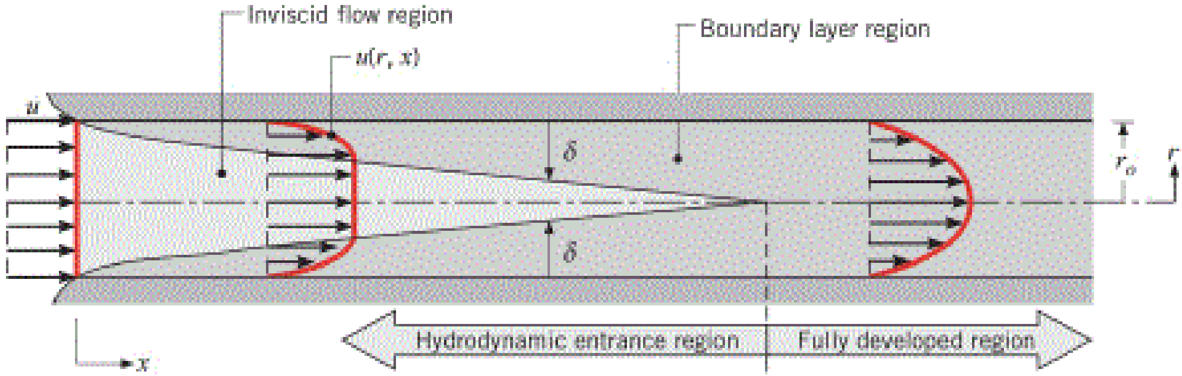
What we will be looking at;

1. No phase change [Single phase]
2. Governing equations [Correlations]

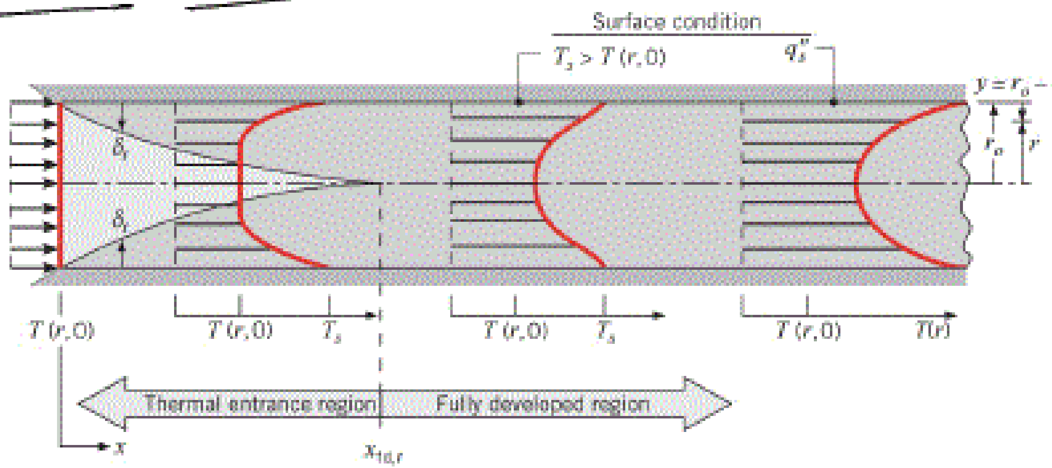
Internal flow:

Hydrodynamic Boundary layer

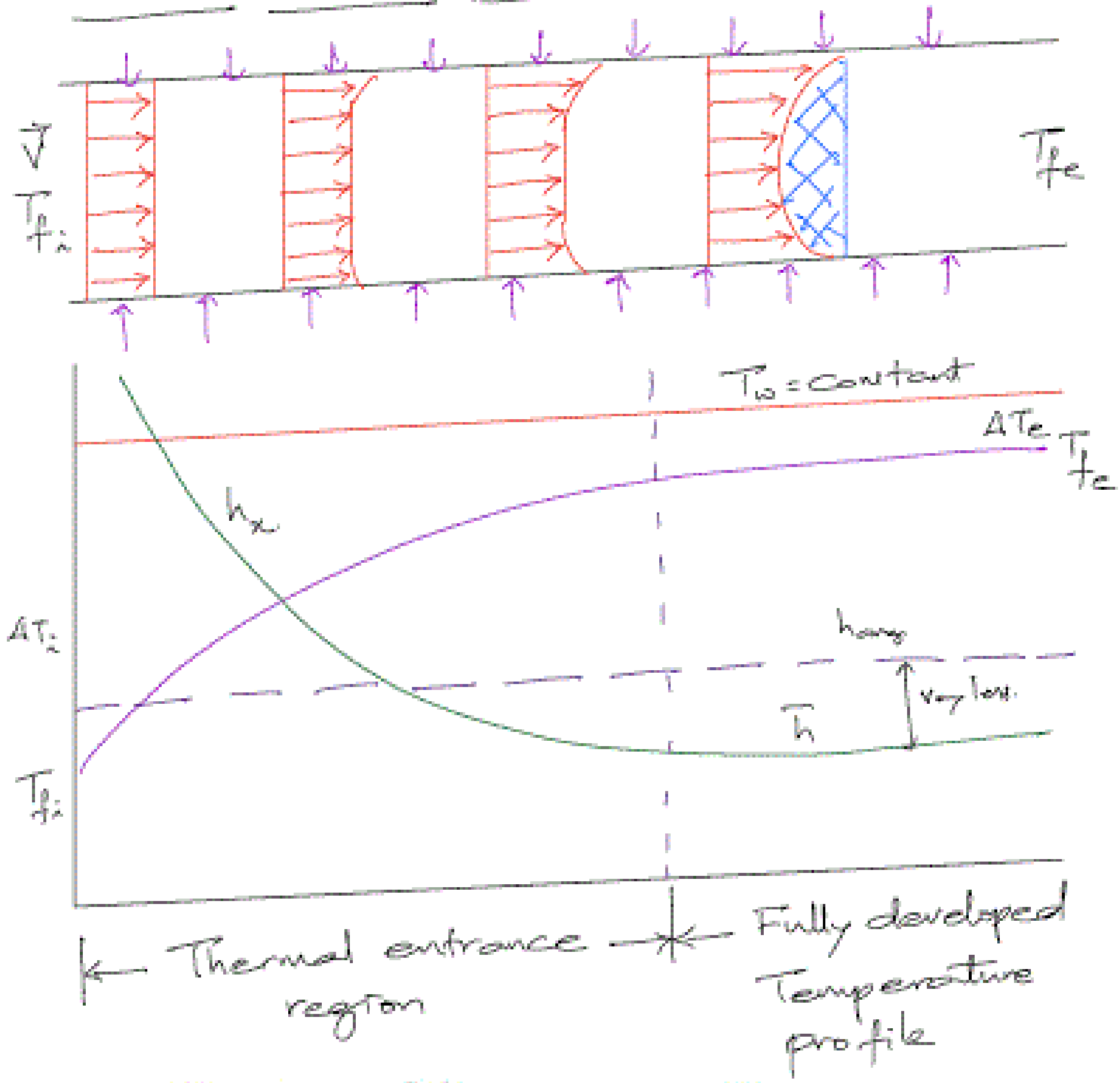


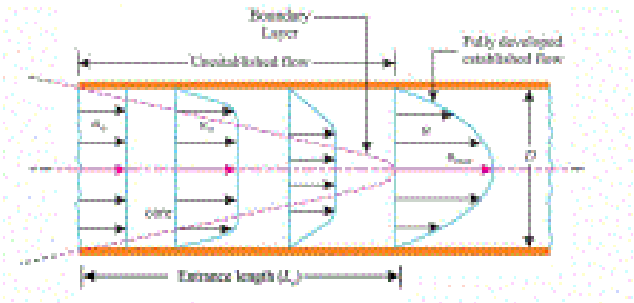
|← Developing length → $x_{fd,h}$

Thermal boundary layer:

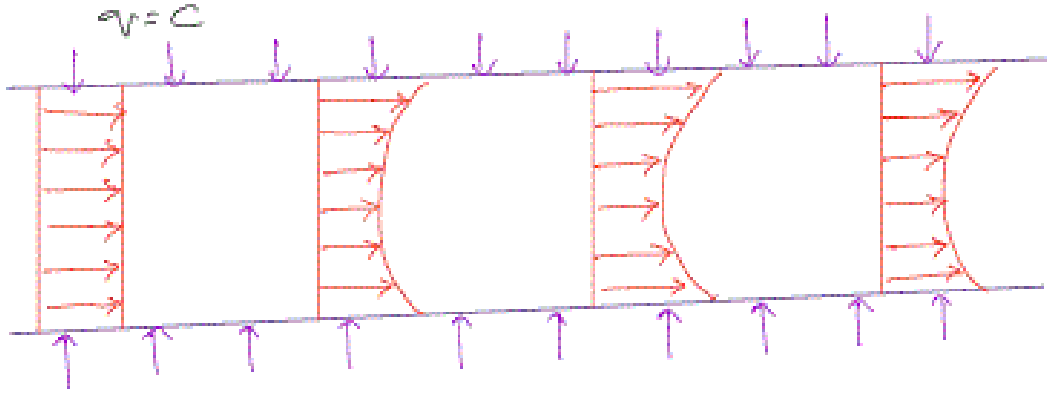


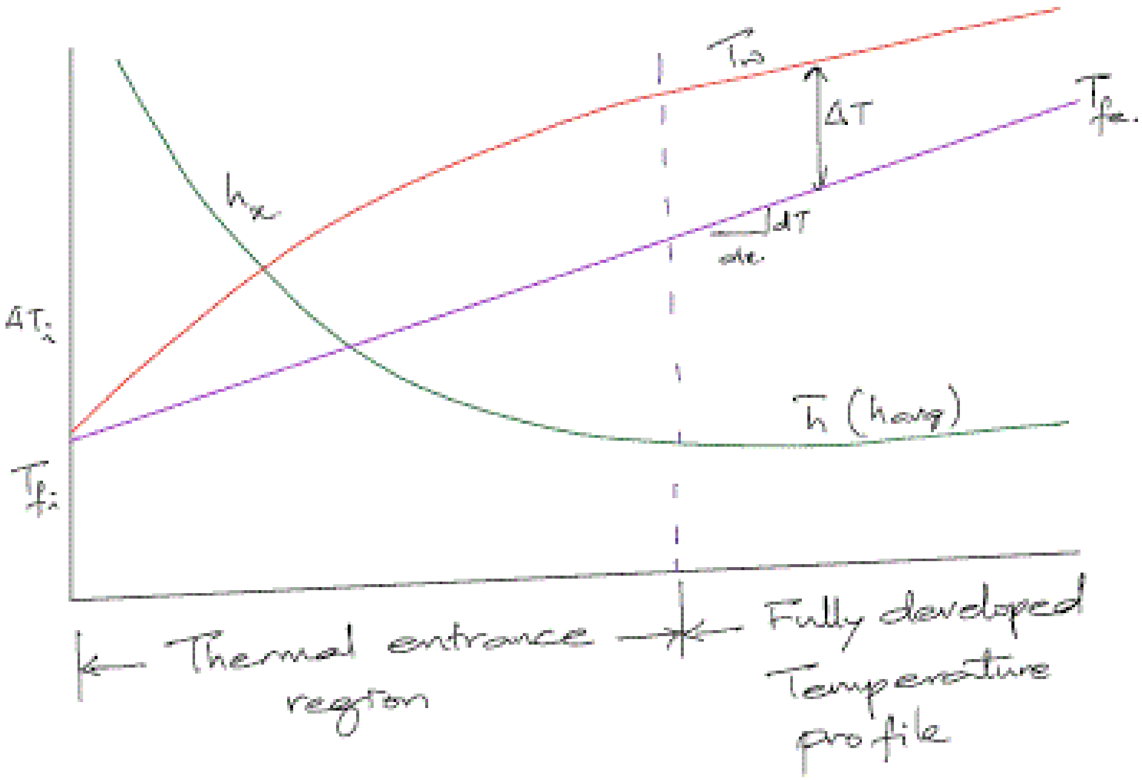
Constant wall temperature (T_w = constant)





Constant wall heat flux [q = constant] $\frac{dT}{dx}$ (linear)





Things which are important for such flows.

1) Average velocity $\bar{u} = \frac{1}{A}\int_A u_x dA$.

2) Mass flow rate $\dot{m} = \rho A \bar{u}$; $Q = A\bar{u}$ ∴ $A = \frac{\pi d^2}{4}$.

3) Bulk mean temperature: It is the temperature at a location 'x' along the pipe, which is the average temperature of the fluid such that the fluid at that location is well mixed to attain a common temperature. Mathematically,

$$T_b = \frac{1}{\bar{u} A}\int_A u \cdot T \cdot dA \qquad T_b = \frac{T_{fi} + T_{fe}}{2}.$$

4) Friction factor [f]

Laminar $\rightarrow f = \frac{64}{Re}$.

Turbulent $\rightarrow$ Refer to Moody's diagram.

5) Pressure drop $\Delta P = f \times \frac{\rho \bar{u}^2}{2} \times \frac{L}{d}$.

6) Reynolds number 'Re'

$Re < 2300 \rightarrow$ Laminar.

$Re > 2300 \rightarrow$ Turbulent.

Flow over flat plate:

Drag coefficient (OR) Skin friction coefficient

i) Local drag coefficient:

$x=0 \quad \tau_{0,x} = \mu \cdot \frac{\partial u}{\partial y}\Big|_x \quad x = x \quad x = L.$

$$C_{f,x} = \frac{\tau_{0,x}}{\rho u_\infty^2/2}$$

ii) Average drag coefficient

$$C_{f_{avg}} = \frac{1}{L}\int_0^L C_{f_x}\,dx.$$

$$\tau_{w,avg} = \frac{\text{Drag force}}{\text{Area}}$$

$$\tau_{0,avg.} = \frac{F_D}{A}$$

$$C_{f_{avg.}} = \frac{\tau_{0,avg}}{\frac{1}{2}\rho u_\infty^2}.$$

$$\left\{ \begin{aligned} Re_x &= \frac{\rho V x}{\mu} \rightarrow \text{Local} \\ Re_L &= \frac{\rho V L}{\mu} \rightarrow \text{Average} \end{aligned} \right\}$$

Drag on a plate:

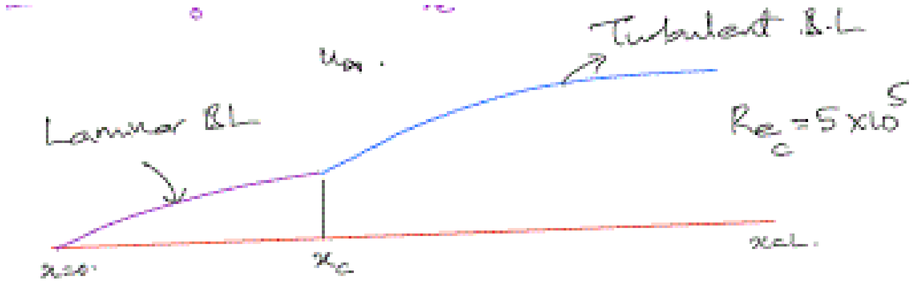
$$\left.\begin{aligned} C_{fx} &= 0.664\, Re_x^{-0.5} \\ C_{fL} &= 1.328\, Re_L^{-0.5} \end{aligned}\right\} \text{for } Re < 10^5, \text{ Laminar}$$

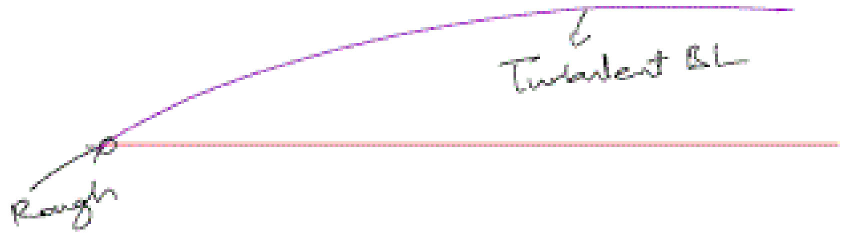
$$C_{f,x} = 0.0592\, Re_x^{-0.2} \qquad 5\times10^5 < Re < 10^7$$

$$C_{f,x} = 0.37\left[\log_{10} Re_x\right]^{-2.584} \qquad Re > 10^7 \qquad \text{Turbulent}$$

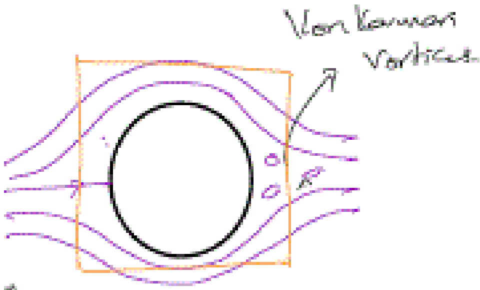
$$C_{fL} = 0.074\, Re_L^{-0.2} - 1742\, Re_L^{-1} \rightarrow \text{Laminar \& Turbulent.}$$

$$\left[C_{fL} = \frac{1}{L}\int^{x_c} C_{fx\,lam}\,dx + \int_{x_c}^{L} C_{fx\,turb}\,dx\right]$$





Flow over cylinder



$A_s = \pi D L$

$Re_D = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$

$C_D = \frac{F_D/A}{\frac{1}{2}\rho u_\infty^2}$ $A \rightarrow$ Projected Area.

Correlation from experimental data

$C_D = 10.41\, Re_D^{-0.6772} \longrightarrow 0.1 < Re_D < 4$

$C_D = 5.67\, Re_D^{-0.2511} \longrightarrow 4 < Re_D < 1000$

$C_D = 1 \longrightarrow 1000 < Re_D < 5000$

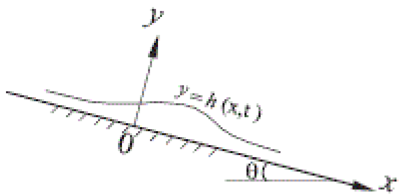
$C_D = 0.310\, Re_D^{0.1525} \longrightarrow 5000 < Re_D < 10^4$

$C_D = 1.14 \longrightarrow 10^4 < Re_D < 2\times10^5$

Inclined flow introduction:

Because of the inherent nonlinearity, most fluid-dynamical problems must be solved by ei-ther analytical approximations or by numerical computations. In this chapter we shall first explain the lubrication approximation, with applications to the flow of thin layers. Atten-tion will then be turned to the slow flow past a sphere and a cylinder. Application to the environmental pblem of aerols will be briefly discussed. Lastly the slow withdrawl of fluid from a straitified reservoir into a sink will be analyzed.

consider the flow of a thin layer of viscous fluid on an inclined plane. Referring to Figure let the x− axis coincide with the plane bed inclined at the angle θ with respect to the horizon, and the y− axis normal to the plane bed,



A thin fluid layer flowing down an incline plane