HEAT TRANSFER BY CONVECTION

CONDUCTION

Mechanism of heat transfer through a solid or fluid in the absence any fluid motion.

CONVECTION

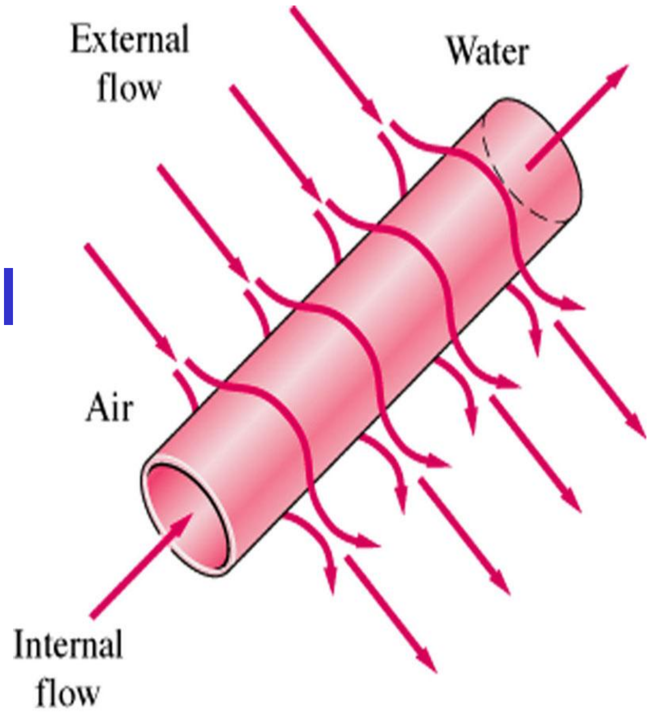
Mechanism of heat transfer through a fluid in the presence of bulk fluid motion

- **Natural (free) Convection**
- **Forced Convection**

(depending on how the fluid motion is initiated)

CLASSIFICATION OF FLUID FLOWS

- **Viscous-inviscid**
- **Internal flow-External flow**
- **Open-closed channel**
- **Compressible-Incompressible**
- **Laminar-Turbulent**
- **Natural- Forced**
- **Steady- Unsteady**
- **One-,two-,three-dimensional**



VISCOSITY

When two fluid layers move relative to each other, a friction force develops between them and the slower layer tries to slow down the faster layer.

internal resistance to flow

- cohesive forces between the molecules in liquid
- molecular collisions in gases.

Viscous flows: viscous effects are significant

Inviscid flow regions: viscous forces are negligibly small compared to inertial or pressure forces.

→ measure of stickness or resistance to deformation

1. **Kinematic viscosity**
2. **Dynamic viscosity**

VISCOSITY DEPENDS ON

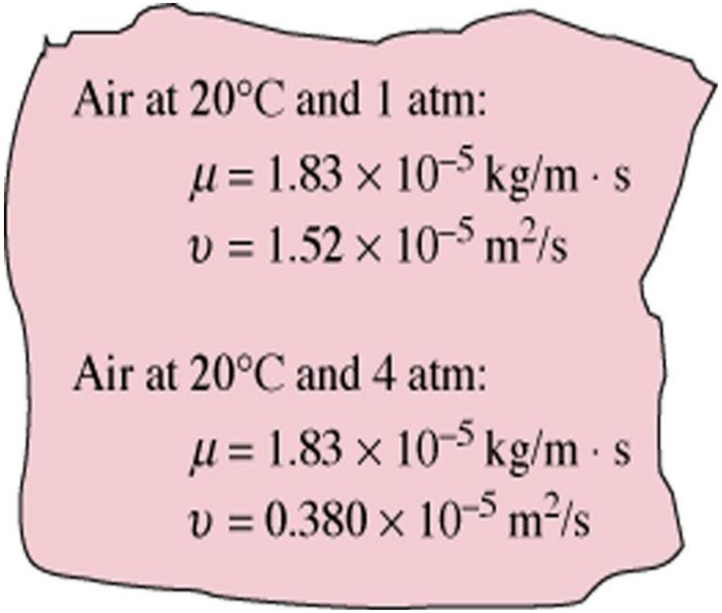
- **TEMPERATURE**
- **PRESSURE**

For liquids dependence of pressure is negligible

For gases kinematic viscosity depends on pressure since its relation to density

μ Dynamic viscosity (kg/m.s or poise)

$$\nu = \frac{\mu}{\rho}$$



Air at 20°C and 1 atm:

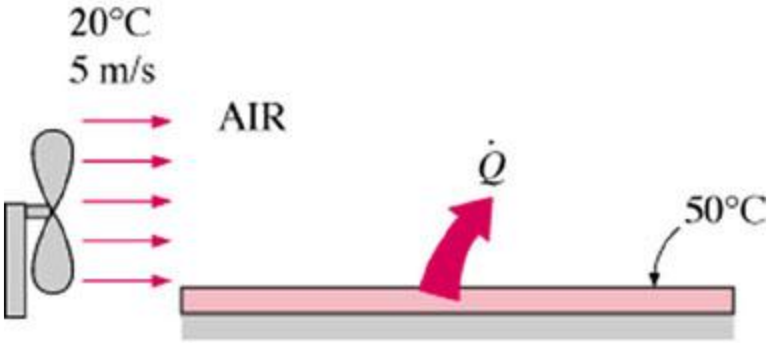
$$\mu = 1.83 \times 10^{-5}\ \mathrm{kg/m \cdot s}$$
$$\upsilon = 1.52 \times 10^{-5}\ \mathrm{m^2/s}$$

Air at 20°C and 4 atm:

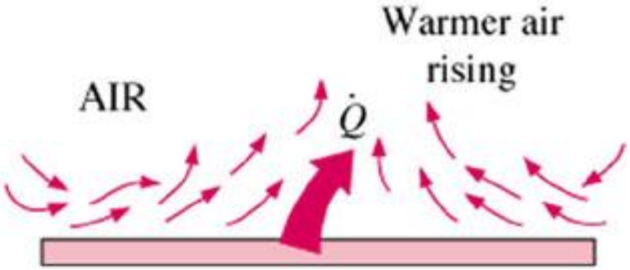
$$\mu = 1.83 \times 10^{-5}\ \mathrm{kg/m \cdot s}$$
$$\upsilon = 0.380 \times 10^{-5}\ \mathrm{m^2/s}$$

ν Kinematic viscosity, m^2/s or stroke

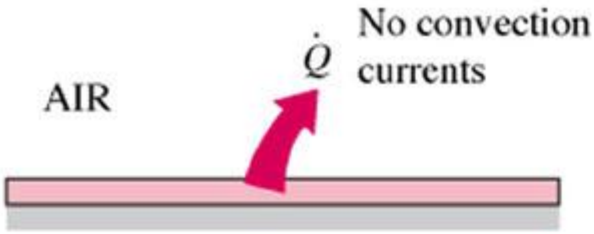
Convection heat transfer



(*a*) Forced convection



(*b*) Free convection



(*c*) Conduction

- Dynamic viscosity
- Thermal conductivity
- Density
- Specific heat
- Fluid velocity
- Geometry
- Roughness
- Type of fluid flow

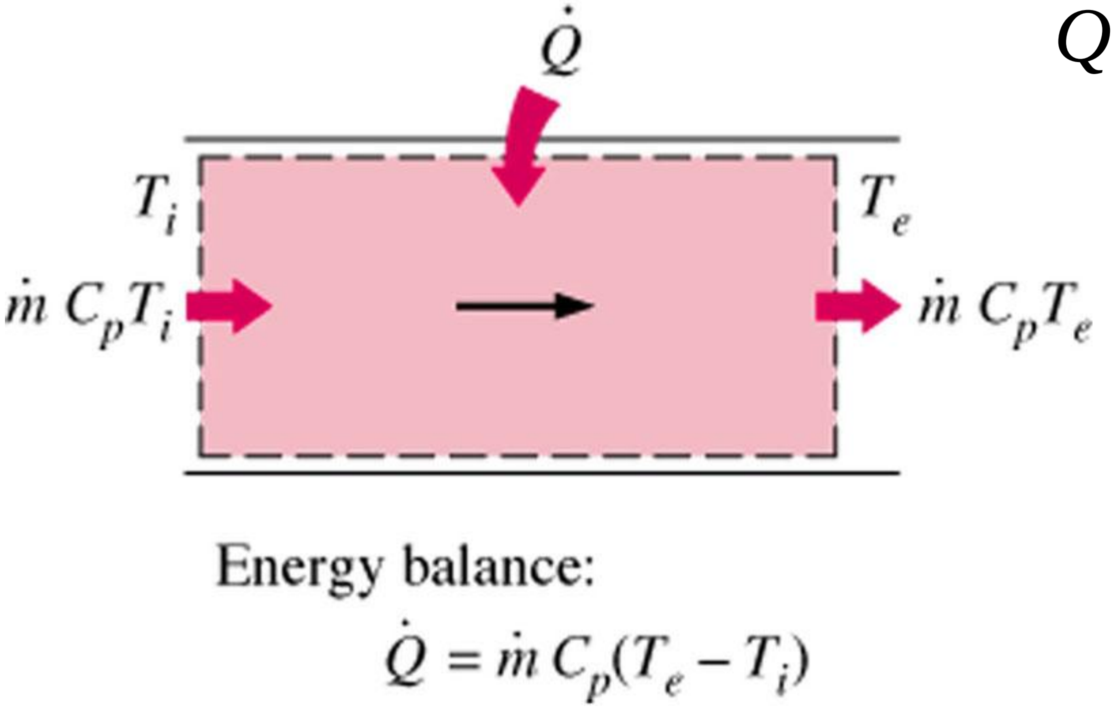
NEWTON'S LAW OF COOLING

$$\dot{Q}_{conv} = hA_S(T_S - T_\infty) \quad \text{(W)}$$

h Convection heat transfer coefficient (W/m^2.^{0}C)

The rate of heat transfer between a solid surface and a fluid per unit surface area per unit temperature difference

GENERAL THERMAL ANALYSIS



$$\dot{Q}_{conv} = hA_S (T_S - T_\infty)$$

$$\dot{Q} = \dot{m} C_p (T_e - T_i)$$

FORCED CONVECTION

- **LAMINAR FLOW**

Smooth streamlines

Highly- ordered motion

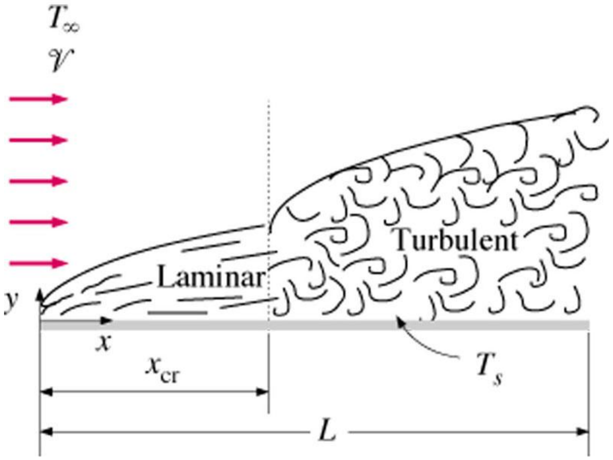
(highly viscous fluids in small pipes)

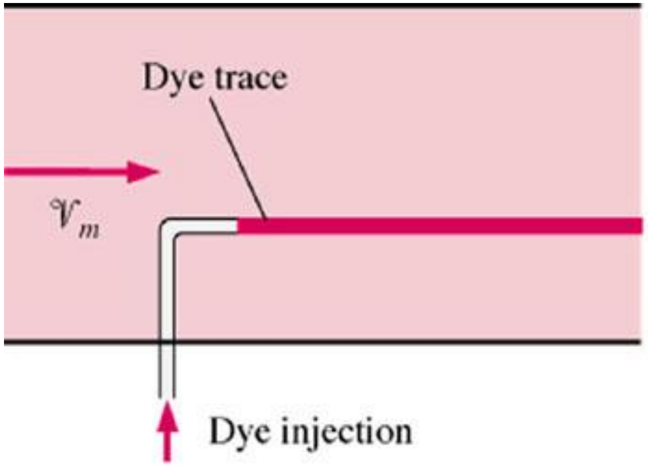
- **TURBULENT FLOW**

Velocity fluctuations

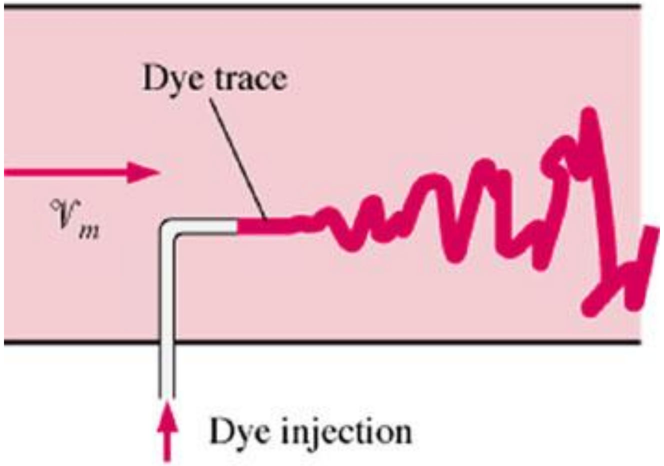
Highly-disordered motion

- **TRANSITIONAL FLOW**





(*a*) Laminar flow



(*b*) Turbulent flow

REYNOLDS NUMBER

Flow Regime:

Geometry

Surface roughness

Flow velocity

Surface temperature

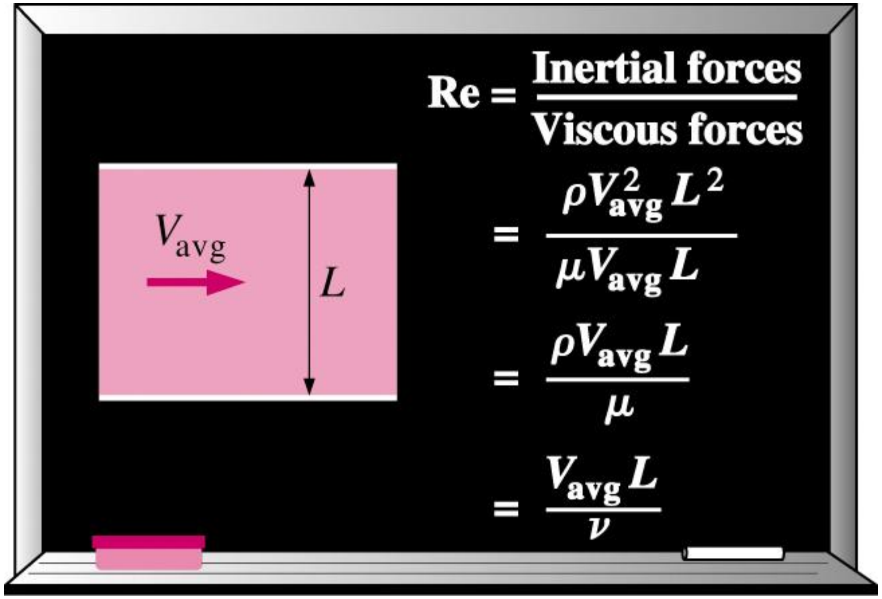
type of fluid

Ratio of the inertial forces to viscous forces in the fluid

$$\mathrm{Re} = \frac{\upsilon_m D}{\nu} = \frac{\rho \upsilon_m D}{\mu}$$

υ_m	Mean flow velocity
D	Characteristic length of the geometry
$\nu = \mu / \rho$	Kinematic viscosity

Definition of Reynolds number



$$\text{Re} = \frac{\text{Inertial forces}}{\text{Viscous forces}} = \frac{\rho V_{\text{avg}}^2 L^2}{\mu V_{\text{avg}} L} = \frac{\rho V_{\text{avg}} L}{\mu} = \frac{V_{\text{avg}} L}{\nu}$$

- Critical Reynolds number (Re_{cr}) for flow in a round pipe

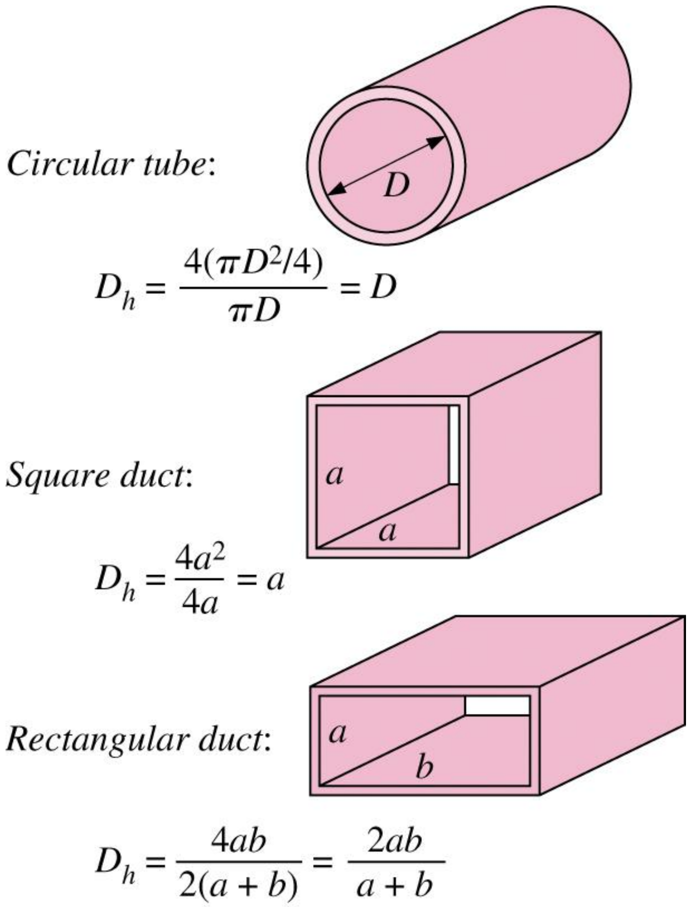
  $\text{Re} < 2300 \Rightarrow$ laminar

  $2300 \leq \text{Re} \leq 4000 \Rightarrow$ transitional

  $\text{Re} > 4000 \Rightarrow$ turbulent

- Note that these values are approximate.
- For a given application, Re_{cr} depends upon
  - Pipe roughness
  - Vibrations
  - Upstream fluctuations, disturbances (valves, elbows, etc. that may disturb the flow)

HYDRAULIC DIAMETER



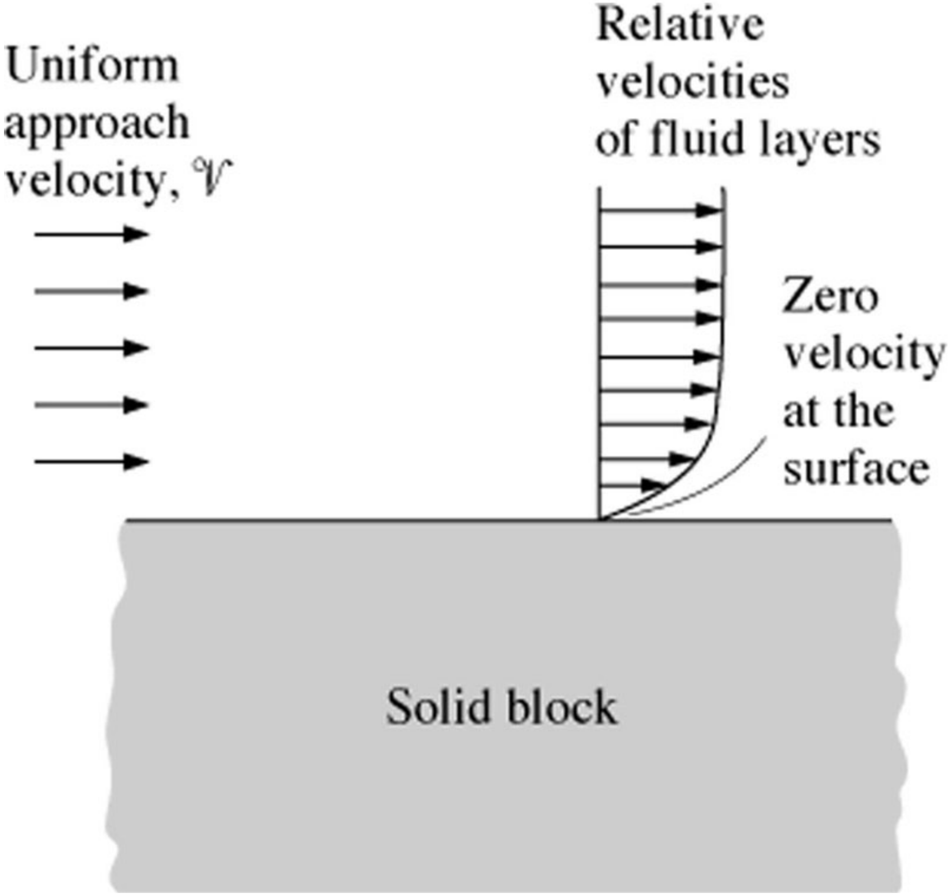
- For <u>non-round</u> pipes,
- the hydraulic diameter $D_h = 4A_c/P$

  A_c = cross-section area

  P = wetted perimeter

Velocity

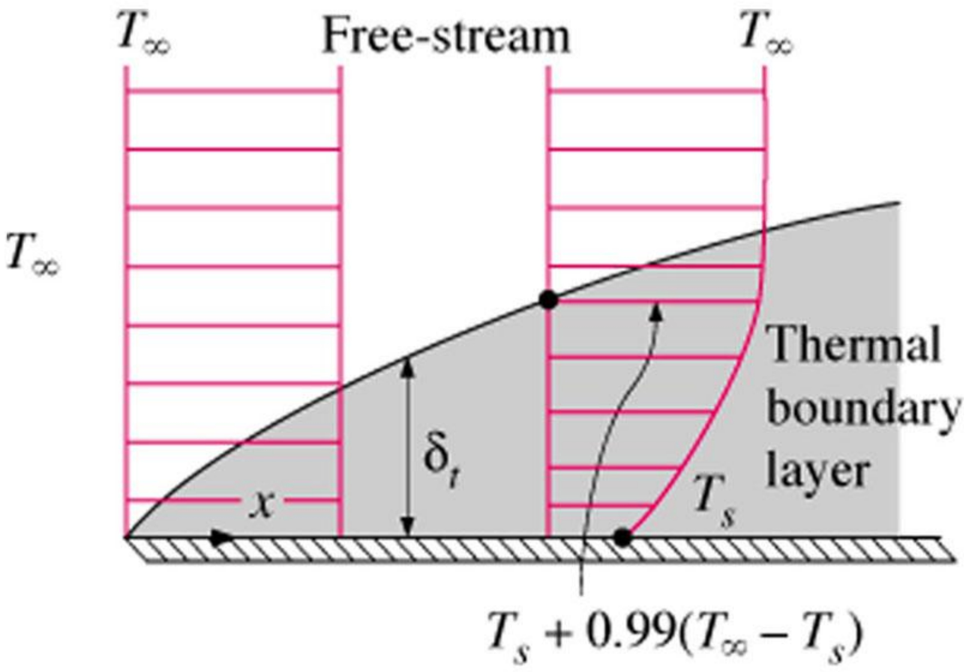
No-slip condition



THERMAL BOUNDARY LAYER

Flow region over the surface in which the temperature variation in the direction normal to the surface

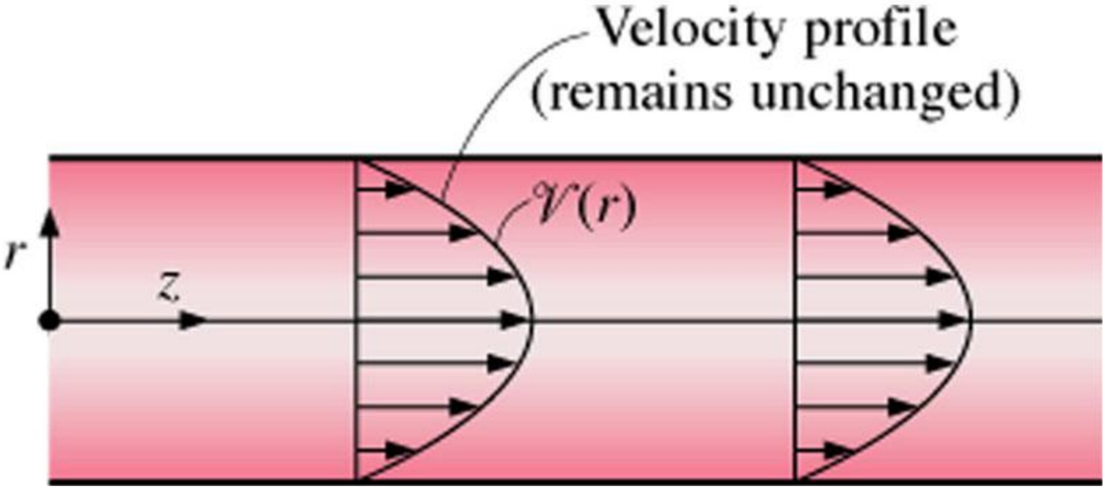
Velocity profile influences temperature profile



VELOCITY

A flow field is best characterized by the velocity distribution, and velocity may vary in three dimension

$\vec{\upsilon}(x, y, z)$ in rectangular $\vec{\upsilon}(r, \theta, z)$ in cylinderical coordinates

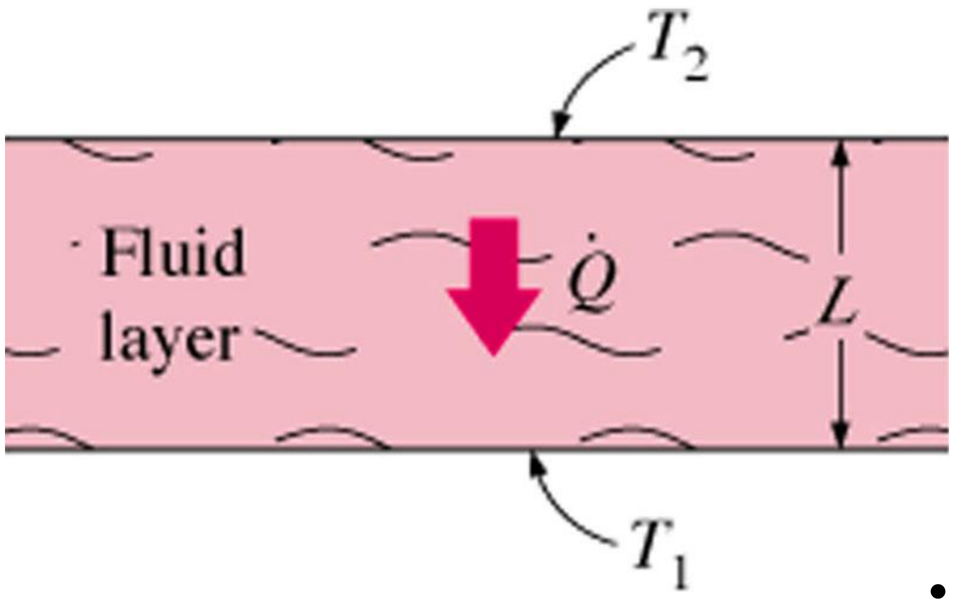


One dimensional flow in a circular pipe

In which direction does the velocity change in this figure???

NUSSELT NUMBER

(Dimensionless number)



$\Delta T = T_2 - T_1$

$$Nu = \frac{hL_c}{k}$$

$$\dot{q}_{cond} = k\frac{\Delta T}{L}$$

$$\dot{q}_{conv} = h\Delta T$$

$$\frac{\dot{q}_{conv}}{\dot{q}_{cond}} = \frac{h\Delta T}{k\Delta T / L} = \frac{hL}{k} = Nu$$

PRANDTL NUMBER

- Boundary layer theory

$$\Pr = \frac{\mu C_p}{k}$$

$$\Pr = \frac{molecular \quad diffusivity \quad of \quad momentum}{molecular \quad diffusivity \quad of \quad heat} = \frac{\nu}{\alpha} = \frac{\mu C_p}{k}$$

Pr<<1 heat diffuses very quickly in liquid metals, *tbl* thicker

Pr>>1 heat diffuses very slowly in oils relative to momentum, *tbl* thinner than *vbl*

PARALLEL FLOW OVER FLAT PLATES

$$\mathrm{Re}_{cr} = \frac{\rho \upsilon\, x_{cr}}{\mu} = 5 \times 10^5$$

$$Nu = \frac{hL}{k} = 0.664 \quad \mathrm{Re}_L^{0.5}\, \mathrm{Pr}^{1/3}$$ $\mathrm{Re}_L < 5 \times 10^5$ laminar

$$Nu = \frac{hL}{k} = 0.037 \quad \mathrm{Re}_L^{0.8}\, \mathrm{Pr}^{1/3}$$ $0.6 \leq \mathrm{Pr} \leq 60$ turbulent

$5 \times 10^5 \leq \mathrm{Re}_L \leq 10^7$

NATURAL CONVECTION

CONVECTIVE HEAT TRANSFER COEFFICIENT

Coefficient of volume expansion

Grashof number

$$Gr_L = \frac{g\beta(T_s - T_\infty)L_C^3}{\upsilon^2}$$

viscosity

Rayleigh number

$$Ra_L = Gr_L \Pr$$

Prandtl number

Nusselt number

$$Nu = \frac{hL_C}{k} = CRa_L^n$$

Table 20-1