



熱交換器技術之選用

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經濟部工業局「低碳製程技術研討會」

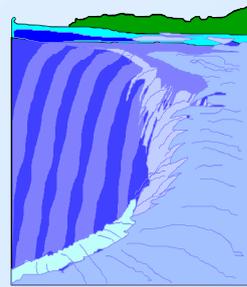
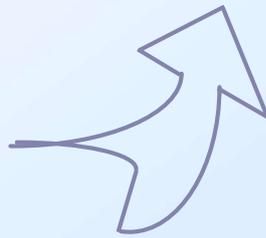
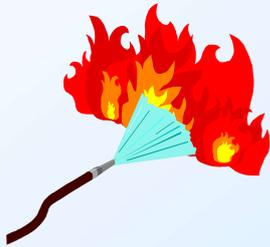


課程大綱：

- 熱交換器型式
- 熱傳管的選用
- 氣冷式熱交換器與鰭片特性
- 熱交換器初步選用
- 小結

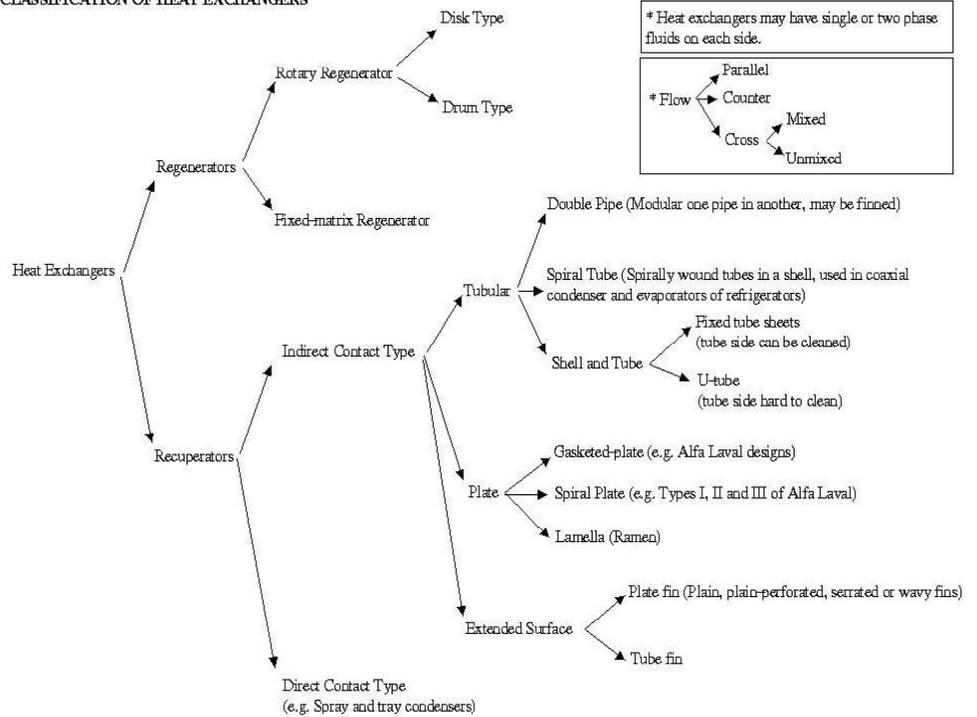
熱交換器的功用

- 不同流體間的換熱
- 易於控制與使用
- 避免流體於熱交換過程的「汙染」



熱交換器的型式

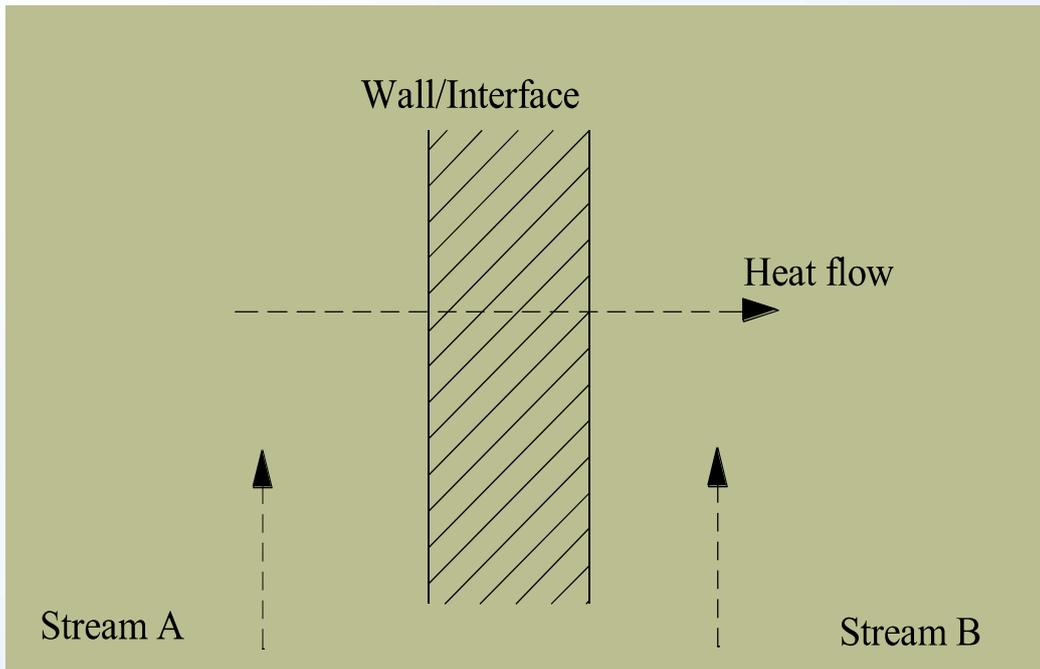
CLASSIFICATION OF HEAT EXCHANGERS



回覆式
Recuperator
→ 最普遍型式

再生式
Regenerator
直接接觸式
Direct Contact Heat Exchanger

Direct Contact Heat Exchanger

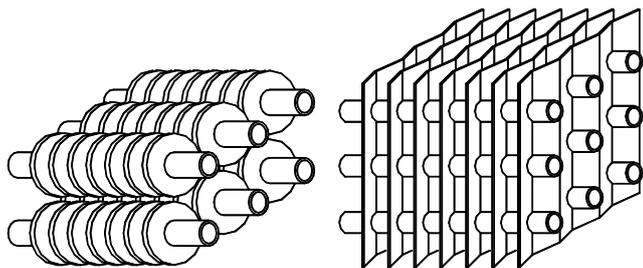


熱交換工作原理



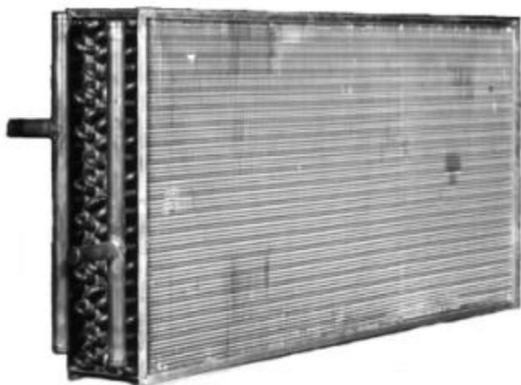
典型 Recuperator

- 鰓管式 (Fin-and-tube Heat Exchanger)
- 殼管式 (Shell and Tube Heat Exchanger)
- 板式 (Plate Heat Exchanger)
- 螺旋式 (Spiral Heat Exchanger)
- 套管式 (Tube in Tube Heat Exchanger)
- Cross flow Heat Exchanger

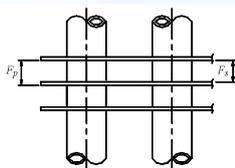


(a)

(b)

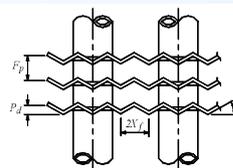


(c)



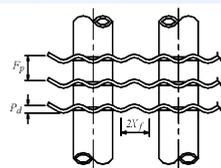
(a) 平板型

Plain fin



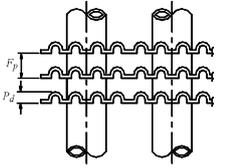
(b) 波浪型

Herringbone wavy fin



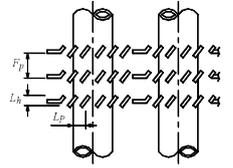
(c) 平滑波浪型

Smooth wavy fin, type (I)



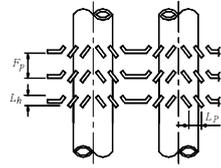
(d) 平滑波浪+平板型

Smooth wavy fin, type (II)



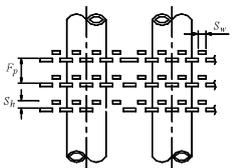
(e) 單向百葉窗型

Louver fin, one-sided



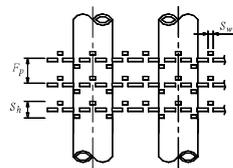
(f) 雙向百葉窗型

Louver fin, with re-direction louver



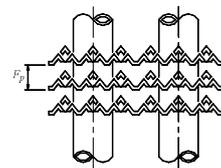
(g) 單向裂口型

Slit fin, one-sided



(h) 雙向裂口型

Slit fin, double-sided



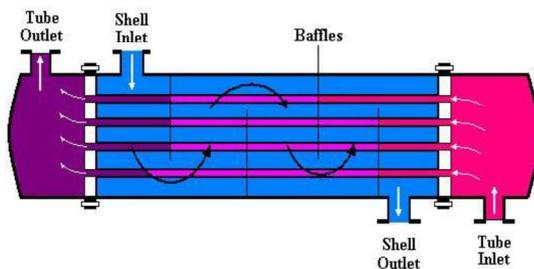
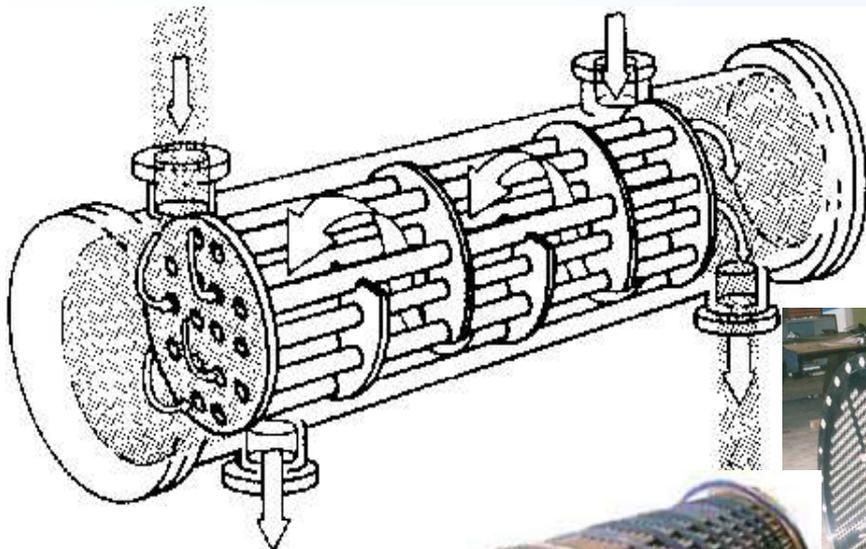
(i) 複合百葉窗型

Convex-louver fin

Typical fin-and-tube heat exchanger (a) individual circular fin; (b) continuous wavy fin; (c) conventional air-cooled heat exchanger



殼管式 Shell and Tube Heat Exchanger

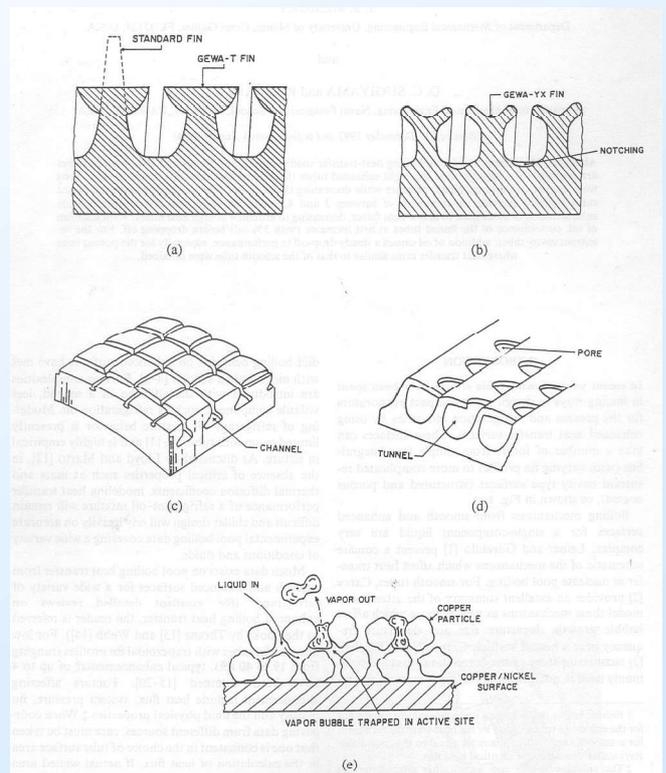
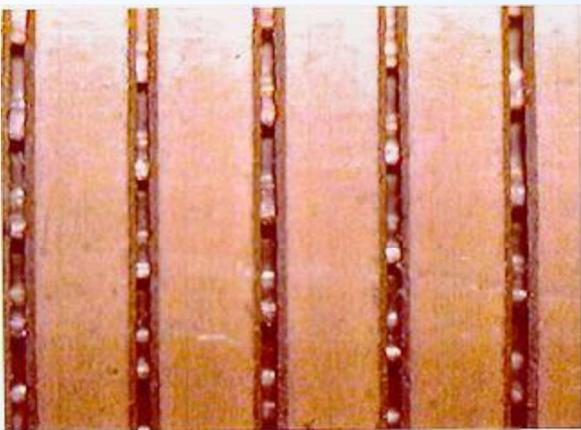
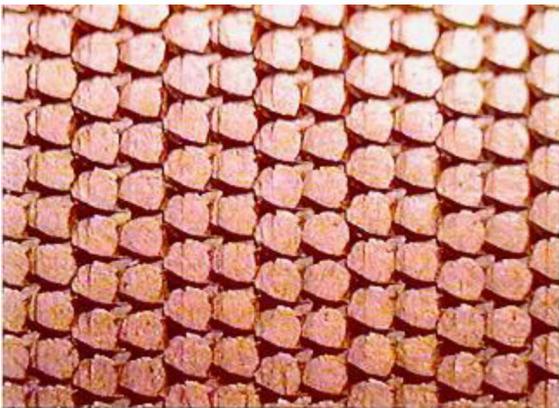




Typical enhanced tubes



典型沸騰(蒸發)管





典型蒸發與冷凝管

Shell side boiling

Shell side condensation

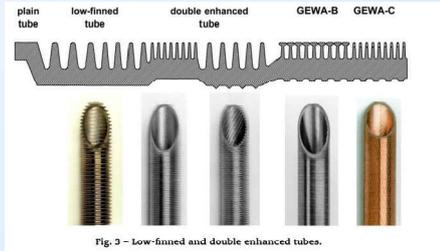
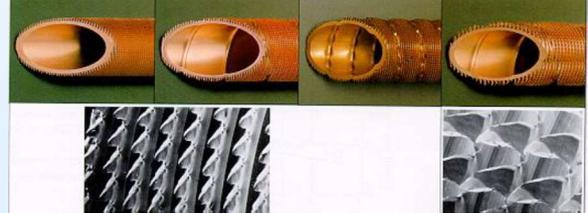
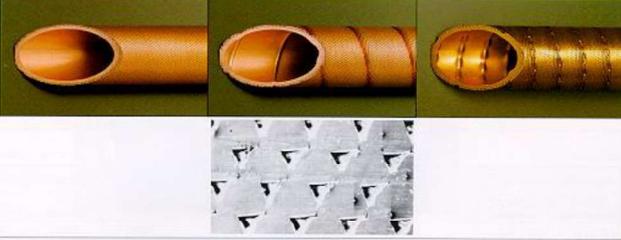
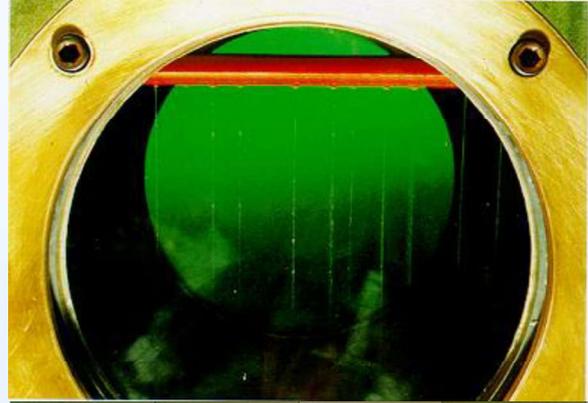


Fig. 3 - Low-finned and double enhanced tubes.



Microfin tube used in tube side augmentation



Benefits: increase 100% more heat transfer coefficients with only 10~50% increase of pressure drops



管的幾何形狀的影響

- 微鰭管促進環狀流即使在低質量流速
- 光滑管中冷媒的潤滑油可能會失去其效益促使環狀流

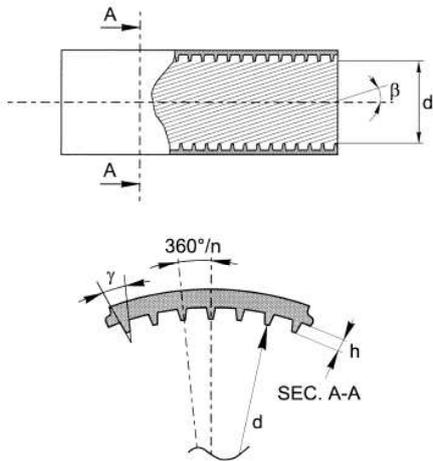
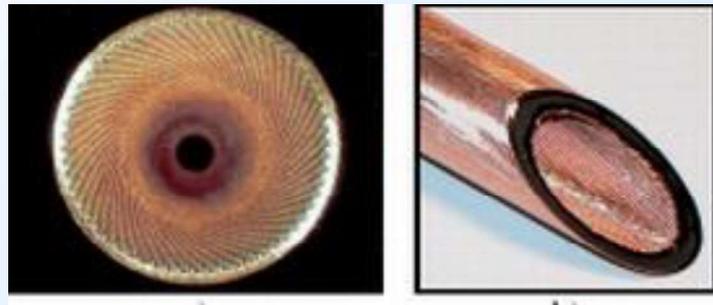


Fig. 1. Characteristic geometrical parameters of inside enhanced tubes.

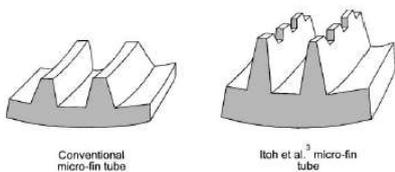


Fig. 3. Comparison between traditional and Itoh et al. [3] micro-fin tube.

Fig. 3. Comparaison entre les tubes à microailettes classiques et d'Itoh et al. [3].



Fig. 4. Shape of Muzzio et al. [4] micro-fin tube.

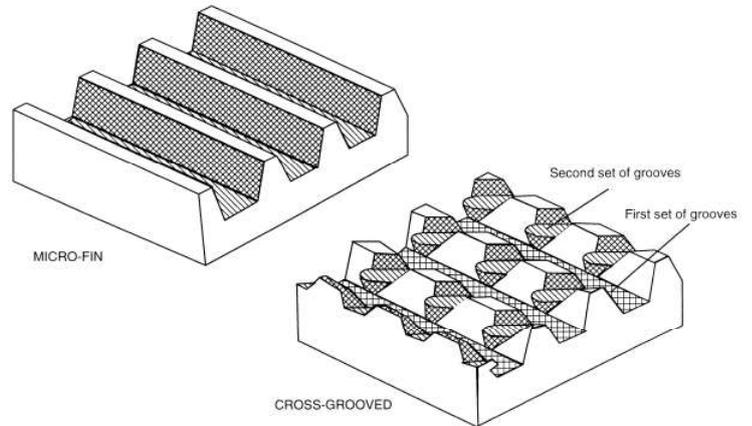


Fig. 2. Typical configuration of micro-fin and cross-grooved surfaces.

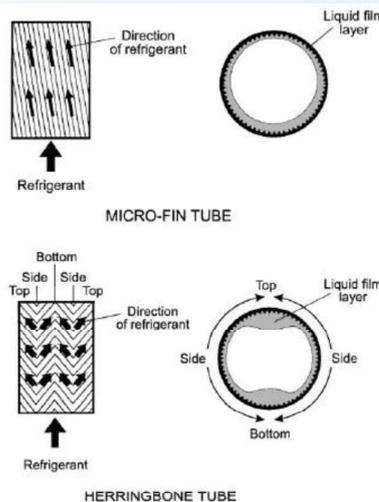


Fig. 5. Comparison between micro-fin and herringbone tubes in annular-type flow pattern.

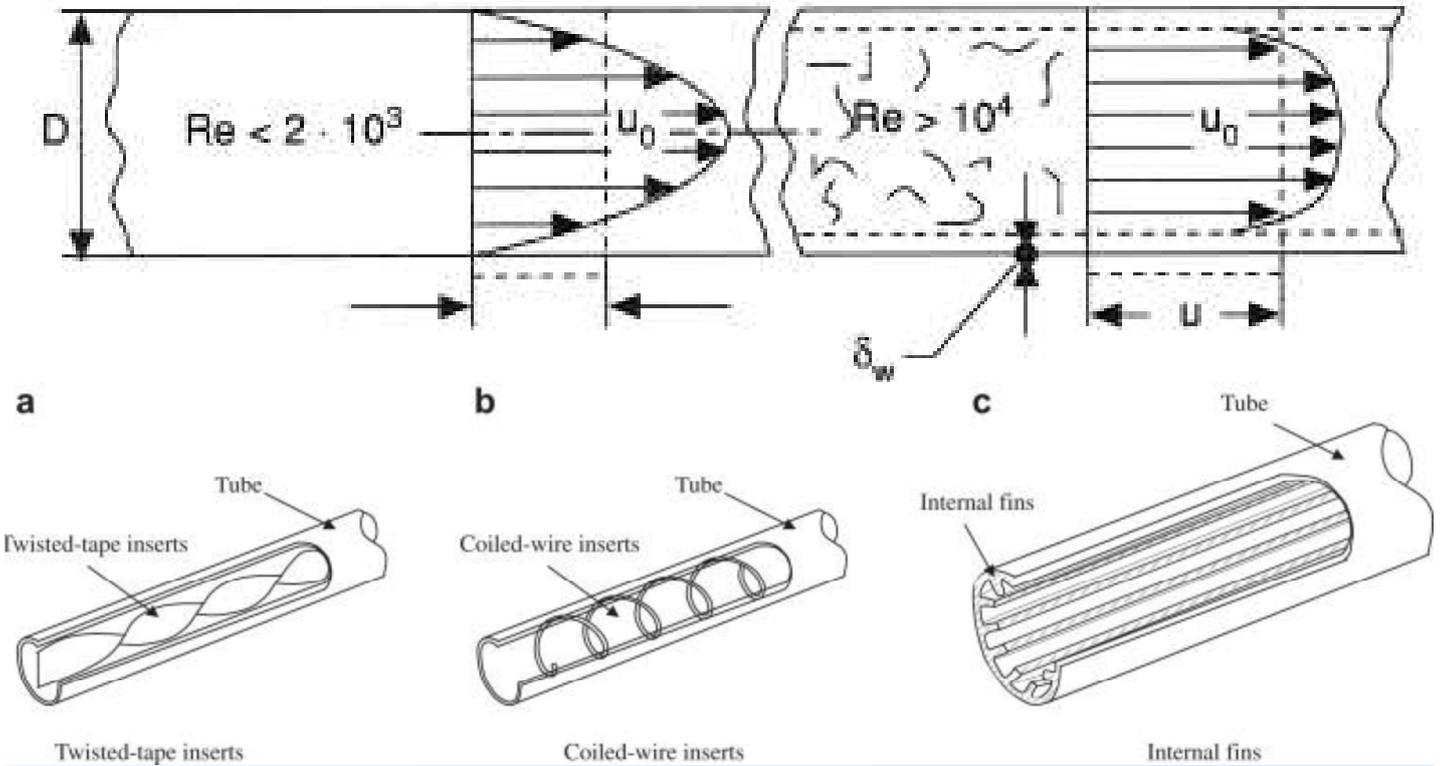
Heat transfer and pressure drop during condensation of refrigerants inside horizontal enhanced tubes, *Int. J. Refrig.*, 23 (2000) 4-25



層流與紊流之熱傳增強概念

層流

紊流



熱傳管幾何尺寸

空調機用熱傳管演進圖

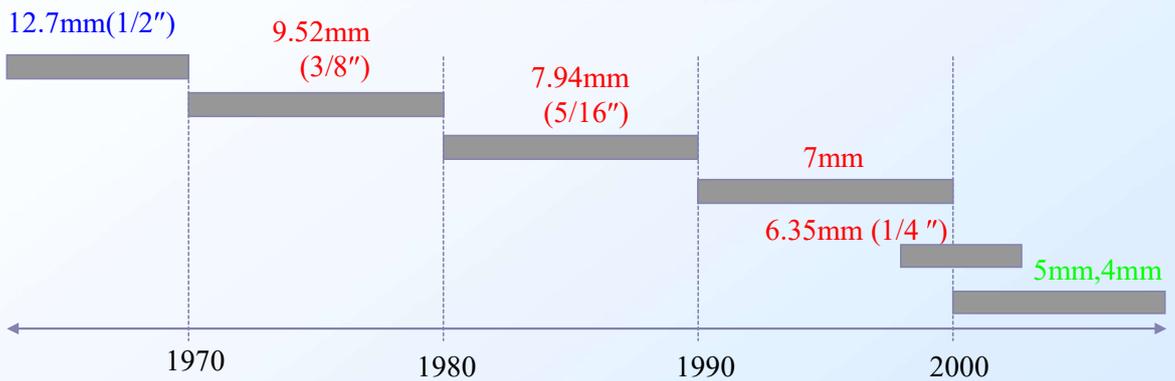
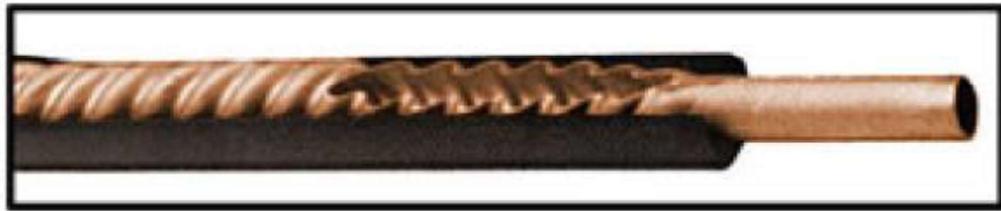


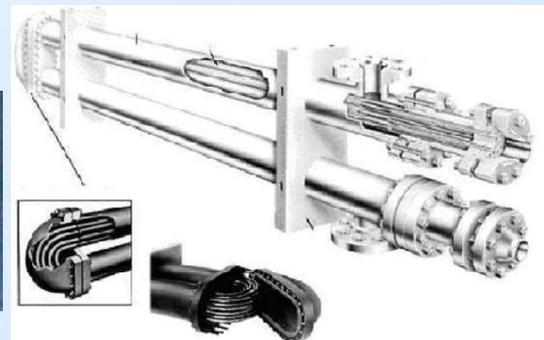
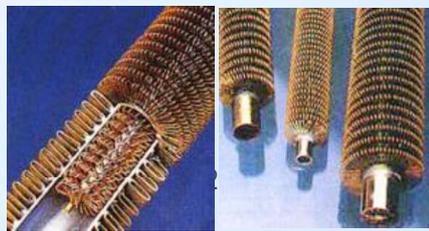
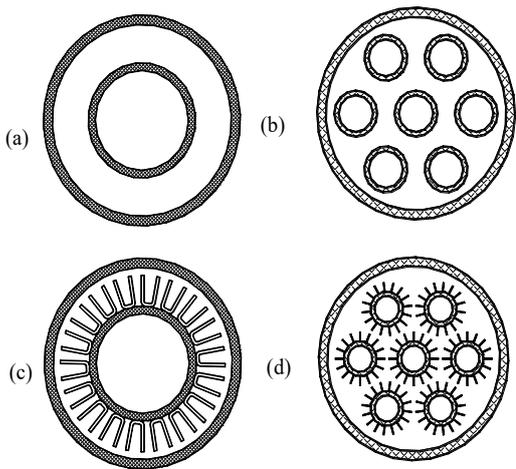
Fig. 各種型式的熱傳增強管



Special Double Pipe Heat Exchanger



套管式 (Tube-in-Tube Heat Exchanger)





套管式熱交換器

- Shell < 100 mm
- 構造簡單，不需擋板(降低Leakage & bypass loss)
- 簡單較佳設計Guideline (ESDU 92013):
 - 殼側熱傳係數約小於管內熱傳係數25%



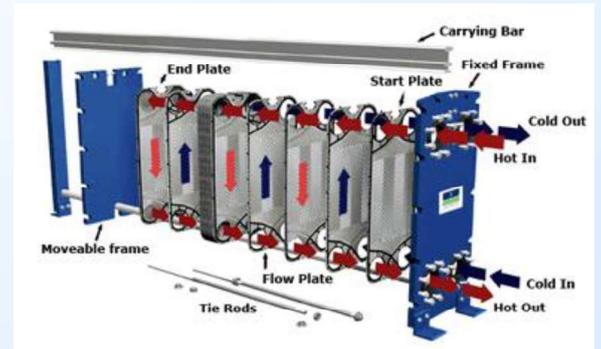
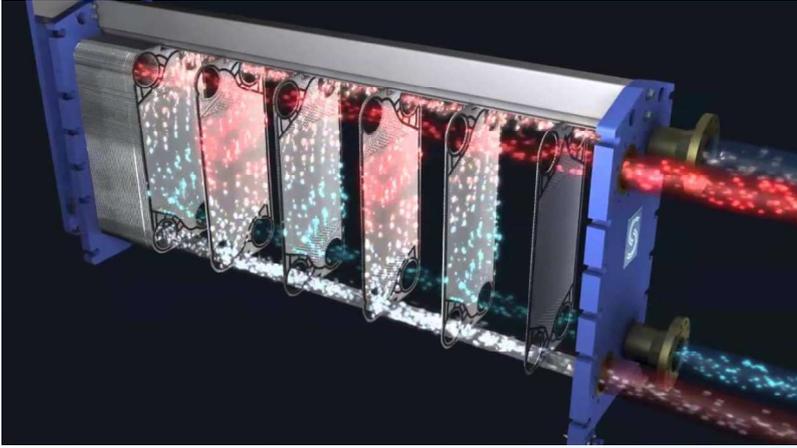
板式熱交換器

- Highly flexible (可拆卸式), sealing may be a problem.
- Maximum temperature/pressure constraints.
- 單相流體應用較適合
- 較佳的熱傳性能(尤其考慮到空間上的限制)

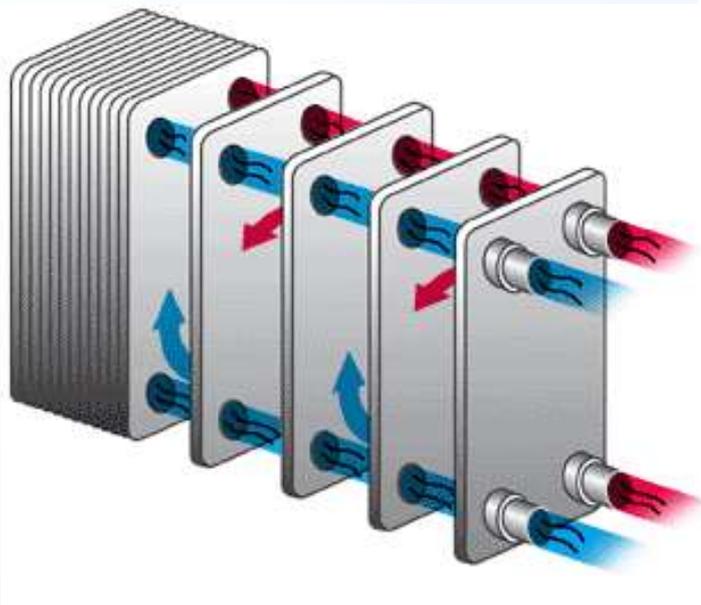




Plate HX

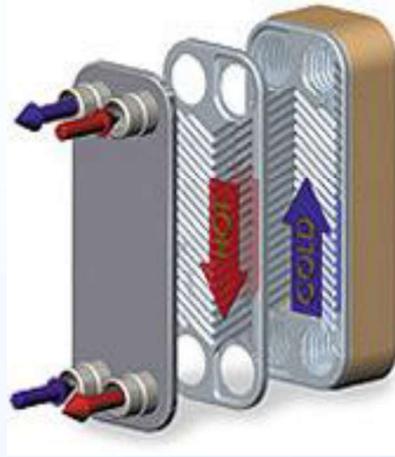


板式熱交換器





(a)



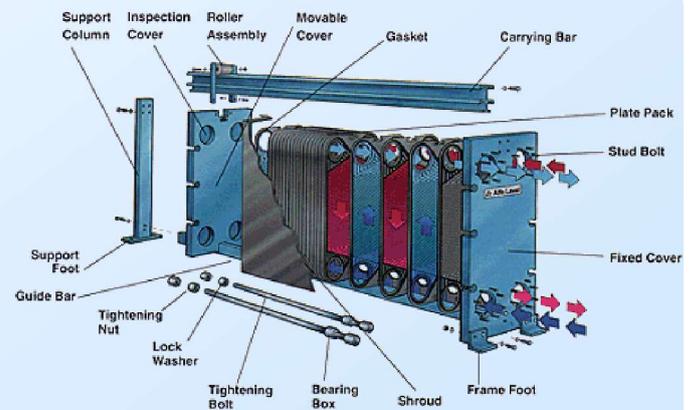
(b)



(c)

板式熱交換器 (a) brazed type;
(b) working principle; (c) cross section

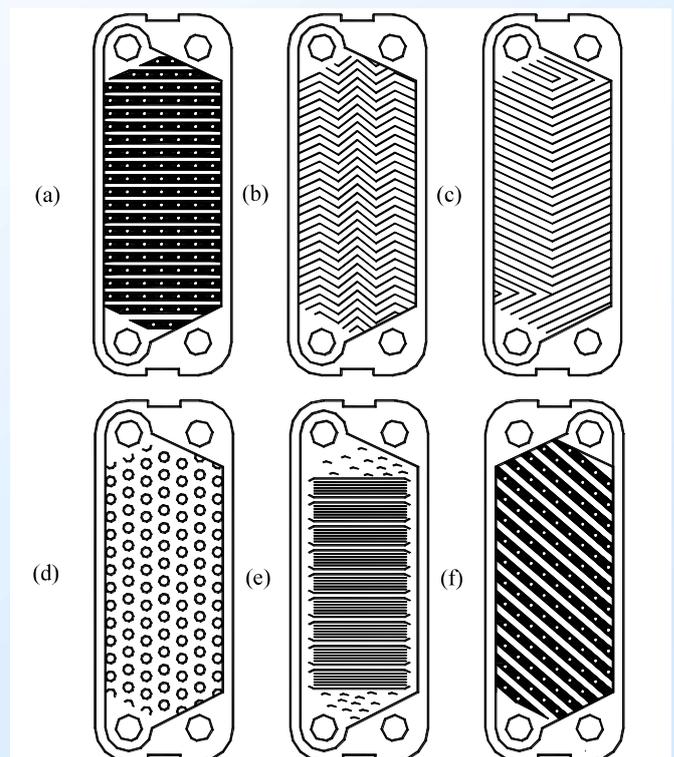
可拆卸式板式熱交換器



板片之構造及板式熱交換器工作原理

- (a) 洗衣板式(washboard)
- (b) Z字型(zig-zag)
- (c) 山型紋(chevron or herringbone)
- (d) 突出及凹入式 (protrusions and depressions)
- (e) 二次起伏之洗衣板式 (washboard with second corrugation),
- (f) 傾斜式洗衣板式(oblique washboard)。

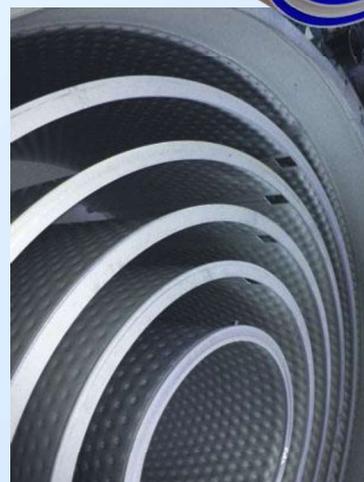
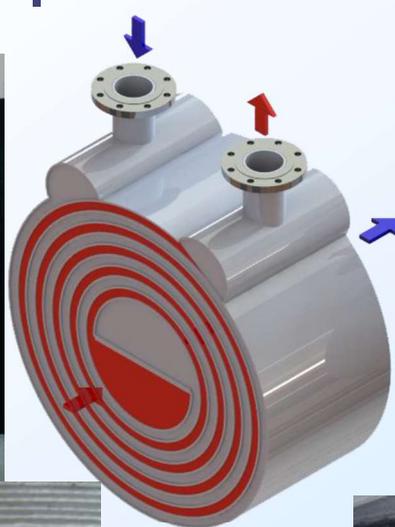
不過在公開的測試資料中，以 (c) 山型紋的資料較多。



板式熱交換器 板式熱交換器的優點

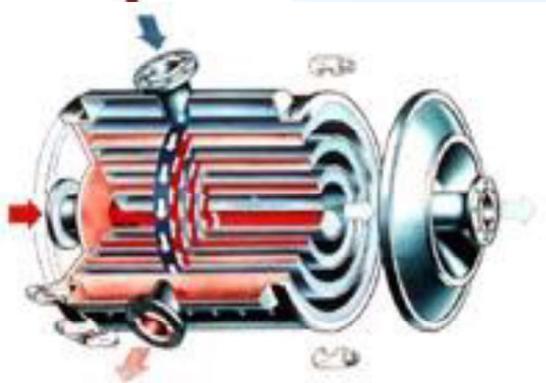
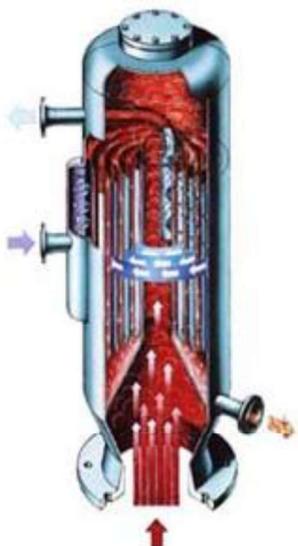
- 易清潔、檢查及保養。
- 可隨負載而增減熱傳面積→藉由板片數、板片大小、板片型式、流場安排等因素之變化(針對組合式而言，硬焊式無此優點)。
- 低污垢阻抗→因內部流場通常是在高度紊流情況下，故其污垢阻抗只有殼管式之10~25%。
- 熱傳面積大→具高熱傳係數、低污垢阻抗、純逆向流動，故在同熱傳量下，熱傳面積約為殼管式之1/2~1/3。
- 低成本。
- 體積小→同熱傳量下，體積約為殼管式之1/4~1/5。
- 重量輕→在相同熱傳量下，重量約為殼管式之1/2。
- 流體滯留時間短且混合佳→可達到均勻之熱交換。
- 容積小→含液量少、快速反應、製程易控制。
- 熱力性能高→溫度回復率可達1°C，有效度可達93%。
- 無殼管式中流體所引起之振動、噪音、熱應力及入口沖擊等問題。
- 適合液對液之熱交換、需要均勻加熱、快速加熱或冷卻之場合。

Spiral HX





Spiral Heat Exchanger



氣冷式熱交換器

- 絕大部分為Cross flow，effectiveness 較低
- 對環境影響遠比Cooling tower 小
- Induced draft 可提供較佳的流量分佈，但fan操作於較高溫度，比較耗功
- A-frame 常用於Steam condensation
- 風扇噪音為使用上的問題
- 最典型的管徑尺寸為1 in. with 2 in. wound fins. Fin pitch ~ 11 fins/in.
- 典型操作面速 2~ 5 m/s.
- Row number: 3~8.

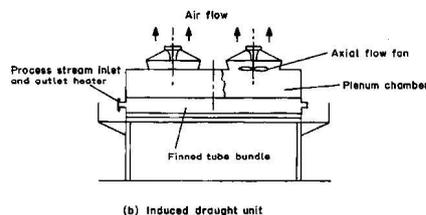
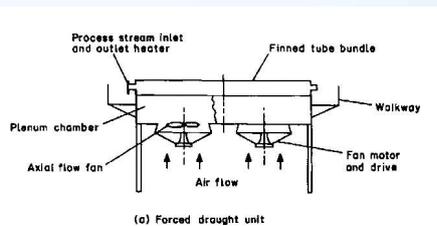
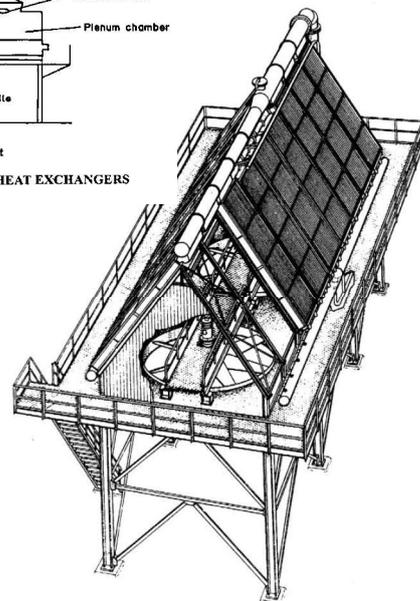
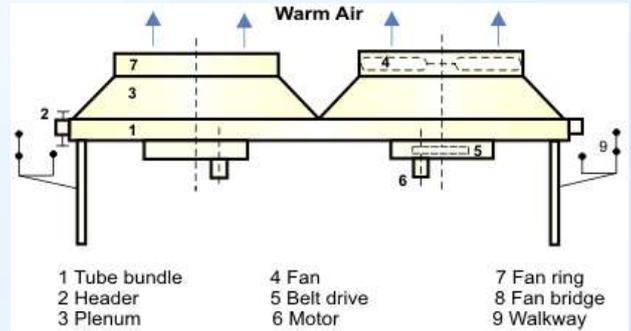


FIGURE 13 AIR-COOLED HEAT EXCHANGERS

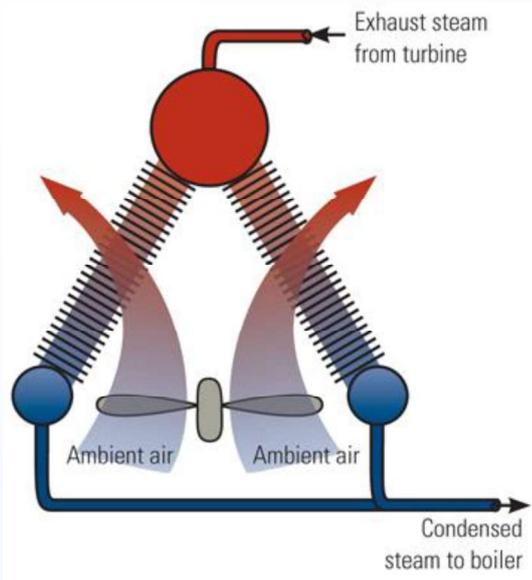


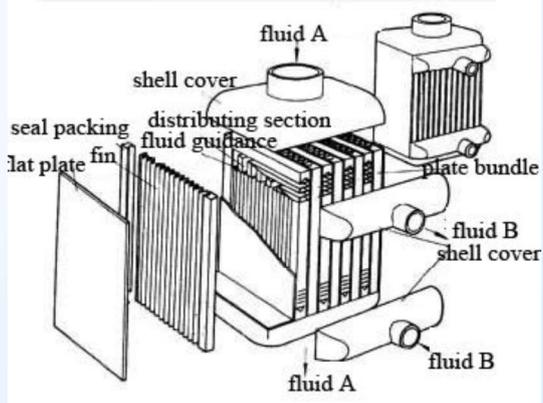
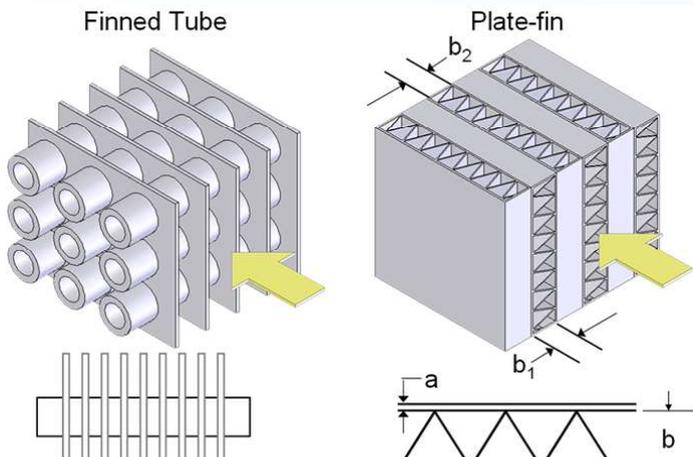


Air-cooled HX

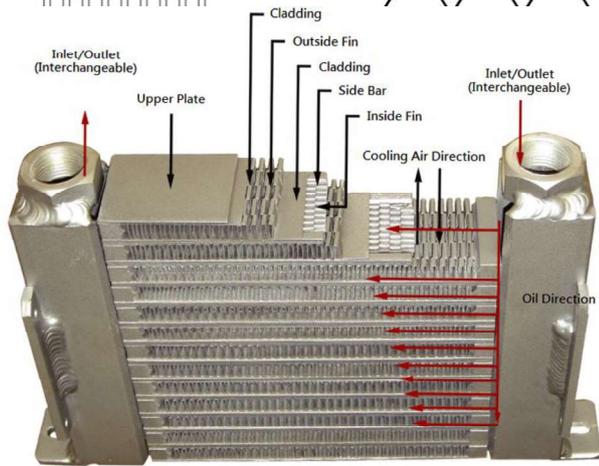


Air-cooled condenser

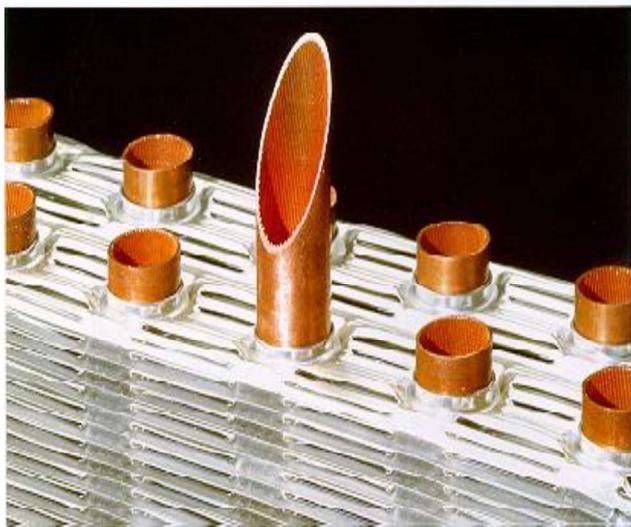
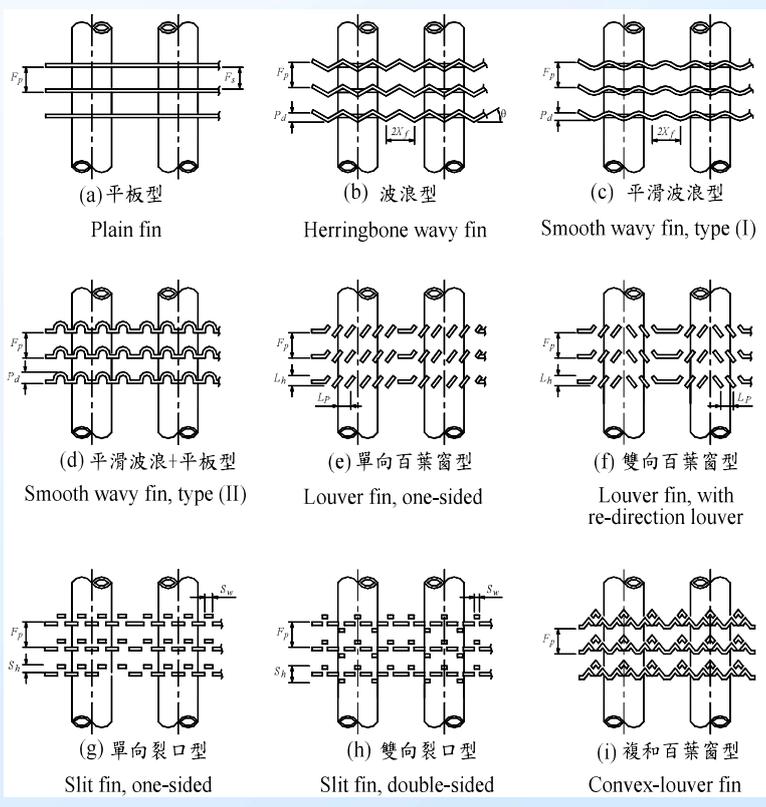




Structure of plate-fin heat exchanger



各式鰭片





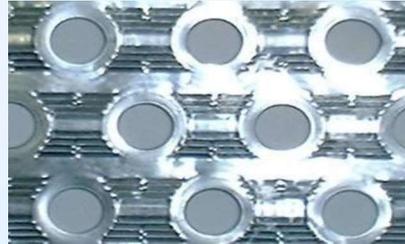
Extended surfaces

波浪鳍片
(wavy)



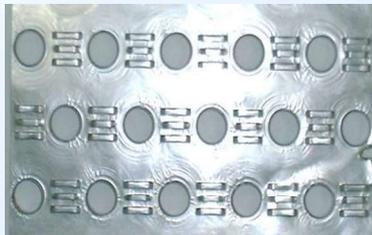
複合百葉窗
鳍片—
convex
louvers

百葉窗鳍片
—單向開口
(louvers)



百葉窗鳍片
—雙向開口
(louvers)

裂口式鳍片
—單向開口
(slit)



裂口式鳍片
—雙向開口
(slit)

Which is better?



斷續型鳍片熱傳增強原理

Boundary layer restart & Mixing

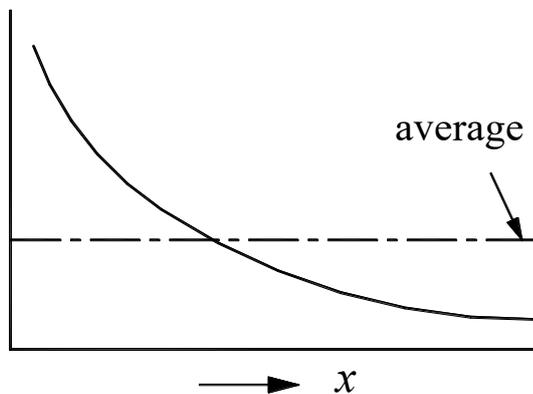
Plain fin - continuous fin



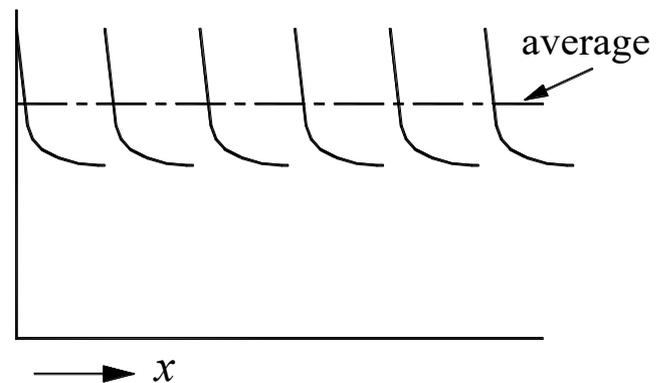
Interrupted surface



Performance



Performance

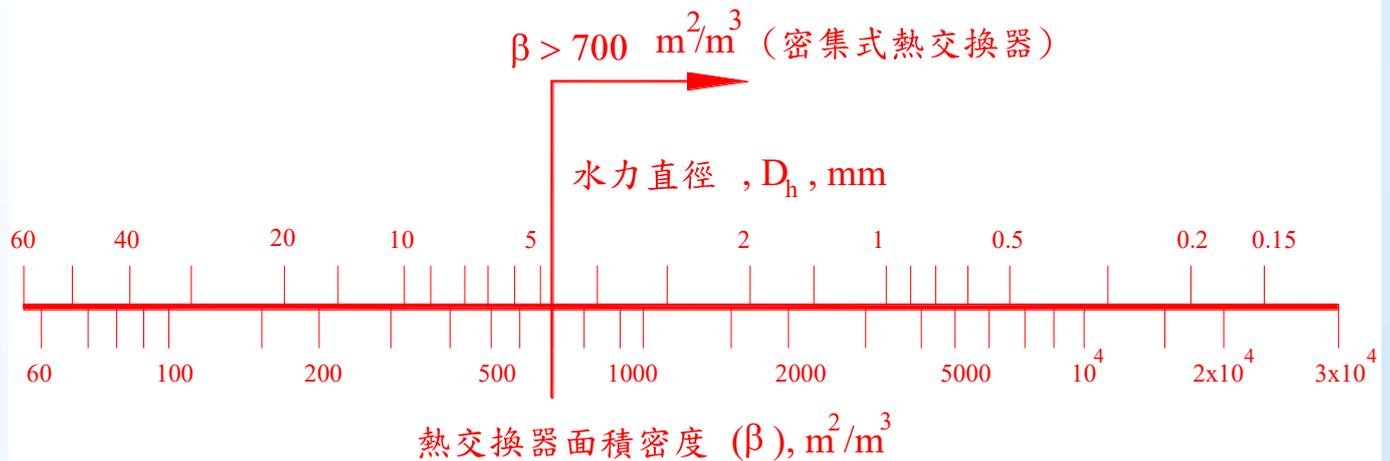


Characteristics: Sufficient Heat Transfer Improvement accompanied with significant pressure drop.

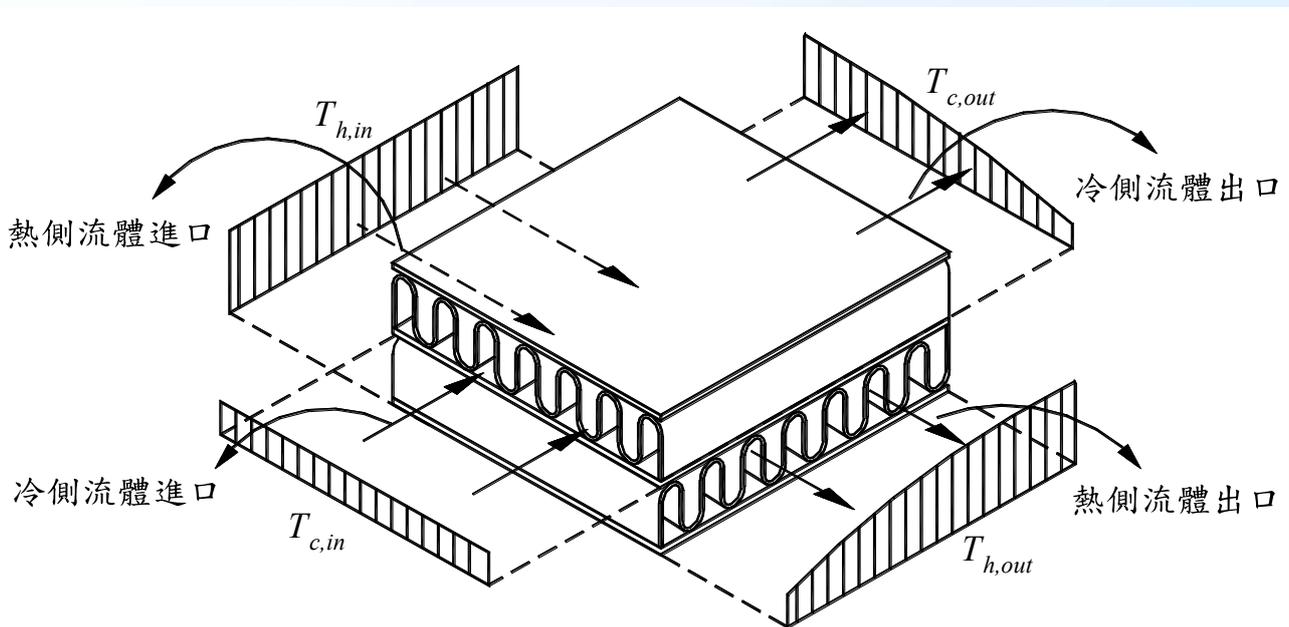
Unable to fulfill heat transfer performance at low velocity operation



熱交換器的熱傳面積與體積的比值超過 $700 \text{ m}^2/\text{m}^3$ ，我們稱之為密集式熱交換器

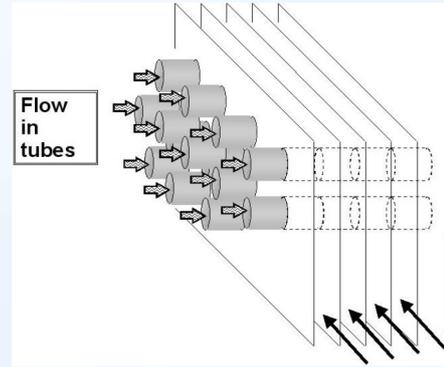


氣對氣的熱交換器進出口溫度的變化示意圖

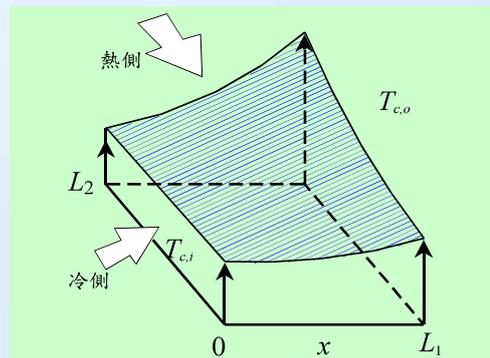


交錯流動型態

交錯流 (crossflow)，係熱側的進口與冷側的進口處剛好垂直，典型的溫度變化如所示，由右圖可知交錯流動下出口溫度呈現一較為複雜的變化。交錯流動時，有時候為了適度提升另一側的溫度差，管路的安排經常會由幾個回數 (pass) 所組成，它的另一個優點就是可將熱交換器較為緊密地安排，一些常見的熱交換器回數安排如後圖說明。



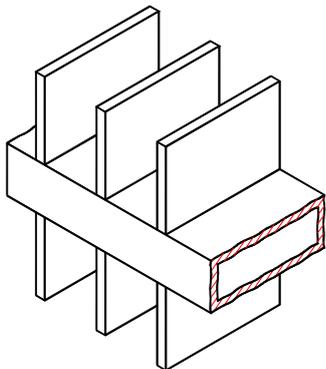
交錯流之流體流動方向示意圖



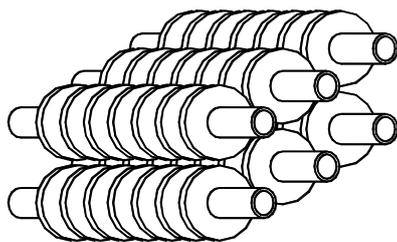
交錯流之溫度變化示意圖

為什麼要用鰭片?

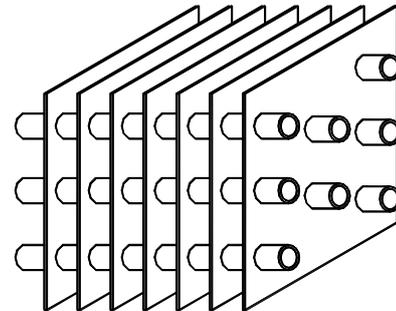
- 因為空氣側較差的熱傳導係數 (thermal conductivity)
- 增加熱傳面積
- 增加密集度 (compactness)



(a) plain



(b) circular

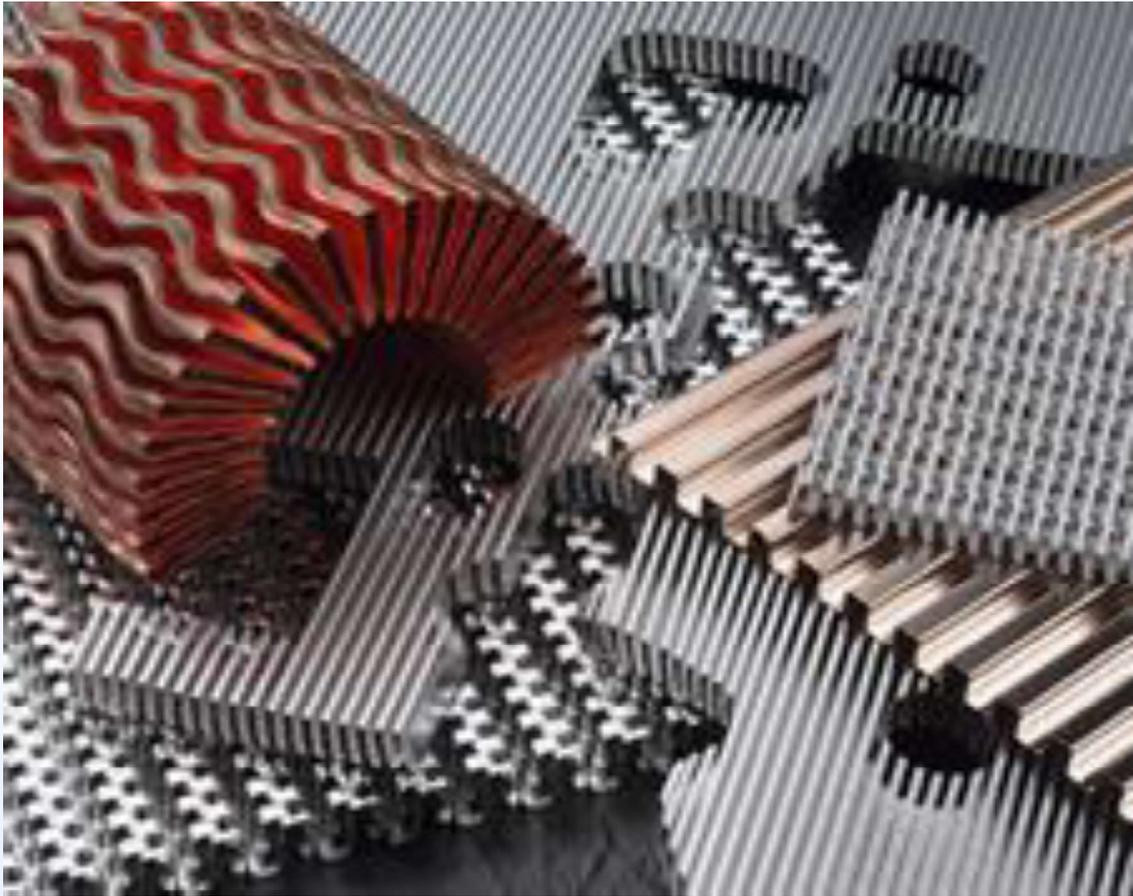


(c) continuous fin

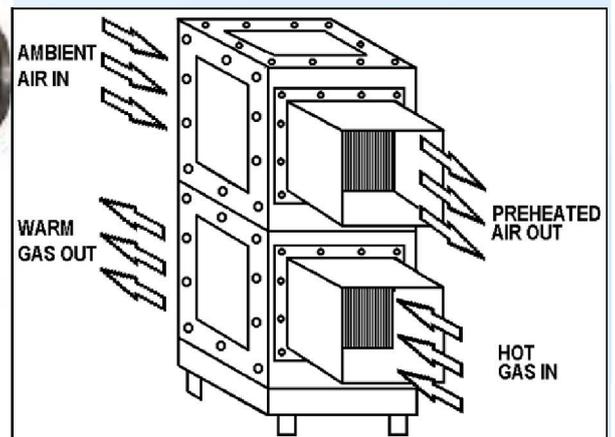
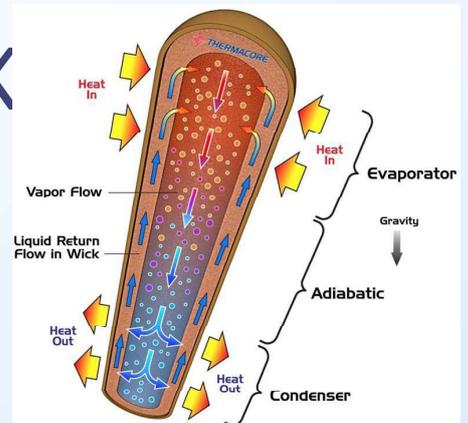
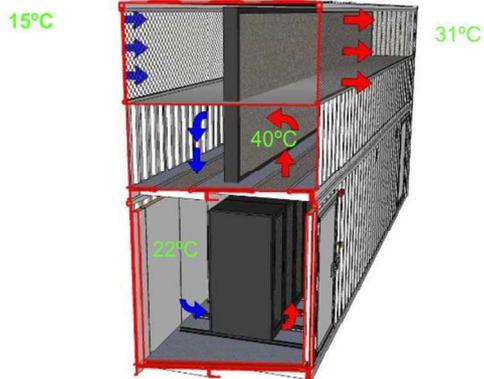
鰭管式熱交換器示意圖



Innovative Designs for Extended Surfaces

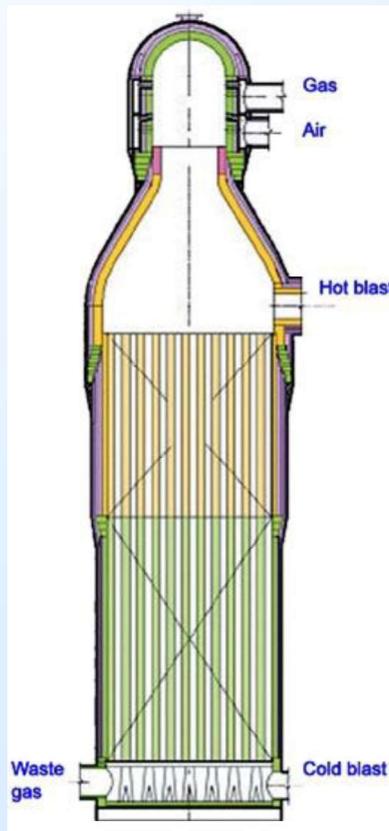
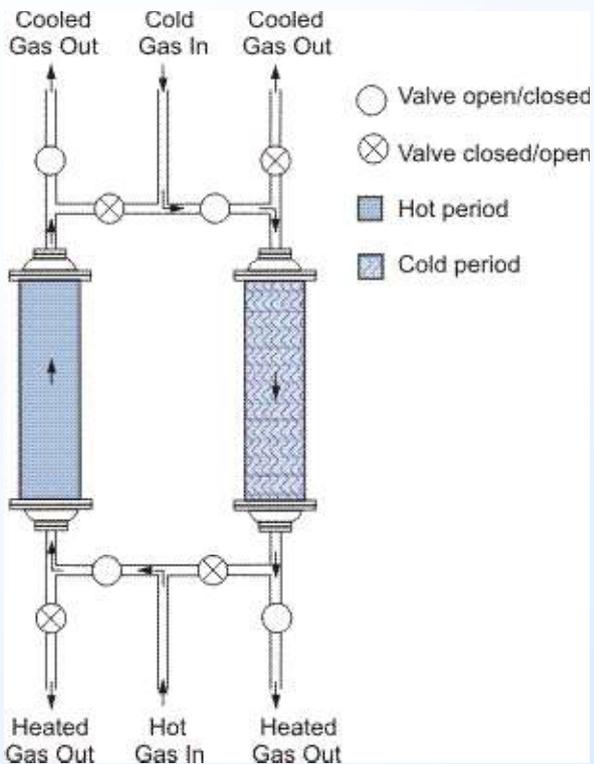


Heat Pipe HX

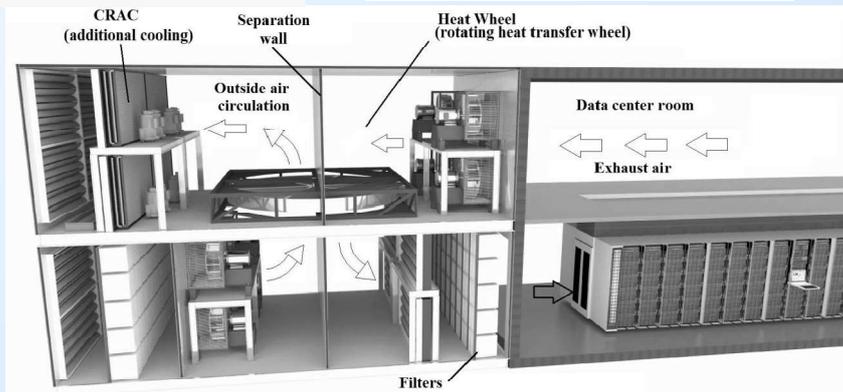
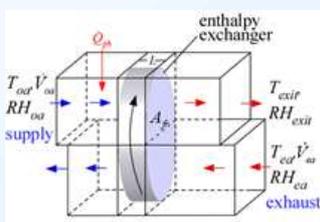
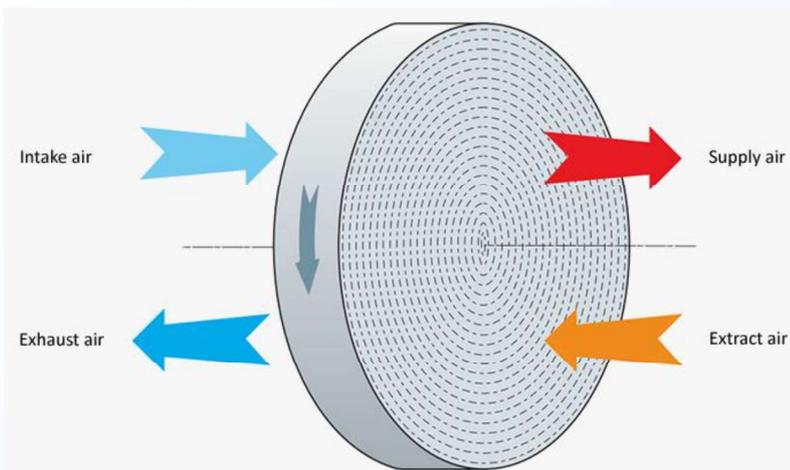




Fixed Bed regenerator



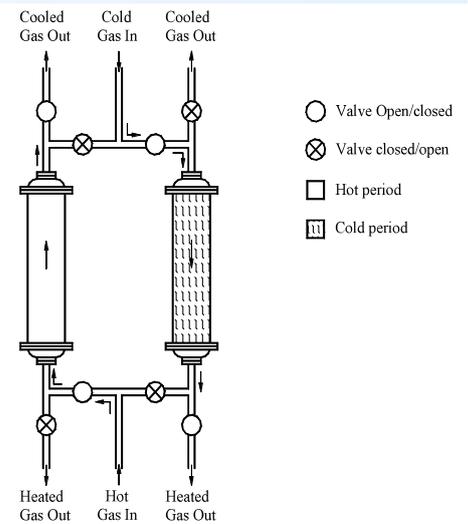
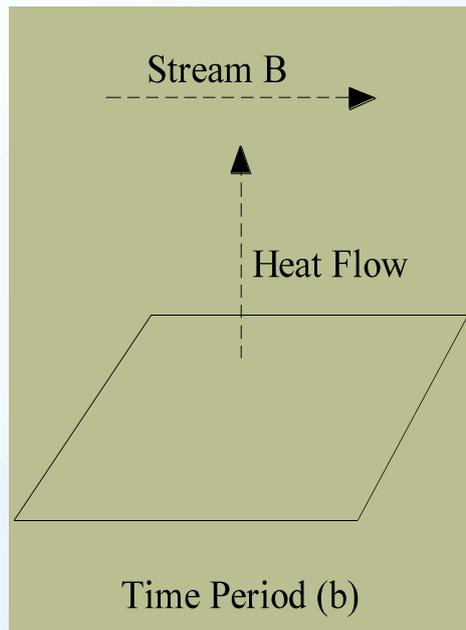
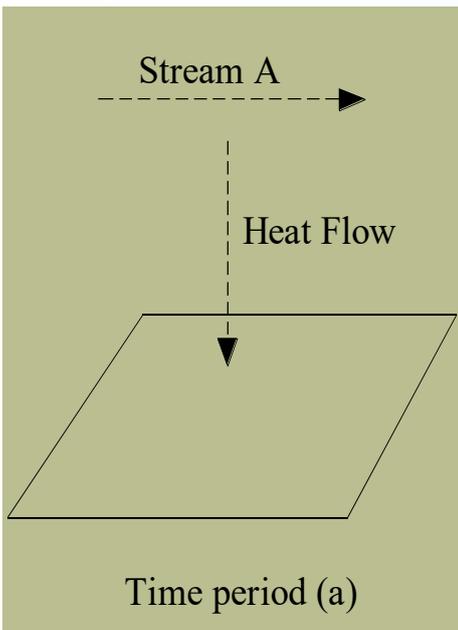
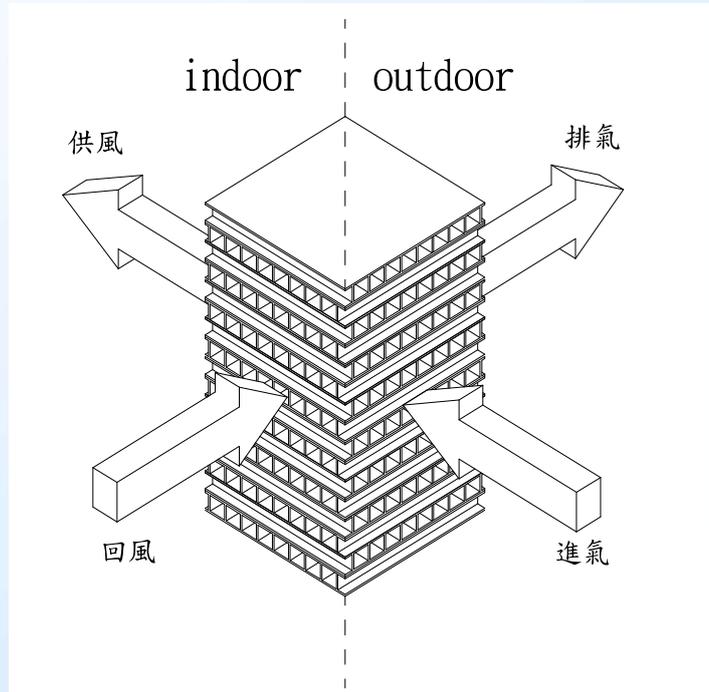
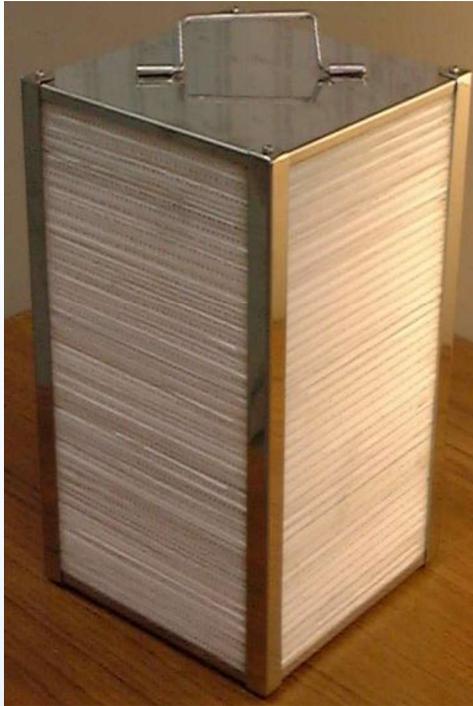
Rotary HX



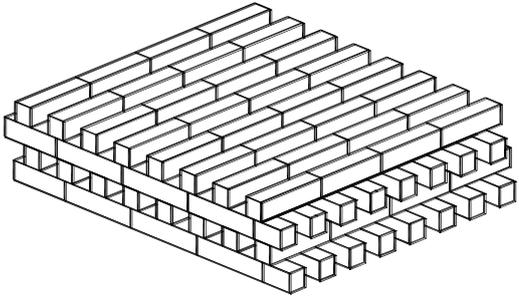
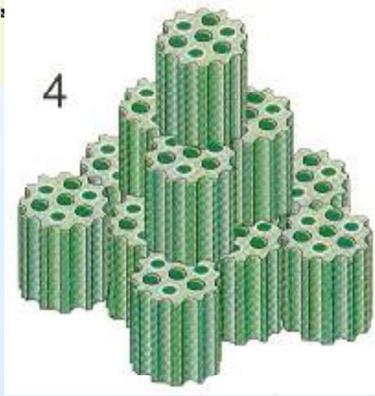
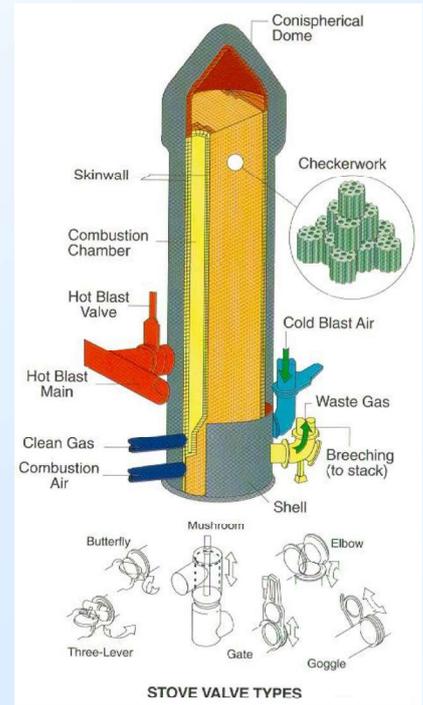
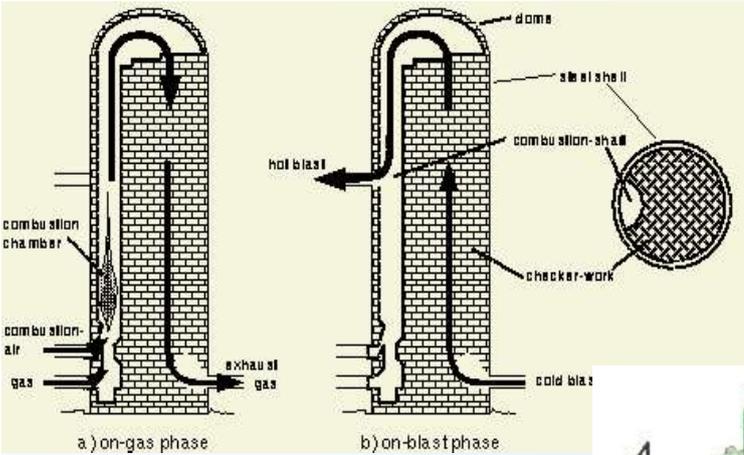


氣對氣交流式熱交換器

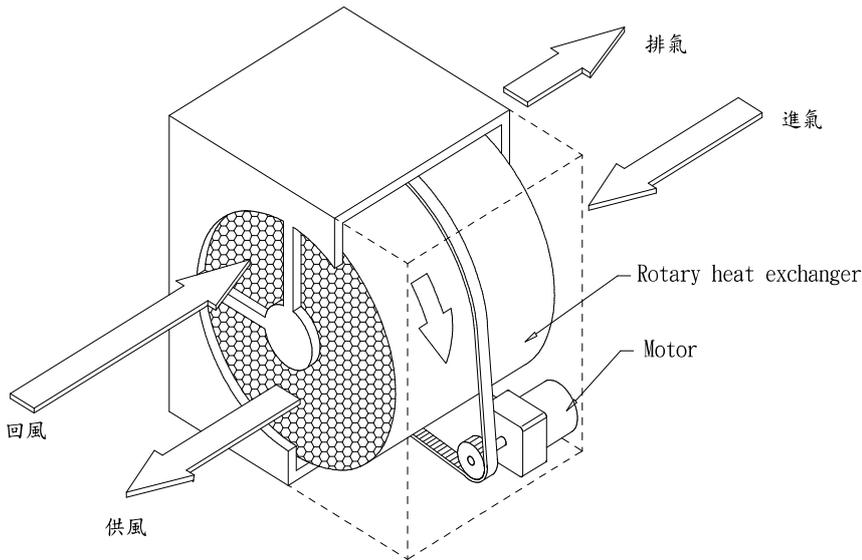
Air-to-air Cross Flow Heat Exchanger



再生式熱交換器工作原理



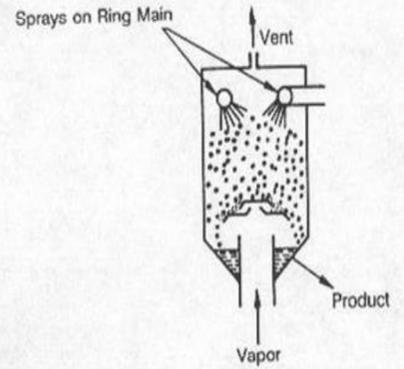
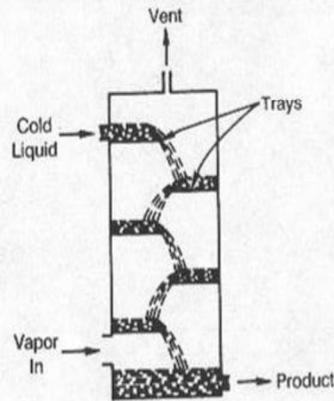
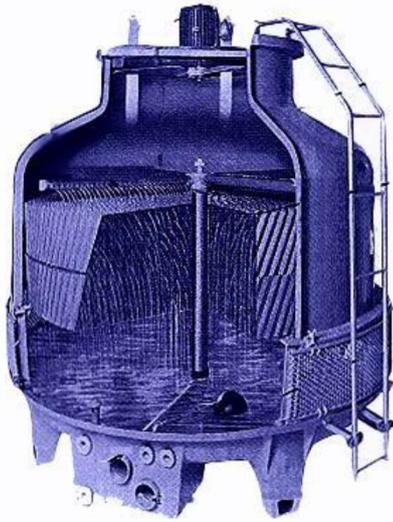
Hot blast stove Fixed Bed type regenerator



轉輪式再生式熱交換器 (a) Working Principle & (b) Rotary wheel



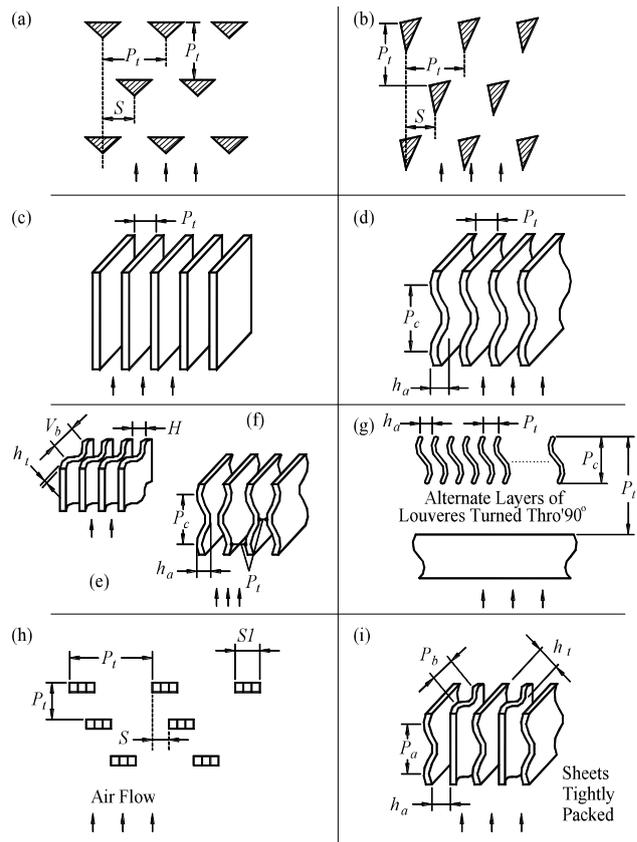
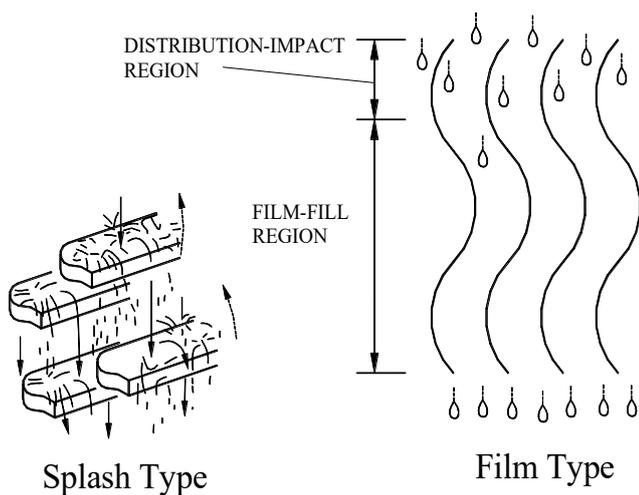
Cooling Tower



Tray-type direct HX & Spray condenser

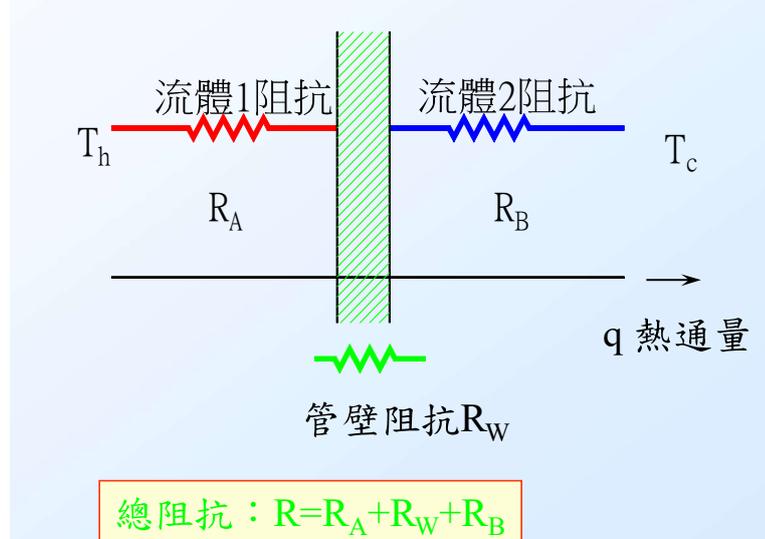
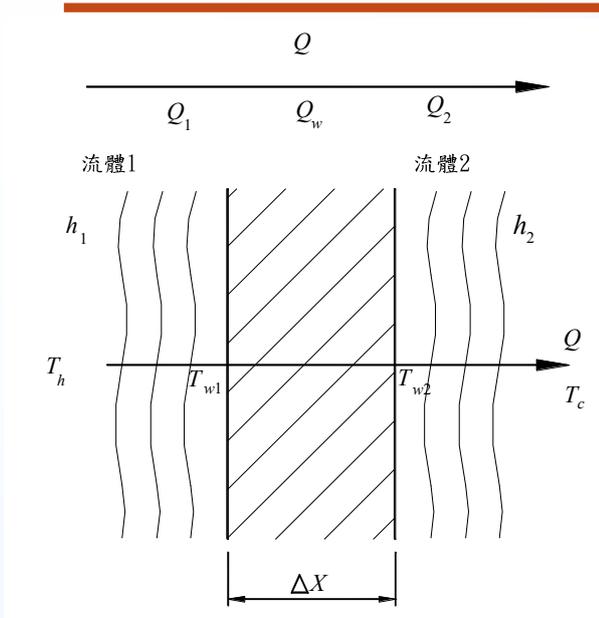


典型填料形狀





熱交換器原理介紹(Cont.)



總阻抗： $R=R_A+R_W+R_B$

熱通量 $q=(T_h-T_c)/R$

$Q=q \cdot A \Rightarrow$ 總熱傳量

Fig. 熱交換器兩側熱對流熱傳示意圖

因此若能確切掌握流體阻抗，即能精確設計熱交換器



熱傳增強技術

Recap & Quick overview

$Q = UA\Delta T_m$

- Q : 熱傳量
- A : 面積
- ΔT_m : 有效溫差



熱交換器選擇考量因素

- 熱流需求：包括熱交換量、工作流體的溫度、壓力與可允許的壓損，選擇的熱交換器當然必須滿足這些熱流的基本需求；且熱交換器能在工作溫度壓力下長期運作，能忍受因溫差所產生的熱應力影響，應力主要由入口壓力與溫度差所引起，常見各種熱交換器所能忍受的最大壓力與溫度範圍大致如下
- 熱交換器與流體的匹配性：熱交換器的材料必須與工作流體能長期搭配，無腐蝕的問題；其中必須特別注意結垢的影響，設計上應同時考慮正常操作設計點下與非設計點上運作時，結垢在不同溫度壓力變化下的影響，一般而言，典型氣對氣熱交換器的結垢影響較小，這是因為許多製程的應用上，氣體多半比液體來的乾淨，而且如果使用轉輪式的再生式熱交換器，氣體在不同時間時相反方向的流動也有助於熱交換器本身的自清，因此結垢的影響相對比液體側小；不過此類再生式熱交換器也因氣體交互流過熱交換器而可能產生污染問題。



熱交換器選擇考量因素 (Conti.)

- 流體型式：由於氣體體的熱傳係數遠低於液體，因此氣對氣熱交換器通常需非常大的熱交換面積，一般的作法乃藉由增加鰭片、縮小水力直徑與使用小管徑熱傳管來增加面積的密集度，密集度增加同時增加流動壓損，氣側壓損的影響相對於液體測重要很多，設計上必須特別注意。對液對液的熱交換而言，為了避免交叉感染的影響，通常不應該考慮使用再生式熱交換器，相較於氣對氣熱交換器，液對液熱交換器的壓損影響較小。對氣對液的熱交換器而言，由於氣側的熱傳係數遠低於液體側，因此設計上的初步原則為盡量平衡兩側的熱傳性能(即 $\eta_o h_o A_o \sim \eta_i h_i A_i$)。
- 維護性：設計時必須考量停機清理與置換的問題；同時應留意製程應用條件改變時所帶來的影響。
- 造價：造價為選擇設非常重要的因素，例如板式熱交換器的造價會比殼管式熱交換器大，但是如果同時考量裝置、操作、維護等成本的影響，板式熱交換器成本可能反而比較便宜。設計上如果比較在意長期操作的成本，則在設計上就必須特別留意流動的壓損而非純粹的熱傳考慮。
- 空間與重量：許多應用上必須考慮到裝置時空間與重量的問題，例如熱交換器裝置於高樓層的重量負荷或是都會區維護空間缺乏的現實問題。



熱交換器選則操作範圍

熱交換器形式	最大壓力 (absolute)	溫度範圍	流體限制	典型熱交換器尺寸範圍	特性
氣冷式 Air-cooled	500 bar (製程側)	600 °C (製程側)	僅受限於材料製作	5 ~ 350 m ² (裸管, 每一單元), 可使用多單元。	通常搭配風扇使用, 並大量使用鰭片
可拆卸板式熱交換器	16~25 bar (某些應用設計可達 40 bar)	-25 ~ 200°C.	通常不適用氣體與兩相流動, 使用上襯墊是決定因素	1 ~ to 1200 m ²	模組化設計, 不易清理
固定床式再生式熱交換器	1 bar	~ 600°C.	常用於燃燒廢氣的熱回收兵用來愈熱空氣	-	製作上常使用磚或陶瓷材料
雙套管式熱交換器	300 bar (殼側) 1400 bar (管側).	-100 to 600°C (使用特殊材料時可更高)	僅受限於材料製作	0.25 ~ 200 m ² per unit – multiple units are often used.	High thermal efficiency, standard modular construction.
熱管熱交換器 Heat-pipe	~ 1 bar	通常低於 200°C, 但可依需要選取管內工作流體, 工作於高溫中	Low pressure gases.	100 ~ 1000 m ² .	可設計成逆向像流動, 冷熱側均可使用鰭片增加面積
板鰭式 Plate-fin	100 bar (鋁合金) 200 bar (不銹鋼)	-273~150°C (鋁合金) ~ 600°C (不銹鋼)	Low fouling.	熱交換器體積通常小於 9 m ³	Very small possible. Incorporation of multiple streams. Very large surface area per unit volume. DT
印刷式 Printed-circuit	1000 bar	800°C (不銹鋼)	Low fouling	1 to 1000 m ²	Very large surface area per unit volume. Stainless steel or higher alloys normal construction material.
轉輪再生式 Rotary regenerators	~ 1 bar	980°C.	Low pressured gases.		Inter-stream leakage must be tolerated
殼管式 Shell-and-tube	300 bar (殼側). 1400 bar (管側).	-25 ~ 600°C (使用特殊材料可操作於更低或更高的溫度)	僅受限於材料製作	10 to 1000 m ² (per shell – multiple shells can be used).	Very adaptable and can be used for nearly all applications.
螺旋式 Spiral	18 bar	~ 400°C	Subject only to materials of construction. Often used for fouling duties.	~ 200 m ² .	High heat transfer efficiency. Cylindrical geometry useful as integral part of distillation tower.



小結

- 熱交換器為能量交換的主要工具，常見的熱交換形式為
 - Recuperator (通常使用金屬與熱傳導率較高的材料)
 - Regenerator (蓄熱型熱交換器)
 - Direct-contact HX (增加接觸面積與時間)
- 熱交換器主要的組成為傳熱管(板片)與鰭片
- 設計上增強側為阻抗較大的一側
- 流動特性的掌握 (單相或兩相熱傳)為高效率熱交換的主要因素



感謝聆聽



敬請賜教

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