Forced Convection

Dr. Majid H. Majeed

Forced Convection on Flat Plate

- **Laminar Flow** Re=$\frac{\rho L u}{\mu} = \frac{L.u}{\nu}$
- $Re < 5 \times 10^5$
- Boundary layer thickness $\delta = \frac{4.91x}{\sqrt{Re_x}}$
- Local Drag of friction coefficient $C_{dx} = \frac{0.664}{\sqrt{Re_x}}$
- Local Nusult number
  Nu $=0.332(Re)^{1/2}(Pr)^{1/3}$

- The mean value along the plate length
- $\bar{C}_{DL} = \frac{1.332}{\sqrt{Re_L}}$ for Re < 5x10^5
- $\overline{Nu} = 0.664(Re)^{1/2}(Pr)^{1/3}$
- Pr=$\frac{\mu.Cp}{k} = \frac{\rho \mathrm{V} Cp}{k}$
- Nu=$\frac{h.L}{k}$.
- To find the heat transfer coefficient $\bar{h} = \frac{Nu.k}{L}$
- $\dot{Q} = \bar{h}A(T_s - T_\infty)$
- The properties are evaluated at Film temperature
- $T_F = \frac{T_S + T_\infty}{2}$

Flow on Flat Plate

- Turbulent flow Re> $5x110^5$
- $\delta = \frac{0.38x}{\sqrt{Re_x}}$ and
- $\overline{C_d}$=$\frac{0.074}{\sqrt{Re_l}}$ $5\times 10^5 \leq Re_L \leq 10^7$
- $Nu_x = 0.0296(Re_x)^{0.8}(Pr)^{1/3}$
- $$\begin{Bmatrix} 0.6 \leq Pr \leq 60 \\ 5 \times 10^5 \leq Re_x \leq 10^7 \end{Bmatrix}$$

- Turbulent mean Nusselt
- Nu=$0.037(Re_L)^{0.8}(Pr)^{1/3} \begin{Bmatrix} 0.6 \le Pr \le 60 \\ 5 \times 10^5 \le 10^7 \end{Bmatrix}$
- For total the plate the average in laminar and turbulent Region
- Nu=$(0.037(Re_L)^{0.8} - 871)(Pr)^{1/3}$
- $\begin{Bmatrix} 0.6 \le Pr \le 60 \\ 5 \times 10^5 \le 10^7 \end{Bmatrix}$

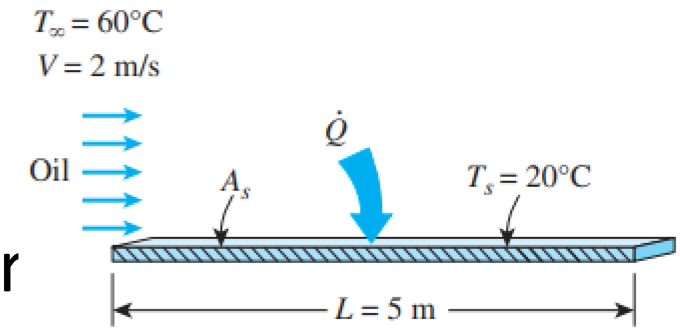
Ex.1 Engine oil at 60^oC flows over the upper surface of a 5m long flat plate whose temperature is 20^oC with a velocity of 2m/s. Determine the total drag force and the rate of heat transfer per unit width of the entire plate.

Solution: $T_\infty = 60^oC$

$T_\infty = 20^oC$, L=5m, u=2m/s

Film temperature $T_F = \frac{T_S + T_\infty}{2}$

$T_F = \frac{20+60}{2} = 30^oC$, The proper



ρ=876kg/ m^3, k=0.1444W/m.k, Pr=2962, ν=2.485x$10^{-4} m^2/s$

- Re=$\frac{L.u}{\nu} = \frac{5\times2}{2.485\times10^{-4}} = 4.0 \times 10^4 < 5\times 10^5$

The flow is laminar

$$\overline{C_{DL}} = \frac{1.332}{\sqrt{Re_L}} = \frac{1.332}{\sqrt{4.0 \times 10^4}} = 0.00666$$

The Drug Force

$$F_D = \overline{C_{DL}} A \frac{\rho u^2}{2} = 0.00666(5 \times 1)\frac{876\times2^2}{2} = 58.34N$$

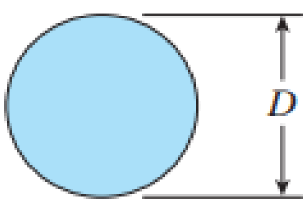
$$\overline{Nu} = 0.664(Re)^{0.5}(Pr)^{1/3} =$$
$$0.664(40000)^{0.5}(2962)^{1/3} = 1907.2$$

$$\bar{h} = \frac{Nu.k}{L} = \frac{1907.2 \times 0.1444}{5.0} = 55.1W/m^2.^o\,C$$

$$\dot{Q} = A\bar{h}(T_\infty - T_s) = (5 \times 1)55.1(60 - 20) = 11020W$$

Heat transfer from cylinders

- For heat transfer from cylinder with cross flow on it $Nu_{cyl} = \frac{h.D}{k} = C(Re)^m (Pr)^{1/3}$

Cross-section of the cylinder	Fluid	Range of Re	Nusselt number
Circle 	Gas or liquid	0.4–4	$Nu = 0.989Re^{0.330} Pr^{1/3}$
		4–40	$Nu = 0.911Re^{0.385} Pr^{1/3}$
		40–4000	$Nu = 0.683Re^{0.466} Pr^{1/3}$
		4000–40,000	$Nu = 0.193Re^{0.618} Pr^{1/3}$
		40,000–400,000	$Nu = 0.027Re^{0.805} Pr^{1/3}$

- This table is used with upper relation

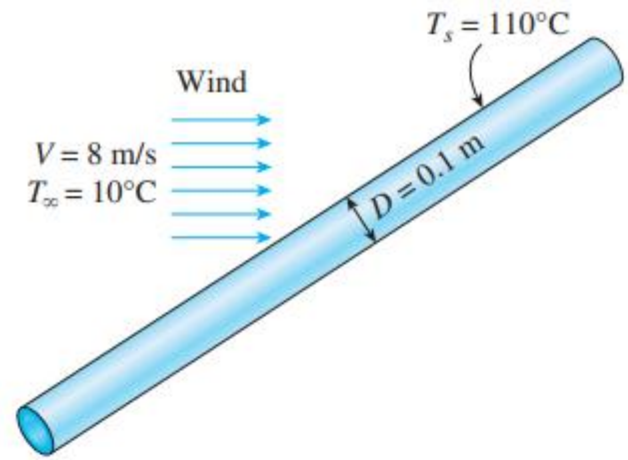
Ex.2. A long 10cm diameter pipe whose external surface temperature is 110^oC, passes through some open area that not protected against the winds. Determine the rate of heat loss from the pipe per unit length when the air at 1atm pressure and 10^oC and the wind is blowing across the pipe at a velocity of 8m/s.

Solution: The pipe is shown in Fig.

$T_s = 110^oC, T_\infty = 10^oC,$

D=0.1m, u=8m/s

$$T_s = \frac{T_s+T_\infty}{2} = \frac{110+10}{2} = 60^oC$$



The Properties of air is evaluated at $T_f = 60^o C$

Pr=0.7202, k=0.02808W/m.K, ν=1.896x$10^{-5} m^2/s$

Re=$\frac{D.u}{\nu} = \frac{0.1\times 8}{1.896\text{x}10^{-5}} = 4.226 \times 10^4$

C=0.027, m=0.805

$$Nu = 0.027(Re)^{.805}(Pr)^{1/3}$$
$$= 0.027(4.226 \times 10^4)^{.805}(0.7202)^{1/3}$$
$$= 128.15$$

$$h = \frac{Nu.k}{d} = \frac{128.15 \times 0.02808}{0.1} = 36W/m^2k$$

$\dot{Q} = Ah(T_s - T_\infty) =$
$(\pi dl)h(T_s - T_\infty)$=$(0.1\pi \times 1)36(110 - 10) =$
$1131W$