Performance Analysis of Heat Exchangers

Capacity of A Simple Heat Exchanger

$\dot{m}_{hot}, T_{h,i}, c_{ph}$ $\dot{m}_{hot}, T_{h,e}, c_{ph}$

$\dot{m}_{cold}, T_{c,i}, c_{pc}$ $\dot{m}_{cold}, T_{c,e}, c_{pc}$

$$\frac{\dot{Q}}{UA} = \frac{\left[\left(\Delta T_{comm,2} - \Delta T_{comm,1}\right)\right]}{\ln\left[\dfrac{\Delta T_{comm,2}}{\Delta T_{comm,1}}\right]}$$

A representative temperature difference for heat communication:

$$\Delta T_{LM} = \frac{\left(\Delta T_{comm,2} - \Delta T_{comm,1}\right)}{\ln\left[\dfrac{\Delta T_{comm,2}}{\Delta T_{comm,1}}\right]}$$

Discussion on LMTD

- LMTD can be easily calculated, when the fluid inlet temperatures are know and the outlet temperatures are specified.
- Lower the value of LMTD, higher the value of overall value of UA.
- For given end conditions, counter flow gives higher value of LMTD when compared to co flow.
- Counter flow generates more temperature driving force with same entropy generation.
- This nearly equal to mean of many local values of ΔT.

Sample Problem

- Problem Statement: A double pipe heat exchanger of the dimensions shown below is employed to heat 5 *kg/s* of ***Dowtherm A*** from 15 to 65^{0}C using waste hot water coming from process equipment, which is cooled from 95 to 75^{0}C.

Effectiveness of A HX

- Ratio of the actual heat transfer rate to maximum available heat transfer rate.

$$\varepsilon = \frac{\dot{Q}_{act}}{\dot{Q}_{\max}}$$

- Maximum available temperature difference of minimum thermal capacity fluid.

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

- Actual heat transfer rate:

$$\dot{Q}_{act} = UA\,\Delta T_{LMTD}$$

Maximum Possible Heat Transfer

$$\dot{Q}_{act} = \left(\dot{m}\, c_p\right)_{\min} \left(T_{h,i} - T_{c,i}\right)$$

$$\varepsilon = \frac{UA\, \Delta T_{LMTD}}{\left(\dot{m}\, c_p\right)_{\min} \left(T_{h,i} - T_{c,i}\right)}$$

Dimensionless Groups for HXs

- Thermal capacity Ratio:

$$R = \frac{(\dot{m}c_p)_{\min}}{(\dot{m}c_p)_{\max}} = \frac{C_{\min}}{C_{\max}}$$

- $R = \boldsymbol{0}$ corresponds to condensing or evaporating HX.
- *$R < 1$ a general heat exchanger.*

- Exchanger heat communicative Effectiveness:

$$\varepsilon = \frac{\dot{Q}_{act}}{\dot{Q}_{\max}}$$

$\dot{Q}_{\max}$: Thermodynamically limited maximum possible heat transfer

Number of Transfer Units

$$\varepsilon = \frac{UA\ \Delta T_{LMTD}}{(\dot{m}\, c_p)_{\min} (T_{h,i} - T_{c,i})}$$

$$\varepsilon = NTU_{\max} \frac{\Delta T_{LMTD}}{(T_{h,i} - T_{c,i})}$$

$$\varepsilon = NTU_{\max} \frac{\dfrac{(\Delta T_{comm,2} - \Delta T_{comm,1})}{\ln\left[\dfrac{\Delta T_{comm,2}}{\Delta T_{comm,1}}\right]}}{(T_{h,i} - T_{c,i})}$$

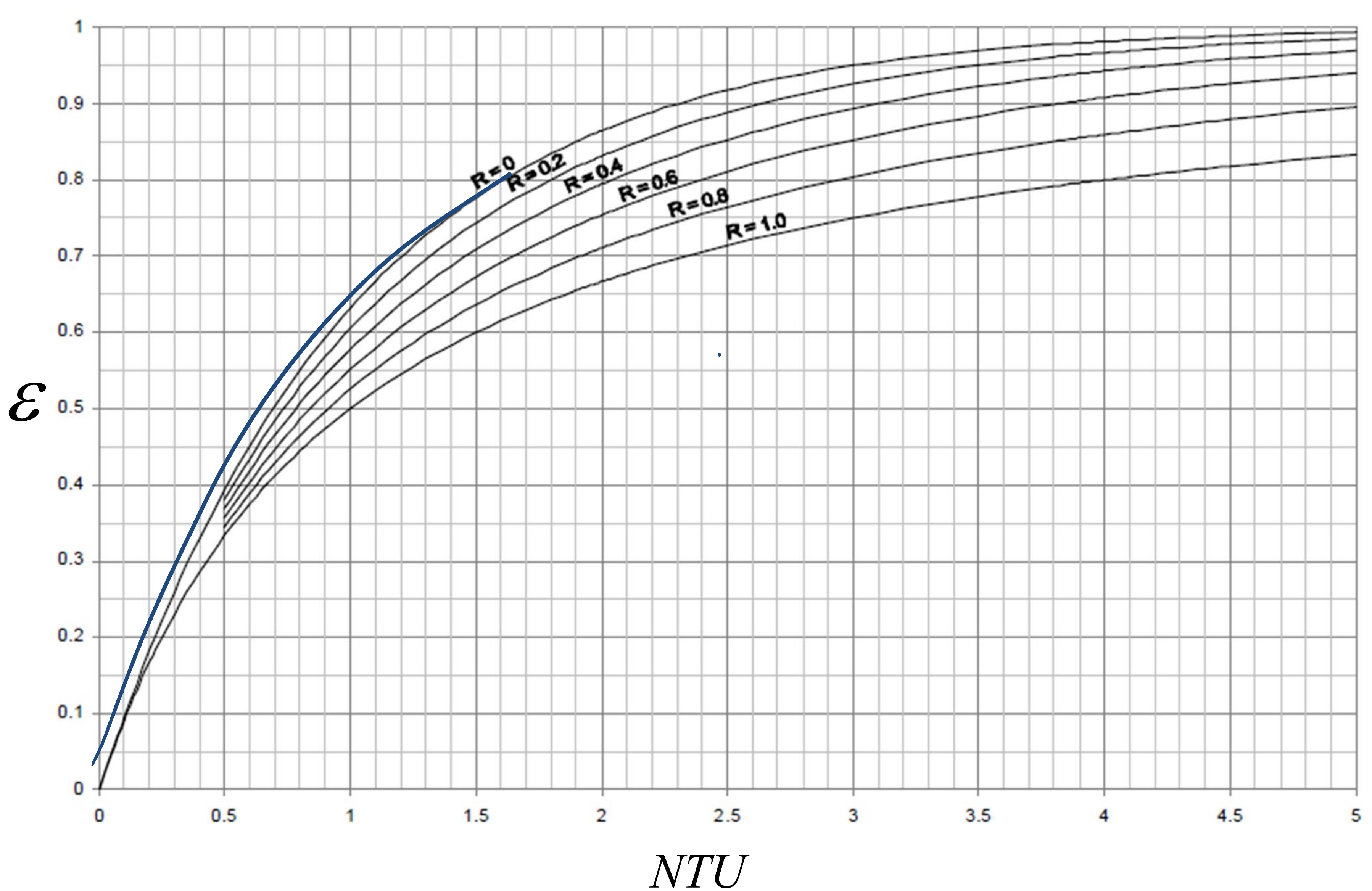
Arithmetic of A Simple Counter Flow HX

$$\varepsilon = \frac{1 - \exp\{NTU \times [R-1]\}}{1 - R \times \exp\{NTU \times [R-1]\}}$$

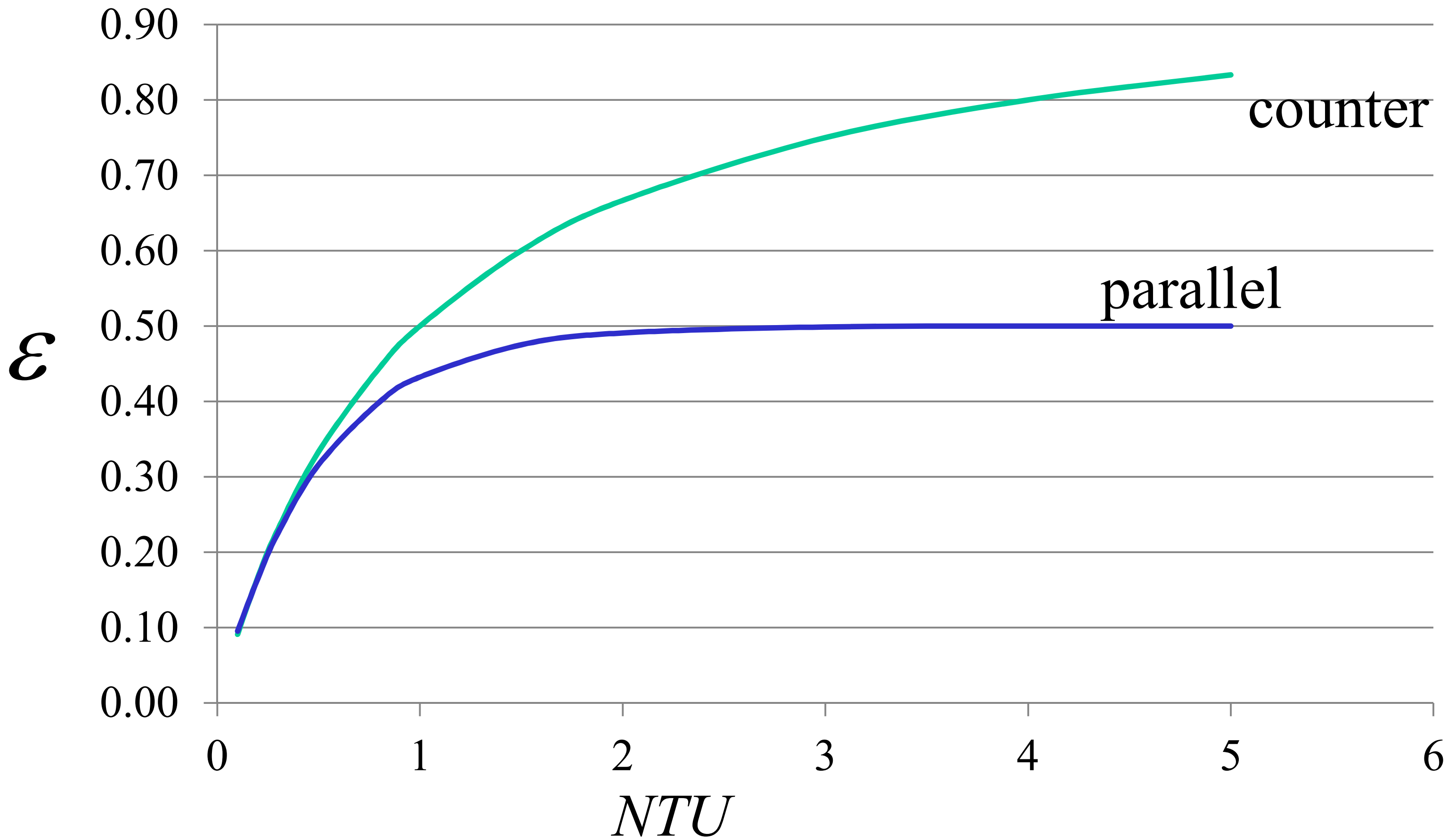
$$NTU = \frac{\ln\left\{\dfrac{(1-\varepsilon)}{(1-R\varepsilon)}\right\}}{1-R}$$

$$R = \frac{(\dot{m}c_p)_{\min}}{(\dot{m}c_p)_{\max}} = \frac{C_{\min}}{C_{\max}}$$

ε– NTU Curves: Counter flow

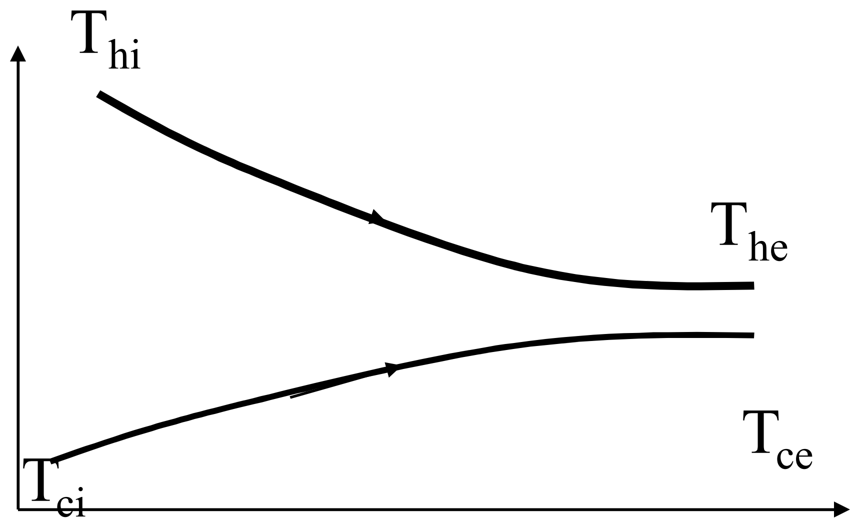


HX with Equal Capacity FLuids



Parallel Flow Heat Ex

$$\Delta T_2 = \Delta T_1 \exp\{-NTU \times [R+1]\}$$



$$T_{he} - T_{ce} = (T_{hi} - T_{ci}) \exp\{-NTU \times [R+1]\}$$

$$\therefore \dot{Q}_{\max} = \dot{m}_c c_{p,c} (T_{h,e} - T_{c,i})$$

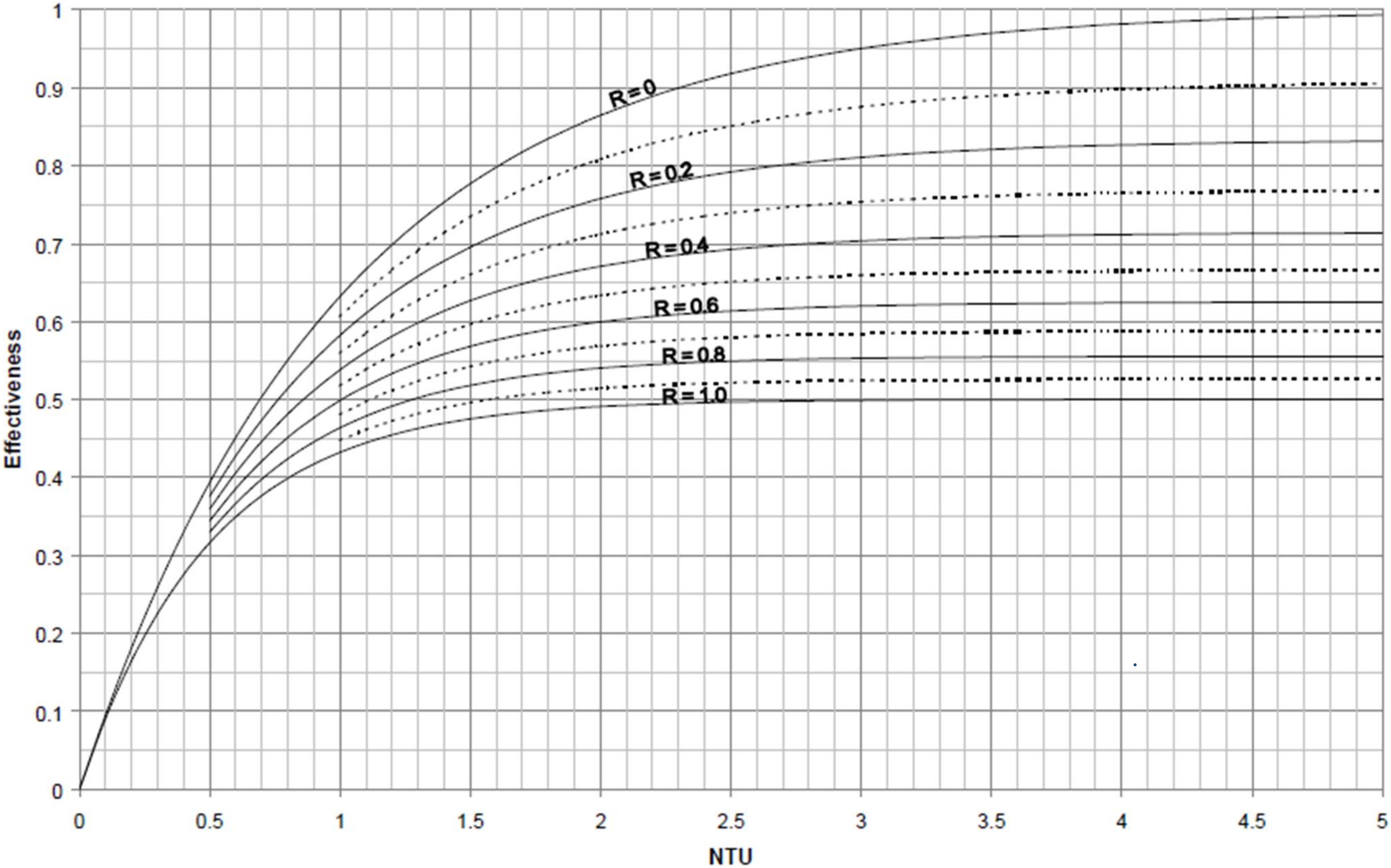
$$\varepsilon = \frac{1 - \exp\{-NTU \times [R+1]\}}{1+R}$$

$$NTU = \frac{1}{1+R} \ln[1 - \varepsilon(1+R)]$$

The limiting case of interest: $R = 1$.

$$\varepsilon = \frac{1 - \exp\{-2 \times NTU\}}{2}$$

ε– NTU Curves: Counter Vs parallel flow



Two limiting cases of interest: $R = 1$

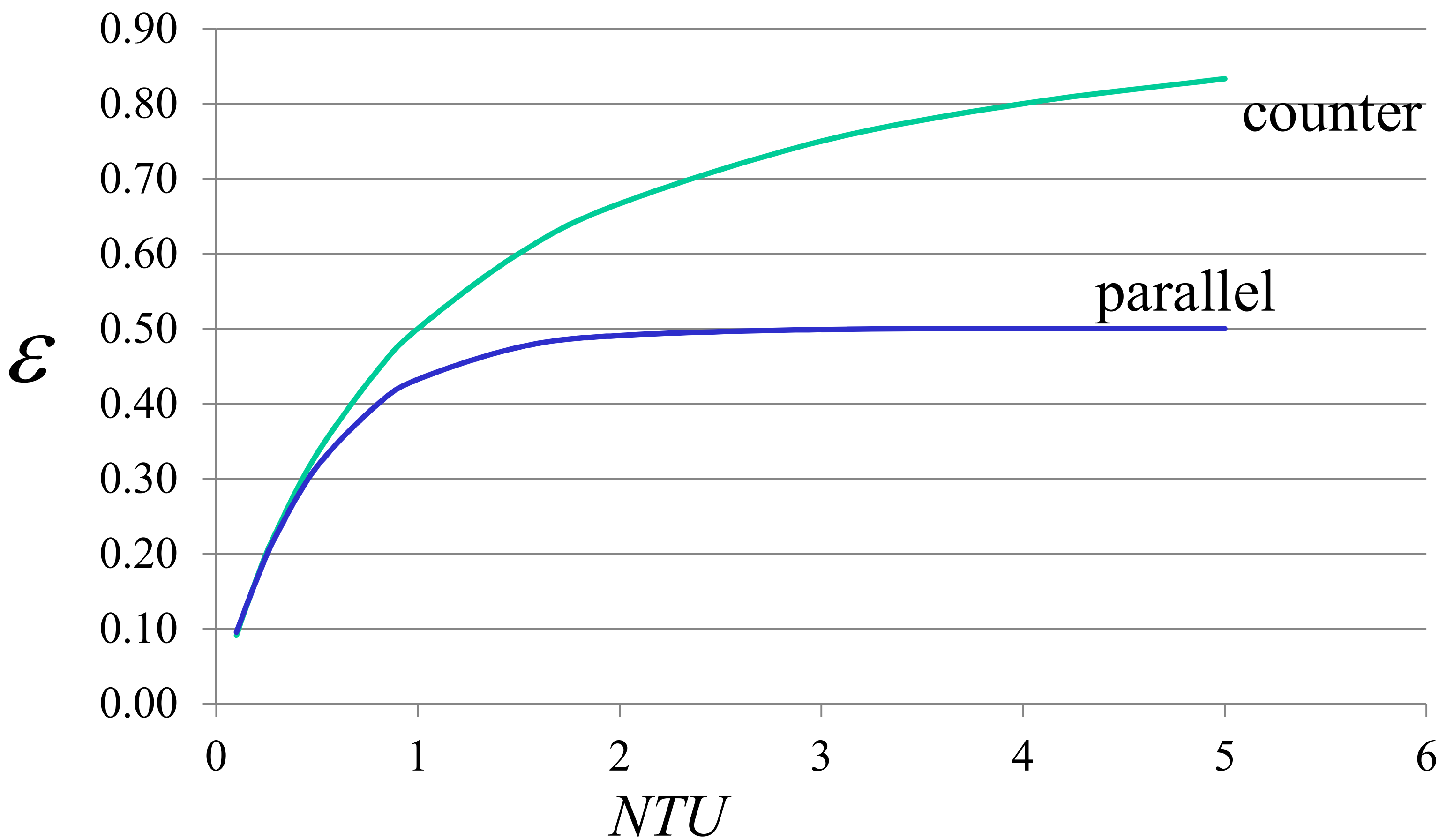
Counter flow Heat exchanger:

$$\varepsilon = \frac{NTU}{1 + NTU}$$

Parallel flow Heat exchanger:

$$\varepsilon = \frac{1 - \exp\{-2 \times NTU\}}{2}$$

HX with Equal Capacity FLuids



Condensing/Evaporative HXs

The limiting case of interest: $R = 0$.

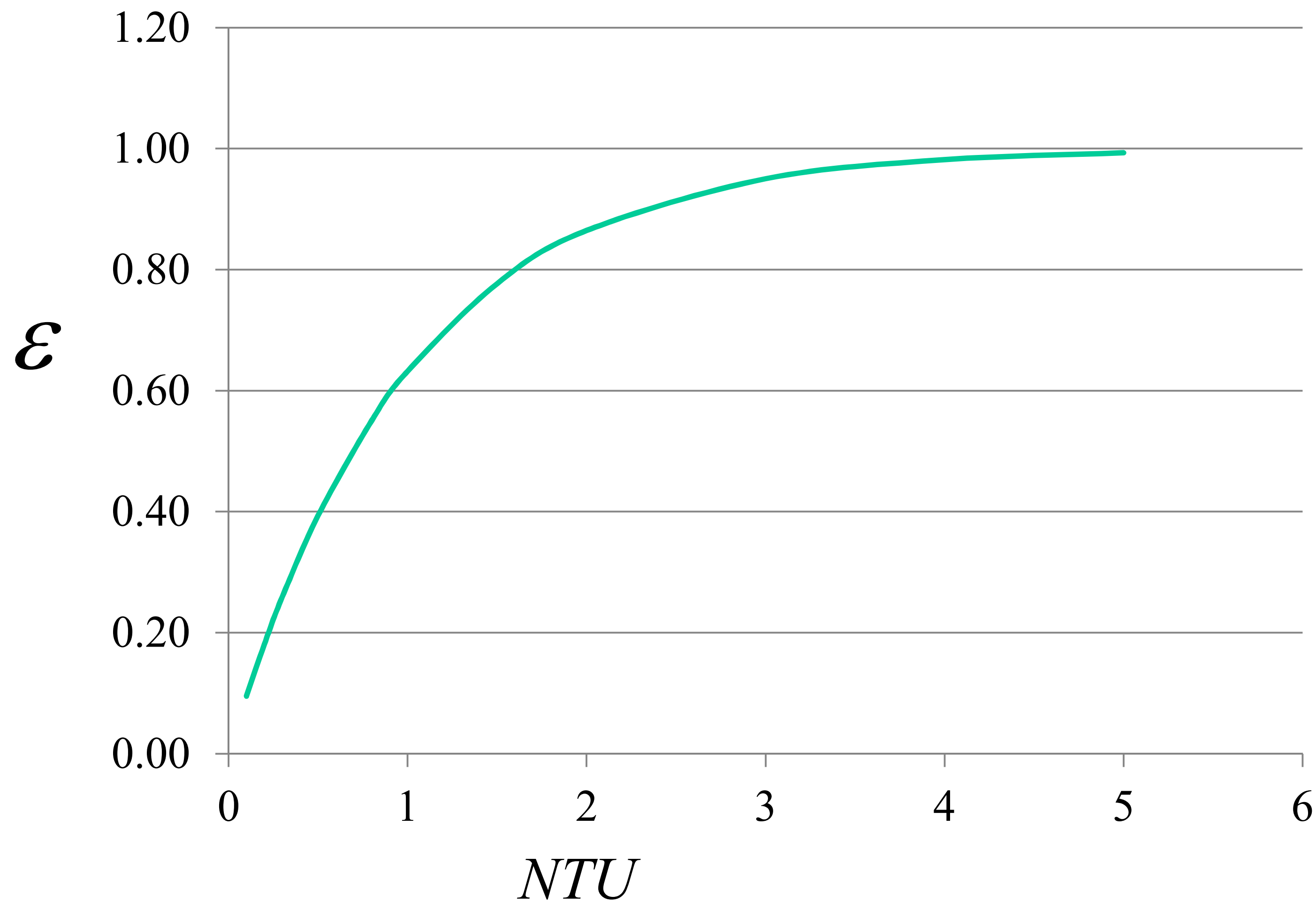
Counter flow Heat exchanger:

$$\varepsilon = \frac{1 - \exp\{-NTU \times [1 - R]\}}{1 - R \times \exp\{-NTU \times [1 - R]\}} = 1 - \exp\{-NTU\}$$

Parallel flow Heat exchanger:

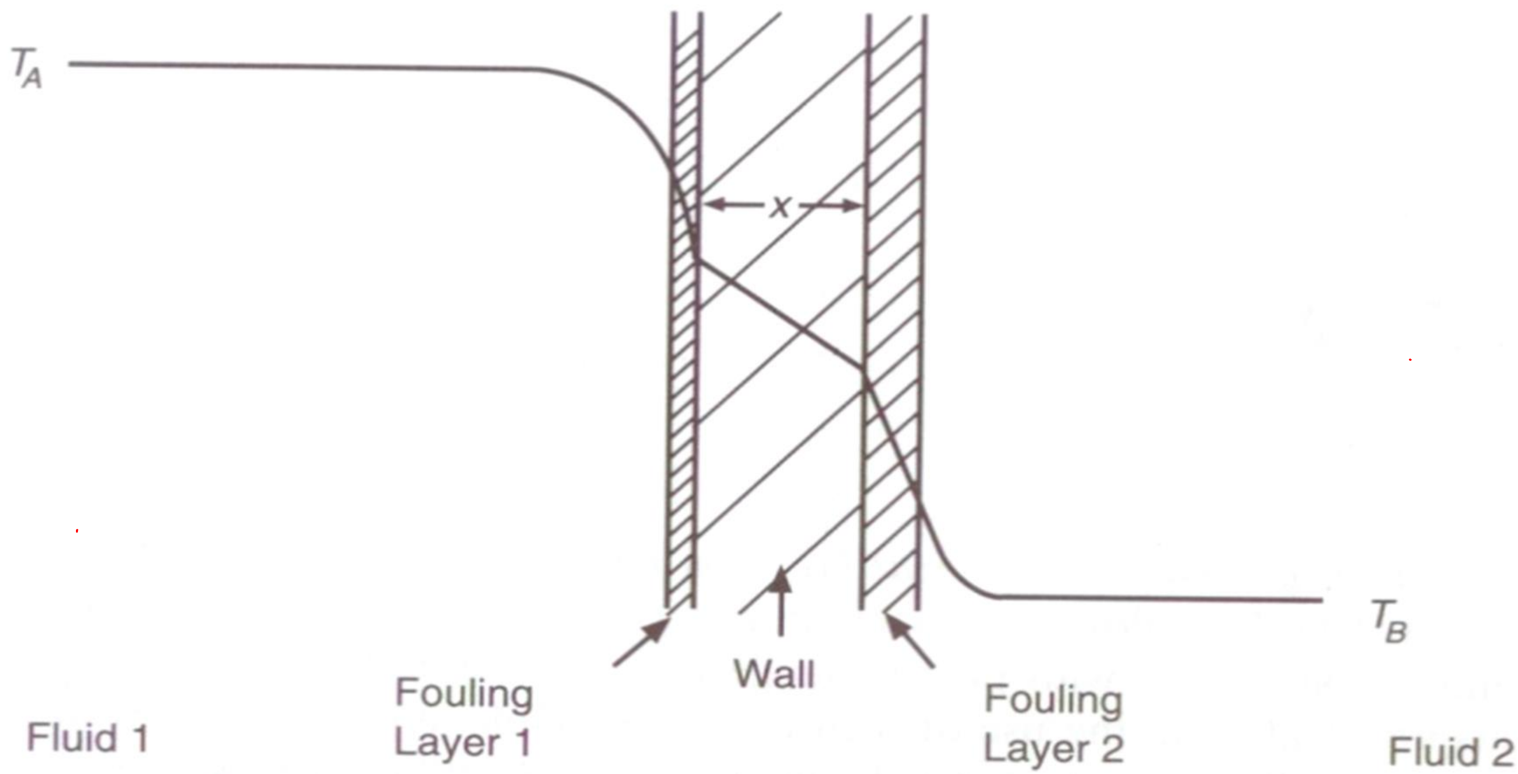
$$\varepsilon = \frac{1 - \exp\{-NTU \times [R + 1]\}}{1 + R} = 1 - \exp\{-NTU\}$$

Condensing/Evaporative HXs



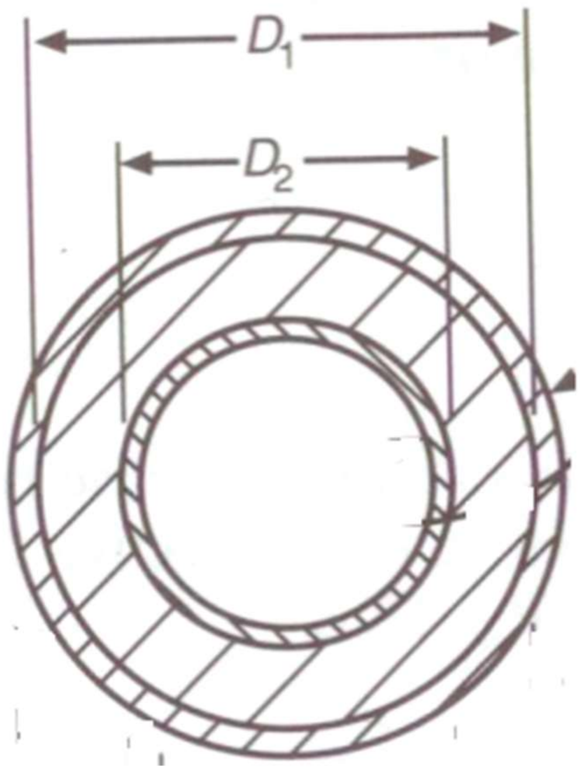
Thermal Resistance of A Finite Heat Exchanger

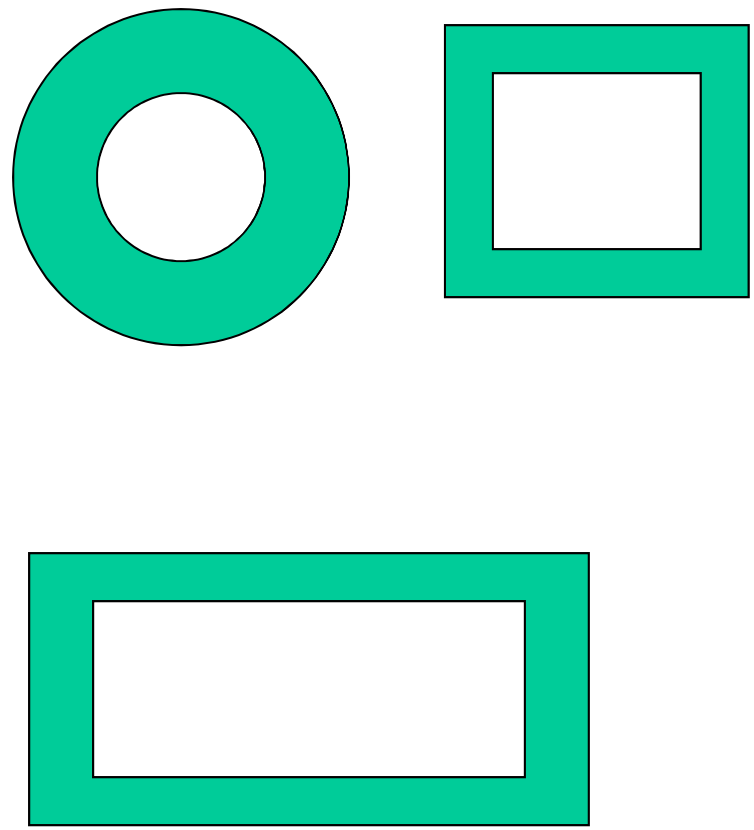
- Thermal resistance of a finite adiabatic Heat Exchanger



Heat transfer between two fluids separated by a planar wall.

Heat Transfer between two fluids separated by finite thick surface wall





First Level Engineering Compromise: Area

$$\dot{m}_{cold}\, c_{p,c}\left(T_{c,e} - T_{c,i}\right) = \dot{Q}_{gain} = \pi D_1 L U_1 \left(\Delta T\right)$$

$$\dot{m}_{hot}\, c_{p,h}\left(T_{h,i} - T_{h,e}\right) = \dot{Q}_{loss} = \pi D_2 L U_2 \left(\Delta T\right)$$

Energy Balance:

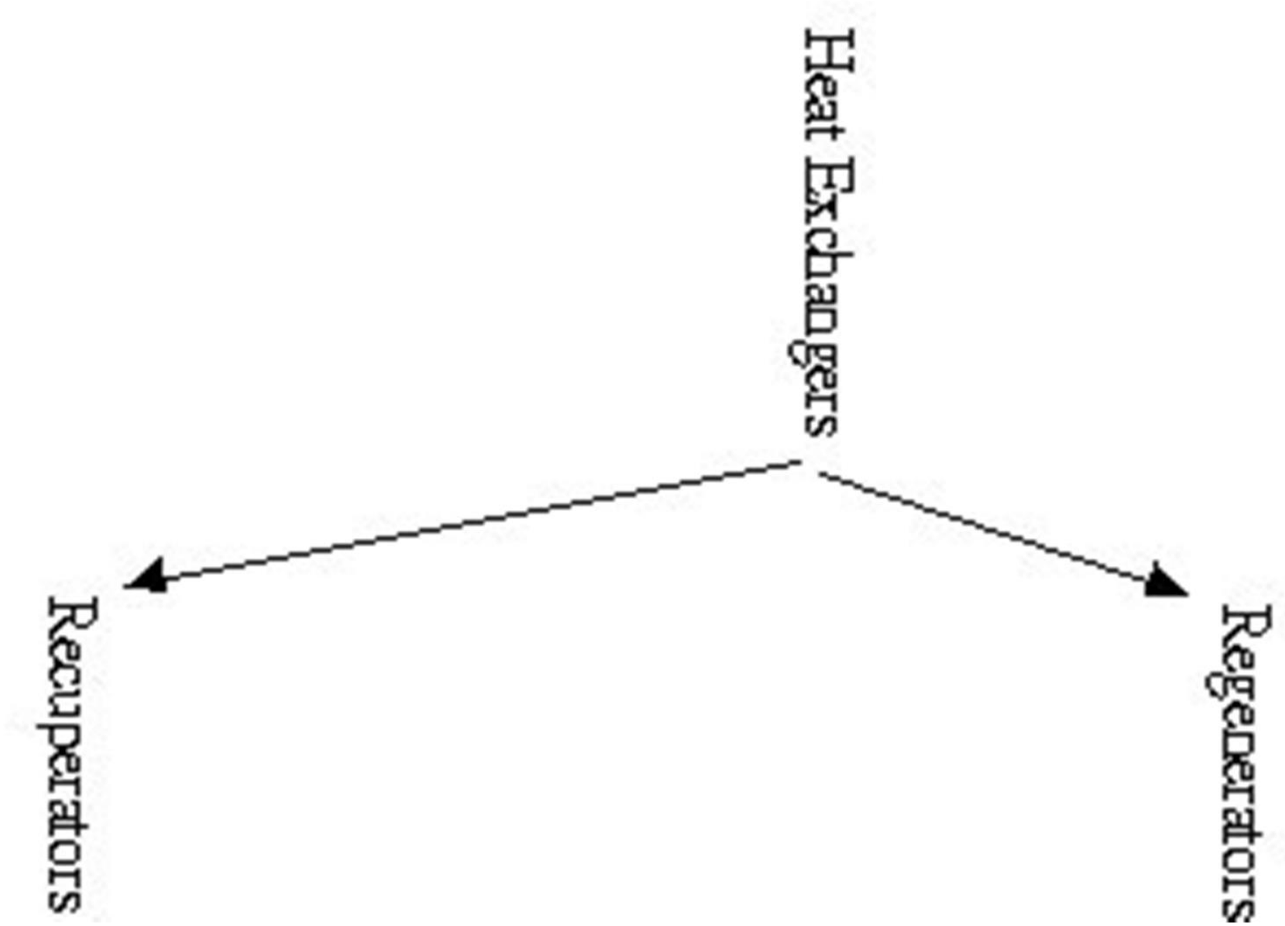
$$U_1 D_1 = U_2 D_2$$

$$\frac{U_1}{D_2} = \frac{U_2}{D_1}$$

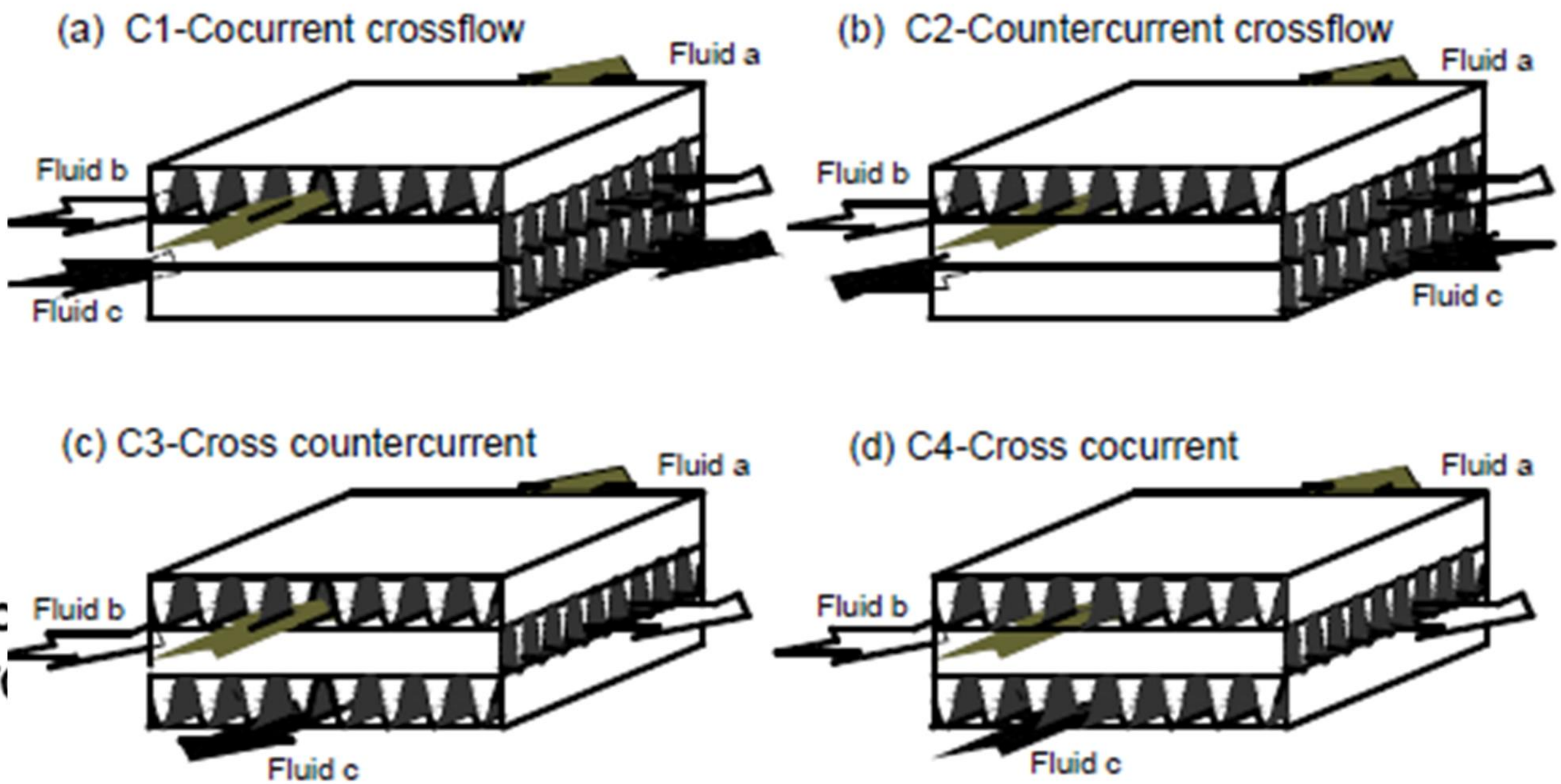
Creative Ideas for Techno-economic Feasibility of a HX.

- For a viable size of a HX:
- How to maximize Effective area of heat communication?.
- How to maximize Overall Heat transfer coefficient?
- How to compute & select the effective temperature difference?
- Should we decrease or increase Effective temperature difference?

Fundamental Classification

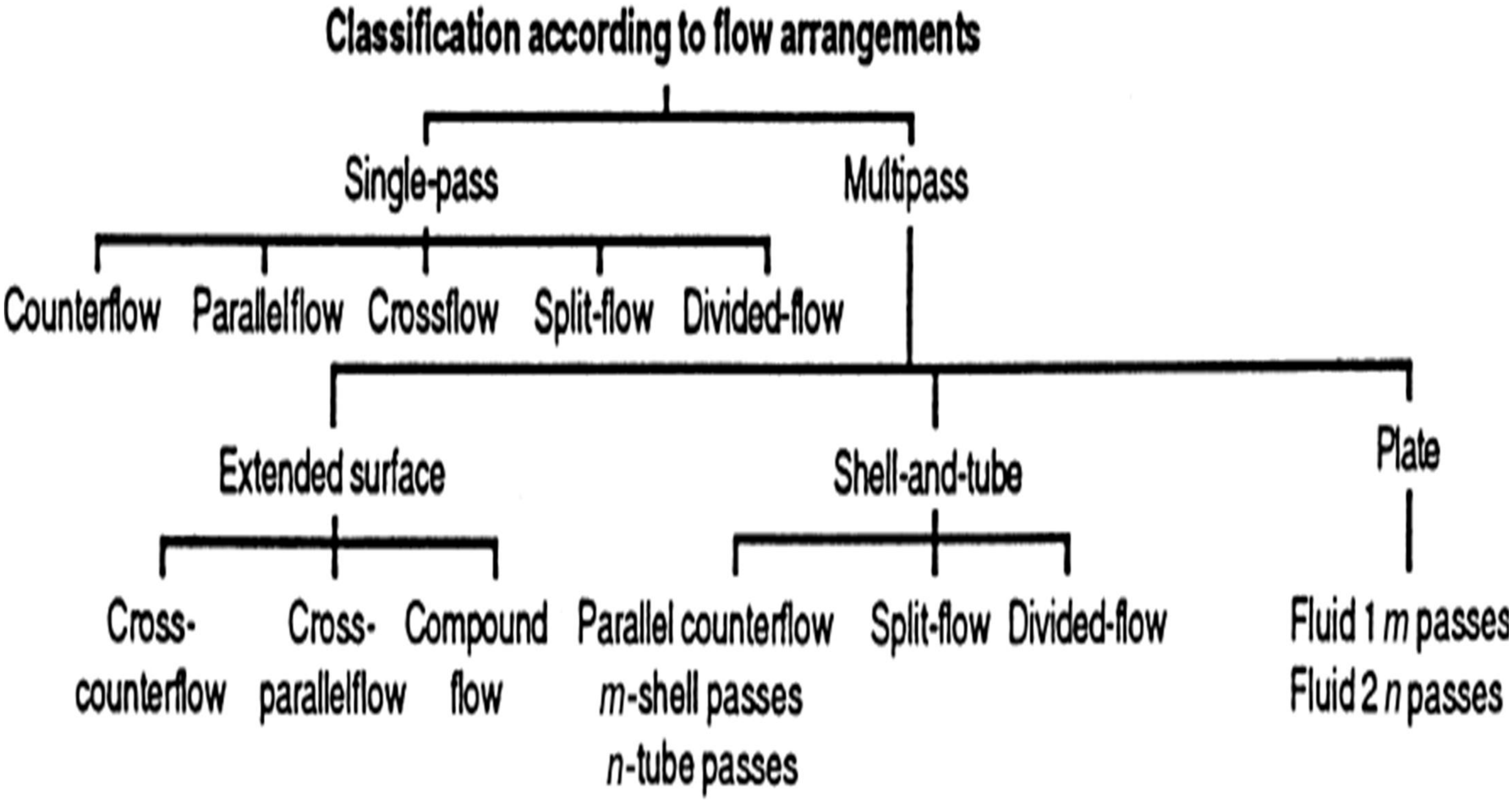


Classification according to number of fluids



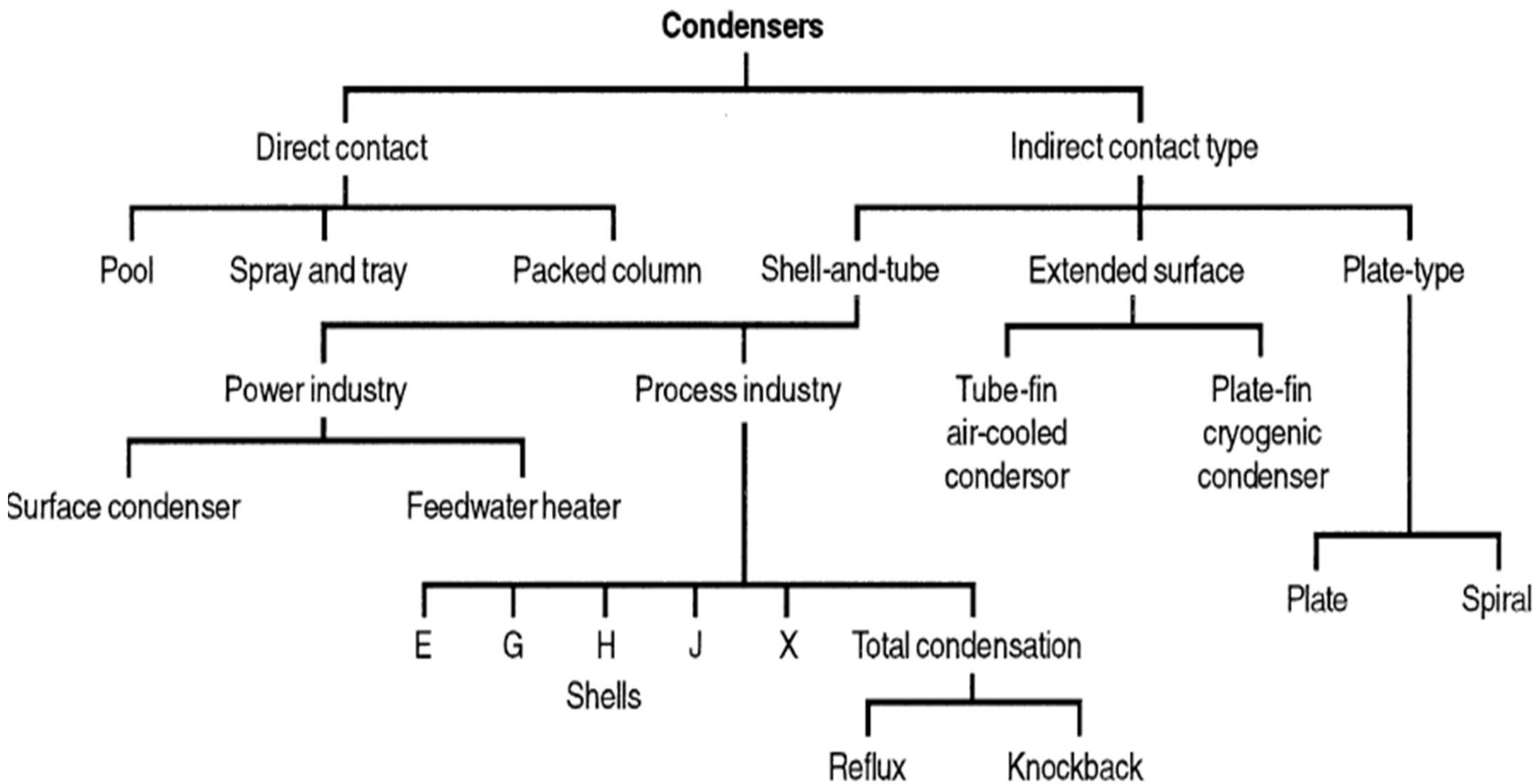
Co

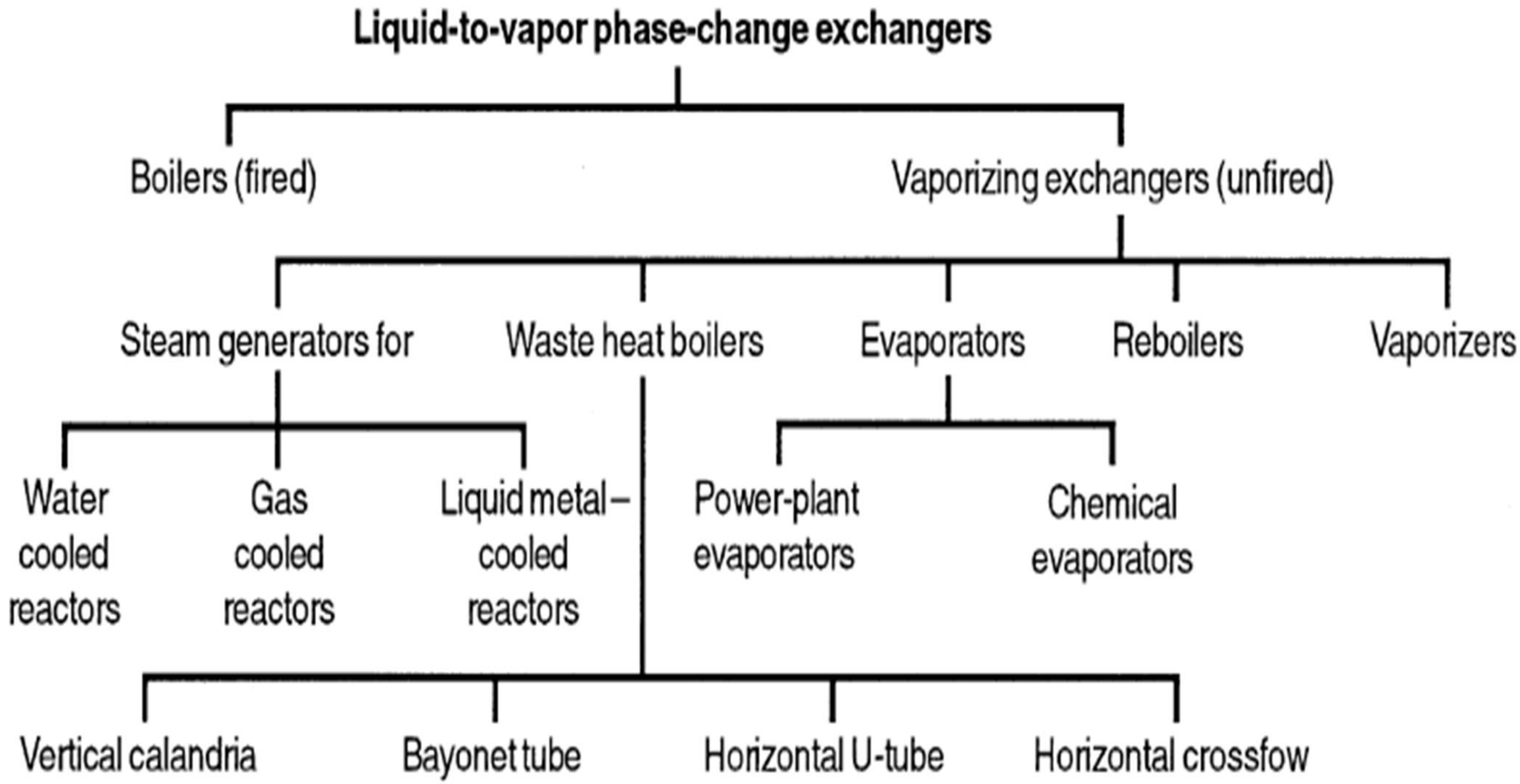
(β ≥ 7

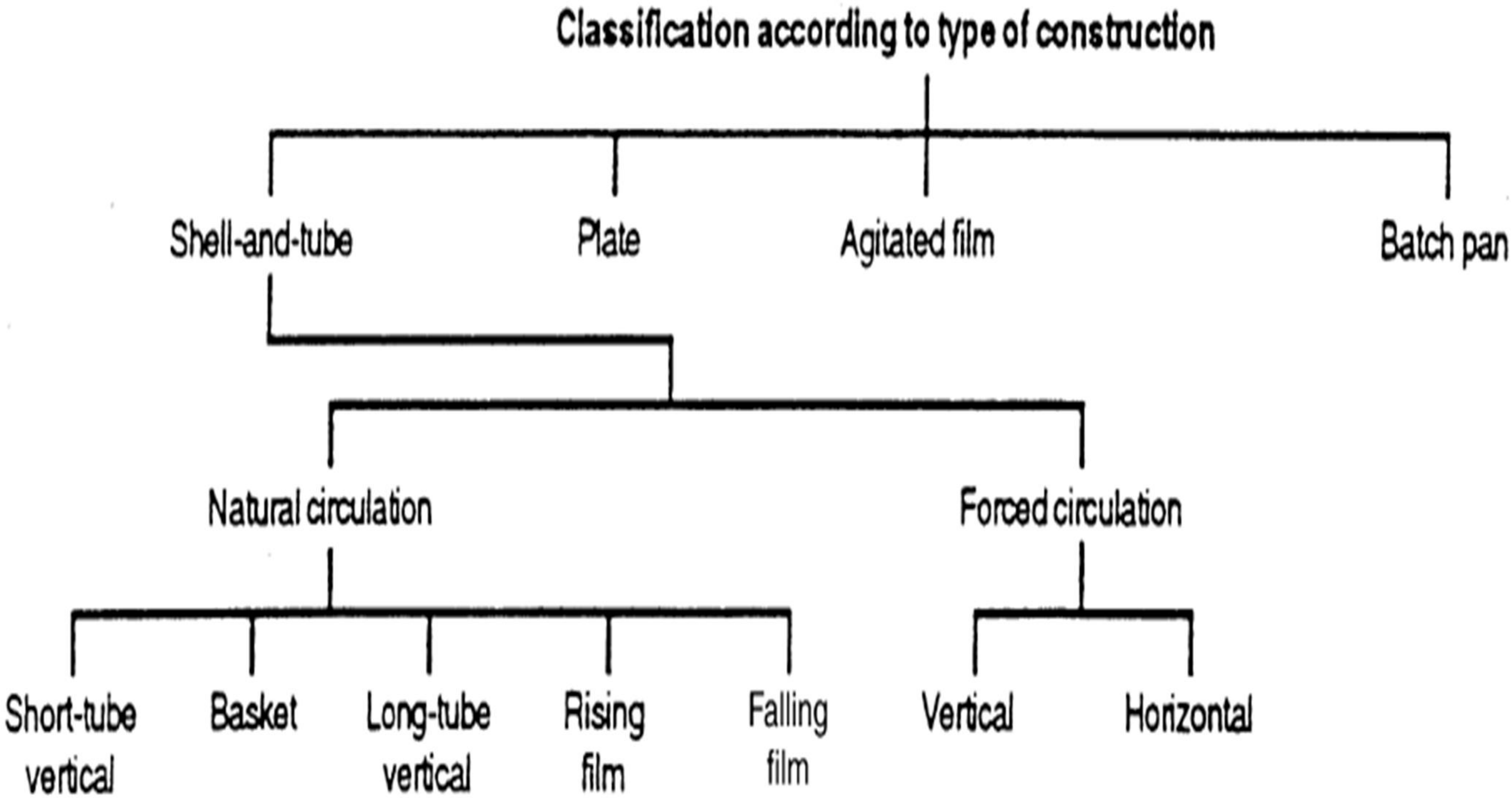

Classification according to flow arrangements
Single-pass
Multipass
Counterflow
Parallelflow
Crossflow
Split-flow
Divided-flow
Extended surface
Shell-and-tube
Plate
Cross-counterflow
Cross-parallelflow
Compound flow
Parallel counterflow m-shell passes n-tube passes
Split-flow
Divided-flow
Fluid 1 m passes
Fluid 2 n passes

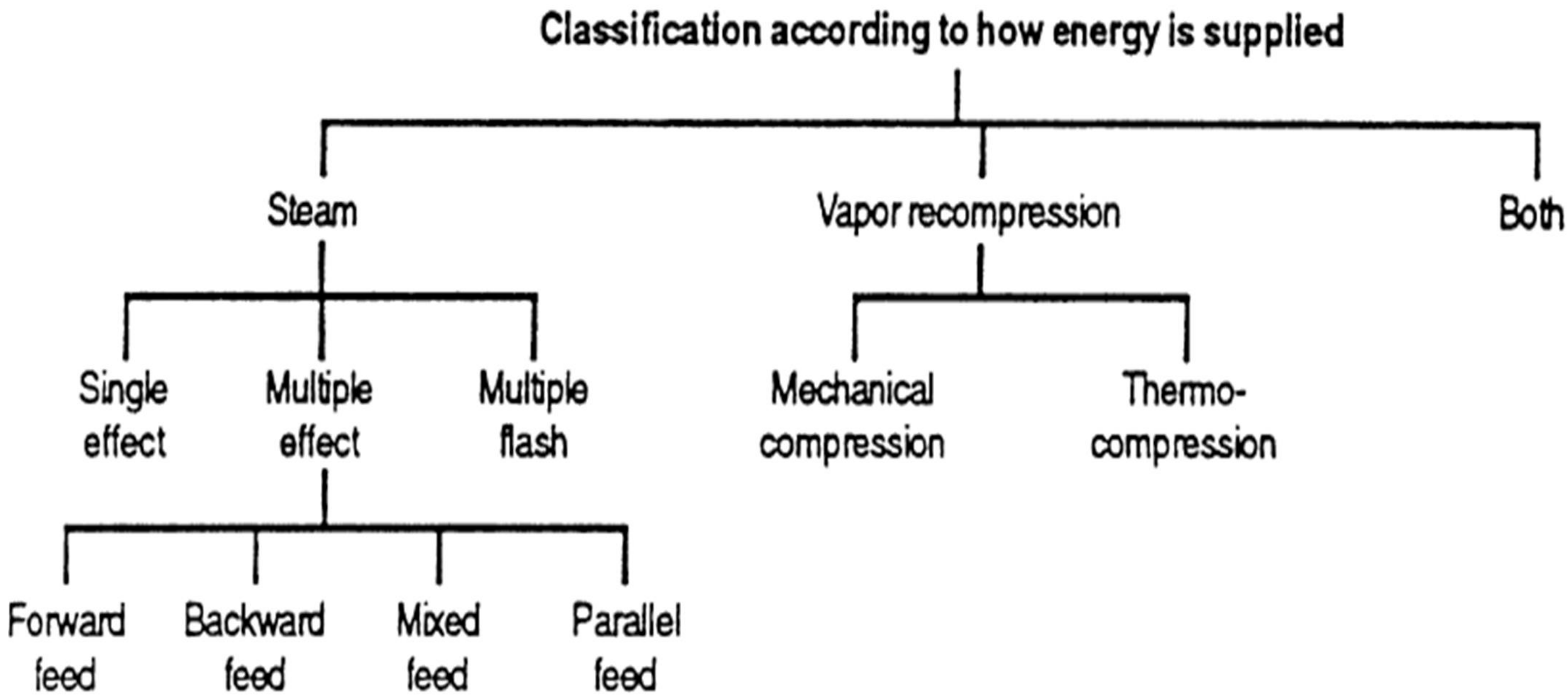
Classification according to heat transfer mechanisms

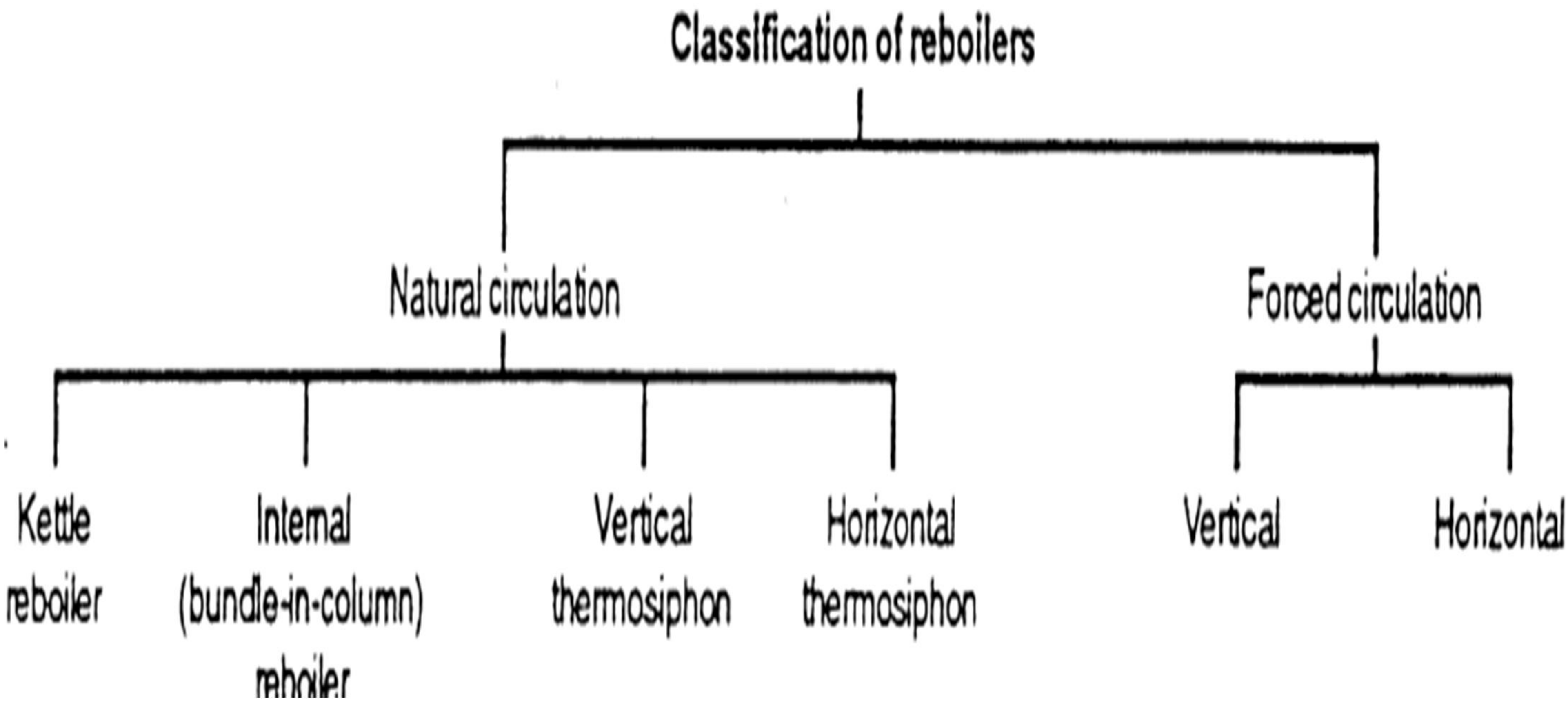
- Single-phase convection on both sides
- Single-phase convection on one side, two-phase convection on other side
- Two-phase convection on both sides
- Combined convection and radiative heat transfer

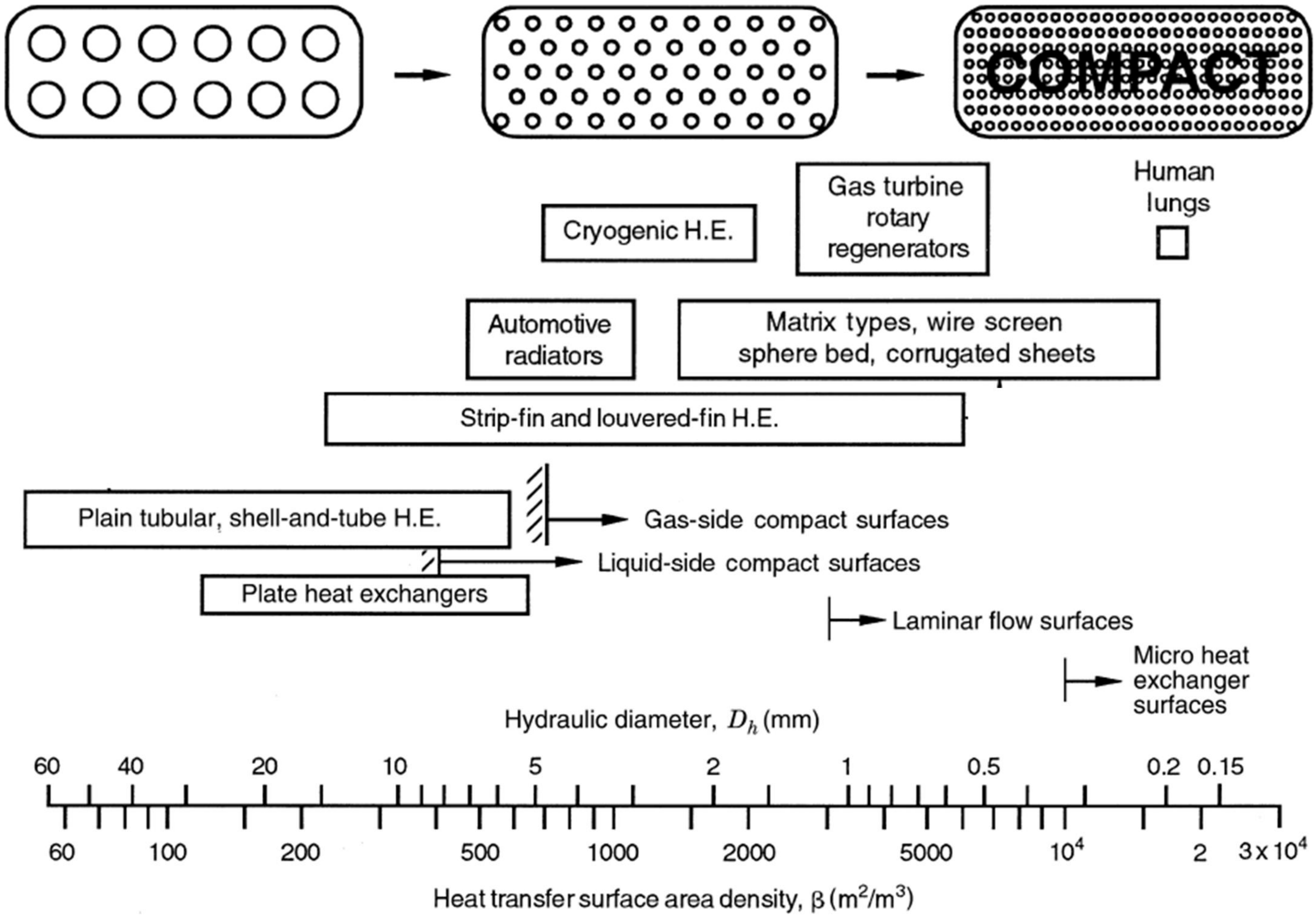

Condensers
Direct contact
Indirect contact type
Pool
Spray and tray
Packed column
Shell-and-tube
Extended surface
Plate-type
Power industry
Process industry
Tube-fin air-cooled condersor
Plate-fin cryogenic condenser
Surface condenser
Feedwater heater
Plate
Spiral
E
G
H
J
X
Total condensation
Shells
Reflux
Knockback


Liquid-to-vapor phase-change exchangers
Boilers (fired)
Vaporizing exchangers (unfired)
Steam generators for
Waste heat boilers
Evaporators
Reboilers
Vaporizers
Water cooled reactors
Gas cooled reactors
Liquid metal – cooled reactors
Power-plant evaporators
Chemical evaporators
Vertical calandria
Bayonet tube
Horizontal U-tube
Horizontal crossfow


Classification according to type of construction
Shell-and-tube
Plate
Agitated film
Batch pan
Natural circulation
Forced circulation
Short-tube vertical
Basket
Long-tube vertical
Rising film
Falling film
Vertical
Horizontal


Classification according to how energy is supplied
Steam
Vapor recompression
Both
Single effect
Multiple effect
Multiple flash
Mechanical compression
Thermo-compression
Forward feed
Backward feed
Mixed feed
Parallel feed


Classification of reboilers
Natural circulation
Forced circulation
Kettle reboiler
Internal (bundle-in-column) reboiler
Vertical thermosiphon
Horizontal thermosiphon
Vertical
Horizontal


COMPACT
Human lungs
Gas turbine rotary regenerators
Cryogenic H.E.
Automotive radiators
Matrix types, wire screen sphere bed, corrugated sheets
Strip-fin and louvered-fin H.E.
Plain tubular, shell-and-tube H.E.
Gas-side compact surfaces
Liquid-side compact surfaces
Plate heat exchangers
Laminar flow surfaces
Micro heat exchanger surfaces
Hydraulic diameter, D_h (mm)
60 40 20 10 5 2 1 0.5 0.2 0.15
60 100 200 500 1000 2000 5000 10^4 2 3×10^4
Heat transfer surface area density, β (m^2/m^3)