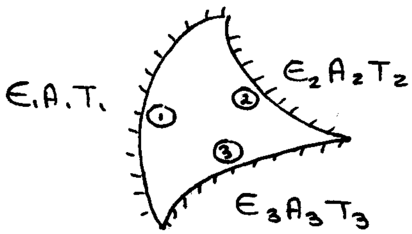
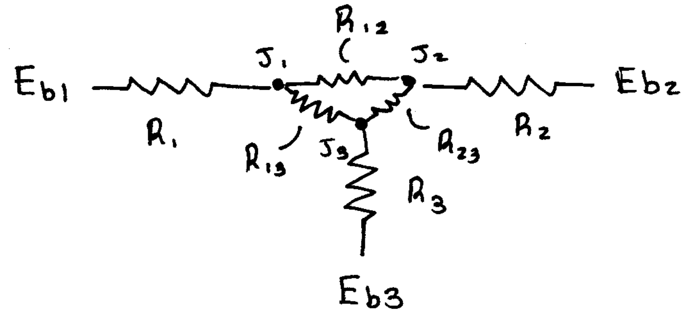
Nov. 21/17
THERMAL

Radiation heat transfer: Three surface enclosures





$$R_1 = \frac{1-\epsilon_1}{A_1\epsilon_1} \qquad R_{12} = \frac{1}{A_1 F_{12}}$$

$$R_2 = \frac{1-\epsilon_2}{A_1\epsilon_2} \qquad R_{13} = \frac{1}{A_1 F_{13}}$$

$$R_3 = \frac{1-\epsilon_3}{A_3\epsilon_3} \qquad R_{23} = \frac{1}{A_2 F_{23}}$$

@ Node 1:

$$\frac{E_{b1} - J_1}{R_1} + \frac{J_2 - J_1}{R_{12}} + \frac{J_3 - J_1}{R_{13}} = 0$$

@ Node 2:

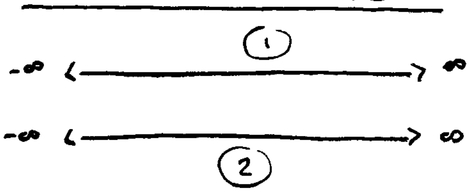
$$\frac{E_{b2} - J_2}{R_2} + \frac{J_2 - J_1}{R_{12}} + \frac{J_3 - J_2}{R_{23}} = 0$$

@ Node 3:

$$\frac{E_{b3} - J_3}{R_3} + \frac{J_3 - J_2}{R_{23}} + \frac{J_3 - J_1}{R_{13}} = 0$$

↳ Homework: Example 13.8

Radiation shield:

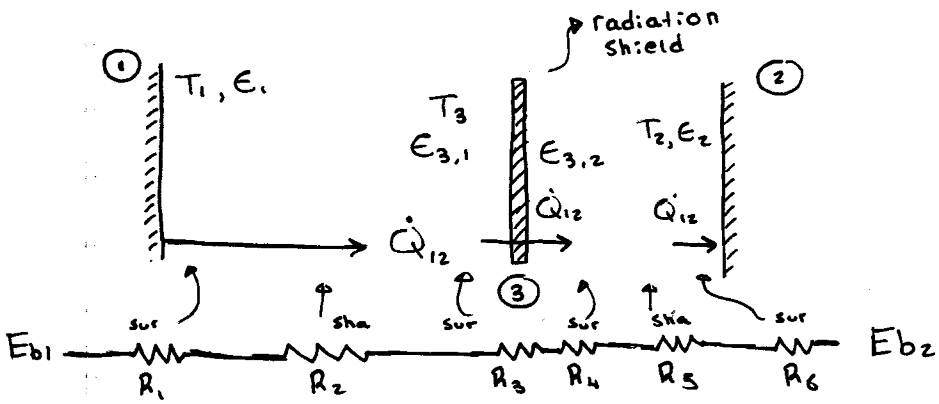


$A_1 = A_2 = A$

$F_{12} = F_{21} = 1$

$$\dot{Q}_{12} = \frac{A\sigma(T_1^4 - T_2^4)}{\left[\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right]}$$

highly reflective surface: high ρ, but low ϵ



$$R_1 = \frac{1-\epsilon_1}{A_1\epsilon_1} \qquad R_2 = \frac{1}{A_1 F_{13}} \qquad R_3 = \frac{1-\epsilon_{3,1}}{A_3\epsilon_{3,1}}$$

$$R_4 = \frac{1-\epsilon_{3/2}}{A_3\epsilon_{3/2}} \qquad R_5 = \frac{1}{A_2\epsilon_2} \qquad R_6 = \frac{1-\epsilon_2}{A_2\epsilon_2}$$

$F_{13} = F_{32} = 1$, $A_1 = A_2 = A_3 = A$

$$\dot{Q}_{12,\text{ one shield}} = \frac{A\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right) + \left(\frac{1}{\epsilon_{3,1}} + \frac{1}{\epsilon_{3,2}} - 1\right)}$$

$$\left[\dot{Q}_{12,\text{ one shield}} = \frac{E_{b1} - E_{b2}}{R_{TOTAL}}\right]$$

$$\dot{Q}_{12,\text{ N Shields}} = \frac{A\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right) + \left(\frac{1}{\epsilon_{3,1}} + \frac{1}{\epsilon_{3,2}} - 1\right) + \cdots + \left(\frac{1}{\epsilon_{N,1}} + \frac{1}{\epsilon_{N,2}} - 1\right)}$$

$$\dot{Q}_{12,\text{ N shields}} = \frac{A\sigma(T_1^4 - T_2^4)}{(N+1)\left(\frac{1}{\epsilon} + \frac{1}{\epsilon} - 1\right)} = \frac{1}{N+1}\dot{Q}_{12,\text{ no shield}}$$

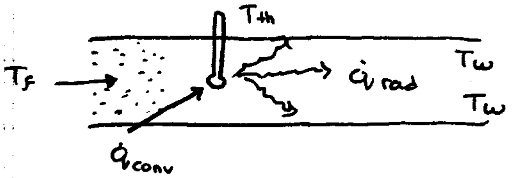
For 1 shield : $\dot{Q}_{12,\text{ 1 shield}} = \frac{1}{1+1}\dot{Q}_{12,\text{ no shield}}$

$= 50\%\ \dot{Q}_{12,\text{ no shield}}$

For 19 shield : $\dot{Q}_{12,\text{ 19 shield}} = \frac{1}{19+1}\dot{Q}_{12,\text{ no shield}}$

$= 5\%\ \dot{Q}_{12,\text{ no shield}}$

Radiation effect on temp. measurement :



At equilibrium :

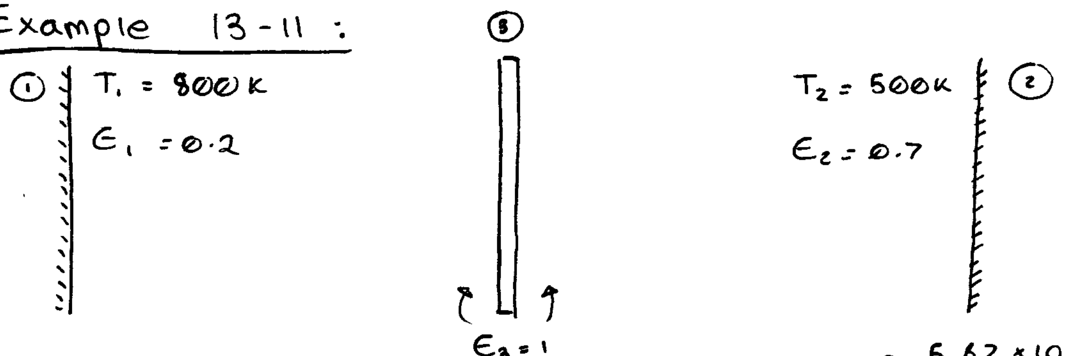
$$\dot{q}_{conv,\ to\ sensor} = \dot{q}_{rad,\ from\ wall}$$

$$h(T_f - T_{th}) = \epsilon\sigma(T_{th}^4 - T_w^4)$$

$$\therefore T_f = T_{th} + \boxed{\frac{\epsilon\sigma(T_{th}^4 - T_w^4)}{h}}$$

→ radiation correction factor

Example 13-11 :



$$\dot{q}_{12,\ no\ shield} = \frac{\dot{Q}_{12}}{A}_{,\ no\ shield} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

(σ = $5.67 \times 10^{-8}\ W/m^2 \cdot K^4$)

$$= \frac{(5.67 \times 10^{-8})(800^4 - 500^4)}{\left(\frac{1}{0.2} + \frac{1}{0.7} - 1\right)}$$

$$= 3624\ W/m^2$$

$$\dot{q}_{12,\ 1\ shield} = \frac{\dot{Q}_{12}}{A}_{,\ 1\ shield} = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right) + \left(\frac{1}{\epsilon_{31}} + \frac{1}{\epsilon_{32}} - 1\right)}$$

$$= 806\ W/m^2$$

$$\%\ \text{reduction} = \frac{3624 - 806}{3624} \cong 75\%$$

Example 13-12:

$$T_f = T_{th} + \frac{\epsilon \sigma (T_{th}^4 - T_w^4)}{h}$$

$$= 650 + \frac{0.6(5.67 \times 10^{-8})[650^4 - 400^4]}{80}$$

$$T_f = 715 \text{ K}$$

Nov. 23/17
THERMAL

Chapter 6 : Fundamentals of Convection

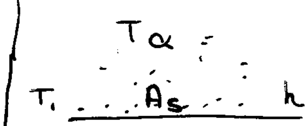
Obj's : 1) Understand the physical mechanism of convection and its classification
2) Learn some important dimensionless group

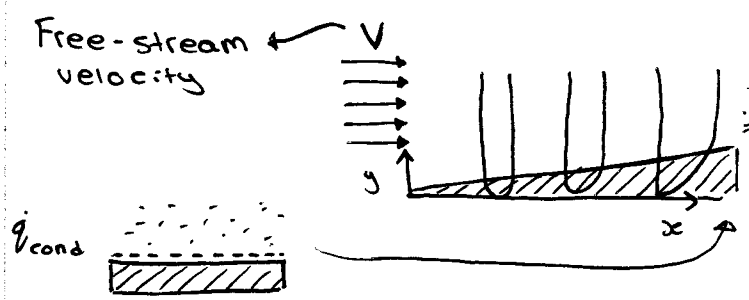
Factors:

1) Fluid Properties μ, k, ρ, c_p
2) Fluid velocity
3) Geometry and roughness
4) Flow type
5) T and P

Newton's Law of Cooling

$\dot{Q}_{conv} = hA_s(T_s - T_\infty)$





no-slip condition

boundary layer
1)
2) vel. P
3) drag

$\dot{q}_{conv} = \dot{q}_{cond} = -k_{fluid}\left(\frac{\delta T}{\delta y}\right)\Big|_{y=0}$ → temp. gradient

$\dot{q}_{conv.} = h(T_s - T_\infty)$ | $h = \dfrac{-k_{fluid}\left(\frac{\delta T}{\delta y}\right)\Big|_{y=0}}{T_s - T_\infty}$

Nusselt number:

(where $\dot{q}_{conv.} = h\Delta T$; $\dot{q}_{cond} = k\frac{\Delta T}{L}$)

$$\frac{\dot{q}_{conv.}}{\dot{q}_{cond.}} = \frac{h\Delta T}{k\,\Delta T/L} \rightarrow \frac{hL}{k} = Nu$$

Classification of Fluid Flow

1. viscous vs. non-viscous
2. Internal vs. external
3. Compressible vs. Incompressible

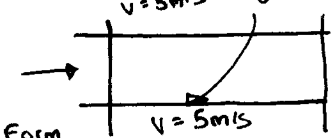
$Ma = \frac{V}{c}$ — V → speed of obj; c → speed of sound

When $Ma < 0.3$

Room temp. air

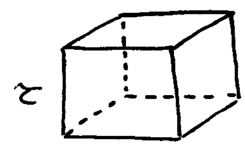
$V = 100$ m/s

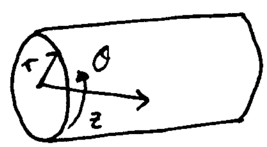
4. Laminar vs. turbulent Flow
5. Steady vs. unsteady



One-two and three-dimensional Flow

1) Cartesian coordinate
2) Cylindrical coordinate





3) Spherical coordinate

Boundary layer thickness : δ

Thermal boundary layer :

δ → vol. layer thickness

δ_t → thermal b. layer thickness

↳ $T - T_s = 0.99(T_\infty - T_s)$

Newton's Law of Viscosity

$\tau \propto \frac{\delta u}{\delta y}$

$\tau = \mu \frac{\delta u}{\delta y}$

$\tau_w = \mu \frac{\delta u}{\delta y}\Big|_{y=0}$

Kinematic viscosity

$\nu = \mu / \rho$

$\tau_w = C_f \frac{\rho U^2}{2}$

↳ Friction Factor (average)

Prandtl number: $Pr = \frac{\nu}{\alpha} = \frac{\mu c_p}{k}$

$\nu \rightarrow \mu/\rho$

$\alpha \rightarrow k/\rho c_p$

Reynold's number: $Re = \frac{\text{Inertia Force}}{\text{Viscous Force}}$

IF $R < 2000$, THEN laminar flow
IF $R > 10000$, THEN turbulent

(Internal flow)

$Re < 5 \times 10^5$ – laminar
$Re > 5 \times 10^5$ – turbulent

Film temp = $T\alpha + T_s$

$\dot{q} = \dot{q}_{cond} = -k_{fluid} \frac{\delta T}{\delta y}\Big|_{y=0}$

$h = \frac{-k_{fluid} \left(\frac{\delta T}{\delta y}\right)_{y=0}}{T_s - T\alpha}$

$\dot{q} = \dot{q}_{conv} = h(T_s - T\alpha)$