DEPARTMENT OF MECHANICAL ENGINEERING, 19MEB302/ Heat and Mass Transfer –

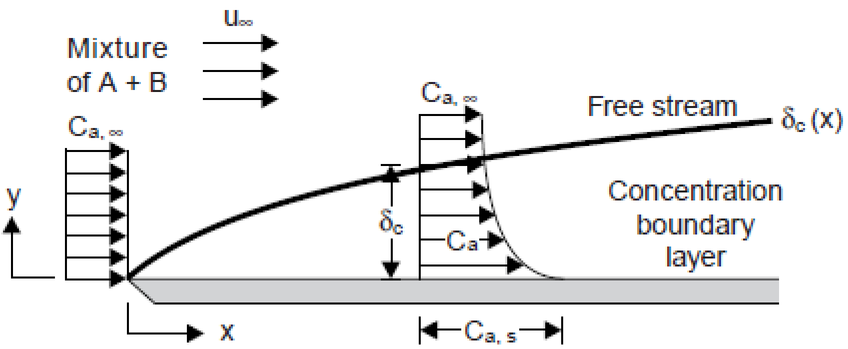
UNIT V - MASS TRANSFER

Topic - Tutorial - Convective Mass Transfer Correlations.

When a medium deficient in a component flows over a medium having an abundance of the component, then the component will diffuse into the flowing medium. Diffusion in the opposite direction will occur if the mass concentration levels of the component are interchanged.

In this case a boundary layer develops and at the interface mass transfer occurs by molecular diffusion (In heat flow at the interface, heat transfer is by conduction). Velocity boundary layer is used to determine wall friction. Thermal boundary layer is used to determine convective heat transfer. Similarly concentration boundary layer is used to determine convective mass transfer.

The Fig.shows the flow of a mixture of components *A* and *B* with a specified constant concentration over a surface rich in component *A*. A concentration boundary layer develops. The concentration gradient varies from the surface to the free stream. At the surface the mass transfer is by diffusion. Convective mass transfer coefficient h_m is defined by the equation, where h_m has a unit of m/s.



Species concentration boundary layer development on a flat plate

$$\text{Mole flow} = h_m (C_{as} - C_{a\infty})$$

The condition for diffusion at the surface is given by

$$\text{Mole flow} = -D_{ab} \left.\frac{\partial C_a}{\partial y}\right|_{y=0}$$

$$\therefore \qquad h_m = \frac{-D_{ab} \cdot \left.\frac{\partial C_a}{\partial y}\right|_{y=0}}{C_{as} - C_{a\infty}}$$

In the above case, if mass flow is to be used then

$$h_m = \frac{-D_{ab} \cdot \left.\frac{\partial \rho_a}{\partial y}\right|_{y=0}}{\rho_{as} - \rho_{a\infty}}$$

Similar to the momentum and energy equation, the mass concentration equatic obtained as below:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu \cdot \frac{\partial^2 u}{\partial y^2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2}$$

$$u\frac{\partial C_a}{\partial x} + v\frac{\partial C_a}{\partial y} = D_{ab}\frac{\partial^2 C_a}{\partial y^2}$$

By similarity the solutions for boundary layer thickness for connective mass can be obtained. This is similar to the heat transfer by analogy. In this case, in the Prandtl number Schmidt number defined by

$$Sc = \nu / D_{ab}$$

Nondimensionalising the equation leads to the condition as below:

$$\delta_m = f(Re, Sc)$$

$$Sh = f(Re, Sc)$$

where Sherwood number Sh is defined as

$$Sh = \frac{h_m x}{D_{ab}}.$$

In the laminar region flow over plate :

$$\delta_{mx} = \frac{5x}{Re_x^{1/2}} \cdot Sc^{-1/3}$$

$$Sh_x = \frac{h_{mx} x}{D_{ab}} = 0.332\, Re_x^{1/2}\, Sc^{1/3}$$

$$\overline{Sh}_L = \frac{h_m L}{D_{ab}} = 0.664\, Re_L^{1/2}\, Sc^{1/3}$$

In the turbulent region $Re > 5 \times 10^5$,

$$\delta_m = \delta_h$$

$$Sh_x = 0.0296\, Re_x^{0.8}\, Sc^{1/3}$$

$$\overline{Sh}_L = 0.037\, Re_L^{0.8}\, Sc^{1/3}$$

For flow through tubes,

In the laminar region, $Re < 2000$

For uniform wall mass concentration,

$$Sh = 3.66$$

For uniform wall mass flux

$$Sh = 4.36$$

For turbulent region,

$$Sh = 0.023\, Re^{0.83}\, Sc^{1/3}$$

References:

1. Kothandaraman C.P “Fundamentals of Heat and Mass Transfer” New Age International, New Delhi,4th Edition 2012 (Unit I, II, III, IV, V).
2. Frank P. Incropera and David P. DeWitt, “Fundamentals of Heat and Mass Transfer”, John Wiley and Sons, New Jersey,6th Edition1998(Unit I,II,III,IV, V)
3. MIT open courseware – https://ocw.mit.edu/courses/mechanical-engineering

Other web sources