Heat Exchanger 3

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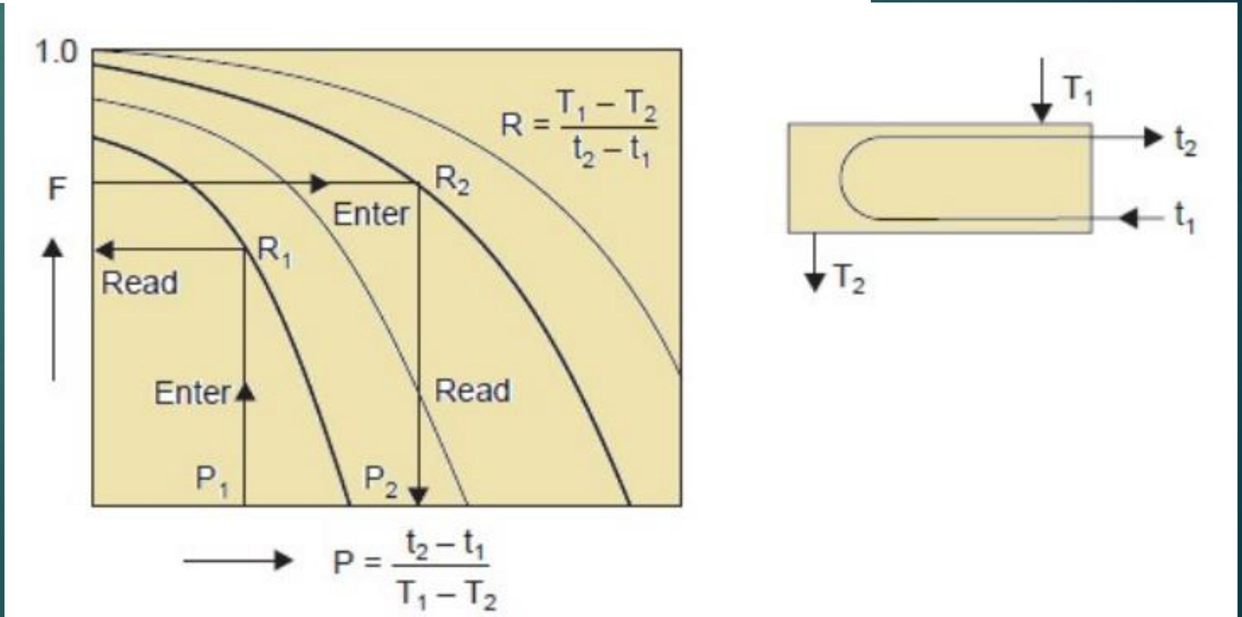
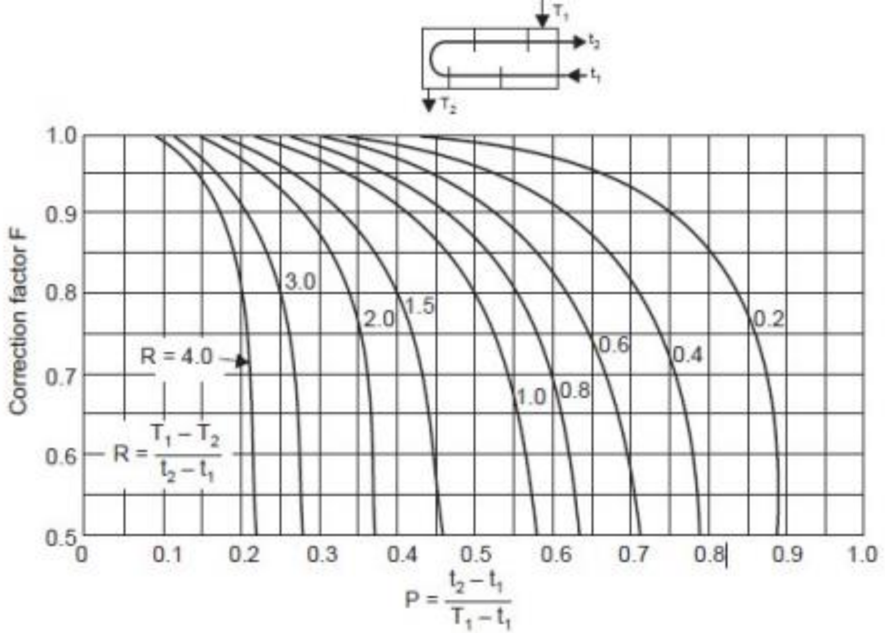
- **Correction Factor for Multi-pass Heat Exchanger:**
- In case of multi-pass heat exchangers and cross flow heat exchangers the LMTD that calculated before must be corrected by a multiplying factor that called the correction factor. The available charts are for the correction F ageist P with R as parameter. Where R is defined as Capacity ratio given by:

$$R = \frac{Hot\ Fluid\ Temperature\ Change}{Cold\ Fluid\ Temperature\ Change} = \frac{T_{hi} - T_{ho}}{T_{co} - T_{ci}}$$

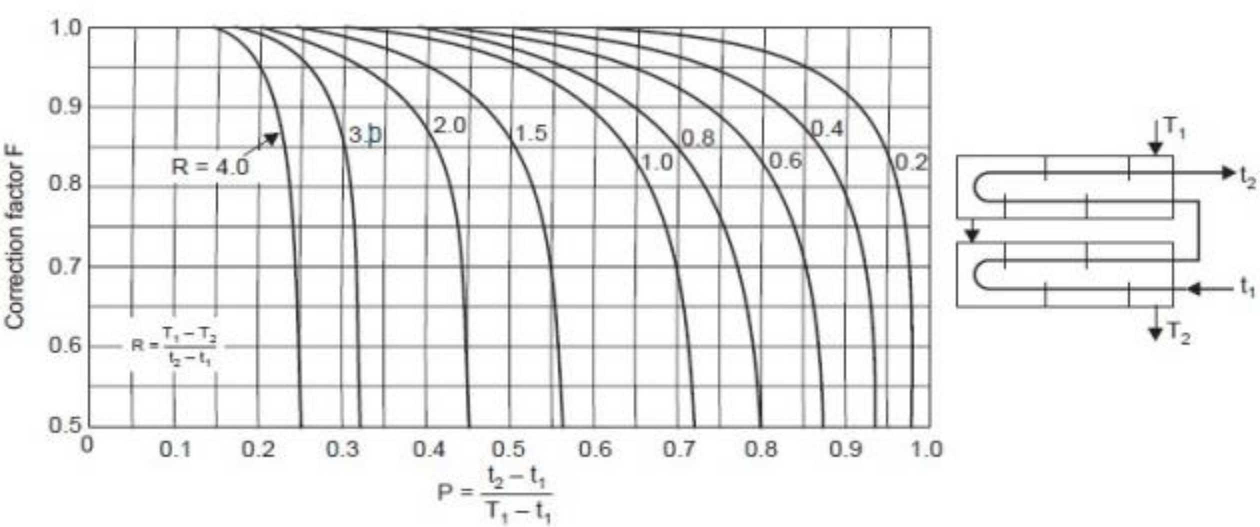
$$P = \frac{The\ Minimum\ Heat\ Capacity\ Fluid\ Temperature\ Rise}{The\ Difference\ Between\ Inlet\ Temperature} = \frac{t_2 - t_1}{T_1 - t_1}$$

- $Q = AUF\Delta T_m$
- **Where F is the**
- **Correction Factor**

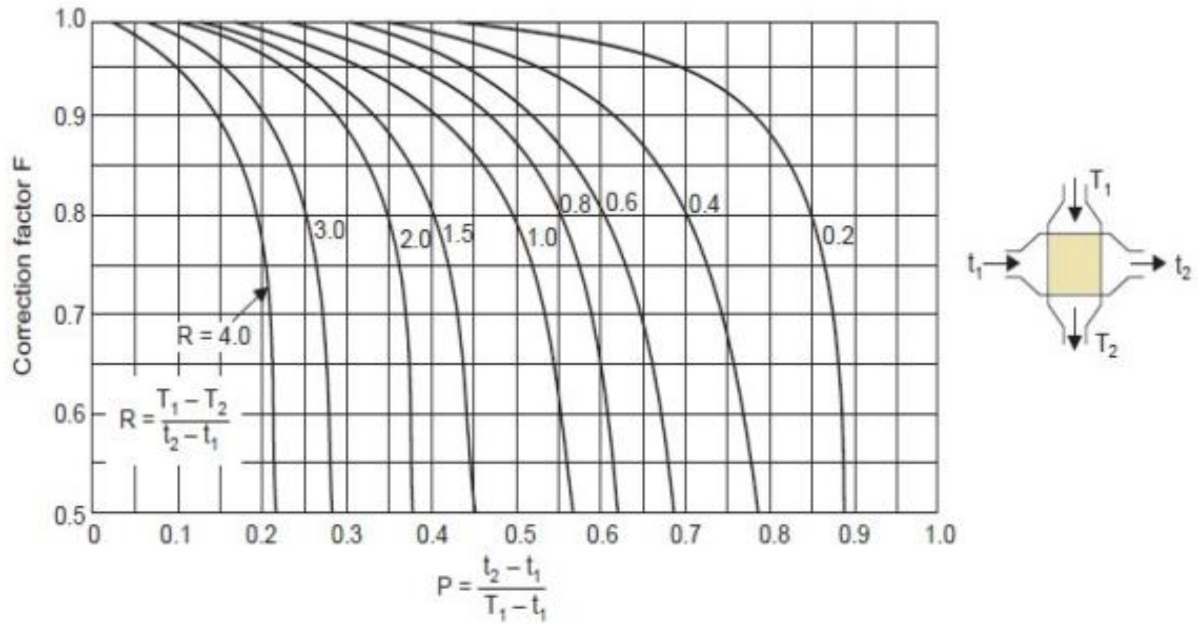




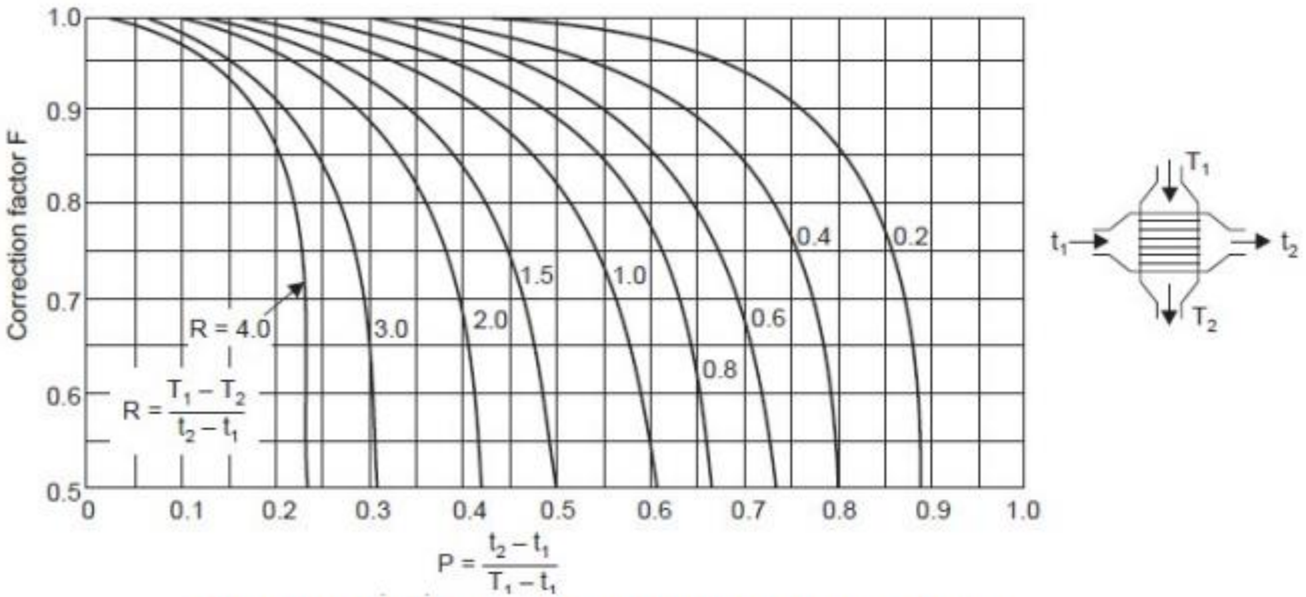
Correction Factor F for Shell and Tube Heat Exchangers With One Shell Pass and Any Multiple of Two Tube Passes (2, 4, 6, etc., Tube Passes)



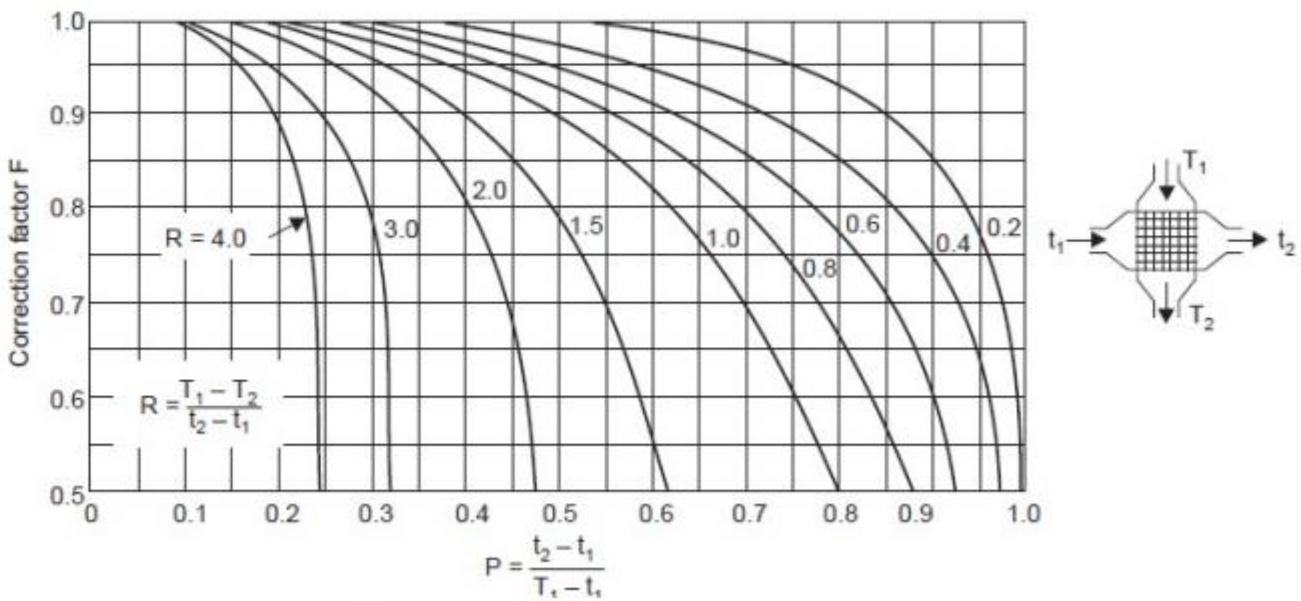
Correction Factor F for Shell and Tube Heat Exchangers With Two Shell Passes And Any Multiple of Four Tube Passes (4, 8, 12, etc., Tube Passes)



Correction Factor F For Cross-Flow (Single-Pass) Heat Exchangers - Both Streams Are Mixed



Correction Factor F For Cross-Flow(Single-Pass) Heat Exchangers - One Stream is Mixed and The Other Unmixed



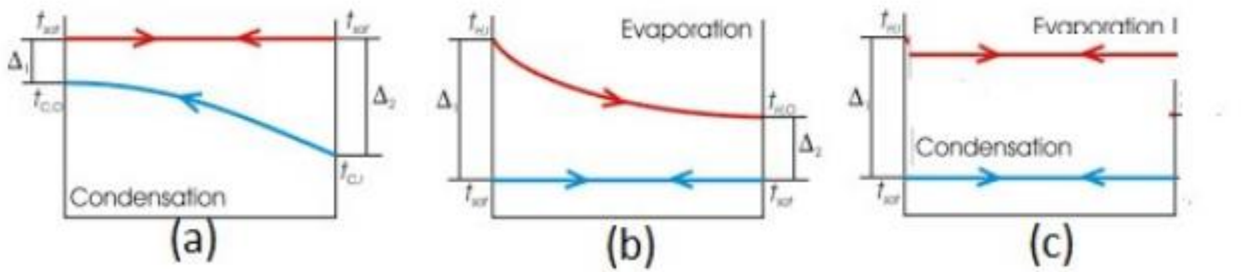
Correction Factor F For Cross-Flow (Single-Pass) Heat Exchangers - Both Streams Are Unmixed

For correction factor the following notes are important

Notes; (1) The (LMTD) for these heat exchangers as counter flow heat exchanger.

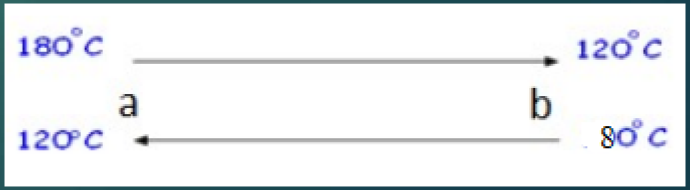
(2)The Correction factors for single pass shell and tubes heat exchanger is equal unity.

(3) For Condensers and Evaporators etc. P will be zero and then F=1. Fig . shows the temperature distribution along the heat exchangers for condenser and evaporator.



(a) Process of Condensing, (b) Process of Evaporating, (c) Process of Condensing and Evaporating Together

- **Example 6:** The hot fluid enters a heat exchanger at (180^oC) and leaves at (120^oC), while the cold fluid flows in at (100^oC) and flows out at (120^oC). Determine the (LMTD) and heat transfer where the heat exchanger area is (20m^2) and overall heat transfer coefficient is (1200W/$m^{2o}C$) in the following cases of arrangement: 1- Counter flow, 2- One shell pass and multi tube passes 3- Two shell pass and multi tube passes 4- Cross flow, both fluids unmixed, 5- Cross flow, cold fluid unmixed.
- **Solution**: heat exchanger with $T_{h1} = 180^oC$ & $T_{h2} = 120^oC$
- $T_{c1} = 80^oC$ & $T_{c2} = 120^oC$, A=20^2C and U=1200W/$m^{2o}C$.
- **Requirements**: LMTD for different arrangements of H.E and heat transfer Q.
- **Analysis**: The Log mean temperature difference in general for counter flow is
- $\Delta T_m = \frac{(\Delta T)_a - (\Delta T)_b}{ln\frac{(\Delta T)_a}{(\Delta T)_b}} = \frac{(180-120)-(120-80)}{ln\frac{(180-120)}{(120-80)}} = 49.33^oC$



- 1) For counter flow F=1
- LMTD=F$\Delta T_m = 1 \times 49.33 = 49.33^oC$

- Q=AU(LMTD)=20x1200x49.33=1183.92kW
- 2) 0ne shall passe and multi-pass tube
- $R = \frac{T_{h1}-T_{h2}}{T_{c2}-T_{c1}} = \frac{180-120}{120-80}$ =1.5
- $P = \frac{t_2-t_1}{T_1-t_1} = \frac{T_{c2}-T_{c1}}{T_{h1}-T_{c1}} = \frac{120-80}{180-80}$ =0.4
- From the Figure of one shall pass and multi-tube pass F=0.8, Then
- $LMTD = F \times \Delta T_m = 0.8 \times 49.44 = 39.46^o C$
- $Q = 20 \times 1200 \times 39.46 = 947.04 kW$
- 3) Two shall passes and multi tube pass: from figure of that F=0.95
- $LMTD = F \times \Delta T_m = 0.95 \times 49.44 = 46.86^o C$
- $Q = 20 \times 1200 \times 46.86 = 1124.64 kW$
- 4) cross flow with both fluid un mixed
- F=0.8

- $LMTD = F \times \Delta T_m = 0.8 \times 49.33 = 39.46^o C$
- $Q = AU(LMTD) = 20 \times 1200 \times 39.46 = 947.04 kW$
- 5) Cross-flow with cold flow unmixed
- F=0.85
- The LMTD=0.85x49.33=41.93$^o C$
- $Q = AU(LMTD) = 20 \times 1200 \times 41.93 = 1006.33 kW$

- **Example 6**. Determine the required area for a heat exchanger of shell and tube with two tube pass for oil cooling at a flow rate of (10kg/Sec) from ($60^o C$) to (30^oC) following in the shell. Using water as cooling fluid passes through the tubes at (20^oC) and heated to (26^oC). The oil specific heat is (2200J/ $kg.^o C$). The overall heat transfer coefficient is (300W/m^{2o}C).
- Solution: shell and tube heat exchanger with two pass. The oil is to be cooled $\dot{m}_h$ = 10kg/sec, $Cp_h = 2200$ J/ $kg.^o C$, $T_{h1} = 60^o C, T_{h2} = 30^o C$. The water is the cooling fluid $Cp_c = 4200 J/kg.^o C, T_{c1} = 20^o C, T_{c2} = 26^o C$, U=250W/$m^{2o} C$.

- **Requirements:** The Area of the heat exchanger
- **Analysis:** The heat transfer from the oil is Q
- $Q = \dot{m}_h Cp_h (T_{h1} - T_{h2}) = 10 \times 2200(60 - 30) = 660000W$
- $\Delta T_m = \frac{(T_{h1}-T_{c2})-(T_{h2}-T_{c1})}{ln\frac{T_{h1}-T_{c2}}{T_{h2}-T_{c1}}} = \frac{(60-26)-(30-20)}{ln\frac{(60-26)}{(30-20)}} = 19.61^oC$
- $R = \frac{T_{h1}-T_{h2}}{T_{c2}-T_{c1}} = \frac{60-30}{26-20} = 5.0$
- $P = \frac{t_2-t_1}{T_1-t_1} = \frac{T_{c2}-T_{c1}}{T_{h1}-T_{c1}} = \frac{26-20}{60-20} = \frac{6}{40} = 0.15$
- From the chart of one shell pass and multi-tube pass F=0.9
- Then $Q = AUF\Delta T_m$
- $660000 = A \times 250 \times 0.9 \times 19.61 \rightarrow A = 149.58m^2$

- **EFFECTVENESS –NTU METHOD**
- The heat exchanger effectiveness (ε) is the ratio of actual heat transfer to the maximum possible heat transfer.
- $\varepsilon = \frac{Actual\ Heat\ Transfer}{Maximum\ Heat\ Transfer} = \frac{\dot{Q}}{\dot{Q}_{max}}$
- The actual heat transfer is determined by using of an balance of energy over either side of the heat exchanger.
- $\dot{Q} = \dot{m}_h Cp_h (T_{h1} - T_{h2}) = \dot{m}_c Cp_c (T_{c2} - T_{c1})$
- The product of mass flow rate with specific capacity is known as fluid heat capacity denoted as C
- $C_c = \dot{m}_c Cp_c$ and $C_h = \dot{m}_h Cp_h$
- The C_{min} is one of them
- If $C_{min} = C_c$ then $\varepsilon = \frac{C_c(T_{c2}-T_{c1})}{C_c(T_{h1}-T_{c1})}$ or $\varepsilon = \frac{(T_{c2}-T_{c1})}{(T_{h1}-T_{c1})}$
- If $C_{min} = C_h$ then $\varepsilon = \frac{C_h(T_{h1}-T_{h2})}{C_h(T_{h1}-T_{c1})}$ or $\varepsilon = \frac{(T_{h1}-T_{h2})}{(T_{h1}-T_{c1})}$
- The capacity ratio $C = \frac{C_{min}}{C_{max}}$

- The number of heat transfer unit is
- $NTU = \frac{AU}{C_{min}}$
- The relation between the effectiveness (ε)and number of heat transfer (NTU) and the capacity ration (C) for different type of heat exchanger

1- For parallel flow heat exchanger is

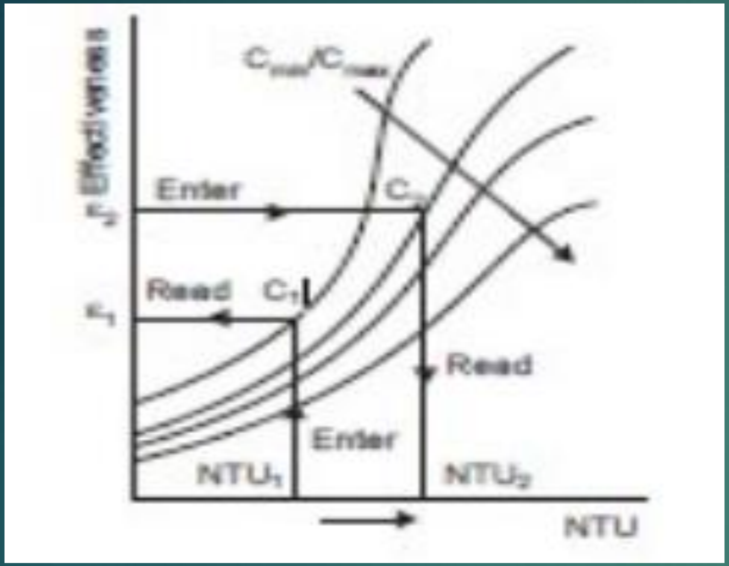
$$\varepsilon = \frac{1 - \exp\left[-NTU(1 + C)\right]}{(1 + C)}$$

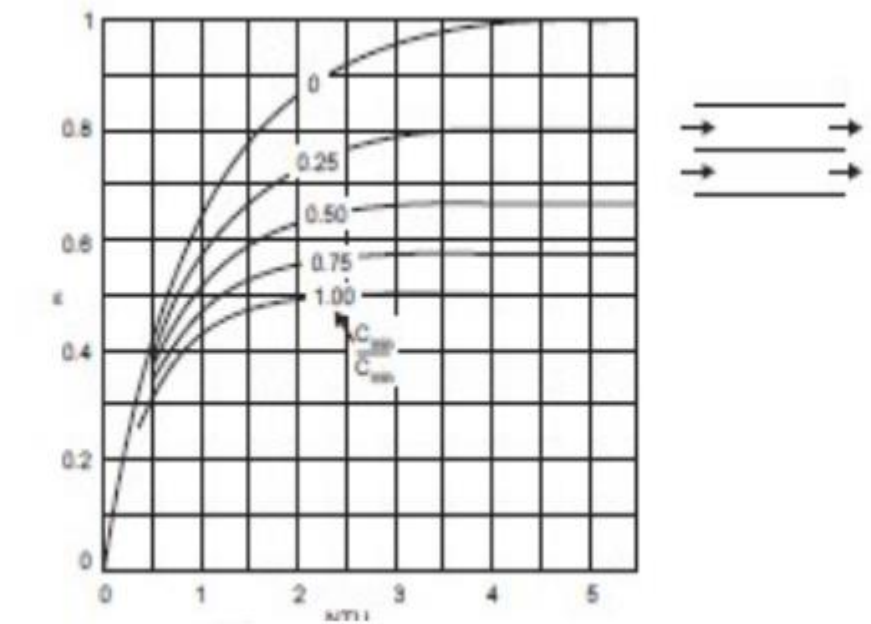
2- For counter flow heat exchanger is

$$\varepsilon = \frac{\exp(NTU[1 - C]) - 1}{\exp(NTU[1 - C]) - C}$$

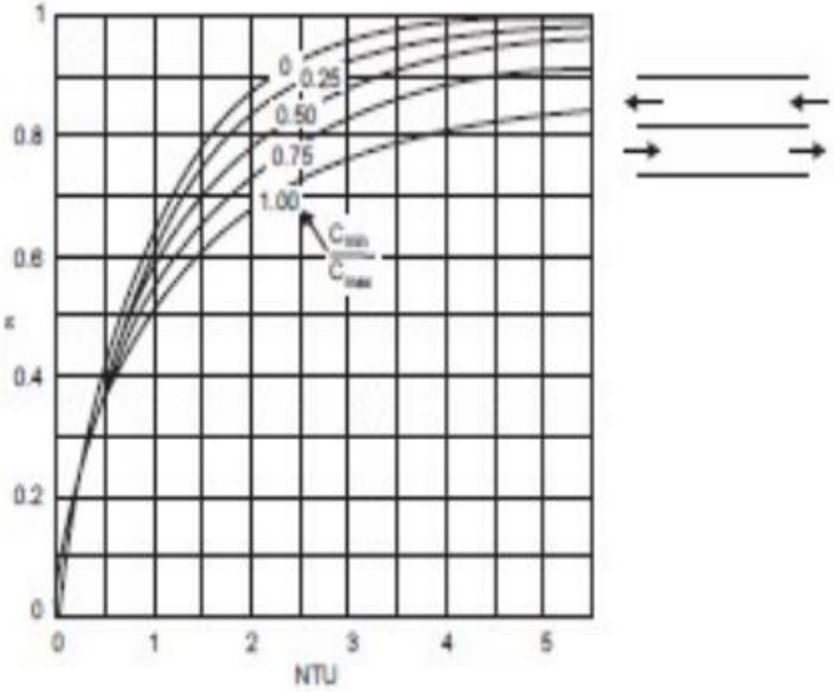
<u>For Condenser and evaporator</u> [$C = \frac{C_{min}}{C_{max}}$=0]

- The effectiveness can also found from the charts which depends on the number of heat transfer unit (NTU)

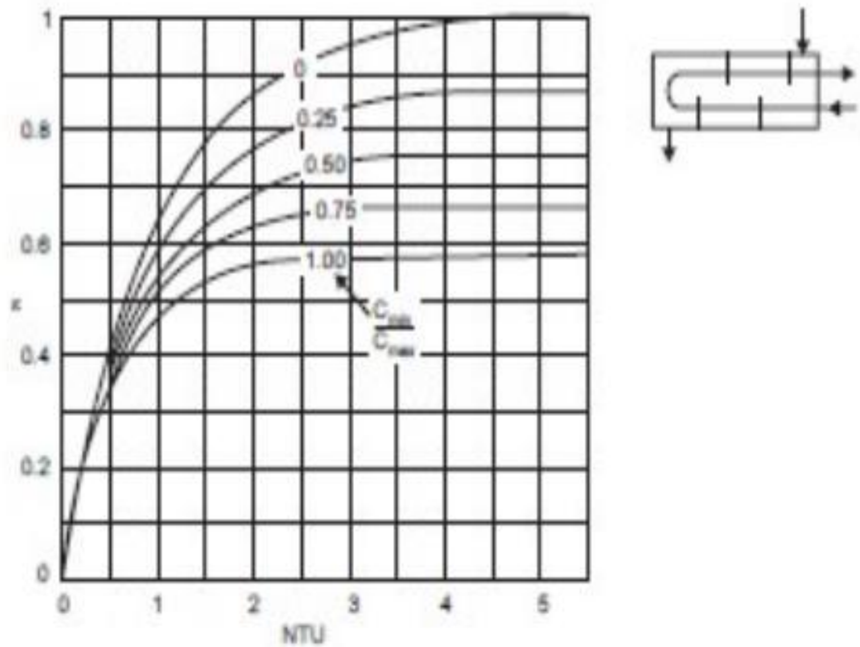




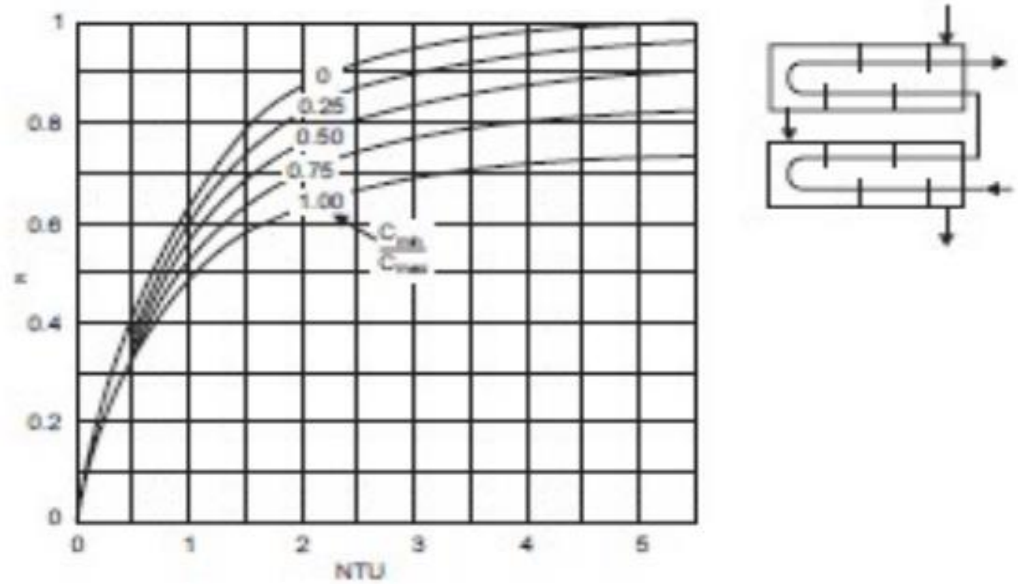
The Effectiveness of a Parallel Flow Heat Exchanger



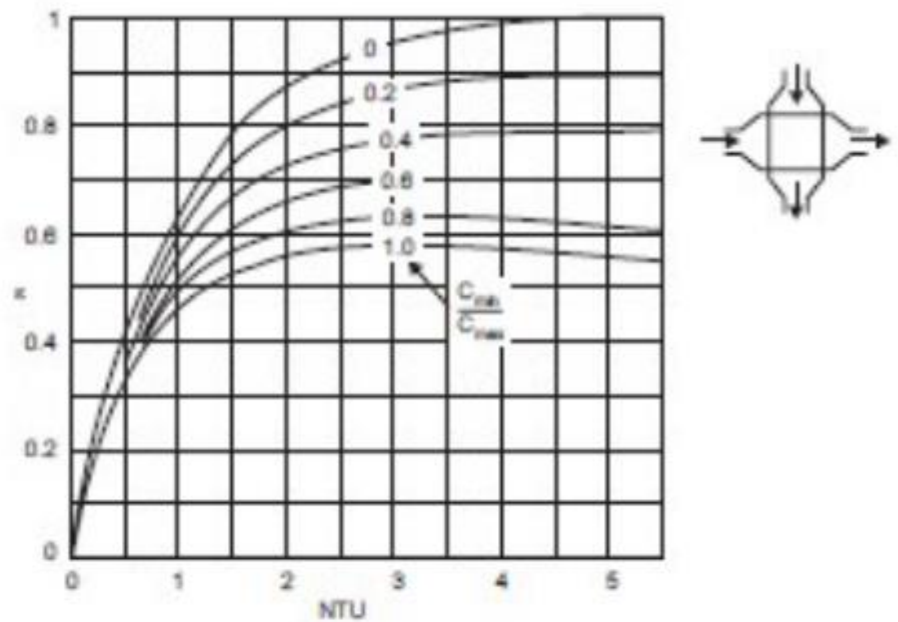
The Effectiveness of a Counter Flow Heat Exchanger



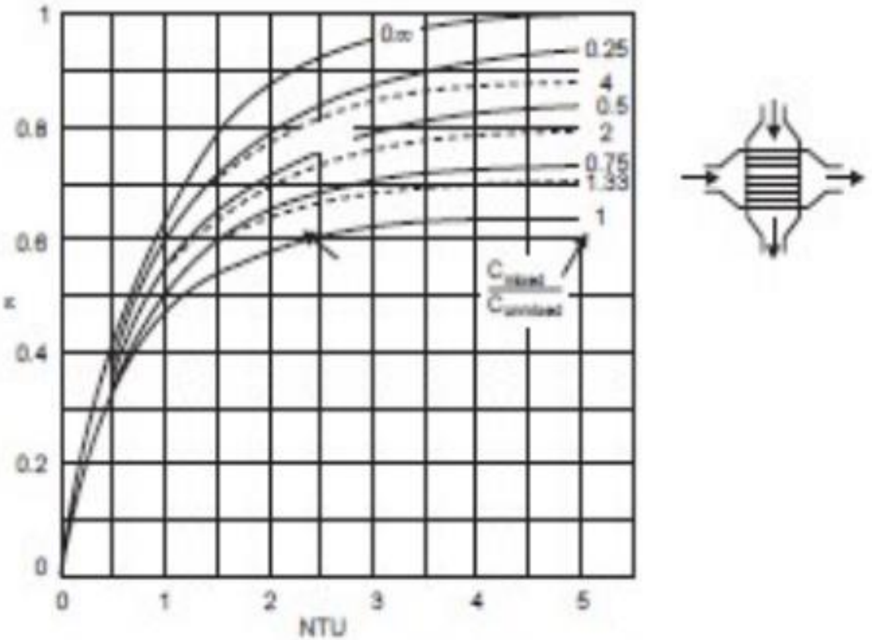
The Effectiveness of Shell- and –Tube Heat Exchangers With One-Shell pass and Multiple of Two Passes (2, 4, 6, etc., tube Passes)



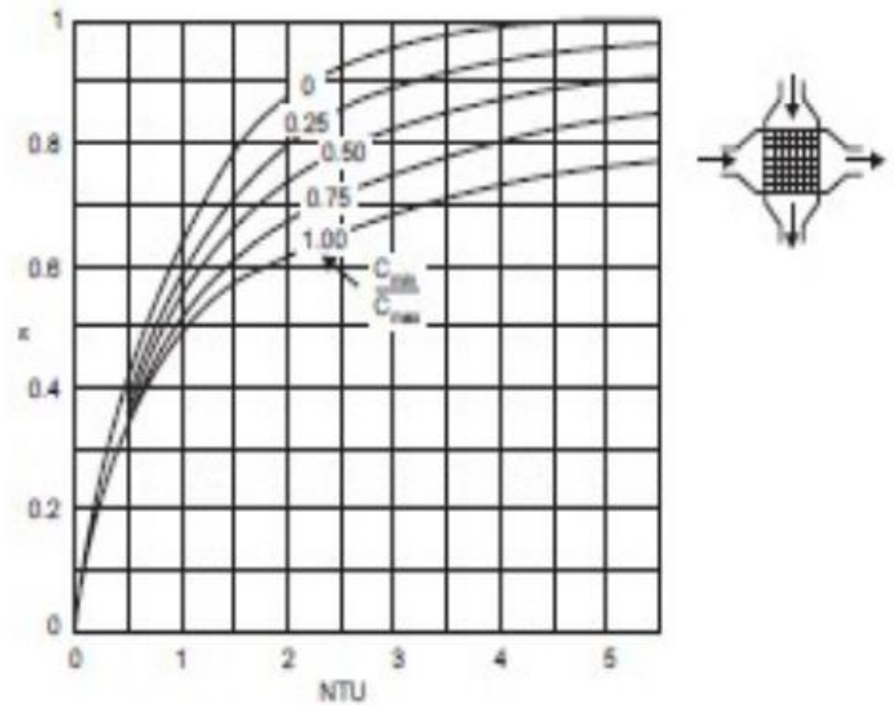
The Effectiveness of Shell and Tube Heat Exchangers With Two Shell Passes and Multiple of Four Tube Passes (4, 8, 12 etc., tube Passes)



Effectiveness of a Cross-Flow (Single – Pass) Heat Exchanger In Which Both Streams are Mixed



The Effectiveness of a Cross-Flow(Single-Pass) Heat Exchanger In Which Stream is Mixed and The Other is Unmixed



The Effectiveness of a Cross-Flow (Single-Pass) Heat Exchanger In Which Both Streams Remain Unmixed

- **Example 7**. A feed water heater of area ($6m^2$) was used to heat water from (30^oC) with a flow rate of (2.7kg/Sec), using steam that was condensing at (120^oC). The water exit temperature was measured to be (85^oC). Determine the overall heat transfer coefficient. After operation of(3years), for the same inlet conditions and flow rates, the outlet temperature measured to be (78^oC). Find the fouling resistance value.
- **Solution**: A feed water heater is a heat exchanger in which the water before entering the boiler is heated by bleeding some steam from turbine.
- $Cp_c = 4200$J/kg.K, $\dot{m}_c = 2.7kg/sec$ $T_{c1} = 30^oC$, $T_{c2} = 85^oC$
- $T_{h1} = T_{h2} = 120^oC$. After three years $T_{c2} = 78^oC$ A=$6m^2$
- **Requirements**: the overall heat transfer coefficient and fouling resistance.
- **Analysis**: By using ε-NTU method
- $C_c = C_{min} = \dot{m}_c Cp_c = 2.7 \times 4200 = 11340 J/^oC$
- C=0 for condenser

- The effectiveness $\varepsilon = \frac{T_{c2}-T_{c1}}{T_{h1}-T_{c1}} = \frac{85-30}{120-30} = 0.6111$
- For C=0 , Then $\varepsilon = 1 - e^{NTU}$
- $-e^{-NTU} = \varepsilon - 1 \rightarrow e^{-NTU} = 1 - \varepsilon$ or NTU=$-ln(1-\varepsilon)$
- Then NTU=$-ln(1-0.6111) = 0.9444$
- NTU=$\frac{AU}{C_{min}} \rightarrow U = \frac{NTU \times C_{min}}{A} = \frac{0.9444 \times 11340}{6} = 1785 \text{W}/m^{2o}C$
- After a service $T_{c2} = 78^{o}C$
- $\varepsilon = \frac{T_{c2}-T_{c1}}{T_{h1}-T_{c1}} = \frac{78-30}{120-30} = 0.5333$
- NTU=$-ln(1-\varepsilon)$=$-ln(1-0.53333) = 0.762$
- $U_d = \frac{NTU \times C_{min}}{A} = \frac{0.762 \times 11340}{6} = 1440.4 \text{W}/m^{2o}C$
- $U_d = \left[\frac{1}{U} + F\right]^{-1}$ or $\frac{1}{U_d} = \frac{1}{U} + F \rightarrow F = \frac{1}{U_d} - \frac{1}{U}$
- $F = \frac{1}{1440.4} - \frac{1}{1785} = 0.000134 m^{2o}C/W$