

# Analytical Fluid Dynamics

- Example: laminar pipe flow

**Assumptions:** Fully developed, Low  $Re = \frac{\rho U D}{\mu} < 2000$

**Approach:** Simplify momentum equation,  $\mu$  integrate, apply boundary conditions to determine integration constants and use energy equation to calculate head loss

$$\cancel{\frac{Du}{Dt}} = -\frac{\partial p}{\partial x} + \mu \left[ \cancel{\frac{\partial^2 u}{\partial x^2}} + \frac{\partial^2 u}{\partial y^2} \right] + \cancel{g_x}$$

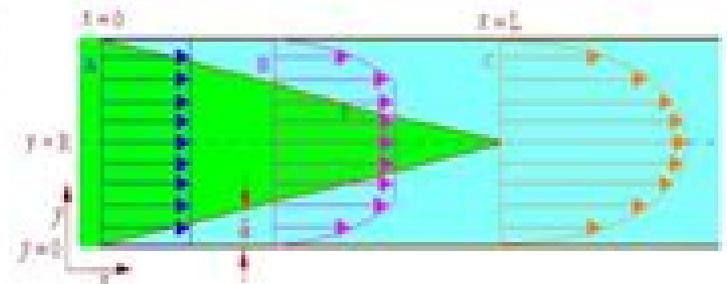
Exact solution :

$$u(r) = \frac{1}{4\mu} \left( -\frac{\partial p}{\partial x} \right) (R^2 - r^2)$$

Friction factor:  $f = \frac{8\tau_w}{\rho \bar{V}^2} = \frac{8\mu \left. \frac{du}{dy} \right|_y=R}{\rho \bar{V}^2} = \frac{64}{Re}$

Head loss:  $\frac{p_1}{\gamma} + z_1 = \frac{p_2}{\gamma} + z_2 + h_f \quad h_f = f \frac{L V^2}{D 2g} = \frac{32\mu L V}{\gamma D^2}$

Schematic



$\delta$  = Boundary layer thickness  
 $R$  = Radius of pipe  
 $L$  = Transition length  
 $v$  = Velocity

Potential flow region
  Boundary layer flow

Development of boundary-layer flow in pipe

# Fluid Dynamics

**Robert R. Redfield**



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