Chap. 28. Convective mass transfer

- convective mass transfer : bulk motion of fluid flow 이 수반되는 계에서의 물질전달현상
  - ~ systems: transport of mass between a boundary surface and a moving fluid
    transport of mass between two immiscible, moving fluids
  - ~ driving force : concentration difference between a boundary and bulk phase
  - ~ types : forced convection by externally generated flow of fluids by pump, fan, ...
    natural convection in gravitational field, interface-tensional field, ...
  - ~ rate (or flux) of convective mass transfer: $N_A = k_c \Delta c_A = k_c(c_{A,s} - c_{A\infty})$
- convective heat transfer : closely similar to convective mass transfer, $q/A = h\Delta T$

1. Fundamental considerations in convective mass transfer
   - 층류(laminar)와 난류(turbulent)에 의한 대류물질전달의 전달메카니즘 구분
     - ~ laminar flow fluid near the surface : means by molecular transport of moving fluids
     - ~ turbulent : movement of packets of mass across streamlines, transport by eddies
   - hydrodynamic boundary layer in convective mass transfer : $N_A = k_c(c_{A,s} - c_{A\infty})$

     N_A : moles of solute A leaving the interface per time and unit interfacial area

     k_c : convective mass transfer coefficient

     $c_{A,s}$: concentration of solute at the interface

     $c_{A,\infty}$: bulk concentration, mixing-cup concentration, average composition of bulk flow
   - evaluation of convective mass transfer coefficient, k_c

2. Significant parameters in convective mass transfer
   - dimensionless parameters to correlate convective mass transport data

   (1) momentum transfer

   Reynolds number, $Re = \frac{\rho D v}{\mu} = \frac{\text{관성력}}{\text{점성력}}$; Euler number, $Eu = \frac{P}{\rho v^2} = \frac{\text{압력힘}}{\text{관성력}}$;

   Froude number, $Fr = \frac{v^2}{gD} = \frac{\text{관성력}}{\text{중력힘}}$

   (2) convective heat transport

   Prandtl number, $Pr = \frac{\nu}{\alpha} = \frac{\text{운동량확산}}{\text{열확산}}$,

   Nusselt number, $Nu = \frac{hL}{k}$

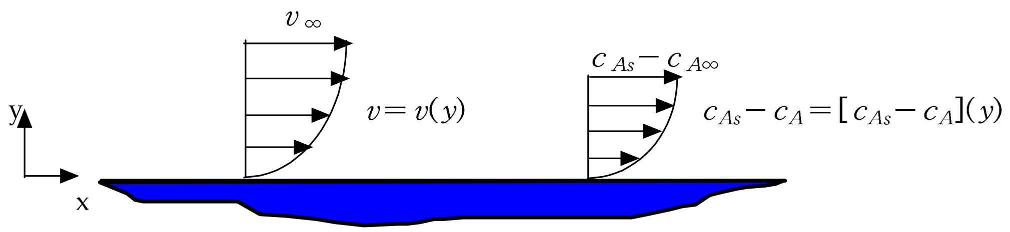
   (3) convective mass transport

   Schmidt number, $Sc = \frac{\nu}{D_{AB}} = \frac{\text{운동량확산}}{\text{물질확산}}$,

   Lewis number, $Le = \frac{\alpha}{D_{AB}} = \frac{Sc}{Pr} = \frac{\text{열확산}}{\text{물질확산}}$

   Sherwood number, $Sh = \frac{k_c L}{D_{AB}}$

· Sherwood number relation



- mass transfer between the surface and the fluid : $N_A=k_c(c_{A,s}-c_{A,\infty})$
- mass transfer by molecular diffusion at the surface: $N_A=-D_{AB}\frac{dc_A}{dy}\mid_{y=0}$
- same flux of component A leaving the surface and entering the fluid

$$N_A=k_c(c_{A,s}-c_{A,\infty})=-D_{AB}\frac{d}{dy}(c_A-c_{A,s})\mid_{y=0}$$

$$\rightarrow\ \frac{k_c}{D_{AB}}=\frac{-d(c_A-c_{A,s})/dy\mid_{y=0}}{(c_{A,s}-c_{A,\infty})}$$

$$\rightarrow\ Sh=\frac{k_cL}{D_{AB}}=\frac{-d(c_A-c_{A,s})/dy\mid_{y=0}}{(c_{A,s}-c_{A,\infty})/L}$$

3. Dimensionless analysis of convective mass transfer

· correlating experimental data into the explicit form of various dimensionless parameters

(1) Transfer into a stream flowing under forced convection

대상 : circular conduit

Variable	Symbol	Dimensions
pipe diameter	D	L
fluid density	ρ	M/L^3
fluid viscosity	μ	M/Lt
fluid velocity	v	L/t
mass diffusivity	D_{AB}	L^2/t
mass-transfer coefficient	k_c	L/t

· Buckingham-π method

number of variable (6); number of dimensions (3: L t , M)

number of core variables = 6 — 3 = 3 (D_{AB}, ρ, D)

$$\pi_1 = D_{AB}{}^a\rho^bD^ck_c,\quad \pi_2 = D_{AB}{}^d\rho^eD^fv,\quad \pi_3 = D_{AB}{}^g\rho^hD^i\mu$$

$[\pi_1]=1=(\frac{L}{t})(\frac{L^2}{t})^a(\frac{M}{L^3})^bL^c$: dimensionless

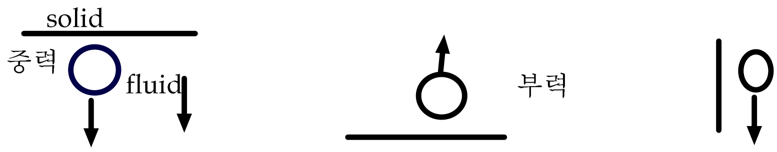
L : 0 = 2a -3b +c +1 ; t : 0 = -a -1 ; M : 0 = b → a = -1 , b = 0

$$\pi_1=\frac{k_cD}{D_{AB}}=Sh,\ \pi_2=\frac{Dv}{D_{AB}},\ \pi_3=\frac{\mu}{\rho D_{AB}}=\frac{\mu/\rho}{D_{AB}}=Sc\ ,\ \frac{\pi_2}{\pi_3}=\frac{\rho Dv}{\mu}=Re$$

$\pi_1=\pi_1(\pi_2,\pi_3)$ → $Sh=f(Re,Sc)$: forced convection in a confined geometry

(2) Transfer into a phase whose motion is due to natural convection

- natural convection(자연대류)에 의한 물질전달



※중력장에서 평형상태에 있는 주변의 유체층에 비하여 중력 또는 부력의 차이로부터 기인되는 유체의 유동에 부가되어 나타나는 물질전달

- 부력의 크기(buoyancy force) : $g\Delta\rho_A$
- important dimensionless parameter: $Gr_{AB}=\dfrac{L^3 g\Delta\rho_A}{\rho\nu^2}$: Grashof number

cf.: $Ra=Gr\Pr=\dfrac{g\beta\Delta c_A L^3}{\alpha D_{AB}}$: Rayleigh number

- Buckingham-π method

Variable	Symbol	Dimensions
characteristic length	L	L
fluid density	ρ	M/L^3
fluid viscosity	μ	M/Lt
buoyant force	$g\Delta\rho_A$	M/L^2t^2
mass diffusivity	D_{AB}	L^2/t
mass-transfer coefficient	k_c	L/t

core variables (3) : (D_{AB}, L, μ)

$$\pi_1 = D_{AB}^a L^b \mu^c k_c, \quad \pi_2 = D_{AB}^d L^e \mu^f \rho, \quad \pi_3 = D_{AB}^g L^h \mu^i g\Delta\rho_A$$

$$\pi_1=\frac{k_c L}{D_{AB}}=Sh_{AB}, \quad \pi_2=\frac{\rho D_{AB}}{\mu}=\frac{1}{Sc}, \quad \pi_3=\frac{L^3 g\Delta\rho_A}{\mu D_{AB}}, \quad \pi_2\pi_3=Gr_{AB}$$

$\pi_1 = \pi_1(\pi_2, \pi_3) \rightarrow Sh = f(Gr_{AB}, Sc)$: natural convection in a gravity field

Ex. Sherwood number correlation

Sc → 물성에 의하여 결정되는 매개인자.
Re(강제대류) or Gr(자연대류) → 외력 (유체유동, 즉 추진력)을 포함하는 매개인자

$$\frac{\left.\frac{dC_A}{dy}\right|_{y=0}}{\frac{\Delta C_A}{L}}=Sh=f(Re, Sc)$$ → 해석적인 상관식 또는 실험적인 상관식의 원형

Blasius flow 의 경우(강제대류) : $Sh=aRe^bSc^c$ → a, b, c 결정(해석적 또는 실험적 방법)

물질전달량: Re, Sc 계산 → $Sh=\dfrac{k_c L}{D_{AB}}$ 계산후 k_c 환산 → $N_A=k_c(c_{A,s}-c_{A,\infty})$ 계산