UNIT-3

Convective heat transfer:

Convection (H.T b/w surface & fluid moving over it)
- → free convection (fluid circulate by National density difference by hot and cold fluid)
- → forced convection (fluid motion created by external agency)

Total / Average heat transfer coefficient / -

We know that local heat flux (q) for an arbitary body of area (A). The temperatures of surface and surroundings are T_s, T_∞.

$$q = h(T_s - T_\infty) \quad -(1)$$

This equation is known as newton's law of cooling for simplicity we are taken the equation but it actual process heat transfer coefficient is a complicated function.

1. Nature of fluid flow
2. Thermal properties of fluid flow
3. Confirication of the system

Due to variation of fluid flow the value of heat flux and h values varies from point to point

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fa find out total heat transfer rate we have to integrate heat flux for over complete area.

$$Q = \int_A q \, dA$$

$$= \int_A h (T_s - T_\infty) dA$$

$$= (T_s - T_\infty) \int_A h \, dA \quad \text{—— ①}$$

Here defining the $\bar{h}$ as average / total heat transfer coefficient for entire surface

$$Q = \bar{h} A (T_s - T_\infty) \quad \text{— ②}$$

$$① = ②$$

$$(T_s - T_\infty) \int_A h \, dA = \bar{h} A (T_s - T_\infty)$$

$$\bar{h} = \frac{1}{A} \int_A h \, dA$$

for a specified length L

$$\bar{h} = \frac{1}{L} \int_0^L h \, dL$$

$L = x$

$$\bar{h} = \frac{1}{x} \int_0^x h \, dx$$

If plate fa point width the above equation becomes for forced convection the heated horizontal plate the

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local heat transfer coefficient may be expressed as

$$h_x = C x^{0.5}$$

$$\therefore \bar{h}_x = \frac{1}{x}\int_0^x C x^{0.5}\, dx$$

$$= \frac{C}{x}\int_0^x \sqrt{x}\, dx$$

$$= \frac{C}{x}\,\frac{x^{0.5}}{0.5}$$

$$= 2 C x^{-0.5}$$

$$\boxed{\therefore \bar{h}_x = 2 h_x}$$

The average heat transfer coefficient is twice to the local value.

Dimensional Analysis (D.A) :-

DA is a mathematically technique to study the dimensional parameters for solving several engineering problem. Its helps to determine a systematic arrangement of the varibles in the physical relationship the dimensional variables to form a non-dimensional parameters Dimensional parameters has became important tooling analysing the fluid flow

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The various physical quantites in fluid phenomena can be expressed in terms of fundamental quantites.

quantity	unit	symbol
Mass	Kg	M
Length	m	L
Temperature	K	θ
Time	sec	T
force	N-(kg-m/s²)	MLT^{-2}
density	kg/m^3	ML^{-3}
Kinematic viscosity	m^2/sec	L^2T^{-1}

Methods of dimensional analysis:-

DA → Rayleigh's method
DA → Buckinghom's π theorem

Buckinghom's π theorem:- Its a thumb rule of determining a number of independent dimensionless groups (π - terms) that can be obtained from a set of varaibles (n) with a fundmental dimensions (m). that is number of

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dimensionless group?

π - terms = n - m

Where

n = No. of dependant & indipendant variable

m = Basis (or) fundamental dimensions

(L, M, Θ, T ...)

for example

$a_1, a_2 \ldots a_6$ are relavant variables in a problem this 6 variables express in terms of 4 basis dimensions

∴ According to the π theorem

π - terms = n - m

= 6 - 4 = 2

It indicates we can fall 2 dimensionless groups. like π_1, π_2 its also expressed as $F(\pi_1, \pi_2) = 0$. for generalized equation it can be written as

$\pi_1 = \phi(\pi_2, \pi_3 \ldots \pi_{n-m})$

$\pi_2 = \phi(\pi_1, \pi_3 \ldots \pi_{n-m})$

Dimensional Analysis applied to forced Convection:

Let as Consider fluid following accurate heated tube

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diameter of pipe	D	m	L
density of the fluid	ρ	kg/m^3	ML^{-3}
viscosity	μ	kg/ms	$ML^{-1}T^{-1}$
velocity	V	m/s	LT^{-1}
Thermal Conductivity	K	$w/m\cdot K$	$MLT^{-3}\theta^{-1}$
heat transfer Coefficient	h	w/m^2K	$MT^{-3}\theta^{-1}$
specific heat	Cp	KJ/kg.k	$L^2T^{-2}\theta^{-1}$

$\pi = n - m$

Total no. of variables $n = 7$

fundamental unit $m = 4$

$\pi = 7 - 4 = 3$

$\pi_1 = D^{a_1} \rho^{b_1} \mu^{c_1} K^{d_1} V$

Take first group

$\pi_1 = (L)^{a_1} (ML^{-3})^{b_1} (ML^{-1}T^{-1})^{c_1} (MLT^{-3}\theta^{-1})^{d_1} (LT^{-1})$

$M^0L^0T^0\theta^0 = L^{a_1} M^{b_1} L^{-3b_1} M^{c_1} L^{-c_1} T^{-c_1} M^{d_1} L^{d_1} T^{-3d_1} \theta^{-d_1} LT^{-1}$

Compare both sides.

$M = 0 = b_1 + c_1 + d_1$ — (1)

$L = 0 = a_1 - 3b_1 - c_1 + d_1 + 1$ — (2)

$T = 0 = -c_1 - 3d_1 - 1$ — (3)

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$\theta = 0 = -d_1$

$d_1 = 0 \quad -(4)$

$c_1 = -1$

$b_1 = 1$

$a_1 = 1$

Substitute all these values in π_1

$\pi_1 = D^{a_1} \rho^{b_1} \mu^{c_1} K^{d_1} V$

$= D^1 \rho^1 \mu^{-1} K^0 V$

$\pi_1 = \frac{D\rho}{\mu} \times K$

This is called Reynold's Number.

$\pi_2 = D^{a_2} \rho^{b_2} \mu^{c_2} K^{d_2} cp$

$= (L)^{a_2} (ML^{-3})^{b_2} (ML^{-1}T^{-1})^{c_2} (MLT^{-3}\theta^{-1})^{d_2} (L^2T^{-2}\theta^{-1})$

$M^0L^0T^0\theta^0 = L^{a_2} M^{b_2} L^{-3b_2} M^{c_2} L^{-c_2} T^{-c_2} M^{d_2} L^{d_2} T^{-3d_2} \theta^{-d_2} L^2 T^{-2} \theta^{-1}$

$0 = b_2 + c_2 + d_2 \quad -(1)$

$0 = a_2 - 3b_2 - c_2 + d_2 + 2 \quad -(2)$

$0 = -c_2 - 3d_2 - 2 \quad -(3)$

$0 = -d_2 - 1 \quad -(4)$

$d_2 = -1$

$c_2 = 1$

$b_2 = 0$

$a_2 = 0$

$\pi_2 = D^0 \rho^0 \mu^1 K^{-1} cp$

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$$\pi_2 = \frac{\mu C_p}{K}$$

This is called prandtl number (Pr)

$$\pi_3 = D^{a_3} \rho^{b_3} \mu^{c_3} K^{d_3} h$$

$$= (L)^{a_3} (ML^{-3})^{b_3} (ML^{-1}T^{-1})^{c_3} (MLT^{-3}\theta^{-1})^{d_3} MT^{-3}\theta^{-1}$$

$$= L^{a_3} M^{b_3} L^{-3b_3} M^{c_3} L^{-c_3} T^{-c_3} M^{d_3} L^{d_3} T^{-3d_3} \theta^{-d_3} M T^{-3} \theta^{-1}$$

$M = 0 = b_3 + c_3 + d_3 + 1$ — (1)

$T = 0 = -c_3 - 3d_3 - 3$ — (2)

$L = 0 = a_3 - 3b_2 - c_3 + d_3$ — (3)

$\theta = 0 = -d_3 - 1$ — (4)

$d_3 = -1$

$c_3 = 0$

$b_3 = 0$

$a_3 = 1$

$$\pi_3 = D^1 \rho^0 \mu^0 K^{-1} h$$

$$= \frac{Dh}{K} \Rightarrow \frac{hD}{K}$$

This is Nusselt Number (Nu)

$$\pi_1 = \phi(\pi_2, \pi_3)$$

$$Re = \phi(Pr, Nu)$$

$$Pr = \phi(Re, Nu)$$

$$Nu = \phi(Re, Pr)$$

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free convection

Variables	Symbol	dimension
Length	L	L
density	ρ	ML^{-3}
Thermal conductivity	K	$MLT^{-3}\theta^{-1}$
H.T coefficient	h	$MT^{-3}\theta^{-1}$
specific heat	CP	$L^2T^{-2}\theta^{-1}$
viscocity	μ	$ML^{-1}T^{-1}$
Boupancy force	$Bg\Delta t$	LT^{-2}

Here heat transfer coefficient "H" will be depends on the same variable in forced convection except the velocity 'v' because which is * not caused by an external agency instead of the fluid circulation is caused by a Bouyance force comes in to plane because of density variation due to temperature difference.

$(L, \rho, \mu, K, h, CP, (Bg\Delta t))$

Bouyancy force considered as

$= Bg\Delta t$

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No. of variables $n = 7$

fundamental dimensions $m = 4$

No. of dimensionless groups

π- terms $= n - m$

$= 7 - 4$

$\pi = 3.$

Now $\pi_1 = L^{a_1} \rho^{b_1} \mu^{c_1} k^{d_1} h$

$\pi_2 = L^{a_2} \rho^{b_2} \mu^{c_2} k^{d_2} cp$

$\pi_3 = L^{a_3} \rho^{b_3} \mu^{c_3} k^{d_3} Bg\Delta t$

$\pi_1 = (L)^{a_1} (ML^{-3})^{b_1} (ML^{-1}T^{-1})^{c_1} (MLT\theta^{-3})^{d_1} MT^{-3}\theta^{-1}$

$M^0T^0L^0\theta^0 = L^{a_1} M^{b_1} L^{-3b_1} M^{c_1} L^{-c_1} T^{-c_1} M^{d_1} L^{d_1} T^{-3d_1} \theta^{-d_1} MT^{-3}\theta^{-1}$

Consider 'M' Terms

$0 = b_1 + c_1 + d_1 + 1 \longrightarrow (1)$

Take T Terms

$0 = -c_1 - 3d_1 - 3 \longrightarrow (2)$

Take 'L' Terms

$0 = a_1 - 3b_1 - c_1 + d_1 \longrightarrow (3)$

Take 'θ' terms

$0 = -d_1 - 1 \longrightarrow (4)$

$d_1 = -1$

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$c_1 = 0$

$b_1 = 0$

$a_1 = 1$

$\pi_1 = L^1 \rho^0 \mu^0 K^{-1} h$

$= \frac{hL}{K}$ Nusslet No

$\pi_2 = (L)^{a_2} (ML^{-3})^{b_2} (ML^{-1}T^{-1})^{c_2} (MLT^{-3}\theta^{-1})^{d_2} (L^2 T^{-2}\theta^{-1})$

$0 = b_2 + c_2 + d_2 \longrightarrow (1)$

$0 = a_2 - 3b_2 - c_2 + d_2 + 2 \longrightarrow (2)$

$0 = -c_2 - 3d_2 - 2 \longrightarrow (3)$

$0 = -d_2 - 1 \longrightarrow (4)$

$d_2 = -1$

$c_2 = 1$

$b_2 = 0$

$a_2 = 0$

$\pi_2 = L^0 \rho^0 \mu^1 K^{-1} Cp$

$= \frac{\mu Cp}{K}$ (Pr)

$\pi_3 = L^{a_3} \rho^{b_3} \mu^{c_3} K^{d_3} (\beta g \Delta t)$

$= L^3 (ML^{-3})^{b_3} (ML^{-1}T^{-1})^{c_3} (MLT^{-3}\theta^{-1})^{d_3} (LT^{-2})$

$0 = b_3 + c_3 + d_3 \longrightarrow (1)$

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$$0 = a_3 - 3b_3 - c_3 + d_3 + 1 \longrightarrow (2)$$

$$0 = -c_3 - 3d_3 - 2 \longrightarrow (3)$$

$$0 = -d_3 \longrightarrow (4)$$

$d_3 = 0, \quad c_3 = -2, \quad b_3 = 2, \quad a_3 = 3$

$$\pi_3 = \frac{L^3 \rho^2}{\mu^2} (\beta g \Delta t)$$

Grassoff Number

dynamic viscocity

$$\mu = \vartheta \rho$$

$$= \frac{L^3 \rho^2 (\beta g \Delta t)}{(\vartheta \rho)^2}$$

$$= \frac{L^3 (\beta g \Delta t)}{\vartheta^2}$$

No. of Number is a function p.r and Gr

$$\pi_1 = \phi(\pi_2, \pi_3)$$

$$\pi_2 = \phi(\pi_1, \pi_3)$$

$$\pi_3 = \phi(\pi_1, \pi_2)$$

Types of Boundary layer:

two types of boundary layers

1, Hydrodynamic (or) velocity boundary layer

2, Thermal boundary layer

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1. Hydrodynamic boundary layer!- In this layer velocity of the fluid is less than 99% of free steam velocity.

2. Thermal boundary layer!- In this temperature of the fluid is less than 99% of free steam temperature

The main aim of Convection chapter is to determine the heat transfer coefficient because it varies depending up on following factors.

1, variation of fluid temperature
2, surface conditions
3, geometry and dientation
4, Thermo physical properties of fluid
5, Nature of fluid flow
6, Type of boundary layer formation.

Thermo physical properties of fluid!-

1, A fluid is following flowing over the surface temperature of fluid is varying hence thermo physical properties are varying

1, Mean film temperature

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

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T_w = Surface temperature

T_∞ = fluid temperature at begining it is for external face

2. Bulk mean temperature.

$$T_b = \frac{T_{mi} - T_{mo}}{2}$$

T_{mi} = inlet temperature of fluid

T_{mo} = exit temperature of fluid

1, Air at 20°C at a pressure of 1 bar is flowing over a flat plate at a velocity of 3m/sec: if the plate is maintained at 60°C calculate heat transfer per unit width of the plate assuming the length of plate along the flow of air is 2m

Sol Given data:

$T_\infty = 20°C$

$P = 1 bar$

$U = 3 m/s$

$T_w = 60°C$

$w = 1 m$

$L = 2 m$

$Q = hA (T_w - T_\infty)$

$$T_f = \frac{T_w + T_\infty}{2} = \frac{60+20}{2} = 40°C$$

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Air properties at film temperature 40°C

density $\rho = 1.128$ kg / m

$\mu = 19.12 \times 10^{-6}$ Ns/m^2

$\vartheta = 16.96 \times 10^{-6}$ m^2/s

$\alpha = 24.306 \times 10^{-6}$ m^2/s

$Pr = 0.699$

$Cp = 1005$ J/kg.K

$k = 0.02756$ w/mK

$$Re = \frac{UL}{\vartheta}$$

$$= \frac{3 \times 2}{16.96 \times 10^{-6}} \Rightarrow 353773.58$$

$$= 3.537 73 \times 10^5$$

$Re < 5 \times 10^5$ (laminar flow)

$Re > 5 \times 10^5$ (Turbulent flow)

$Re = 3.537 \times 10^5 < 5 \times 10^5$

flow is laminar

$$h = \frac{2hx}{}$$

$$Nu_x = \frac{h_x L}{K}$$

$$Nu_x = 0.332\ Re_x^{0.5}\ Pr^{0.333}$$

$$= 0.332 \times (3.537 \times 10^5)^{0.5} \times (0.699)^{0.333}$$

$$= 175.25$$

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$$h_x = \frac{Nu_x \times K}{L}$$

$$= \frac{175.25 \times 0.02756}{2} = 2.414 \ w/m^2K$$

local heat transfer coefficient (H.T.C)

$$h_x = 2.414 W/m^2K$$

overall H.T.C $h = 2h_x$

$$= 2 \times 2.414 = 4.828 \ w/m^2k$$

$$Q = hA\ (T_w - T_\infty)$$

$$= 4.828 \times (2 \times 1) \times (60 - 20)$$

$$= 386.24 \text{ watts}$$

2. At temperature 20°c air at atmospheric pressure flow over a plate with velocity 3m/s the plate is 1m wide and 80°c calculate the following at a distance $x = 300$ mm

1. Hydrodynamic boundary layer thickness
2. Thermal boudary layer thickness
3. Local friction coefficient
4. Average friction coefficient
5. Local heat transfer coefficient
6. Average heat transfer coefficient
7. heat transfer rate

Sol. Gr.P $T_\infty = 20°c$

$P = 1$ bar

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$U = 3\ m/s$

$w = 1\ m$

$T_w = 80^\circ C$

$x = 300\ mm = 0.3\ m$

$$T_f = \frac{T_w + T_\infty}{2} = \frac{80+20}{2} = 50^\circ C$$

at 50°C air properties

$\rho = 1.093\ kg/m^3$

$\mu = 19.61 \times 10^{-6}$

$\upsilon = 17.95 \times 10^{-6}$

$\alpha = 25.722 \times 10^{-6}$

$Pr = 0.698$

$CP = 1005$

$K = 0.02826$

$$Re = \frac{UL}{\upsilon} = \frac{3 \times 0.3}{17.95 \times 10^{-6}}$$

$= 50139.2$

$= 0.50 \times 10^5 < 5 \times 10^5$

flow is laminar

1, Hydrodynamic boundary layer thickness

$$Sh_x = 5x\ Re_x^{-0.5}$$

$$= 5 \times 0.3 \times [0.5 \times 10^5]^{-0.5}$$

$$= 6.7 \times 10^{-3}$$

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2. Thermal boundary layer thickness

$$\delta_{Tx} = Sh_x Pr^{-0.333}$$

$$= 6.7 \times 10^{-3} \times 0.698^{-0.333}$$

$$= 2.55 \times 10^{-3}$$

3. local friction coefficient

$$C_{fx} = 0.664 Re^{-0.5}$$

$$= 0.664 \times (0.5 \times 10^5)^{-0.5}$$

$$= 2.969 \times 10^{-3}$$

4. Average friction coefficient

$$C_{fL} = 1.328 Re_L^{-0.5}$$

$$= 1.328 \times (0.5 \times 10^5)^{-0.5}$$

$$= 5.938 \times 10^{-3}$$

5. local heat transfer coefficient

$$Nu_x = 0.332 Re_x^{0.5} Pr^{0.333}$$

$$= 0.332 \times (0.5 \times 10^5)^{0.5} \times (0.698)^{0.333}$$

$$= 65.86$$

$$h_x = \frac{Nu_x \times k}{L}$$

$$= \frac{65.86 \times 0.02826}{0.3} = 6.2 \ w/m^2K$$

6. Overall H.T.C $h = 2 \times h_p$

$$h = 2 \times 6.2$$

$$= 12.4 \ w/m^2K$$

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2. $Q = hA(T_w - T_\infty)$

$= 18.4 \times (0.3 \times 1) \times (80 - 20)$

$= 223.2$ watts.

3. Air at 20°c at atmospheric pressure flowing over a flat plate at a velocity 3.5 m/s if the plate is 0.5 m wide and at 60°c Calculate the following $x = 0.4$ m 1. Hydrodynamic boundary layer thickness 2. thermal boundary layer thickness

Sol! G.D

$T_\infty = 20°c$

$U = 3.5 m/s$

$w = 0.5 m$

$x = 0.4 m$

$T_w = 60°c$

$T_f = \frac{T_w + T_\infty}{2} = \frac{60+20}{2} = 40°c$

$\rho = 1.128 \ kg/m^3$

$\vartheta = 16.96 \times 10^{-6} \ m^2/s$

$k = 0.02756 \ w/mk$

$Pr = 0.699$

$Re_x = \frac{UL}{\vartheta}$

$= \frac{3.5 \times 0.4}{16.96 \times 10^{-6}} = 82547.16$

$= 0.82547 \times 10^5$

$Re_x = 0.82 \times 10^5$

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flow is laminar

$$Nu_x = 0.332\, Re_x^{0.5}\, Pr^{0.333}$$

$$= 0.332\,(0.82\times10^5)^{0.5} \times (0.699)^{0.333}$$

$$= 84.38$$

$$h_x = \frac{Nu_x \times k}{L}$$

$$= \frac{84.38 \times 0.0275}{0.4}$$

$$h_x = 5.81$$

$$h = 2 \times h_x$$

$$= 2 \times 5.81 = 11.62$$

$$Sh_x = 5x\, Re_x^{-0.5}$$

$$= 5\times0.4 \times (0.82\times10^5)^{-0.5}$$

$$= 6.98\times10^{-3}$$

$$ST_x = Sh_x\, Pr^{-0.333}$$

$$= 6.9\times10^{-3} \times (0.699)^{-0.333}$$

$$= 7.77\times10^{-3}$$

$$c_{fx} = 0.664\, Re^{-0.5}$$

$$= 0.664 \times (0.82\times10^5)^{-0.5}$$

$$= 2.31\times10^{-3}$$

$$c_{fL} = 1.328 \times Re_L^{-0.5}$$

$$= 1.328\,(0.82\times10^5)^{-0.5}$$

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$= 4.63 \times 10^{-3}$

$Q = hA(T_w - T_\infty)$

$= 11.62 \times (0.4 \times 1) \times (60 - 20)$

$= 11.62 \times 0.4 \times 40$

$= 185.92$

4. Air at 30°c and 1.013 bar flows over a flat plate at a velocity 50 m/s the plate is 1.5 m long and it is maintained at 70°c calculate the heat transfer rate per unit width considered laminar – Turbulent flow.

Sol: G.D $T_\infty = 30°c$

$P = 1.013$ bar

$L = 1.5$ m

$V = 15$ m/s

$T_w = 70°c$

$w = 1$ m

$T_f = \frac{T_w + T_\infty}{2} = \frac{70 + 30}{2} = 50°c$

$\rho = 1093$ kg/m^3

$k = 0.02826$ w/mk

$\nu = 17.95 \times 10^{-6}$ m^2/s

$Pr = 0.698$

$Re = \frac{VL}{\nu} = \frac{5 \times 1.5}{17.95 \times 10^{-6}} = 41.78 \times 10^5$

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$$Nu_L = Pr^{0.333}\left[0.037 Re_L^{0.8} - 871\right]$$

$$= 0.698^{0.333}\left[0.037 (41.78\times10^5)^{0.8} - 871\right]$$

$$= 5728.28$$

$$Nu_L = \frac{hL}{K}$$

$$h = \frac{Nu_x \times K}{L}$$

$$= \frac{5728.28 \times 0.02826}{1.5} = 107.9 \ w/m^2K$$

$$Q = hA(T_w - T_\infty)$$

$$= 107.9 \times 1.5 \times 1 \times (70-30)$$

$$= 6474 \text{ watts}$$

5. Air at 15°c 30 km per hr flows over a cylinder of diameter 400mm and 1500mm height with surface temperature of 45°c calculate the heat loss.

Sol: G.D

$T_\infty = 15°C$

$d = 400 mm = 0.4 m$

$h = L = 1500 mm = 1.5 m$

$U = 30 km per hr$

$$= \frac{30\times10^3}{3600} = 8.33 \ m/s$$

$T_w = 45°C$

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$$T_f = \frac{T_w + T_\infty}{2} = \frac{15+45}{2} = 30^\circ C$$

At 30°c air properties.

$$\rho = 1.165$$

$$\mu = 18.63 \times 10^{-6}$$

$$\nu = 16.00 \times 10^{-6}$$

$$Pr = 0.701$$

$$k = 0.02675$$

$$C_p = 1005$$

$$Re_D = \frac{VD}{\nu} = \frac{8.33 \times 0.4}{16.00 \times 10^{-6}}$$

$$= 2.08 \times 10^5$$

$$Nu_D = C\, Re_D^{m}\, Pr^{0.333}$$

$$C = 0.0266, \quad m = 0.805$$

$$Nu_D = 0.0266 \times (2.08 \times 10^5)^{0.805} \times (0.701)^{0.333}$$

$$= 451.38$$

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

$$h = \frac{Nu_D \times k}{D} = \frac{451.38 \times 0.02675}{0.4}$$

$$= 30.18 \ w/m^2k$$

$$Q = hA(T_w - T_\infty)$$

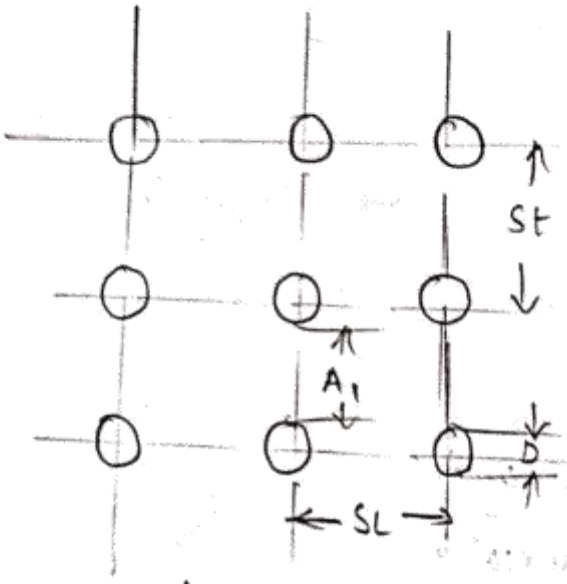
$$= 30.18 \times \pi \times 0.4 \times 1.5 \times (45-15)$$

$$= 1706.63 \ w$$

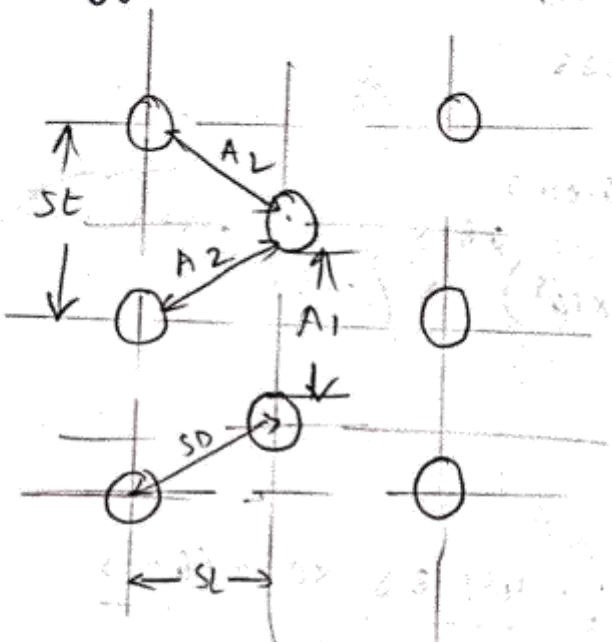
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Flow over bank of tubes!

1. In line



2. Staggered.



D = diameter of tube

St = transfas pitch

SL = longitudinal pitch

SD = diagonal pitch

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$$Re_D = \frac{U_{max} \pi D}{\upsilon}$$

$$U_{max} = \frac{S_t}{S_t - D} U$$

U_{max} > maximum velocity

υ = velocity of fluid

$$Nu = 1.13 \times (Pr)^{0.333} \cdot C \cdot Re^{n}$$

1, In a single condenser water flows through staggered tubes by air is passed across the flow over the tubes The temperature and velocity of air of 30°c, 8m/s the longitudinal and transfers pitches are 22, 20mm respecitively the tube outside diameter is 18mm and surface temperature is 90°c calculate the heat transfer coefficient

Sol Gr.D $T_\infty = 30^\circ c$

$U = 8 m/s$

$S_L = 22mm = 0.022 m$

$S_t = 20mm = 0.02 m.$

$D = 18mm = 0.018 m$

$T_W = 90^\circ c$

$$T_f = \frac{T_\infty + T_W}{2} = \frac{90+30}{2} = 60^\circ c$$

at air 60°c properties

$\rho = 1.060 \ kg/m^3$

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$\mu = 20.10 \times 10^{-6}$

$\upsilon = 18.97 \times 10^{-6}$

$Pr = 0.696$

$k = 0.02896$

$$Re = \frac{U_{max} \times D}{\upsilon}$$

$$U_{max} = \frac{St}{St - D} U$$

$$= \frac{0.02}{0.02 - 0.018} \times 8$$

$U_{max} = 80$

$$Re = \frac{80 \times 0.018}{18.97 \times 10^{-6}}$$

$$= 75909.3$$

$Re = 0.759 \times 10^5 < 5 \times 10^3$

it is a laminar flow

$$Nu = 1.13 \times (Pr)^{0.333} (c\, Re^n)$$

$$\frac{St}{D} = \frac{0.02}{0.018} = 1.11$$

$$\frac{SL}{D} = \frac{0.022}{0.018} = 1.22$$

$c = 0.519, \quad n = 0.556$

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$$Nu = 1.13 \times (0.696)^{0.333} \times 0.519 \times (0.75 \times 10^5)^{0.556}$$

$$Nu = 268.68$$

$$Nu = \frac{h \cdot D}{K}$$

$$h = \frac{Nu\, K}{D}$$

$$= \frac{268.68 \times 0.02896}{432.27} = 432.27\ w/m^2K$$

Internal flow :-

formulas use in flow through cylinders

1. Bulk mean temperature (T_m)

$$T_m = \left(\frac{T_{mi} + T_{mo}}{2}\right)$$

T_{mi} = inlet temperature

T_{mo} = outlet temperature

2. Rey. No $Re = \frac{\rho VD}{\mu}$

< 2300 laminar

> 2300 Turbulent

3. for laminar Nu. No.

$$Nu = 3.66 + \frac{0.668\,(D/L)\,Re_D\,Pr}{1 + 0.04\,((D/L)\,Re_D\,Pr)^{0.67}}$$

4. If it is Turbulent

$$Nu = 0.036\, Re_D^{0.8}\, Pr^{0.333}\, (D/L)^{0.055}$$

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$$Nu = 0.023\, Re_D^{0.8}\, Pr^{n}$$

$n = 0.4$ for heating process

$n = 0.3$ for cooling process.

$$0.6 < Pr < 100$$

$$Re > 10000$$

$$\frac{L}{D} > 60$$

5. Equivalent diameter for rectangular section

$$D_h \text{ (or) } D_c = \frac{4A}{P}$$

$$= \frac{4(L \times w)}{2(L+w)}$$

6. for hallow section

$$D_h \text{ (or) } D_c = \frac{4A}{P}$$

$$= \frac{4 \times \pi/4 (D_o^2 - D_i^2)}{\pi (D_o + D_i)}$$

7. heat transfer

$$Q = hA(T_w - T_m)$$

T_w = wall temperature

T_m = mean temperature

(or)

$$Q = mC_p(T_{mo} - T_{mi})$$

m = mass flow rate

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$$m = \rho A U$$

1. Water flows inside a tube of 20mm diameter and 3m long at a velocity of 0.03 m/s the water gets heated from 40° to 120°c while passing through the tube wall is maintained at temperature of 160°c find the heat transfer

Sol G.D

$$d = 20mm = 0.02 m$$

$$L = 3 m$$

$$U = 0.03 m/s$$

$$T_{mi} = 40°C$$

$$T_{mo} = 120°C$$

$$T_w = 160°C$$

$$T_m = \frac{T_{mi} + T_{mo}}{2} = \frac{40+120}{2} = 80°C$$

at 60°c properties of water

$$\rho = 974 \ kg/m^3$$

$$\nu = 0.364 \times 10^{-6} \ m^2/s$$

$$Pr = 2.220$$

$$C = 4195 \ J/kg.k$$

$$K = 0.6687 \ w/mk.$$

$$Re = \frac{UD}{\nu}$$

$$= \frac{0.03 \times 0.02}{0.364 \times 10^{-6}} = 1648.35$$

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$1648.35 < 2300$

for laminar nusselt Number

$$Nu = 3.66 + \frac{0.0668\ (P/L)\ Re_D\ Pr}{1 + 0.04\left((P/L)\ Re_D\ Pr\right)^{0.67}}$$

$$= 3.66 + \frac{0.0668\left(\frac{0.02}{3}\right) 1648.35 \times 2.220}{1 + 0.04\left(\left(\frac{0.02}{3}\right) 1648.35 \times 2.220\right)^{0.67}}$$

$$= 4.876$$

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

$$h = \frac{Nu \times K}{D}$$

$$= \frac{4.876 \times 0.6687}{0.02}$$

$$h = 163.02\ w/m^2K$$

$$Q = hA\ (T_w - T_m)$$

$$= 163.02 \times (\pi \times 0.02 \times 3) \times (160 - 80)$$

$$= 2458.28\ w$$

$$= 2.4\ kw$$

2. When 0.6 kg of water per minute is passed through a tube of 2cm diameter it found to be heated from 20°c to 60°c the heating is achived by condensing steam on the surface of the tube subsequently maintained at constant temperature of 90°c determine the lngth of the pipe required for fully developed flow 0.01 kg/sec

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Sol Given

$$m = 0.6 \quad = \frac{0.6}{160} = 0.01$$

$D = 2cm$

$T_{mi} = 20^\circ C$

$T_{mo} = 60^\circ C$

$T_w = 90^\circ C$

$U = 0.6\ kg$

$$T_m = \frac{T_{mi} + T_{mo}}{2} = \frac{20+60}{2} = 40^\circ C$$

at 40°C properties of air

$v = 0.657 \times 10^{-6}\ m^2/s$

$\rho = 995\ kg/m^3$

$Pr = 4.340$

$k = 0.6280\ w/mK$

$cp = 4178\ J/kg.K$

$m = \rho A U$

$$U = \frac{m}{\rho A} = \frac{0.01}{995 \times \frac{\pi}{4}(0.02)^2}$$

$$U = 0.031\ m/s$$

$$Re = \frac{UD}{\nu}$$

$$= \frac{0.031 \times 0.02}{0.657 \times 10^{-6}} = 943.6$$

$$= 943.6 < 2300$$

943.

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fully developed

$$Nu = 3.66$$

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

$$= \frac{3.66 \times 0.6280}{0.02} = 114.924$$

$$Q = \dot{m} c_p (T_{mo} - T_{mi})$$

$$= 0.01 \times 4178 (60 - 20)$$

$$= 1671.2.$$

Substitute this value

$$Q = hA (T_w - T_m)$$

$$1671.2 = 114.924 \times \pi \times 0.02 \times L \times (90 - 40)$$

$$L = \frac{1671.2}{114.924 \times \pi \times 0.02 \times (90-40)}$$

$$L = 4.62 \text{ m}.$$

1. Water at 30°c, 20 m per sec flows through a straight tube of 60 mm diameter the tube surface is maintained at 70°c and outlet temperature of water is 50°c find heat transfer coefficient from the tube surface to water and heat transfer with in the tube and tube length.

Sol Gr.D

$$U = 20 \text{ m/s}$$

$$D = 60 \text{ mm} = 0.06 \text{ m}$$

$$T_{mi} = 30^\circ C$$

$$T_{mo} = 50^\circ C$$

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$T_w = 70^\circ C$

$$T_m = \frac{T_{mi} + T_{mo}}{2} = \frac{30+50}{2} = 40^\circ C$$

at 40°c properties of air

$\rho = 995 \ kg/m^3$

$\nu = 0.657 \times 10^{-6} \ m^2/s$

$Pr = 4.340$

$k = 0.6280 \ w/mK$

$Cp = 4178 \ J/kgK.$

$$Re = \frac{VD}{\nu}$$

$$= \frac{20 \times 0.06}{0.657 \times 10^{-6}} = 1826484.0$$

$$= 1.8 \times 10^6 > 2300$$

Turbulent flow

$n = 0.4$ for heating of fluids.

$$Nu = 0.023 \ Re_D^{0.8} \ Pr^n$$

$$= 0.023 \times (1.8 \times 10^6)^{0.8} \times (4.340)^{0.4}$$

$$Nu = 4177.74$$

$$h = \frac{Nu \times K}{D}$$

$$= \frac{4177.74 \times 0.6280}{0.06}$$

$$= 43727.012$$

$$Q = m C_p (T_{mo} - T_{mi})$$

$$m = \rho A V$$

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$$m = 995 \times \frac{\pi}{4} (D^2) \times 20$$

$$= 995 \times \frac{\pi}{4} (0.06^2) \times 20$$

$$m = 56.26 \text{ kg/s}$$

$$Q = 56.26 \times 4178 \times (50 - 30)$$

$$= 4701085.6 \text{ watts}$$

$$= 4.7 \times 10^6 \text{ w}$$

$$Q = hA (T_w - T_m)$$

$$A = \frac{Q}{h(T_w - T_m)}$$

$$L = \frac{4.7 \times 10^6}{4372.12 \times (70 - 40) \pi (0.06)}$$

$$L = 19 \text{ m}$$

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Free convection:-

If the fluid motion is produced due to change in density resulting from temperature rating this mode of heat transfer is set to be free or natural convection.

Ex:

1. The heat of rooms by use of radiators
2. Cooling of transmission lines electrical transformers and rectifiers
3. The heat transfer from the pipe carrying steam from the wall of furnaces, from the wall of air conditioning house from the refrigerater condenser unit the rate of heat transfer is given below

$$Q = hA(T_w - T_\infty)$$

T_w = pipe surface temperature

T_∞ = fluid temperature

A = surface area

1. film temperature $T_f = \frac{T_w + T_\infty}{2}$

2. Coefficient of thermal expansion

$$\beta = \frac{1}{T_f \text{ in } K}$$

3. Nusselt Number

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

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4. Grassoff Number of vertical plate

$$Gr = \frac{g\beta L^3 \Delta T}{\upsilon^2}$$

L = length of plate

$\Delta T = T_w - T_\infty$

υ = kinematic viscosity

5. If $Gr.Pr < 10^9$

flow is laminar

$Gr.Pr > 10^9$

flow is Turbulent

6. for laminar $Nu = 0.59 (Gr.Pr)^{0.25}$

for $10^4 < GrPr < 10^9$

7. for turbulent (vertical plate)

$$Nu = 0.10 (Gr.Pr)^{0.333}$$

8. heat transfer (vertical plate)

$$Q = hA (T_w - T_\infty)$$

9. for horizontal plate

$$Gr = \frac{g\beta L_c^3 \Delta T}{\upsilon^2}$$

L_c = characteristic

w = width

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10. Nusselt Number

for horizontal plate upper surface heated

$$Nu = 0.54 (Ga.Pr)^{0.25}$$

for $2 \times 10^4 < Ga.Pr < 8 \times 10^6$

$$Nu = 0.15 (Ga.Pr)^{0.333}$$

for $8 \times 10^6 < Ga.Pr < 10^{11}$

11. lower surface heated.

$$Nu = 0.27 (Ga.Pr)^{0.25}$$

for $10^5 < GaPr < 10^{11}$

12. Heat transfer horizontal

$$Q = (h_u + h_l)(A)(T_w - T_\infty)$$

h_u = upper surface heat transfer coefficient

h_l = lower surface H.T.C

13. for horizontal cylinder

$$Nu = C(Ga.Pr)^m$$

14) for Horizontal cylinder

$$Q = hA(T_w - T_\infty)$$

$$A = \pi DL$$

15. for sphere

$$Nu = 2 + 0.43 (Ga.Pr)^{0.25}$$

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$$Q = hA(T_w - T_\infty)$$

$$A = 4\pi r^2$$

16. Boundary layer thickness

$$\delta x = \left[3.98 \times (Pr)^{-0.5} (0.952 + Pr)^{0.25} \times Gr^{-0.25}\right] x$$

17. Maximum velocity

$$v_x = 0.766 \times 10 \times (0.952 + Pr)^{-1/2} \times \left[\frac{g\beta(T_w - T_\infty)}{v^2}\right]^{1/2} \times x^{1/2}$$

18. Mass flow rate

$$m = 1.7 \rho v \left[\frac{Gr}{(Pr)^2 (Pr - 0.952)}\right]^{0.25}$$

1. A vertical plate of 0.75 m high is a 170°c exposed to air and 105°c and one atmosphere calculate mean heat transfer coefficient. rate of heat transfer for unit width of plate

Sol:- Gr.D

$L = 0.75 m$

$T_w = 170°c$

$T_\infty = 105°c$

$$T_f = \frac{170 + 105}{2} = 137.5°c$$

$$= 140°c$$

$$\beta = \frac{1}{T_f \text{ in } K}$$

$$= \frac{1}{137.5 + 273}$$

$$\beta = 2.4 \times 10^{-3} K^{-1}$$

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properties of air at $-140^{\circ}c$

$\rho = 0.854$

$\mu = 23.73 \times 10^{-6}$

$\vartheta = 27.80 \times 10^{-6} \ m^2/s$

$Pr = 0.684$

$Cp = 1013$

$k = 0.03489 \ w/mK$

$$Gr = \frac{g\beta L^3 \Delta T}{\vartheta^2}$$

$$= \frac{9.81 \times 2.4 \times 10^{-3} \times (0.75)^3 \times (170-105)}{(27.80 \times 10^{-6})^2}$$

$$= 8.4 \times 10^8$$

$$Gr.Pr = 8.4 \times 10^8 \times 0.684$$

$$= 5.71 \times 10^8 < 10^9$$

flow is laminar

$$Nu = 0.59 (Gr.Pr)^{0.25}$$

$$= 0.591 (5.71 \times 10^8)^{0.25}$$

$$Nu = 91.2$$

$$Q = hA (T_w - T_\infty)$$

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

$$h = \frac{Nu\,k}{L}$$

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$$= \frac{91.2 \times 0.03489}{0.75}$$

$$h = 4.242624$$

$$Q = hA\,(T_w - T_\infty)$$

$$= 4.24 \times \pi \times 0.75\,(170 - 105)$$

$$Q = 649.36$$

2. A steam pipe 10cm outside dia runs horizontally in a room at 23°C take the outside surface temperature of pipe as 165°C determine heat loss per meter length of pipe

Sol: Given $D = 10cm = 0.1m$

$T_\infty = 23°C$

$T_w = 165°C$

$$T_f = \frac{T_w + T_\infty}{2} = \frac{165+23}{2} = 94°C$$

properties of air at 95°C

$\rho = 0.995\ kg/m^3$

$\nu = 22.615 \times 10^{-6}$

$Pr = 0.689$

$k = 0.03169$

$$\beta = \frac{1}{T_f \text{ in } K} = \frac{1}{94+273} = 2.72 \times 10^{-3}$$

$$Gr = \frac{g\beta L^3 \Delta T}{\nu^2}$$

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$$= \frac{9.81 \times 2.72 \times 10^{-3} \times 0.1^3 (165-23)}{(22.615 \times 10^{-6})^2}$$

$$Gr = 7.4 \times 10^6$$

$$Gr.Pr = 7.4 \times 10^6 \times 0.689$$

$$= 5.09 \times 10^6$$

laminar flow

$$C = 0.48 \quad , m = 0.25$$

$$Nu = C (Gr Pr)^m$$

$$= 0.48 (5.09 \times 10^6)^{0.25}$$

$$= 22.79$$

$$h = \frac{Nu\,K}{D}$$

$$= \frac{22.79 \times 0.03169}{0.1}$$

$$h = 7.22 \text{ w/mk}$$

$$Q = hA (Tw - T\infty)$$

$$= 7.22 \times \pi \times 0.1 \times L (165 - 23)$$

$$Q/L = 322.18 \text{ w/m}$$

3, A large vertical plate 5m high maintained at 100°c and exposed to air at 30°c. Calculate the heat transfer coefficient.

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20) Gr.D

$L = 5m$

$T_\infty = 30^\circ C$

$T_w = 100^\circ C$

$T_f = \frac{30+100}{2} = 65^\circ C$

properties of $65^\circ C$

$\rho = 1.0445 \ kg/m^3$

$\vartheta = 19.495 \times 10^{-6} \ m^2/s$

$Pr = 0.695$

$k = 0.02931 \ w/mK$

$\beta = \frac{1}{T_f in\ k} = \frac{1}{65+273} = 2.95 \times 10^{-3}$

$Gr = \frac{g\beta L^3 \Delta T}{\vartheta^2}$

$= \frac{9.81 \times (2.95 \times 10^{-3})(5^3)(100-30)}{(19.495 \times 10^{-6})^2}$

$= 6.6 \times 10^{11}$

$Gr.Pr = 6.6 \times 10^{11} \times 0.695$

$= 4.587 \times 10^{11}$

Turbulent flow

$Nu = 0.10 (Gr.Pr)^{0.333}$

$= 0.10 (4.587 \times 10^{11})^{0.333}$

$= 764.3$

$h = \frac{Nu\,k}{L}$

$= \frac{764.3 \times 0.0293}{5}$

$h = 4.48 \ w/mK$

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