Heat Transfer/Heat Exchanger

- How is the heat transfer?
- Mechanism of Convection
- Applications .
- Mean fluid Velocity and Boundary and their effect on the rate of heat transfer.
- Fundamental equation of heat transfer
- Logarithmic-mean temperature difference.
- Heat transfer Coefficients.
- Heat flux and Nusselt correlation
- Simulation program for Heat Exchanger

How is the heat transfer?

- Heat can transfer between the surface of a solid conductor and the surrounding medium whenever temperature gradient exists.

  Conduction

  Convection

  - Natural convection
  - Forced Convection

Natural and forced Convection

- Natural convection occurs whenever heat flows between a solid and fluid, or between fluid layers.
- As a result of heat exchange

  Change in density of effective fluid layers taken place, which causes upward flow of heated fluid.

If this motion is associated with heat transfer mechanism only, then it is called Natural Convection

Forced Convection

- If this motion is associated by mechanical means such as pumps, gravity or fans, the movement of the fluid is enforced.
- And in this case, we then speak of Forced convection.

Heat Exchangers

- A device whose primary purpose is the transfer of energy between two fluids is named a Heat Exchanger.

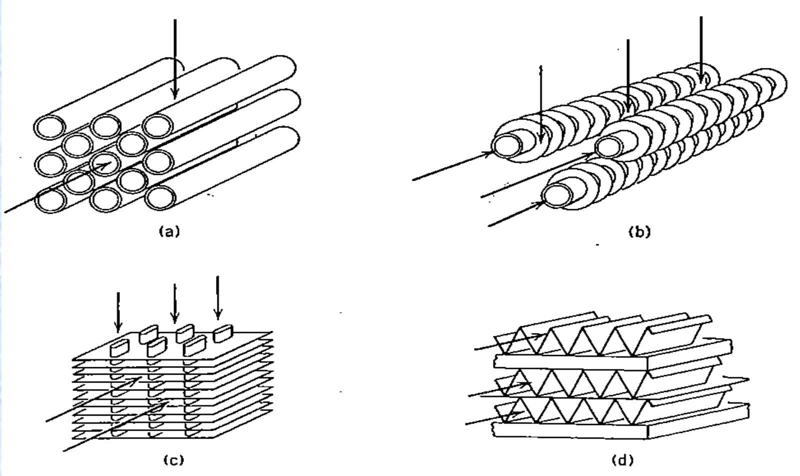
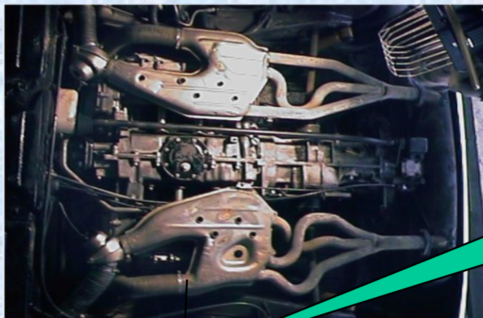
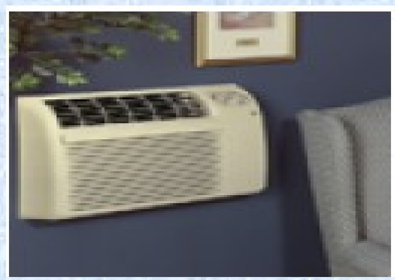


Figure 22.4 Compact heat-exchanger configurations.

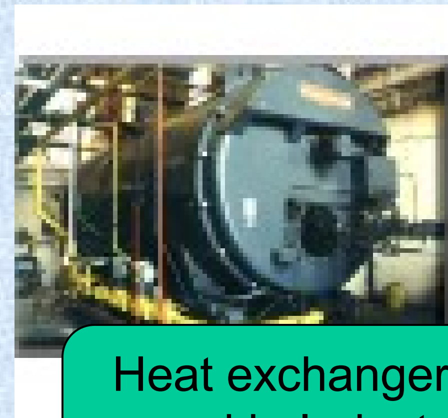
Applications of Heat Exchangers



Heat Exchangers prevent car engine overheating and increase efficiency



Heat exchangers are used in AC and furnaces



Heat exchangers are used in Industry for heat transfer

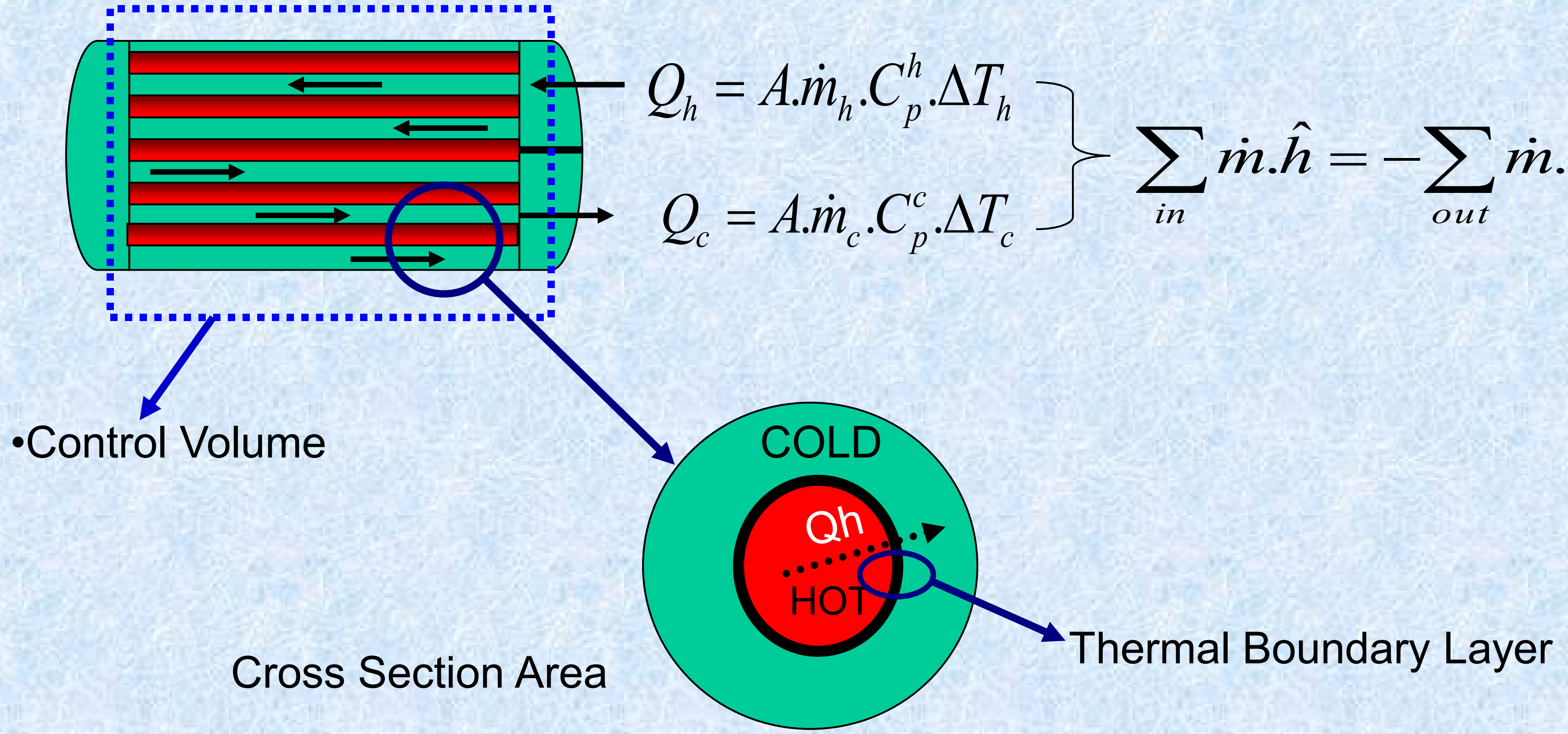
- The closed-type exchanger is the most popular one.
- One example of this type is the Double pipe exchanger.

- In this type, the hot and cold fluid streams do not come into direct contact with each other. They are separated by a tube wall or flat plate.

Principle of Heat Exchanger

- First Law of Thermodynamic: *"Energy is conserved."*

$$\frac{dE}{dt}^{\,0} = \left(\sum_{in} \dot{m}.\hat{h}_{in} - \sum_{out} \dot{m}.\hat{h}_{out} \right) + \dot{q}^{\,0} + \dot{w}_s^{\,0} + \dot{e}_{generated}^{\,0}$$



$$Q_h = A.\dot{m}_h.C_p^h.\Delta T_h$$

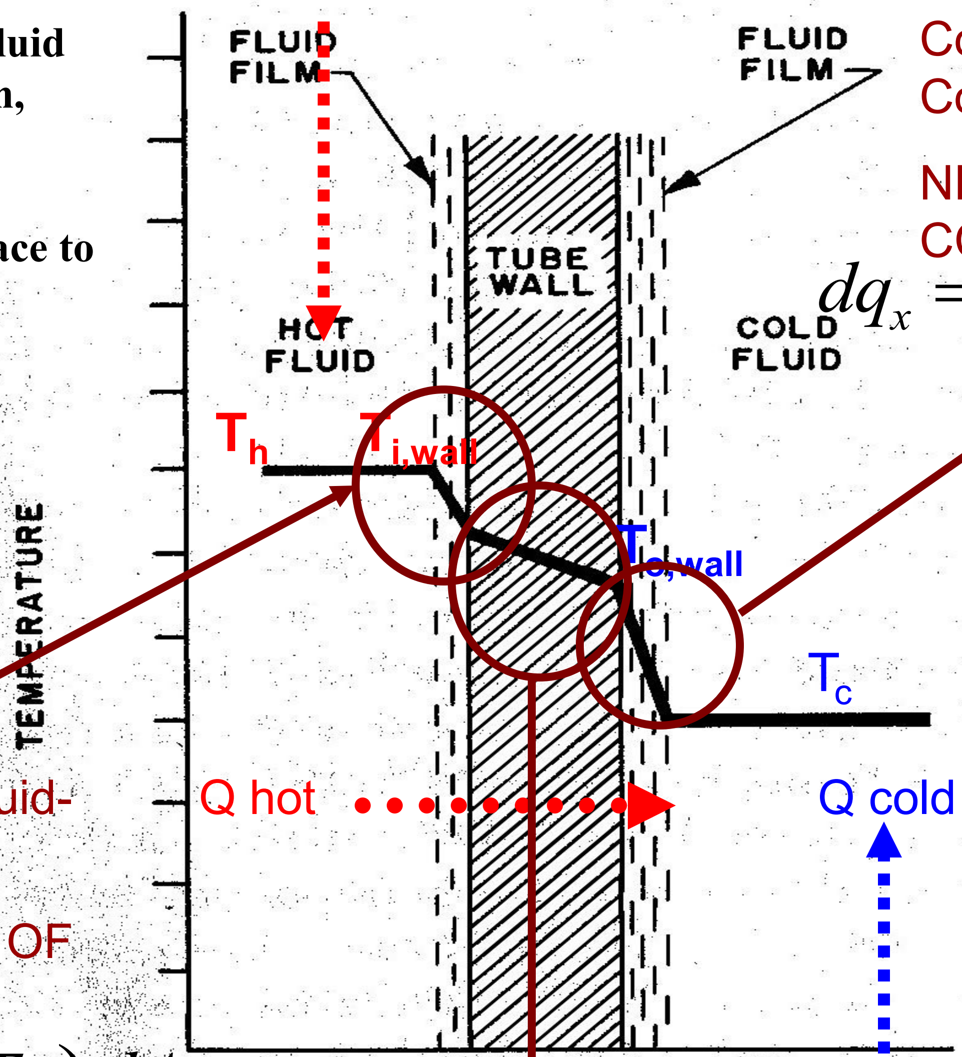
$$Q_c = A.\dot{m}_c.C_p^c.\Delta T_c$$

$$\sum_{in} \dot{m}.\hat{h} = -\sum_{out} \dot{m}.\hat{h}$$

THERMAL

BOUNDARY LAYER

Energy moves from hot fluid to a surface by convection, through the wall by conduction, and then by convection from the surface to the cold fluid.



Region III: Solid – Cold Liquid Convection

NEWTON'S LAW OF CCOLING

$$dq_x = h_c.(T_{ow} - T_c).dA$$

Region I : Hot Liquid-Solid Convection

NEWTON'S LAW OF CCOLING

$$dq_x = h_h.(T_h - T_{iw}).dA$$

Region II : Conduction Across Copper Wall

FOURIER'S LAW

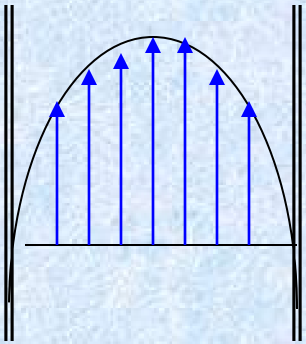
$$dq_x = -k.\frac{dT}{dr}$$

- **Velocity distribution and boundary layer**

When fluid flow through a circular tube of uniform cross-suction and fully developed,

The velocity distribution depend on the type of the flow.

In laminar flow the volumetric flowrate is a function of the radius.



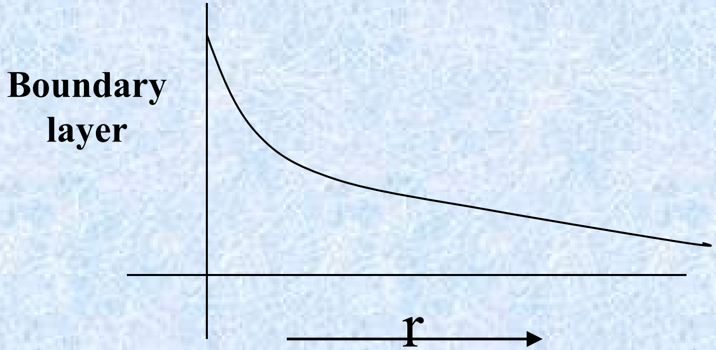
$$V = \int_{r=0}^{r=D/2} u 2\pi r dr$$

V = volumetric flowrate

u = average mean velocity

- In turbulent flow, there is no such distribution.

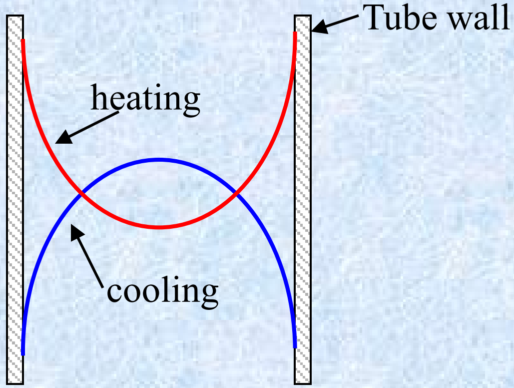
- The molecule of the flowing fluid which adjacent to the surface have zero velocity because of mass-attractive forces. Other fluid particles in the vicinity of this layer, when attempting to slid over it, are slow down by viscous forces.

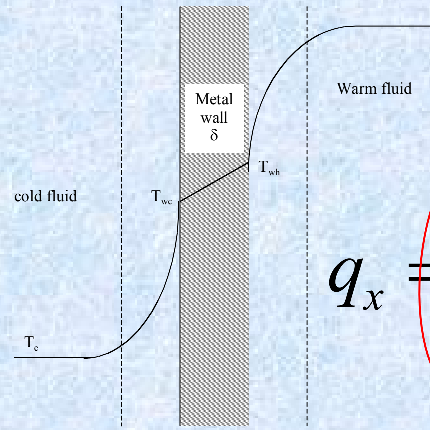


- Accordingly the temperature gradient is larger at the wall and through the viscous sub-layer, and small in the turbulent core.

$$q_x = hA\Delta T$$

$$q_x = hA(T_w - T)$$





$$q_x = \frac{k}{\delta} A(T_w - T)$$

h

- The reason for this is

1) Heat must transfer through the boundary layer by conduction.

2) Most of the fluid have a low thermal conductivity (k)

3) While in the turbulent core there are a rapid moving eddies, which they are equalizing the temperature.

U = The Overall Heat Transfer Coefficient [W/m.K]

Region I : Hot Liquid – Solid Convection

$$q_x = h_{hot}.(T_h - T_{iw}).A \rightarrow T_h - T_{iw} = \frac{q_x}{h_h . A_i}$$

Region II : Conduction Across Copper Wall

$$q_x = \frac{k_{copper}.2\pi L}{\ln \frac{r_o}{r_i}} \rightarrow T_{o,wall} - T_{i,wall} = \frac{q_x . \ln\left(\frac{r_o}{r_i}\right)}{k_{copper}.2\pi L}$$

Region III : Solid – Cold Liquid Convection

$$q_x = h_c\left(T_{o,wall} - T_c\right)A_o \rightarrow T_{o,wall} - T_c = \frac{q_x}{h_c . A_o}$$

+

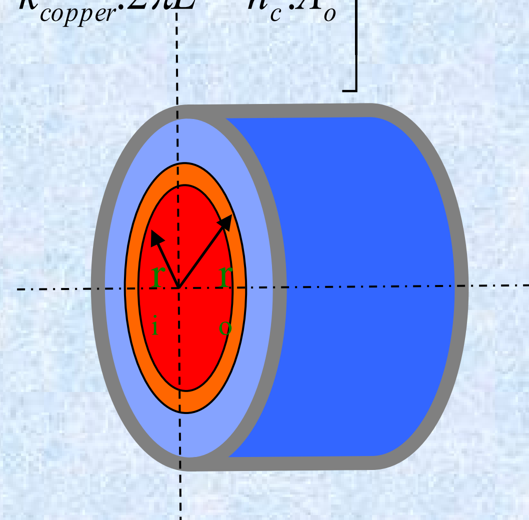
$$T_h - T_c = q_x\left[\frac{1}{h_h . A_i} + \frac{\ln\left(\frac{r_o}{r_i}\right)}{k_{copper}.2\pi L} + \frac{1}{h_c . A_o}\right]$$

$$T_h - T_c = \frac{q_x}{R_1 + R_2 + R_3}$$

$$q_x = U.A.(T_h - T_c)$$

$$U = \frac{1}{A.\Sigma R}$$

$$U = \left[\frac{r_o}{h_{hot}.r_i} + \frac{r_o . \ln\left(\frac{r_o}{r_i}\right)}{k_{copper}.r_i} + \frac{1}{h_{cold}}\right]^{-1}$$



Calculating U using Log Mean Temperature

Hot Stream : $dq_h = \dot{m}_h.C_p^h.dT_h$

Cold Stream: $dq_c = \dot{m}_c.C_p^c.dT_c$

$$d(\Delta T) = dT_h - dT_c$$
$$\Delta T = T_h - T_c$$

$$\rightarrow d(\Delta T) = \left(\frac{dq_h}{m_h.C_p^h} - \frac{dq_c}{m_c.C_p^c}\right)$$

$$dq = -dq_{hot} = dq_{cold}$$
$$-dq = -U.\Delta T.dA$$

$$d(\Delta T) = -U.\Delta T.dA.\left(\frac{1}{m_h.C_p^h} + \frac{1}{m_c.C_p^c}\right)$$

$$\int_{\Delta T_1}^{\Delta T_2} \frac{d(\Delta T)}{\Delta T} = -U.\left(\frac{\Delta T_h}{q_h} + \frac{\Delta T_c}{q_c}\right).\int_{A_1}^{A_2} dA$$

$$\int_{\Delta T_1}^{\Delta T_2} \frac{d(\Delta T)}{\Delta T} = -U.\left(\frac{1}{m_h.C_p^h} + \frac{1}{m_c.C_p^c}\right).\int_{A_1}^{A_2} dA$$

$$\ln\left(\frac{\Delta T_2}{\Delta T_1}\right) = -\frac{U.A.}{q}(\Delta T_h + \Delta T_c) = -\frac{U.A}{q}\left[\left(T_h^{in} - T_h^{out}\right) - \left(T_c^{in} - T_c^{out}\right)\right]$$

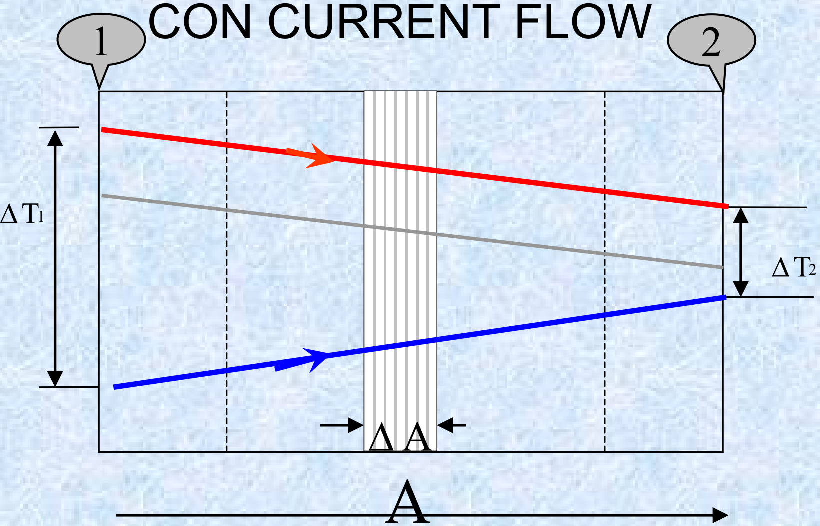
$$q = U.A\frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

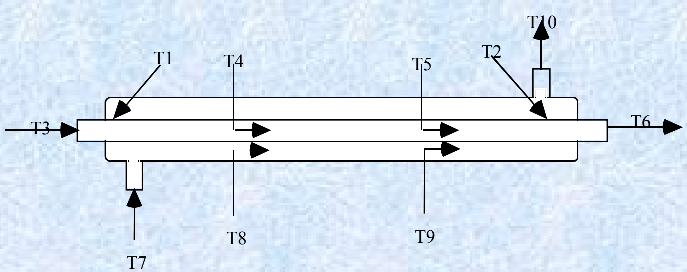
Log Mean Temperature

Log Mean Temperature evaluation

$$\Delta T_{Ln} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \longrightarrow U = \frac{\dot{m}_h.\dot{C}_p^h.(T_3 - T_6)}{A.\Delta T_{Ln}} = \frac{\dot{m}_c.\dot{C}_p^c.(T_7 - T_{10})}{A.\Delta T_{Ln}}$$

CON CURRENT FLOW



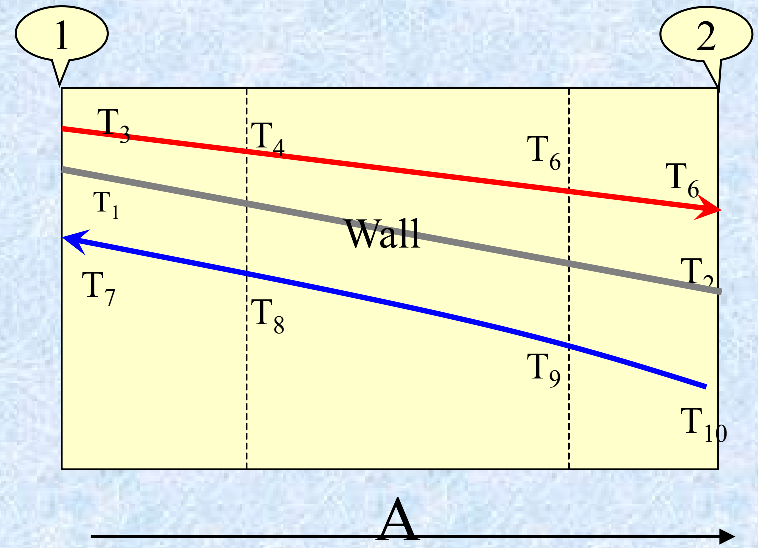


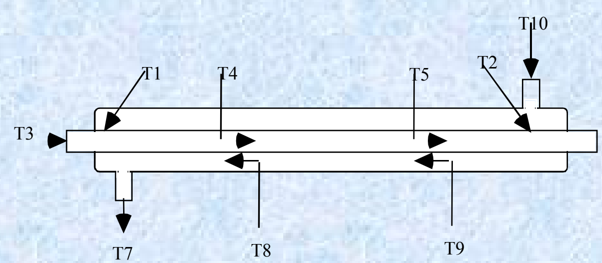
Parallel Flow

$$\Delta T_1 = T_h^{in} - T_c^{in} = T_3 - T_7$$

$$\Delta T_2 = T_h^{out} - T_c^{out} = T_6 - T_{10}$$

COUNTER CURRENT FLOW





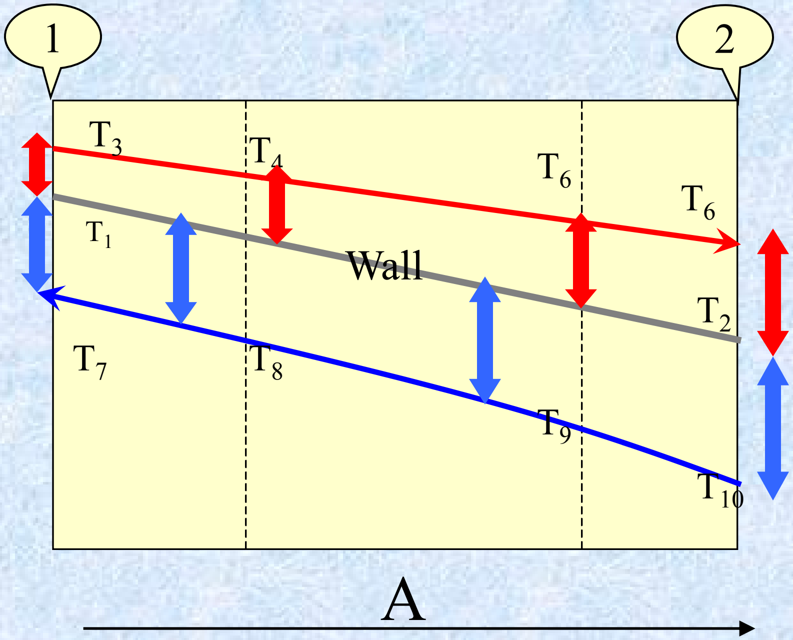
Counter - Current Flow

$$\Delta T_1 = T_h^{in} - T_c^{out} = T_3 - T_7$$

$$\Delta T_2 = T_h^{out} - T_c^{in} = T_6 - T_{10}$$

$$q = h_h \, A_i \, \Delta T_{lm}$$

$$\Delta T_{lm} = \frac{(T_3 - T_1) - (T_6 - T_2)}{\ln \dfrac{(T_3 - T_1)}{(T_6 - T_2)}}$$



$$q = h_c \, A_o \, \Delta T_{lm}$$

$$\Delta T_{lm} = \frac{(T_1 - T_7) - (T_2 - T_{10})}{\ln \dfrac{(T_1 - T_7)}{(T_2 - T_{10})}}$$

DIMENSIONLESS ANALYSIS TO CHARACTERIZE A HEAT EXCHANGER

$$Nu = f(\mathrm{Re}, \mathrm{Pr}, L/D, \mu_b/\mu_o)$$

$$\frac{h.D}{k} \qquad \frac{v.D.\rho}{\mu} \qquad \frac{C_p.\mu}{k}$$

- **Further Simplification:**

$$Nu = a.\mathrm{Re}^b.\mathrm{Pr}^c$$

$$Nu = \frac{D}{\delta}$$

Can Be Obtained from 2 set of experiments

One set, run for constant Pr

And second set, run for constant Re

$$q = \frac{k}{\delta} A(T_w - T)$$

h

•Empirical Correlation

- For laminar flow

Nu = 1.62 (Re*Pr*L/D)

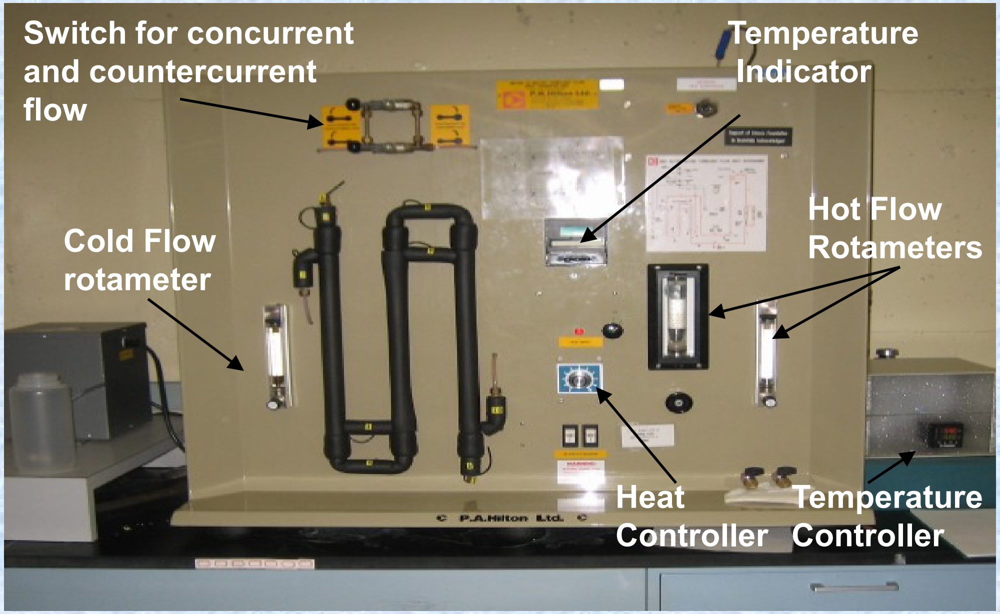
- For turbulent flow

$$Nu_{Ln} = 0.026 . \mathrm{Re}^{0.8} . \mathrm{Pr}^{1/3} . \left(\frac{\mu_b}{\mu_o} \right)^{0.14}$$

- Good To Predict within 20%
- Conditions: L/D > 10
  0.6 < Pr < 16,700
  Re > 20,000

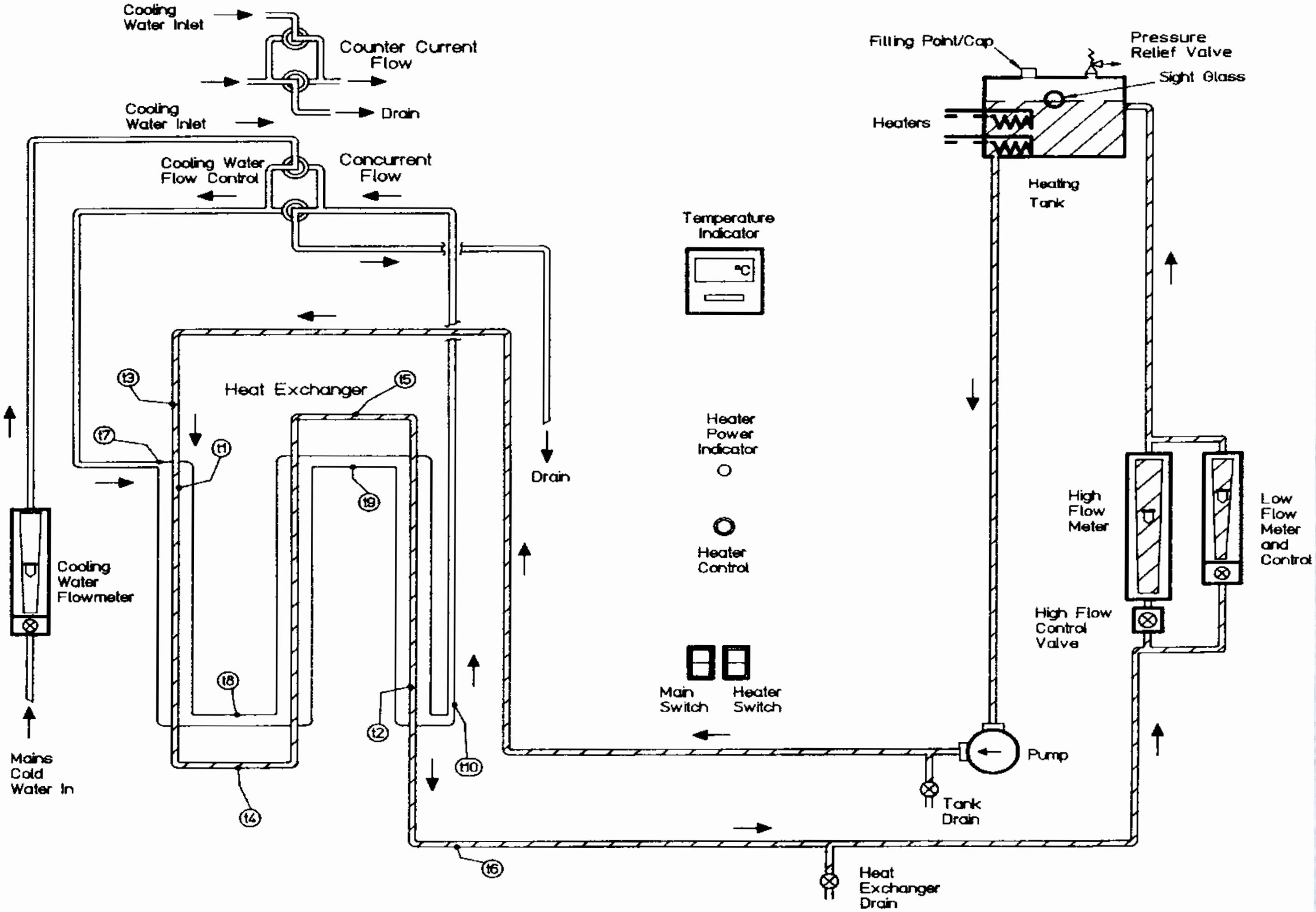
Experimental

Apparatus



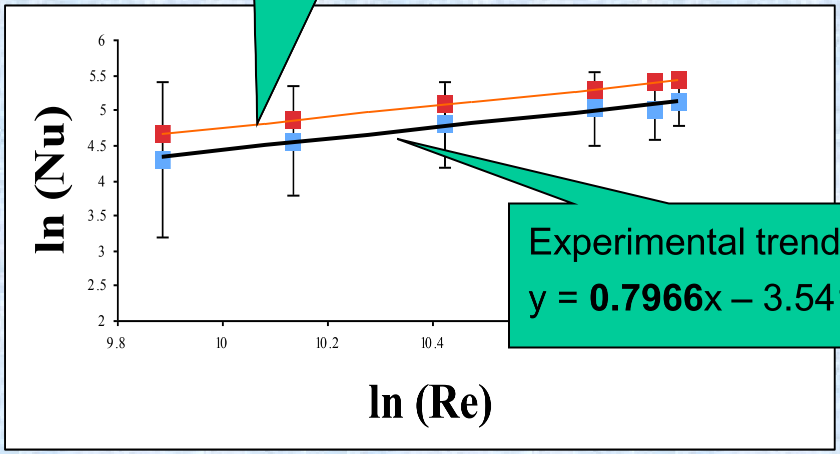
- Two copper concentric pipes
  - Inner pipe (ID = 7.9 mm, OD = 9.5 mm, L = 1.05 m)
  - Outer pipe (ID = 11.1 mm, OD = 12.7 mm)
- Thermocouples placed at 10 locations along exchanger, T1 through T10

WATER-WATER TURBULENT FLOW HEAT EXCHANGER



Examples of Exp. Results

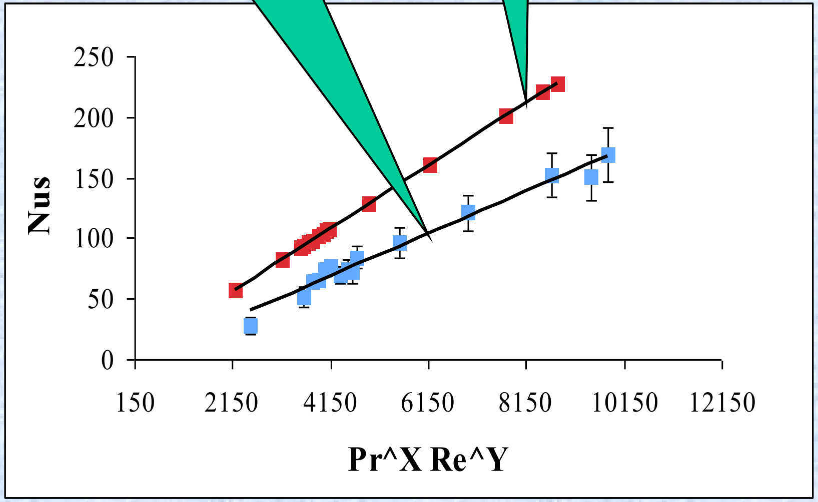
Theoretical trend
y = **0.8002**x – 3.0841



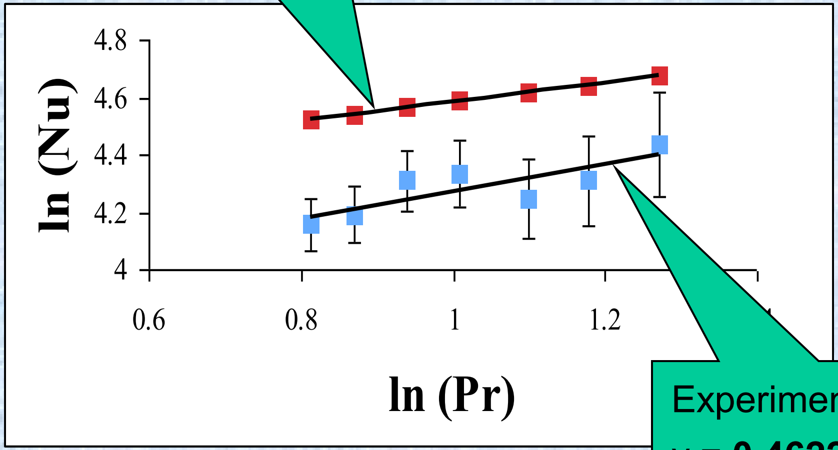
Experimental trend
y = **0.7966**x – 3.5415

Theoretical trend
y = **0.026**x

Experimental trend
y = **0.0175**x – 4.049



Theoretical trend
y = **0.3317**x + 4.2533



Experimental trend
y = **0.4622**x – 3.8097

Experimental $Nu = 0.0175Re^{0.7966}Pr^{0.4622}$

Theoretical $Nu = 0.026Re^{0.8}Pr^{0.33}$

Effect of core tube velocity on the local and over all Heat Transfer coefficients