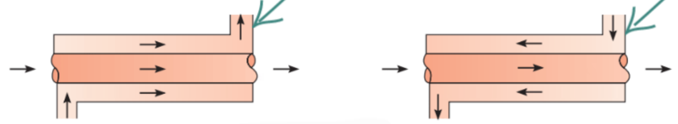
Heat Exchangers

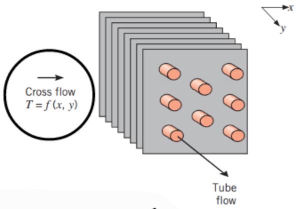
Heat exchangers
- → Type of construction
- → flow arrangement

Types of heat exchangers:

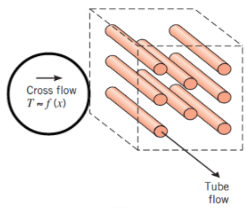
1- Simple: hot and cold fluids moves in $\underbrace{\text{same}}_{\text{parallel flow}}$ or $\underbrace{\text{opposite}}_{\text{counter flow}}$ direction in a concentric tube



2- Cross flow: by finned or unfinned tubuler heat exchangers

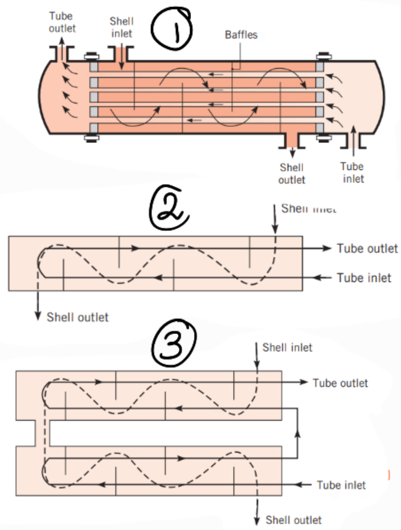


finned with both fluids unmixed



finned with one fluid mixed and the other unmixed

3- Shell and tube heat exchanger
- single tube and shell passes
- single shell pass and two tube passes
- Two shell passes and four tube passes



4. Compact heat exchanger

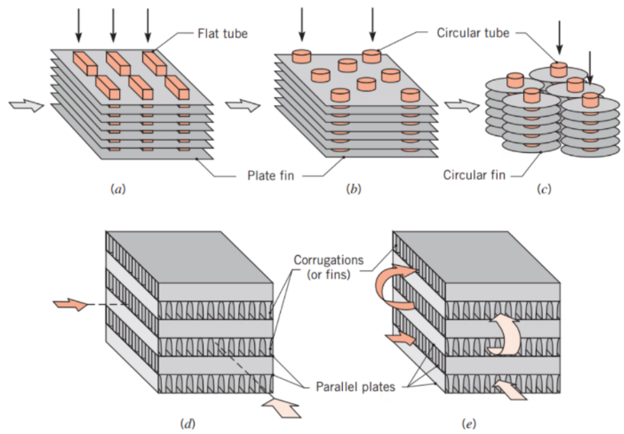


FIGURE 11.5 Compact heat exchanger cores. (a) Fin–tube (flat tubes, continuous plate fins). (b) Fin–tube (circular tubes, continuous plate fins). (c) Fin–tube (circular tubes, circular fins). (d) Plate–fin (single pass). (e) Plate–fin (multipass).

Overall heat transfer coefficient

- For a wall separating two streams, the overall heat coefficient

$$\frac{1}{UA} = \frac{1}{U_c A_c} = \frac{1}{U_h A_h} = \frac{1}{(hA)_c} + R_w + \frac{1}{(hA)_h}$$

c: cold
h: hot

Notice that: $U_c A_c = U_h A_h$ But: $U_c \neq U_h$ if $A_c \neq A_h$

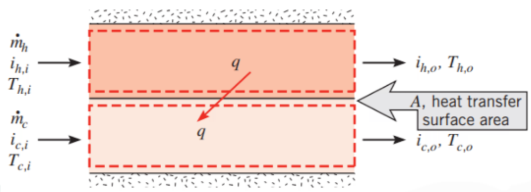
TABLE 11.2 Representative Values of the Overall Heat Transfer Coefficient

Fluid Combination	U (W/m$^2 \cdot$ K)
Water to water	850–1700
Water to oil	110–350
Steam condenser (water in tubes)	1000–6000
Ammonia condenser (water in tubes)	800–1400
Alcohol condenser (water in tubes)	250–700
Finned-tube heat exchanger (water in tubes, air in cross flow)	25–50

Heat exchanger analysis

$$\left.\begin{aligned} q &= \dot{m}_c c_{p,c} (T_{c,o} - T_{c,i}) \\ q &= \dot{m}_h c_{p,h} (T_{h,i} - T_{h,o}) \end{aligned}\right\}$$

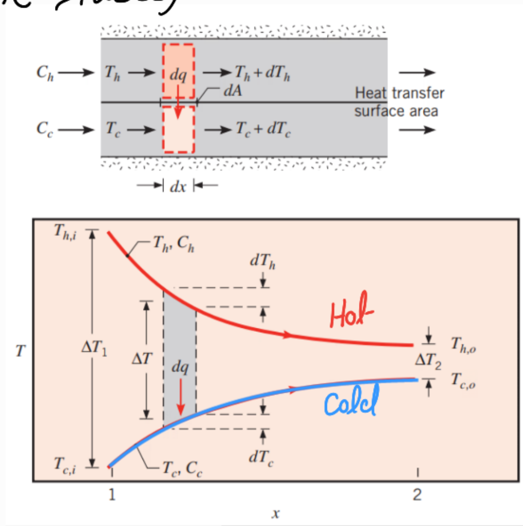
These are independent of flow arrangement and heat exchanger type



log mean method (for concentric tubes)

parallel flow heat exchanger

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



Assumptions for this equation:

1. The heat exchanger is insulated from its surroundings, in which case the only heat exchange is between the hot and cold fluids.
2. Axial conduction along the tubes is negligible.
3. Potential and kinetic energy changes are negligible.
4. The fluid specific heats are constant.
5. The overall heat transfer coefficient is constant.

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$

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

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

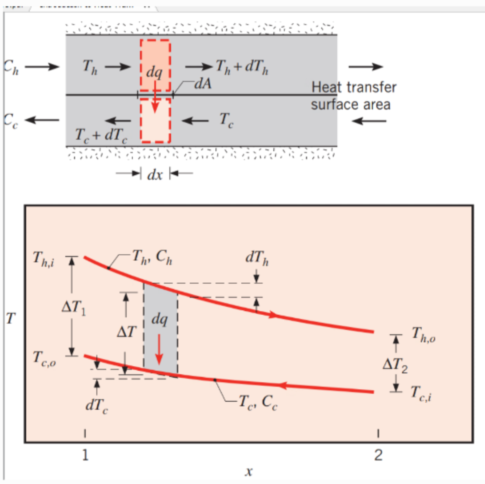
Note

$T_{c,o}$ should not be be higher than $T_{h,o}$

Counter flow heat exchanger

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

$A = \pi DL$



$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$

$\Delta T_2 = T_{h,o} - T_{c,i} = T_{h,2} - T_{c,2}$

$\Delta T_1 = T_{h,i} - T_{c,o} = T_{h,1} - T_{c,1}$

Note, to reduce L, we use shell heat exchanger with multiple tubes

Note

$T_{c,o}$ can be higher than $T_{h,o}$

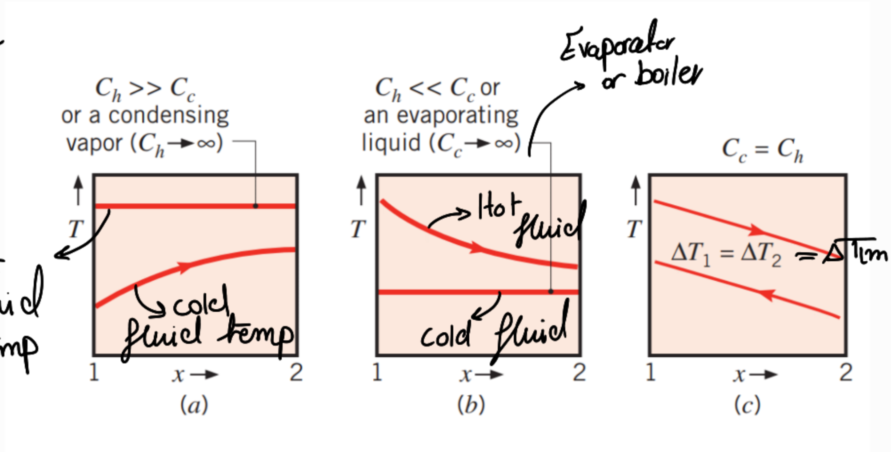
Conditions under which heat exchangers may be operated

C: heat capacity rate

$C_h = \dot{m}_h c_{p,h}$

$C_c = \dot{m}_c c_{p,c}$

hot fluid Temp



For other types of heat exchangers

corrected log mean is used in which

$$q = UA\,F\,\Delta T_{lm}$$

Correction factor

Heat exchanger analysis : NTU method

If only inlet temperatures are known we use this method

Effectiveness : → $\varepsilon = \dfrac{q}{q_{max}}$

→ $q_{max} = C_{min}\,(T_{h,i} - T_{c,i})$

$C_h < C_c$: $C = C_h$

$C_h > C_c$: $C = C_c$

→ $q = \dot{m}_c c_{p,c}(T_{c,o} - T_{c,i}) = \dot{m}_h c_{p,h}(T_{h,i} - T_{h,o})$

If $C_{min} = C_h$: $\varepsilon = \dfrac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}}$

If $C_{min} = C_c$: $\varepsilon = \dfrac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{c,i}}$

$0 \leq \varepsilon \leq 1$

- To find q by NTU method

$$q = \varepsilon\, C_{min}\,(T_{h,i} - T_{c,i})$$

- For any heat exchanger

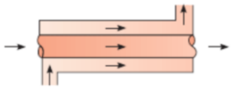
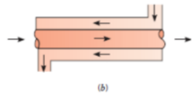
$$NTU = \frac{UA}{C_{min}}$$

NTU: number of transfer units

$C_r = C_{min} / C_{max}$

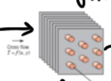
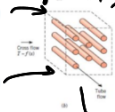
$C_r = 0$ If the heat exchanger is with evaporation or

Table 11.3 Heat Exchanger Effectiveness Relations [5]

Flow Arrangemen		Relation	
Parallel flo		$\varepsilon = \dfrac{1 - \exp[-\mathrm{NTU}(1 + C_r)]}{1 + C_r}$	
Counterflo		$\varepsilon = \dfrac{1 - \exp[-\mathrm{NTU}(1 - C_r)]}{1 - C_r \exp[-\mathrm{NTU}(1 - C_r)]}$	$(C_r < 1)$
		$\varepsilon = \dfrac{\mathrm{NTU}}{1 + \mathrm{NTU}}$	$(C_r = 1)$

$$C_r \equiv C_{min}/C_{max}.$$

$$\boxed{\mathrm{NTU} \equiv \frac{UA}{C_{min}}}$$

Shell-and-tube	
One shell pass (2, 4, . . . tube passes)	$\varepsilon_1 = 2\left\{1 + C_r + (1 + C_r^2)^{1/2} \times \dfrac{1 + \exp[-(\mathrm{NTU})_1(1 + C_r^2)^{1/2}]}{1 - \exp[-(\mathrm{NTU})_1(1 + C_r^2)^{1/2}]}\right\}^{-1}$
n shell passes ($2n$, $4n$, . . . tube passes)	$\varepsilon = \left[\left(\dfrac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1}\right)^n - 1\right]\left[\left(\dfrac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1}\right)^n - C_r\right]^{-1}$
Cross-flow (single pass	finned
Both fluids unmixed	 $\varepsilon = 1 - \exp\left[\left(\dfrac{1}{C_r}\right)(\mathrm{NTU})^{0.22}\{\exp[-C_r(\mathrm{NTU})^{0.78}] - 1\}\right]$
	Unfinned
C_{max} (mixed), C_{min} (unmixed)	 $\varepsilon = \left(\dfrac{1}{C_r}\right)(1 - \exp\{-C_r[1 - \exp(-\mathrm{NTU})]\})$
C_{min} (mixed), C_{max} (unmixed)	$\varepsilon = 1 - \exp(-C_r^{-1}\{1 - \exp[-C_r(\mathrm{NTU})]\})$
$\boxed{C_{max} \to \infty}$ **All exchangers ($C_r = 0$)**	$\varepsilon = 1 - \exp(-\mathrm{NTU})$

Heat exchanger with condensing/evaporation Cr=0

داخل الأنابيب بجري mixed

If ε is given and NTU is needed

Table 11.4 Heat Exchanger NTU Relations

Flow Arrangement	Relation		
Parallel flow	$\mathrm{NTU} = -\dfrac{\ln[1 - \varepsilon(1 + C_r)]}{1 + C_r}$		(11.28b)
Counterflow	$\mathrm{NTU} = \dfrac{1}{C_r - 1}\ln\left(\dfrac{\varepsilon - 1}{\varepsilon C_r - 1}\right)$	$(C_r < 1)$	
	$\mathrm{NTU} = \dfrac{\varepsilon}{1 - \varepsilon}$	$(C_r = 1)$	(11.29b)
Shell-and-tube			
One shell pass (2, 4, . . . tube passes)	$(\mathrm{NTU})_1 = -(1 + C_r^2)^{-1/2}\ln\left(\dfrac{E - 1}{E + 1}\right)$		(11.30b)
	$E = \dfrac{2/\varepsilon_1 - (1 + C_r)}{(1 + C_r^2)^{1/2}}$		(11.30c)
n shell passes ($2n$, $4n$, . . . tube passes)	Use Equations 11.30b and 11.30c with		
	$\varepsilon_1 = \dfrac{F - 1}{F - C_r}$ $\quad F = \left(\dfrac{\varepsilon C_r - 1}{\varepsilon - 1}\right)^{1/n}$ $\quad \mathrm{NTU} = n(\mathrm{NTU})_1$		(11.31b, c, d)
Cross-flow (single pass) Just unfinned			
C_{max} (mixed), C_{min} (unmixed)	$\mathrm{NTU} = -\ln\left[1 + \left(\dfrac{1}{C_r}\right)\ln(1 - \varepsilon C_r)\right]$		(11.33b)
C_{min} (mixed), C_{max} (unmixed)	$\mathrm{NTU} = -\left(\dfrac{1}{C_r}\right)\ln[C_r \ln(1 - \varepsilon) + 1]$		(11.34b)
All exchangers ($C_r = 0$)	$\mathrm{NTU} = -\ln(1 - \varepsilon)$		(11.35b)

Instead of equations use graphs shown below

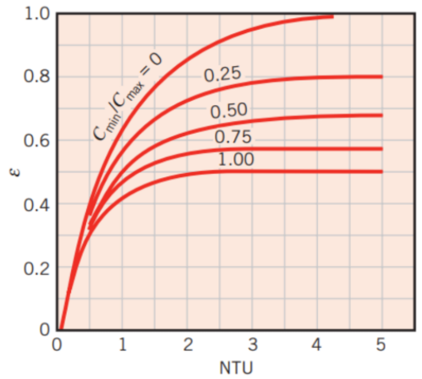


FIGURE 11.10 Effectiveness of a parallel-flow heat exchanger (Equation 11.28).

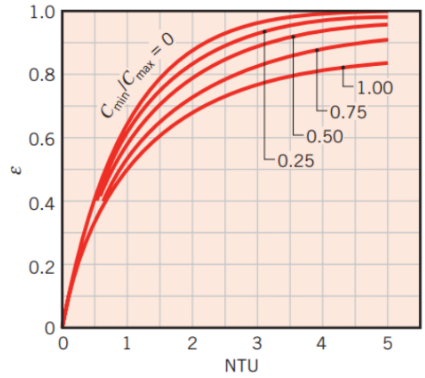


FIGURE 11.11 Effectiveness of a counterflow heat exchanger (Equation 11.29).

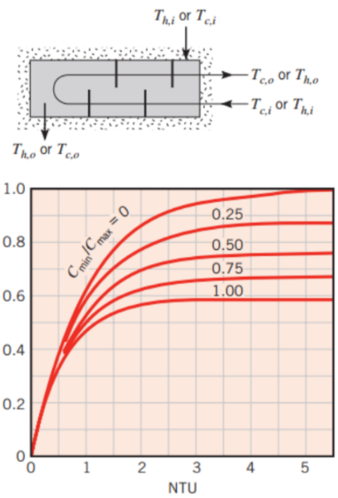


FIGURE 11.12 Effectiveness of a shell-and-tube heat exchanger with one shell and any multiple of two tube passes (two, four, etc., tube passes) (Equation 11.30).

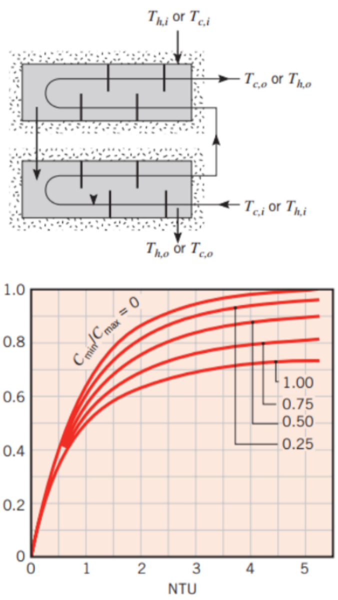


FIGURE 11.13 Effectiveness of a shell-and-tube heat exchanger with two shell passes and any multiple of four tube passes (four, eight, etc., tube passes) (Equation 11.31 with $n = 2$).

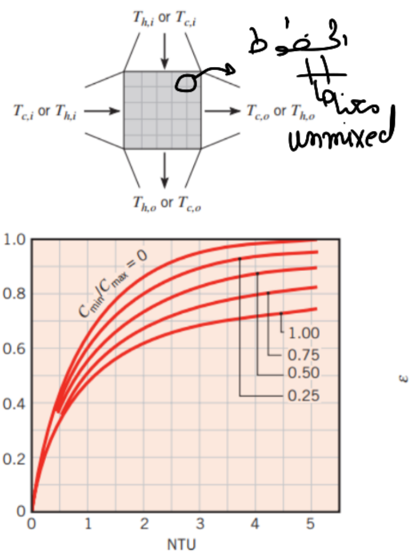


FIGURE 11.14 Effectiveness of a single-pass, cross-flow heat exchanger with both fluids unmixed (Equation 11.32).

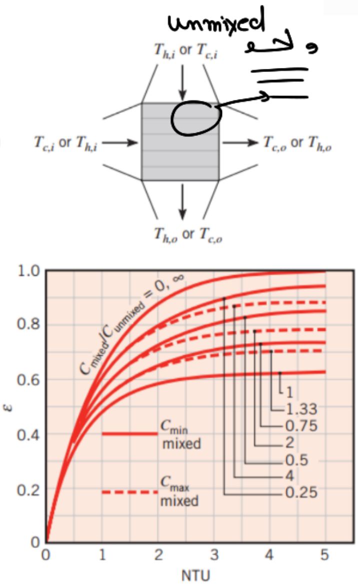


FIGURE 11.15 Effectiveness of a single-pass, cross-flow heat exchanger with one fluid mixed and the other unmixed (Equations 11.33, 11.34).

Notes:

for annulus cylinders:

$$Re = \frac{4\dot{m}}{\pi (D_o + D_i)\mu}$$

if annuls H.E is very long:-

$$\boxed{q = q_{max}}$$

In counter flow: $T_{c,o} = T_{h,i}$

In parallel flow: $T_{c,o} = T_{h,o}$