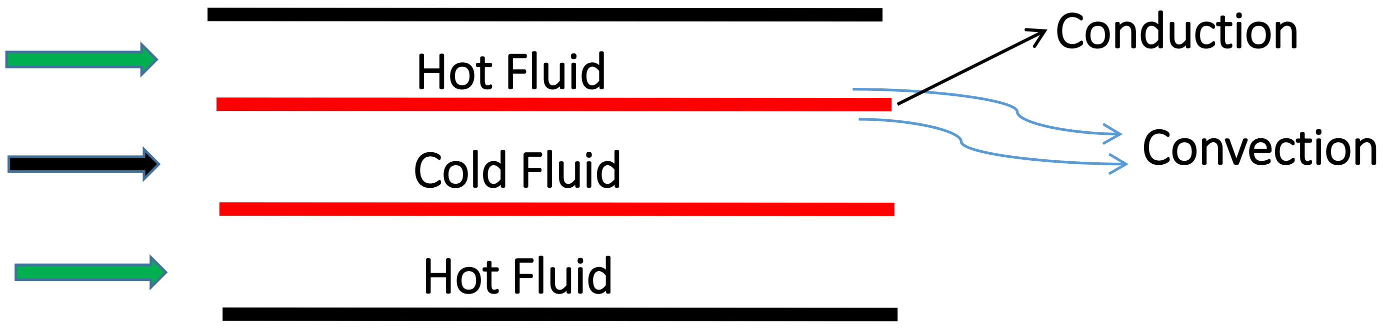
Heat Exchangers

- **Device that facilitates the exchange of heat between two fluids that are at different temperatures without mixing each other.**
- **Heat transfer on a heat exchanger involves**

  Convection in each fluid

  Conduction through the wall separating the two fluids

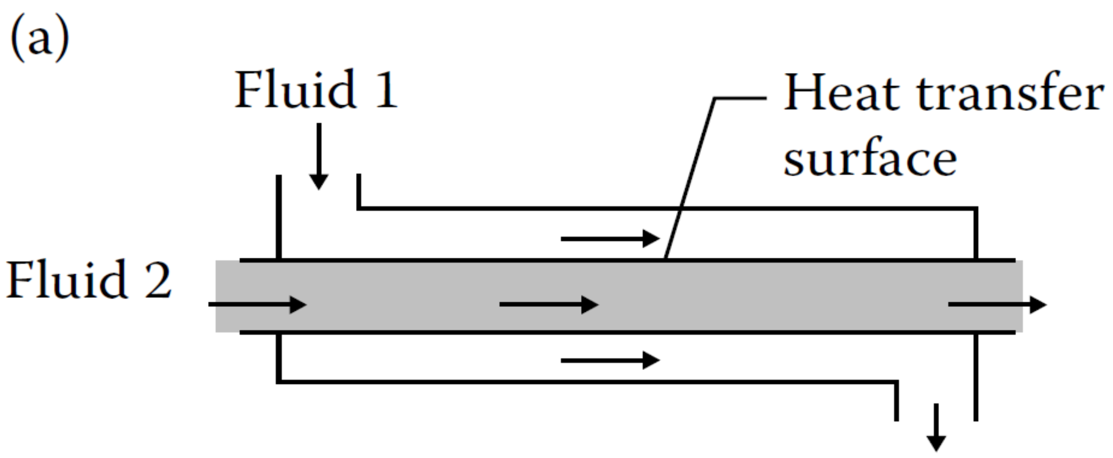


- **Overall heat transfer coefficient accounts for the above conduction and convection effects.**
- **LMTD-F approach- Temps known,**$\Delta T_{1M} - \dot{m} - U$ **cal** A_s
- **Є-NTU approach- Find** $\dot{Q}, T_{co}$ & T_{ho}, **known-** $\dot{m}_c, \dot{m}_n, T_{ci}, T_{hi}, T_{ype}$ & **size of heat exchanger**

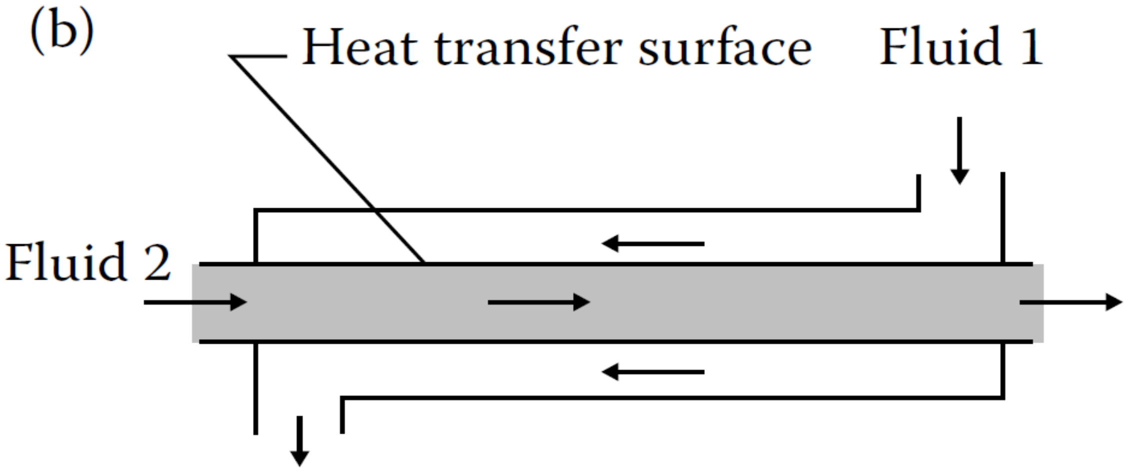
- **LMTD-F approach :**
  - **known – Temperatures (ΔT_{lmtd}), mass flow rates, overall heat transfer coefficient, Calculate the size of the heat exchanger (heat transfer area)**

- **ϵ-NTU approach :**
- **Known: inlet temperatures on cold side and hot side, type and size of the heat exchanger, calculate the outlet temperatures, load of the heat exchanger**

- **Overall heat transfer coefficient accounts for the above conduction and convection effects.**
- **LMTD-F approach- Temps known,** $\Delta T_{lM}, \dot{m}, U$ **calculate** A_s
- **Є-NTU approach- Find** $\dot{Q}, T_{co}$ & T_{ho}, **known-** $\dot{m}_c, \dot{m}_n, T_{ci}, T_{hi}, T_{ype}$ & **size of HE**



Parallel flow, with two fluids flowing in the same direction



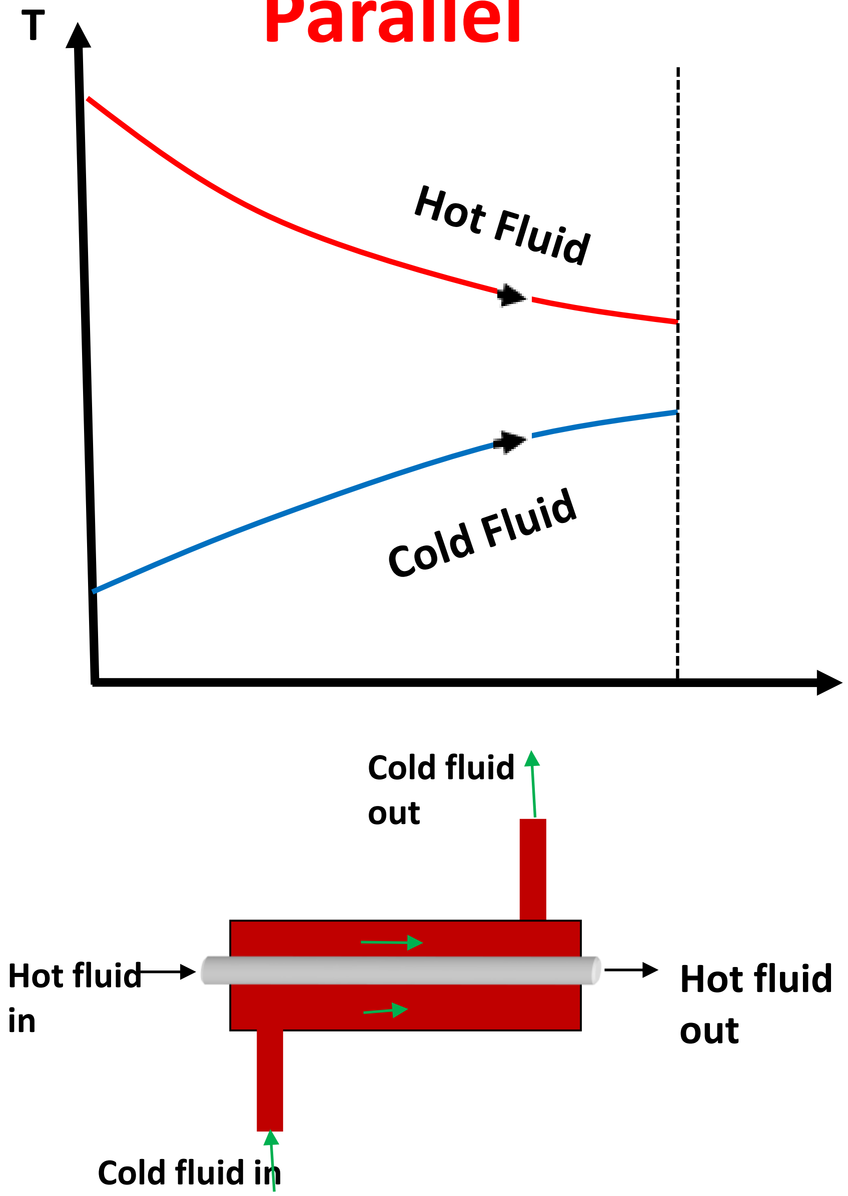
counterflow, with two fluids flowing parallel to one another but in opposite directions

TYPES OF HEAT EXCHANGERS

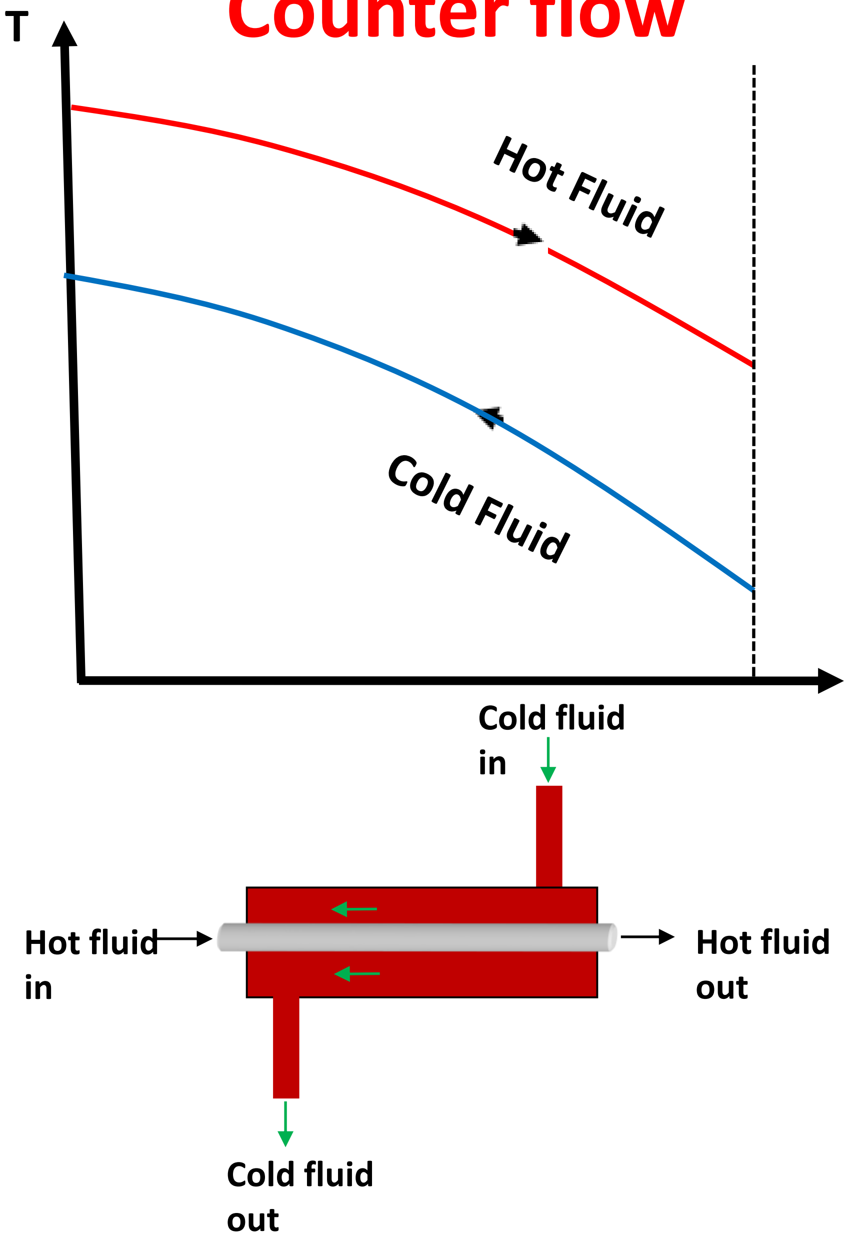
- COUNTER FLOW HE
- PARALLEL FLOW HE
- DOUBLE PIPE HE

Double pipe heat exchanger:

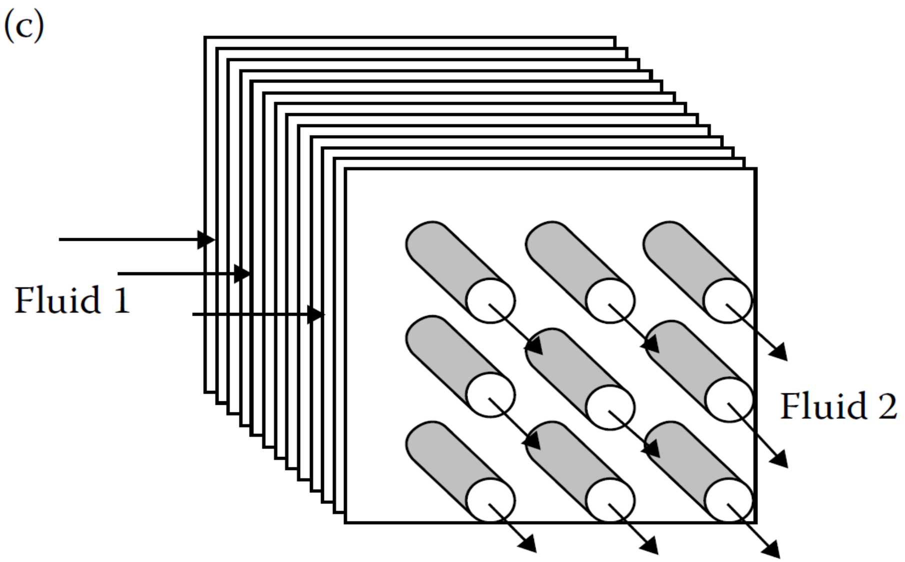
Parallel

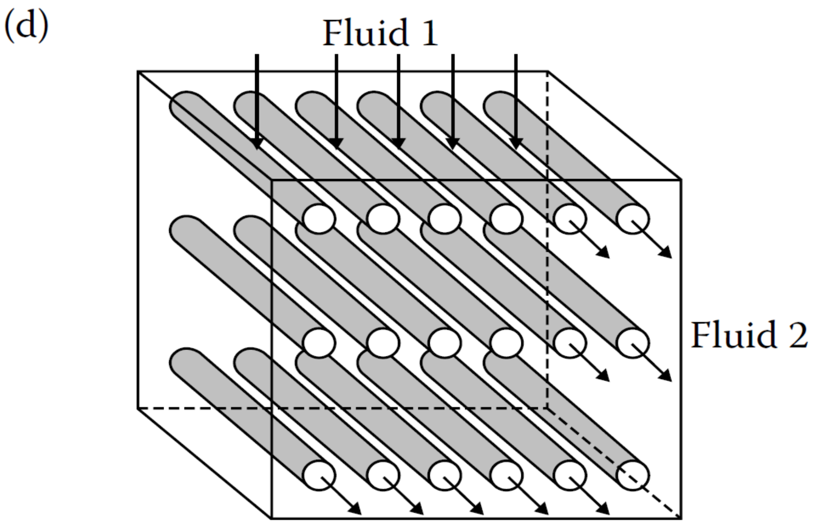


Counter flow



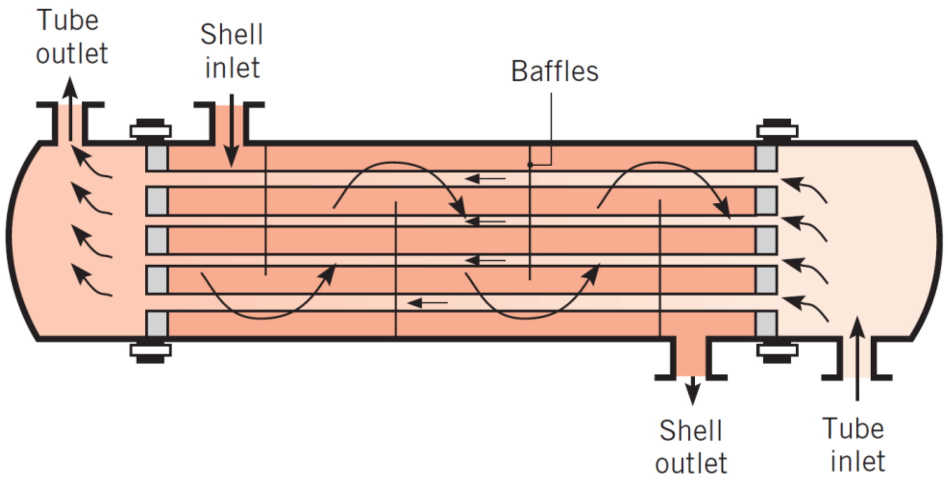
CROSS FLOW HEAT EXCHANGER:



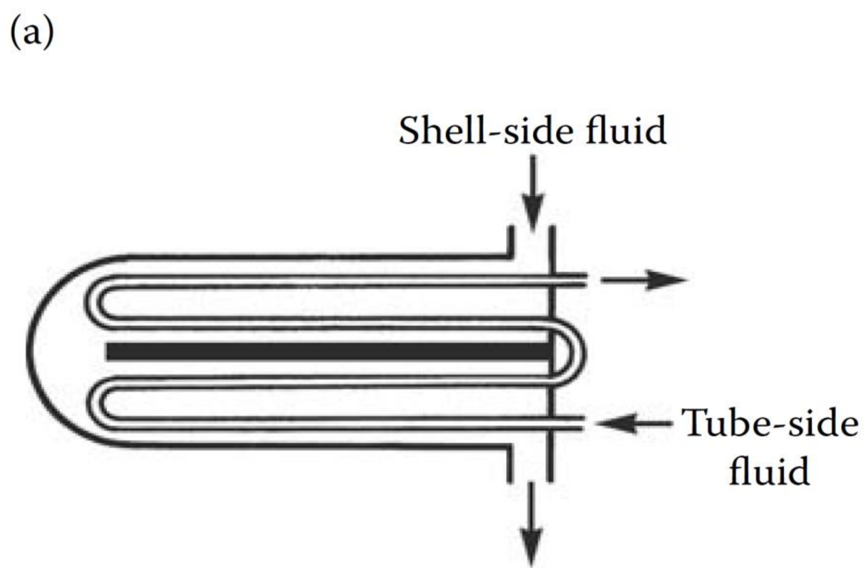


Crossflow, with two fluids crossing each other

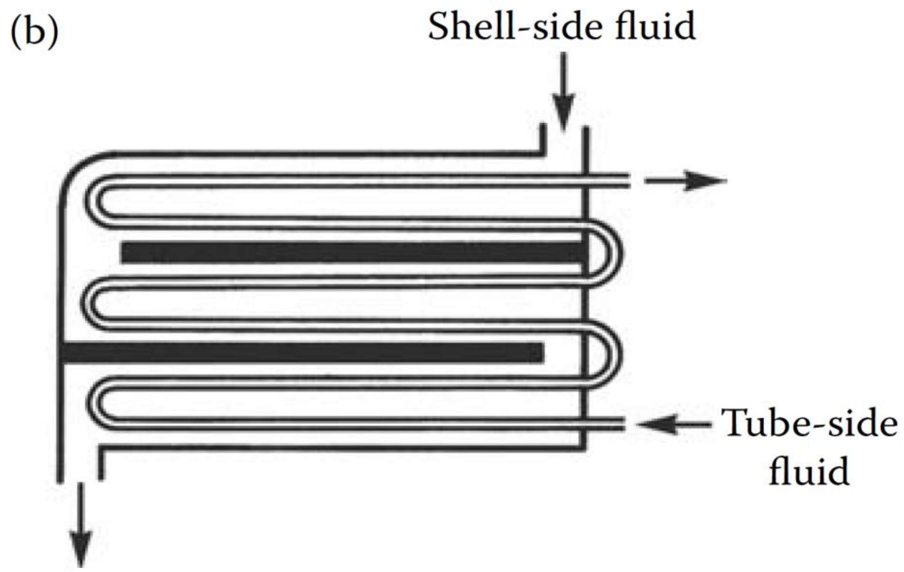
SHELL AND TUBE HEAT EXCHANGER (ONE SHELL- ONE TUBE PASS):



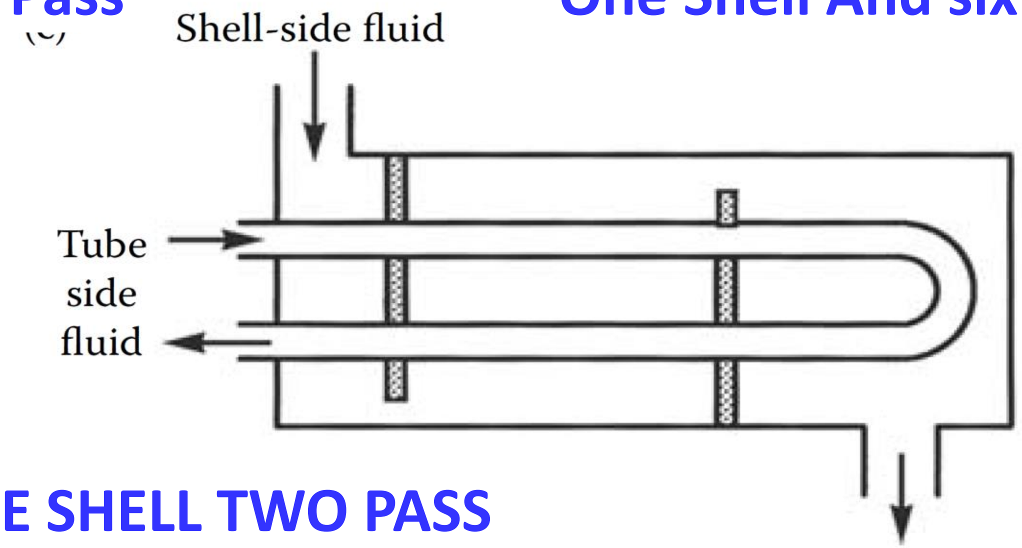
Multipass and multipass crossflow arrangements



One Shell And Four Pass

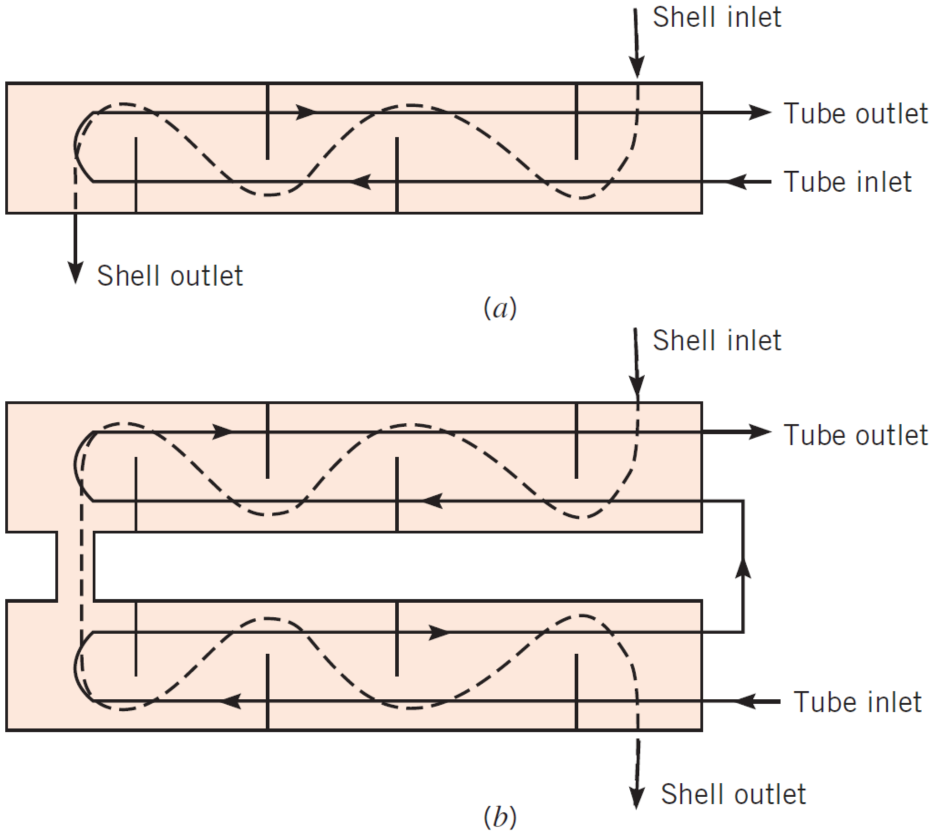


One Shell And six Pass



ONE SHELL TWO PASS

Mixed flow where both fluids are simultaneously in parallel flow, in counterflow (Figure a and b) and in multipass crossflow (Figure c)



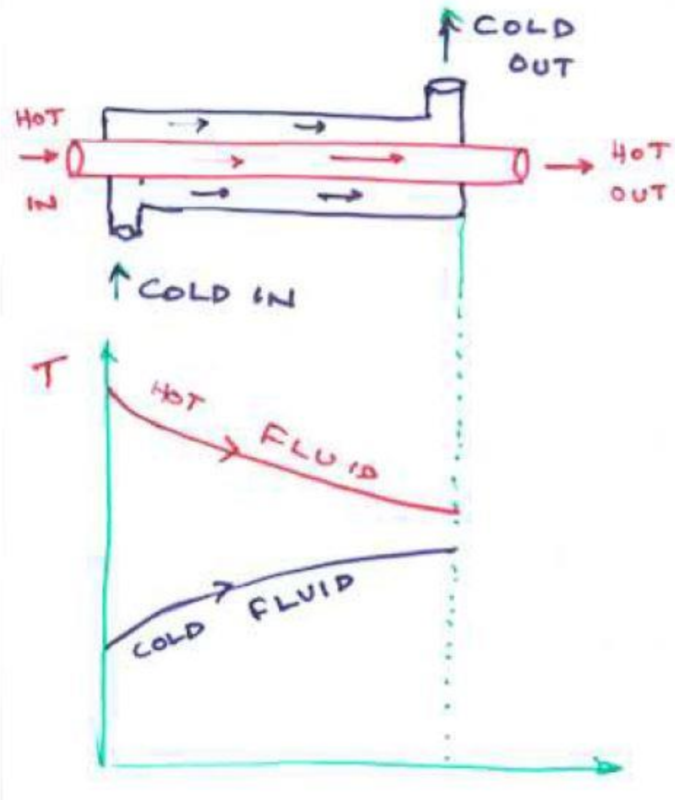
ONE SHELL-TWO TUBE PASS

TWO SHELL-FOUR TUBE PASS

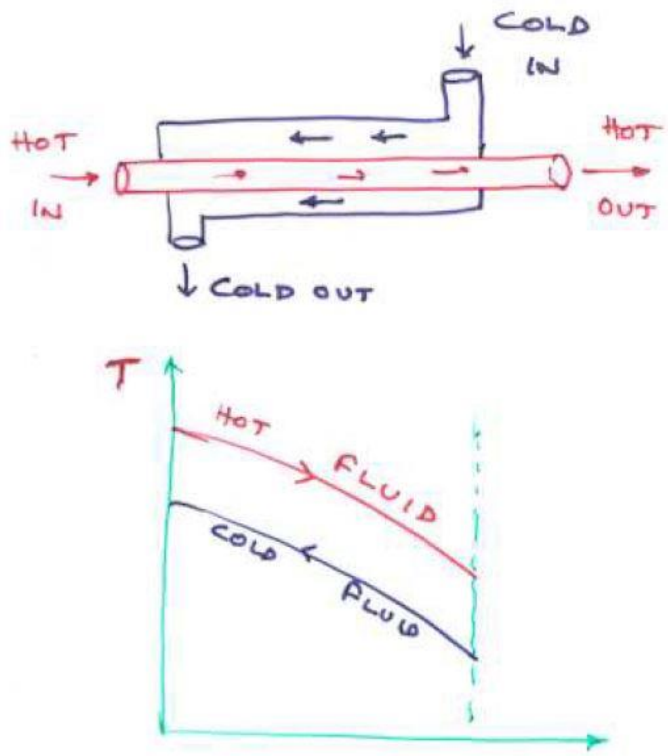
TYPES OF HEAT EXCHANGERS

DOUBLE PIPE HEAT EXCHANGERS:

PARALLEL



COUNTER



COMPACT HEAT EXCHANGER:

$$Area\ density = \frac{Heat\ transfer\ surface\ area}{Heat\ exchanger\ volume} = \beta$$

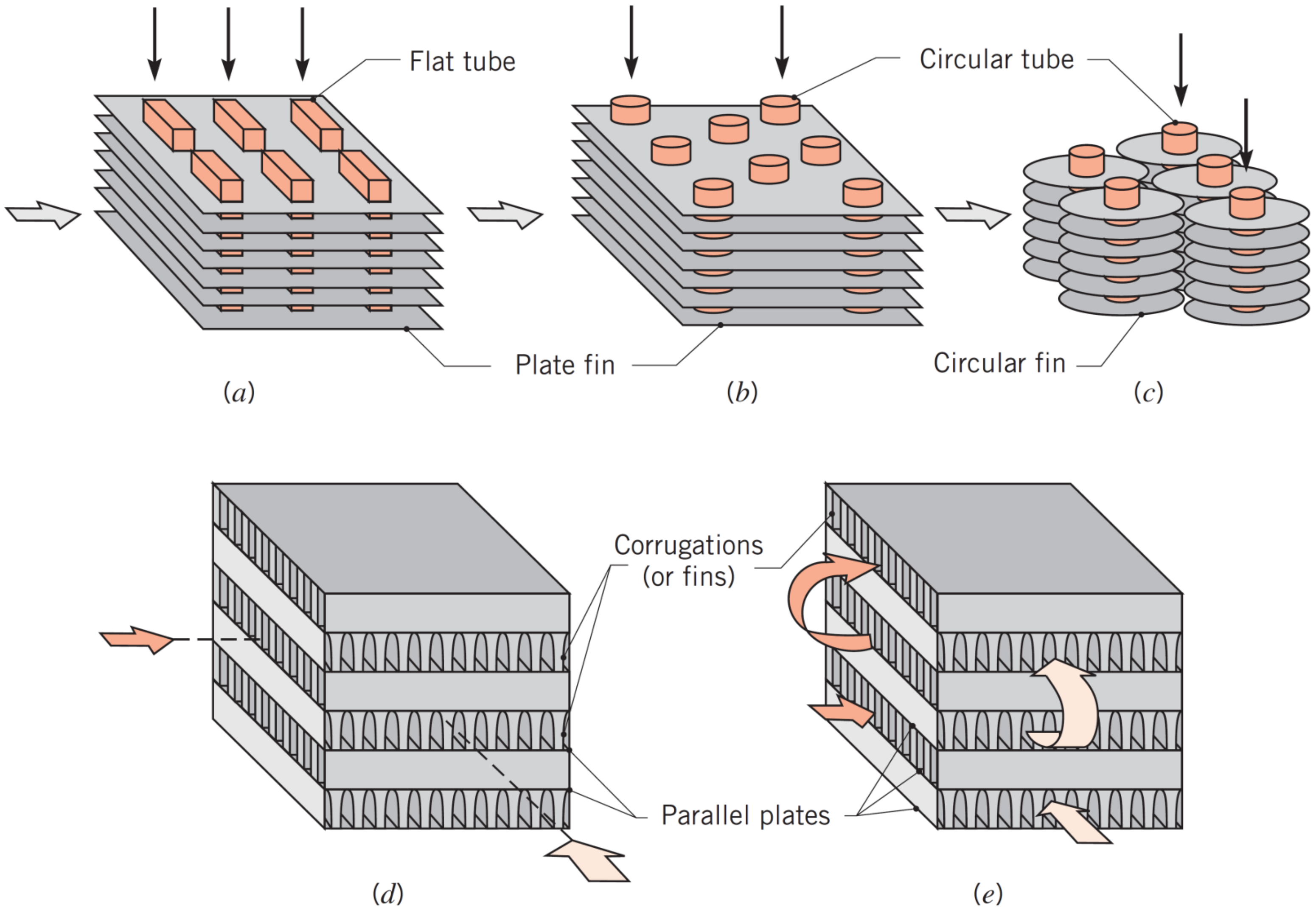
β > 700 $\frac{m^2}{m^3}$ - Compact

Car radiator – 1000 $\frac{m^2}{m^3}$

Gas turbine H.E – 6000 $\frac{m^2}{m^3}$

Human Lung – 20000 $\frac{m^2}{m^3}$

Achieve high heat transfer rates between two fluids in a small volume



Compact heat exchanger cores. (*a*) Fin–tube (flat tubes, continuous plate fins). (*b*) Fin–tube (circular tubes, continuous plate fins). (*c*) Fin–tube (circular tubes, circular fins). (*d*) Plate–fin (single pass). (*e*) Plate–fin (multipass).

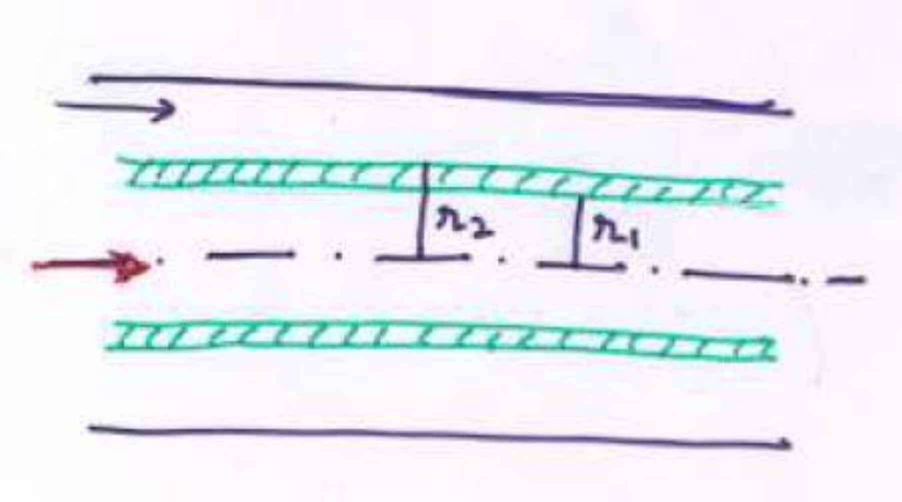
COMPACT HEAT EXCHANGER

- Gas to gas
- Gas to liquid or liquid to gas

  Low h.t.c in gas flow-Increased $A_s(Fins)$

  Ex: Radiator (Water to air H.E)- Fins on air side

OVERALL HEAT TRANSFER COEFFICIENT



A_i-Inside area of the tube
A_o-outside area of the tube
h_i-Inside h.t.c
h_o-outside h.t.c
k-Thermal conductivity of tube

Total thermal resistance= $R_{total} = R_i + R_{wall} + R_o$

$$= \frac{1}{h_i A_i} + \frac{ln\left(\frac{r_a}{r_i}\right)}{2\pi L k} + \frac{1}{h_o A_o}$$

$$\frac{1}{U_i A_i} = \frac{1}{U_o A_o} = \frac{1}{h_i A_i} + \frac{ln\left(\frac{r_a}{r_i}\right)}{2\pi L k} + \frac{1}{h_o A_o}$$

U is meaningless unless A is specified

If $R_{wall} = 0 \qquad A_i = A_0$

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

U is dominated by smaller convection coefficient

One fluid is gas the other fluid is liquid

Fins- Gas side- $UA_s \uparrow$

TUBE IS FINNED

$$\frac{1}{U_iA_i} = \frac{1}{U_oA_o} = \frac{1}{\eta_ih_iA_i} + \frac{ln\left(\frac{r_a}{r_i}\right)}{2\pi Lk} + \frac{1}{\eta_oh_oA_o}$$

η- Fin efficiency

TYPICAL OVERALL HEAT TRANSFER COEFFICIENTS:

Shell and Tube Heat exchanger	$U\ \left(\frac{W}{m^2 K}\right)$
Gas (1 bar) tube side and gas (1 bar) shell side	5-35
Gas (200-300 bar) tube side and gas (200-300 bar) shell side	150-500
Liquid tube side and gas shell side	15-70
Gas (200-300 bar) tube side and liquid shell side	200-400
Liquid tube side and shell side	150-1200
Superheated vapour tube side and liquid shell side	300-1200
EVAPORATORS	
Steam on tube side- Natural circulation	300-900
Steam on tube side- Forced circulation	600-1700

TYPICAL OVERALL HEAT TRANSFER COEFFICIENTS:

	$U\ \left(\frac{W}{m^2 K}\right)$
CONDENSERS	
Cooling water tube side & ORGANIC VAPOUR ON SHELL SIDE	300-1200
Steam turbine condenser	1500-4000
GAS HEATER	
Liquid tube side and shell side	150-1200
Superheated vapour tube side and liquid shell side	300-1200
EVAPORATORS	
Steam or hot water tube side & gas on shell side	
a. Free convection	5-12
b. Forced flow	15-20

TYPICAL OVERALL HEAT TRANSFER COEFFICIENTS:

Double pipe heat exchanger	$U\ \left(\frac{W}{m^2K}\right)$
Gas (1 bar) tube & gas shell	10-35
H.P gas tube & L.P gas shell	20-60
H.P gas tube & H.P gas shell	150-500
H.P gas tube & liquid shell side	200-600
Liquids on tube & shell side	300-1400

FOULING- Phenomenon of deposition of material on the tube surfaces from the fluids on the form of scales, layered sediments or biological agents.

Fouling increase Resistance to heat transfer

CHEMICAL TREATMENT PLANT- P_H

PERIODIC CLEANING – DOWN TIME - PENALTIES

$$\frac{1}{U_iA_i} = \frac{1}{U_oA_o} = \frac{1}{h_iA_i} + \frac{R_{f \cdot i}}{A_i} + \frac{ln\left(\frac{r_2}{r_1}\right)}{2\pi Lk} + \frac{R_{f \cdot 0}}{A_0} + \frac{1}{h_oA_o}$$

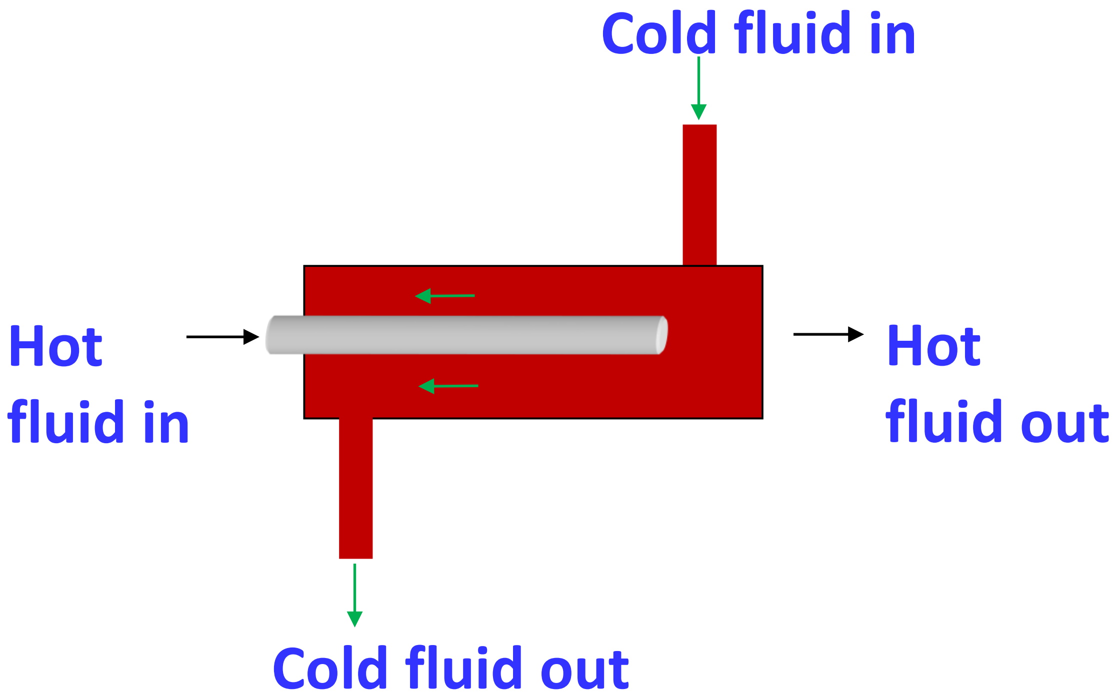
$$A_i = \pi D_i L \qquad\qquad A_0 = \pi D_0 L$$

$$\frac{1}{U_iA_i} = \frac{1}{U_oA_o} = \frac{1}{h_iA_i} + \frac{R_{f\cdot i}}{A_i} + \frac{ln\left(\frac{r_2}{r_1}\right)}{2\pi Lk} + \frac{R_{f\cdot 0}}{A_0} + \frac{1}{h_oA_o}$$

$A_i = \pi D_i L$ $\qquad$ $A_0 = \pi D_0 L$

FLUID		$R_f\ (m^2.\frac{K}{W})$
Distilled water, sea water, River water	Below $50^0\ C$	0.0001
	Above $50^0\ C$	0.0002
Fuel oil		0.0009
Steam (oil free)		0.0001
Refrigerants (liquid)		0.0002
Refrigerants (Vapour)		0.0004
Alcohol vapors		0.0001
Air		0.0004

FOULING - $10^{-4}\ m^2.\frac{K}{W} \cong$
$0.2\ mm$ thick limestone
($k = 2.9\ W/m^2K$)
$per\ unit\ surface\ area$



$$R_{steel} = 15.00 \frac{w}{m^0C}$$

$$D_0 = 1.9\ cm$$

$$h_0 = 1200 \frac{w}{m^{2\ 0}C}$$

$$R_{f,0} = 0.0001 \frac{m^{2\ 0}C}{W}$$

$$D_i = 1.5\ cm$$

$$h_i = 800 \frac{w}{m^{2\ 0}C}$$

$$R_{f,i} = 0.0004 \frac{m^{2\ 0}C}{W}$$

$$A_i = \pi D_i L = \pi\left(1.5 \times 10^{-2}\right)(1) = 0.0471\, m^2$$

$$A_0 = \pi D_0 L = \pi\left(1.9 \times 10^{-2}\right)(1) = 0.0597\, m^2$$

$$\frac{1}{U_i A_i} = \frac{1}{U_o A_o} = \frac{1}{h_i A_i} + \frac{R_{f \cdot i}}{A_i} + \frac{ln\left(\frac{r_2}{r_1}\right)}{2\pi L k} + \frac{R_{f \cdot 0}}{A_0} + \frac{1}{h_o A_o}$$

$$= \frac{1}{800 \times 0.0471} + \frac{0.0004}{0.0471} + \frac{ln\left(\frac{1.9}{1.5}\right)}{2\pi(1)(15.1)} + \frac{0.0001}{0.0597} + \frac{1}{1200 \times 0.0597}$$

$$= 26.54 \times 10^{-3} + 8.493 \times 10^{-3} + 2.491 \times 10^{-3} + 1.675 \times 10^{-3} + 13.96 \times 10^{-3}$$

$$= 53.159 \times 10^{-3}\ {}^{0}C/W$$

$$= 53.159 \times 10^{-3}\ {}^{0}C/W$$

$$U_i = 399.4 \frac{W}{m^2\,{}^{0}C} \quad \left(\frac{1}{53.159 \times 10^{-3} \times 0.0471}\right)$$

$$U_o = 315\frac{W}{m^{2\,0}C}\left(\frac{1}{53.159\times 10^{-3}\times 0.0597}\right)$$

Copper tube - $\frac{ln\left(\frac{1.9}{1.5}\right)}{2\pi(1)(400)} = 9.4\times 10^{-5} = 0.094\times 10^{-3}$ **(negligibly small)**

$$\dot{Q} = m_c C_{pc}\left(T_{c,o} - T_{c,i}\right) = m_h C_{ph}\left(T_{h,i} - T_{h,o}\right)$$

Heat capacity rate $C_h = \dot{m}_h C_{ph}$; $C_c = \dot{m}_c C_{pc}$

FLUID- Large heat capacity Rate – Small ΔT

Doubling $\dot{m} \rightarrow \frac{1}{2}\Delta T$

$$\dot{Q} = C_c\left(T_{c,o} - T_{c,i}\right) = C_h\left(T_{h,i} - T_{h,o}\right)$$

$(\Delta T)_{cold\ fluid} = (\Delta T)_{hot\ fluid}$ **when** $C_c = C_h$

ANALYSIS OF HEAT EXCHANGERS

LMTD APPROACH- Select a H.E that will achieve specified temp change on a fluid stream of known $\dot{m}$

Є-NTU APPROACH – Predict the outlet temperature of hot and cold stream in a specified H.E

Assumptions

- Steady flow devices
- K.E & P.E changes are negligible
- Thermophysical properties are constant over the entire length
- No heat loss to surroundings
- H.T.C is assumed to be constant over the entire length

PARALLEL FLOW HEAT EXCHANGER

$$\delta\dot{Q} = U\,(T_h - T_c)dA_s$$

$$\Delta T_1 = (T_{h,i} - T_{c,i})$$

$$\Delta T_2 = (T_{h,o} - T_{c,o})$$

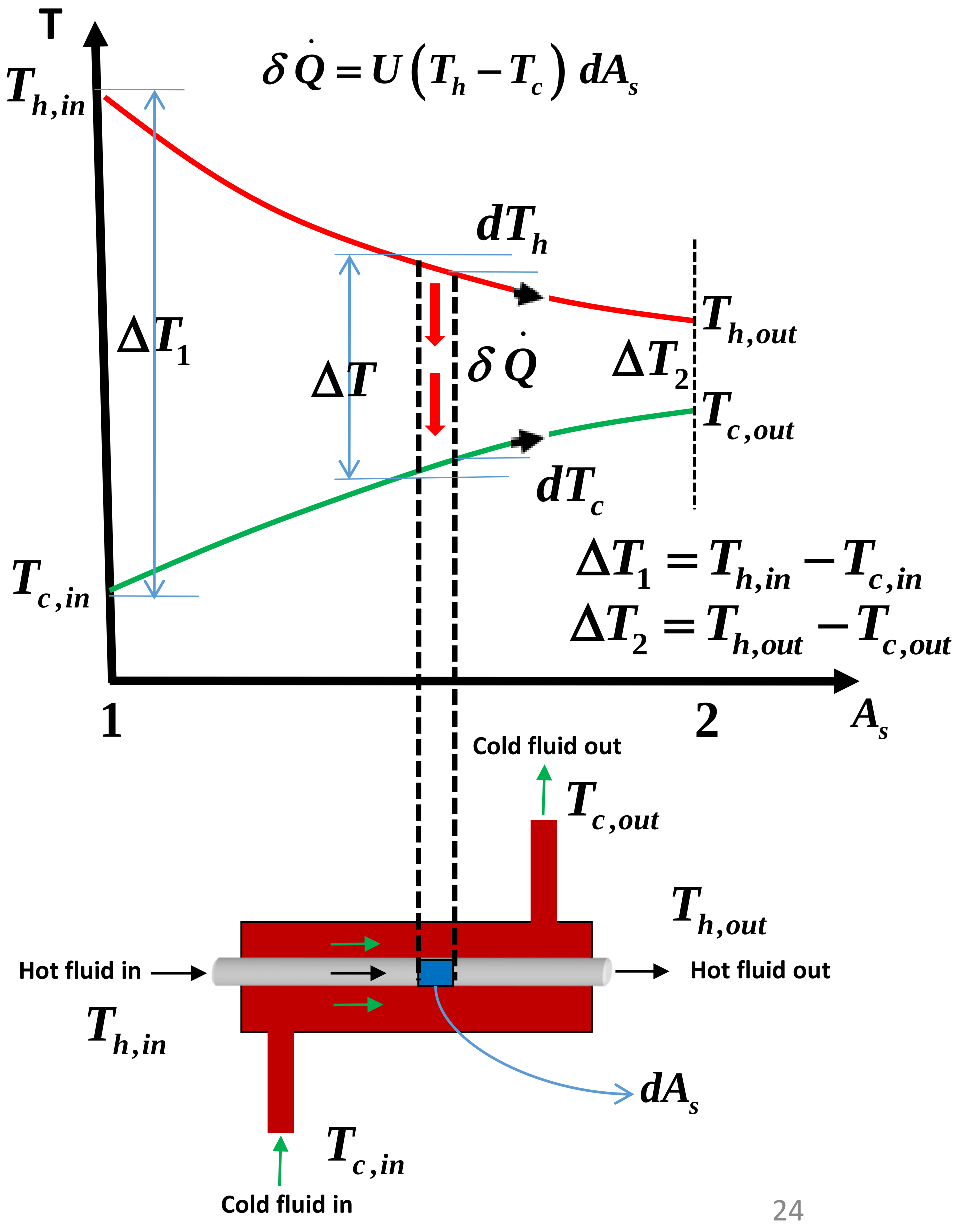
$$\delta\dot{Q} = \dot{m}_c C_{pc} dT_c \qquad T \uparrow \uparrow x$$

$$\delta\dot{Q} = -\dot{m}_h C_{ph} dT_h \qquad T \downarrow \uparrow x$$

$$\mathrm{d}T_h = -\frac{\delta\dot{Q}}{\dot{m}_h C_{ph}} \qquad \mathrm{d}T_c = \frac{\delta\dot{Q}}{\dot{m}_c C_{pc}}$$

$$\mathrm{d}T_h - \mathrm{d}T_c = d(T_h - T_c) = -\delta\dot{Q}\left[\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right]$$

$$\delta\dot{Q} = U\,(T_h - T_c)dA_s$$



$$\int_i^o \frac{d(T_h - T_c)}{(T_h - T_c)} = \int_i^o -\cup\, dA_s \left[\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right]$$

$$\ln\frac{(T_{h,o} - T_{c,o})}{(T_{h,i} - T_{c,i})} = -\cup\, A_s \left[\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right]$$

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,o} - T_{c,i}) \qquad \dot{Q} = \dot{m}_h C_{ph}(T_{h,i} - T_{h,o})$$

$$\ln\frac{(T_{h,o} - T_{c,o})}{(T_{h,i} - T_{c,i})} = -\cup\, A_s \left[\frac{(T_{h,i} - T_{h,o})}{\dot{Q}} + \frac{(T_{c,o} - T_{c,i})}{\dot{Q}}\right]$$

$$\dot{Q} = -\cup\, A_s \left[\frac{(T_{h,i} - T_{c,i}) - (T_{h,o} - T_{c,o})}{\ln\frac{(T_{h,o} - T_{c,o})}{(T_{h,i} - T_{c,i})}}\right] \qquad \dot{Q} = \cup\, A_s \left[\frac{(T_{h,o} - T_{c,o}) - (T_{h,i} - T_{c,i})}{\ln\frac{(T_{h,o} - T_{c,o})}{(T_{h,i} - T_{c,i})}}\right]$$

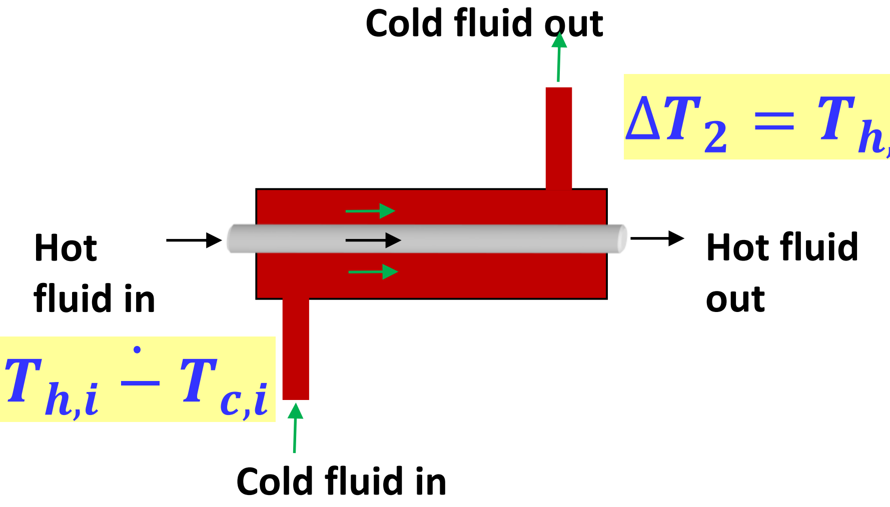
$$\dot{Q} = U A_s \Delta T_{lm}$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$\Delta T_1 = T_{h,i} - T_{c,i}$ $\quad$ $\Delta T_2 = T_{h,o} - T_{c,o}$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

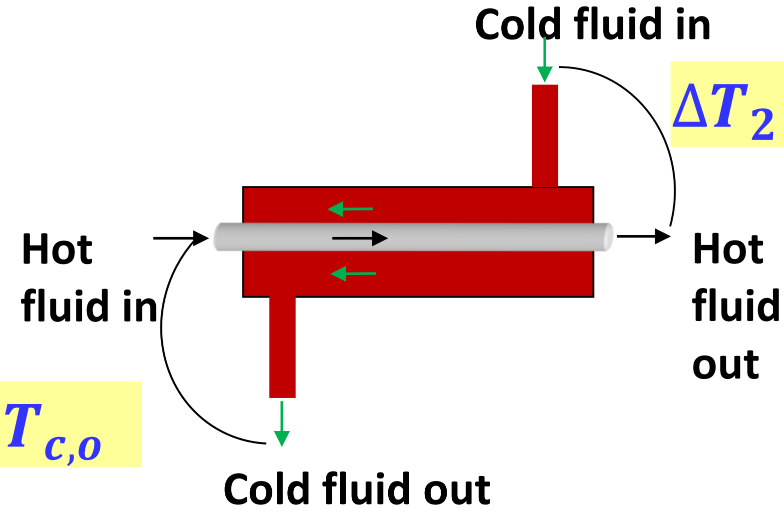
$\Delta T_1 = T_{h,i} - T_{c,o}$ $\quad$ $\Delta T_2 = T_{h,o} - T_{c,i}$



$\Delta T_2 = T_{h,o} - T_{c,o}$

$\Delta T_1 = T_{h,i} - T_{c,i}$

Parallel flow HE

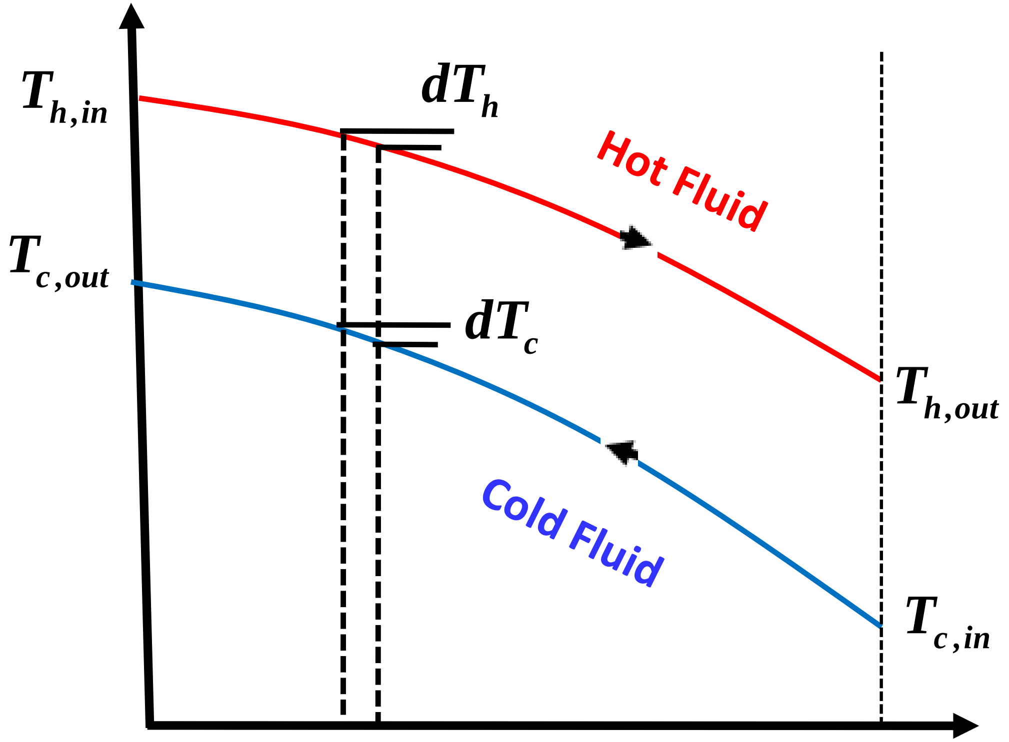


$\Delta T_2 = T_{h,o} - T_{c,i}$

$\Delta T_1 = T_{h,i} - T_{c,o}$

Counter flow HE

COUNTERFLOW HEAT EXCHANGER



$$\dot{Q} = \dot{m}_h C_{ph}\left(T_{h,i} - T_{h,o}\right)$$

$$\dot{Q} = \dot{m}_c C_{pc}\left(T_{c,o} - T_{c,i}\right)$$

$$\delta\dot{Q} = -\dot{m}_c C_{pc} dT_c \qquad T \downarrow \uparrow x$$

$$\delta\dot{Q} = -\dot{m}_h C_{ph} dT_h \qquad T \uparrow \downarrow x$$

$$dT_h = -\frac{\delta\dot{Q}}{\dot{m}_h C_{ph}} \qquad dT_c = -\frac{\delta\dot{Q}}{\dot{m}_c C_{pc}}$$

$$dT_h - dT_c = d(T_h - T_c) = -\frac{\delta\dot{Q}}{\dot{m}_h C_{ph}} + \frac{\delta\dot{Q}}{\dot{m}_c C_{pc}} = -\delta\dot{Q}\left[\frac{1}{\dot{m}_h C_{ph}} - \frac{\delta\dot{Q}}{\dot{m}_c C_{pc}}\right]$$

COUNTERFLOW HEAT EXCHANGER

$$dT_h - dT_c = d(T_h - T_c) = -\frac{\delta\dot{Q}}{\dot{m}_h C_{ph}} + \frac{\delta\dot{Q}}{\dot{m}_c C_{pc}} = -\delta\dot{Q}\left[\frac{1}{\dot{m}_h C_{ph}} - \frac{1}{\dot{m}_c C_{pc}}\right]$$

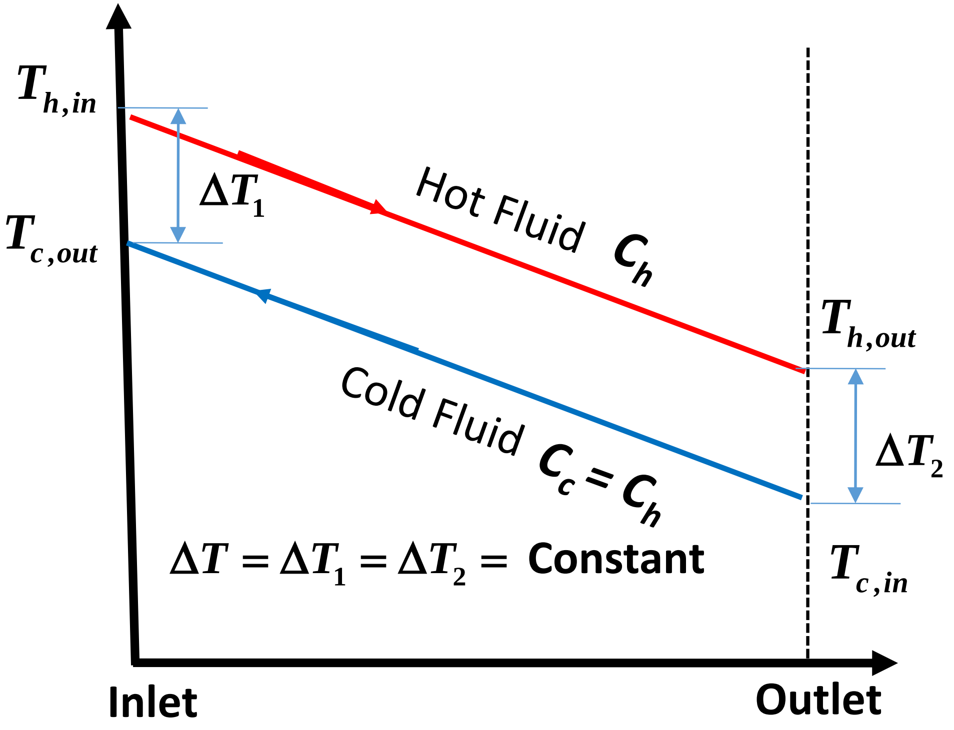
$$\int_{T_{h,i}-T_{c,o}}^{T_{h,o}-T_{c,i}} \frac{d(T_h - T_c)}{T_h - T_c} =-\cup\, dA_s\left[\frac{1}{\dot{m}_h C_{ph}} - \frac{1}{\dot{m}_c C_{pc}}\right]$$

$$\delta\dot{Q} =\cup\,(T_h - T_c)dA_s$$

$$\ln\frac{T_{h,o} - T_{c,i}}{T_{h,i} - T_{c,o}} =-\cup\, A_s\left[\frac{T_{h,i} - T_{h,o}}{\dot{Q}} - \frac{T_{c,o} - T_{c,i}}{\dot{Q}}\right]$$

$$\dot{Q} =\cup\, A_s\left[\frac{\left(T_{h,o} - T_{c,i}\right) - \left(T_{h,i} - T_{c,o}\right)}{\left[\ln\frac{T_{h,o} - T_{c,i}}{T_{h,i} - T_{c,o}}\right]}\right]$$

Heat exchanger with same specific heats and mass flow rates



$$\dot{Q} = \dot{m}_h C_{ph}(T_{h,i} - T_{h,o}) = C_h(T_{h,i} - T_{h,o})$$

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,o} - T_{c,i}) = C_c(T_{c,o} - T_{c,i})$$

$$C_h = C_c$$

$$\Delta T_1 = \Delta T_2 = \Delta T = constant$$

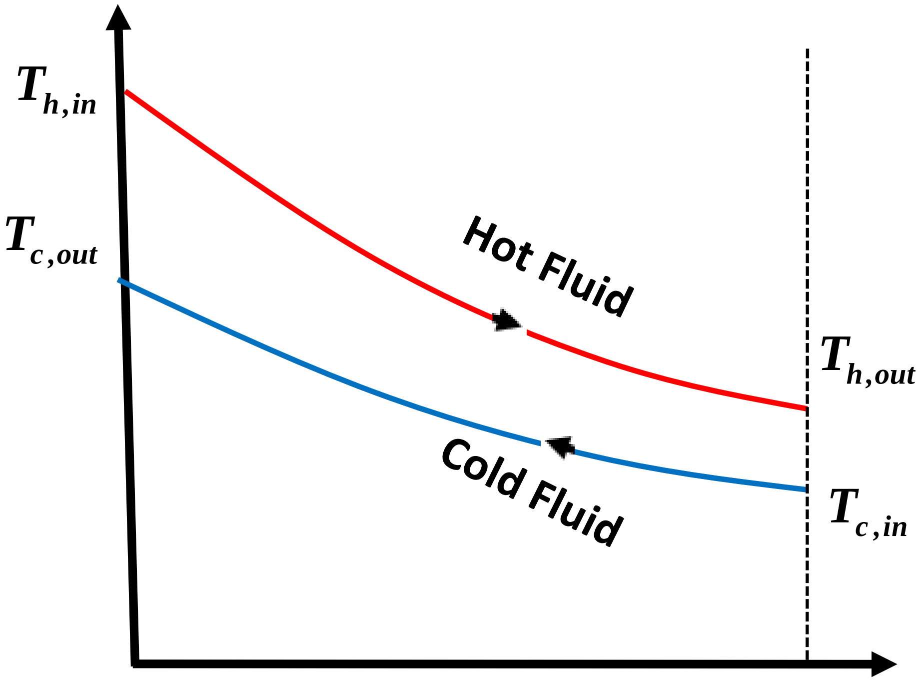
$$\Delta T_1 = T_{h,i} - T_{c,o}$$

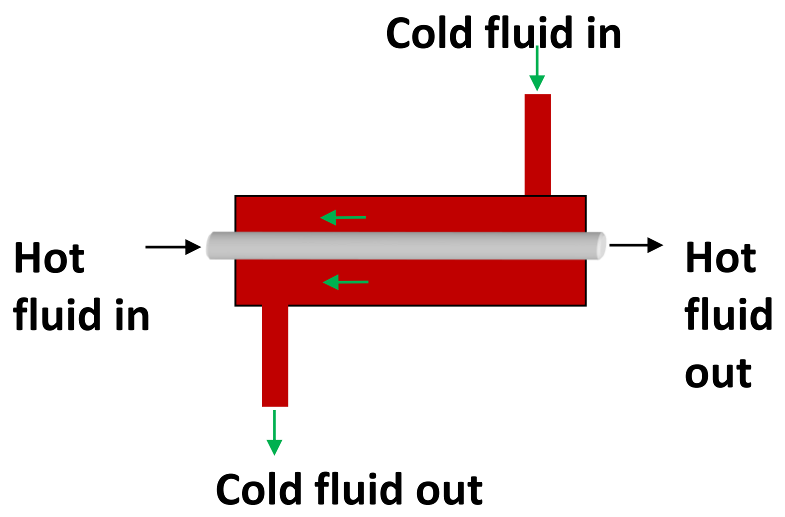
$$\Delta T_2 = T_{h,o} - T_{c,i}$$

$$\dot{Q} = \cup A_s \Delta T_{lm}$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

COUNTER FLOW HEAT EXCHANGER





$$\dot{Q} = UA_s \frac{\left[\left(T_{h,o} - T_{c,i}\right) - \left(T_{h,i} - T_{c,o}\right)\right]}{\ln\left[\dfrac{T_{h,o} - T_{c,i}}{T_{h,i} - T_{c,o}}\right]}$$

$$\Delta T_1 = T_{h,i} - T_{c,o}$$
$$\Delta T_2 = T_{h,o} - T_{c,i}$$

LIMITING CASE:

- Cold fluid is heated to inlet temperature of the hot fluid.
- $T_{c,o}$ can never exceed $T_{h,i}$ – Violation of II law

SPECIFIED INLET TEMPERATURES:

$$(LMTD)_{counter\ flow} > (LMTD)_{parallel\ flow}$$

COUNTER FLOW HEAT EXCHANGER A_s – smaller

$\therefore$ Counter Flow Heat Exchanger are Popular

LMTD OF COUNTER FLOW HE IS HIGHER THAN PARALLEL FLOW HE

$$T_{h,i} = 110°\text{C} \qquad T_{c,i} = 30°\text{C}$$
$$T_{h,o} = 60°\text{C} \qquad T_{c,o} = 55°\text{C}$$

Counter flow heat exchanger

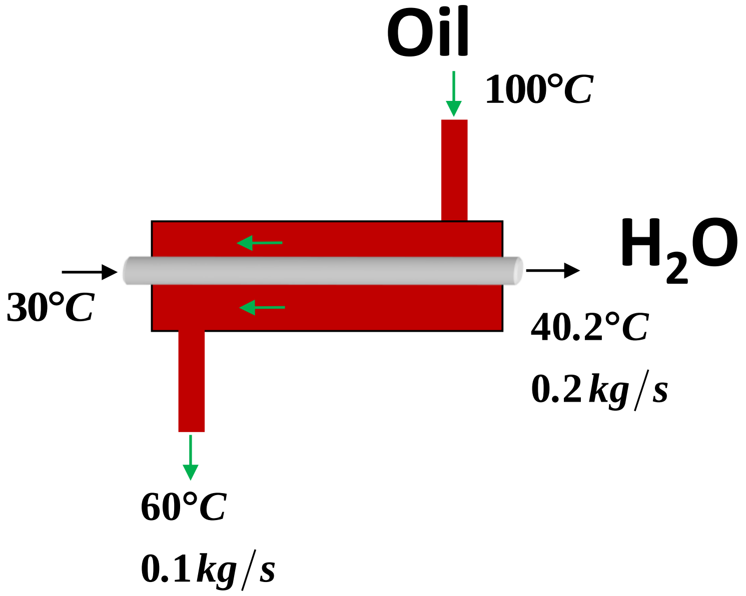
$$\Delta T_{LM}]_{counter} = \frac{[(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})]}{\ln\left[\frac{T_{h,i} - T_{c,o}}{T_{h,o} - T_{c,i}}\right]} = \frac{[(110 - 55) - (60 - 30)]}{\ln\left[\frac{110 - 55}{60 - 30}\right]} = 41.24°\text{C}$$

Parallel flow heat exchanger

$$\Delta T_{LM}]_{parallel} = \frac{[(T_{h,i} - T_{c,i}) - (T_{h,o} - T_{c,o})]}{\ln\left[\frac{T_{h,i} - T_{c,i}}{T_{h,o} - T_{c,o}}\right]} = \frac{[(110 - 30) - (60 - 55)]}{\ln\left[\frac{110 - 30}{60 - 55}\right]} = 27.05°\text{C}$$

$$(LMTD)_{counter\ flow} > (LMTD)_{parallel\ flow}$$

COUNTER FLOW HEAT EXCHANGER



$$D_i = 25mm$$
$$D_o = 45mm$$
$$\Delta T_1 = 100 - 40.2 = 59.8$$
$$\Delta T_2 = 60 - 30 = 30$$

WATER

$$C_p = 4178\ J/kg.K$$
$$\mu = 725 \times 10^{-6}\ Pa.s$$
$$k = 0.625\,W/m.K$$
$$Pr = 4.85$$

OIL

$$C_p = 2131\,J/kg.K$$
$$\mu = 3.25 \times 10^{-2}\ Pa.s$$
$$k = 0.138\ W/m.K$$
$$Pr = 501.87$$

- Counter flow HE
- Water flows through the inner tube
- Oil Flows through annulus

Find Surface area

COUNTER FLOW HEAT EXCHANGER

$\Delta T_1 = 100 - 40.2 = 59.8$
$\Delta T_2 = 60 - 30 = 30$

WATER

$C_p = 4178\ J/kg.K$
$\mu = 725 \times 10^{-6}\ Pa.s$
$k = 0.625\ w/m.K$
$Pr = 4.85$

$\dot{Q} = (0.1)(2131)(100 - 60) = 8524\ W --- OIL$

$8524 = (0.2)(4178)\left(T_{c,o} - 30\right), -\ Water \qquad T_{c,o} = 40.2℃$

$$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{\ln\frac{\Delta T_1}{\Delta T_2}} = \frac{59.8 - 30}{\ln\frac{59.8}{30}} = 43.2℃$$

Water Side:

$D_i = 25mm$
$D_o = 45mm$

$$Re_D = \frac{4\dot{m}}{\pi D_i \mu} = \frac{4(0.2)}{\pi(25 \times 10^{-3})(725 \times 10^{-6})} = 14050$$

$$Nu_D = 0.023 Re_D^{4/5} Pr^{0.4} = 90 \qquad Nu_D = \frac{hD_i}{k_f} = 90 = \frac{h(25 \times 10^{-3})}{0.625}$$

$$h_i = 2250 \frac{W}{m^2K}$$

COUNTER FLOW HEAT EXCHANGER

OIL

$$C_p = 2131\, J/kg.K$$
$$\mu = 3.25 \times 10^{-2}\ pa.s$$
$$k = 0.138\ w/m.K$$
$$Pr = 501.87$$

$$D_i = 25mm$$
$$D_o = 45mm$$

OIL Side: $D_h = D_o - D_i = 45 - 25 = 20mm$

$$Re_D = \frac{\rho u_m D_h}{\mu} = \frac{\rho D_h}{\mu} \times \frac{\dot{m}_h}{\rho \frac{\pi}{4}\left(D_o^2 - D_i^2\right)} = \frac{20 \times 10^{-3}}{3.25 \times 10^{-2}} \cdot \frac{0.1}{\frac{\pi}{4}[(45 \times 10^{-2})^2 - (25 \times 10^{-3})^2]}$$

$$Re_D = 56 \quad for\ \frac{D_i}{D_o} = 0.56 \qquad Nu_i = \frac{h_o D_h}{k} = 5.56 = \frac{h_o(20 \times 10^{-3})}{0.138}$$

$$h_o = 38.4 \frac{W}{m^2 K}$$

COUNTER FLOW HEAT EXCHANGER

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} = \frac{1}{2250} + \frac{1}{38.4}$$

$$U = 37.76 \frac{W}{m^2K}$$

$$Q = U\pi D_i L \Delta T_{lm}$$

$$8524 = (37.26)\pi\left(25 \times 10^{-3}\right)L(43.2)$$

$$L = 66.54\ m$$

COMMENTS

- h_o Controls the overall heat transfer coefficients
- $h_i >> h_o$ wall temperature will follow that of the coolant water. Accordingly, assumption of UNIFORM WALL TEMPERATURE.

COUNTER FLOW HEAT EXCHANGER

$$\frac{1}{U}=\frac{1}{h_i}+\frac{1}{h_o}=\frac{1}{2250}+\frac{1}{38.4}$$

$$U=37.76\frac{W}{m^2K}$$

$$Q=U\pi D_iL\Delta T_{lm}$$

$$8524=(37.26)\pi\left(25\times10^{-3}\right)L(43.2)$$

$$L=66.54\,m$$

$$\frac{1}{UA}=\frac{1}{h_iA_i}+\frac{1}{h_oA_o}=\frac{1}{h_i(\pi D_iL)}+\frac{1}{h_o(\pi D_oL)}$$

$$\frac{1}{UA}=\frac{1}{2250(\pi)(25\times10^{-3})L}+\frac{1}{38.4(\pi)(45\times10^{-3})L}$$

$$\frac{1}{UA}=\frac{1}{176.71L}+\frac{1}{5.429L}=\frac{1}{L}\left(\frac{1}{176.71}+\frac{1}{5.429}\right)$$

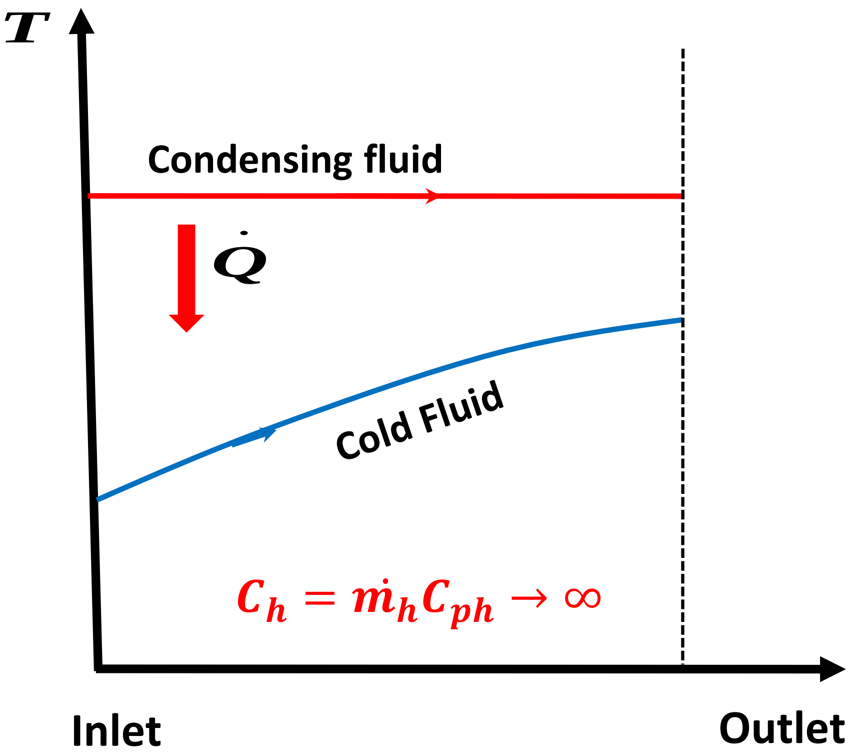
$$\frac{1}{UA}=\frac{0.1899}{L}\Rightarrow UA=5.267L\frac{W}{m^2K}$$

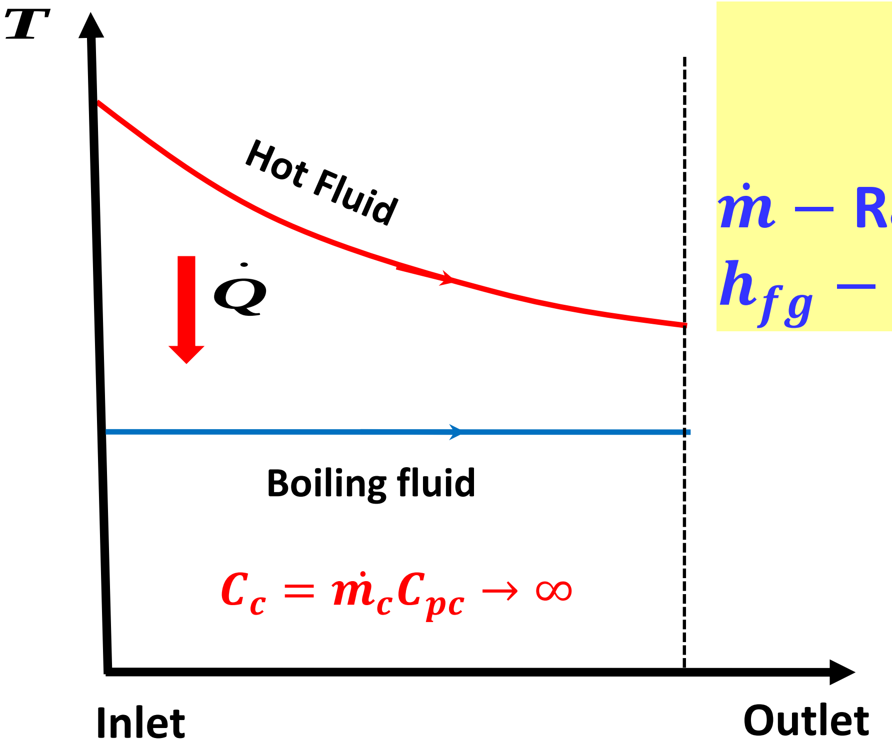
$$Q=UA\Delta T_{lm}$$

$$8524=(5.267L)(43.2)$$

$$L=37.46\,m$$

CONDENSER and EVAPORATOR





$$\dot{Q} = \dot{m} h_{fg}$$

$\dot{m}$ – Rate of condensation
h_{fg} – Latent heat of condensation

$$C_h = \dot{m}_h C_{ph} \to \infty \qquad \Delta T \to 0$$

$$\dot{Q} = \dot{m}_h C_{ph} \Delta T - Finite$$

$$C_c = \dot{m}_c C_{pc} \to \infty \qquad \Delta T \to 0$$

Rate of heat transfer in Heat Exchanger

$$\dot{Q} = U A_s \Delta T_{lm}$$

U – Overall heat transfer coefficients
A_s – Heat transfer area
ΔT_{lm} – Approximate temperature difference

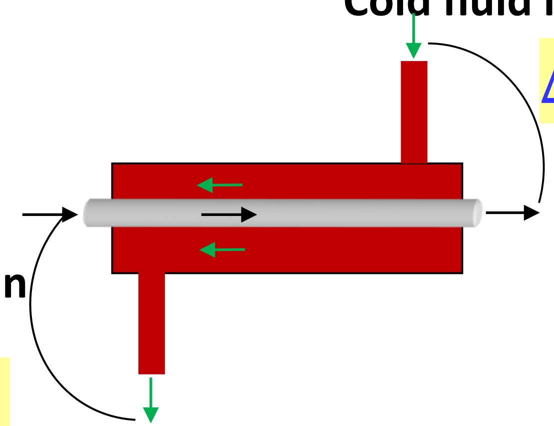
LMTD-F approach

LMTD-F approach :

Select HE that will achieve specified temperature range in a fluid stream of known mass flow rate

1. **Select the type of heat exchanger suitable for the application**
2. **Determine any unknown inlet or outlet temperature and the heat transfer rate using an energy balance**
3. **Calculate the log mean temperature difference and the correction factor F, if necessary**
4. **Obtain (select or calculate) the value of the overall heat transfer coefficient**
5. **Calculate the heat transfer area**

MULTI-PASS AND CROSS FLOW HEAT EXCHANGERS



$$\Delta T_2 = T_{h,o} - T_{c,i}$$

$$\Delta T_1 = T_{h,i} - T_{c,o}$$

Cross tube or multi pass shell and tube heat exchanger

Heat Transfer rate

$$\dot{Q} = U A_s F \Delta T_{lm}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$$\Delta T_1 = T_{h,i} - T_{c,o} \qquad \Delta T_2 = T_{h,o} - T_{c,i}$$

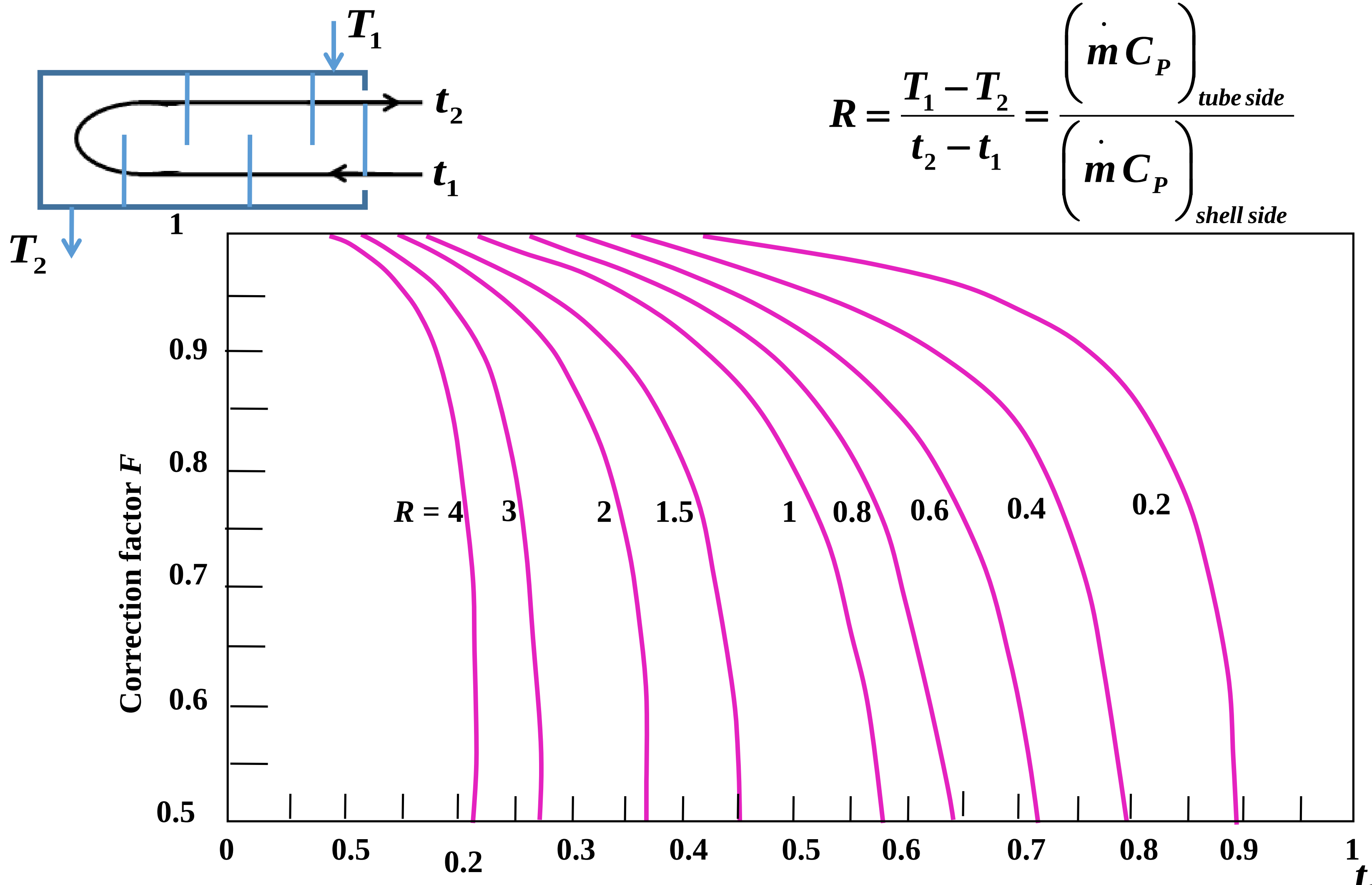
F is obtained by charts

F is the correction factor which takes into account of the deviation of the given heat exchanger away from the counter flow heat exchanger

F = 1 implies perfect counter flow heat exchanger

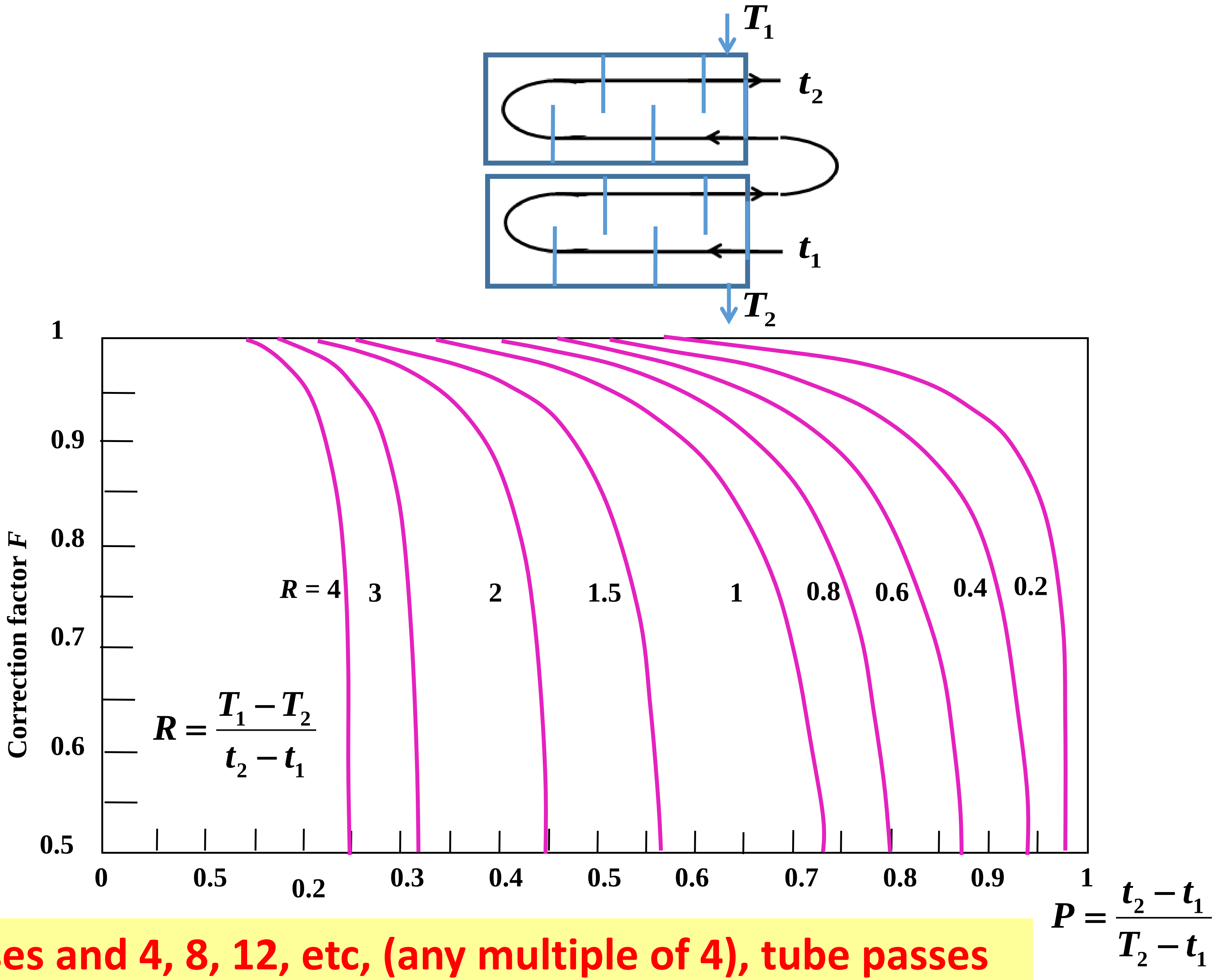
Generally, F < 1

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{\left(\dot{m} C_P\right)_{tube\ side}}{\left(\dot{m} C_P\right)_{shell\ side}}$$

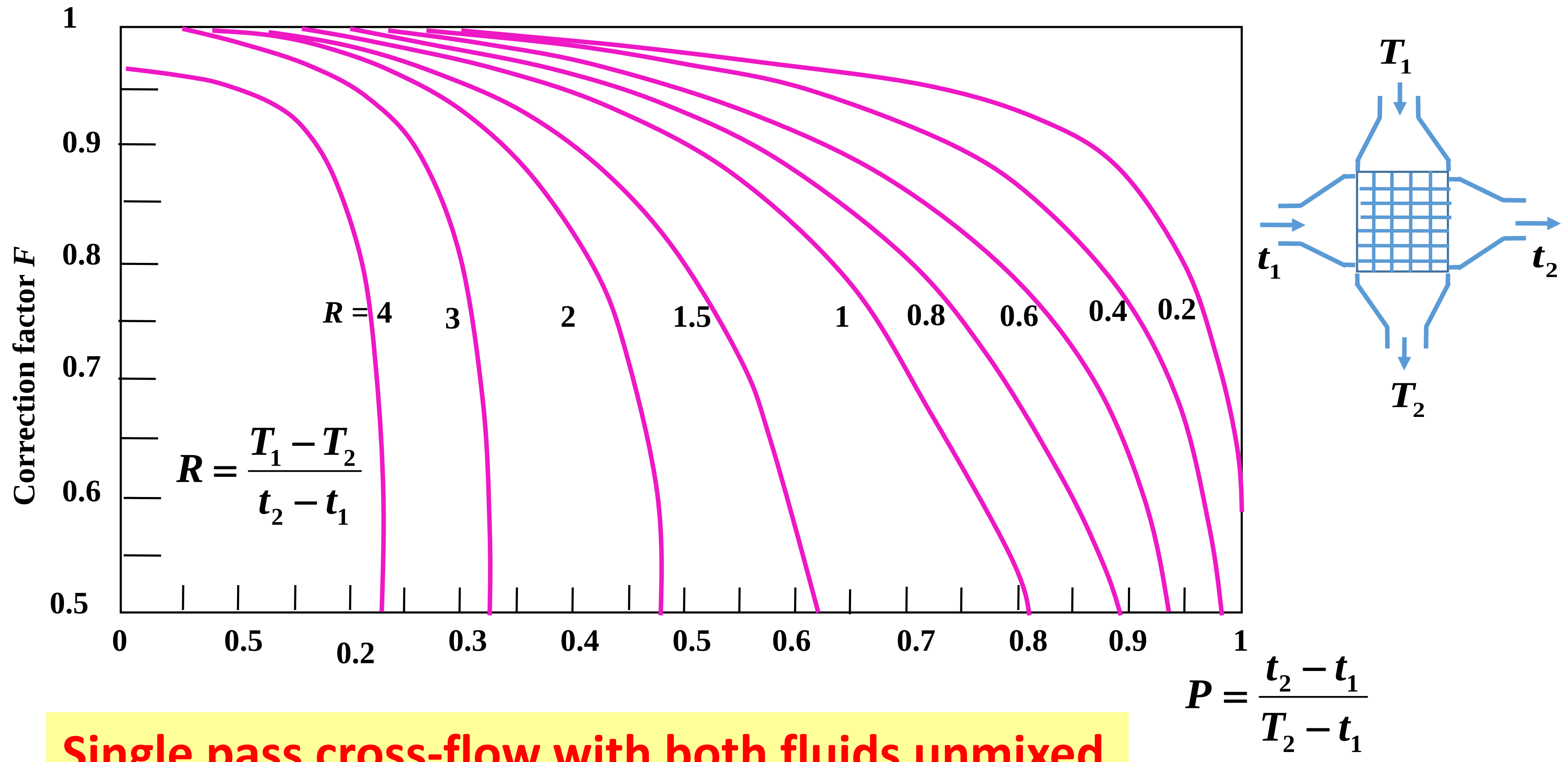


$$P = \frac{t_2 - t_1}{T_2 - t_1}$$

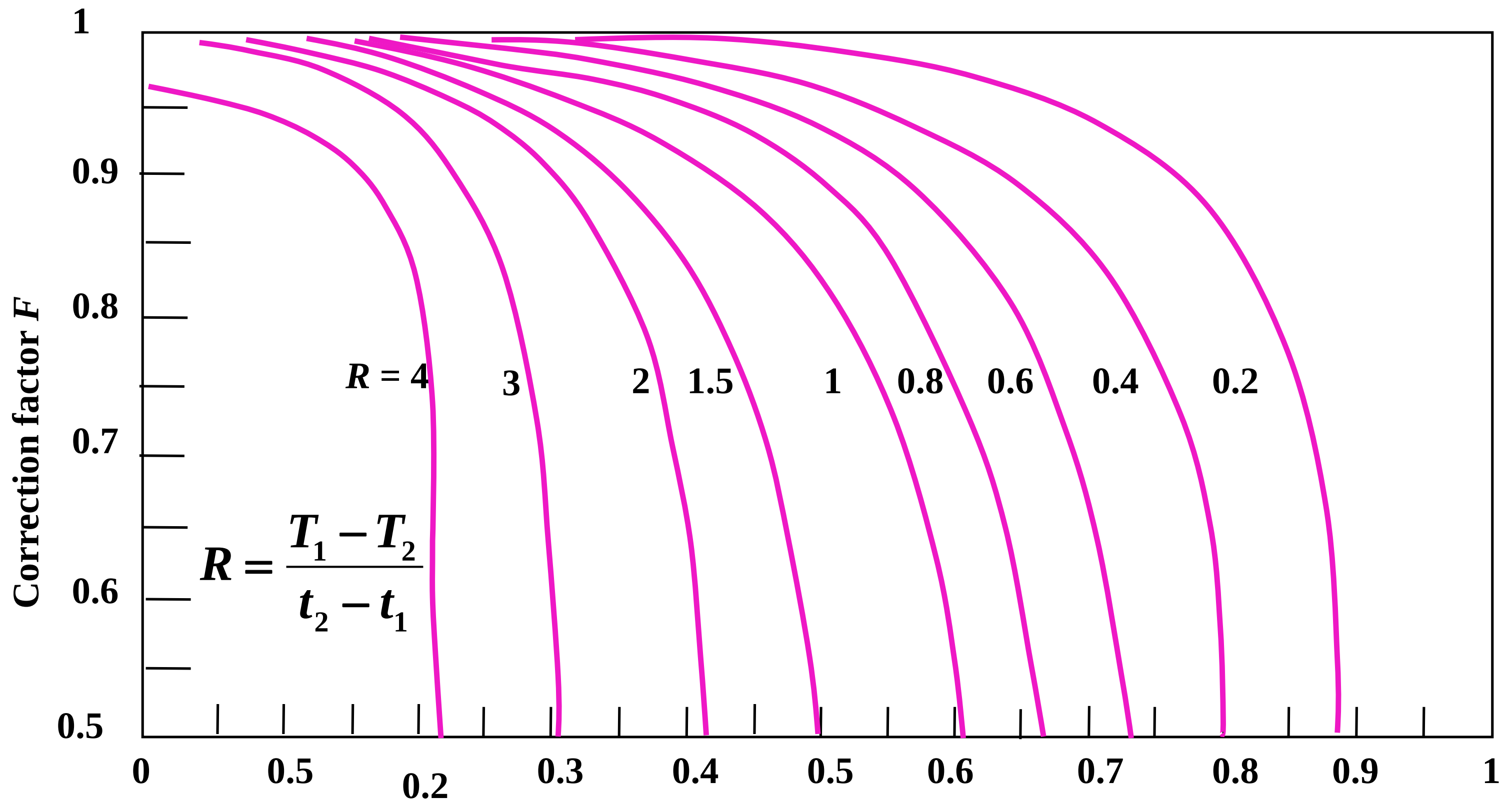
One shell pass and 2,4,6 etc (any multiples of 2), tube passes

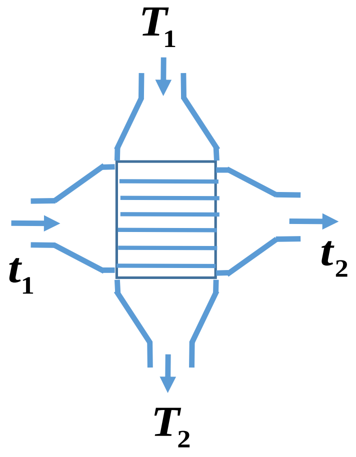


Two-shell passes and 4, 8, 12, etc, (any multiple of 4), tube passes



Single pass cross-flow with both fluids unmixed





Single pass cross-flow with one fluid mixed and other unmixed

$$P = \frac{t_2 - t_1}{T_2 - t_1}$$

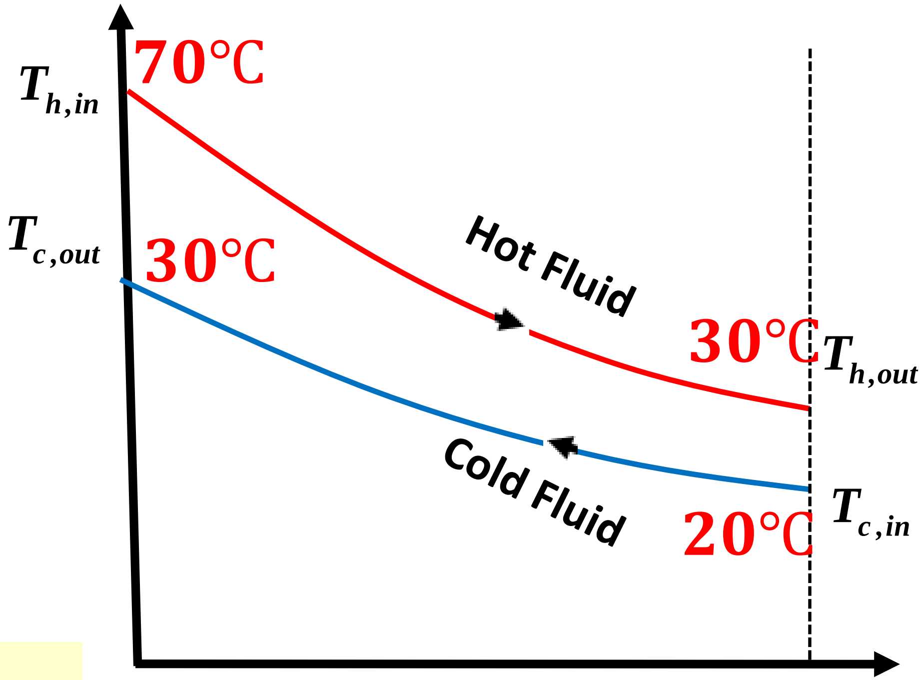
OIL COOLER

COOLING WATER (shell side)

$$T_{c,i} = 20℃$$
$$T_{c,o} = 30℃$$
$$C_{pc} = 4200\frac{J}{kg.K}$$
$$\dot{m}_c = ?$$

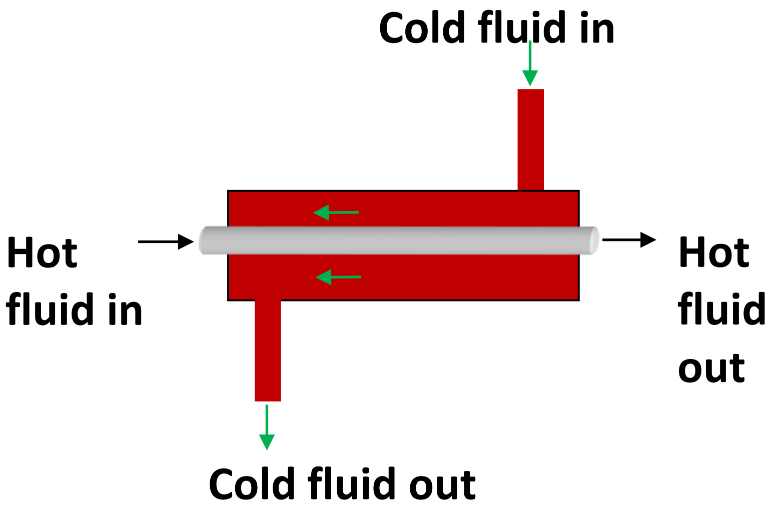
OIL (tube side)

$$T_{h,i} = 70℃$$
$$T_{h,o} = 30℃$$
$$C_{ph} = 2000\frac{J}{kg.K}$$
$$\dot{m}_h = 4\frac{Kg}{s}$$



HEAT BALANCE

$$\dot{m}_c.C_{pc}(T_{c,o} - T_{C,i}) = \dot{m}_h.C_{ph}(\dot{T}_{h,i} - T_{h,o})$$
$$\dot{m}_c.(4200)(30 - 20) = 4(2000)(70 - 30)$$
$$m_c = 7.62\ Kg/s$$

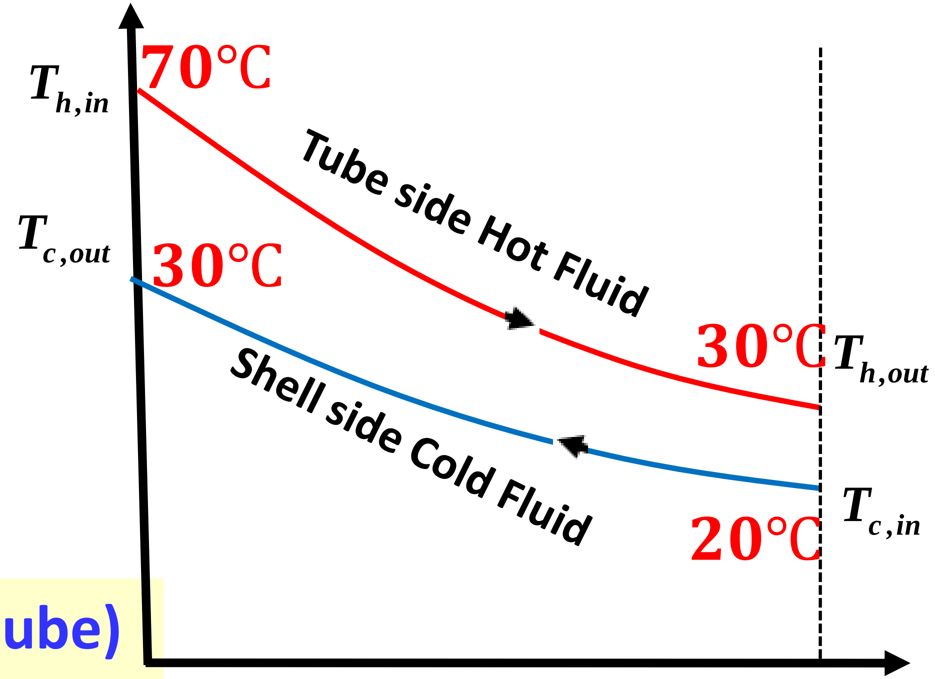


P & R

$$R = \frac{\dot{m}_c C_{pc}}{\dot{m}_h C_{ph}} = \frac{T_{h,i} - T_{h,o}}{T_{c,o} - T_{c,i}} = \frac{7.62 \times 4200}{4 \times 2000}$$

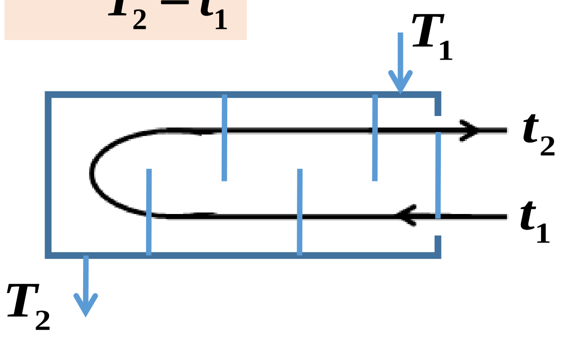
$$R = 4.0$$

$$P = \frac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{c,i}} = \frac{30 - 20}{70 - 20} = 0.2$$



$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{\left(\dot{m} C_P\right)_{\text{tube side}}}{\left(\dot{m} C_P\right)_{\text{shell side}}}$$

$$P = \frac{t_2 - t_1}{T_2 - t_1}$$



F factor F = 0.8 (Two pass shell and tube)
F = 0.92 (Unmixed cross flow)

$$\Delta T_{LM} = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln \frac{T_{h,o} - T_{c,o}}{T_{h,o} - T_{c,i}}} = \frac{(70 - 30) - (30 - 20)}{ln \frac{70 - 30}{30 - 20}} = 21.64℃$$

$$\Delta T_M = F \Delta T_{LM} = 0.8 \times 21.64 = 17.3℃ \; (\mathit{Shell} \;\&\; \mathit{tube})$$

$$= 0.92 \times 21.64 = 19.9℃ \; (\mathit{Unmixed\ cross\ flow})$$

$$T_{h,in} = 400^\circ C; T_{h,out} = 400^\circ C; T_{c,in} = 25^\circ C; T_{c,out} = 193.75^\circ C$$

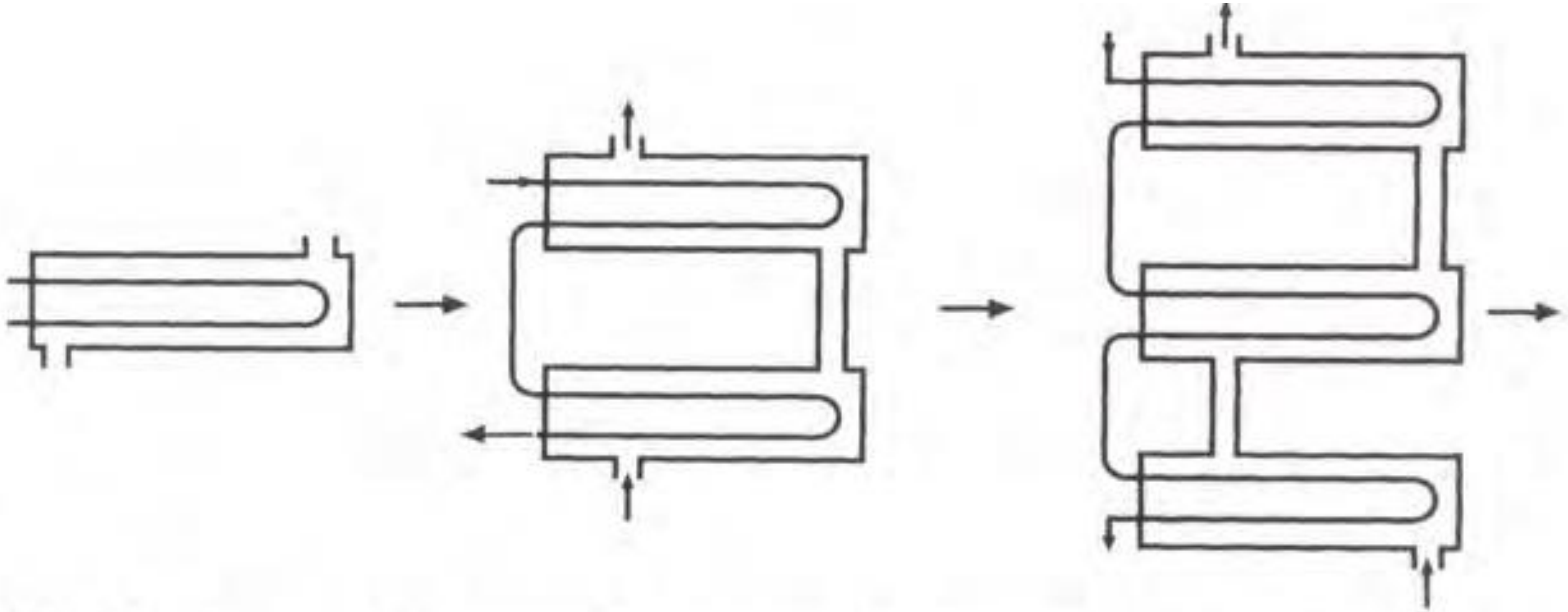
$$R = \frac{T_{h,in} - T_{h,out}}{T_{c,out} - T_{c,in}} = \frac{400 - 62.5}{193.75 - 25} = 2 = \frac{\dot{m}_c C_{pc}}{\dot{m}_h C_{ph}}$$

$$P = \frac{T_{c,out} - T_{c,in}}{T_{h,in} - T_{c,in}} = \frac{193.75 - 62.5}{400 - 25} = 0.45$$

- F < 0.3 single shell and tube heat exchanger
- F = 0.85 Two shell and tube heat exchanger
- F = 0.87 Three shell and tube heat exchanger
- F = 0.95 Four shell and tube heat exchanger
- F = 0.98 Six shell and tube heat exchanger
- F = 0.65 Cross flow heat exchanger (unmixed)
- F = 0.75 Cross flow heat exchanger (one stream mixed)

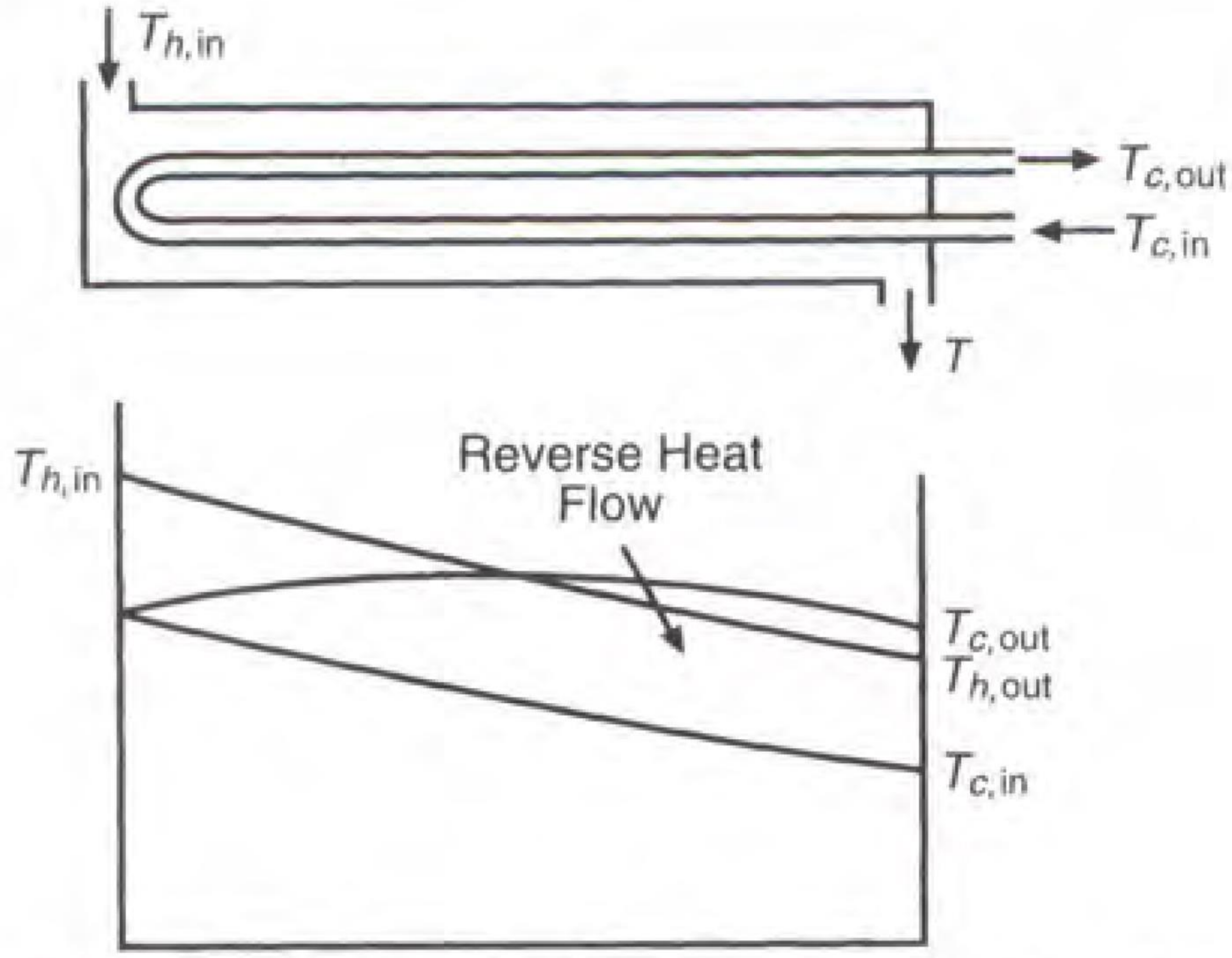
Few salient design features to be taken care of in the design of heat exchangers

- F as a function of P for a given R tends to fall very steeply indicating a considerable sensitivity to the temperatures used in definition of P.
- Local reversal of the transfer process due to the multi-pass operation ; F> 0.8.
- For achieving F > 0.8, multiple shells in series are used.



Approaching counter flow operation by increasing the number of shells

Occurrence of “temperature cross” in a two pass heat exchanger



- Cold fluid reaches a higher temperature than the hot fluid, ie., “temperature cross”.
- Zone of reverse heat transfer represents inefficient use of the heat transfer surface.

MULTIPLE SHELL AND TUBE HEAT EXCHANGER

- **THUMB RULE - $F > 0.8$**

- **Number of Shell (in Series) are increased results in closer to counter current flow – $F \uparrow$**

LMTD-F METHOD

- **Select type of Heat Exchanger suitable for application**
- **Find unknown inlet or outlet temperature and heat transfer rate by energy balance**
- **Find ΔT_{lm}, F**
- **Find U**
- **Calculate A_s**