(conduction resistance)[℃/W]

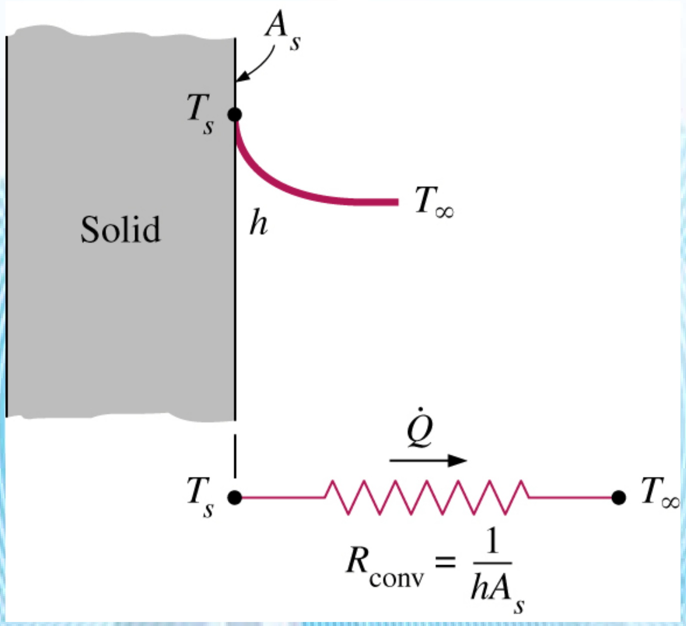
$$R_{cd} = \frac{L}{kA} \qquad (2-5)$$

$$I = \frac{V_1 - V_2}{R_e} \qquad (2-6)$$

$R_e = \frac{L}{\sigma_e A}$: 전기저항[Ω]

σ_e : 전기전도도 또는 도전도[$(\Omega m)^{-1}$]

■ 평면벽에서의 정상 열전도

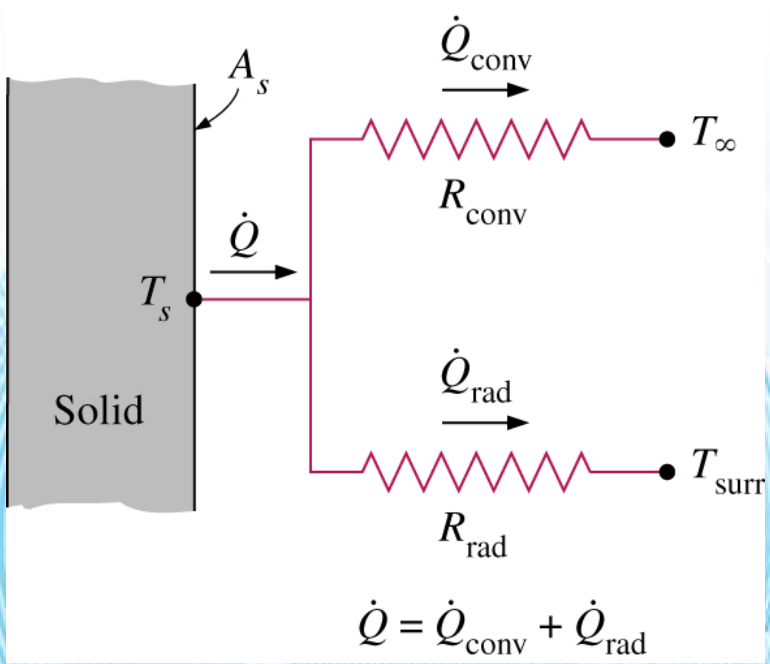


$$\dot{Q}_{cv} = \frac{T_s - T_\infty}{R_{cv}} \qquad (2-7)$$

R_{cv} : 대류저항(*convection resistance*)[℃/W]
h_{cv} : 대류열전달계수[W/m^2℃]

$$R_{cv} = \frac{1}{h_{cv} A_s} \qquad (2-8)$$

■ 평면벽에서의 정상 열전도



$$\dot{Q}_{rd} = \epsilon\sigma A_s(T_s^4 - T_{surr}^4) = h_{rd}A_s(T_s - T_{surr}) = \frac{T_s - T_{surr}}{R_{rd}} \quad (2-9)$$

R_{rd}: 복사저항(radiation resistance)[K/W]
h_{rd}: 복사열전달계수[W/m^2K]

$$R_{rd} = \frac{1}{h_{rd}A_s} \quad (2-10)$$

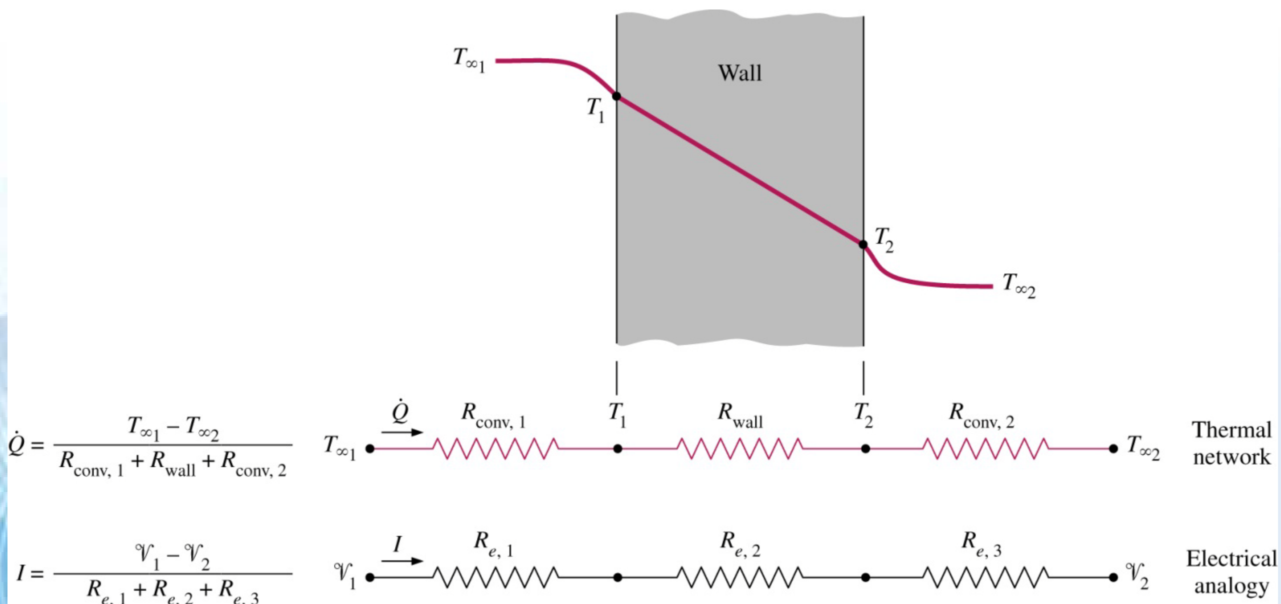
$$h_{rd} = \frac{\dot{Q}_{rd}}{A_s(T_s - T_{surr})} = \epsilon\sigma(T_s^2 + T_{surr}^2)(T_s + T_{surr}) \quad (2-11)$$

$$h_{cb} = h_{cv} + h_{rd} \quad (2-12)$$

h_{cb}: 복합열전달계수[W/m^2K]

■ 평면벽에서의 정상 열전도

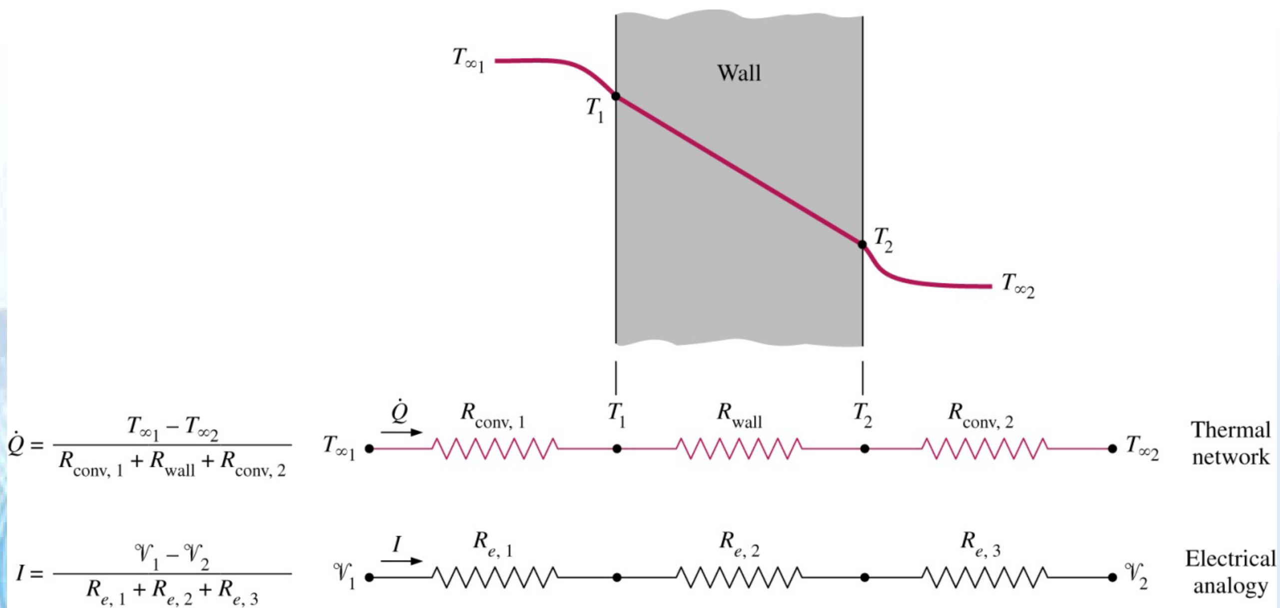
▣ 열저항 회로



$$
\begin{aligned}
\dot{Q} &= h_{cv1} A (T_{\infty 1} - T_1) \\
&= kA \frac{T_1 - T_2}{L} \\
&= h_{cv2} A (T_2 - T_{\infty 2})
\end{aligned}
\qquad (2-13)
$$

■ 평면벽에서의 정상 열전도

▣ 열저항 회로



$$
\begin{aligned}
\dot{Q} &= h_{cv1}A(T_{\infty 1} - T_1) = \frac{T_{\infty 1} - T_1}{(1/h_{cv1}A)} \\
&= kA\frac{T_1 - T_2}{L} \qquad = \frac{T_1 - T_2}{(L/kA)} \qquad\qquad (2-14) \\
&= h_{cv2}A(T_2 - T_{\infty 2}) = \frac{T_2 - T_{\infty 2}}{(1/h_{cv2}A)}
\end{aligned}
$$

■ 평면벽에서의 정상 열전도

▣ 열저항 회로

$$\begin{aligned}\dot{Q} &= h_{cv1}A(T_{\infty1} - T_1) = \frac{T_{\infty1} - T_1}{(1/h_{cv1}A)} \\ &= kA\frac{T_1 - T_2}{L} \qquad = \frac{T_1 - T_2}{(L/kA)} \\ &= h_{cv2}A(T_2 - T_{\infty2}) = \frac{T_2 - T_{\infty2}}{(1/h_{cv2}A)}\end{aligned} \qquad (2-14)$$

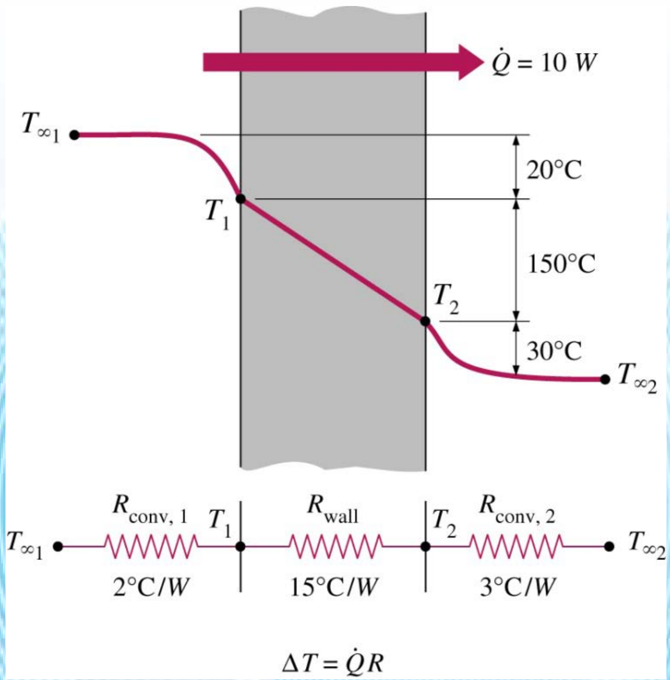
$$\dot{Q} = \frac{T_{\infty1} - T_{\infty2}}{R_{tt}} \qquad (2-15)$$

R_{tt} : 전체열저항 (*total heat resistance*) $[K/W]$ or $[℃/W]$

$$\begin{aligned}R_{tt} &= R_{cv1} + R_{cd} + R_{cv2} \\ &= \frac{1}{h_{cv1}A} + \frac{L}{kA} + \frac{1}{h_{cv2}A}\end{aligned} \qquad (2-16)$$

■ 평면벽에서의 정상 열전도

▣ 열저항 회로



$$\Delta T = \dot{Q}R \qquad (2-17)$$

$$\dot{Q} = UA\Delta T \qquad (2-18)$$

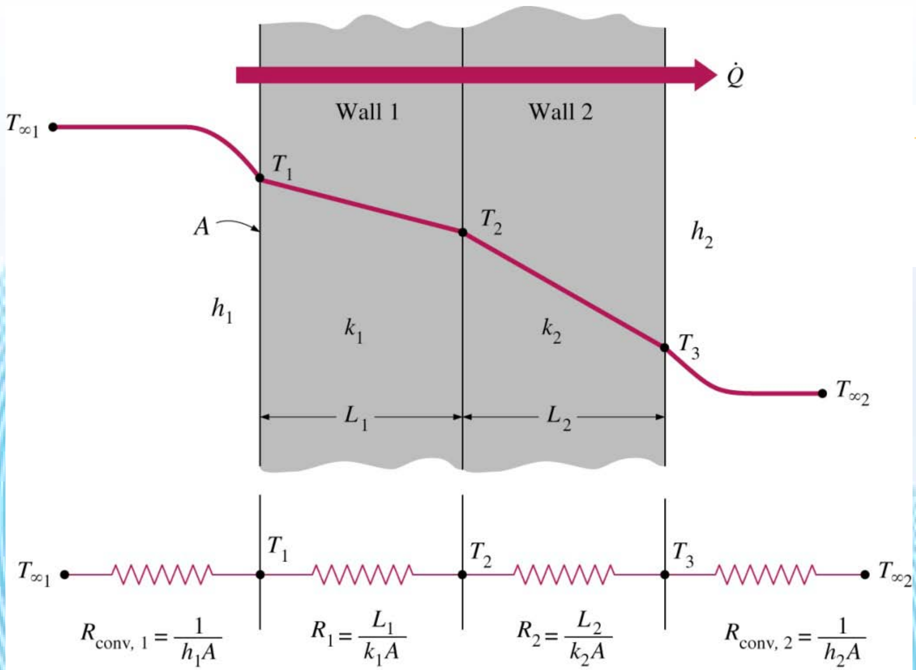
U: 열관류율(*total heat transfer coefficient*)[W/K] or [$W/℃$]

$$UA = \frac{1}{R_{tt}} \qquad (2-19)$$

$$\dot{Q} = \frac{T_{\infty 1} - T_1}{R_{cv1}} = \frac{T_{\infty 1} - T_1}{(1/h_{cv1}A)} \qquad (2-20)$$

■ 평면벽에서의 정상 열전도

▣ 다층 평면벽



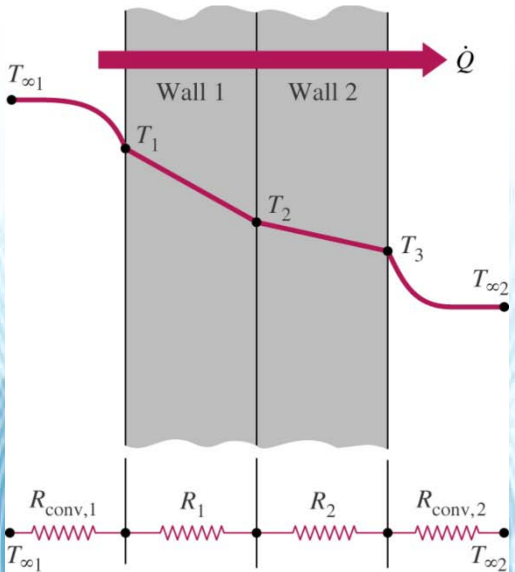
$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{tt}} \qquad (2-15)$$

$$\begin{aligned} R_{tt} &= R_{cv1} + R_{cd1} + R_{cd2} + R_{cv2} \\ &= \frac{1}{h_{cv1} A} + \frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{1}{h_{cv2} A} \end{aligned} \qquad (2-22)$$

$$\dot{Q} = \frac{T_i - T_j}{R_{tt,\, i-j}} \qquad (2-23)$$

■ 평면벽에서의 정상 열전도

▣ 열저항 회로



To find T_1: $\dot{Q} = \dfrac{T_{\infty 1} - T_1}{R_{\text{conv},1}}$

To find T_2: $\dot{Q} = \dfrac{T_{\infty 1} - T_2}{R_{\text{conv},1} + R_1}$

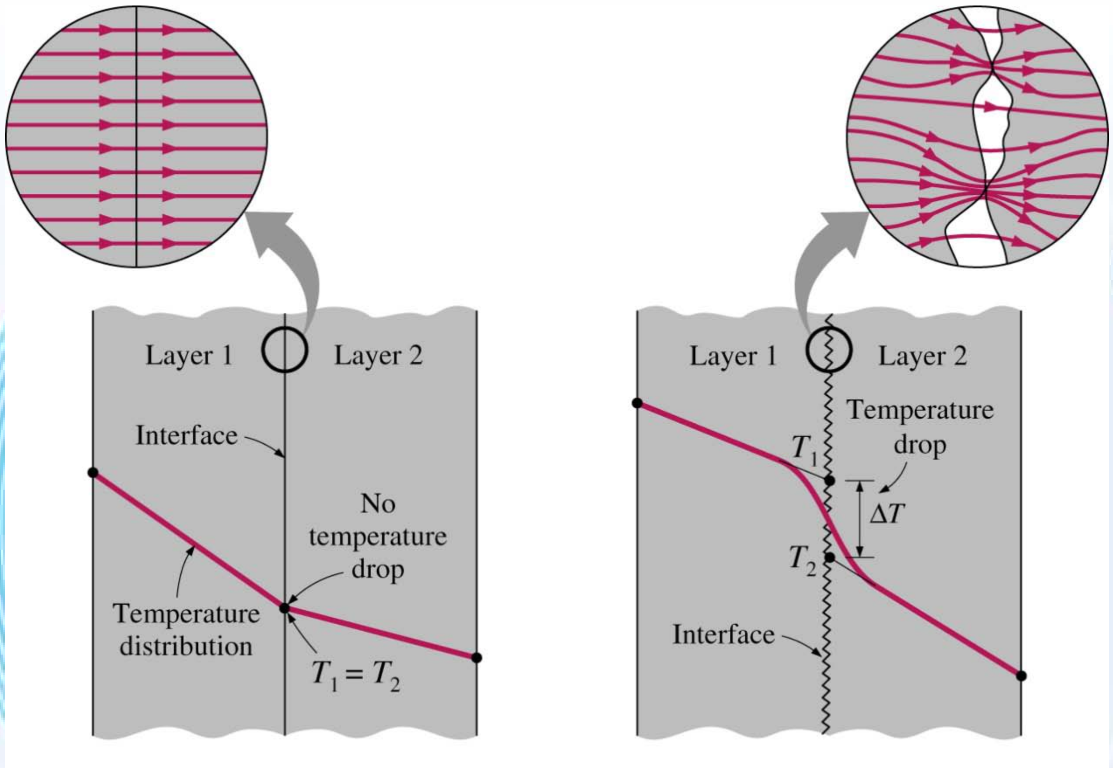
To find T_3: $\dot{Q} = \dfrac{T_3 - T_{\infty 2}}{R_{\text{conv},2}}$

$$\dot{Q} = \frac{T_i - T_j}{R_{tt,\,i-j}} \qquad (2-23)$$

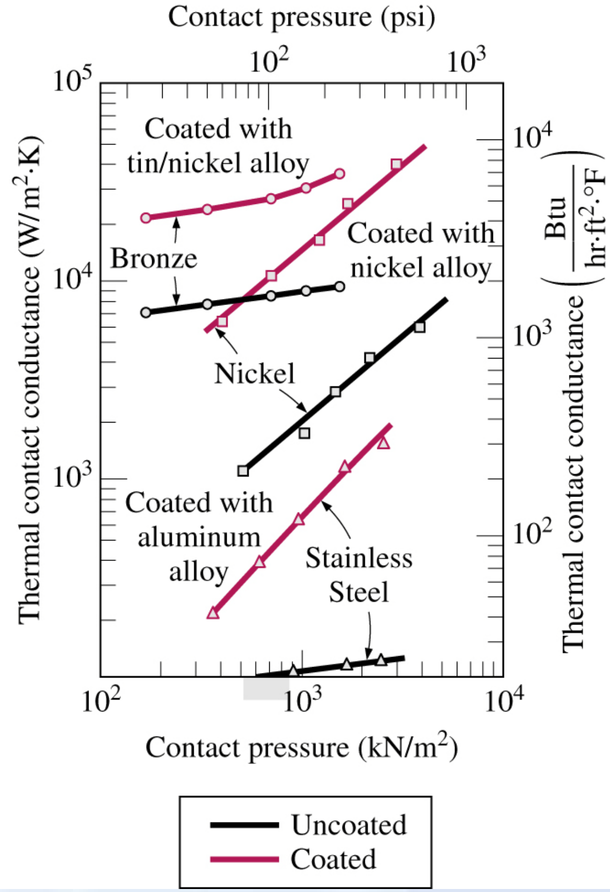
$$\dot{Q} = \frac{T_{\infty 1} - T_2}{R_{cv1} + R_{cd1}} = \frac{T_{\infty 1} - T_2}{(1/h_{cv}A) + (L_1/k_1 A)} \qquad (2-24)$$

< 예제 1 및 예제 2 >

■ 열접촉 저항(Thermal contact resistance)



(*a*) Ideal (perfect) thermal contact (*b*) Actual (imperfect) thermal contact



■ 열접촉 저항(Thermal contact resistance)

$$\dot{Q} = \dot{Q}_{contact} + \dot{Q}_{gap} \qquad (2-25)$$

$$\dot{Q} = h_c A \Delta T_{csf} \qquad (2-26)$$

h_c: 열접촉 컨덕턴스($thermal\ contact\ conductance$)$[W/m^2℃]$
ΔT_{csf}: 접촉면에서의 유효온도차$[℃]$

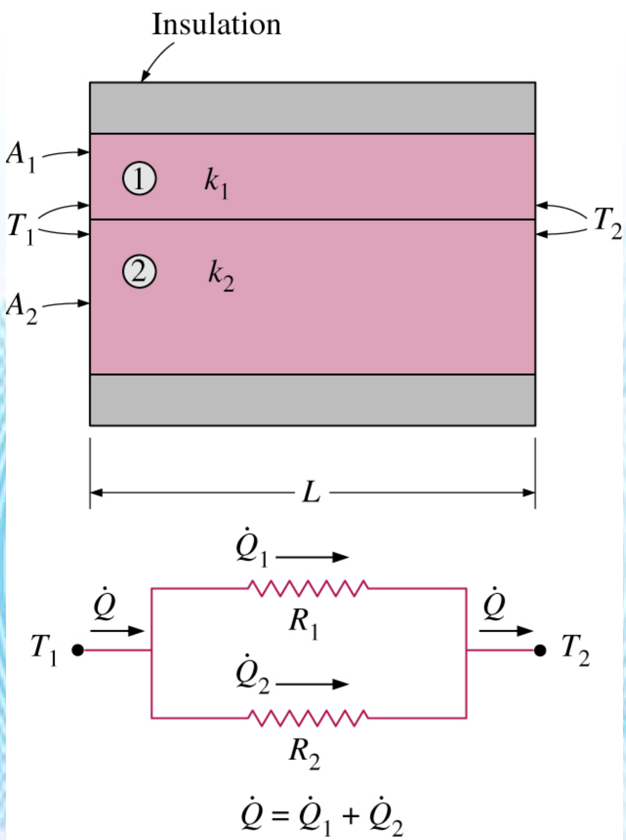
$$h_c = \frac{\dot{Q}/A}{\Delta T_{csf}} \qquad (2-27)$$

$$R_c = \frac{1}{h_c} = \frac{\Delta T_{csf}}{(\dot{Q}/A)} \qquad (2-28)$$

R_c: 열접촉저항($thermal\ contact\ resistance$)$[m^2℃/W]$

■ 열저항 회로의 일반화

o 열저항이 병렬일 경우

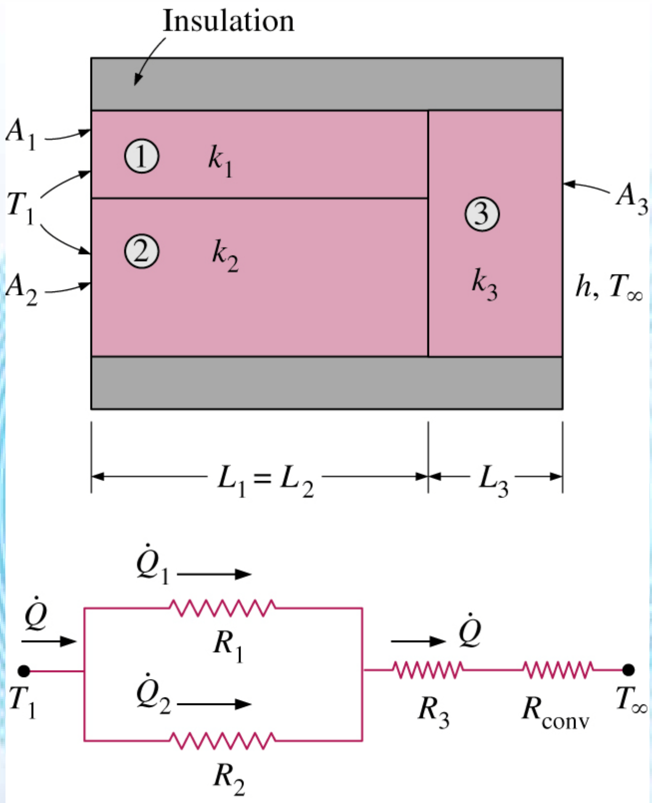


$$\begin{aligned}\dot{Q} &= \dot{Q}_1 + \dot{Q}_2 \\ &= \frac{T_1 - T_2}{R_1} + \frac{T_1 - T_2}{R_2} \\ &= (T_1 - T_2)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\end{aligned} \qquad (2-29)$$

$$\dot{Q} = \frac{T_1 - T_2}{R_{tt}} \qquad (2-30)$$

$$\frac{1}{R_{tt}} = \frac{1}{R_1} + \frac{1}{R_2} \quad \Rightarrow \quad R_{tt} = \frac{R_1 R_2}{R_1 + R_2} \qquad (2-31)$$

■ 열저항 회로의 일반화



o 열저항이 복합배열일 경우

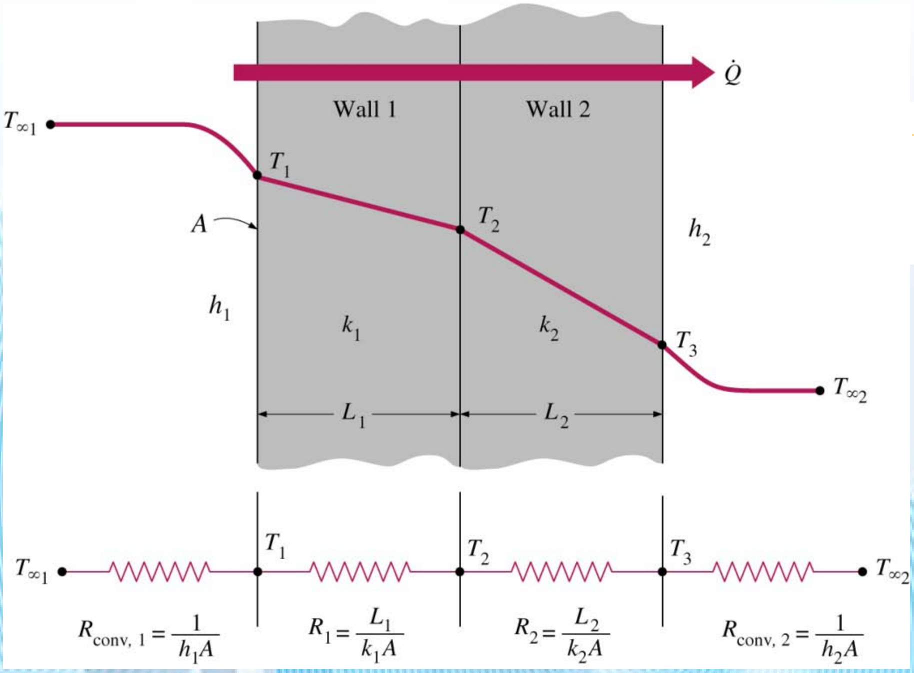
$$\dot{Q} = \frac{T_1 - T_\infty}{R_{tt}} \qquad (2-32)$$

$$\begin{aligned} R_{tt} &= R_{12} + R_3 + R_{cv} \\ &= \frac{R_1 R_2}{R_1 + R_2} + R_3 + R_{cv} \end{aligned} \qquad (2-33)$$

$$R_1 = \frac{L_1}{k_1 A_1},\ R_2 = \frac{L_2}{k_2 A_2},\ R_3 = \frac{L_3}{k_3 A_3},\ R_{cv} = \frac{1}{h_{cv} A_3} \qquad (2-34)$$

▣ 종합요약

◈ 1차원 열전달(벽)



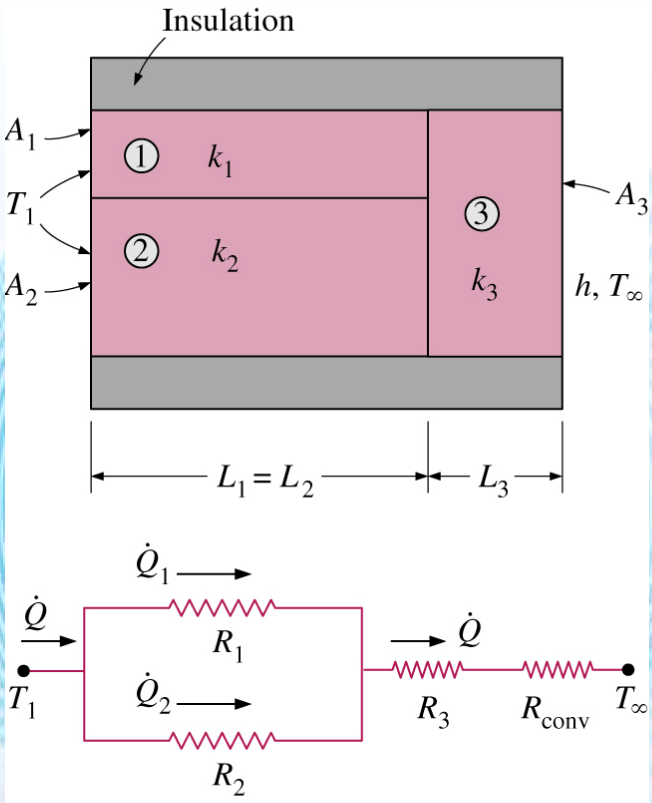
$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{tt}} \qquad (2-15)$$

$$R_{tt} = R_{cv1} + R_{cd1} + R_{cd2} + R_{cv2}$$
$$= \frac{1}{h_{cv1}A} + \frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{1}{h_{cv2}A} \qquad (2-22)$$

$$\dot{Q} = \frac{T_i - T_j}{R_{tt,\,i-j}} \qquad (2-23)$$

▣ 종합요약

◈ 1차원 열전달(벽)



$$\dot{Q} = \frac{T_1 - T_\infty}{R_{tt}} \qquad (2-32)$$

$$R_{tt} = R_{12} + R_3 + R_{cv} = \frac{R_1 R_2}{R_1 + R_2} + R_3 + R_{cv} \qquad (2-33)$$

$$R_1 = \frac{L_1}{k_1 A_1},\ R_2 = \frac{L_2}{k_2 A_2},\ R_3 = \frac{L_3}{k_3 A_3},\ R_{cv} = \frac{1}{h_{cv} A_3} \qquad (2-34)$$

◈ 다음강의(4주차)

- 원형관 및 구에서의 정상 열전도
- 임계반지름
- fin 방정식

감사합니다.