열유체공학실험

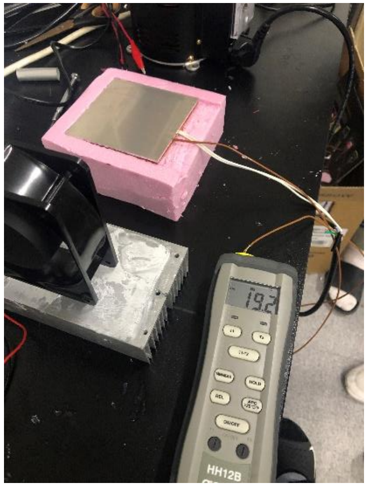
전도/ 대류 실험

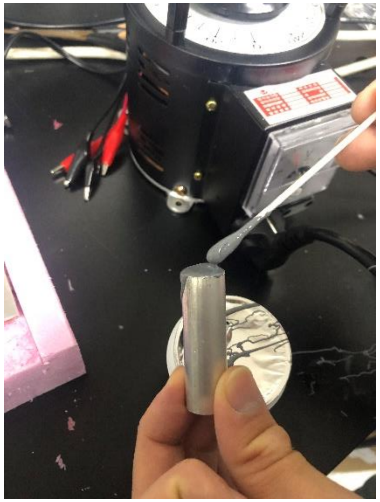
실험 개요

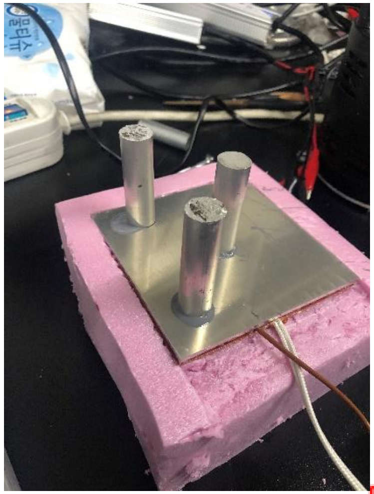
실험목적

- 이 실험의 목적은 가열된 플레이트 위에 설치된 원형 핀과 주변 공기와의 열전달에 관한 실험으로 핀의 갯수와 배치에 따른 열전도 및 대류 열전달 성능차이를 확인하고 이를 열저항 컨셉에 적용하는것을 목적으로 한다.

- 아래 그림과 같은 100(W) x 100(L) x 5(H) mm 크기의 알루미늄 판이 정상상태에 있다. 판의 바닥면은 q = 90W 용량의 패치히터를 이용하여 가열할수 있고 가열된 열은 판의 상부에서 팬을 이용하여 식혀진다. 공기의 온도와 속도는 TSI probemeter (OMEGA HHF81) 를 이용하여 측정할수 있다. 판 및 핀의 온도는 k-Type 열전대 (theromocouple)을 이용하여 측정할 예정이다.
- 총 세가지 다른 종류의 실험을 진행한다:
- 1) 알루미늄판
- 2) 알루미늄판에 한개의 원형 핀
- 3) 알루미늄판에 다섯개의 원형 핀
- 원형 핀은 모두 판과 같은 알루미늄 재질이며 판위에 원형핀을 설치시 접촉저항을 최소화 하기 위해 Thermal paste(OMEGA THERM 201)을 이용하여 접착한다.

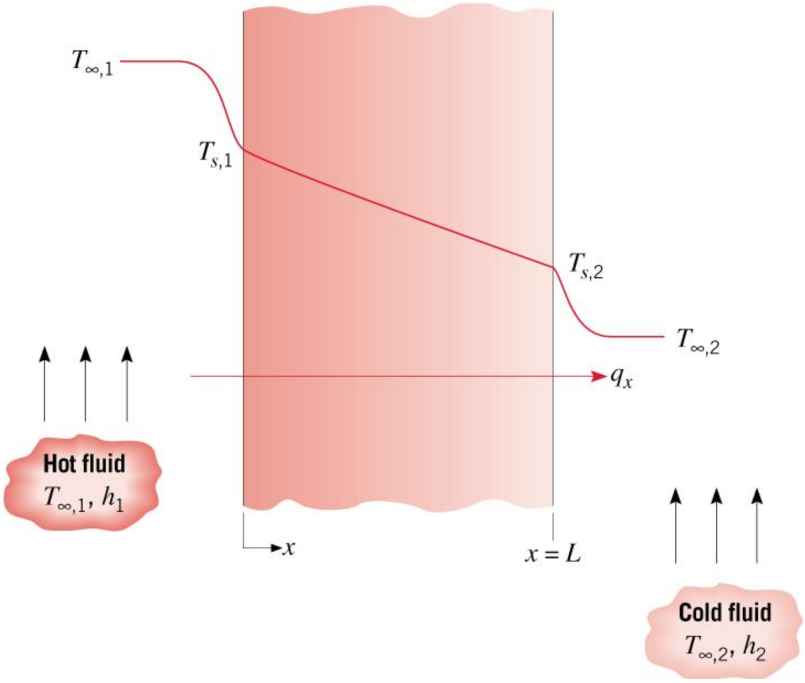






실험 이론

- Consider a plane wall between two fluids of different temperature:



- Heat Equation:

$$\frac{d}{dx}\left(k\frac{dT}{dx}\right) = 0$$

- Implications:

Heat flux $\left(q''_x\right)$ is independent of x.

Heat rate $\left(q_x\right)$ is independent of x.

- Boundary Conditions: $T(0) = T_{s,1}, \quad T(L) = T_{s,2}$

- Temperature Distribution for Constant k:

$$T(x) = T_{s,1} + \left(T_{s,2} - T_{s,1}\right)\frac{x}{L}$$

Plane Wall (cont.)

- Heat Flux and Heat Rate:

$$q''_x = -k\frac{dT}{dx} = \frac{k}{L}\left(T_{s,1} - T_{s,2}\right) \quad (3.5)$$

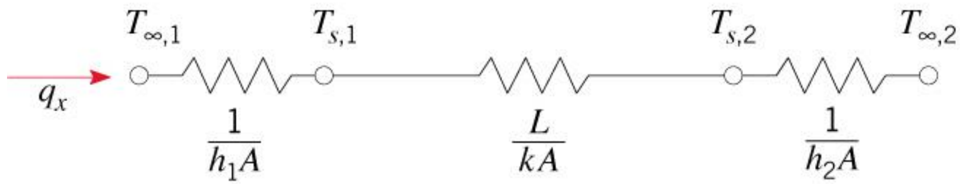
$$q_x = -kA\frac{dT}{dx} = \frac{kA}{L}\left(T_{s,1} - T_{s,2}\right) \quad (3.4)$$

- Thermal Resistances $\left(R_t = \frac{\Delta T}{q}\right)$ and Thermal Circuits:

Conduction in a plane wall: $$R_{t,\text{cond}} = \frac{L}{kA} \quad (3.6)$$

Convection: $$R_{t,\text{conv}} = \frac{1}{hA} \quad (3.9)$$

Thermal circuit for plane wall with adjoining fluids:



$$R_{\text{tot}} = \frac{1}{h_1 A} + \frac{L}{kA} + \frac{1}{h_2 A} \quad (3.12)$$

$$q_x = \frac{T_{\infty,1} - T_{\infty,2}}{R_{\text{tot}}} \quad (3.11)$$

- Thermal Resistance for Unit Surface Area:

$$R''_{t,\text{cond}} = \frac{L}{k} \qquad R''_{t,\text{conv}} = \frac{1}{h}$$

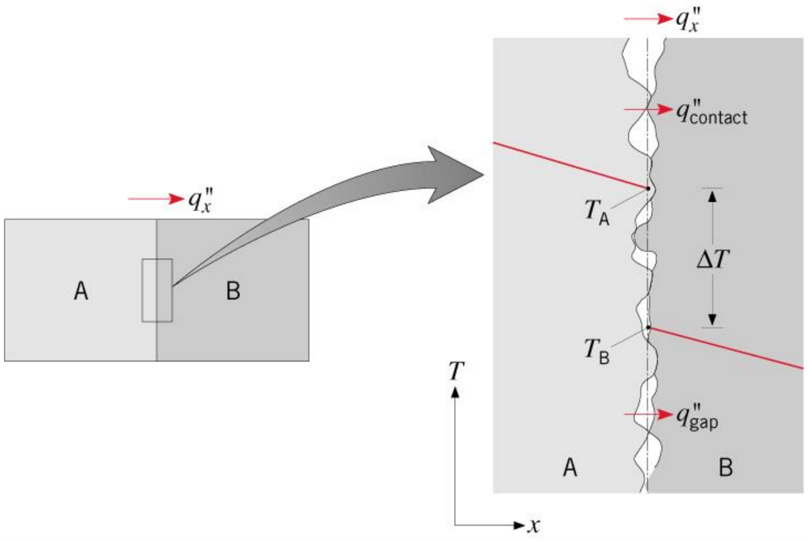
Units: $R_t \leftrightarrow \text{K/W} \qquad R''_t \leftrightarrow \text{m}^2 \cdot \text{K/W}$

- Radiation Resistance:

$$R_{t,\text{rad}} = \frac{1}{h_r A} \qquad R''_{t,\text{rad}} = \frac{1}{h_r}$$

$$h_r = \varepsilon\sigma\left(T_s + T_{\text{sur}}\right)\left(T_s^2 + T_{\text{sur}}^2\right) \qquad (1.9)$$

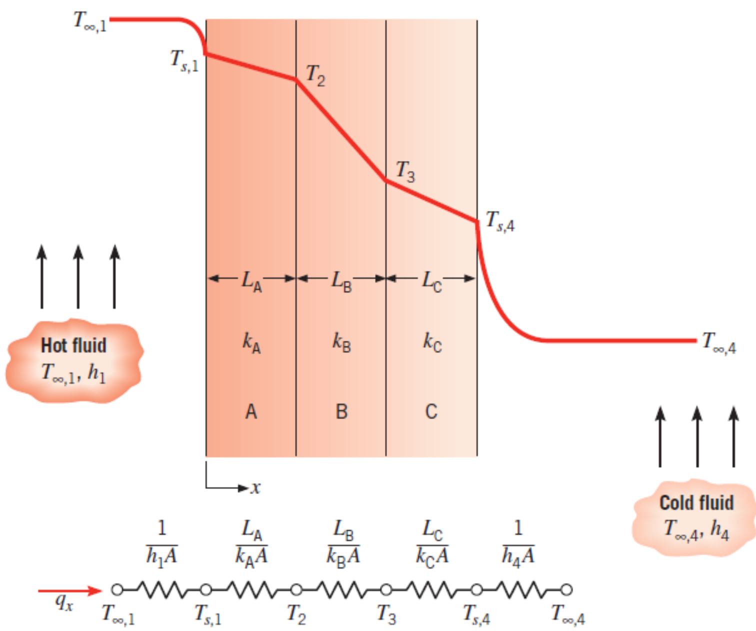
- Contact Resistance:



$$R''_{t,c} = \frac{T_A - T_B}{q''_x} \qquad R_{t,c} = \frac{R''_{t,c}}{A_c}$$

Values depend on: Materials A and B, surface finishes, interstitial conditions, and contact pressure (Tables 3.1 and 3.2)

- Composite Wall with Negligible Contact Resistance:



$$q_x = \frac{T_{\infty,1} - T_{\infty,4}}{\sum R_t} \qquad (3.14)$$

For the temperature distribution shown, $k_A > k_B < k_C$.

$$\sum R_t = R_{tot} = \frac{1}{A}\left[\frac{1}{h_1} + \frac{L_A}{k_A} + \frac{L_B}{k_B} + \frac{L_C}{k_C} + \frac{1}{h_4}\right] = \frac{R''_{tot}}{A}$$

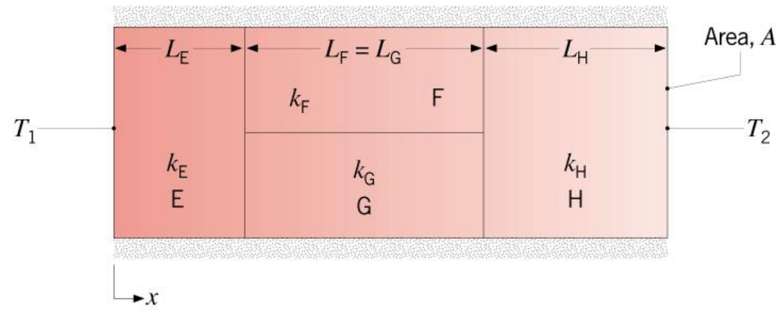
- Overall Heat Transfer Coefficient (U) :

A modified form of Newton's law of cooling to encompass multiple resistances to heat transfer.

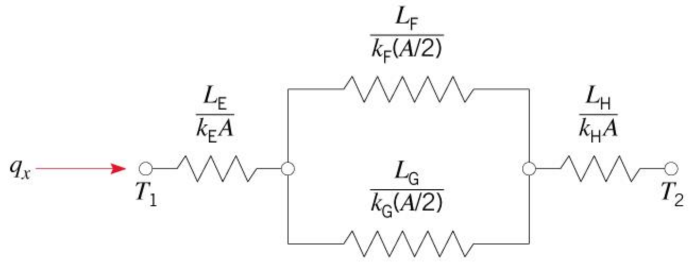
$$q_x = UA\Delta T_{overall} \qquad (3.17)$$

$$R_{tot} = \frac{1}{UA} \qquad (3.19)$$

- Series – Parallel Composite Wall:

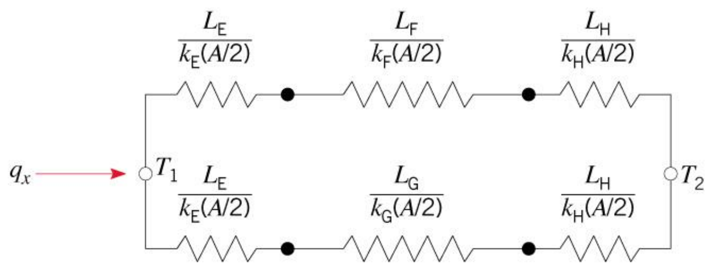


Assuming isothermal surfaces perpendicular to *x*-direction.



(*a*)

Assuming adiabatic surfaces parallel to *x*-direction.



(*b*)

- Note departure from one-dimensional conditions for $k_F \neq k_G$.

- Circuits based on assumption of isothermal surfaces normal to *x* direction or adiabatic surfaces parallel to *x* direction provide approximations for q_x .

The Fin Equation

- Assuming one-dimensional, steady-state conduction in an extended surface of constant conductivity (k) and uniform cross-sectional area (A_c), with negligible generation $(\dot{q}=0)$ and radiation $(q''_{\text{rad}}=0)$, the *fin equation* is of the form:

$$\frac{d^2T}{dx^2}-\frac{hP}{kA_c}(T-T_\infty)=0 \qquad (3.67)$$

or, with $m^2 \equiv (hP/kA_c)$ and the reduced temperature $\theta \equiv T-T_\infty$,

$$\frac{d^2\theta}{dx^2}-m^2\theta=0 \qquad (3.69)$$

How is the fin equation derived?

Base ($x = 0$) condition

$$\theta(0) = T_b - T_\infty \equiv \theta_b$$

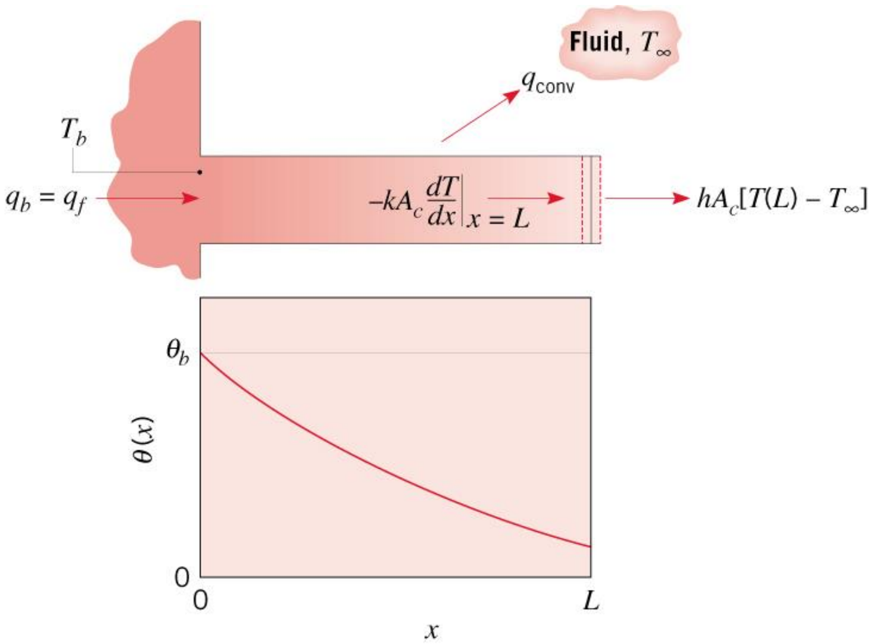
Tip ($x = L$) conditions

A. Convection: $-k d\theta / dx|_{x=L} = h\theta(L)$

B. Adiabatic: $d\theta / dx|_{x=L} = 0$

C. Fixed temperature: $\theta(L) = \theta_L$

D. Infinite fin ($mL > 2.65$): $\theta(L) = 0$



- Fin Heat Rate:

$$q_f = -kA_c \frac{d\theta}{dx}|_{x=0} = \int_{A_f} h\theta(x) dA_s$$

- Solutions (Table 3.4):

Fin Performance Parameters

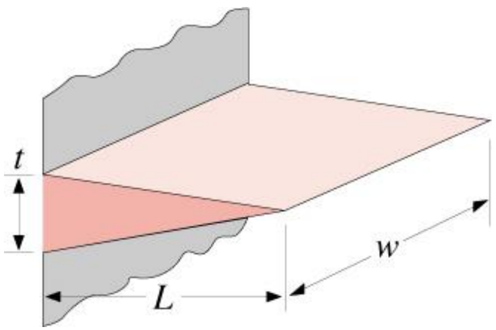
- Fin Efficiency:

$$\eta_f \equiv \frac{q_f}{q_{f,\,\max}} = \frac{q_f}{hA_f\theta_b} \qquad \text{where } 0 \le \eta_f \le 1 \qquad (3.91)$$

How is the efficiency affected by the thermal conductivity of the fin?

Expressions for η_f are provided in Table 3.5 for common geometries.

Consider a triangular fin:



$$A_f = 2w\left[L^2 + (t/2)^2\right]^{1/2}$$

$$A_p = (t/2)L$$

$$\eta_f = \frac{1}{mL}\frac{I_1(2mL)}{I_0(2mL)}$$

- Fin Effectiveness:

$$\varepsilon_f \equiv \frac{q_f}{hA_{c,b}\theta_b} \qquad (3.86)$$

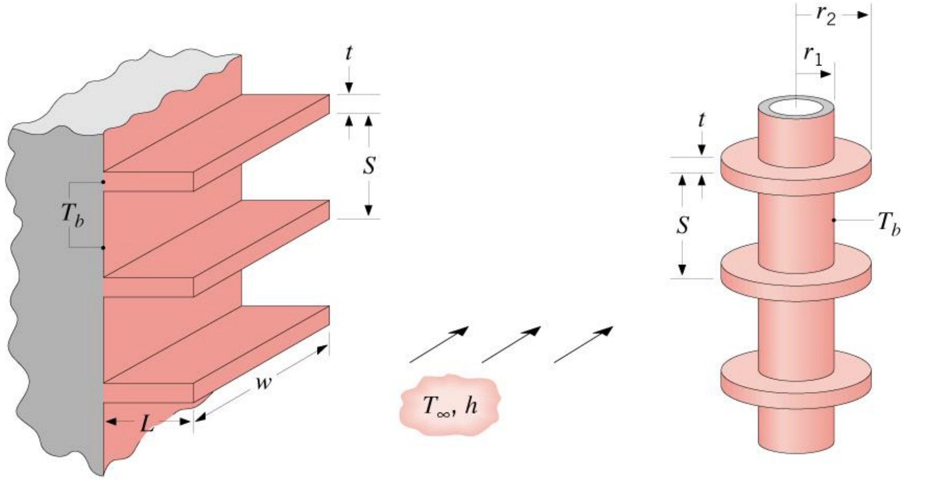
$$\varepsilon_f \uparrow \text{ with } \downarrow h, \uparrow k \text{ and } \downarrow A_c / P$$

- Fin Resistance:

$$R_{t,f} \equiv \frac{\theta_b}{q_f} = \frac{1}{hA_f\eta_f} \qquad (3.97)$$

Fin Arrays

- Representative arrays of
  (a) rectangular and
  (b) annular fins.



(a) (b)

– Total surface area:

$$A_t = NA_f + A_b \quad (3.104)$$

Number of fins — Area of exposed base (*prime* surface)

– Total heat rate:

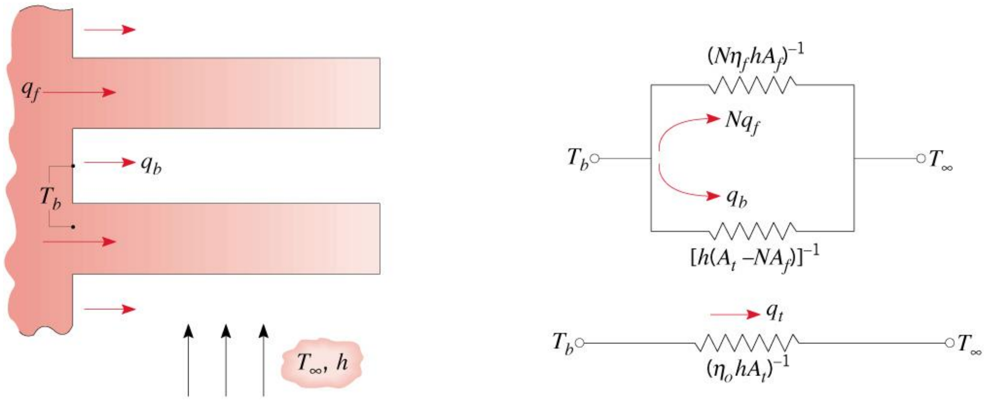
$$q_t = N\eta_f hA_f\theta_b + hA_b\theta_b \equiv \eta_o hA_t\theta_b = \frac{\theta_b}{R_{t,o}} \quad (3.105)$$

– Overall surface efficiency and resistance:

$$\eta_o = 1 - \frac{NA_f}{A_t}\left(1-\eta_f\right) \quad (3.107)$$

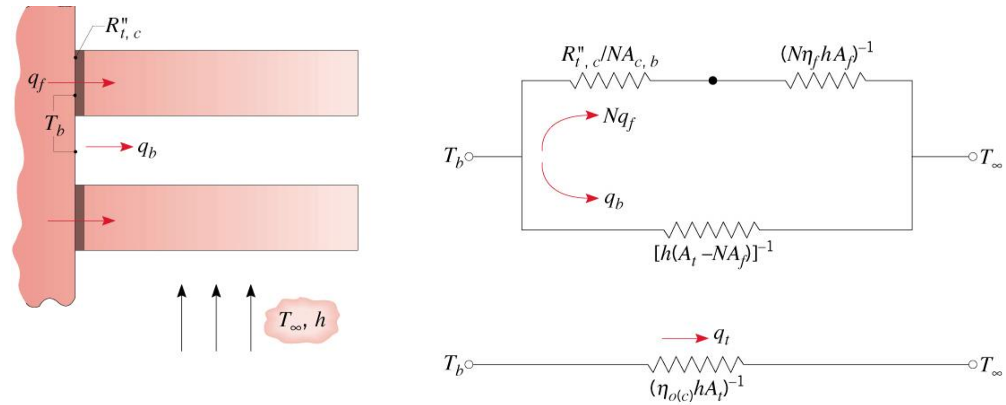
$$R_{t,o} = \frac{\theta_b}{q_t} = \frac{1}{\eta_o hA_t} \quad (3.108)$$

- Equivalent Thermal Circuit:



(a)

- Effect of Surface Contact Resistance:



(b)

$$q_t = \eta_{o(c)} h A_t \theta_b = \frac{\theta_b}{R_{t,o(c)}}$$

$$\eta_{o(c)} = 1 - \frac{NA_f}{A_t}\left(1 - \frac{\eta_f}{C_1}\right) \quad (3.110a)$$

$$C_1 = 1 + \eta_f h A_f \left(R''_{t,c} / A_{c,b}\right) \quad (3.110b)$$

$$R_{t,o(c)} = \frac{1}{\eta_{o(c)} h A_t} \quad (3.109)$$