Module 3: Physics of Combustion

Lecture 15: Energy transport equation

The Lecture Contains:

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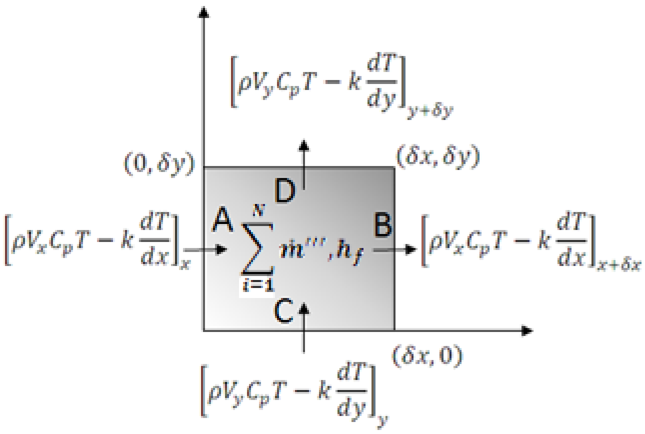
Lecture 15: Energy transport equation

Energy transport equation



$$\left\{\begin{array}{l}\text{Rate of energy accumulation}\\ \text{in fluid element}\end{array}\right\} = \left\{\begin{array}{l}\text{Rate of energy into}\\ \text{fluid element}\end{array}\right\}$$

$$- \left\{\begin{array}{l}\text{Rate of energy out of fluid}\\ \text{element}\end{array}\right\} + \left\{\begin{array}{l}\text{Rate of heat added by}\\ \text{chemical reactions}\end{array}\right\}$$

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Heat accumulated in the fluid element $= \frac{\partial}{\partial t}\left[\rho C_p T(\delta x \times \delta y \times 1)\right]$

Amount of heat entering into fluid element through face 'A' is given by:

$$\left(\rho V_x \times C_p T \times \delta y \times 1\right) + \left(-k\frac{\partial T}{\partial x}\right)(\delta y \times 1)$$

Amount of heat leaving from the fluid element through face 'B' is given by:

$$\left[\left(\rho V_x \times C_p T \times \delta x \times 1\right) + \left(-k\frac{\partial T}{\partial x}\right)(\delta y \times 1)\right]$$
$$+ \left[\frac{\partial}{\partial x}\left(\rho V_x \times C_p T \times \delta y \times 1\right) + \left(-k\frac{\partial T}{\partial x}\right)(\delta y \times 1)\right](\delta x)$$

Net efflux in x direction

$$\frac{\partial}{\partial x}\left[\left(\rho V_x \times C_p T \times \delta y \times 1\right) + \left(-k\frac{\partial T}{\partial x}\right)(\delta y \times 1)\right](\delta x)$$

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Amount of heat interaction in y-direction through faces 'C' and 'D' is

$$\frac{\partial}{\partial x}\left[\left(-\rho V_y \times C_p T \times \delta x \times 1\right) + \left(k\frac{\partial T}{\partial x}\right)(\delta y \times 1)\right](\delta x)$$

In a fluid element, heat may be absorbed or removed due to chemical reaction

$$F + Ox \rightarrow P$$

The amount of heat interaction in fluid element per unit area:

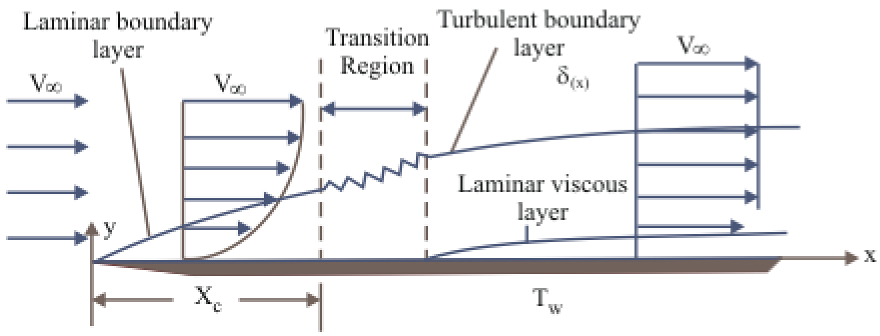
$$\sum_{i}^{N} \dot{m}_i''' h_{f,i}^0 (\delta x \times \delta y)$$

By striking out an energy balance, the energy equation for a multi-component reactive system because.

$$\frac{\partial}{\partial t}\left(\rho C_p T\right) + \frac{\partial}{\partial x}\left(\rho V_x C_p T\right) + \frac{\partial}{\partial y}\left(\rho V_y C_p T\right) = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) - \sum_{i}^{N} \dot{m}_i'' h_{f,i}^0$$

Boundary layer concept

- Velocity of fluid increases from zero at wall to free stream velocity
- Velocity gradients appear near a thin region adjacent to wall



Flow of viscous fluid over a flat plate

(Figure 15.1)

- The thin region adjacent to wall surface is the boundary layer
- Wall friction-causes reduction in velocity near the wall

- Boundary layer thickness $(\delta) = 0.99$ times the free stream velocity V_∞

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