

# SCAMBIATORI DI CALORE

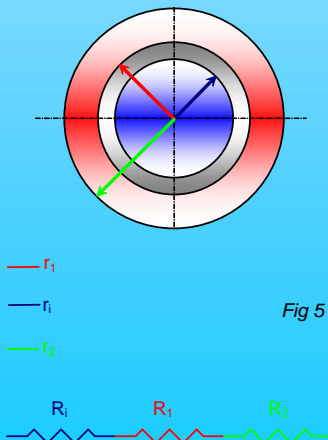
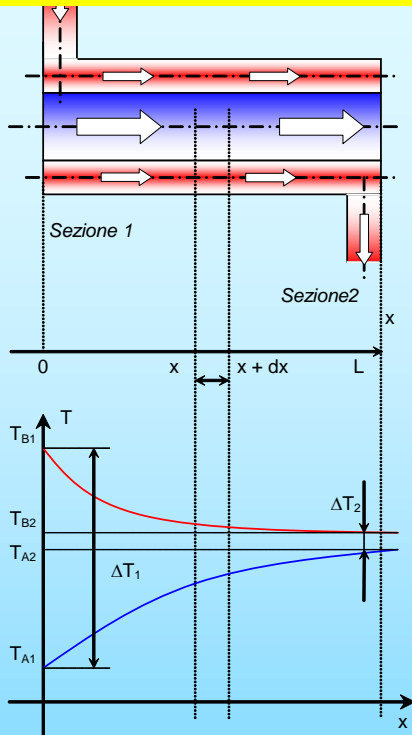


Fig 5

## ATTRIBUTI

- Compatti [ $>700 \text{ m}^2/\text{m}^3$ ]
  - A flussi incrociati con flussi misti o puri
- Tubo in tubo
- A tubi e mantello (shell and tube)
- A piastre
- Rigenerativi
  - Statici
  - Dinamici
- Controcorrente
- Equicorrente
- A flussi incrociati con flussi misti o puri
- Evaporatori
- Condensatori
- Desurriscaldatori
- Sottoraffreddatori

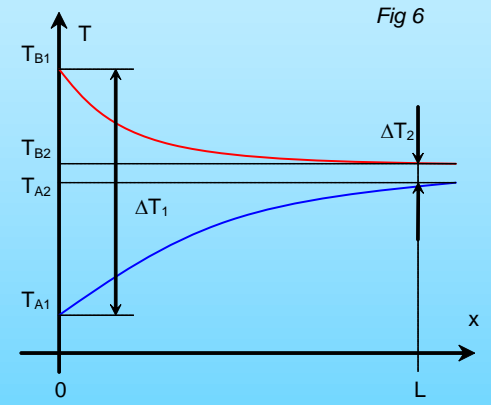
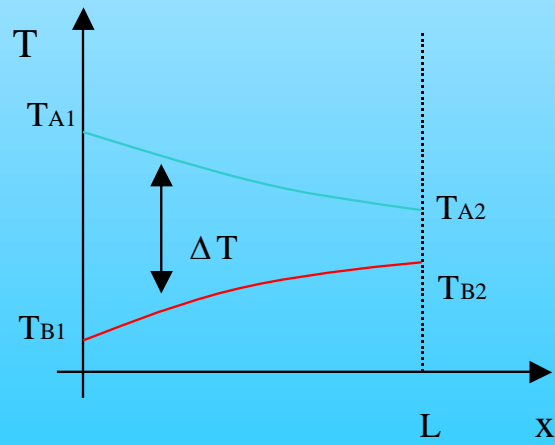
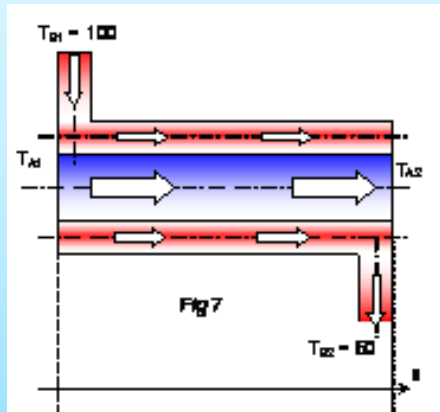


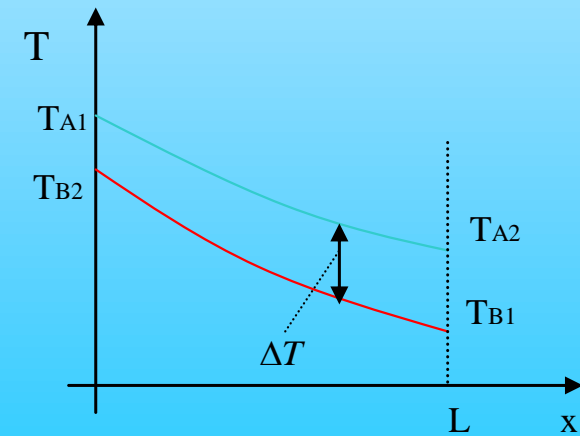
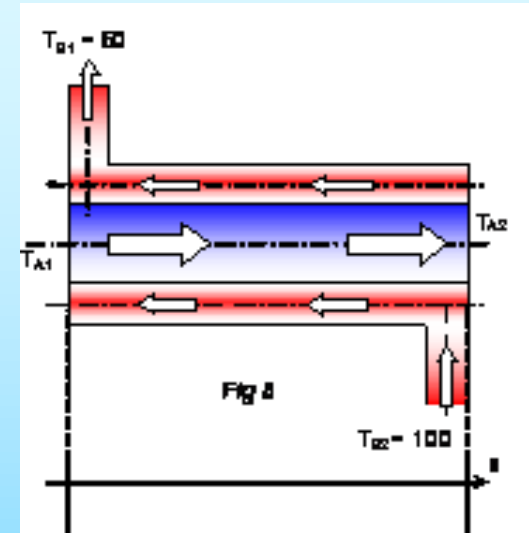
Fig 6

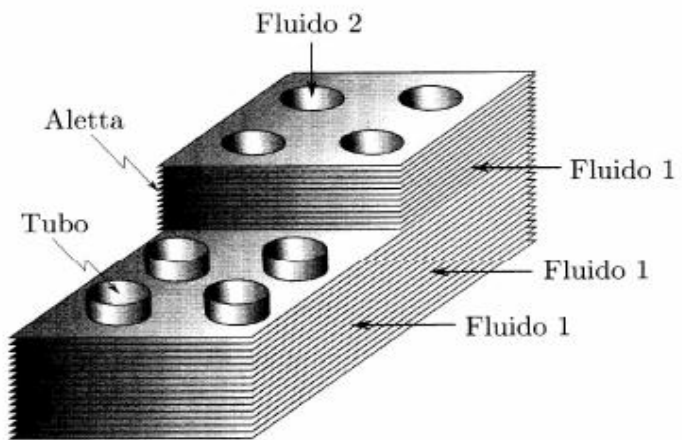
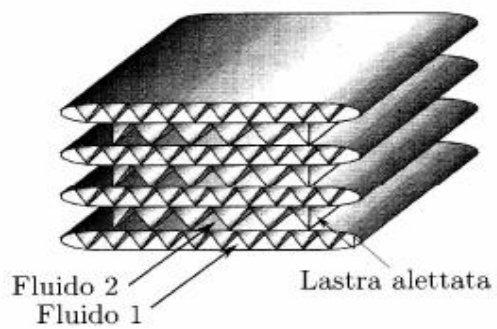
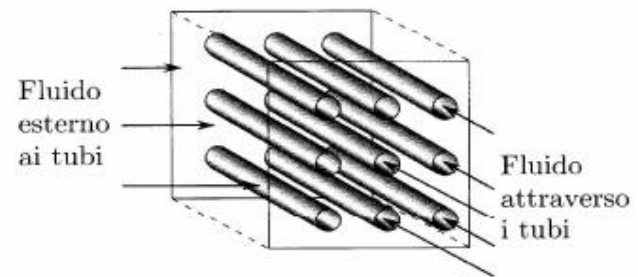
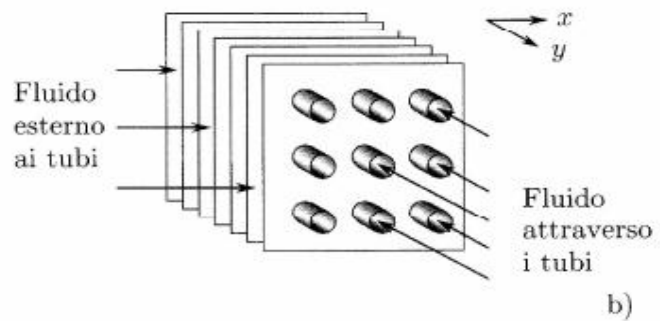
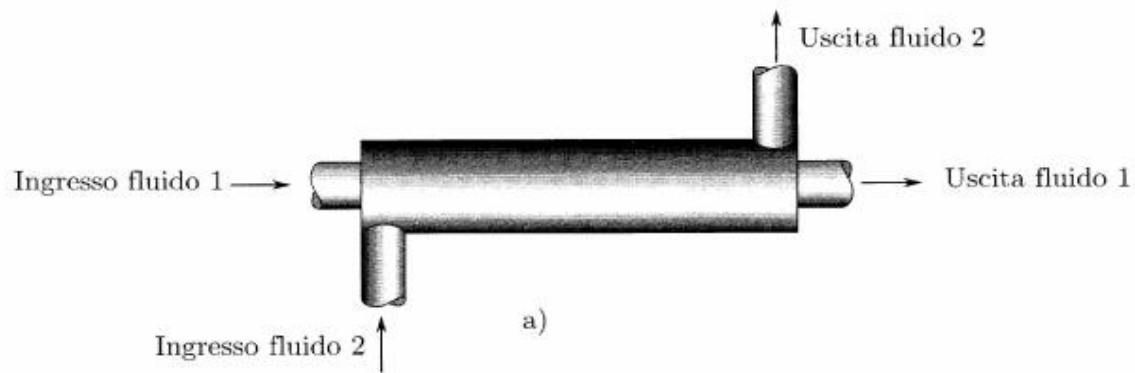
# SCAMBIATORI DI CALORE

## EQUICORRENTE

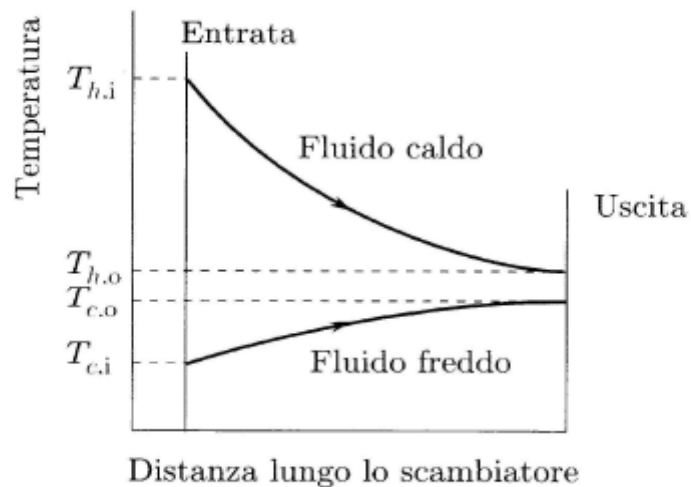
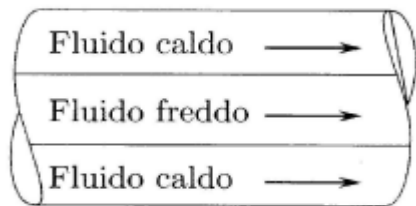


## CONTROCORRENTE

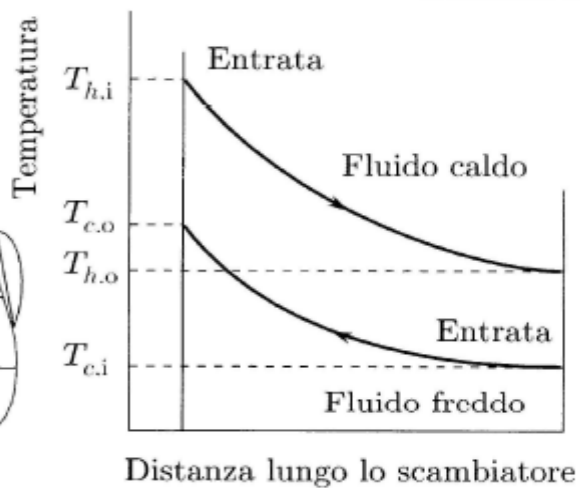
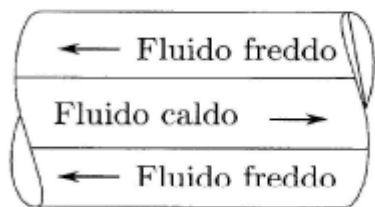




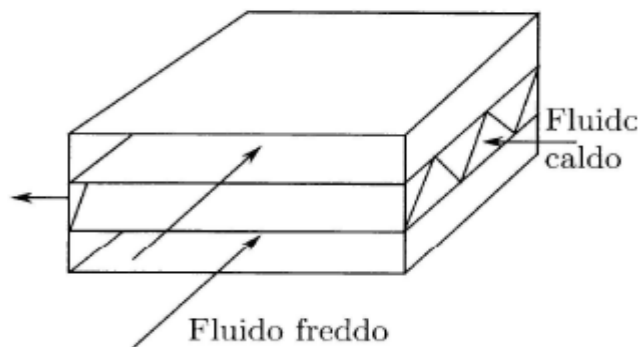
c)



a)



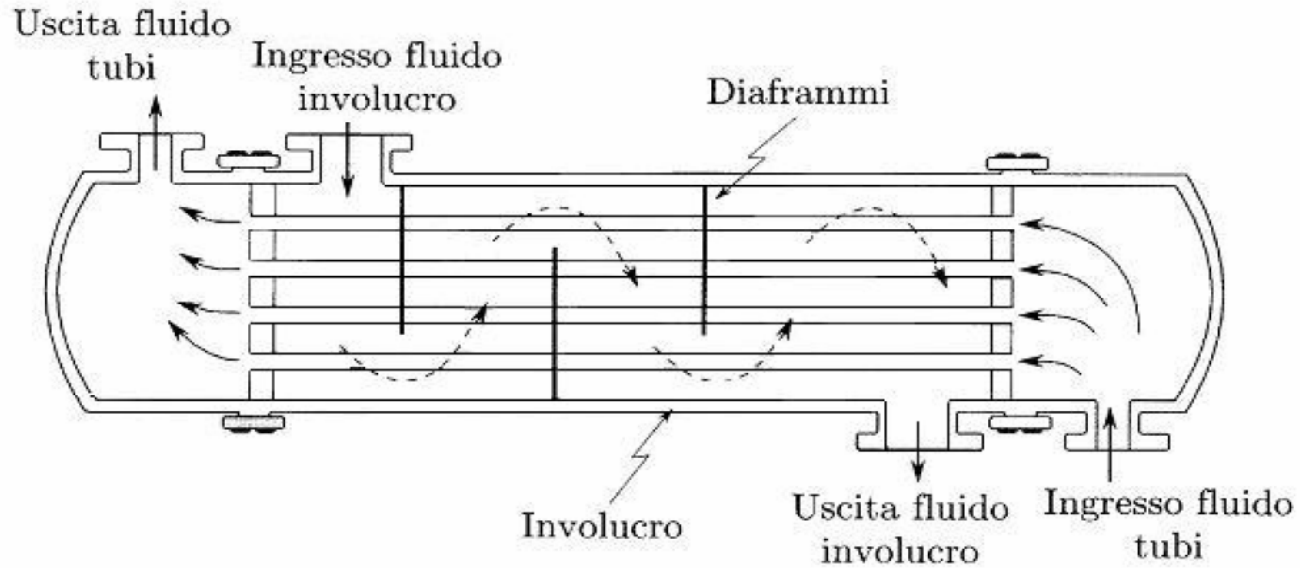
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c)

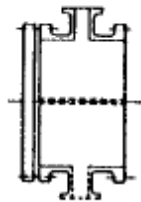
Configurazioni di moto nello scambiatore: a) correnti parallele equiverse, b) contro-corrente, c) moto incrociato.

Una delle configurazioni più comuni è quella dello scambiatore a fascio tubiero. In tale schema un fluido passa entro un fascio di tubi e l'altro entro il volume libero tra i tubi e il mantello dello scambiatore. Appositi setti verticali costringono il fluido che scorre entro il mantello ad assumere un moto sinuoso, onde potenziare lo scambio termico convettivo.



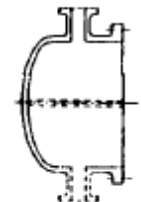
**Tipi di testata  
anteriore**

**A**



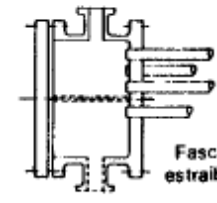
Distributore e coperchio flangiati

**B**

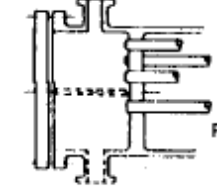


Distributore flangiato  
a fondo bombato

**C**



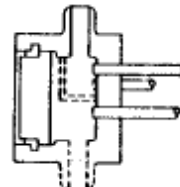
Fascio  
estraiabile



Piastra  
fissa

Distributore solidale  
alle piastra tubiera

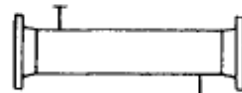
**D**



Testa speciale per alte pressioni

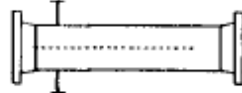
**Tipi di  
mantello**

**E**



Un passaggio lato mantello

**F**



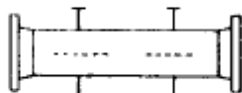
Due passaggi con diaframma  
longitudinale

**G**



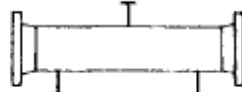
Flusso ripartito

**H**



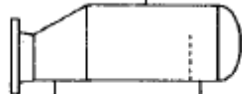
Doppie ripartizione di flusso

**J**



Flusso diviso

**K**



Ribollitore Kettle

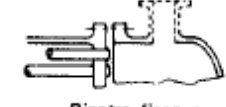
**Tipi di testata  
posteriore**

**L**



Piastra fissa e  
canale flangiato

**M**



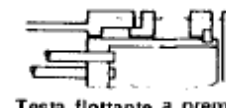
Piastra fissa e  
canale bombato

**N**



Piastra fissa solidale  
al distributore

**P**



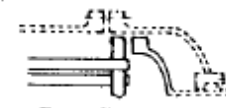
Testa flottante a premistoppa

**S**



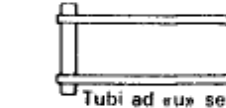
Testa flottante  
smontabile

**T**



Testa flottante passante

**U**



Tubi ad «u» senza  
distributore posteriore

**W**

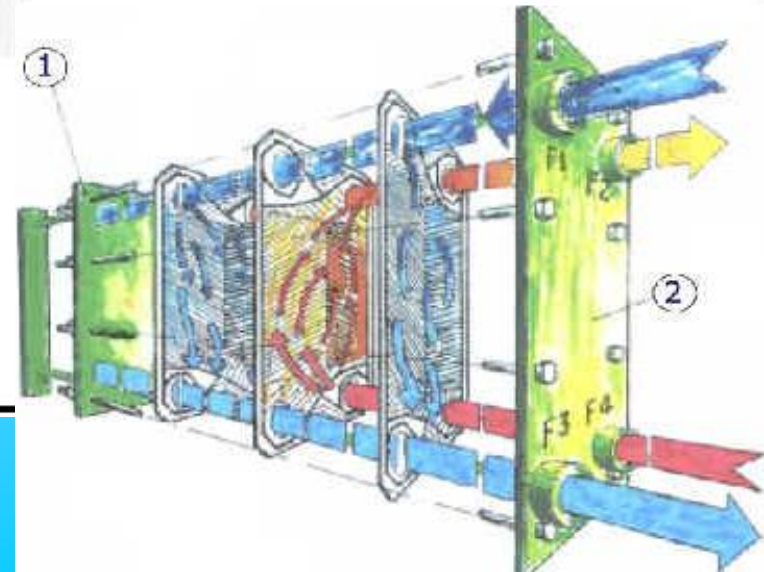
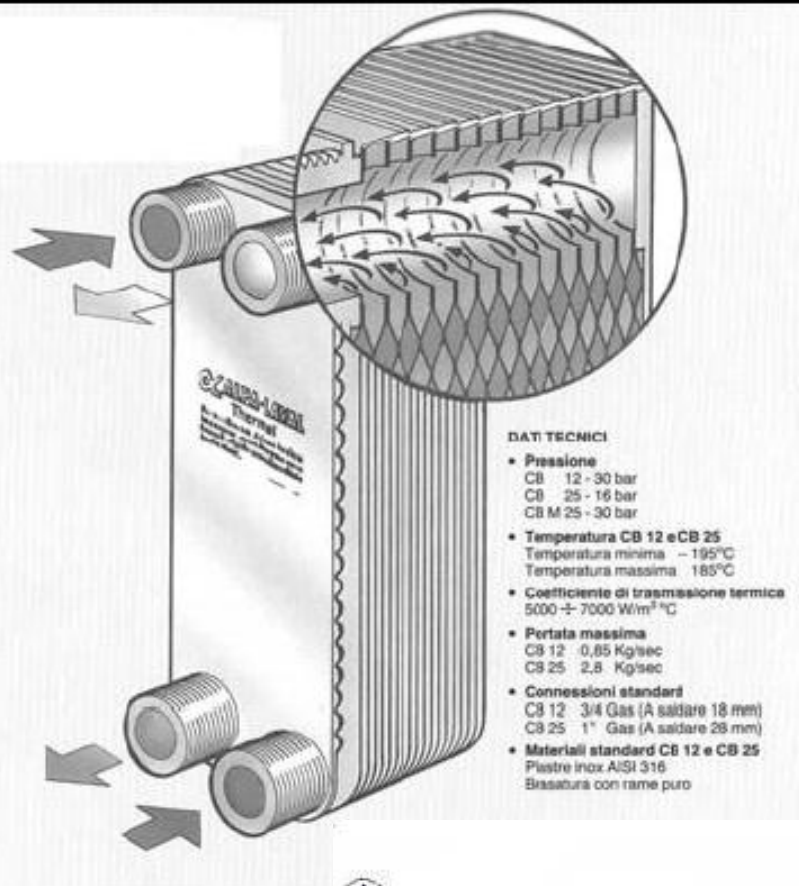
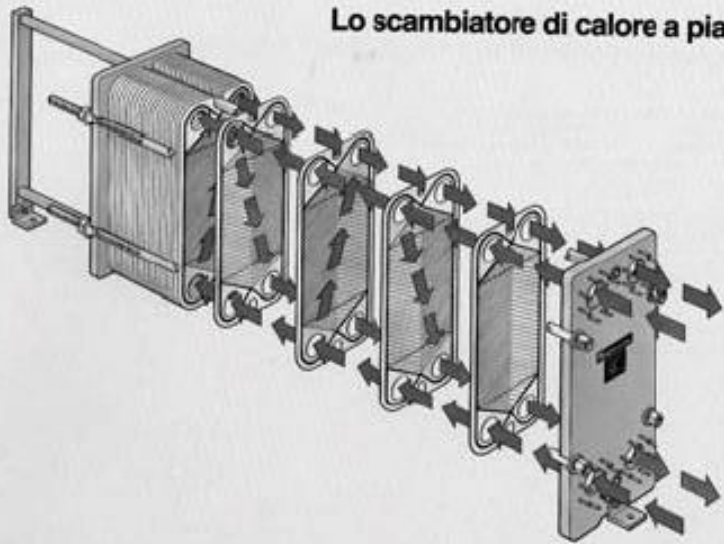


Piastra tubiera  
flottante

Fig. 1 - Tipi di testate e mantelli per scambiatori a fascio tubiero. Classificazione T.E.M.A.

Per taglie piccole e medie si è avuto un largo sviluppo degli scambiatori di calore a piastre saldobrasate con forti vantaggi nella compattezza, nell'efficienza dello scambio termico e nella carica di refrigerante:

Lo scambiatore di calore a piastre



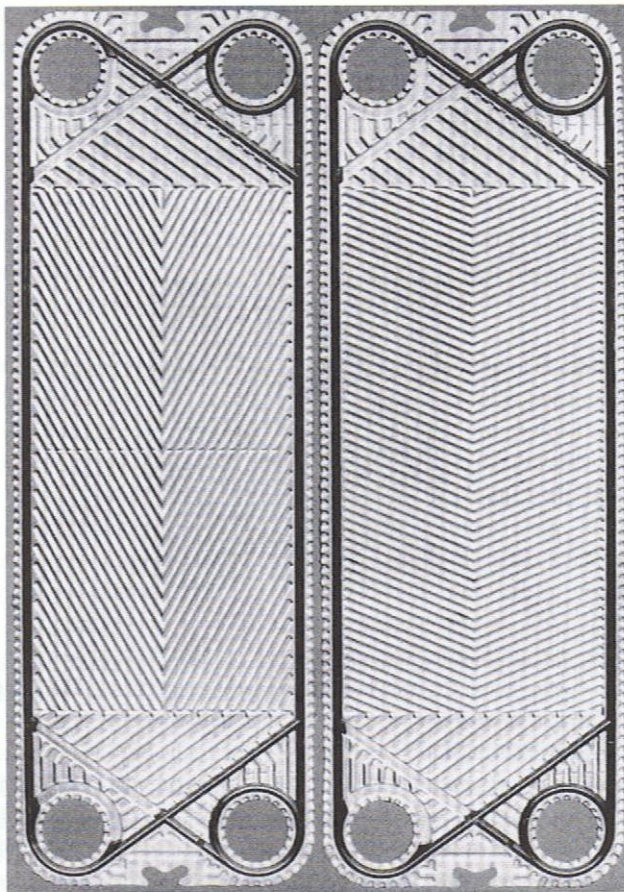


Figure 1.16 Corrugated plate geometry used in plate-type heat exchangers. (Photograph courtesy of Alfa-Laval.)

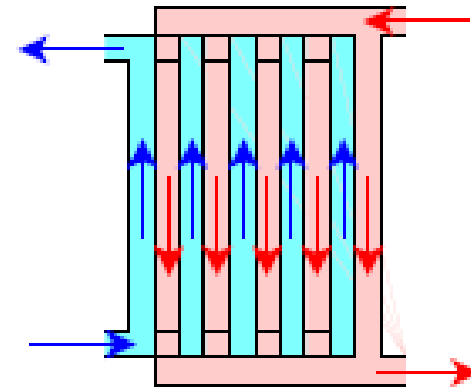
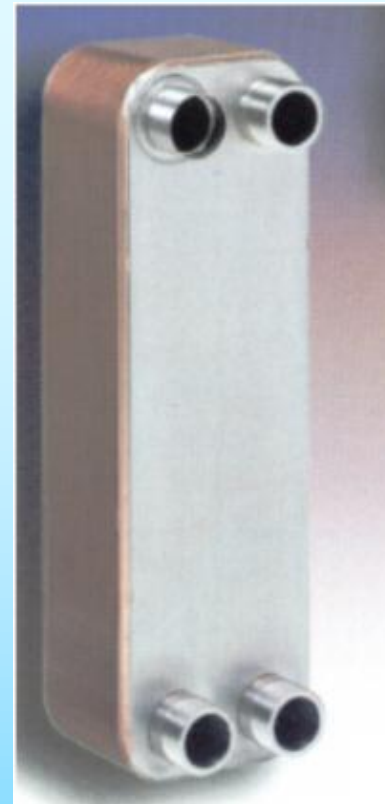
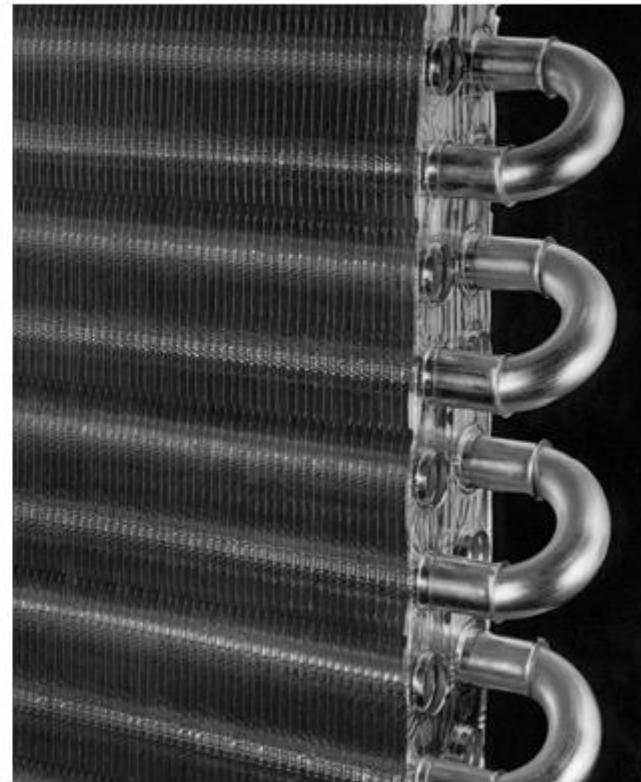
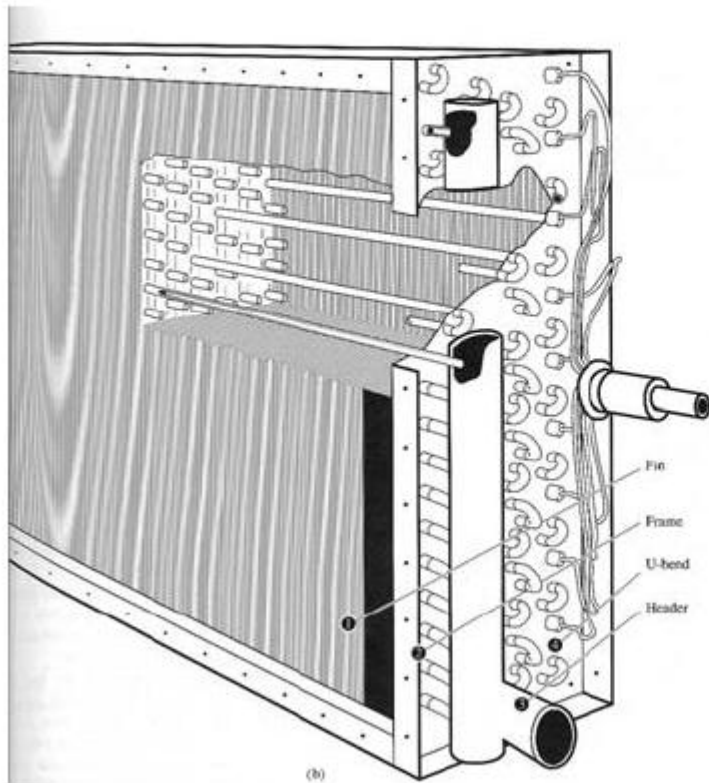
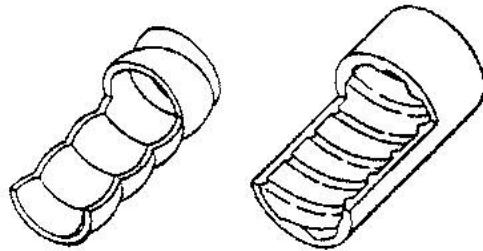


Figura 4: Schema dei flussi in uno scambiatore a piastre.

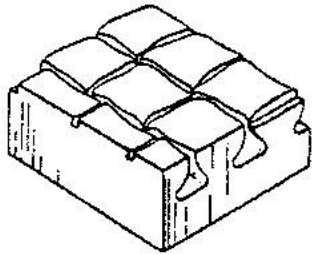


Anche gli evaporatori possono essere realizzati nella forma di una batteria alettata con espansione diretta:

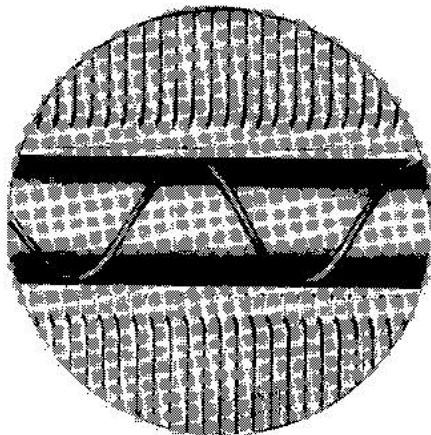




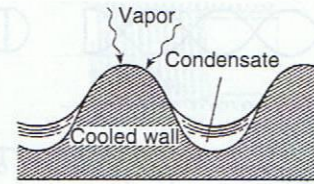
(a)



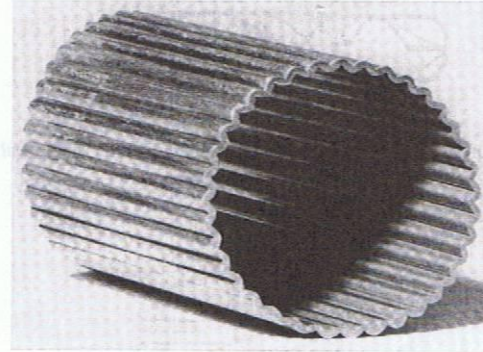
(b)



(c)



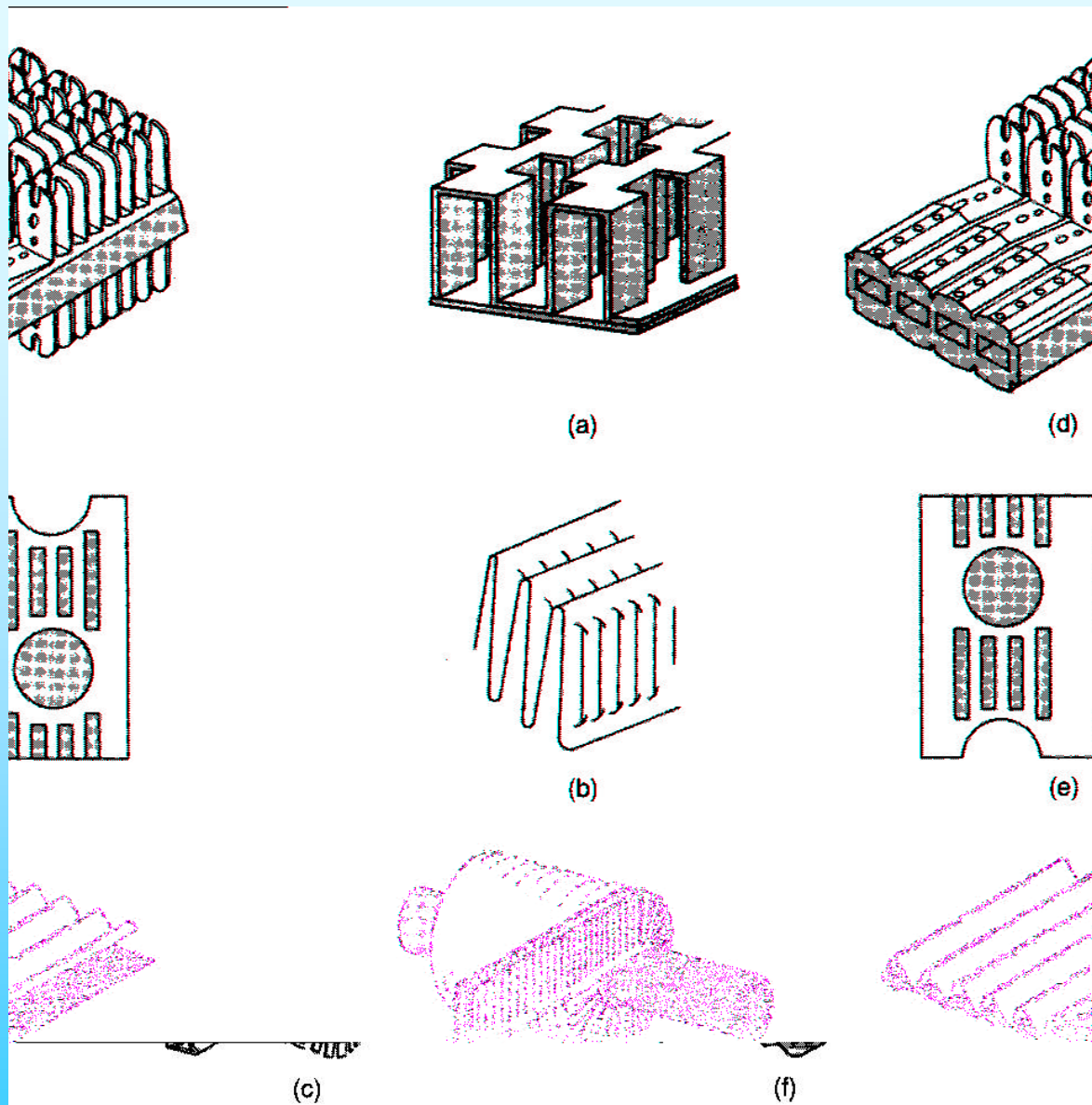
(a)



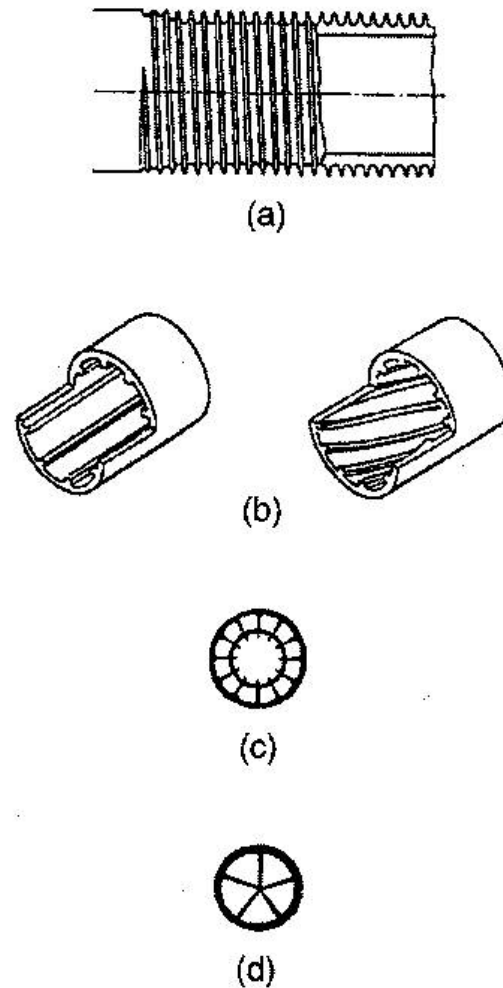
(b)

Figure 1.8 (a) Illustration of surface tension drainage from the flutes into drainage channels. (b) Fluted tube used for condensation in the vertical orientation.

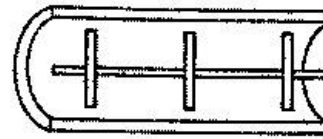
Figure 1.2 (a) Tube-side roughness for single-phase or two-phase flow, (b) “rough” surface for nucleate boiling, (c) wire-coil insert.



**Figure 1.3** Enhanced surfaces for gases. (a) Offset strip fins used in plate-fin heat exchanger, (b) louvers used in automotive heat exchangers, (c) segmented fins for circular tubes, (d) integral aluminum strip-finned tube, (e) louvers tube-and-plate fin, (f) corrugated plates used in rotary regenerators. (From Webb and Bergles [1984].)



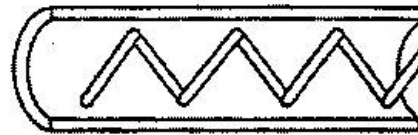
**Figure 1.4** (a) Integral fins on outer tube surface, (b) internally finned tubes (axial and helical fins), (c) cross sections of multiply internally finned tubes, (d) tube with aluminum star insert.



(a)

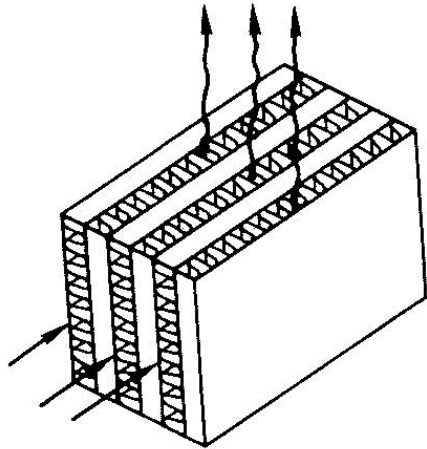


(b)

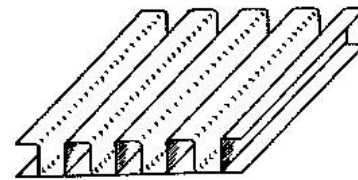


(c)

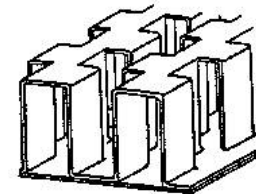
**Figure 1.5** (a) Spaced disk devices, (b) spaced streamline-shaped insert devices, (c) displaced wire-coil insert. (From Webb [1987].)



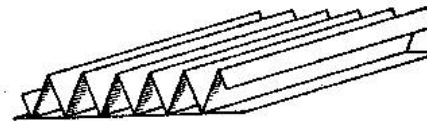
**Figure 5.1** A cross-flow plate-and-fin heat exchanger geometry.



(a) Rectangular



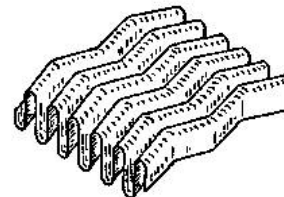
(d) Offset strip fin



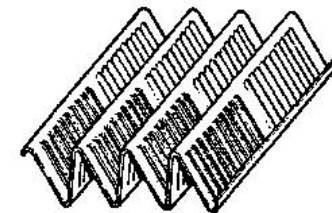
(b) Triangular



(e) Perforated

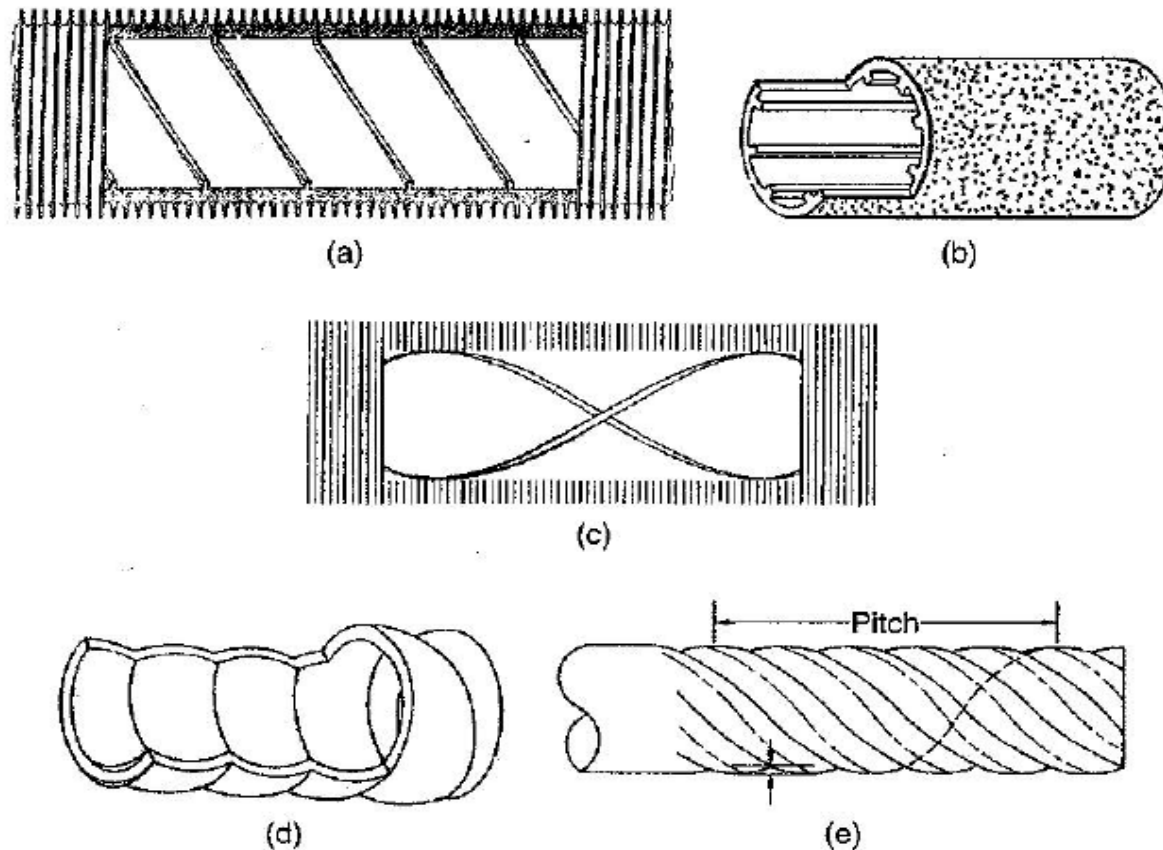


(c) Wavy

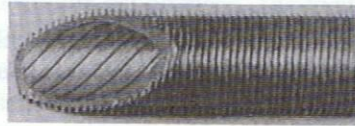


(f) Louvered

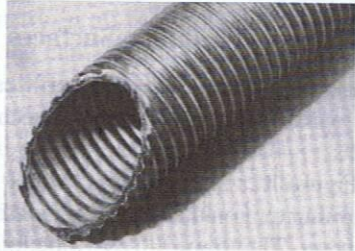
**Figure 5.2** Plate-fin exchanger surface geometries: (a) plain rectangular fins, (b) plain triangular, (c) wavy, (d) offset strip, (e) perforated, (f) louvered. (From Webb [1987].)



**Figure 1.11** Methods used to make doubly enhanced tubes. (a) Helical rib roughness on inner surface and integral fins on outer surface. (b) Internal fins on inner surface and coated (porous boiling surface) on outer surface. (c) Insert device (twisted tape) with integral fins on outer surface. (d) Corrugated inner and outer surfaces. (e) Corrugated strip rolled in tubular form and seam welded. (From Webb [1987].)

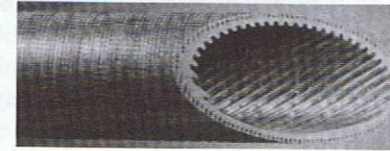


(a)

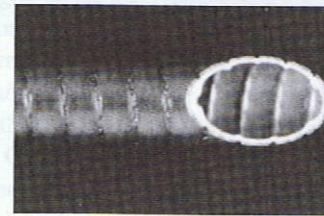


(b)

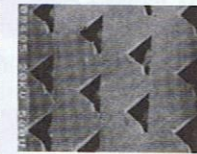
**Figure 1.12** (a) Wolverine Turbo-Chil tube (integral fin outside surface and 10 start heli rib roughness). (b) Wieland NW tube (11 fins/m on outer surface and a wavy inside roughness).



(a)



(b)



(c)

**Figure 1.14** Enhanced boiling tubes: (a) the Wolverine Turbo-B, (b) the Hitachi ThermoExcel-E, and (c) the Wieland TW.



**Figure 1.15** The Ripple-fin, or "microfin" tube having 0.2-mm-high triangular fins. (Photograph courtesy of Wieland-Werke AG.)



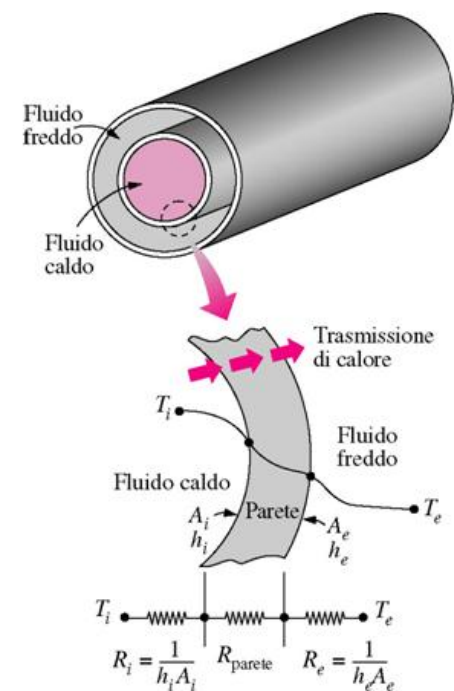
# COEFFICIENTE GLOBALE DI SCAMBIO TERMICO

$$\dot{Q} = UA\Delta T = U_i A_i \Delta T = U_e A_e \Delta T$$

$$UA = \frac{1}{R_{tot}} = \frac{1}{R_i} + \frac{1}{R_{cond}} + \frac{1}{R_2}$$

$$U_i A_i = \frac{1}{\frac{1}{h_i A_i} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi L \lambda} + \frac{1}{h_e A_e}} = U_e A_e$$

$$U_i = U_e \frac{A_e}{A_i}$$



**TABELLA 15.1**

Valori caratteristici dei coefficienti globali di scambio termico negli scambiatori di calore

Tipologia di scambiatore di calore	$U$ , $W/(m^2 \cdot ^\circ C)$
Acqua-acqua	850 ÷ 1700
Acqua-olio	100 ÷ 350
Acqua-benzina o cherosene	300 ÷ 1000
Acqua di alimentazione dei riscaldatori	1000 ÷ 8500
Vapore d'acqua-olio combustibile leggero	200 ÷ 400
Vapore d'acqua-olio combustibile pesante	50 ÷ 200
Condensatore di vapore d'acqua	1000 ÷ 6000
Condensatore di freon (raffreddato ad acqua)	300 ÷ 1000
Condensatore di ammoniaca (raffreddato ad acqua)	800 ÷ 1400
Condensatore di alcool	250 ÷ 700
Gas-gas	10 ÷ 40
Acqua-aria in tubi alettati (acqua nei tubi)	30 ÷ 60*
	400 ÷ 850**
Vapore d'acqua-acqua in tubi alettati (vapore nei tubi)	30 ÷ 300*
	400 ÷ 4000**

\* Relativo alla superficie di scambio lato aria.

\*\* Relativo alla superficie di scambio lato acqua o lato vapore.

## FATTORE DI INCROSTAZIONE - - RESISTENZA ADDIZIONALE

$$U_i A_i = \frac{1}{\frac{1}{h_i A_i}} + \frac{1}{\frac{R_{d,i}}{A_i}} + \frac{1}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi L \lambda}} + \frac{1}{\frac{R_{d,e}}{A_e}} + \frac{1}{\frac{1}{h_e A_e}} = U_e A_e$$

Temperatura di esercizio e della velocità dei fluidi nello scambiatore

$$R_{d,i} = 10^{-4} \frac{m^2 K}{W}$$

$$\lambda_{calcare} = 2.9 \frac{W}{m K}$$

**TABELLA 15.2**

Valori caratteristici dei coefficienti di incrostazione (resistenza termica per unità di area di scambio dovuta ai depositi)

Fluido	$R_{d,i}$ ( $m^2 \cdot ^\circ C/W$ )
Acqua distillata, acqua di mare, acqua di fiume, acqua di alimentazione delle caldaie	
A temperatura inferiore ai 50°C	0.0001
A temperatura superiore ai 50°C	0.0002
Olio combustibile	0.0009
Vapore d'acqua (privo di vapori di olio)	0.0001
Refrigeranti (liquido)	0.0002
Refrigeranti (vapore)	0.0004
Vapori di alcool	0.0001
Aria	0.0004

Fonte: Tubular Exchanger Manufacturers Association

# DIFFERENZA MEDIA LOGARITMICA DI TEMPERATURA

$$\delta\dot{Q} = -\dot{m}_c c_p dT_c = -\dot{m}_f c_f dT_f$$

$$dT_c = -\frac{\delta\dot{Q}}{\dot{m}_c c_p} \quad dT_c - dT_f = d(T_c - T_f) = -\delta\dot{Q} \left( \frac{1}{\dot{m}_c c_p} + \frac{1}{\dot{m}_f c_f} \right)$$

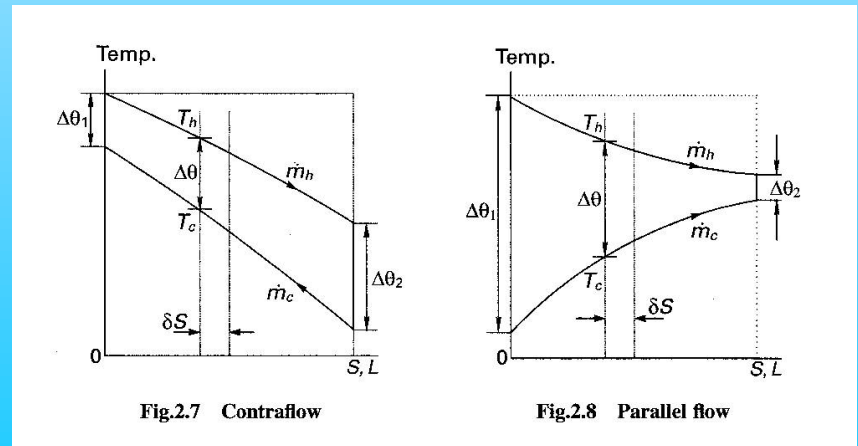
$$dT_f = \frac{\delta\dot{Q}}{\dot{m}_f c_f} \quad \delta\dot{Q} = U(T_c - T_f) dA$$

$$\frac{d(T_c - T_f)}{(T_c - T_f)} = -U dA \left( \frac{1}{\dot{m}_c c_p} + \frac{1}{\dot{m}_f c_f} \right)$$

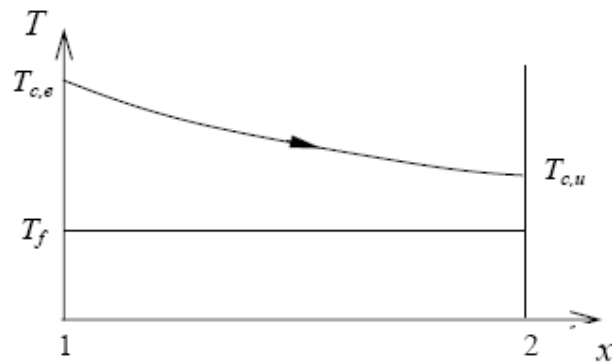
$$\ln \frac{(T_{c,u} - T_{f,u})}{(T_{c,e} - T_{f,e})} = -UA \left( \frac{1}{\dot{m}_c c_p} + \frac{1}{\dot{m}_f c_f} \right)$$

$$\dot{Q} = UA \Delta T_{ml}$$

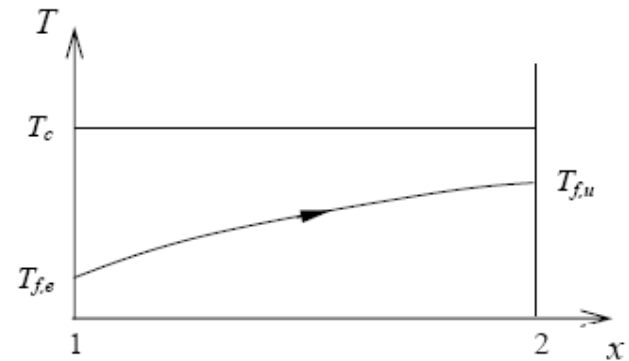
$$\Delta T_{ml} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}$$



# DIFFERENZA MEDIA LOGARITMICA DI TEMPERATURA

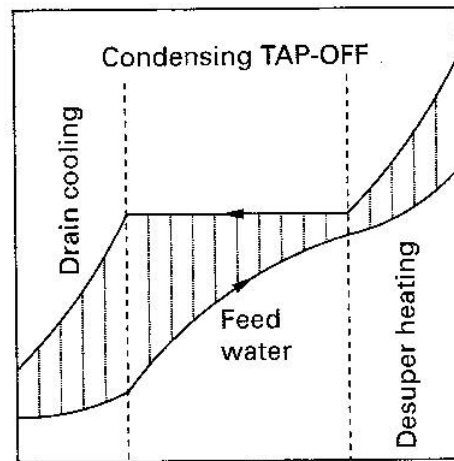


(a) Evaporatore.

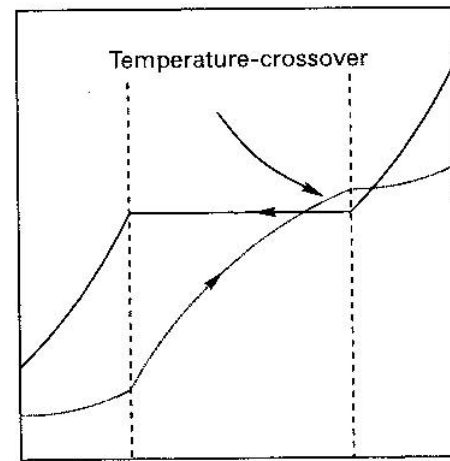


(b) Condensatore.

**Figura 17:** Andamento delle temperature quando un fluido subisce cambiamento di fase.



**Fig.2.5** Desuperheating feed-heater with phase changes



**Fig.2.6** Temperature cross-over in feed-heater

# FATTORE DI CORREZIONE

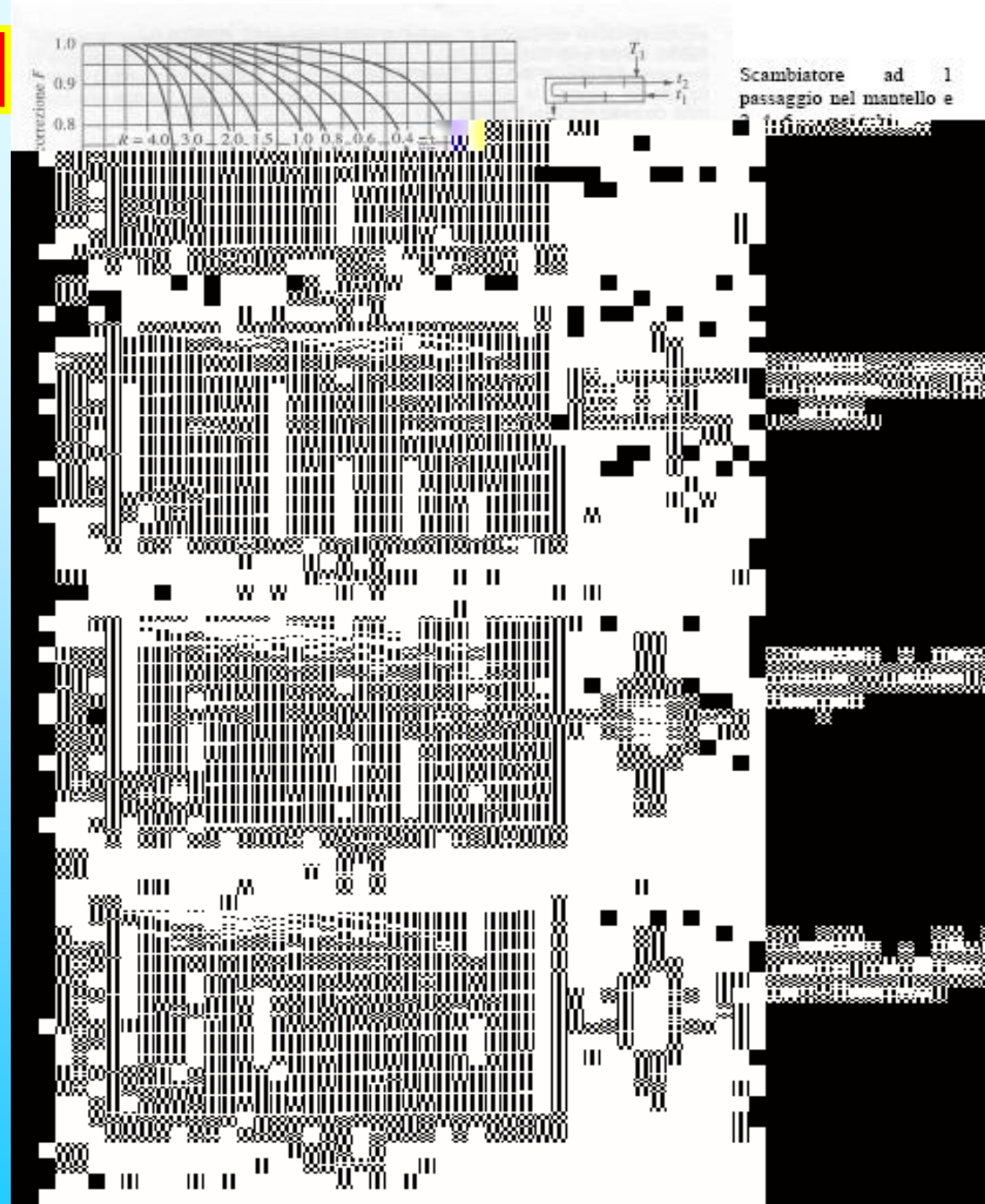
Rispetto alla configurazione in controcorrente

$$\dot{Q} = UAF \Delta T_{ml,cc}$$

$$P = \frac{t_2 - t_1}{T_1 - t_1} \quad 0 < P < 1$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{(\dot{m}c_p)_{\text{lato tubo}}}{(\dot{m}c_p)_{\text{lato mantello}}}$$

$$0 < R < \infty$$



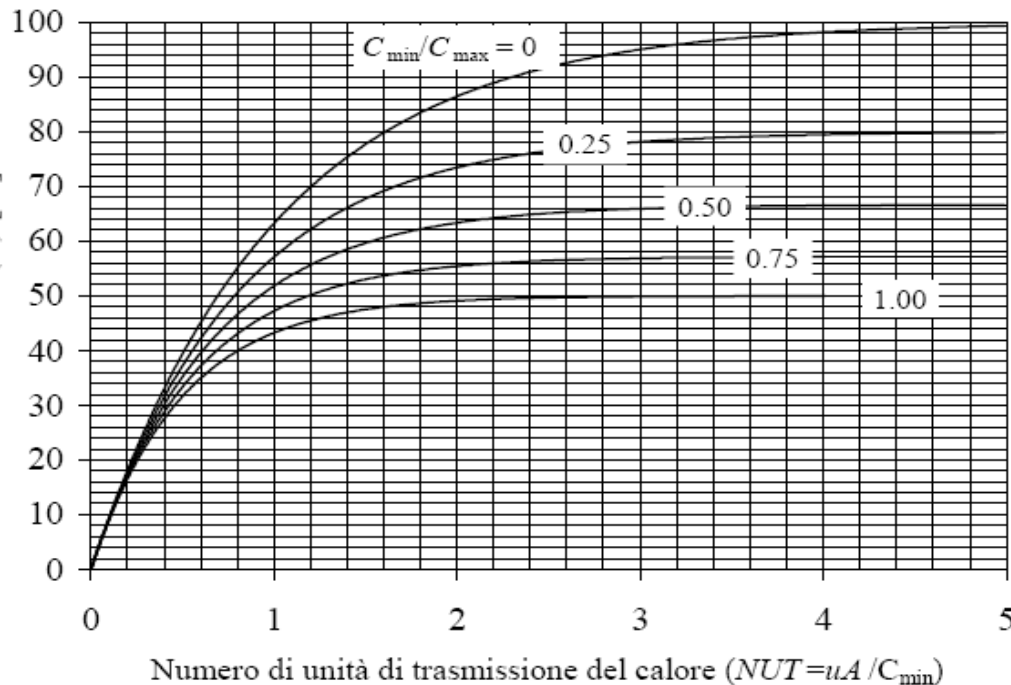
## IL METODO $\varepsilon$ - NTU

$$\varepsilon = \frac{Q_{scambiato}}{Q_{Max\ scambiabile}} = \frac{(m c_p)_c (T_{ci} - T_{cu})}{(m c_p)_{\min} (T_{ci} - T_{fi})} = \frac{(m c_p)_f (T_{fi} - T_{fu})}{(m c_p)_{\min} (T_{ci} - T_{fi})}$$

$$\varepsilon \equiv \frac{W_t}{W_{t,max}} \quad (0 < \varepsilon < 1)$$

$$W_{t,max} = C_f (T_{c,e} - T_{f,e}) \quad (\text{se } C_c > C_f)$$

$$W_{t,max} = C_c (T_{c,e} - T_{f,e}) \quad (\text{se } C_c < C_f)$$

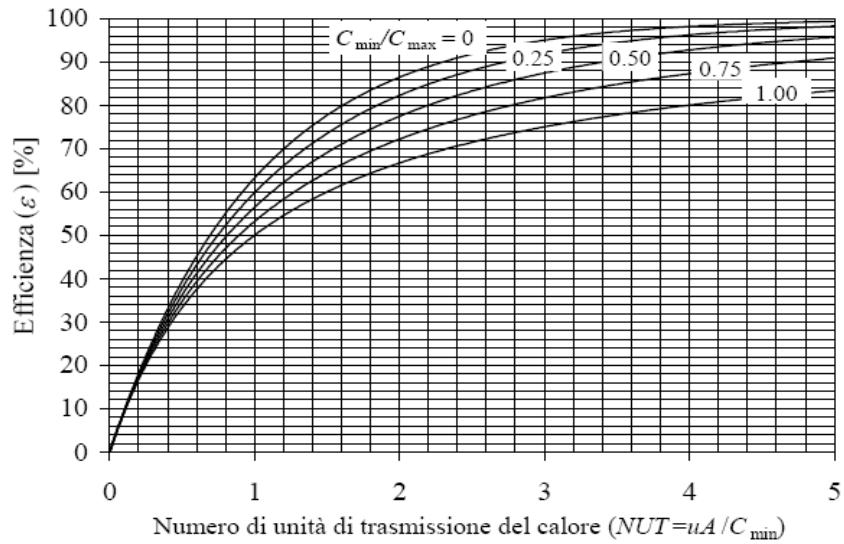


$$W_{t,max} = C_{\min} (T_{c,e} - T_{f,e})$$

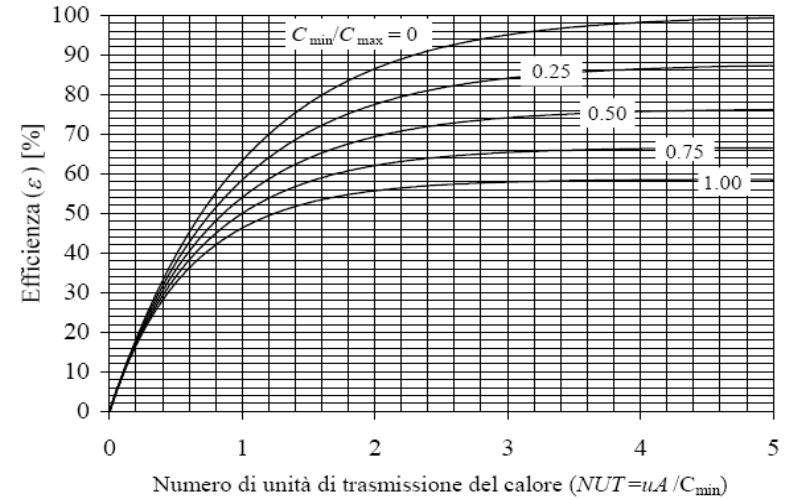
$$NUT \equiv \frac{uA}{C_{\min}} = \frac{1}{R_t C_{\min}}$$

$$C = \frac{C_{\min}}{C_{\max}}$$

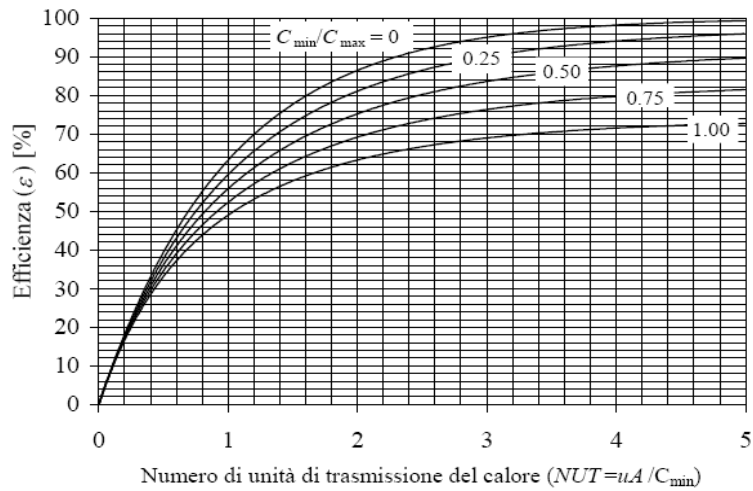
$$\varepsilon = f(NUT, C)$$



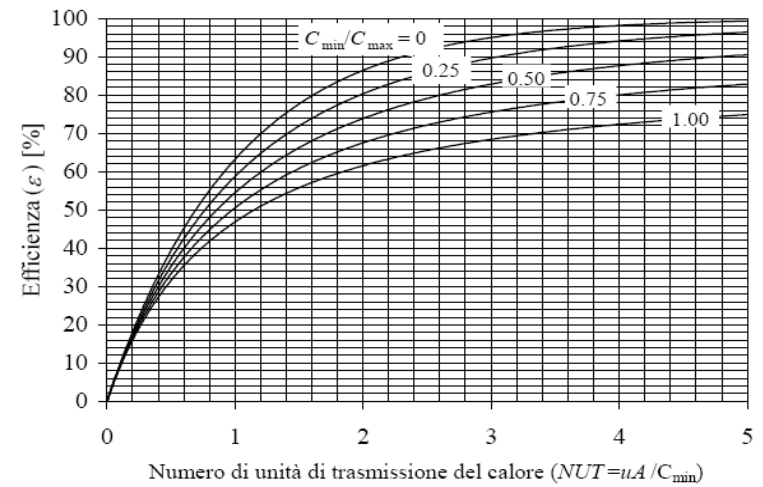
**Figura 11:** Efficienza di uno scambiatore di calore a controcorrente.



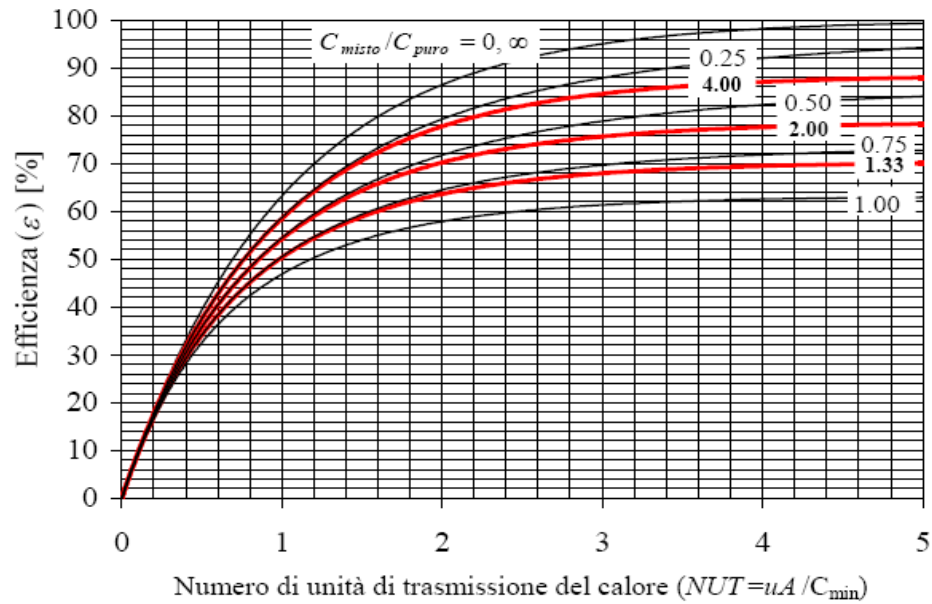
**Figura 12:** Efficienza di uno scambiatore ad 1 passaggio nel mantello e 2, 4, 6, ... nei tubi.



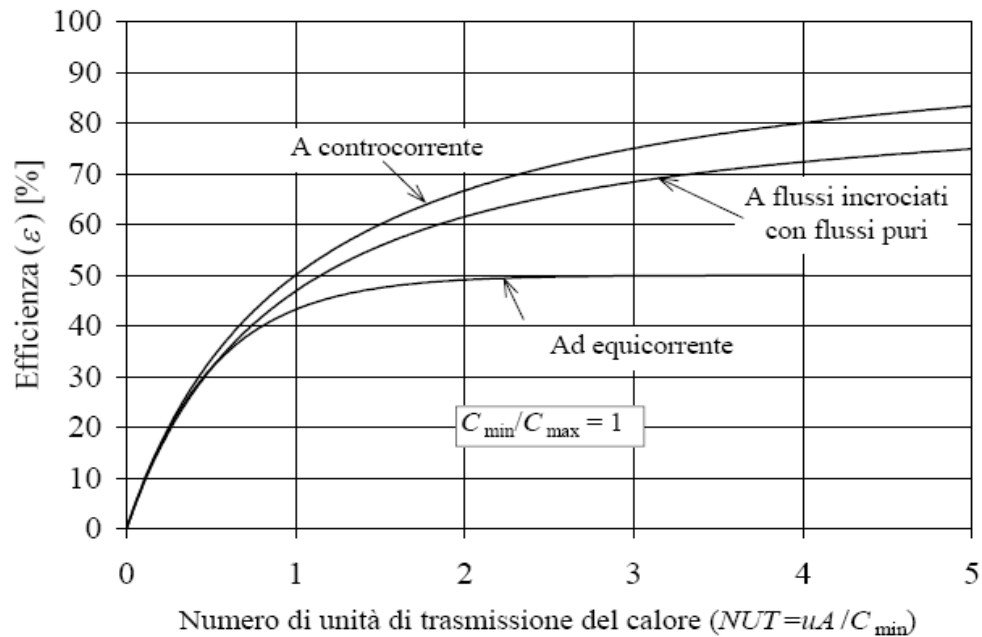
**Figura 13:** Efficienza di uno scambiatore a 2 passaggi nel mantello e 4, 8, 12, ... nei tubi.



**Figura 14:** Efficienza di uno scambiatore a flussi incrociati con entrambi i fluidi puri.



**Figura 15:** Efficienza di uno scambiatore a flussi incrociati con un fluido puro e l'altro misto.





**TABELLA 15.4**

Relazioni che permettono di valutare l'efficacia degli scambiatori di calore:

$$NTU = UA/C_{\min} \text{ e } C = C_{\min}/C_{\max} = (\dot{m} c_p)_{\min} / (\dot{m} c_p)_{\max}$$

Tipologia di scambiatore di calore	Relazione per l'efficacia
<b>1. A doppio tubo</b>	
In equicorrente	$\varepsilon = \frac{1 - \exp[-NTU(1+C)]}{1+C}$
In controcorrente	$\varepsilon = \frac{1 - \exp[-NTU(1-C)]}{1 - C \exp[-NTU(1-C)]}$
<b>2. A tubi e mantello</b>	
Un passaggio nel mantello e 2, 4 ... nei tubi	
	$\varepsilon = 2 \left\{ 1 + C + \sqrt{1+C^2} \frac{1 + \exp[-NTU\sqrt{1+C^2}]}{1 - C \exp[-NTU\sqrt{1+C^2}]} \right\}^{-1}$
<b>3. A flussi incrociati (singolo passaggio)</b>	
Entrambi i flussi puri	
	$\varepsilon = 1 - \exp \left\{ \frac{NTU^{0.22}}{C} [\exp(-CNTU^{0.78}) - 1] \right\}$
$C_{\max}$ misto, $C_{\min}$ puro	$\varepsilon = \frac{1}{C} (1 - \exp[-C(1 - \exp(-NTU))])$
$C_{\min}$ misto, $C_{\max}$ puro	$\varepsilon = 1 - \exp \left\{ -\frac{1}{C} [1 - \exp(-CNTU)] \right\}$
<b>4. Qualsiasi scambiatore di calore con <math>C = 0</math></b>	$\varepsilon = 1 - \exp(-NTU)$

**1. A doppio tubo**

In equicorrente

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

In controcorrente

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

**2. A tubi e mantello**

Un passaggio nel mantello e 2, 4 ... nei tubi

$$\varepsilon = 2 \left\{ 1 + C + \sqrt{1+C^2} \frac{1 + \exp[-NTU\sqrt{1+C^2}]}{1 - C \exp[-NTU\sqrt{1+C^2}]} \right\}^{-1}$$

**3. A flussi incrociati (singolo passaggio)**

Entrambi i flussi puri

$$\varepsilon = 1 - \exp \left\{ \frac{NTU^{0.22}}{C} [\exp(-CNTU^{0.78}) - 1] \right\}$$

 $C_{\max}$  misto,  $C_{\min}$  puro

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

 $C_{\min}$  misto,  $C_{\max}$  puro

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

**4. Qualsiasi scambiatore di calore con  $C = 0$**   $\varepsilon = 1 - \exp(-NTU)$

**TABELLA 15.5**

Relazioni che permettono di valutare NTU per gli scambiatori di calore:

$$NTU = UA/C_{\min} \quad \text{e} \quad C = C_{\min} / C_{\max} = (\dot{m} c_p)_{\min} / (\dot{m} c_p)_{\max}$$

Tipologia di scambiatore di calore	Relazione per l'efficacia
<b>1. A doppio tubo</b>	
In equicorrente	$NTU = \frac{\ln[1 - \varepsilon(1 + C)]}{1 + C}$
In controcorrente	$NTU = \frac{1}{C - 1} \ln \left( \frac{\varepsilon - 1}{\varepsilon C - 1} \right)$
<b>2. A tubi e mantello</b>	
Un passaggio nel mantello e 2, 4 ... nei tubi	$NTU = \frac{1}{\sqrt{1 + C^2}} \ln \left( \frac{2/\varepsilon - 1 - C - \sqrt{1 + C^2}}{2/\varepsilon - 1 - C + \sqrt{1 + C^2}} \right)$
<b>3. A flussi incrociati (singolo passaggio)</b>	
$C_{\max}$ misto, $C_{\min}$ puro	$NTU = -\ln \left[ 1 + \frac{\ln(1 - \varepsilon C)}{C} \right]$
$C_{\min}$ misto, $C_{\max}$ puro	$NTU = -\frac{\ln[C \ln(1 - \varepsilon) + 1]}{C}$
<b>4. Qualsiasi scambiatore di calore con <math>C = 0</math></b>	$NTU = -\ln(1 - \varepsilon)$