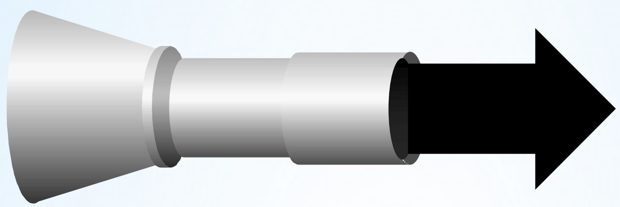
Heat Transfer

Heat Transfer

"A Practical Approach "

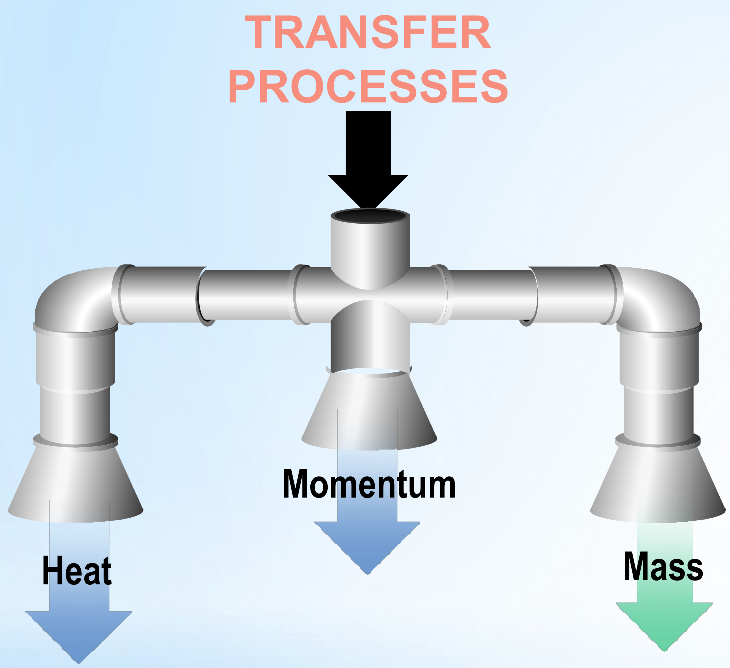
Yunus A. Cengel



MAIN REFERENCE OF THE COURSE

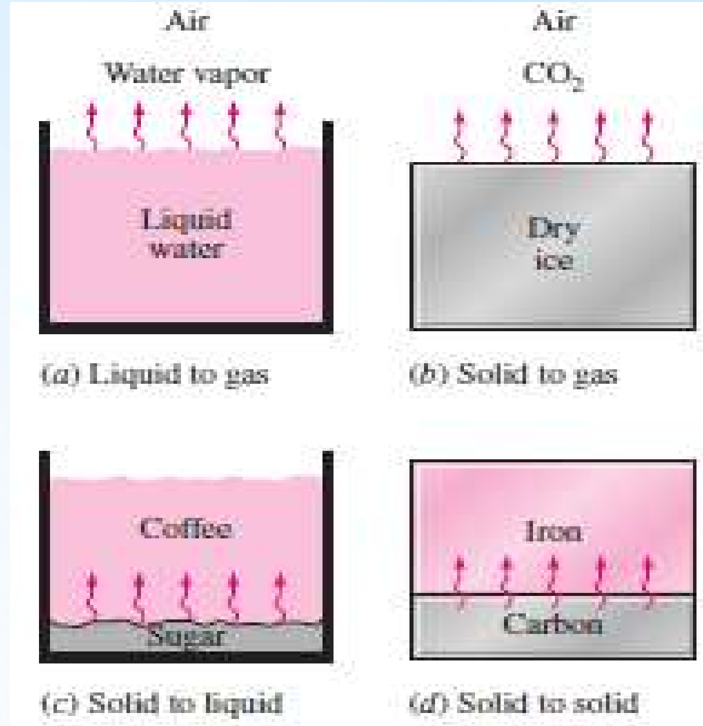
Mass Transfer

Mass transfer occurs whenever there is a **gradient in the concentration** of a species.



Molecular Diffusion

Convection Mass Transfer

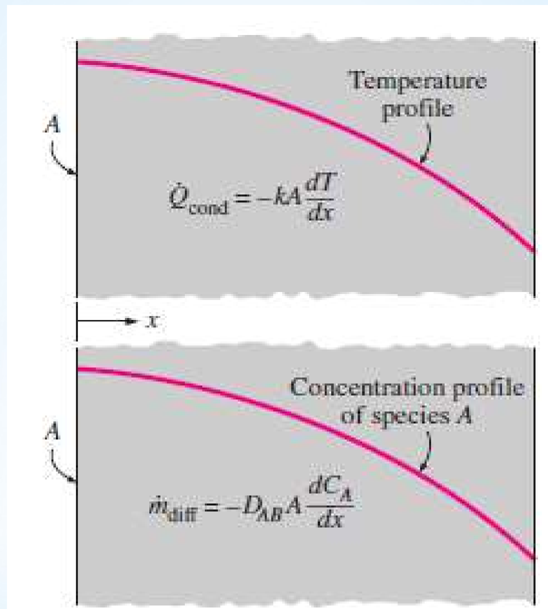


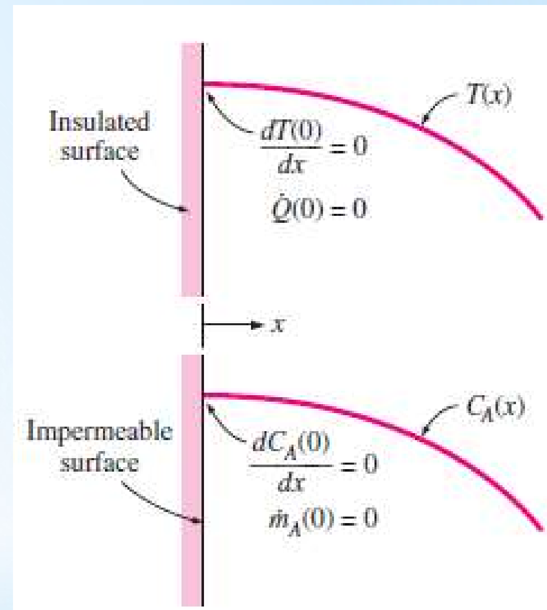
Whenever there is concentration difference in a medium, nature tends to equalize things by forcing a flow from the high to the low concentration region.

Mass Transfer Relations

Fick's law: linear relation between the rate of diffusion of chemical species and the concentration gradient of that species.

$$\dot{m}_{diff} = -D_{AB}A\frac{dC_A}{dx}$$





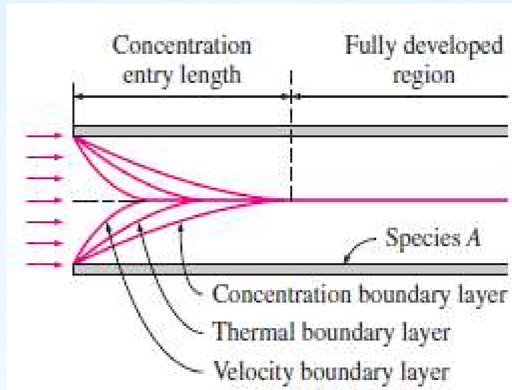
Molecular diffusion

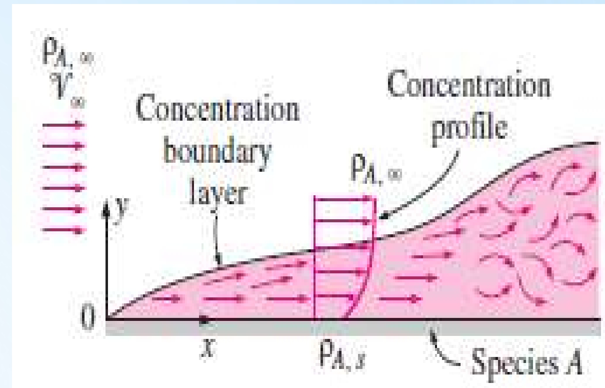
The diffusion of molecules when the whole bulk fluid is not moving but stationary. Diffusion of molecules is due to a concentration gradient.

Convection Mass Transfer

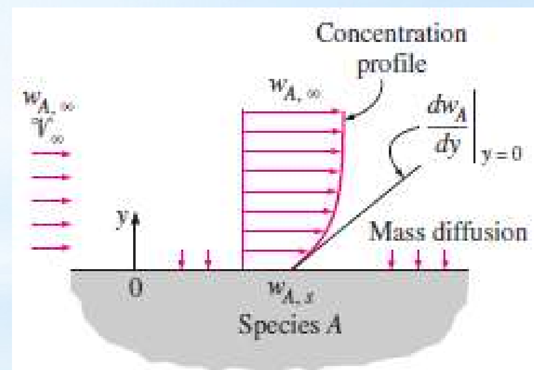
When a fluid flowing outside a solid surface in forced convection motion, rate of convective mass transfer is given by:

$$\dot{m}_{conv} = h_{mass} A_s (C_s - C_\infty)$$





$$\dot{m}_{conv} = h_{mass} A(\rho_{A,s} - \rho_{A,\infty}) = h_{mass} \rho A (w_{A,s} - w_{A,\infty})$$



$$-D_{AB} \left.\frac{\partial C_A}{\partial y}\right|_{y=0} = h_{mass}(w_{A,s} - w_{A,\infty})$$

Schmidt number: $\quad Sc = \frac{\nu}{D_{AB}} = \frac{\text{Momentum diffusivity}}{\text{Mass diffusivity}}$

$$\frac{\delta_{velocity}}{\delta_{thermal}} = Pr^n, \quad \frac{\delta_{velocity}}{\delta_{concentration}} = Sc^n, \quad \text{and} \quad \frac{\delta_{thermal}}{\delta_{concentration}} = Le^n$$

$$Le = \frac{Sc}{Pr} = \frac{\alpha}{D_{AB}}$$

Thermal diffusivity (α)

Mass diffusivity (D_{AB})

Heat transfer: $\quad Nu = \frac{h_{conv} L}{k}$

Mass transfer: $\quad Sh = \frac{h_{mass} L}{D_{AB}}$

$$\dot{m}_{\text{diff, A, wall}} = \frac{w_{A,1} - w_{A,2}}{L/\rho D_{AB} A} = \frac{w_{A,1} - w_{A,2}}{R_{\text{diff, wall}}}$$

$$R_{\text{diff, wall}} = \frac{L}{\rho D_{AB} A}$$

Convective Heat Transfer	Convective Mass Transfer
1. *Forced Convection over a Flat Plate*	
(*a*) Laminar flow ($Re < 5 \times 10^5$)	
$Nu = 0.664\, Re_L^{0.5}\, Pr^{1/3}$, $Pr > 0.6$	$Sh = 0.664\, Re_L^{0.5}\, Sc^{1/3}$, $Sc > 0.5$
(*b*) Turbulent flow ($5 \times 10^5 < Re < 10^7$)	
$Nu = 0.037\, Re_L^{0.8}\, Pr^{1/3}$, $Pr > 0.6$	$Sh = 0.037\, Re_L^{0.8}\, Sc^{1/3}$, $Sc > 0.5$
2. *Fully Developed Flow in Smooth Circular Pipes*	
(*a*) Laminar flow ($Re < 2300$)	
$Nu = 3.66$	$Sh = 3.66$
(*b*) Turbulent flow ($Re > 10{,}000$)	
$Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$, $0.7 < Pr < 160$	$Sh = 0.023\, Re^{0.8}\, Sc^{0.4}$, $0.7 < Sc\ 160$
3. *Natural Convection over Surfaces*	
(*a*) Vertical plate	
$Nu = 0.59(Gr\, Pr)^{1/4}$, $10^5 < Gr\, Pr < 10^9$	$Sh = 0.59(Gr\, Sc)^{1/4}$, $10^5 < Gr\, Sc < 10^9$
$Nu = 0.1(Gr\, Pr)^{1/3}$, $10^9 < Gr\, Pr < 10^{13}$	$Sh = 0.1(Gr\, Sc)^{1/3}$, $10^9 < Gr\, Sc < 10^{13}$
(*b*) Upper surface of a horizontal plate	
Surface is hot ($T_s > T_\infty$)	Fluid near the surface is light ($\rho_s < \rho_\infty$)
$Nu = 0.54(Gr\, Pr)^{1/4}$, $10^4 < Gr\, Pr < 10^7$	$Sh = 0.54(Gr\, Sc)^{1/4}$, $10^4 < Gr\, Sc < 10^7$
$Nu = 0.15(Gr\, Pr)^{1/3}$, $10^7 < Gr\, Pr < 10^{11}$	$Sh = 0.15(Gr\, Sc)^{1/3}$, $10^7 < Gr\, Sc < 10^{11}$
(*c*) Lower surface of a horizontal plate	
Surface is hot ($T_s > T_\infty$)	Fluid near the surface is light ($\rho_s < \rho_\infty$)
$Nu = 0.27(Gr\, Pr)^{1/4}$, $10^5 < Gr\, Pr < 10^{11}$	$Sh = 0.27(Gr\, Sc)^{1/4}$, $10^5 < Gr\, Sc < 10^{11}$