HeKy

٢٢٧ 2019/3/5

Non-dimensional Groups

In convection, it is a common practice to non-dimensionalize the governing equations and combine the variables which group together into dimensionless numbers (groups).

Nusselt number: non-dimensional heat transfer coefficient

$$\boxed{Nu = \frac{h\delta}{K}}$$

where δ is the characteristic length, i.e. D for the tube and L for the flat plate. Nusselt number represents the enhancement of heat transfer through a fluid as a result of convection relative to conduction across the same fluid layer.

Reynolds number: ratio of inertia forces to viscous forces in the fluid

$$Re = \frac{inertia\ forced}{viscus\ forced} = \frac{\rho u \delta}{\mu}$$

At large Re numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces; thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid (turbulent regime).

Prandtl number: is a measure of relative thickness of the velocity and thermal boundary layer

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

laminar turbulent

where fluid properties are:

mass density : ρ, (kg/m^3) specific heat capacity : C_p ($J/kg \cdot K$)

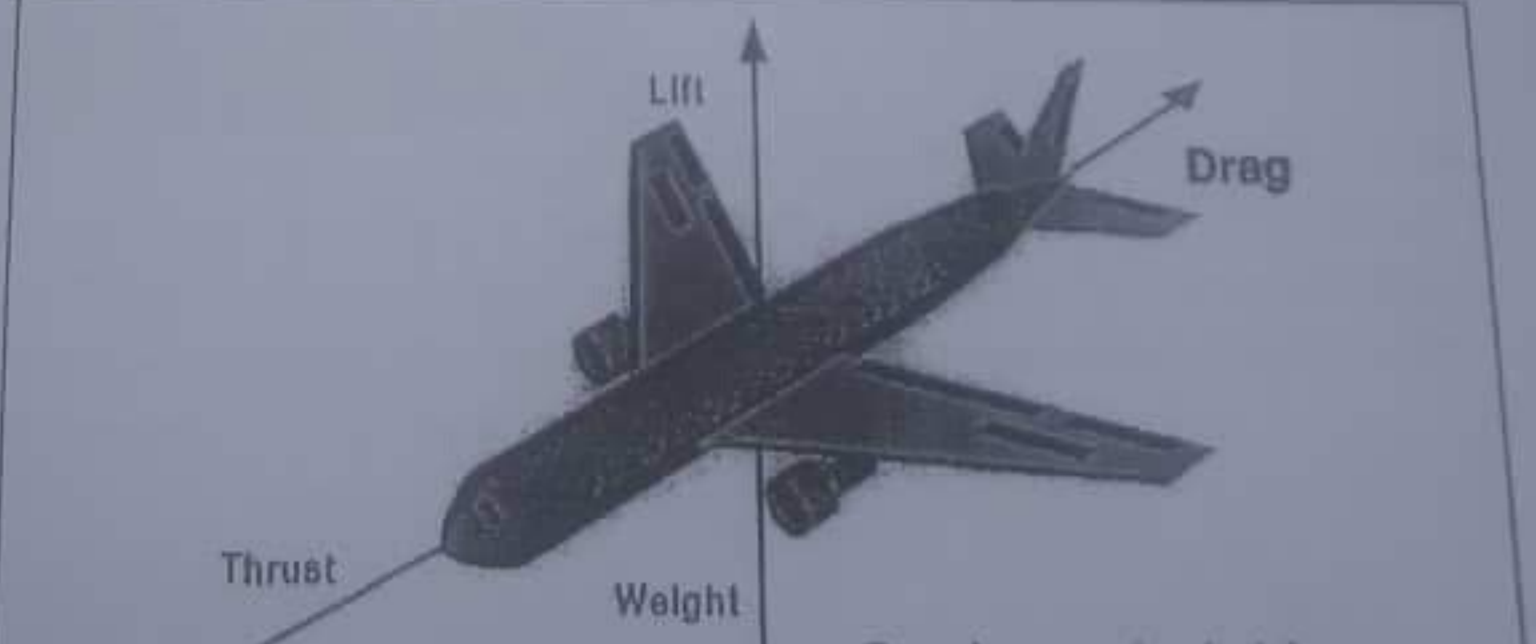
dynamic viscosity : μ, ($N \cdot s/m^2$) kinematic viscosity : ν, μ/ρ (m^2/s)

thermal conductivity : k, ($W/m \cdot K$) thermal diffusivity : α, $k/(\rho \cdot C_p)$ (m^2/s)

What is Drag?

Drag is a mechanical force. It is generated by the interaction and contact of a solid body with a fluid. For drag to be generated, the solid body must be in contact with the fluid. If there is no fluid, there is no drag. Drag is generated by the difference in velocity between the solid object and the fluid. There must be motion between the object and the fluid. If there is no motion, there is no drag. It makes no difference whether the object moves through a static fluid or whether the fluid object moves past a static solid object. Drag acts in a direction that opposes the motion. (Lift acts perpendicular to the motion.)

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



Drag is a mechanical force generated by a solid object moving through a fluid.

- We can think of **drag** as friction, and one of the sources of drag is the **skin friction** between the molecules of the fluid and the solid surface of object.
- Because the skin friction is an interaction between a solid and a gas, the magnitude of the skin friction depends on properties of both solid and gas.
- For the solid, a smooth, waxed surface produces less skin friction.
- For the gas, the magnitude depends on the viscosity of the air
- This source of drag depends on the shape of the aircraft and is called **form drag**.
- As air flows around a body, the local velocity and pressure are changed. A varying pressure distribution will produce a force on the body.
- We can determine the magnitude of the force by integrating (or adding up) the local pressure times the surface area around the entire body.
- The component of the force that is opposed to the motion is the drag;
- The component perpendicular to the motion is the lift.

Factors that affect drag

Aircraft geometry has a large effect on the amount of drag generated. As with lift, the drag depends linearly on the size of the object moving through the air. The cross-sectional shape of an object determines the **form drag** created by the pressure variation around the object.

If we think of drag as aerodynamic friction, then the amount of drag depends on the surface roughness of the object; a smooth, waxed surface will produce less drag than a roughened surface. This effect is called **skin friction** and is usually included in the drag coefficient.

Motion of the Air

Drag is associated with the movement of the aircraft through the air, so drag will then depend on the velocity of the air. Like lift, drag actually varies with the square of the velocity between the object and the air. How the object is inclined to the flow will also affect the amount of drag generated. If the object moves through the air at speeds near the speed of sound, shock waves may be formed on the object which create an additional drag component called **wave drag**. The motion of the object through the air also causes boundary layers to form on the object. A boundary layer is a region of very low speed flow near the surface which contributes to the **skin friction**.

Properties of the Air

Drag depends directly on the mass of the flow going past the aircraft. The drag also depends in a complex way on two other properties of the air: its viscosity and its compressibility. These factors affect the **wave drag** and **skin friction** which are described above.

We can gather all of this information on the factors that affect drag into a single mathematical equation called the Drag Equation. With the drag equation we can predict how much drag force will be generated by a given body moving at a given speed through a given fluid.

Friction and Pressure Drag

The drag force is the net force exerted by a fluid on a body in the direction of flow due to the combined effects of wall shear and pressure forces. The part of drag that is due directly to wall shear stress τ_w is called the skin friction drag (or just friction drag) since it is caused by frictional effects, and the part that is due directly to pressure P is called the pressure drag (also called the form drag because of its strong dependence on the form or shape of the body).

When the friction and pressure drag coefficients are available, the total drag coefficient is determined by simply adding them, The drag force F_D depends on the density of the fluid, the upstream

$$C_D = C_{D,friction} + C_{D,pressure}$$

velocity, and the size, shape, and orientation of the body, among other things.

The drag characteristics of a body is represented by the dimensionless drag coefficient C_D defined as

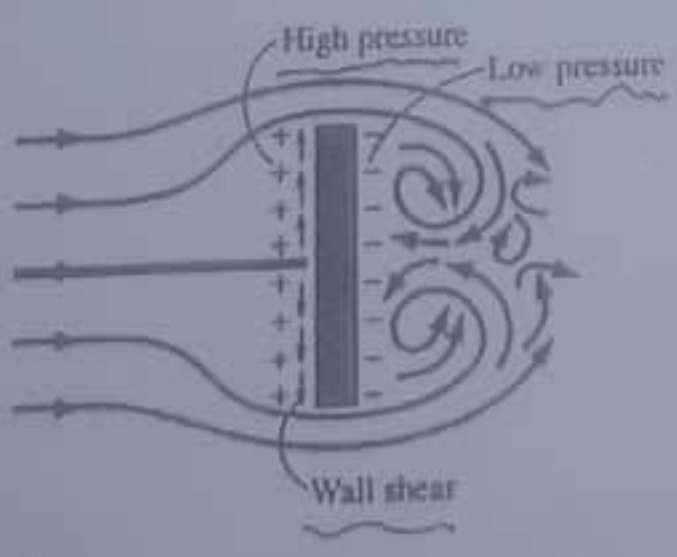
$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$$

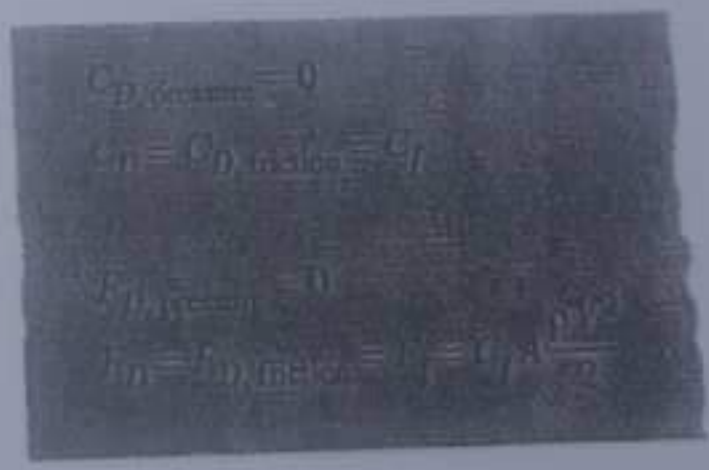
- **Frictional drag comes from friction** between the fluid and the surfaces over which it is flowing. This friction is associated with the development of boundary layers, and it scales with Reynolds number as we have seen above.
- **Pressure drag comes from the eddying motions** that are set up in the fluid by the passage of the body. This drag is associated with the formation of a wake.
- **Formally, both types of drag are due to viscosity** (if the body was moving through an inviscid fluid there would be no drag at all), **but the distinction is useful because the two types of drag are due to different flow phenomena.**
- Frictional drag is important for attached flows (that is, there is no separation), and it is related to the surface area exposed to the flow. Pressure drag is important for separated flows, and it is related to the cross-sectional area of the body.

For the flow of an "idealized" fluid with zero viscosity past a body, both the friction drag and pressure drag are zero regardless of the shape of the body.

$F_D = 0$ if $\mu = 0$

Two Opposite Situation





Drag force acting on a flat plate normal to flow depends on the pressure only and is independent of the wall shear, which acts normal to flow

For parallel flow over a flat plate, the pressure drag is zero, and thus the drag coefficient is equal to the friction coefficient and the drag force is equal to the friction force

The average friction coefficient over the entire plate is determined by

Laminar: $C_f = \frac{1.328}{Re_L^{1/2}}$ $\quad \boxed{Re_L < 5 \times 10^5}$

Turbulent: $C_f = \frac{0.074}{Re_L^{1/5}}$ $\quad \boxed{5 \times 10^5 \leq Re_L \leq 10^7}$

In some cases, a flat plate is sufficiently long for the flow to become turbulent, but not long enough to disregard the laminar flow region

$$\boxed{C_f = \frac{1}{L}\left(\int_0^{x_{cr}} C_{f,x\text{ laminar}}\,dx + \int_{x_{cr}}^{L} C_{f,x,\text{ turbulent}}\,dx\right)}$$

$$C_f = \frac{1}{L}\int_0^L C_{f,x}\,dx = \frac{1}{L}\int_0^L \frac{0.664}{Re_x^{1/2}}\,dx = \frac{0.664}{L}\left(\frac{V}{\nu}\right)^{-1/2}\int_0^L x^{-1/2}\,dx = \frac{0.664}{L}\left(\frac{V}{\nu}\right)^{-1/2}\left[\frac{x^{1/2}}{\frac{1}{2}}\right]_0^L = \frac{2 \times 0.664}{L}\left(\frac{VL}{\nu}\right)^{-1/2} = \frac{1.328}{Re_L^{1/2}}$$

The average friction coefficient over the entire plate is determined to be

$$C_f = \frac{0.074}{Re_L^{1/5}} - \frac{1742}{Re_L} \qquad 5 \times 10^5 \leq Re_L \leq 10^7$$

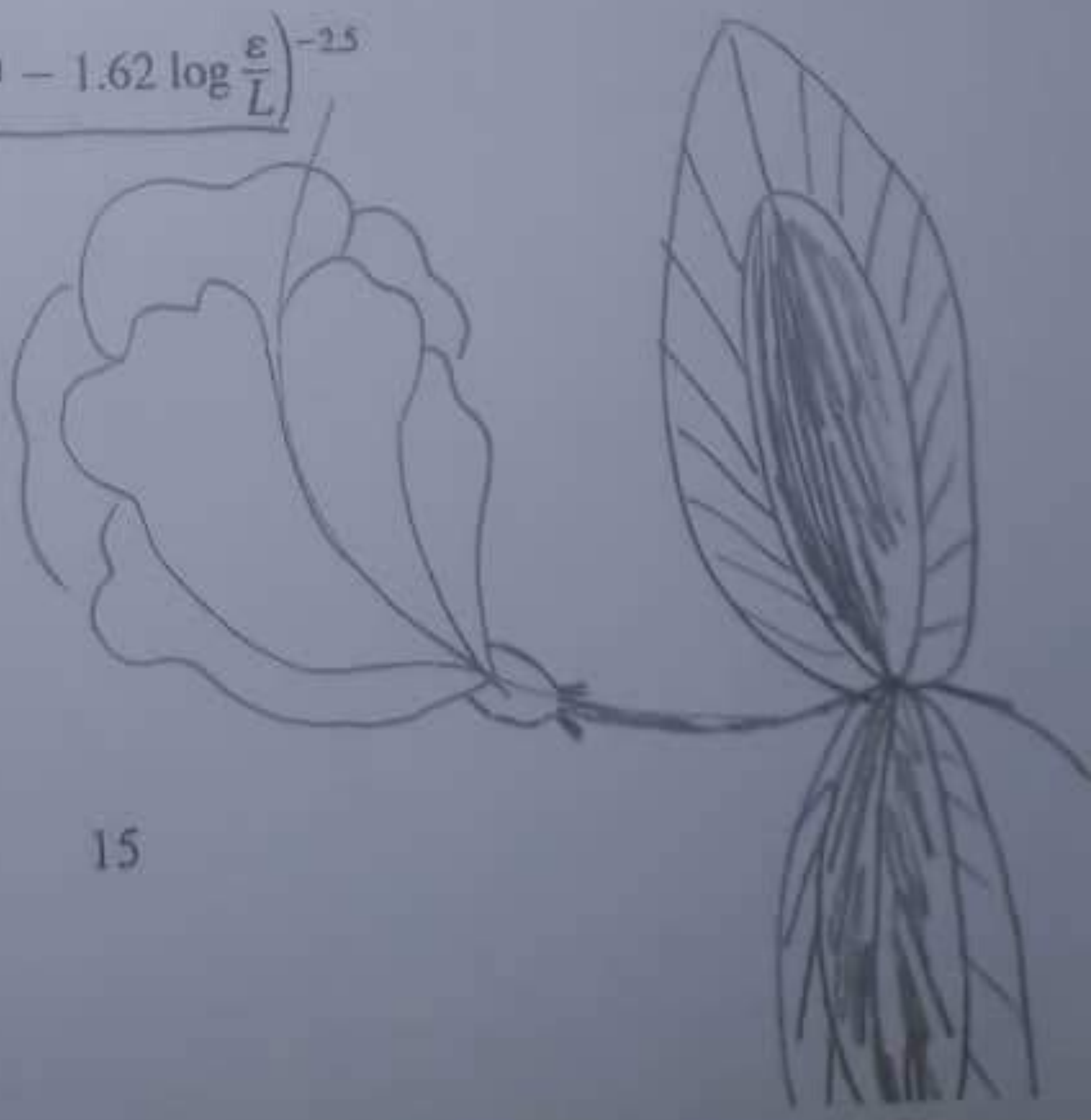
C_f for turbulent flow

For laminar flow, the friction coefficient depends on only the Reynolds number, and the surface roughness has no effect.
For turbulent flow, however, surface roughness causes the friction coefficient to increase severalfold, to the point that in fully turbulent regime the friction coefficient is a function of surface roughness alone, and independent of the Reynolds number

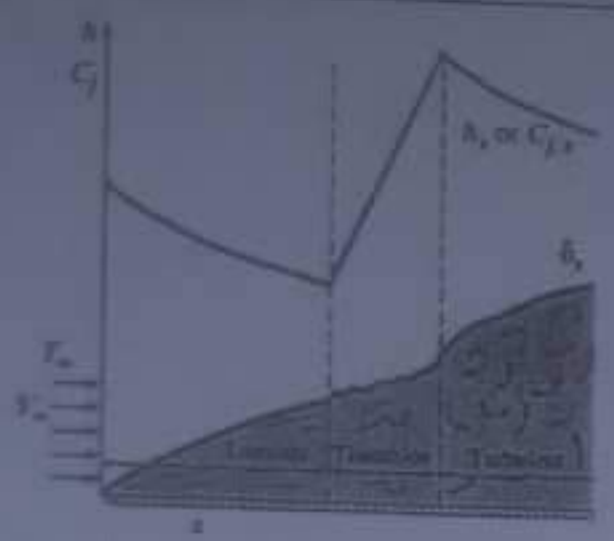
Relative roughness, ε/L	Friction coefficient C_f
0.0*	0.0029
1×10^{-5}	0.0032
1×10^{-4}	0.0049
1×10^{-3}	0.0084

*Smooth surface for $Re = 10^7$. Others calculated from Eq. 7-18.

Rough surface, turbulent: $\quad C_f = \left(1.89 - 1.62 \log \frac{\varepsilon}{L}\right)^{-2.5}$



Variation with x



Laminar flow	$Nu_x = \frac{h_x x}{k} = 0.332 Re_x^{0.5} . Pr^{1/3}$	$Pr > 0.6$
	$C_{f,x} = \frac{0.664}{Re_x^{1/2}}$	$Re_x < 5 \times 10^5$
Turbulent flow	$Nu_x = \frac{h_x x}{k} = 0.0296 Re_x^{0.8} . Pr^{1/3}$	$0.6 \le Pr \le 60$ $5 \times 10^5 \le Re_x \le 10^7$
	$C_{f,x} = \frac{0.0592}{Re_x^{1/5}}$	$5 \times 10^5 \le Re_x \le 10^7$

plate

Average Coefficient

$Rc = \frac{\rho u x_{cr}}{\mu}$

Average quantities

$$C_D = \frac{1}{L}\int_0^L C_{D,x} dx$$

$$h = \frac{1}{L}\int_0^L h_x dx$$

$Nu = 0.03 Re_L^{0.8} Pr^{1/3}$

Laminar flow	$Nu = \frac{hL}{k} = 0.664 Re_L^{0.5} . Pr^{1/3}$	$Pr > 0.6$ $Re_x < 5 \times 10^5$
Turbulent flow	$Nu = \frac{hL}{k} = 0.037 Re_L^{0.8} . Pr^{1/3}$	$0.6 \le Pr \le 60$ $5 \times 10^5 \le Re_x \le 10^7$

h for combined laminar and turbulent flow

In some cases, a flat plate is sufficiently long for the flow to become turbulent, but not long enough to disregard the laminar flow region

$$\boxed{h = \frac{1}{L}\left(\int_0^{x_{cr}} h_{x,laminar} dx + \int_{x_{cr}}^{L} h_{x,turbulent} dx\right)}$$

The average h over the entire plate is determined to be

Turbulent flow $\quad Nu = \frac{h.L}{k} = \left(0.037\,Re_L^{0.8} - 871\right) Pr^{1/3}$ $\quad 0.6 \le Pr \le 60$, $5 \times 10^5 \le Re_L \le 10^7$

كامل

Taking the critical Reynolds number to be $Re_{cr} = 5 \times 10^5$

Liquid metals such as mercury have high thermal conductivities. However, they have very small Prandtl numbers, and thus the thermal boundary layer develops much faster than the velocity boundary layer. Then we can assume the velocity in the thermal boundary layer to be constant at the free stream value and solve the energy equation. It gives

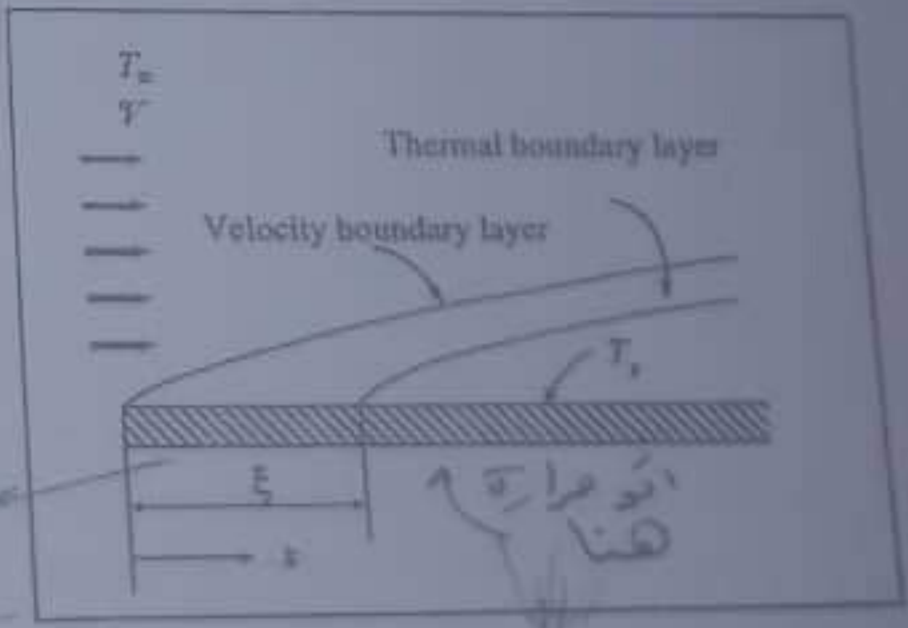
$$Nu_x = \frac{h_x.x}{k} = 0.565\left(Re_x.Pr\right)^{1/2} \qquad \boxed{Pr < 0.05}$$

It is desirable to have a single correlation that applies to all fluids, including liquid metals

Churchill and Ozoe : $\quad Nu_x = \frac{h_x.x}{k} = \frac{0.3387\,Re_x^{0.5}.Pr^{1/3}}{\left[1+\left(0.0468/Pr\right)^{2/3}\right]^{1/4}}$

Applicable for all Prandtl numbers and is claimed to be accurate to 1%.

Flat plate with unheated starting length



Using integral solution methods, the local Nusselt numbers for both laminar and turbulent flows are determined to be

باردة ماكو حرارة

Laminar: $\quad Nu_x = \frac{Nu_{x\,(\text{for } \xi=0)}}{[1-(\xi/x)^{3/4}]^{1/3}} = \frac{0.332\,Re_x^{0.5}\,Pr^{1/3}}{[1-(\xi/x)^{3/4}]^{1/3}}$

Turbulent: $\quad Nu_x = \frac{Nu_{x\,(\text{for } \xi=0)}}{[1-(\xi/x)^{9/10}]^{1/9}} = \frac{0.0296\,Re_x^{0.8}\,Pr^{1/3}}{[1-(\xi/x)^{9/10}]^{1/9}}$

The determination of the average Nusselt number for the heated section of a plate requires the integration of the local Nusselt number

Laminar:

$$\bar{h} = \frac{2[1-(\xi/x)^{3/4}]}{1-\xi/L} h_{x=L}$$

Turbulent:

$$\bar{h} = \frac{5[1-(\xi/x)^{9/10}]}{4(1-\xi/L)} h_{x=L}$$

Uniform Heat Flux

When a flat plate is subjected to *uniform heat flux* instead of uniform temperature, the local Nusselt number is given by

Laminar:

$$Nu_x = 0.453\, Re_x^{0.5}\, Pr^{1/3}$$

Turbulent:

$$Nu_x = 0.0308\, Re_x^{0.8}\, Pr^{1/3}$$

For Unheated starting length, the same relation used for constant temperature boundary condition can be used for constant heat flux condition

$$Nu_x = \frac{Nu_{x(\text{for } \xi=0)}}{\left[1-\left(\frac{\xi}{x}\right)^{3/4}\right]^{1/3}} \longleftarrow Nu_x = 0.453 Re_x^{0.5} Pr^{1/3}$$

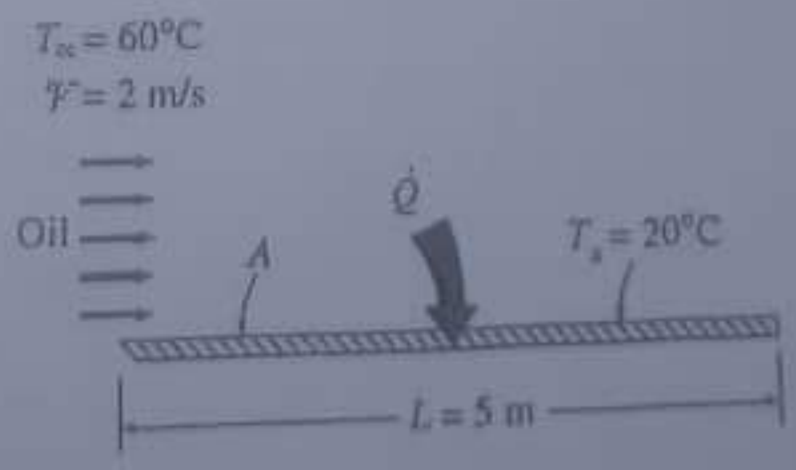
$$Nu_x = \frac{Nu_{x(\text{for } \xi=0)}}{\left[1-\left(\frac{\xi}{x}\right)^{9/10}\right]^{1/9}} \longleftarrow Nu_x = 0.0308 Re_x^{0.8} Pr^{1/3}$$

When heat flux $\dot{q}_s$ is prescribed, the rate of heat transfer to or from the plate and the surface temperature at a distance x are determined from

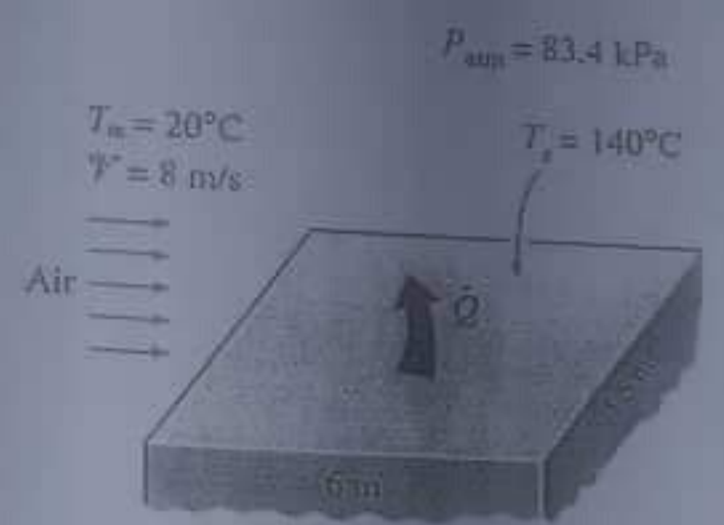
$$\dot{Q} = \dot{q}_s A_s$$

$$\dot{q}_s = h_x[T_s(x) - T_\infty] \longrightarrow T_s(x) = T_\infty + \frac{\dot{q}_s}{h_x}$$

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



Ex₂: The local atmospheric pressure in Denver, Colorado (elevation 1610 m), is 83.4 kPa. Air at this pressure and 20°C flows with a velocity of 8 m/s over a 1.5 m x 6 m flat plate whose temperature is 140°C . Determine the rate of heat transfer from the plate if the air flows parallel to the (*a*) 6-m-long side and (*b*) the 1.5-m side.



Sheet No.2 External forced convection

Q1: During a cold winter day, wind at 55 km/h is blowing parallel to a 4-m-high and 10-m-long wall of a house. If the air outside is at 5°C and the surface temperature of the wall is 12°C, determine the rate of heat loss from that wall by convection. What would your answer be if the wind velocity was doubled?

Q2: A 15-cm x15-cm circuit board dissipating 15 W of power uniformly is cooled by air, which approaches the circuit board at 20°C with a velocity of 5 m/s. Disregarding any heat transfer from the back surface of the board, determine the surface temperature of the electronic components (*a*) at the leading edge and (*b*) at the end of the board. Assume the flow to be turbulent since the electronic components are expected to act as turbulators.

Q3: Air at 25°C and 1 atm is flowing over a long flat plate with a velocity of 8 m/s. Determine the distance from the leading edge of the plate where the flow becomes turbulent, and the thickness of the boundary layer at that location.

Q4: Consider a hot automotive engine, which can be approximated as a 0.5-m-high, 0.40-m-wide, and 0.8-m-long rectangular block. The bottom surface of the block is at a temperature of 80°C and has an emissivity of 0.95. The ambient air is at 20°C, and the road surface is at 25°C. Determine the rate of heat transfer from the bottom surface of the engine block by convection and radiation as the car travels at a velocity of 80 km/h. Assume the flow to be turbulent over the entire surface because of the constant agitation of the engine block.

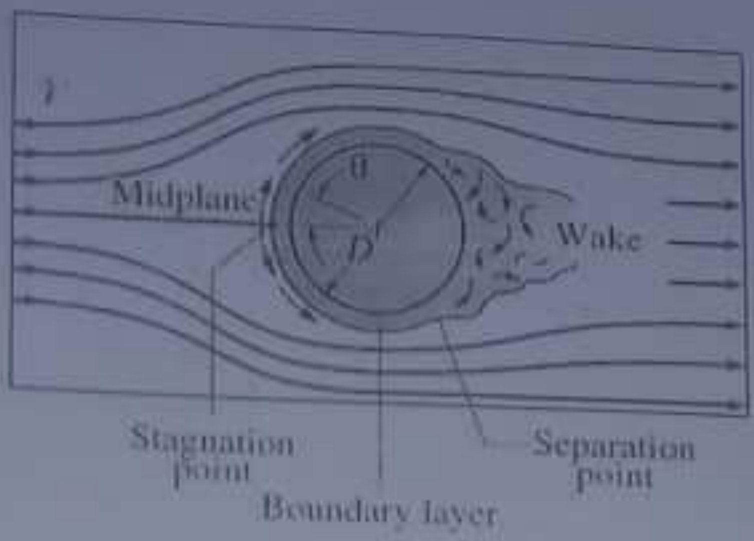
External forced convection

الجريان على الأسطوانة و الكرة

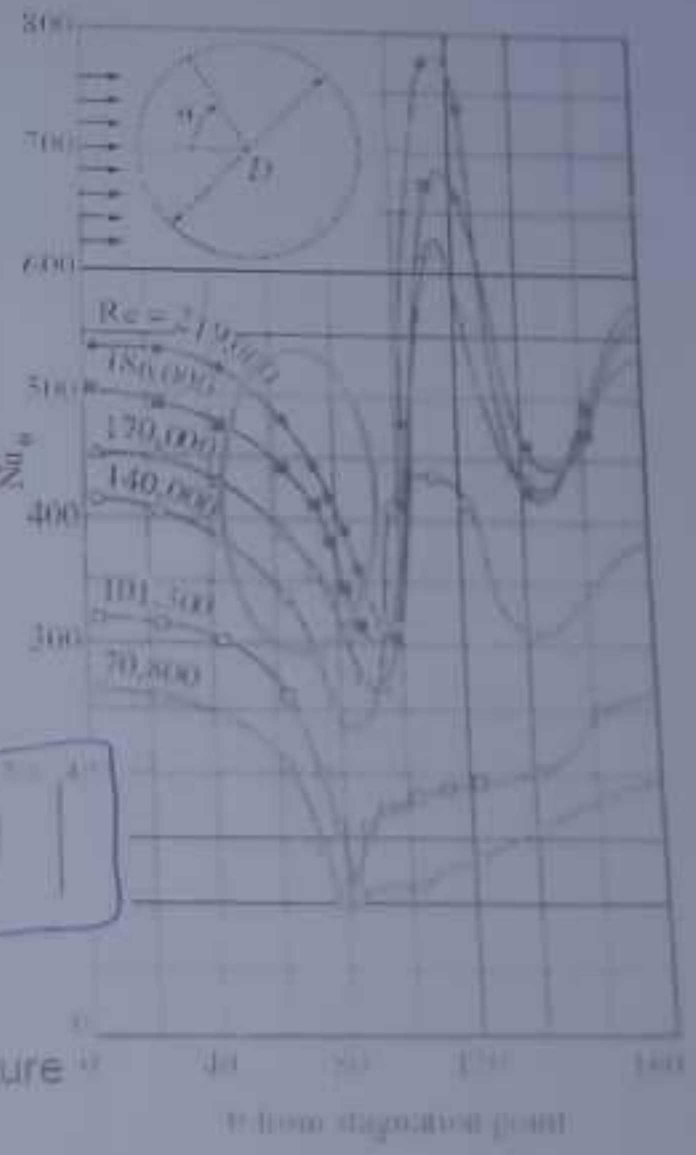
Flow over a cylinder and sphere

Flow across cylinders and spheres is frequently encountered in practice. For example, the tubes in a shell-and-tube heat exchanger involve both *internal flow* through the tubes and *external flow* over the tubes, and both flows must be considered in the analysis of the heat exchanger. Also, many sports such as soccer, tennis, and golf involve flow over spherical balls.

صناعة مطلوبة اشكال الحرارة



Nusselt number distribution



Two minima because of
(i) Laminar to Turbulent conversion
(ii) Separation point at the turbulent flow

للاطلاع

Average Nusselt number for cross flow over a cylinder, proposed by Churchill and Bernstein

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$$\boxed{Nu_{cyl} = \frac{hD}{k} = 0.3 + \frac{0.62\, Re^{1/2}\, Pr^{1/3}}{[1 + (0.4/Pr)^{2/3}]^{1/4}}\left[1 + \left(\frac{Re}{282{,}000}\right)^{5/8}\right]^{4/5}}$$

Reasonably good for Re.Pr < 0.2
Properties need to calculate at film temperature

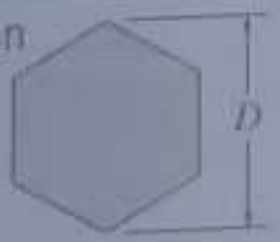
Flow over a sphere

- For flow over a sphere, Whitaker recommends the following comprehensive correlation

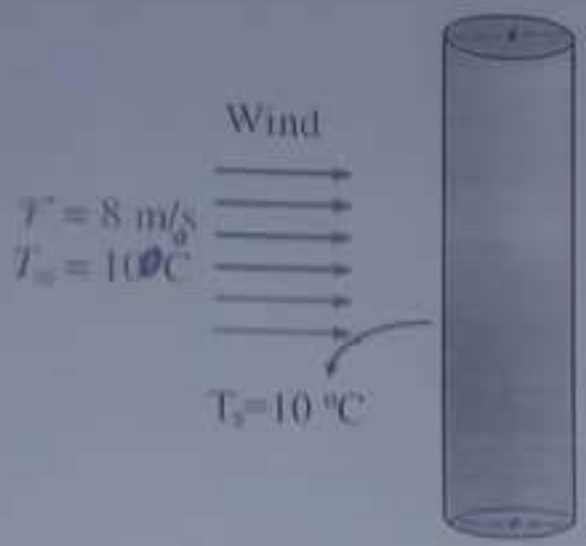
تجريبية

$$\boxed{Nu_{sph} = \frac{hD}{k} = 2 + [0.4\,Re^{1/2} + 0.06\,Re^{2/3}]\,Pr^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}}$$

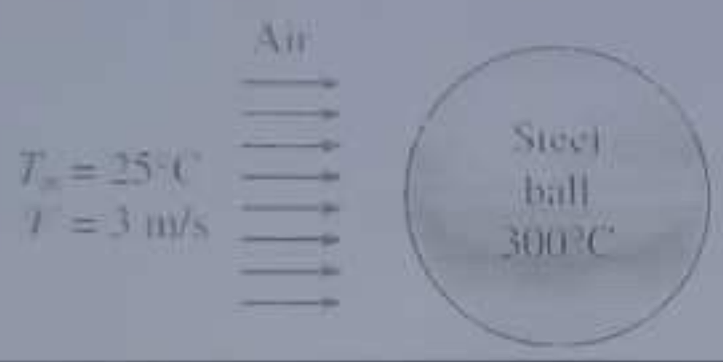
- which is valid for $3.5 \le Re \le 80{,}000$ and $0.7 \le Pr \le 380$. The fluid properties in this case are evaluated at the free-stream temperature T_∞, except for μ_s ,which is evaluated at the surface temperature T_s.
- The average Nusselt number for flow across cylinders can be expressed compactly as $Nu_{cyl} = CRe^m Pr^n$. Properties need to calculate at film temperature

Cross-section of the cylinder	Fluid	Range of Re	Nusselt number
Circle 	Gas or liquid	0.4–4 4–40 40–4000 4000–40,000 40,000–400,000	$Nu = 0.989Re^{0.330}\,Pr^{1/3}$ $Nu = 0.911Re^{0.385}\,Pr^{1/3}$ $Nu = 0.683Re^{0.466}\,Pr^{1/3}$ $Nu = 0.193Re^{0.618}\,Pr^{1/3}$ $Nu = 0.027Re^{0.805}\,Pr^{1/3}$
Square 	Gas	5000–100,000	$Nu = 0.102Re^{0.675}\,Pr^{1/3}$
Square (tilted 45°) 	Gas	5000–100,000	$Nu = 0.246Re^{0.588}\,Pr^{1/3}$
Hexagon 	Gas	5000–100,000	$Nu = 0.153Re^{0.638}\,Pr^{1/3}$
Hexagon (tilted 45°) 	Gas	5000–19,500 19,500–100,000	$Nu = 0.160Re^{0.638}\,Pr^{1/3}$ $Nu = 0.0385Re^{0.782}\,Pr^{1/3}$
Vertical plate 	Gas	4000–15,000	$Nu = 0.228Re^{0.731}\,Pr^{1/3}$
Ellipse 	Gas	2500–15,000	$Nu = 0.248Re^{[illegible]}\,Pr^{1/3}$

Ex₁: A long 10-cm-diameter steam pipe whose external surface temperature is 110°C passes through some open area that is not protected against the winds. Determine the rate of heat loss from the pipe per unit of its length when the air is at 1 atm pressure and 10°C and the wind is blowing across the pipe at a velocity of 8 m/s.



Ex₂: A 25-cm-diameter stainless steel ball ($\rho = 8055$ kg/m³, $Cp = 480$ J/kg · °C) is removed from the oven at a uniform temperature of 300°C . The ball is then subjected to the flow of air at 1 atm pressure and 25°C with a velocity of 3 m/s. The surface temperature of the ball eventually drops to 200°C. Determine the average convection heat transfer coefficient during this cooling process and estimate how long the process will take.

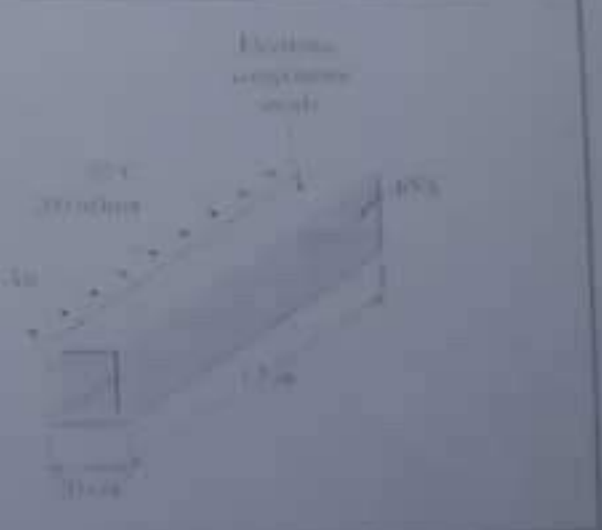


Sheet No.3 External forced convection(Cylinder and sphere)

Q1: A6-mm-diameter electrical transmission line carries an electric current of 50 A and has a resistance of 0.002 ohm per meter length. Determine the surface temperature of the wire during a windy day when the air temperature is 10°C and the wind is blowing across the transmission line at 40 km/h.

Q2: A1.8-m-diameter spherical tank of negligible thickness contains iced water at 0°C. Air at 25°C flows over the tank with a velocity of 7 m/s. Determine the rate of heat transfer to the tank and the rate at which ice melts. The heat of fusion of water at 0°C is 333.7 kJ/kg.

Q3: The components of an electronic system are located in a 1.5-m-long horizontal duct whose cross section is 20 cm 20 cm. The components in the duct are not allowed to come into direct contact with cooling air, and thus are cooled by air at 30°C flowing over the duct with a velocity of 200 m/min.
If the surface temperature of the duct is not to exceed 65°C, determine the total power rating of the electronic devices that can be mounted into the duct.



Q4: Repeat Problem Q2 for a location at 4000-m altitude where the atmospheric pressure is 61.66 kPa.

الملزمة الثالثة
ص22

Ex//1

$$T_f = \frac{T_s + T_\infty}{2}$$

$$= \frac{110+10}{2} = 60\ C^\circ$$

$k = 0.02808$ $\qquad$ $P_r = 0.7202$

$\nu = 1.896 \times 10^{-5}$

$$Re = \frac{UD}{\nu} = \frac{8(0.1)}{1.896 \times 10^{-5}} = 4.219 \times 10^{4}$$

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

$$= 0.3 + \frac{0.62\, Re^{1/2}\, P_r^{1/3}}{[1+(0.4/P_r)^{2/3}]^{1/4}} \left[1+\left(\frac{Re}{282000}\right)^{5/8}\right]^{4/5}$$

$= 124$

$$h = \frac{k}{D} Nu$$

$= 34.4\ W/m^2.C$

$A_s = \pi D L$

$= \pi(0.1)(1) = 0.314\ m^2$

$Q = h A_s (T_s - T_\infty)$

$= 34.8(0.314) \times (110-10)$

$= 1093\ W$

RAMY

$$A_s = \pi D^2$$
$$= \pi (0.25)^2$$
$$= 0.1963 \ m^2$$

$$Q_{ave} = h A_s (T_s - T_\infty)$$
$$= 13.8 (0.1963)(250 - 25)$$
$$= 610 \ W$$

$$m = \rho v = 8055 \left(\frac{1}{6} \pi (0.25)^3 \right) = 65.9 \ kg$$

$$Q_{total} = m C_p (T_2 - T_1)$$
$$= 65.9 \times (480)(300 - 25)$$
$$= 3163000 \ J$$

$$t = \frac{Q}{Q} = \frac{3163000}{610}$$
$$= 5182.24 \ sec$$
$$= 86 \ min$$

$$A_s = \pi D L$$

$$= 0.01885\ m^2$$

$$Q = h A_s (T_s - T_\infty)$$

$$T_s = T_\infty + \frac{Q}{h A_s}$$

$$= 10 + \frac{5}{146.3(0.01885)}$$

$$= 11.8\ C^\circ$$

التاريخ / /

الموضوع:

Ex// 2

ص 122

كرة قطرها D

$T_{s_{av}} = \frac{300 + 200}{2} = 250$

μ_s at 250 C $= 2.76 \times 10^{-5}$ kg/m.s

at T_∞

$k = 0.02551$

$\mu = 1.849 \times 10^{-5}$

$\nu = 1.562 \times 10^{-5}$

$P_r = 0.7296$

$R_e = \frac{UD}{\nu} = \frac{3 \times 0.25}{1.562 \times 10^{-5}}$

$= 4.802 \times 10^{4}$

$N_u = \frac{hD}{k}$

=

$N_u = 135$

$h = \frac{K}{D} N_u = 13.8$ w/m^2.c

RAMY

التاريخ / /

الموضوع

Q/1

اول خطوة لازم نحسب $\underline{\underline{T_f}}$

هنا لا نحسب لان T_s مجهولة

$Q = I^2 R$

$= (50)^2 (0.002)$

$= 5 \quad W$

كمية الحرارة المفقودة

نفرض T_s

assum $T_s = 15\ C^{\circ}$

$T_f = \frac{15+10}{2} = 12.5$

$\rho = 1.246 \qquad k = 0.02439$

$\nu = 1.426 \times 10^{-5} \qquad P_r = 0.7336$

$Re = \frac{U_\infty D}{\nu} = 4674$

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

$= 0.3 + \frac{0.62 Re^{0.5} P_r^{1/3}}{[1 + (0.4/P_r)^{2/3}]^{1/4}} \left[1 + \left(\frac{Re}{282000}\right)^{5/8}\right]^{4/5}$

$Nu = 36$

$h = \frac{k}{h} Nu = 146.3$

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