

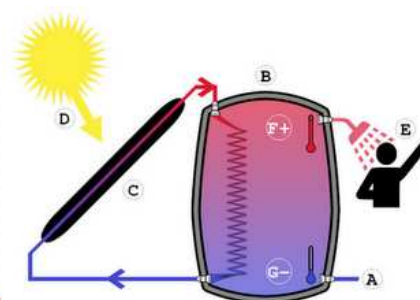
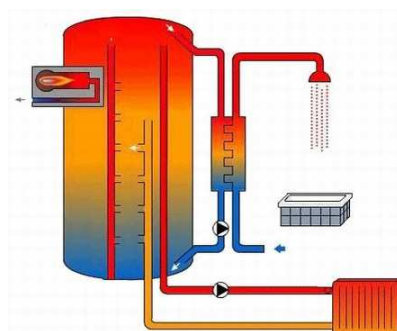
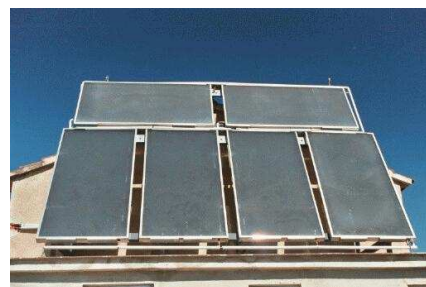
11. GAIA

BERO-TRUKAGAILUAK

11.0 - HELBURUAK

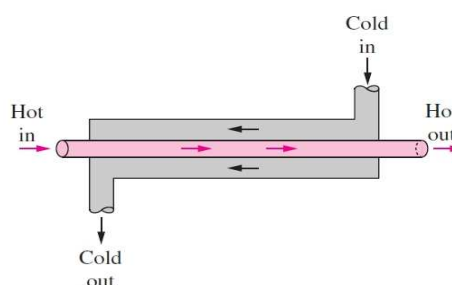
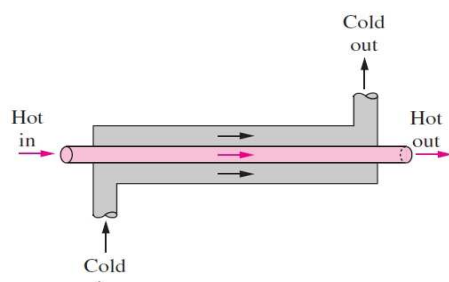
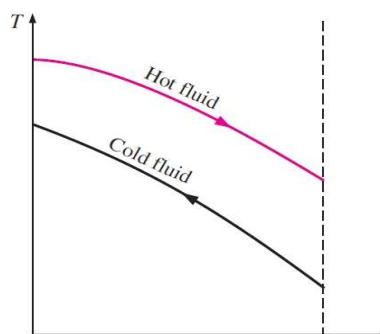
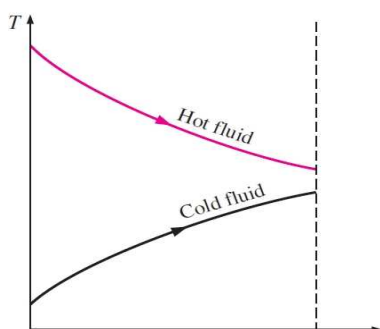
2/27

- **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 temperatura-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

- Hodi bikoitzeko bero-trukagailuak → Konfiguraziorik sinpleena



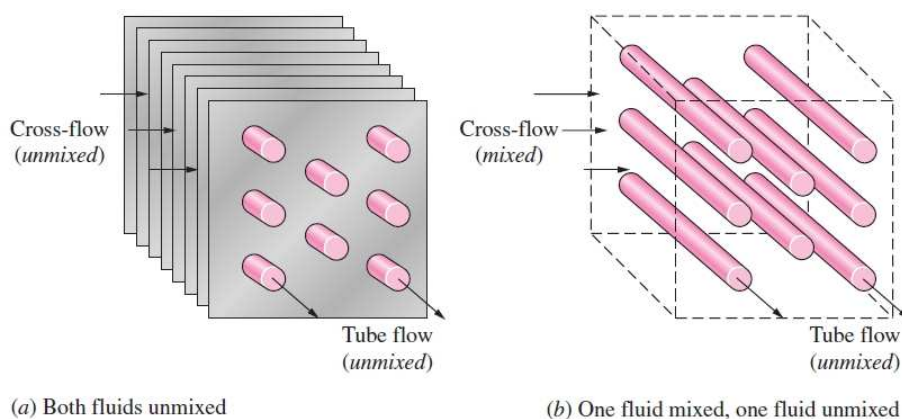
Fluxu paraleloa

Kontrako fluxua

- Bero trukagailu **trinkoa** → $\beta = \frac{A_s}{Vol} > 700 \text{ m}^2/\text{m}^3$

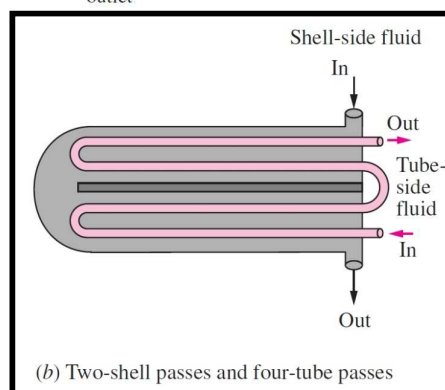
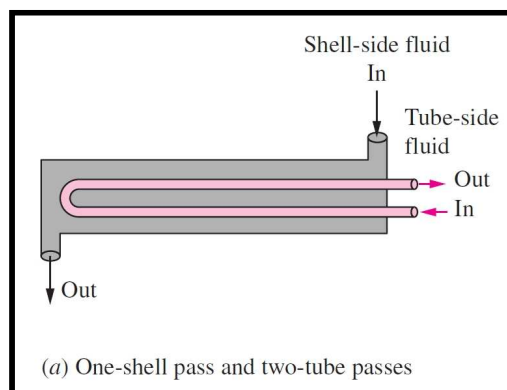
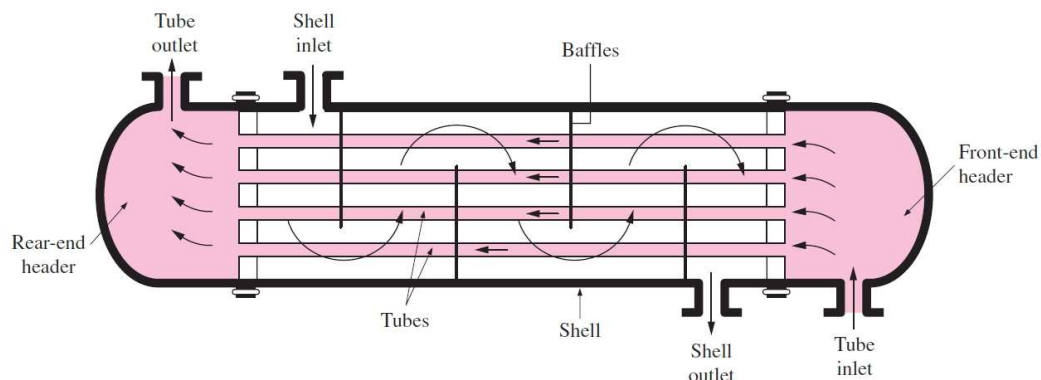
Azalera-dentsitatea

- Fluxu-gurutzatuko** bero trukagailua

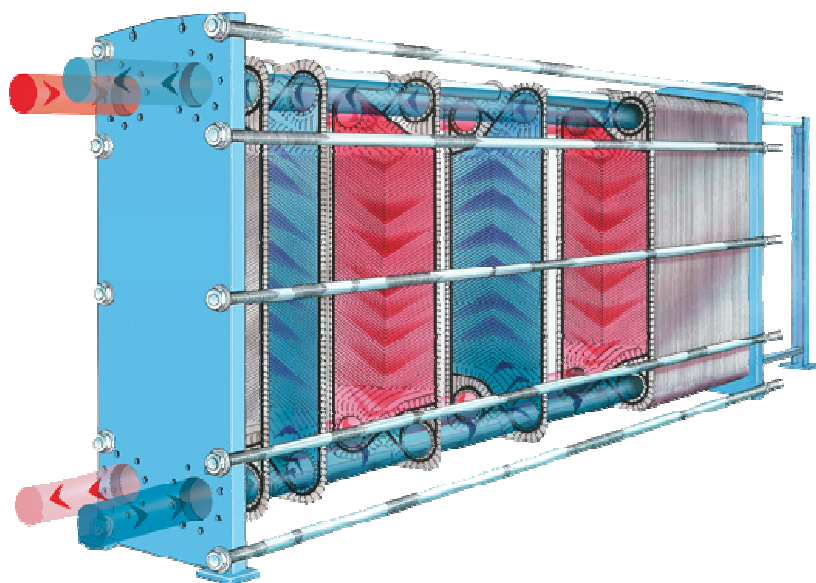


11.1 – BERO-TRUKAGAILU MOTAK

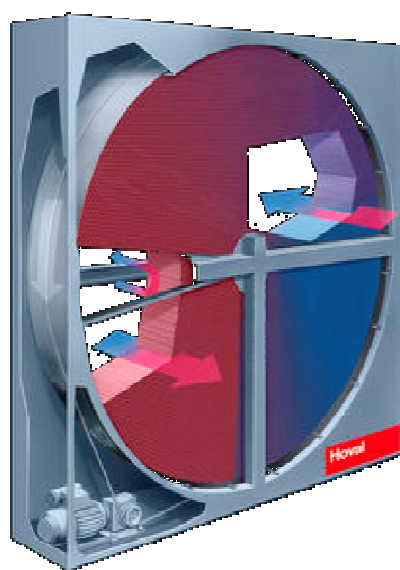
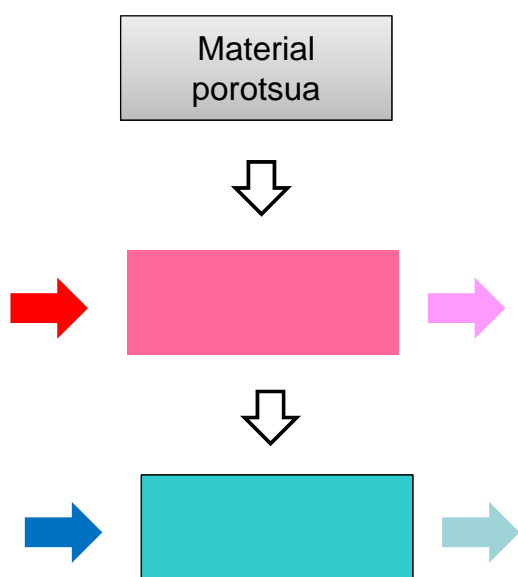
- Karkasa eta hodi** erako bero-trukagailua



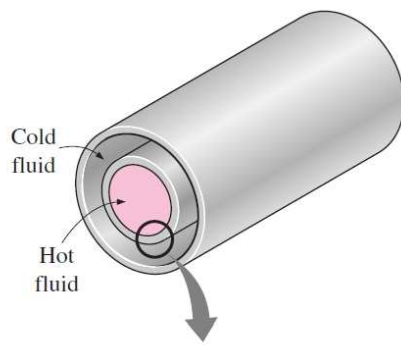
- Xafla eta bastidore bero-trukagailuak



- Birsorgailu bero-trukagailuak

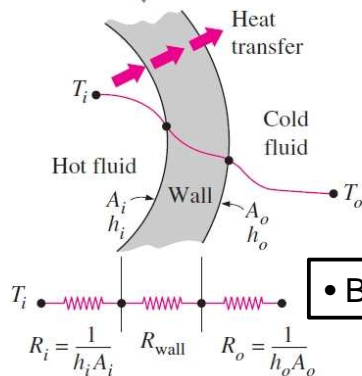


Bero-trukagailuetan → Kondukzio, konbekzio eta erradiazio motako bero-transferentziak (azken biak orokorrean konbinatzen dira).



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

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



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

• Baldin $R_{wall} \cong 0$:

$$\rightarrow A \cong A_i \cong A_o \rightarrow$$

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

11.2 – BERO-TRANSFERENTZIAREN KOEFIZIENTE OROKORRA

Representative values of the overall heat transfer coefficients in heat exchangers

| Type of heat exchanger | U , $W/m^2 \cdot ^\circ C^*$ |
|---|--------------------------------|
| 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 $Btu/h \cdot ft^2 \cdot ^\circ F$.

[†]Based on air-side surface area.

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

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

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

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 , $m^2 \cdot ^\circ C/W$ |
|--|--------------------------------|
| 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 |

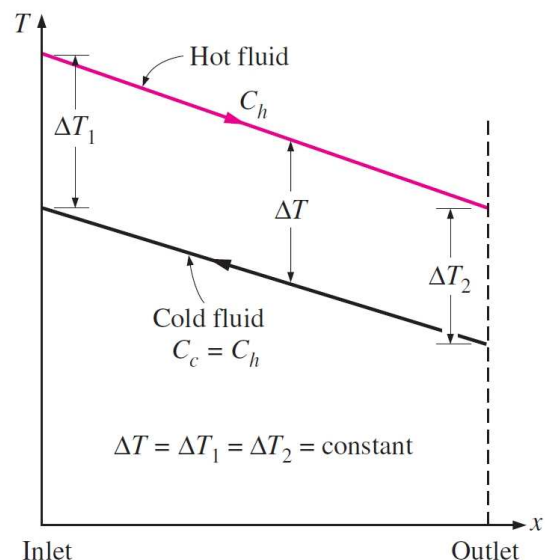
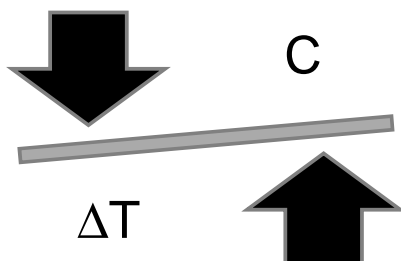
11.3 – BERO-TRUKAGAILUEN ANALISIA

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

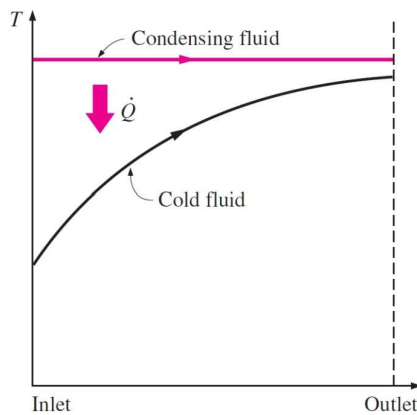
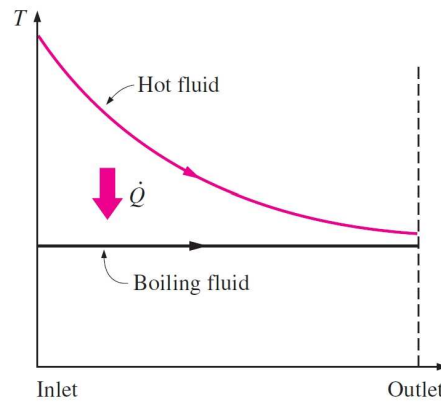
$$\dot{Q} = \dot{m}_h c_{ph} (T_{h,in} - T_{h,out}) \quad \Rightarrow \quad \text{Jariakin beroa (hozten dena)}$$

Bero-ahalmena

$$C_i = \dot{m}_i c_{pi}$$



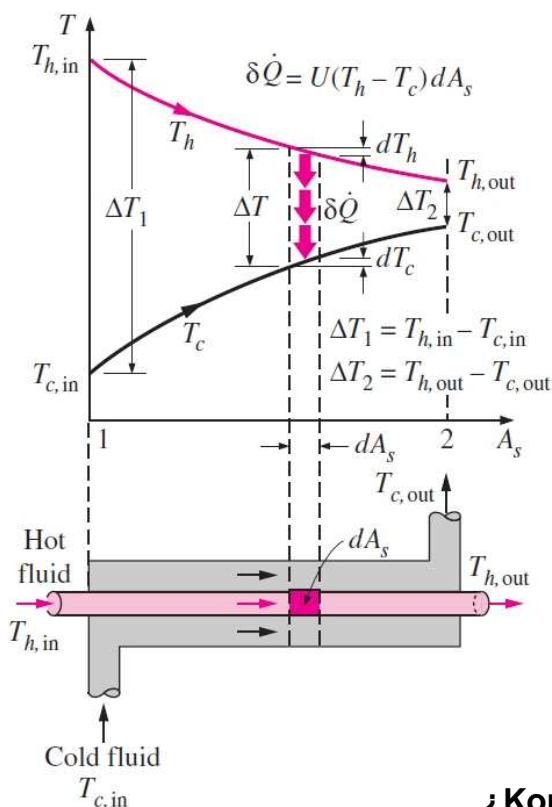
- Bero-transferentzia sentikorra (ΔT) $\Rightarrow \dot{Q} = \dot{m}c_p \Delta T$
- Bero-transferentzia sorra ($T = \text{cte}$) $\Rightarrow \dot{Q} = \dot{m}h_{fg}$

(a) Condenser ($C_h \rightarrow \infty$)(b) Boiler ($C_c \rightarrow \infty$)

$$\dot{Q} = UA_s \Delta T_m$$

TERMOTEKNIA

11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA



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



$$\dot{Q} = UA_s \Delta T_{lm}$$

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



¿Kontrako fluxuan?

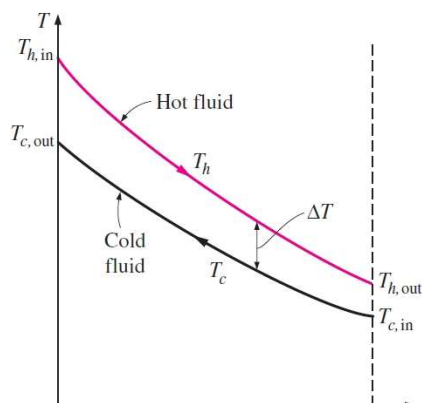
NOTA : $\Delta T_{lm} < \Delta T_{am}$

TERMOTEKNIA

11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

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KONTRAKO FLUXUKO BERO-TRUKAGAILUAK

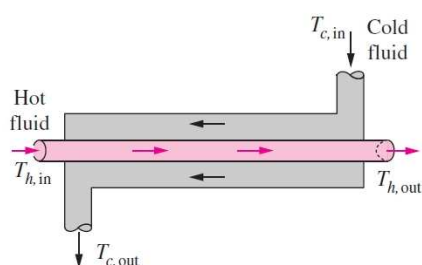


Sarrerako eta irteerako tenperaturak berdinak izanik:

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



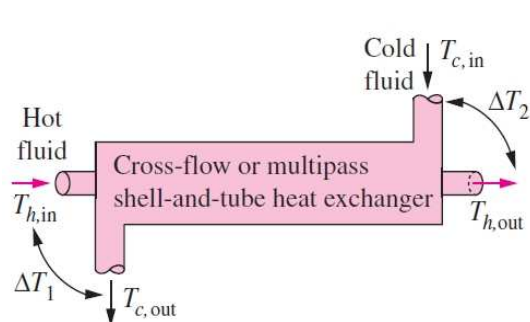
$$C_h = C_c \rightarrow \Delta T_{lm} ?$$



11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

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



Heat transfer rate:

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

where

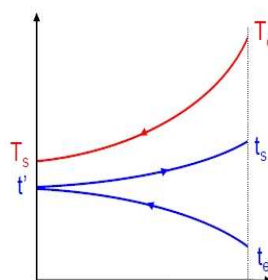
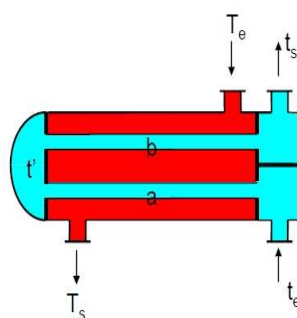
$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

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

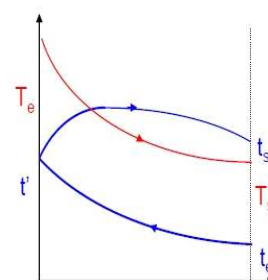
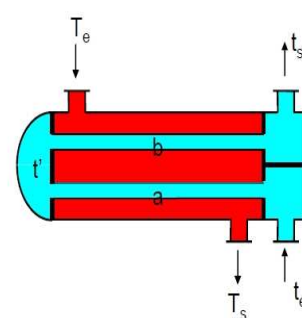
$$\Delta T_2 = T_{h,out} - T_{c,in}$$

and

$$F = \dots \text{ (Fig. 13-18)}$$



- a: equicorriente
- b: contracorriente

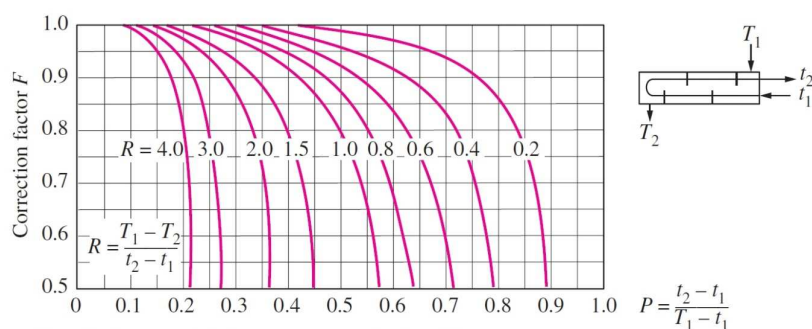


- a: contracorriente
- b: equicorriente

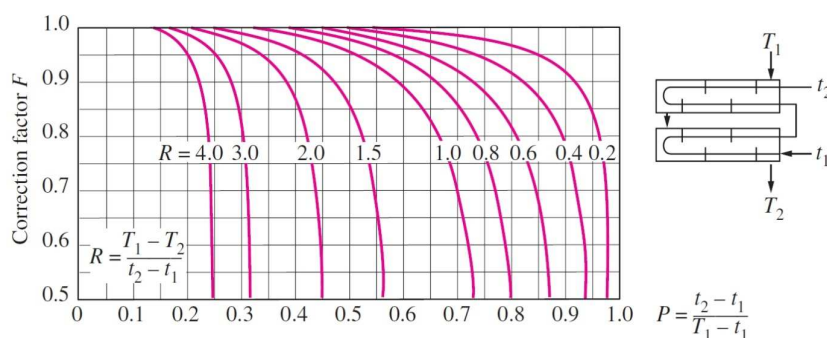
11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

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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

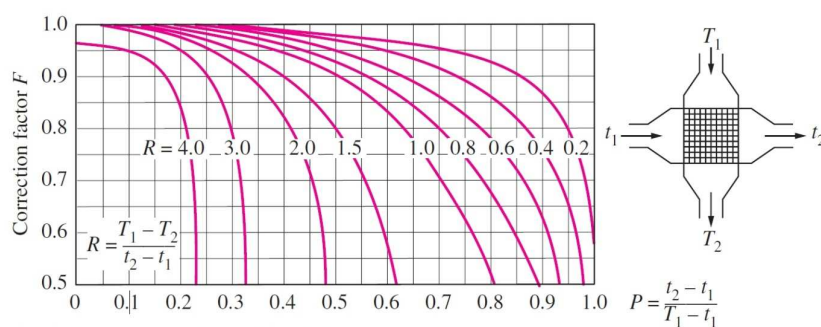


(b) Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes

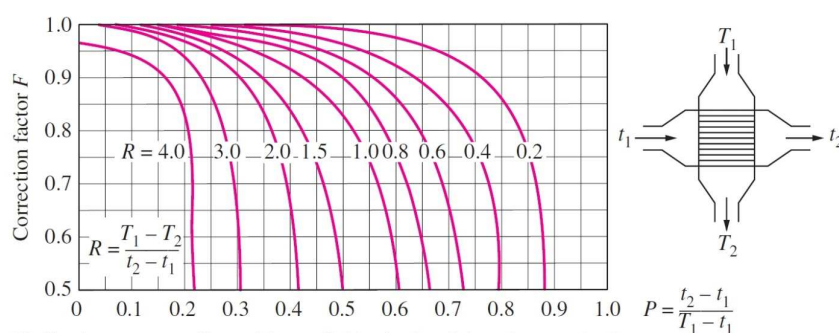
11.4 – BATEZ BESTEKO TENPERATURA-DIFERENTZIA LOGARITMIKOAREN METODOA

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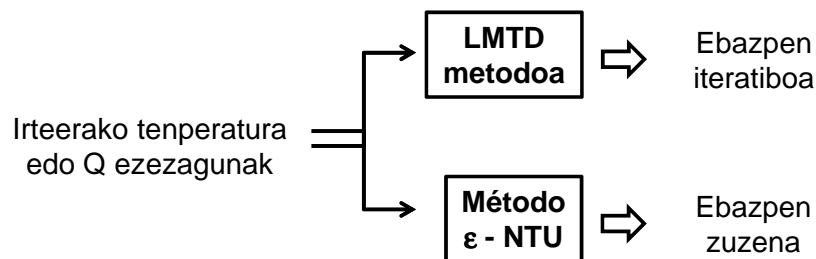
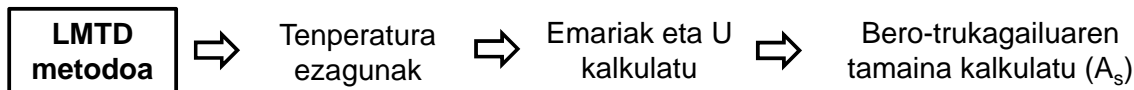
IRAGANALDI ANITZEKO ETA FLUXU GURUTZATUKO BERO TRUKAGAILUAK:
ZUZENKETA-FAKTOREEN ERABILERA



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

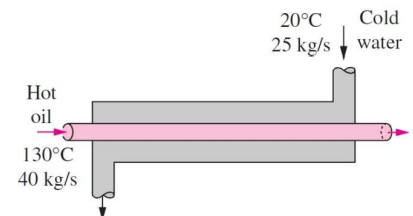


(d) Single-pass cross-flow with one fluid *mixed* and the other *unmixed*



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

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



$$C_c = \dot{m}_c C_{pc} = 104.5 \text{ kW/}^\circ\text{C}$$

$$C_h = \dot{m}_c C_{ph} = 92 \text{ kW/}^\circ\text{C}$$

$$C_{\min} = 92 \text{ kW/}^\circ\text{C}$$

$$\Delta T_{\max} = T_{h,in} - T_{c,in} = 110^\circ\text{C}$$

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

11.5 – ERAGINKORTASUN-NTU METODOA

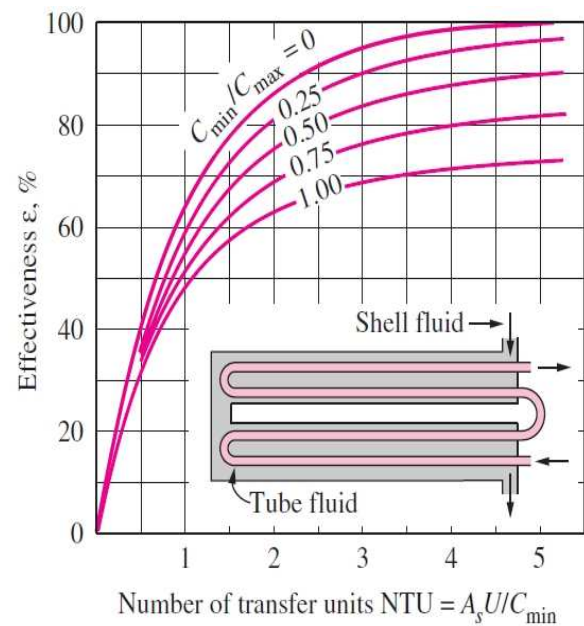
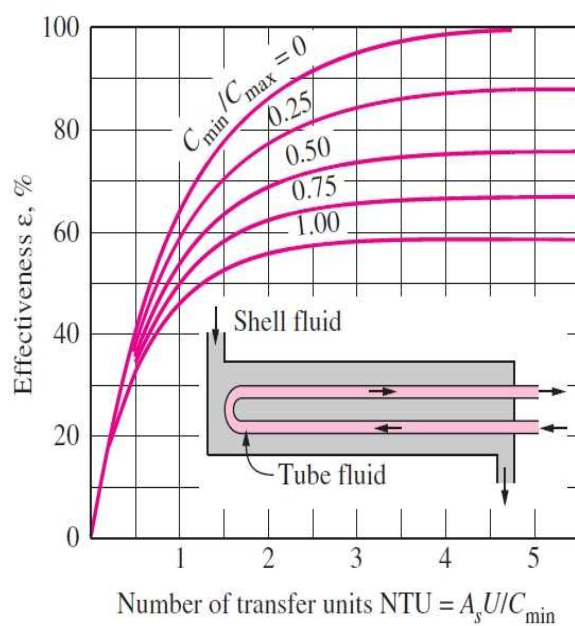
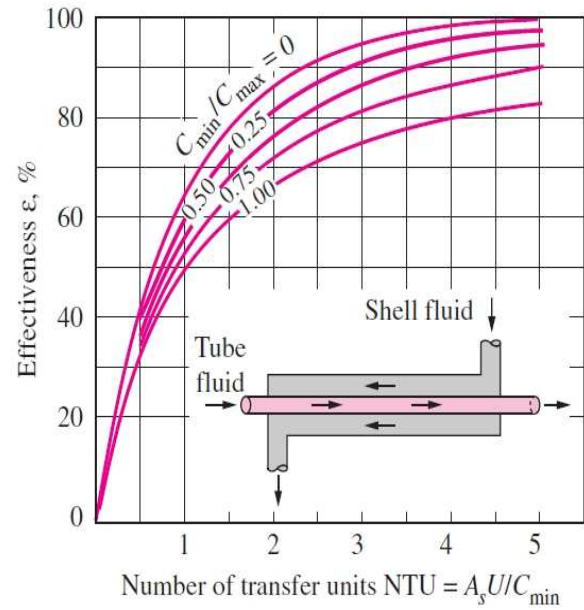
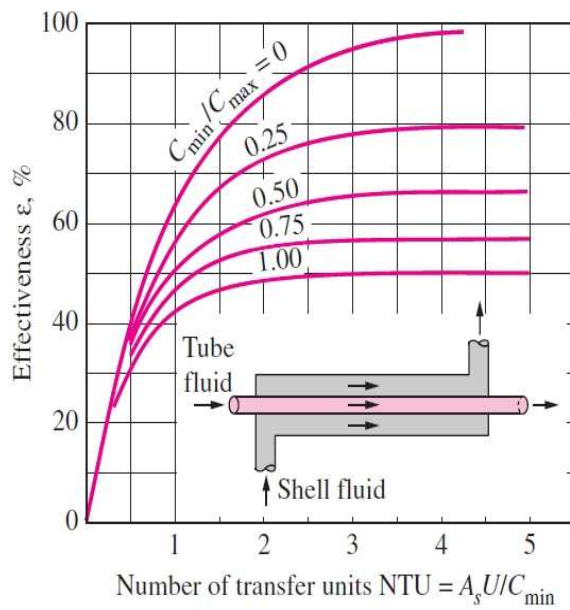
$$NTU = \frac{UA_s}{C_{\min}}$$

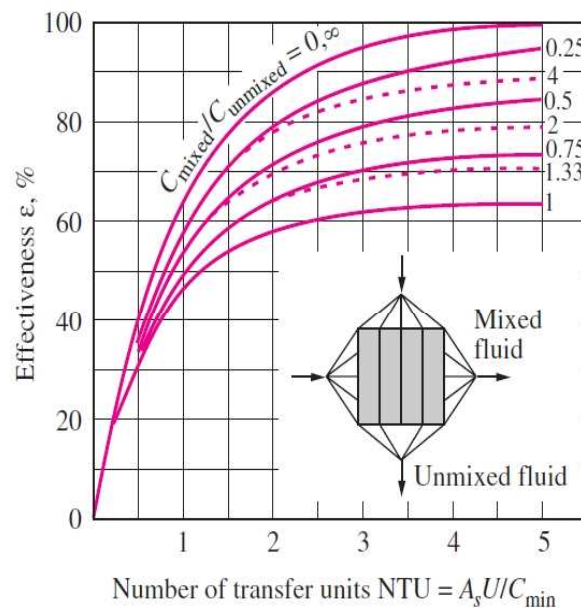
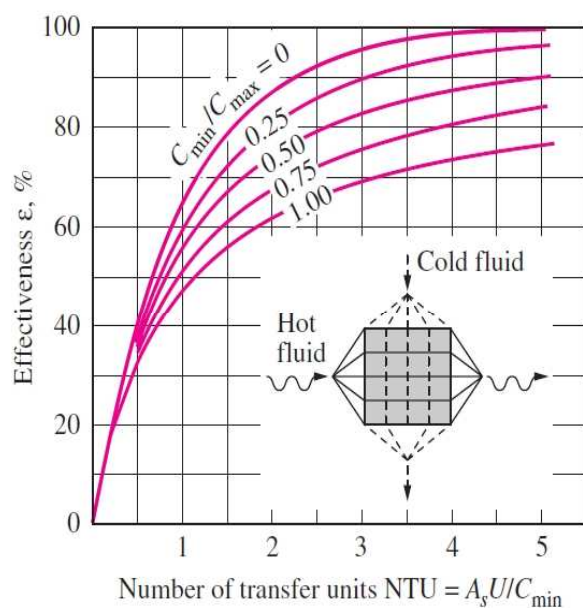
$$c = \frac{C_{\min}}{C_{\max}}$$

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

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 <i>Double pipe:</i> Parallel-flow | $\epsilon = \frac{1 - \exp[-NTU(1 + c)]}{1 + c}$ |
| Counter-flow | $\epsilon = \frac{1 - \exp[-NTU(1 - c)]}{1 - c \exp[-NTU(1 - c)]}$ |
| 2 <i>Shell and tube:</i> One-shell pass 2, 4, . . . tube passes | $\epsilon = 2 \left\{ 1 + c + \sqrt{1 + c^2} \frac{1 + \exp[-NTU\sqrt{1 + c^2}]}{1 - \exp[-NTU\sqrt{1 + c^2}]} \right\}^{-1}$ |
| 3 <i>Cross-flow (single-pass)</i> Both fluids unmixed | $\epsilon = 1 - \exp \left\{ \frac{NTU^{0.22}}{c} [\exp(-c NTU^{0.78}) - 1] \right\}$ |
| C_{\max} mixed, C_{\min} unmixed | $\epsilon = \frac{1}{c} (1 - \exp \{1 - c[1 - \exp(-NTU)]\})$ |
| C_{\min} mixed, C_{\max} unmixed | $\epsilon = 1 - \exp \left\{ -\frac{1}{c} [1 - \exp(-c NTU)] \right\}$ |
| 4 <i>All heat exchangers with $c = 0$</i> | $\epsilon = 1 - \exp(-NTU)$ |





11.5 – ERAGINKORTASUN-NTU METODOA

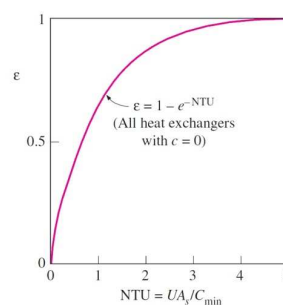
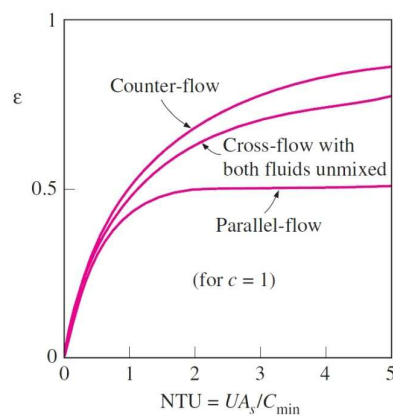
Iruzkina:

1. $NTU \downarrow \rightarrow \Delta \varepsilon \uparrow$, baina $NTU \uparrow \rightarrow \Delta \varepsilon \downarrow \rightarrow$ (justifikazio ekonomikoa $NTU < 3$)

2. NTU eta c zehatz batzuetarako \rightarrow

3. $NTU < 0.3$ denean $\rightarrow \varepsilon = \varepsilon(NTU)$

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



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

$$\bullet \varepsilon \uparrow \rightarrow \Delta P \uparrow$$



Jariakin biskosoena:

¿Hodien barnealdetik edo karkasatik?

BERO-TRANSFERENTZAIREN ABIADURA

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

KOSTUA

- Eskaerapeko bero-trukagailuaren kostua >> Seriean egindako bero-trukagailuaren kostua
- Operazio + Mantentze lanak

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 arabera.

MATERIALAK

- Tentsio-efektu termikoak (dilatazioak)
- Korrosioareiko erresistentzia

