basicThermals

Heat transfer modes

Conduction

Fourier's law

Convection

Newton's law of cooling

Radiation

Stephan-Boltzman law

Dimensionless numbers

[YouTube]

	Reynold	Prantl	Grashoff	Nusselt	Reyleigh
Range	> 0	≥ 1			

Terminology

Kinematic viscosity

Represents how easily air flows due to internal resistances, independent of external forces.

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

μ is dynamic viscosity $kg.m^{-1}s^{-1}$
ρ is density kg/m^3

Dynamic viscosity

Represents how much force is needed to move one layer of fluid relative to another

$$\tau = \mu\frac{du}{dy}$$

τ is shear stress N/m^2
du/dy is velocity gradient $1/s$
μ is dynamic viscosity $Pa.s, kg./m^{-1}s^{-1}$

Reynold's number

Ratio of inertial forces to viscous forces

$$R_e = \frac{\rho V L_c}{\mu}$$

V is air velocity m/s
L_c characteristic length m
μ is dynamic viscosity of fluid $Pa.s$
ρ density of fluid

L_c depends on the flow configuration

- for pipe flow $L_c = r_{pipe}$
- for cross-flow over a cylinder (flow perpendicular to axis) $L_c = 2r_{cylinder})$

R_e **upper limit for** $\rightarrow$	**Laminar**	**Transitional**	**Turbulent**
Internal flow e.g., inside a pipe	2300	3500	> 3500
External flow e.g., over cylinder, sphere	10^5	3×10^5	$> 3 \times 10^5$
Flat plate boundary layer	$< 5 \times 10^5$	10^6	$> 10^6$

Prantl

It is the ratio of momentum diffusivity and thermal diffusivity
It relate the behavior of the thermal boundary layer and velocity boundary layer $L_{vbl}/L_{tbl} = P_r^n$

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

C_p is specific heat capacity $J.kg^{-1}K^{-1}$
μ is fluid dynamic viscosity $kg.m^{-1}s^{-1}$
k is fluid thermal conductivity $W.m^{-1}K^{-1}$

Grashof

It quantifies the ratio of buoyancy forces to viscous forces
Higher the ratio, more dominant are the buoyancy forces $\implies$ stronger natural convection

$$G_r = \frac{g\beta(T_s - T_{ambient})L_c^3}{\nu^2}$$

g gravitational constant m/s^2
$\beta = 1/T_{avg}$
T_s is surface temperature
L_c is characteristic length ^1ffba7
ν is kinematic viscosity $m^2.s$ (yes, meter squared)

Nusselt

N_u is the ratio of convection and conduction heat transfer at the layer of the fluid

$$N_u \geq 1$$

If $N_u = 1$, heat transfer only happens from conduction, i.e., no contribution from fluid motion.
The most important application of N_u is the calculation of the convective heat transfer of a fluid.

Rayleigh

Biot B_i

- Biot number is the ratio of thermal resistance for conduction inside a body to the resistance for convection at the surface of the body.
- Problems involving small Biot number ($<< 1$) are analytically simpler.
  - this makes temperature uniform inside the body
  - enabling lumped capacitance modeling for body temperature evolution

$$B_i = \frac{h}{k} L_c$$

$$L_c = \frac{Body\ volume}{Heated/cooled\ surface\ area}$$

h is convective heat transfer $W.m^{-2}K{-1}$
k is thermal conductivity $W.m^{-1}K^{-1}$
L_c is characteristic length m

How to calculate these numbers for complex shapes?

Terminologies

1. dynamic pressure
2. viscosity
   1. dynamic viscosity
   2. turbulent dynamic viscosity
3. Biot number