PERPINDAHAN PANAS

KONVEKSI

DEFINISI

- Panas yang ditransfer dari suatu permukaan / dinding ke aliran fluida atau sebaliknya

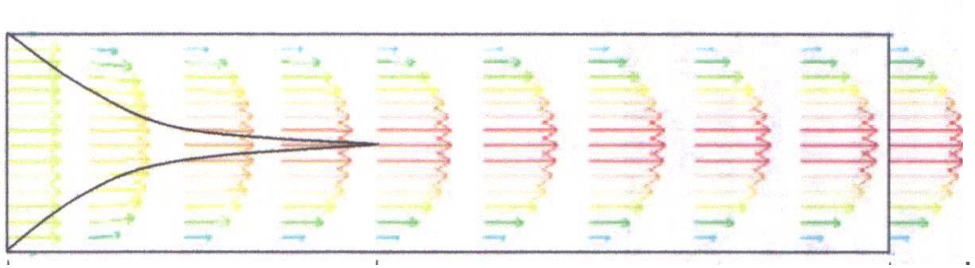
atau :

- Panas ditransfer dari suatu titik ke titik lain dalam aliran fluida

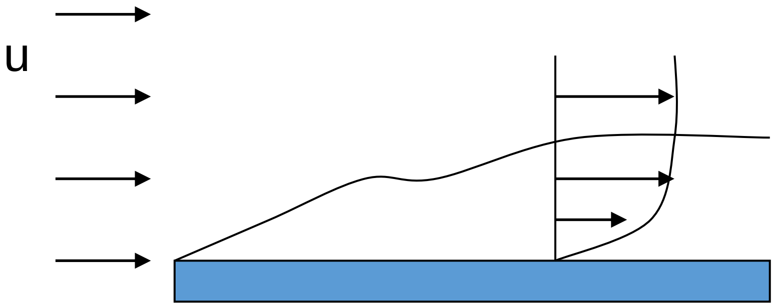
ALIRAN FLUIDA

- Terbagi atas :

  aliran internal (mis. dalam pipa)

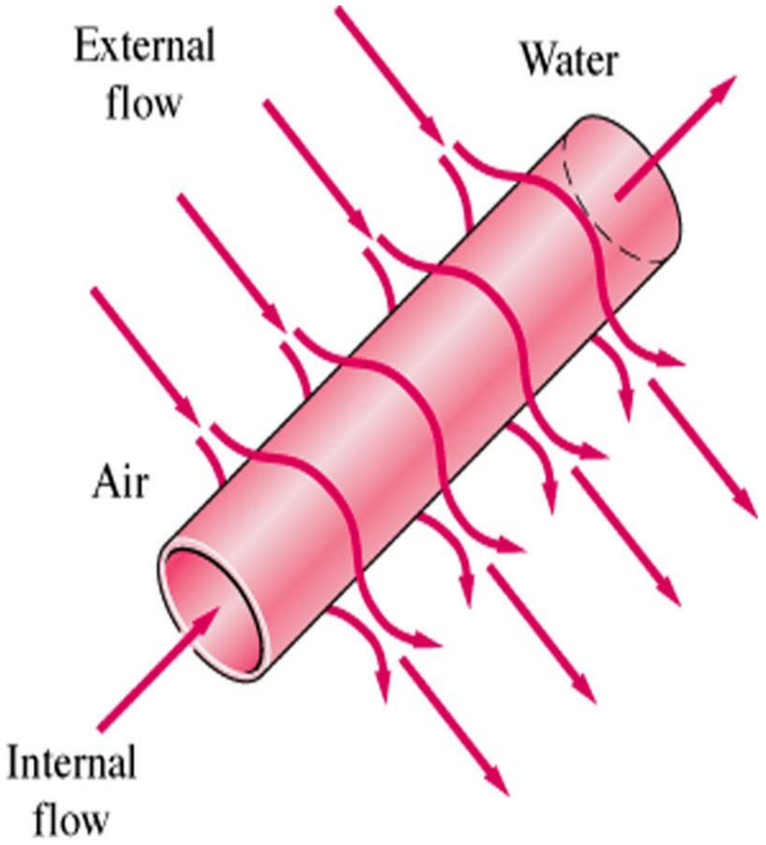


  aliran eksternal (mis. dekat dinding)



CLASSIFICATION OF FLUID FLOWS

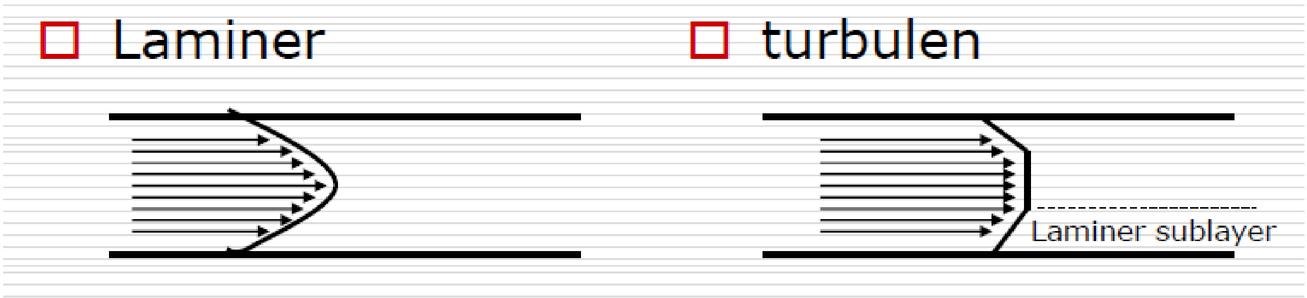
- Viscous / inviscid
- Internal / External flow
- Open-closed channel
- Compressible / Incompressible
- Laminar /Turbulent
- Natural /Forced
- Steady / Unsteady
- One-,two-,three-dimensional



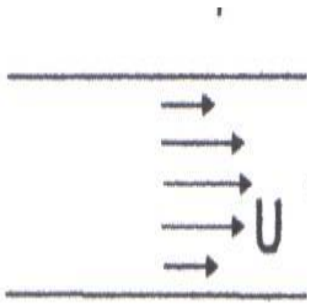
Atau :

aliran laminer

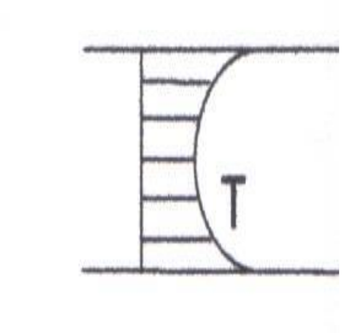
aliran turbulen



Ditentukan oleh bilangan Reynolds (Re)



profil kecepatan



profil suhu

Bilangan Reynold

$$Re = \frac{\rho V L}{\mu} = \frac{V L}{v}$$

$$Re = \frac{F_{inertia}}{F_{viscous}} = \frac{\frac{kg}{m^3} \times \frac{m}{s} \times m}{Pa \times s} = \frac{F}{F}$$

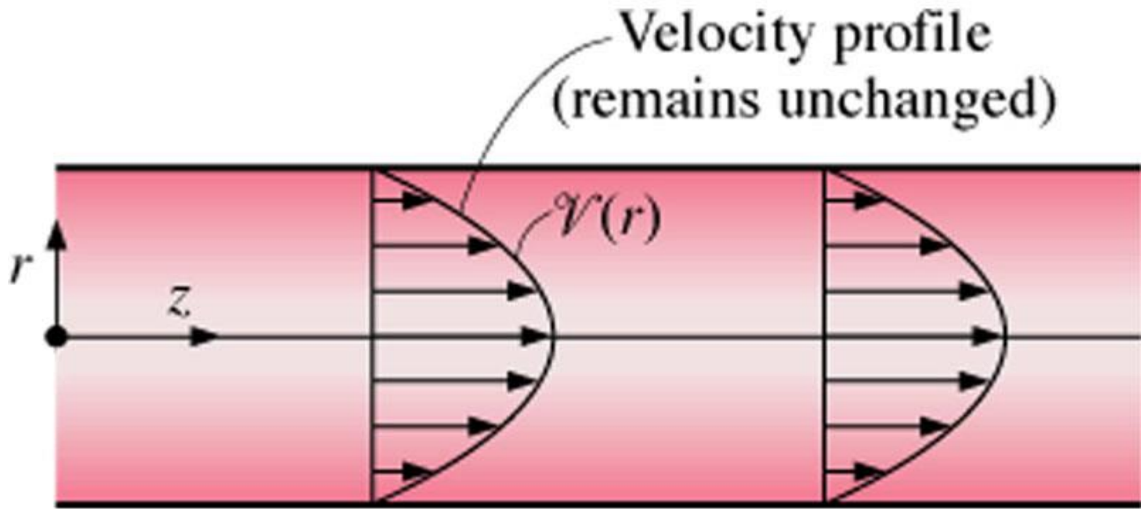
Laminer < 2300 < transisi < 4000 < turbulent

VELOCITY

Distribusi kecepatan aliran fluida dapat berubah dalam 3 dimensi.

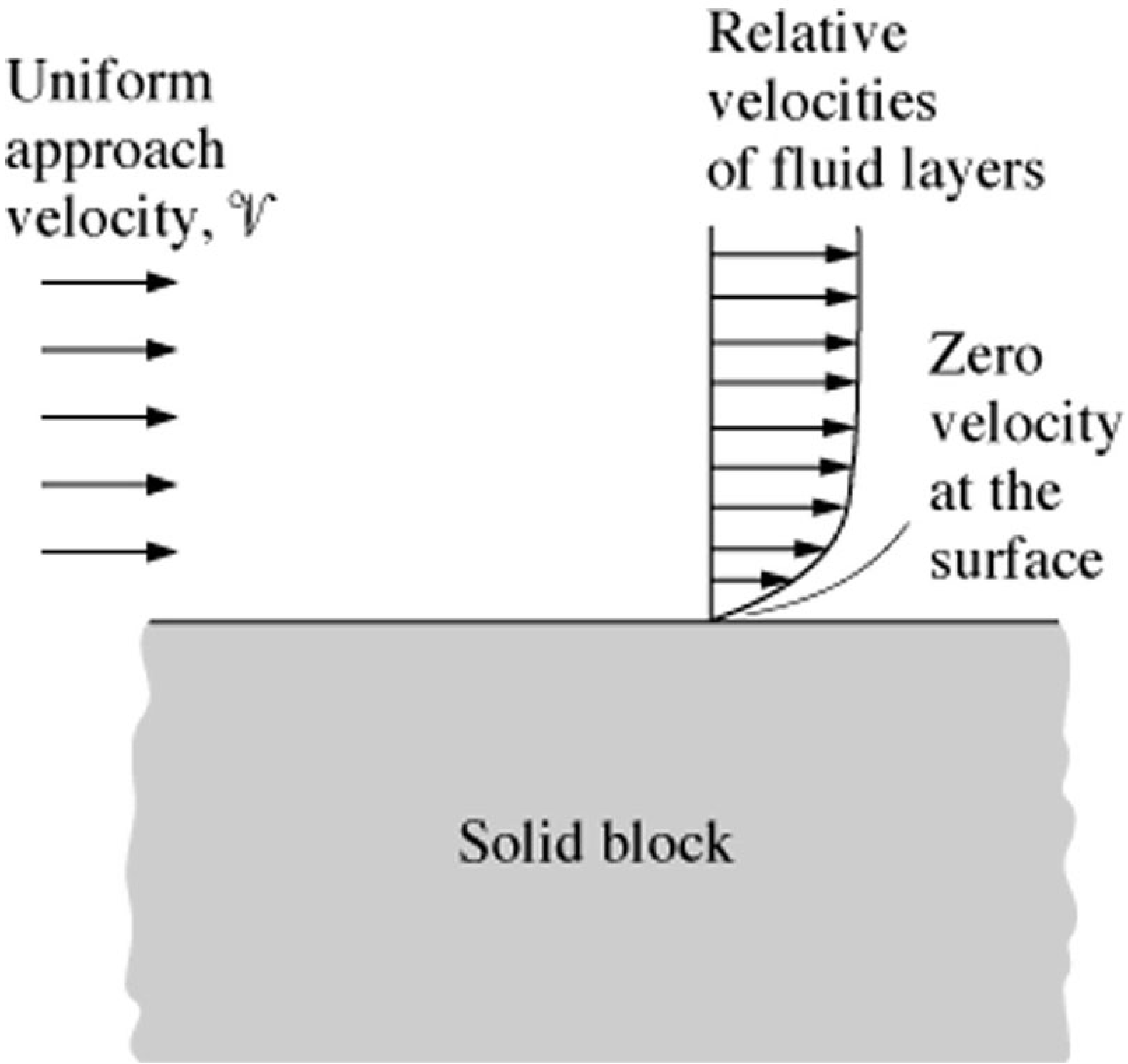
$\vec{\upsilon}(x, y, z)$ Koordinat rectangular

$\vec{\upsilon}(r, \theta, z)$ Koordinat silindris



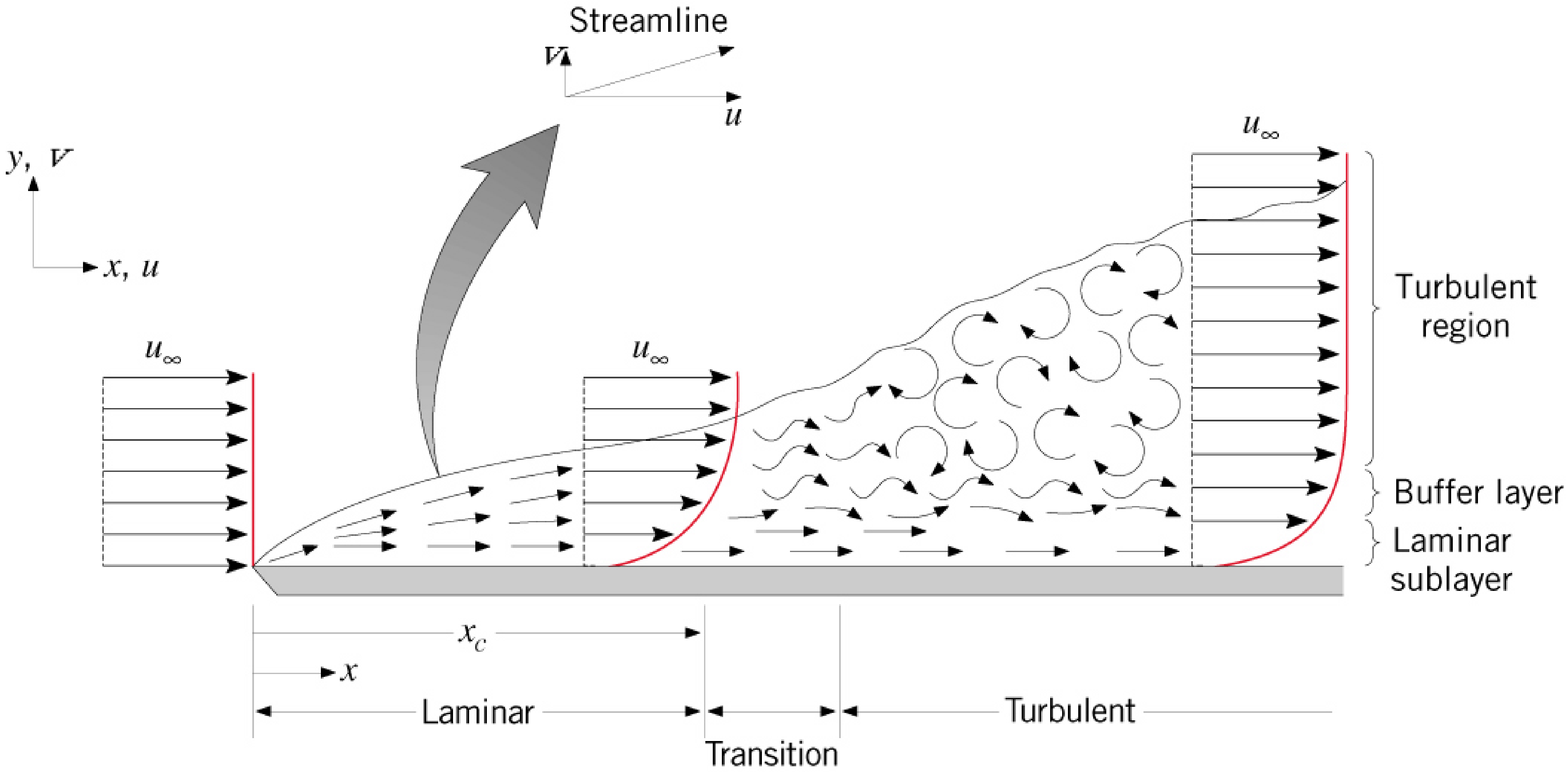
One dimensional flow in a circular pipe

Ke arah mana terjadi perubahan distribusi kecepatan ?



Velocity

No-slip condition


Streamline
v
u
y, v
x, u
u∞
u∞
u∞
Turbulent region
Buffer layer
Laminar sublayer
x_c
x
Laminar
Transition
Turbulent

Statements

- Kecepatan perpindahan panas pada dinding = 0
- Panas berpindah dari dinding ke fluida secara konduksi
- Fluks panas lokal / satuan luas :

  $q_w /A = q' = -k \partial T / \partial y_{\text{wall}}$

Hukum Newton tentang pendinginan :

  $q' = h (Tw - T\sim)$

- Sehingga :

  $h = \{- k \partial T / \partial y_{\text{wall}}\} / (Tw - T\sim)$

Koefisien transfer panas konveksi (h)

- Nilainya berbeda pada setiap kondisi yang berbeda
- Sangat tergantung pada berbagai parameter

Parameters

- The Bulk motion velocity, u, (m/s)
- The dimension of the body, L, (m)
- The surface temperature, Ts, ^{o}C or K
- The bulk fluid temperature, $T\infty$, ^{o}C or K
- The density of the fluid, ρ , kg/m^3
- The thermal conductivity of the fluid, k, (W/m.K)
- The dynamic viscosity of the fluid, μ , (kg/m.s)
- The specific heat of the fluid, Cp , (J/kg.K)
- The change in specific weight, Δρg, $(kg/(m^2s^2)$ or (N/m^3)
- The shape and orientation of the body, S

Bilangan tak berdimensi

$h = f(u, L, Ts, T\infty, \rho, k, \mu, Cp, \Delta\rho g, S)$

dengan analisis dimensi diperoleh :

$$\frac{hL}{k} = F\left(\frac{\rho u L}{\mu}, \frac{\mu c_p}{k}, \frac{\rho g \Delta\rho L^3}{\mu^2}, \frac{T_s}{T_\infty}, \frac{u^2}{c_p T_\infty}, S\right)$$

Cont'd

- Nusselt $$\frac{hL}{k}$$
- Prandtl $$\frac{\mu c_p}{k}$$
- Reynold $$\frac{\rho u L}{\mu}$$
- Eckert $$\frac{u^2}{c_p T_\infty}$$
- Grashoff $$\frac{\rho g \Delta\rho L^3}{\mu^2}$$
- Temperature ratio $$\frac{T_s}{T_\infty}$$

KLASIFIKASI PP KONVEKSI

- KONVEKSI PAKSA
  (FORCED CONVECTION)

- Aliran fluidanya disebabkan oleh adanya daya dorong dari luar (mis.pompa, blower, dll)

- KONVEKSI BEBAS / ALAMIAH
  (FREE / NATURAL CONVECTION)

- Aliran fluidanya terjadi karena adanya perbedaan suhu yang menyebabkan beda densitas pada kedua posisi.

BTB dalam pp konveksi

- Konveksi paksa

- Reynold (Re)
- Prandtl (Pr)
- Nusselt (Nu)

- Konveksi alamiah

- Reynold (Re)
- Grashoff (Gr)
- Nusselt (Nu)

KONVEKSI PAKSA

FORCED CONVECTION

- **LAMINAR FLOW**

Smooth streamlines

Highly- ordered motion

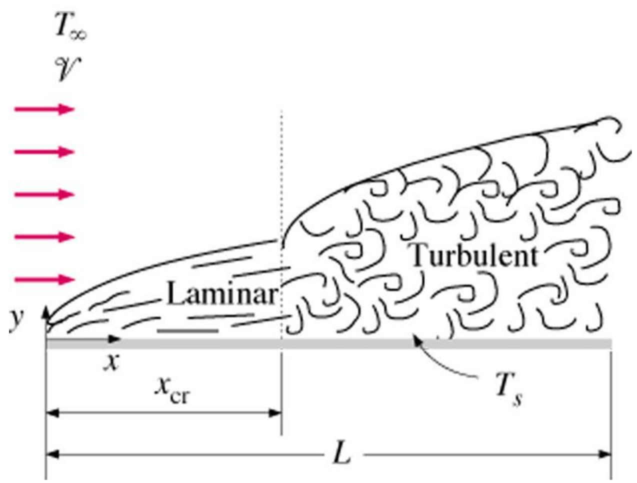
(highly viscous fluids in small pipes)

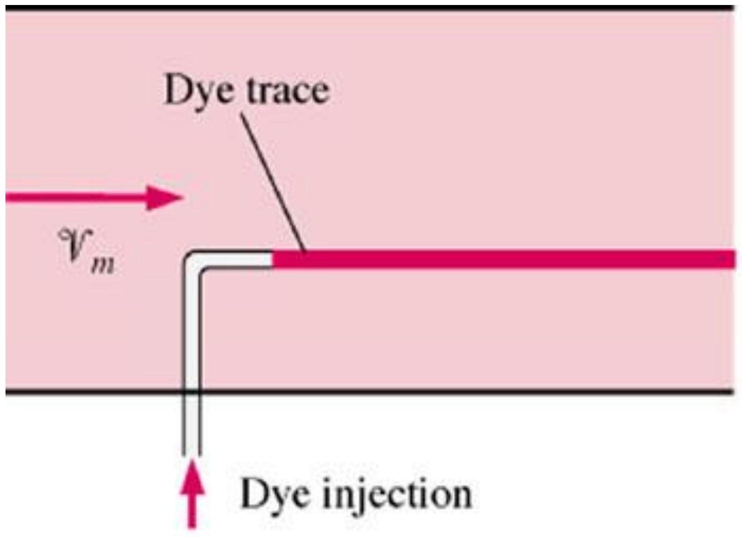
- **TURBULENT FLOW**

Velocity fluctuations

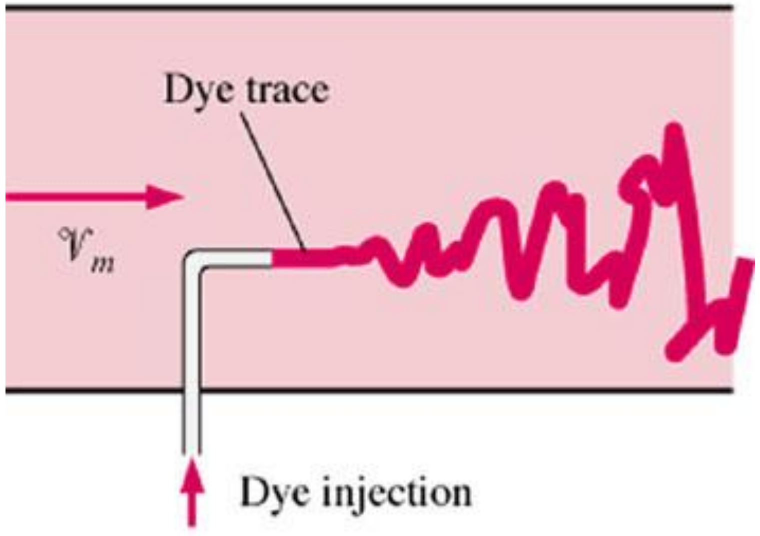
Highly-disordered motion

- **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

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

υ_m Mean flow velocity

D Characteristic length of the geometry

$v = \mu / \rho$ Kinematic viscosity

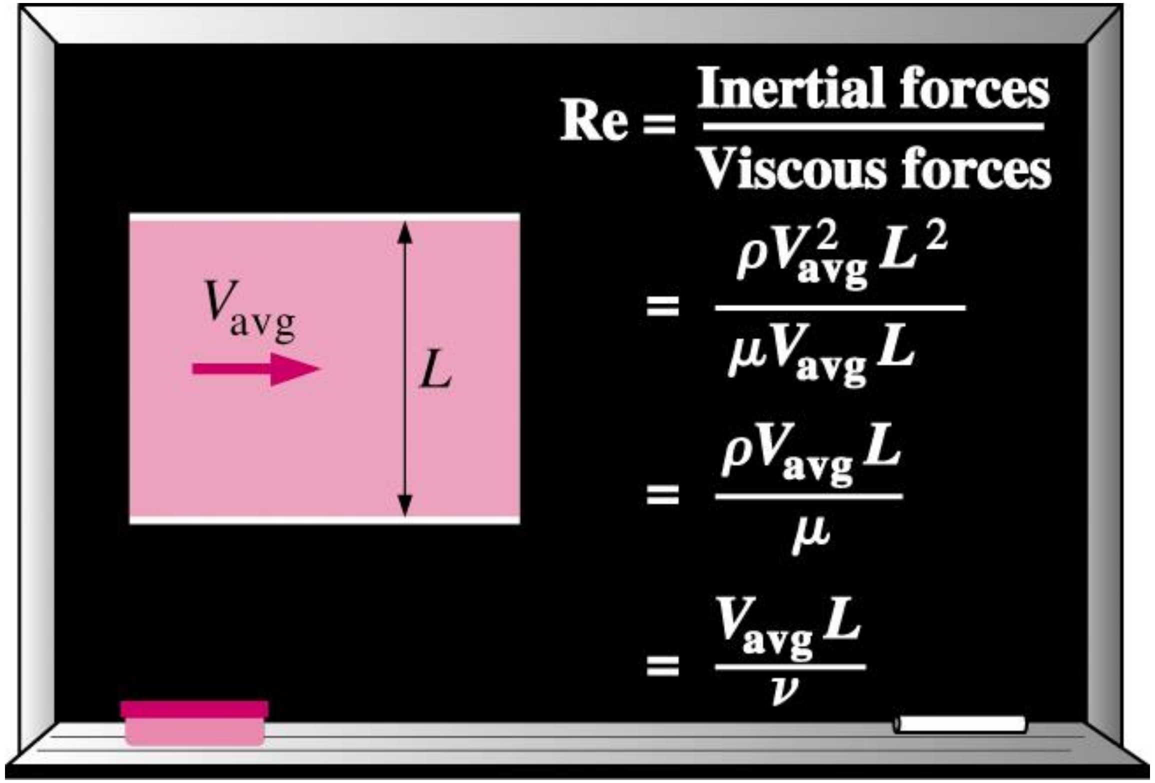
- Critical Reynolds number (Re_{cr}) for flow in a round pipe

$Re < 2300 \Rightarrow$ laminar

$2300 \leq Re \leq 4000 \Rightarrow$ transitional

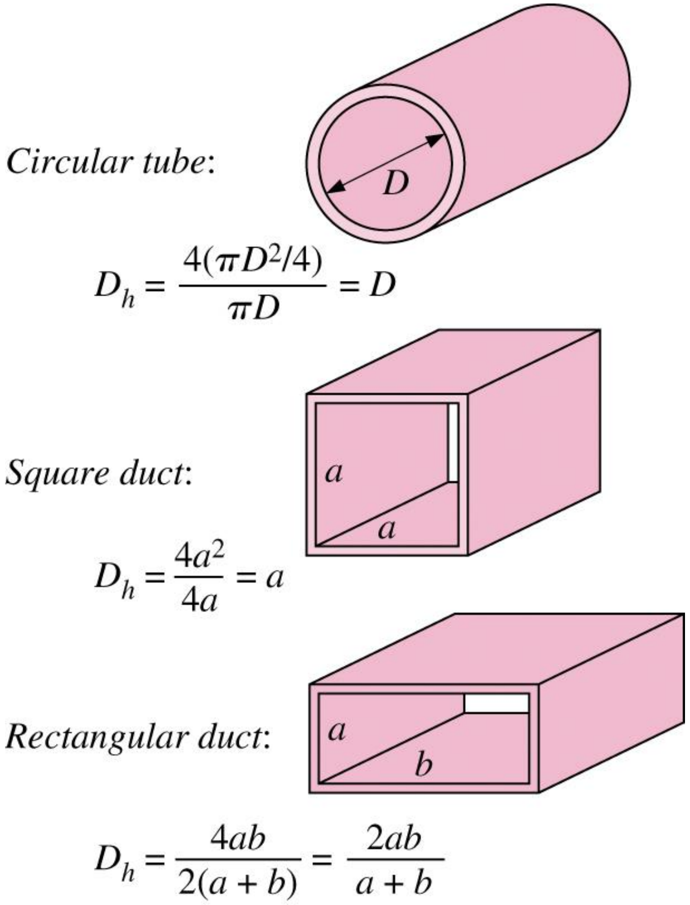
$Re > 4000 \Rightarrow$ turbulent

Definition of Reynolds number



- 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



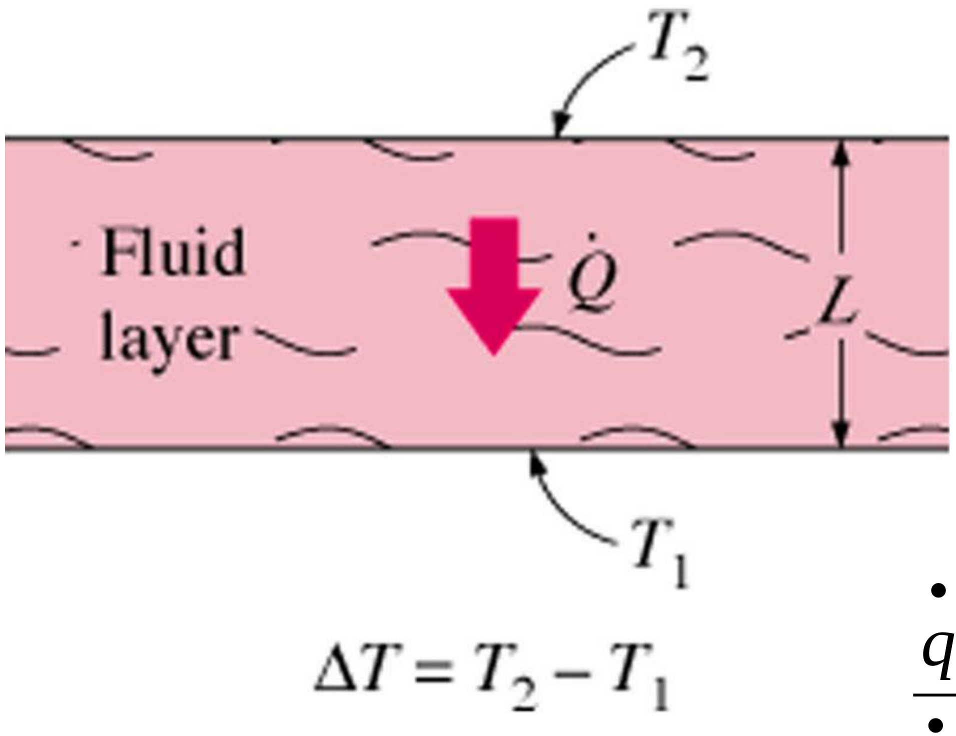
- For <u>non-round</u> pipes,

the hydraulic diameter
$D_h = 4A_c/P$

A_c = cross-section area

P = wetted perimeter

NUSSELT NUMBER



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

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

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

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

PRANDTL NUMBER

- Boundary layer theory

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

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

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

$$\mathrm{Re}_{cr} = \frac{\rho \upsilon\ x_{cr}}{\mu} = 5\times10^{5}$$

$$Nu = \frac{hL}{k} = 0.664\ \ \mathrm{Re}_L^{0.5}\ \mathrm{Pr}^{1/3}$$

$\mathrm{Re}_L < 5\times10^{5}$ laminar

$$Nu = \frac{hL}{k} = 0.037\ \ \mathrm{Re}_L^{0.8}\ \mathrm{Pr}^{1/3}$$

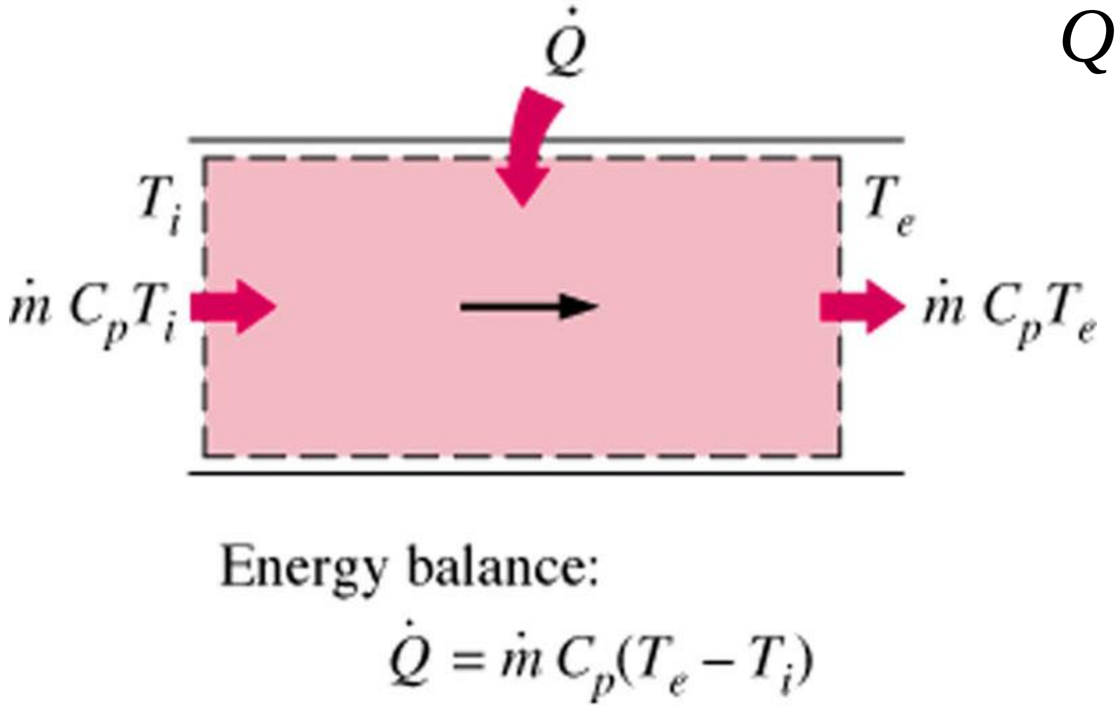
$0.6 \le \mathrm{Pr} \le 60$ turbulent

$5\times10^{5} \le \mathrm{Re}_L \le 10^{7}$

RUMUS –RUMUS EMPIRIS

- Penyelesaian praktis utk kasus aliran laminer sebelum mencapai kondisi “fully developed” dan sistem aliran di mana sifat fluida sangat dipengaruhi suhu, serta aliran turbulen.

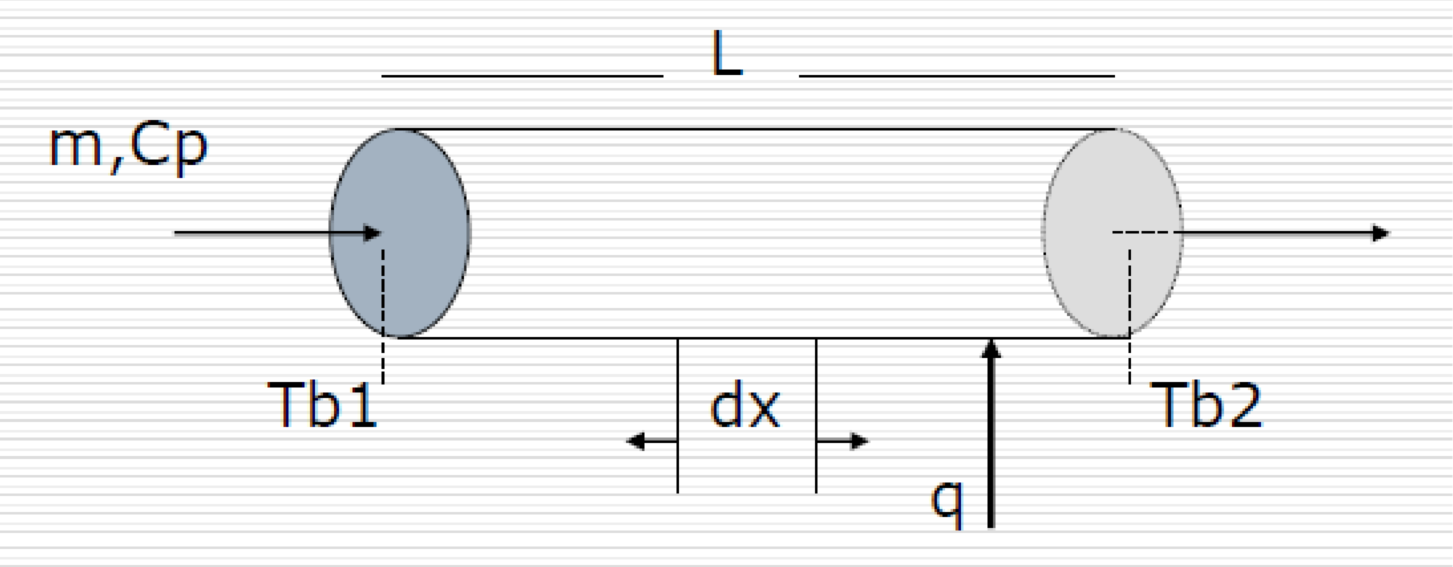
ANALISIS TERMAL PERUBAHAN SUHU DALAM PIPA



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

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

Bulk Temperature



$q = m\ Cp\ (Tb1 - Tb2)$

Kalor dq yang ditambahkan sepanjang dx :

$dq = m\ Cp\ dTb = h\ (2\Pi r)dx\ (Tw - Tb)$

Aliran turbulen dalam tabung licin

- Persamaan Dietus – Boelter

$$Nu = 0{,}023\ Re^{0{,}8}\ Pr^{\,n}$$

- sifat fluida ditentukan oleh bulk temperatur
- n = 0,4 → pemanasan
- n = 0,3 → pendinginan

Table 6-8 | Summary of forced-convection relations. (See text for property evaluation.)

Subscripts: b = bulk temperature, f = film temperature, ∞ = free stream temperature, w = wall temperature

Geometry	Equation	Restrictions	Equation number
Tube flow	$\mathrm{Nu}_d = 0.023\,\mathrm{Re}_d^{0.8}\mathrm{Pr}^n$	Fully developed turbulent flow, $n = 0.4$ for heating, $n = 0.3$ for cooling, $0.6 < \mathrm{Pr} < 100$, $2500 < \mathrm{Re}_d < 1.25 \times 10^5$	(6-4*a*)
Tube flow	$\mathrm{Nu}_d = 0.0214(\mathrm{Re}_d^{0.8} - 100)\mathrm{Pr}^{0.4}$	$0.5 < \mathrm{Pr} < 1.5$, $10^4 < \mathrm{Re}_d < 5 \times 10^6$	(6-4*b*)
	$\mathrm{Nu}_d = 0.012(\mathrm{Re}_d^{0.87} - 280)\mathrm{Pr}^{0.4}$	$1.5 < \mathrm{Pr} < 500$, $3000 < \mathrm{Re}_d < 10^6$	(6-4*c*)
Tube flow	$\mathrm{Nu}_d = 0.027\,\mathrm{Re}_d^{0.8}\mathrm{Pr}^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14}$	Fully developed turbulent flow	(6-5)
Tube flow, entrance region	$\mathrm{Nu}_d = 0.036\,\mathrm{Re}_d^{0.8}\mathrm{Pr}^{1/3}\left(\frac{d}{L}\right)^{0.055}$ See also Figures 6-5 and 6-6	Turbulent flow $10 < \frac{L}{d} < 400$	(6-6)
Tube flow	Petukov relation	Fully developed turbulent flow, $0.5 < \mathrm{Pr} < 2000$, $10^4 < \mathrm{Re}_d < 5 \times 10^6$, $0 < \frac{\mu_b}{\mu_w} < 40$	(6-7)

Table 6-8 | Summary of forced-convection relations. (See text for property evaluation.)

Subscripts: b = bulk temperature, f = film temperature, ∞ = free stream temperature, w = wall temperature

Geometry	Equation	Restrictions	Equation num
Tube flow	$\mathrm{Nu}_d = 0.023\,\mathrm{Re}_d^{0.8}\mathrm{Pr}^n$	Fully developed turbulent flow, $n = 0.4$ for heating, $n = 0.3$ for cooling, $0.6 < \mathrm{Pr} < 100$, $2500 < \mathrm{Re}_d < 1.25 \times 10^5$	(6-4*a*)
Tube flow	$\mathrm{Nu}_d = 0.0214(\mathrm{Re}_d^{0.8} - 100)\mathrm{Pr}^{0.4}$	$0.5 < \mathrm{Pr} < 1.5$, $10^4 < \mathrm{Re}_d < 5 \times 10^6$	(6-4*b*)
	$\mathrm{Nu}_d = 0.012(\mathrm{Re}_d^{0.87} - 280)\mathrm{Pr}^{0.4}$	$1.5 < \mathrm{Pr} < 500$, $3000 < \mathrm{Re}_d < 10^6$	(6-4*c*)
Tube flow	$\mathrm{Nu}_d = 0.027\,\mathrm{Re}_d^{0.8}\mathrm{Pr}^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14}$	Fully developed turbulent flow	(6-5)
Tube flow, entrance region	$\mathrm{Nu}_d = 0.036\,\mathrm{Re}_d^{0.8}\mathrm{Pr}^{1/3}\left(\frac{d}{L}\right)^{0.055}$ See also Figures 6-5 and 6-6	Turbulent flow $10 < \frac{L}{d} < 400$	(6-6)
Tube flow	Petukov relation	Fully developed turbulent flow, $0.5 < \mathrm{Pr} < 2000$, $10^4 < \mathrm{Re}_d < 5 \times 10^6$, $0 < \frac{\mu_b}{\mu_w} < 40$	(6-7)
Tube flow	$\mathrm{Nu}_d = 3.66 + \frac{0.0668(d/L)\,\mathrm{Re}_d\mathrm{Pr}}{1 + 0.04[(d/L)\,\mathrm{Re}_d\mathrm{Pr}]^{2/3}}$	Laminar, $T_w = \text{const.}$	(6-9)

Tube flow	$\mathrm{Nu}_d = 1.86(\mathrm{Re}_d \mathrm{Pr})^{1/3} \left(\frac{d}{L}\right)^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$	Fully developed laminar flow, $T_w = \text{const.}$ $\mathrm{Re}_d \mathrm{Pr} \frac{d}{L} > 10$	(6-10)
Rough tubes	$\mathrm{St}_b \mathrm{Pr}_f^{2/3} = \frac{f}{8}$ or Equation (6-7)	Fully developed turbulent flow	(6-12)
Noncircular ducts	Reynolds number evaluated on basis of hydraulic diameter $D_H = \frac{4A}{P}$ $A =$ flow cross-section area, $P =$ wetted perimeter	Same as particular equation for tube flow	(6-14)
Flow across cylinders	$\mathrm{Nu}_f = C\, \mathrm{Re}_{df}^n\, \mathrm{Pr}^{1/3}$ C and n from Table 6-2	$0.4 < \mathrm{Re}_{df} < 400{,}000$	(6-17)
Flow across cylinders	$\mathrm{Nu}_{df} = 0.3 + \frac{0.62\, \mathrm{Re}_f^{1/2}\, \mathrm{Pr}^{1/3}}{\left[1 + \left(\frac{0.4}{\mathrm{Pr}}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{\mathrm{Re}_f}{282{,}000}\right)^{5/8}\right]^{4/5}$	$10^2 < \mathrm{Re}_f < 10^7$, $\mathrm{Pe} > 0.2$	(6-21)
Flow across cylinders		See text	(6-18) to (6-20) (6-22) to (6-24)
Flow across noncircular cylinders	$\mathrm{Nu} = C\, \mathrm{Re}_{df}^n\, \mathrm{Pr}^{1/3}$ See Table 6-3 for values of C and n.		(6-17)

Table 6-8 | (*Continued*).

Subscripts: b = bulk temperature, f = film temperature, ∞ = free stream temperature, w = wall temperature

Geometry	Equation	Restrictions	Equation number
Flow across spheres	$\mathrm{Nu}_{df} = 0.37\,\mathrm{Re}_{df}^{0.6}$	$\mathrm{Pr} \sim 0.7$ (gases), $17 < \mathrm{Re} < 70{,}000$	(6-25)
	$\mathrm{Nu}_d \mathrm{Pr}^{-0.3} (\mu_w/\mu)^{0.25} = 1.2 + 0.53\,\mathrm{Re}_d^{0.54}$	Water and oils $1 < \mathrm{Re} < 200{,}000$ Properties at T_∞	(6-29)
	$\mathrm{Nu}_d = 2 + \left(0.4\,\mathrm{Re}_d^{1/2} + 0.06\,\mathrm{Re}_d^{2/3}\right) \mathrm{Pr}^{0.4} (\mu_\infty/\mu_w)^{1/4}$	$0.7 < \mathrm{Pr} < 380$, $3.5 < \mathrm{Re}_d < 80{,}000$, Properties at T_∞	(6-30)
Flow across tube banks	$\mathrm{Nu}_f = C\mathrm{Re}_{f,\max}^n \mathrm{Pr}_f^{1/3}$ C and n from Table 6-4	See text	(6-17)
Flow across tube banks	$\mathrm{Nu}_d = C\mathrm{Re}_{d,\max}^n \mathrm{Pr}^{0.36} \left(\dfrac{\mathrm{Pr}}{\mathrm{Pr}_w}\right)^{1/4}$	$0.7 < \mathrm{Pr} < 500$, $10 < \mathrm{Re}_{d,\max} < 10^6$	(6-34)
Liquid metals		See text	(6-37) to (6-48)
Friction factor	$\Delta p = f(L/d)\rho u_m^2/2g_c$, $u_m = \dot{m}/\rho A_c$		(6-13)

Ex. 6-1 Holman

Turbulent Heat Transfer in a Tube

EXAMPLE 6-1

Air at 2 atm and 200°C is heated as it flows through a tube with a diameter of 1 in (2.54 cm) at a velocity of 10 m/s. Calculate the heat transfer per unit length of tube if a constant-heat-flux condition is maintained at the wall and the wall temperature is 20°C above the air temperature, all along the length of the tube. How much would the bulk temperature increase over a 3-m length of the tube?

Solution

We first calculate the Reynolds number to determine if the flow is laminar or turbulent, and then select the appropriate empirical correlation to calculate the heat transfer. The properties of air at a bulk temperature of 200°C are

$$\rho = \frac{p}{RT} = \frac{(2)(1.0132 \times 10^5)}{(287)(473)} = 1.493 \text{ kg/m}^3 \qquad [0.0932 \text{ lb}_m/\text{ft}^3]$$

$$\text{Pr} = 0.681$$

$$\mu = 2.57 \times 10^{-5} \text{ kg/m} \cdot \text{s} \qquad [0.0622 \text{ lb}_m/\text{h} \cdot \text{ft}]$$

$$k = 0.0386 \text{ W/m} \cdot {}^\circ\text{C} \qquad [0.0223 \text{ Btu/h} \cdot \text{ft} \cdot {}^\circ\text{F}]$$

$$c_p = 1.025 \text{ kJ/kg} \cdot {}^\circ\text{C}$$

$$\text{Re}_d = \frac{\rho u_m d}{\mu} = \frac{(1.493)(10)(0.0254)}{2.57 \times 10^{-5}} = 14{,}756$$

so that the flow is turbulent. We therefore use Equation (6-4*a*) to calculate the heat-transfer coefficient.

$$\text{Nu}_d = \frac{hd}{k} = 0.023 \, \text{Re}_d^{0.8} \, \text{Pr}^{0.4} = (0.023)(14{,}756)^{0.8}(0.681)^{0.4} = 42.67$$

$$h = \frac{k}{d}\text{Nu}_d = \frac{(0.0386)(42.67)}{0.0254} = 64.85 \text{ W/m}^2 \cdot {}^\circ\text{C} \qquad [11.42 \text{ Btu/h} \cdot \text{ft}^2 \cdot {}^\circ\text{F}]$$

The heat flow per unit length is then

$$\frac{q}{L} = h\pi d(T_w - T_b) = (64.85)\pi(0.0254)(20) = 103.5 \text{ W/m} \qquad [107.7 \text{ Btu/ft}]$$

We can now make an energy balance to calculate the increase in bulk temperature in a 3.0-m length of tube:

$$q = \dot{m} c_p \Delta T_b = L\left(\frac{q}{L}\right)$$

We also have

$$\dot{m} = \rho u_m \frac{\pi d^2}{4} = (1.493)(10)\pi \frac{(0.0254)^2}{4}$$
$$= 7.565 \times 10^{-3} \text{ kg/s} \qquad [0.0167 \text{ lb}_m/\text{s}]$$

so that we insert the numerical values in the energy balance to obtain

$$(7.565 \times 10^{-3})(1025)\Delta T_b = (3.0)(103.5)$$

and

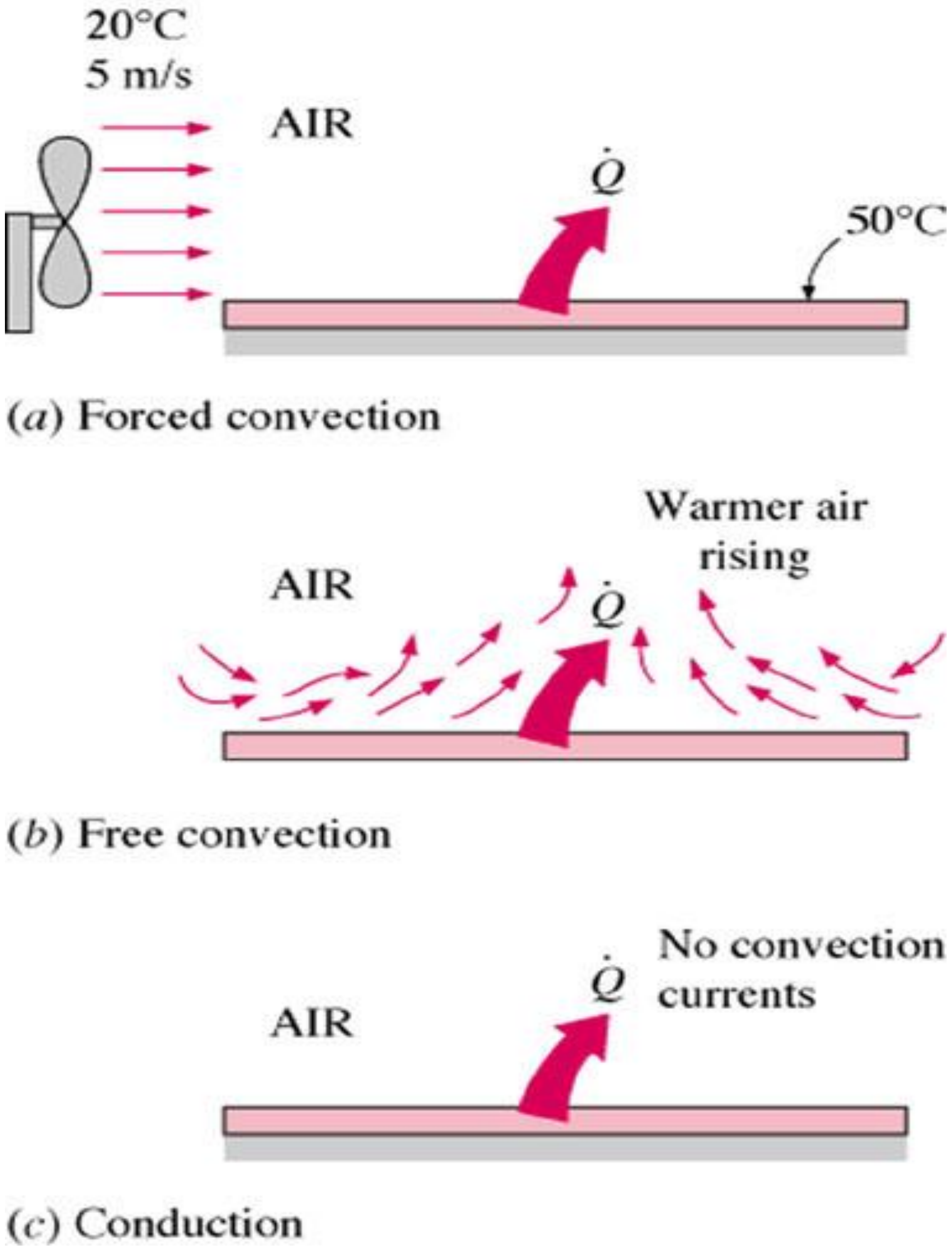
$$\Delta T_b = 40.04°\text{C} \qquad [104.07°\text{F}]$$

Soal

- Air dengan suhu bulk rata-rata 80^0F mengalir dalam tabung licin horisontal dengan suhu dinding 180^0F. Panjang tabung 6 ft dan diameternya 0,125 in. Kecepatan alir air 0,125 ft/s. Hitunglah laju perpindahan kalor !

KONVEKSI BEBAS / ALAMIAH

NATURAL / FREE CONVECTION


20°C
5 m/s
AIR
Q̇
50°C
(a) Forced convection
Warmer air
rising
AIR
Q̇
(b) Free convection
No convection
currents
Q̇
AIR
(c) Conduction

CONVECTIVE HEAT TRANSFER COEFFICIENT

Coefficient of volume expansion → β

Grashof number

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

viscosity → υ

Rayleigh number

$$Ra_L = Gr_L \Pr$$

Prandtl number

Nusselt number

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

Persamaan empiris konveksi alamiah

- Lihat di buku Holman chap 7

Langkah penyelesaian soal

- Cermati kondisi dan geometri sistem yang terjadi
- Tentukan suhu yang dirujuk (Tb, Tf)

  Tb umumnya utk suhu fluida dlm tabung

  Tf umumnya utk konveksi permukaan
- Tentukan sifat fisis fluida pada T tsb.
- Hitung BTB yang diperlukan (Re, Pr, dst)
- Tentukan persamaan empiris yg digunakan
- Hitung h (koef.pp konveksi)
- Hitung q (=h A ΔT)

Ex 7-3 Holman

EXAMPLE 7-3 Heat Transfer from Horizontal Tube in Water

A 2.0-cm-diameter horizontal heater is maintained at a surface temperature of 38°C and submerged in water at 27°C. Calculate the free-convection heat loss per unit length of the heater.

Solution

The film temperature is

$$T_f = \frac{38+27}{2} = 32.5°\text{C}$$

From Appendix A the properties of water are

$$k = 0.630 \text{ W/m} \cdot °\text{C}$$

and the following term is particularly useful in obtaining the Gr Pr product when it is multiplied by $d^3 \Delta T$:

$$\frac{g\beta\rho^2 c_p}{\mu k} = 2.48 \times 10^{10} \qquad [1/\text{m}^3 \cdot °\text{C}]$$

$$\text{Gr Pr} = (2.48 \times 10^{10})(38-27)(0.02)^3 = 2.18 \times 10^6$$

Using Table 7-1, we get $C = 0.53$ and $m = \frac{1}{4}$, so that

$$\text{Nu} = (0.53)(2.18 \times 10^6)^{1/4} = 20.36$$

$$h = \frac{(20.36)(0.63)}{0.02} = 642 \text{ W/m}^2 \cdot °\text{C}$$

The heat transfer is thus

$$\frac{q}{L} = h\pi d(T_w - T_\infty)$$

$$= (642)\pi(0.02)(38-27) = 443 \text{ W/m}$$

- Pelajari contoh-contoh soal bab 6-7 Holman
- Kerjakan beberapa soal bab 6-7.