ME-662 CONVECTIVE HEAT AND MASS TRANSFER

A. W. Date
Mechanical Engineering Department
Indian Institute of Technology, Bombay
Mumbai - 400076
India

LECTURE-1 INTRODUCTION

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1. Modes of Heat and Mass Transfer
2. Important Definitions
3. Examples of Convective Heat and Mass Transfer
4. Syllabus and References

MODES OF HEAT TRANSFER - L1($\frac{1}{15}$)

Whenever Temperature Difference exists,
Heat Transfer Q (J / s = W) takes place **Spontaneously** by

1. CONDUCTION (Solid, Liquid, Gas)
   Molecular Phenomenon
2. RADIATION (Transparent Medium including Vaccuum)
   Electromagnetic Phenomenon
3. CONVECTION (Liquid, Gas)
   Transfer of Energy by Bulk Motion and Conduction

MODES OF MASS TRANSFER - L1($\frac{2}{15}$)

Whenever Concentration Difference exists,
Mass Transfer $\dot{m}$ (kg / s) takes place **Spontaneously** by

1. DIFFUSION (Solid, Liquid, Gas)
   Molecular Phenomenon
2. CONVECTION (Liquid, Gas)
   Transfer of Mass by Bulk Motion and Diffusion

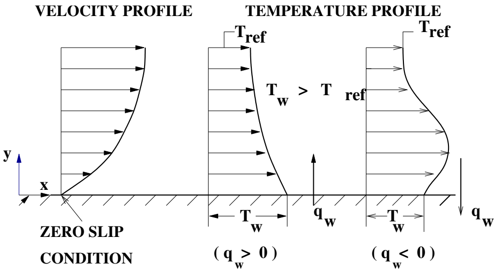
There is no RADIATION-LIKE counterpart in Mass Transfer

SCOPE OF THIS COURSE - L1($\frac{3}{15}$)

1. The Course Content is designed for MTech and PhD students - careers in Research and Development.
2. Our concern is with CONVECTIVE phenomena
3. Familiarity with Introductory PG courses in **Fluid Mechanics**, **Heat Transfer** and **Thermodynamics** is assumed.

1. You have already determined Heat and mass Transfer Coefficients from **Experimental Correlations** (eg. $Nu = C\, Re^m\, Pr^n$)
2. The aim of this course is to determine coefficients from Theory of Mass, Momentum and Energy transfer in moving fluids

Definition of Heat Flux - L1($\frac{4}{15}$)



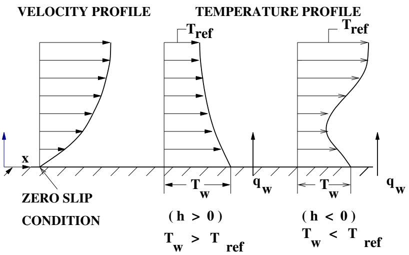
Due to No-slip condition, Heat Transfer Flux q_w across interface area A is defined as

$$q_w = \frac{Q_w}{A} = -k_f \frac{\partial T}{\partial y}|_{y=0} \qquad [\frac{W}{m^2}] \qquad (1)$$

Definition of H T Coef 'h' - L1($\frac{5}{15}$)

$$
\begin{aligned}
h &\equiv \frac{q_w}{(T_w - T_{ref})} \quad (\textit{Experiment}) \\
&\equiv \frac{-k_f\, \partial T / \partial y\, |_{y=0}}{(T_w - T_{ref})} \quad (\textit{Theory})
\end{aligned}
$$

1. In general, h (W / m^2-K) can be both positive or negative
2. T_{ref} must be known or *knowable*
3. k_f is fluid conductivity

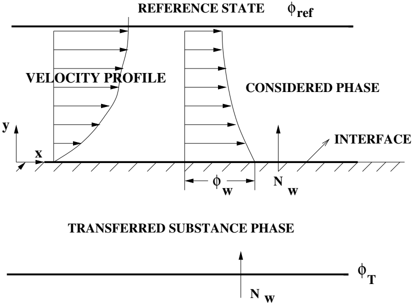


q_w, T_w and T_{ref} need be defined.

Definition of M T Coef 'g' - L1($\frac{6}{15}$)

1. Unlike heat transfer, in mass transfer 3 states must be considered:
    1. Reference state (ref) far into the *Considered Phase*
    2. Interface state (w)
    3. Trans Subs state (T) deep into *Transferred Substance Phase*
2. M T Flux (N_w) kg / m^2-s is defined as

$$N_w \equiv g \times B \qquad (2)$$



$$B = \frac{\Phi_{ref} - \Phi_w}{\Phi_w - \Phi_T} \qquad (3)$$

M T Coef (g) kg / m^2 - s , B is dimensionless, Φ is a *Conserved Property*.

Mass Transfer Considerations - L1($\frac{7}{15}$)

In general, there are 3 types of mass transfer

1. *Mass Transfer* without heat transfer and chemical reaction
2. *Mass Transfer* with heat transfer but without chemical reaction
3. *Mass Transfer* with heat transfer and chemical reaction

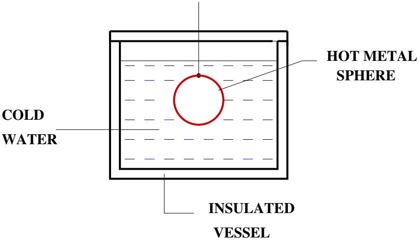
In each case, Conserved Property Φ must be appropriately defined - details will be considered later

Engineer's Tasks - L1($\frac{8}{15}$)

1. Engineer is concerned with *Design* and *Performance Evaluation*
2. Design implies
    1. **Sizing** (For a given Q_w, A must be determined)
    2. **Safety** (For a given q_w, $T_w < T_{safe}$)
    3. **Economy** (Capital cost and compactness are related to A and Running cost is related to *pressure drop*)
    4. Hence, A must be so structured that Δp is small
3. Fluid Mechanics determines Δp and velocity profile. The latter determines the T and/or Φ profiles and hence, their *gradients* at the wall/interface
4. Thermodynamics cannot help *Design*. Knowledge of 'h' and/or 'g' is required. Thermodynamics can help performance evaluation. Examples follow.

Cooling Rate - L1($\frac{9}{15}$)

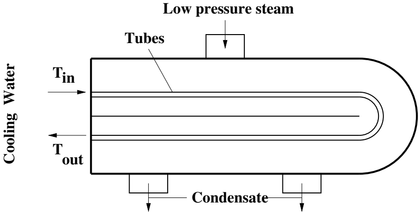
1. A hot metal sphere is dropped in cold water in an insulated vessel
2. Thermodynamics can determine the final temperature T_f of water and sphere
3. Thermodynamics cannot answer: What is the *cooling rate* of the sphere ?



Knowledge of ’h’ between sphere and water is required

Sizing a Condenser - L1($\frac{10}{15}$)

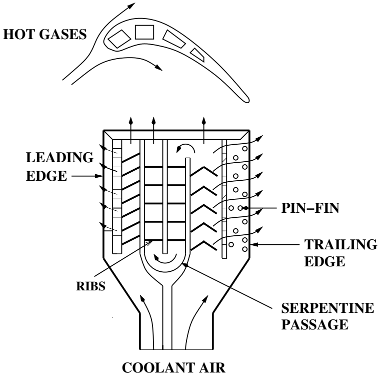
1. In a Steam Condenser, knowing $\dot{m}_{st}$ and condenser pressure, Thermodynamics can determine $\dot{m}_{water}$ when allowable temperature rise $\Delta T_{cooling}$ is specified.
2. Thermodynamics cannot determine tube-surface area A (dia, length, number of tubes) for allowable pressure drops on shell and tube side



1. Knowledge of ’h’ on steam and water side is required.
2. Pressure drops must be determined from fluid mechanics

Gas Turbine Blade Cooling - L1($\frac{11}{15}$)

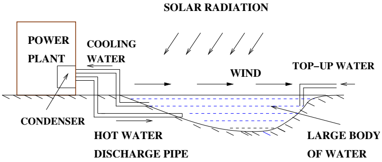
1. Thermodynamics dictates that T_{gas} leaving the Comb Chamber must be high
2. Designer must ensure that $T_{blade} < T_{safe}$ to prevent blade twisting
3. Cooling air from Compressor must be as small to prevent reduction in engine thrust



How should the internal passages be shaped ? Rib Roughness, Bends, Jet impingement increase 'h'

Cooling Water Pond - L1($\frac{12}{15}$)

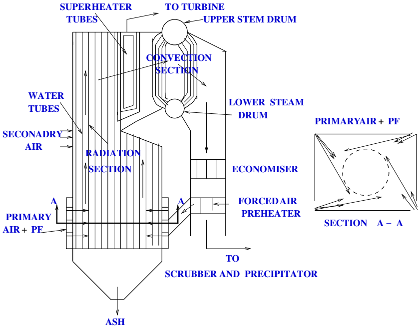
1. Thermal Power Plants often use cold water from Ponds as Condenser Cooling water
2. It is of interest to determine *evaporation loss* under the action of wind and solar radiation
3. Daily *Topping-up water* can be estimated from knowledge of 'g' between water surface and air



1. Driving force B depends on water vapour mass fractions $\Phi = \omega_v$ and temperatures $\Phi = T$ in air, water surface and deep inside the pond
2. Simultaneous Heat and Mass transfer must be considered

Pulverised Fuel Furnace - L1($\frac{13}{15}$)

1. In a PF boiler, coal particles ($< 250\ \mu$m) are injected with air in the form of a jet
2. It is of interest to determine *Particle Burning Rate* to size the furnace
3. Secondary air is added to reduce NO_x emissions



Simultaneous Heat and Mass transfer with Chemical Reaction must be considered

Syllabus - L1($\frac{14}{15}$)

1. Definitions and Flow Classifications (2)
2. Derivation of Transport Equations s (4)
3. 2D Laminar Velocity and Temperature Boundary Layers Solutions (6)
4. Developing and Fully Developed Laminar Duct Flow and Heat Transfer Solutions (8)
5. Nature of Turbulent flows & Wall Laws (4)

1. 2D Turbulent Velocity and Temperature Boundary Layer Solutions (4)
2. Energy Budgets and Modeling (2)
3. Formulation of the Mass Transfer Problem using different Models (6)
4. Application of Reynolds Flow Model to different problems (4)

References - L1($\frac{15}{15}$)

1. **Kays W M and Crawford M E**, *Convective Heat and Mass Transfer*, McGraw-Hill, 3rd Edition, (1993)
2. **Spalding D B**, *Introduction to Convective Mass Transfer* McGraw-Hill, (1963)
3. **Bird R B, Stewart W E and Lightfoot E N**, *Transport Phenomena* , John Wile& Sons, (1960)
4. **Schlichting H**, *Boundary Layer Theory*, 6th Edition, McGraw-Hill , (1968)
5. **Incropera F P and DeWitt D P**, *Fundamentals of Heat and Mass Transfer*, 4th Edition, John-Wiley & Sons, (1996)
6. **Cebeci T and Cousteix J**, *Modeling and Computation of Boundary Layer Flows*, 2nd Edition, Springer, (2005)

Additional references will be given during the lectures