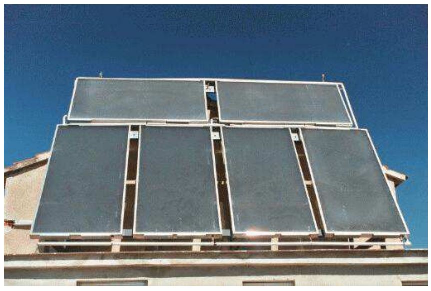
11. GAIA

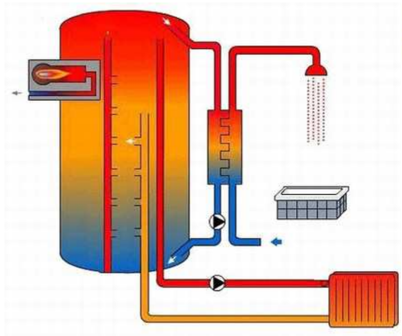
BERO-TRUKAGAILUAK

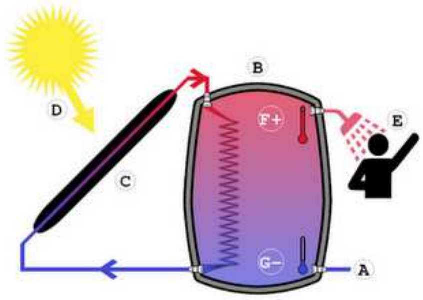
11.0 - HELBURUAK

- **Bero-trukagailu motak** bereizi eta sailkatu
- Gainazaletan metakinak pilatzeak duen eraginaz jabetu eta bero-trukagailu baten **bero-transferentziaren koefiziente orokorra** kalkulatu
- Bero-trukagailuen **energia-analisi orokorrak** egin
- **LMTD metodoan** erabiltzeko **batez besteko tenperatura-diferentzia logaritmikoaren** erlazioa lortu, eta bero-trukagailu desberdinetarako moldatu, **zuzenketa-faktoreak** erabiliz
- Eraginkortasun-erlazioak garatu, eta bero-trukagailuak **eraginkortasun-NTU metodoarekin** analizatu, irteera-tenperatura ezezaguna denean
- Bero-trukagailuak aukeratzeko **oinarrizko irizpideak** zein diren jakin.

11.1 – BERO-TRUKAGAILU MOTAK

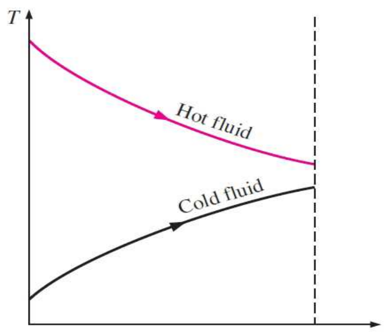


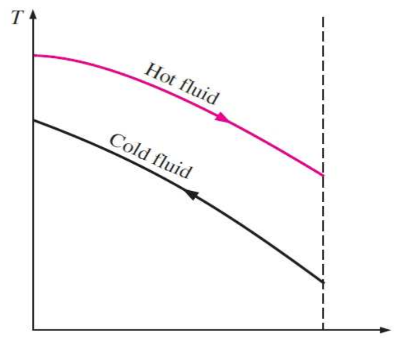


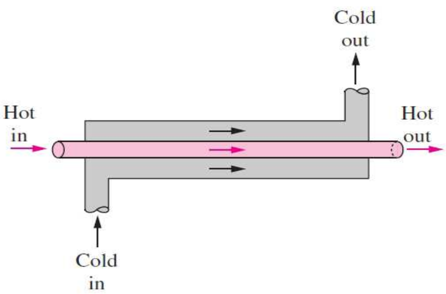


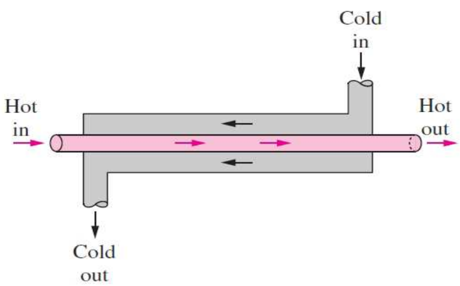
11.1 – BERO-TRUKAGAILU MOTAK

• **Hodi bikoitzeko** bero-trukagailuak → Konfiguraziorik sinpleena









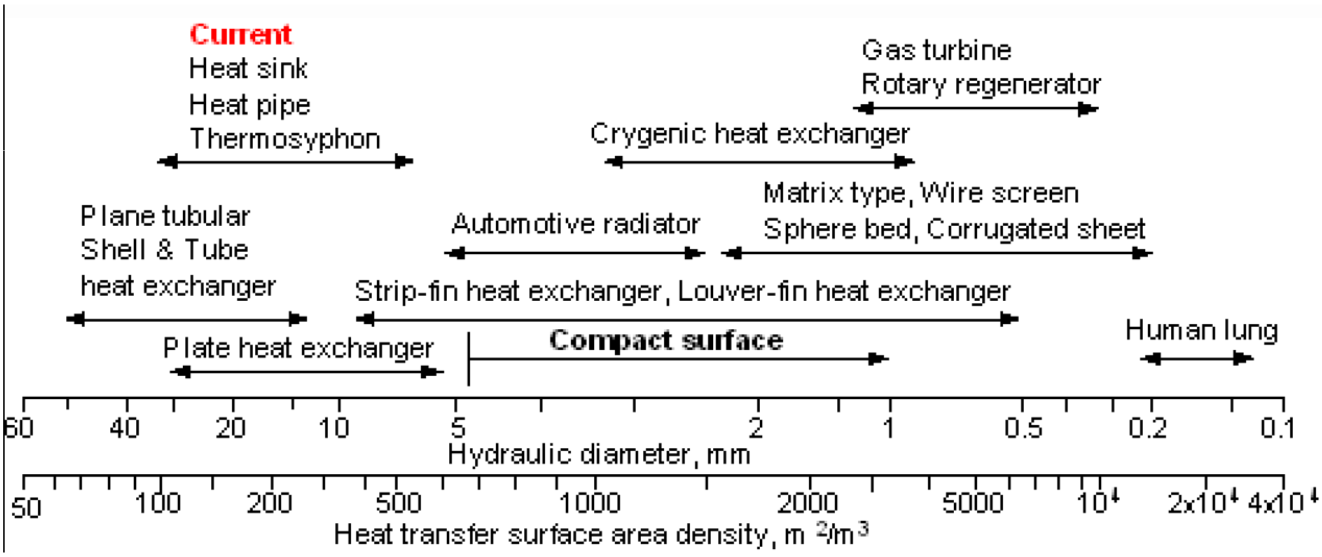
Fluxu paraleloa

Kontrako fluxua

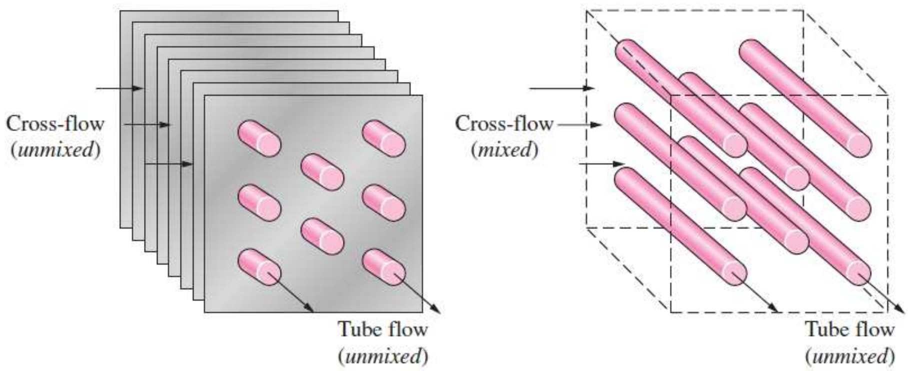
- Bero trukagailu **trinkoa** →

$$\beta = \frac{A_S}{Vol} > 700\, m^2/m^3$$

↓ Azalera-dentsitatea

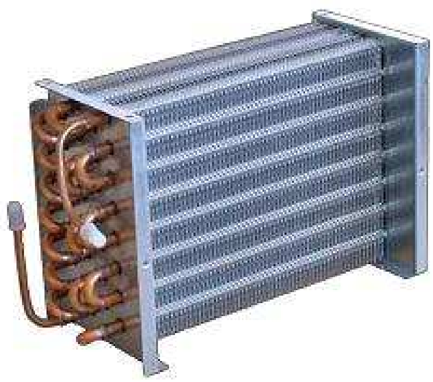


- **Fluxu-gurutzatuko** bero trukagailua

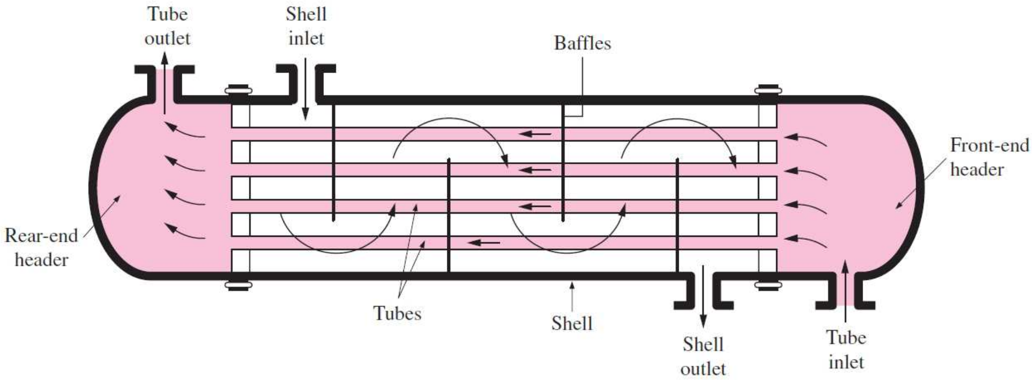


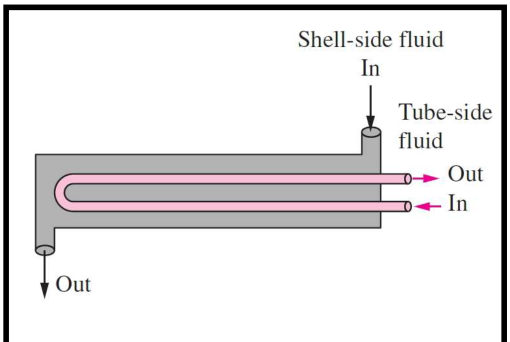
(a) Both fluids unmixed

(b) One fluid mixed, one fluid unmixed

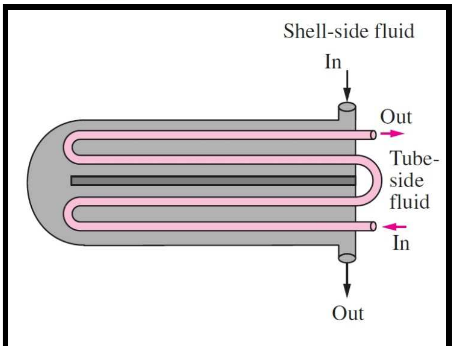


- **Karkasa eta hodi** erako bero-trukagailua



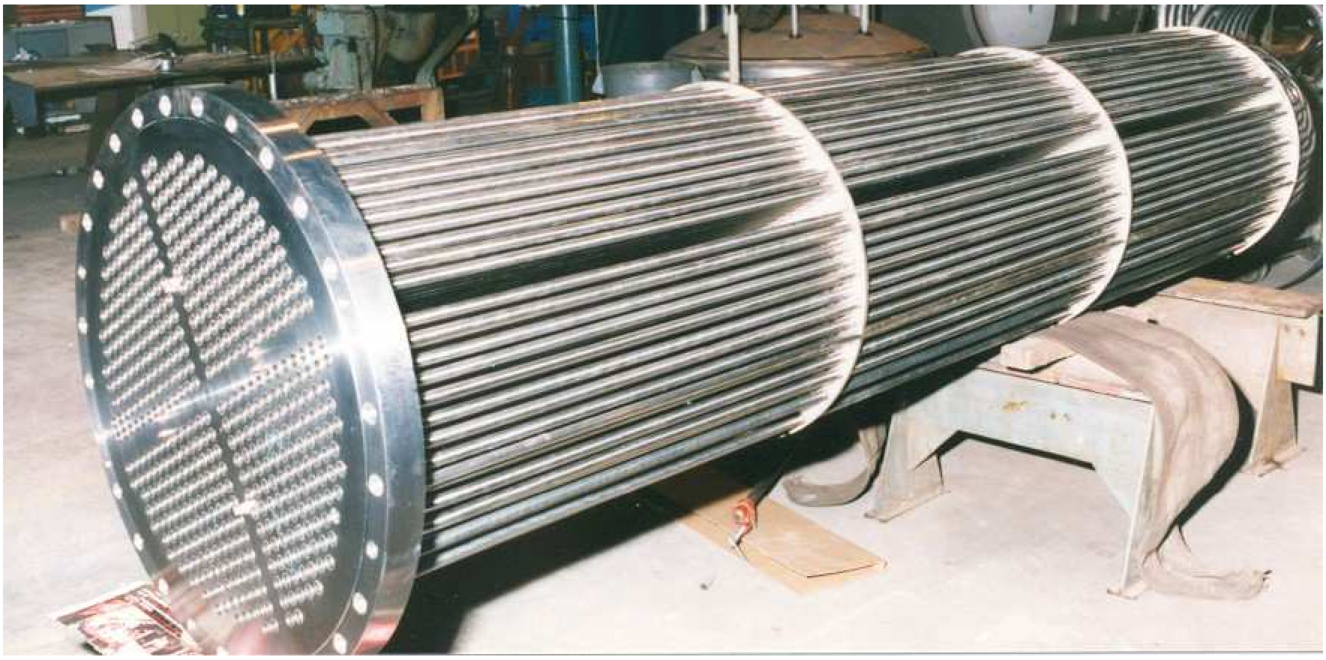


(*a*) One-shell pass and two-tube passes



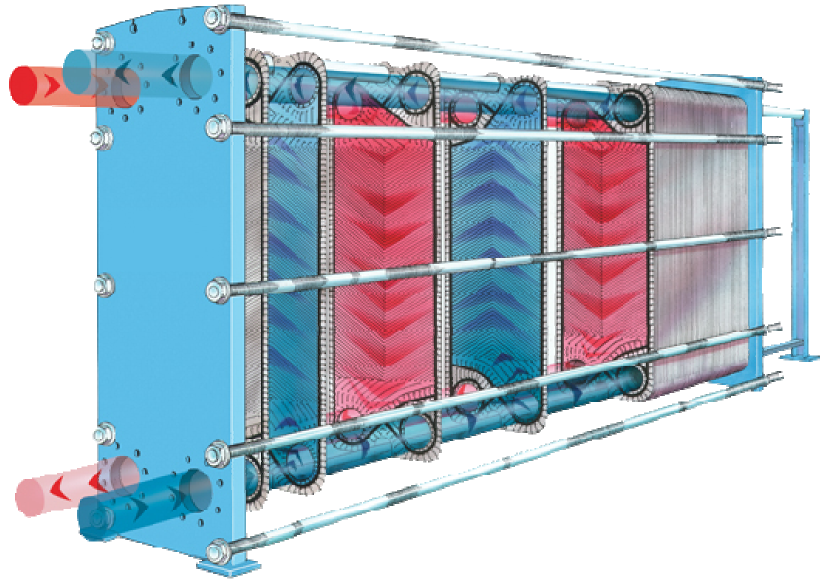
(*b*) Two-shell passes and four-tube passes

- **Karkasa eta hodi** erako bero-trukagailua



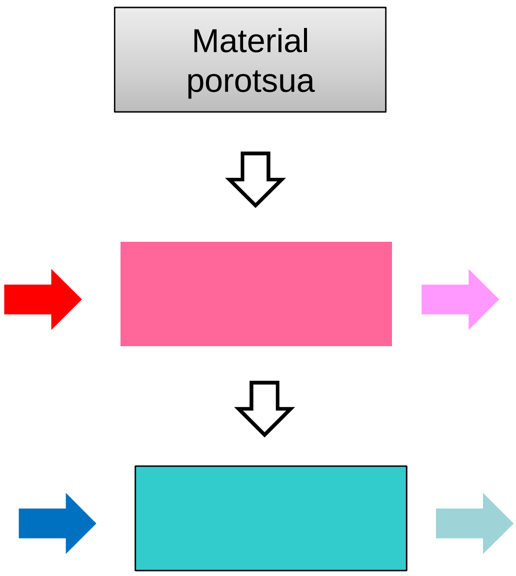
11.1 – BERO-TRUKAGAILU MOTAK

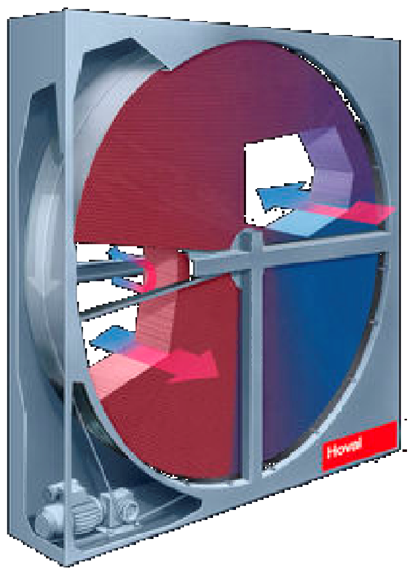
- **Xafla eta bastidore** bero-trukagailuak



11.1 – BERO-TRUKAGAILU MOTAK

- **Birsorgailu** bero-trukagailuak

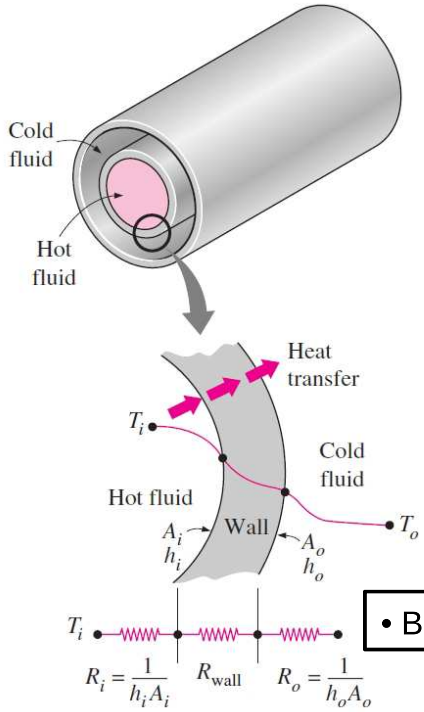




Estatikoa

Dinamikoa

Bero-trukagailuetan → Kondukzio, konbekzio eta erradiazio motako bero-transferentziak (azken biak orokorrean konbinatzen dira).



$$R_{total} = R_i + R_{wall} + R_o \Rightarrow$$

$$\Rightarrow R_{total} = \frac{1}{h_i A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{1}{h_o A_o}$$

$$\dot{Q} = \frac{\Delta T}{R_{total}} = UA\Delta T = U_i A_i \Delta T = U_o A_o \Delta T$$

• Baldin $R_{wall} \cong 0$: → $A \cong A_i \cong A_o$ → $\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$

Representative values of the overall heat transfer coefficients in heat exchangers

Type of heat exchanger	U, W/m^2 · °C*
Water-to-water	850–1700
Water-to-oil	100–350
Water-to-gasoline or kerosene	300–1000
Feedwater heaters	1000–8500
Steam-to-light fuel oil	200–400
Steam-to-heavy fuel oil	50–200
Steam condenser	1000–6000
Freon condenser (water cooled)	300–1000
Ammonia condenser (water cooled)	800–1400
Alcohol condensers (water cooled)	250–700
Gas-to-gas	10–40
Water-to-air in finned tubes (water in tubes)	30–60†
	400–850†
Steam-to-air in finned tubes (steam in tubes)	30–300†
	400–4000‡

*Multiply the listed values by 0.176 to convert them to Btu/h · ft^2 · °F.

†Based on air-side surface area.

‡Based on water- or steam-side surface area.

$$\text{Hegal laburra } (T_s = \text{cte}) \rightarrow A_s = A_{unfinned} + A_{fin}$$

$$\text{Hegal luzea } (T_s \neq \text{cte}) \rightarrow A_s = A_{unfinned} + \eta_{fin} A_{fin}$$

11.2 – BERO-TRANSFERENTZIAREN KOEFIZIENTE OROKORRA

METAKETA-FAKTOREA (zikintze faktorea)

Metaketa motak:

- ✓ Metakin solidoen prezipitatzea
- ✓ Korrosioa eta kimikoa
- ✓ Biologikoa

→ **Metaketa faktorea R_f**

(erresistentzia gehigarria)

$$R_{total} = \frac{1}{UA_s} = \frac{1}{h_i A_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi k L} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o A_o}$$

(*Source:* Tubular Exchange Manufacturers Association.)

Fluid	R_f, m^2 · °C/W
Distilled water, sea water, river water, boiler feedwater:	
Below 50°C	0.0001
Above 50°C	0.0002
Fuel oil	0.0009
Steam (oil-free)	0.0001
Refrigerants (liquid)	0.0002
Refrigerants (vapor)	0.0004
Alcohol vapors	0.0001
Air	0.0004

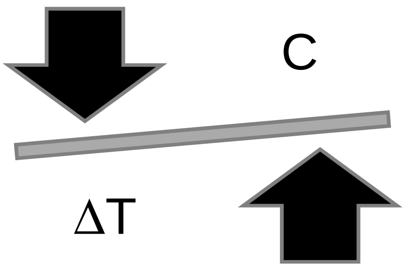
11.3 – BERO-TRUKAGAILUEN ANALISIA

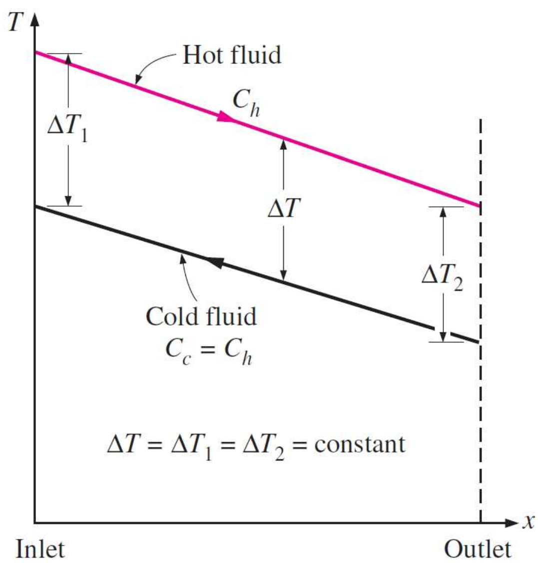
$$\dot{Q} = \dot{m}_c c_{pc} (T_{c,out} - T_{c,in})$$ ⇨ **Jariakin hotza** (berotzen dena)

$$\dot{Q} = \dot{m}_h c_{ph} (T_{h,in} - T_{h,out})$$ ⇨ **Jariakin beroa** (hozten dena)

Bero-ahalmena

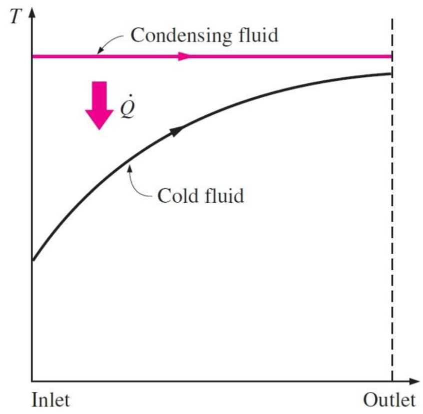
$$C_i = \dot{m}_i c_{pi} \quad \begin{cases} C_h = \dot{m}_h c_{ph} \\ C_c = \dot{m}_c c_{pc} \end{cases}$$



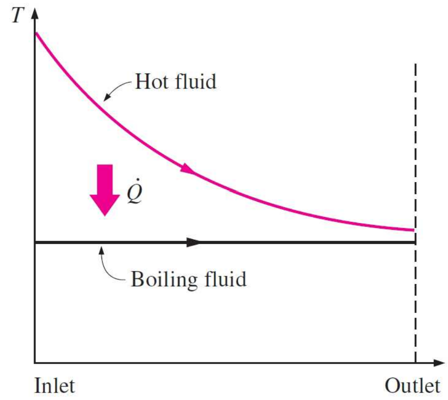


11.3 – BERO-TRUKAGAILUEN ANALISIA

- **Bero-transferentzia sentikorra** (ΔT) ⟹ $\dot{Q} = \dot{m} c_p \Delta T$
- **Bero-transferentzia sorra** (T=cte) ⟹ $\dot{Q} = \dot{m} h_{fg}$



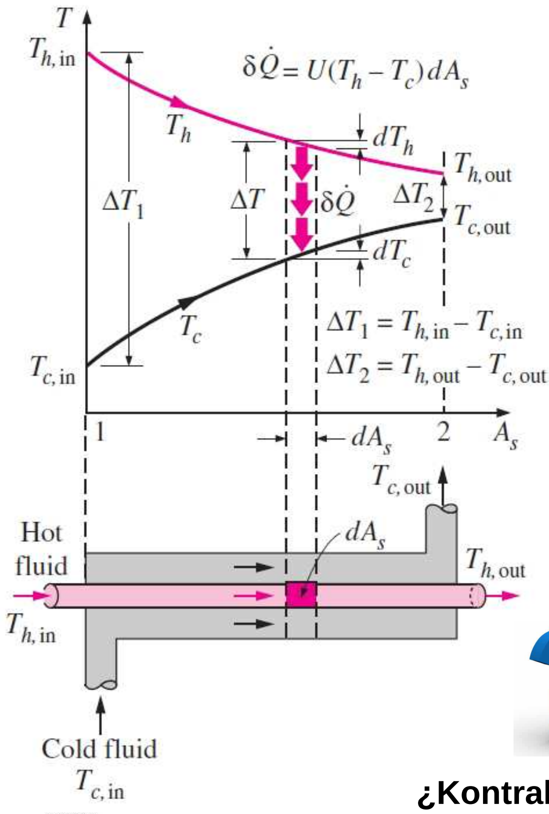
(a) Condenser ($C_h \to \infty$)



(b) Boiler ($C_c \to \infty$)

$$\dot{Q} = U A_s \Delta T_m$$

11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA



$$\begin{cases} \delta\dot{Q} = -\dot{m}_h c_{ph} dT_h \\ \delta\dot{Q} = \dot{m}_c c_{pc} dT_c \\ \delta\dot{Q} = U\left(T_h - T_c\right) dA_s \end{cases}$$

⇓

$$\dot{Q} = U A_s \Delta T_{lm}$$

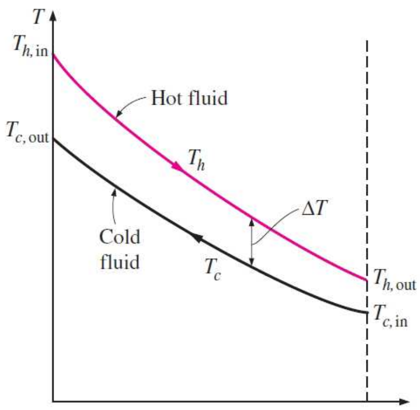
$$\Delta T_{lm} = \frac{\Delta T_{in} - \Delta T_{out}}{\ln\left(\dfrac{\Delta T_{in}}{\Delta T_{out}}\right)}$$

¿Kontrako fluxuan?

$$\text{OHARRA} : \Delta T_{lm} < \Delta T_{am}$$

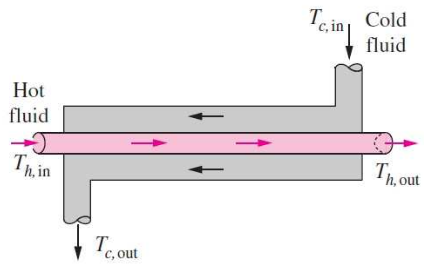
11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

KONTRAKO FLUXUKO BERO-TRUKAGAILUAK



Sarrerako eta irteerako tenperaturak berdinak izanik:

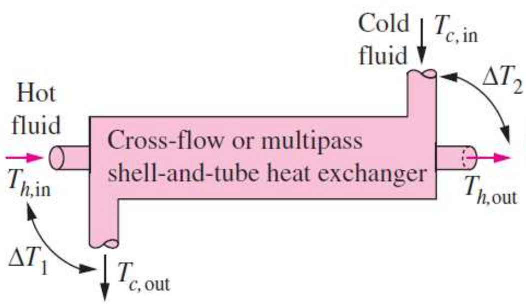
$$\Delta T_{lm,CF} > \Delta T_{lm,PF}$$



$C_h = C_c \rightarrow \Delta T_{lm}$?

11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

IRAGANALDI ANITZEKO ETA FLUXU GURUTZATUKO BERO TRUKAGAILUAK: ZUZENKETA-FAKTOREEN ERABILERA

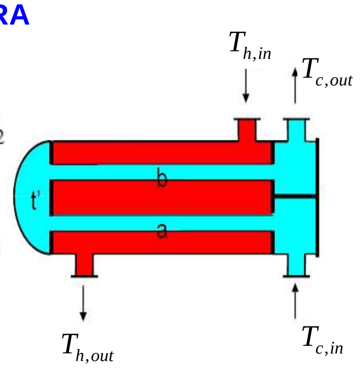


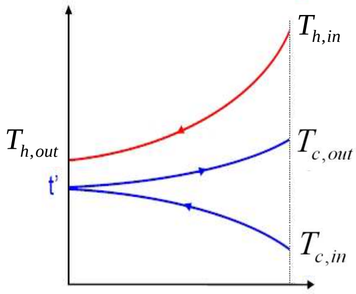
Heat transfer rate:

$$\dot{Q} = UA_s F \Delta T_{lm,CF}$$

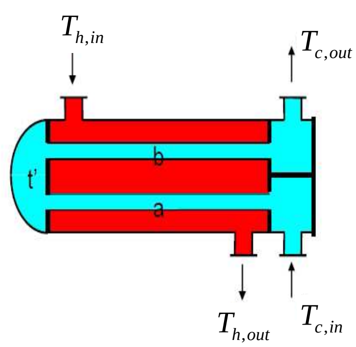
where
$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$$
$$\Delta T_1 = T_{h,in} - T_{c,out}$$
$$\Delta T_2 = T_{h,out} - T_{c,in}$$

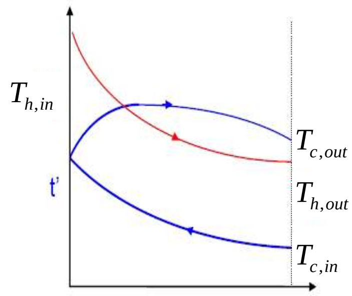
and $F = \ldots$ (Fig. 13–18)





- a: *Parallel flow*
- b: *Counter flow*

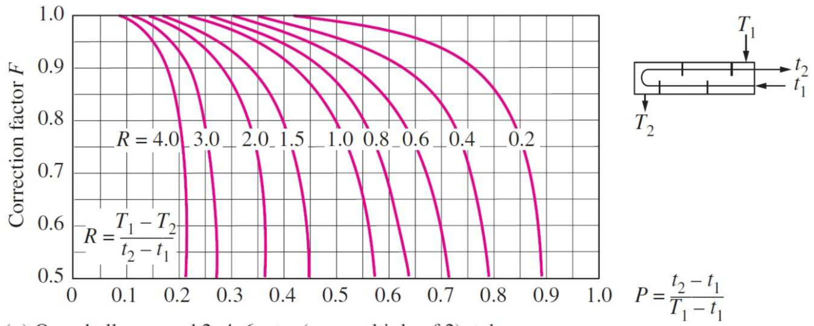




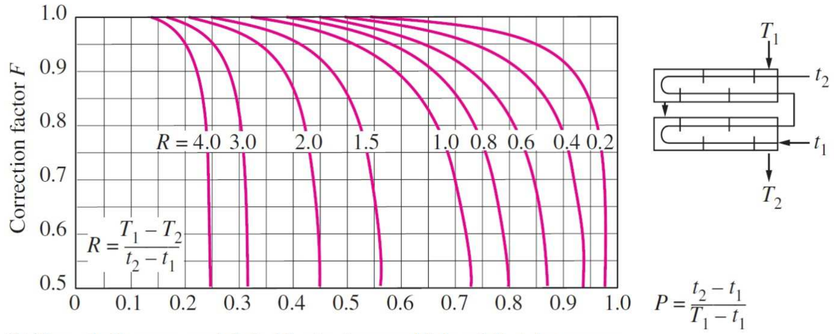
- a: *Parallel flow*
- b: *Counter flow*

11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

IRAGANALDI ANITZEKO ETA FLUXU GURUTZATUKO BERO TRUKAGAILUAK: ZUZENKETA-FAKTOREEN ERABILERA



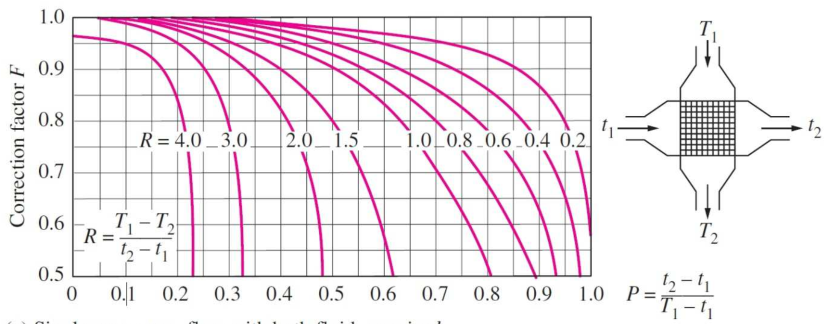
(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



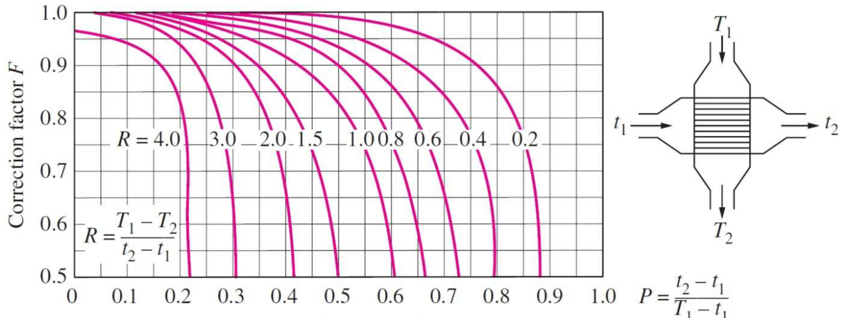
(*b*) Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes

11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

IRAGANALDI ANITZEKO ETA FLUXU GURUTZATUKO BERO TRUKAGAILUAK: ZUZENKETA-FAKTOREEN ERABILERA



(*c*) Single-pass cross-flow with both fluids *unmixed*



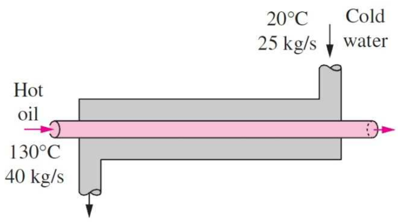
(*d*) Single-pass cross-flow with one fluid *mixed* and the other *unmixed*

LMTD metodoa ⇨ Tenperatura ezagunak ⇨ Emariak eta U kalkulatu ⇨ Bero-trukagailuaren tamaina kalkulatu (A_s)

Irteerako tenperatura edo Q ezezagunak
- **LMTD metodoa** ⇨ Ebazpen iteratiboa
- **Método ε - NTU** ⇨ Ebazpen zuzena

$$\varepsilon = \frac{\text{Bero-transferentzia abiadura erreala}}{\text{Bero-transferentzia abiadura maximoa}} = \frac{\dot{Q}}{\dot{Q}_{max}}$$

$$\dot{Q}_{max} = C_{min}\left(T_{h,in} - T_{c,in}\right)$$



$C_c = \dot{m}_c C_{pc} = 104.5$ kW/°C

$C_h = \dot{m}_c C_{ph} = 92$ kW/°C

$C_{min} = 92$ kW/°C

$\Delta T_{max} = T_{h,in} - T_{c,in} = 110$°C

$\dot{Q}_{max} = C_{min}\,\Delta T_{max} = 10{,}120$ kW

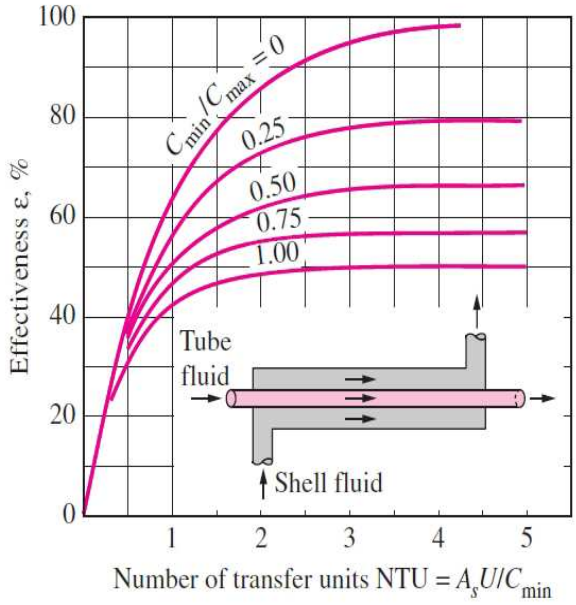
$$NTU = \frac{UA_s}{C_{min}}$$

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

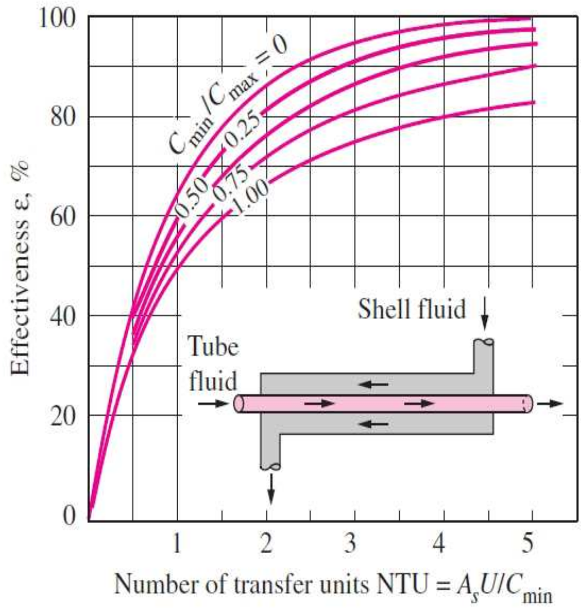
$$\varepsilon = \varepsilon(NTU, c)$$

Effectiveness relations for heat exchangers: NTU $= UA_s/C_{min}$ and $c = C_{min}/C_{max} = (\dot{m}C_p)_{min}/(\dot{m}C_p)_{max}$ (Kays and London, Ref. 5.)

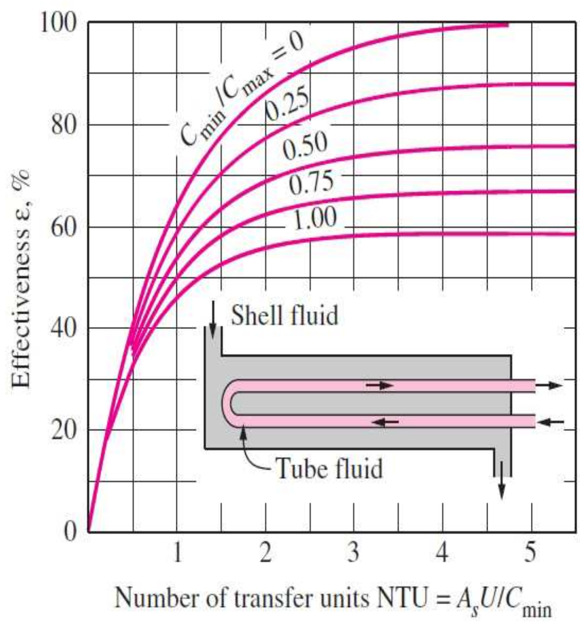
Heat exchanger type	Effectiveness relation
1 *Double pipe:* Parallel-flow	$\varepsilon = \dfrac{1 - \exp[-\text{NTU}(1+c)]}{1+c}$
Counter-flow	$\varepsilon = \dfrac{1 - \exp[-\text{NTU}(1-c)]}{1 - c\exp[-\text{NTU}(1-c)]}$
2 *Shell and tube:* One-shell pass 2, 4, . . . tube passes	$\varepsilon = 2\left\{1 + c + \sqrt{1+c^2}\,\dfrac{1+\exp[-\text{NTU}\sqrt{1+c^2}]}{1-\exp[-\text{NTU}\sqrt{1+c^2}]}\right\}^{-1}$
3 *Cross-flow (single-pass)* Both fluids unmixed	$\varepsilon = 1 - \exp\left\{\dfrac{\text{NTU}^{0.22}}{c}[\exp(-c\ \text{NTU}^{0.78}) - 1]\right\}$
C_{max} mixed, C_{min} unmixed	$\varepsilon = \dfrac{1}{c}(1 - \exp\{1 - c[1 - \exp(-\text{NTU})]\})$
C_{min} mixed, C_{max} unmixed	$\varepsilon = 1 - \exp\left\{-\dfrac{1}{c}[1 - \exp(-c\ \text{NTU})]\right\}$
4 *All heat exchangers with c = 0*	$\varepsilon = 1 - \exp(-\text{NTU})$



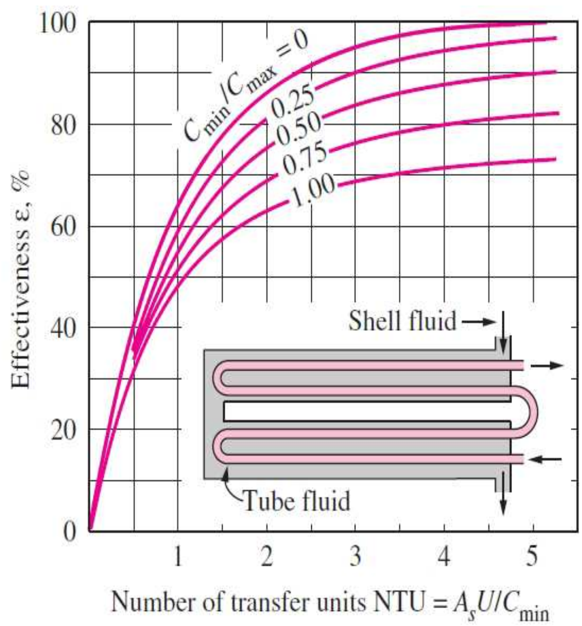
100
80
60
40
20
0
Effectiveness ε, %
$C_{min}/C_{max} = 0$
0.25
0.50
0.75
1.00
Tube fluid
Shell fluid
1
2
3
4
5
Number of transfer units NTU = A_sU/C_{min}



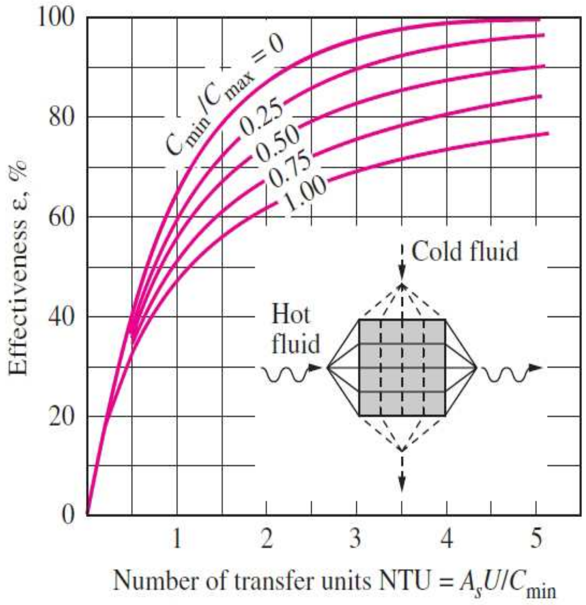
100
80
60
40
20
0
Effectiveness ε, %
$C_{min}/C_{max} = 0$
0.25
0.50
0.75
1.00
Shell fluid
Tube fluid
1
2
3
4
5
Number of transfer units NTU = A_sU/C_{min}

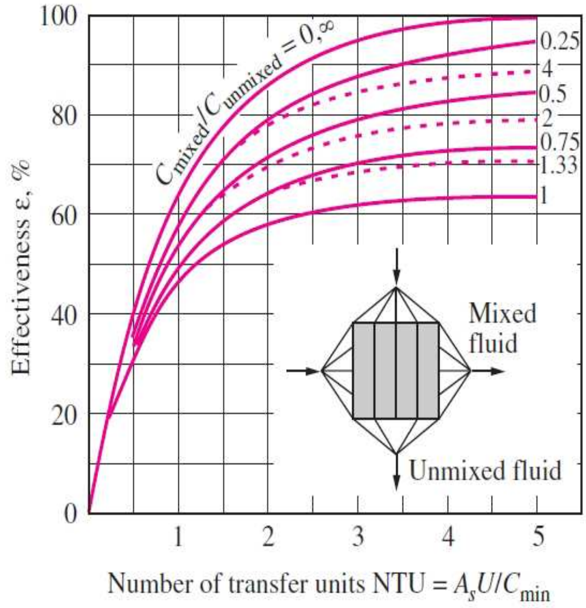


100
80
60
40
20
0
Effectiveness ε, %
$C_{min}/C_{max} = 0$
0.25
0.50
0.75
1.00
Shell fluid
Tube fluid
1
2
3
4
5
Number of transfer units NTU = A_sU/C_{min}



100
80
60
40
20
0
Effectiveness ε, %
$C_{min}/C_{max} = 0$
0.25
0.50
0.75
1.00
Shell fluid
Tube fluid
1
2
3
4
5
Number of transfer units NTU = A_sU/C_{min}

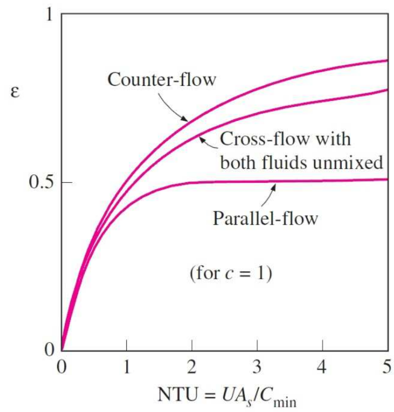




Iruzkinak:

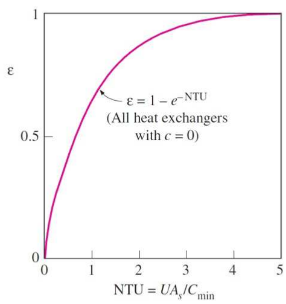
1. NTU ↓ → Δε ↑ , baina NTU ↑ → Δε ↓ → (justifikazio ekonomikoa NTU < 3)

2. NTU eta c zehatz batzuetarako →



3. NTU < 0.3 denean → ε = ε (NTU)

4. c = 0 denean → $\varepsilon_{max} = 1 - \exp(-NTU)$



11.6 – BERO-TRUKAGAILUEN AUKERAKETA

• U-ren kalkulua %30-eko ziurgabetasuna → Bero-trukagailuen gaindimentsionaketa

• $\varepsilon \uparrow \rightarrow \Delta P \uparrow$

Jariakin biskosoena:

¿Hodien barnealdetik edo karkasatik?

BERO-TRANSFERENTZIAREN ABIADURA

$$\dot{Q}_{\max} = \dot{m} c_p \left(T_{in} - T_{out} \right)$$

KOSTUA

• Eskaerapeko bero-trukagailuaren kostua >> Seriean egindako bero-trukagailuaren kostua

• Operazio + Mantentze lanak

11.6 – BERO-TRUKAGAILUEN AUKERAKETA

PONPATZE-POTENTZIA

• Operazio lanak = Ponpatze potentzia [kW] x Operazio-orduak [h] x Elektrizitatearen kostua energia unitateko [€/kWh]

• Operazio lanak vs Hasierako kostua

• Abiadura muga → Higadura, zarata, bibrazioak eta presio galerak txikitzeko.

TAMAINA ETA PISUA

• Tamaina ↑ → Prezioa ↑

MOTA

• Erabiliko ditugun jariakin moten eta daukagun espazioaren araberakoa.

MATERIALAK

• Tentsio-efektu termikoak (dilatazioak)

• Korrosioarekiko erresistentzia

11.7 – IRAKATSIKO EZ DIREN ATALAK