Chap 9. 자연대류 (Natural convection)

9-1. 서론, 9-2. 기본개념, 9-3. 평판, 9-4. 원통, 9-5. 구
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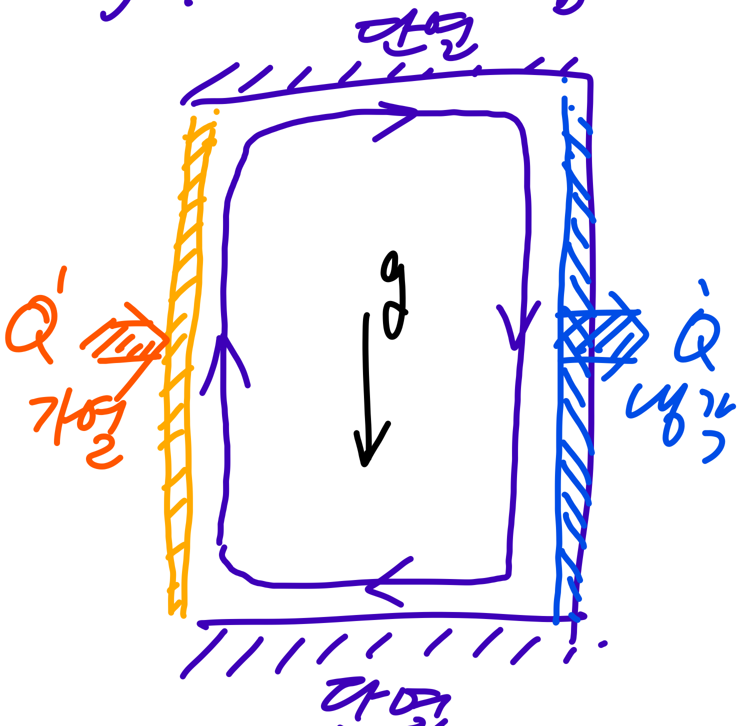
§9-1. 서론

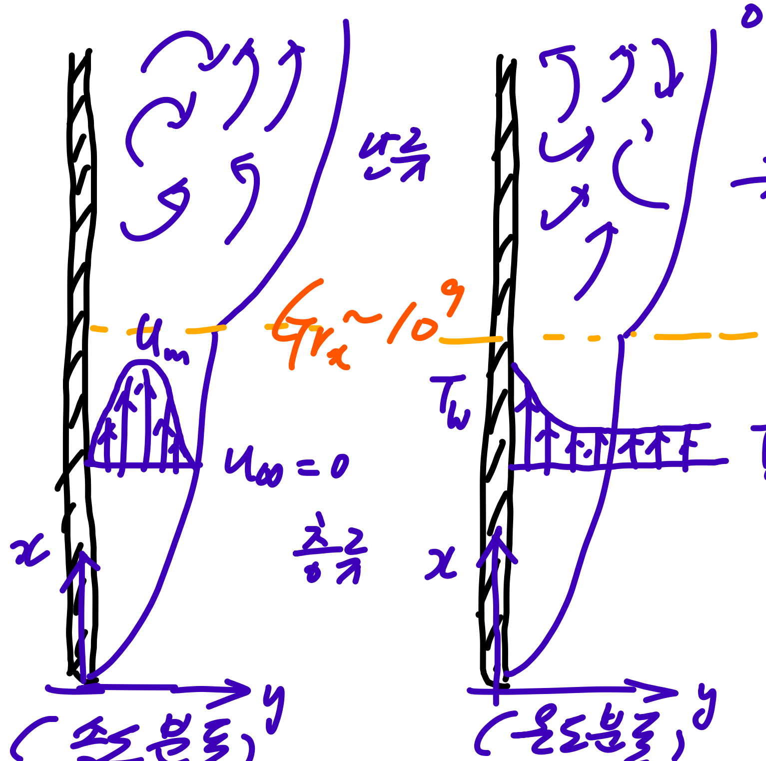
∘ 자연대류 현상 : 유체를 강제로 유동시키지 않아도 대류현상 발생

∘ 자연대류 발생순서

(고체 → 유체) 열전도 발생 (Triggering) ⟹ (유체의) 온도구배 ⟹ 밀도구배 ⟹ 부력발생 ⟹ 대류유동 열전달

§9-2. 기본개념





강제대류의 속도분포와 상이　　강제대류의 온도분포와 유사

∘ 지배방정식(운동량) 차이 for 자연대류

$$\rightarrow u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \underbrace{g\beta(T_w - T_\infty)}_{\text{부력항}} + \nu\frac{\partial^2 u}{\partial y^2}$$

- β : 체적열팽창계수

$$\Longrightarrow \beta = \frac{1}{T_f}$$

T_f : 유체온도

(1) Grashof & Rayleigh 수 ; 자연대류의 Nusselt number 함수

° 강제대류 vs 자연대류의 Nu number

$$Nu = f(Re, Pr) \iff Nu = f(Gr, Pr)$$

° Grashof number (Gr_x) c.f. $Re_x \equiv \frac{관성력}{점성력}$ for 강제대류

$$- Gr_x \equiv \frac{부력}{점성력} = \frac{g\beta x^3 (T_w - T_\infty)}{\nu^2} \quad \cdots (9\text{-}4)$$

· $Gr_x < 10^9$: 층류, $Gr_x \geq 10^9$: 난류

° Rayleigh 수 (Ra_x), $Ra_x \equiv Gr_x \cdot Pr = \frac{g\beta x^3 (T_w - T_\infty)}{\nu \cdot \alpha}$ (9-5)

§9-3. plate

(1) 수직평판

· $T_w = const.$ → $T_f = (T_w + T_\infty)/2$ 물성 ⟹ $\dot{Q} = h_m \cdot A \cdot (T_f - T_\infty)$

· $q_w'' = const.$ → $T_{w,L/2}$: 평판 중간온도 사용 ⟹ $h_m A (T_{w,L/2} - T_\infty)$

① $$Nu_m = 0.68 + \frac{0.67 Re_L^{1/4}}{[1 + (0.492/Pr)^{9/16}]^{4/9}}, \quad 10^{-1} < Ra_L < 10^9$$

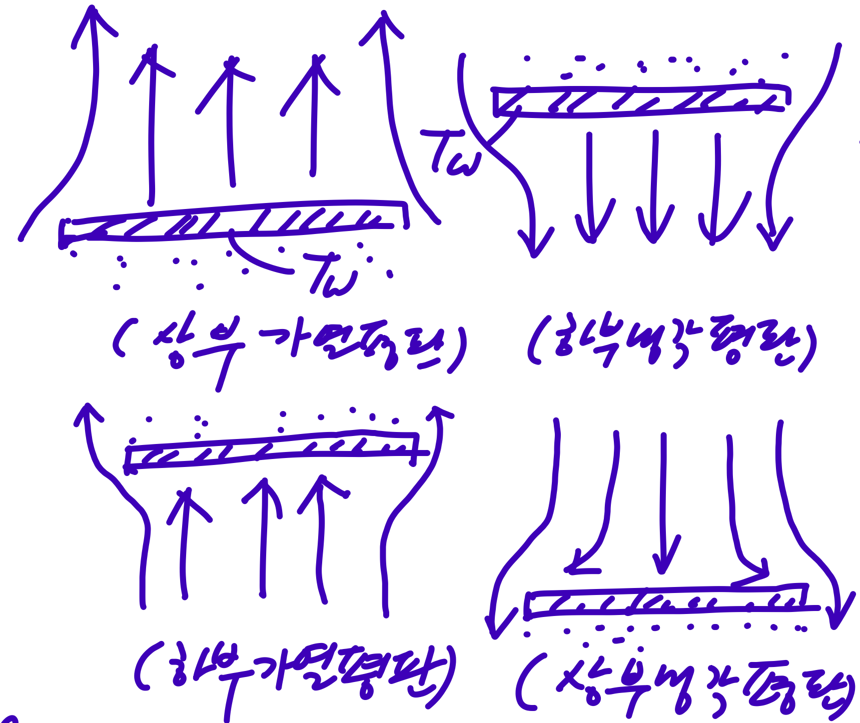
② $$Nu_m = [0.825 + 0.387 Ra^{1/6} \cdot f(Pr)]^2, \quad 10^{-1} < Ra_L < 10^{12}$$

$$f(Pr) = (1 + 0.671 Pr^{-9/16})^{-8/27} \quad 0.001 < Pr < \infty$$

(2) 수평평판 < ① 상부방향 / ② 하부방향

※ 특성길이(x) for $Gr_x = \frac{g\beta x^3 (T_w - T_\infty)}{\nu^2}$

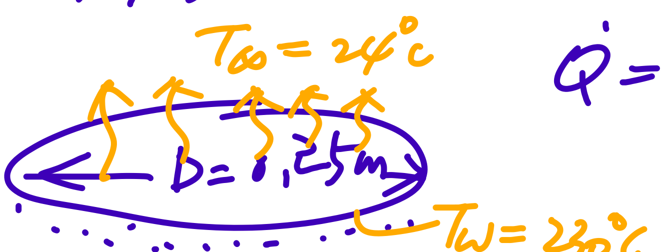
⟹ 직사각형$\left(\frac{a+b}{2}\right)$, 원판$(0.9D)$ for



⟹
$$Nu_m = 0.96\, Ra_L^{1/6} \quad 1 < Ra_L < 200 \ (9\text{-}9)$$
$$Nu_m = 0.59\, Ra_L^{1/4} \quad 200 < Ra_L < 10^4 \ (9\text{-}10)$$
$$Nu_m = 0.54\, Ra_L^{1/4} \quad 10^4 < Ra_L < 10^7 \ (9\text{-}11)$$
$$Nu_m = 0.15\, Ra_L^{1/3} \quad 10^7 < Ra < 10^{11} \ (9\text{-}12)$$

⟹
$$Nu_m = 0.27\, Ra_L^{1/4}, \quad 10^5 < Ra < 10^{10} \ (9\text{-}13)$$

(EX.) 9-3.



$\dot{Q} = ?$

(sol) $T_f = \frac{230+24}{2} = 127 = 400K$

$\therefore \beta = \frac{1}{T} = \frac{1}{400} = 0.0025K^{-1}$, $\nu = 26.41 \times 10^{-6} m^2/s$

$k = 0.0338\ W/mK$, $Pr = 0.69$

- $Gr_L = \frac{g\beta L^3 (T_w - T_\infty)}{\nu^2}$ ($L^3 \rightarrow (0.9D)^3$) $= \frac{9.8 \times 0.0025 \times (0.9 \times 0.25)^3 \times (230-24)}{26.41 \times 10^{-6}}$

$= 82.5 \times 10^6$ $\quad \therefore Ra_L = Gr_L \cdot Pr = 57,196,850$

→ $Nu_m = 0.15 Ra_L^{1/3}$ $(\because 10^7 < Ra_L < 10^{11}) = 0.15 \times (57,196,850)^{0.33} = 57.8$

즉, $Nu_m = \frac{h_m \cdot L}{k} = 57.8$ 이므로 $\therefore h_m = 8.68 (W/m^2K)$ $\therefore \dot{Q} = h_m \cdot A \cdot \Delta T = 87.8 (kW)$

§9-4. 원통 (Cylinder)

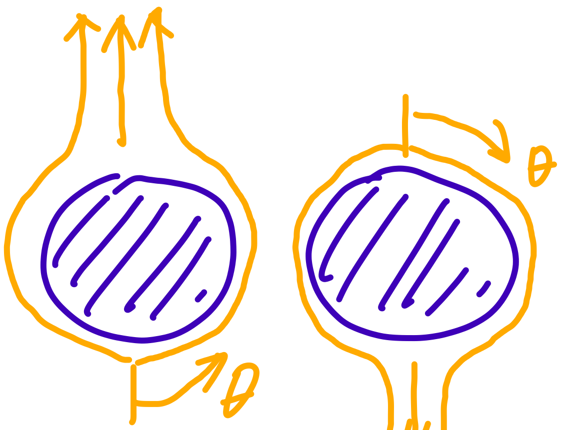
(1) 수평원통

∘ $$Gr_D = \frac{g\beta (T_w - T_\infty)\cdot D^3}{\nu^2} \quad \cdots (9\text{-}16)$$

(T_f 온도적용)

∘ $$Nu_m = \left\{ 0.6 + \frac{0.387\, Ra_D^{1/6}}{\left[1 + (0.559/Pr)^{9/16}\right]^{8/27}} \right\}^2, \quad 10^{-5} < Ra_D < 10^{13} \cdots (9\text{-}17)$$

$$Nu_m = 0.36 + \frac{0.518\, Ra_D^{1/4}}{\left[1 + (0.559/Pr)^{9/16}\right]^{4/9}}, \quad 10^{-6} < Ra_D < 10^{9} \cdots (9\text{-}18)$$



(가열) (냉각)

(수평원통)

(2) 수직원통 : $\frac{L/D}{Gr_L^{1/4}} < 0.025$