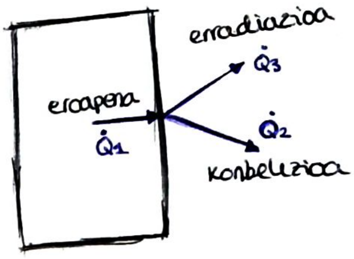
# Oinarrizko kontzeptuak

Bero-fluxua ($\dot{q}$)

$$\dot{q} = \frac{\dot{Q}}{A} \quad [W/m^2]$$




Bero-transferentzia abiadura ($\dot{Q}$)
presio konstantepeko gas ideala:

$$\dot{Q} = \dot{m} C_p \Delta T \quad [W]$$

$C_p \equiv$ bero espezifikoa [kJ/kg]

$C_p > C_v$ beti

Masa-fluxua ($\dot{m}$)

$$\dot{m} = \rho V A_c \quad [kg/s]$$

## EROAPENA

Partikulen arteko elkarrekintzen ondorioz substantzia bateko energia handiagoko partikuletatik energia txikiagoko inguruko partikuletara gertatzen den energia-transferentzia.

Fourier-en bero-eroapenaren legea:

$$\dot{Q}_{eroap} = -k \cdot A \frac{dT}{dx} \quad [W]$$

non $k \equiv$ eroankortasun termikoa [W/m°C]

Difusibitate termikoa ($\alpha$):

$$\alpha = \frac{k}{\rho C_p} \quad [m^2/s]$$

Bero-difusioa materialetan zenbateko abiaduraz gertatzen den adierazten du.

## KONBEKZIOA

Gainazal solido baten eta haren inguruan mugimenduan dagoen likido edo gasaren artean energia transferitzeko modua.

Newtonen hozte-legea:

$$\dot{Q}_{konb} = h A_s (T_s - T_\infty) \quad [W]$$

non
$h \equiv$ konbekzio koef. [W/m²°C]
$T_s \equiv$ gainazal tenp. [°C edo K]
$T_\infty \equiv$ aire tenperatura [°C edo K]

## ERRADIAZIOA

Materiak, atomoen edo molekulen konfigurazio elektronikoaren aldaketen ondorioz, uhin elektromagnetiko moduan igortzen duen energia.

Stefan-Boltzmann-en legea:

$$\dot{Q}_{emit} = \varepsilon \sigma A_s T_s^4 \quad [W]$$

non
$\varepsilon$ = emisibitatea [-]
$\sigma = 5'67 \cdot 10^{-8}$ [W/m²K⁴]

$$\dot{Q}_{emit\,max} = \sigma A_s T_s^4 \quad [W]$$

Kirchoff-en legea:

$$\dot{Q}_{rad} = \varepsilon \sigma A_s (T_s^4 - T_{surr}^4) \quad [W]$$

Erradiazio bidezko bero-transferentziak ez du bitartekorik behar. Besteak baino azkarragoa da eta ez da hutsean moteltzen.

# Bero eroapen ekuazioa

Fourier-en legea:

$$\dot{Q}_{eroap} = -kA\frac{dT}{dx} \quad [W]$$

non $k \equiv$ eroankortasun termikoa $[W/m°C]$

Horma laua

Eroankortasun konstantea:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\dot{e}_{gen}}{k} = \frac{1}{\alpha}\cdot\frac{\partial T}{\partial t}$$

non $\alpha \equiv$ difusibita termikoa $[m^2/s]$

$\dot{e}_{gen} \equiv$ bero-sorrera abiadura $[W/m^3]$

Difusibitate termikoa ($\alpha$):

$$\alpha = \frac{k}{\rho C_p} \quad [m^2/s]$$

Zilindro luzea

Eroankortasun konstantea:

$$\frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{\dot{e}_{gen}}{k} = \frac{1}{\alpha}\cdot\frac{\partial T}{\partial t}$$

Esfera

Eroankortasun konstantea:

$$\frac{1}{r^2}\cdot\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right) + \frac{\dot{e}_{gen}}{k} = \frac{1}{\alpha}\cdot\frac{\partial T}{\partial t}$$

Gai honetan ekuazio diferentzial hauetatik informazio lortzeko integrazioak egin beharko dira.

Bero-sorrera abiadura ($\dot{e}_{gen}$)

$$\dot{e}_{gen} = \frac{E_{gen}}{V} = kte \quad [W/m^3]$$

non $V \equiv$ bolumena $[m^3]$

$E_{gen} \equiv$ bero-sorrera $[W]$

3. gaia.

# Bero-eroapen geldikorra

↳ $\dot{Q}_1 = \dot{Q}_2$

Fourier-en bero-eroapenaren legea:

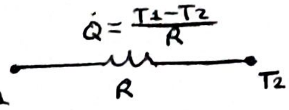
$$\dot{Q}_{eroap} = -kA\frac{dT}{dx} \quad [W]$$

$K \equiv$ eroankortasun termikoa $[W/m°C]$

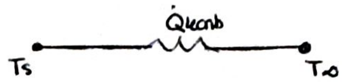
## Horma-laua.

Erresistentzia termikoaren kontzeptua

$$\dot{Q}_{eroap} = \frac{\Delta T}{R_{wall}}$$ non $$R_{wall} = \frac{L}{KA_s} \quad [°C/W]$$




- Konbekzioan: $R_{konb} = \frac{1}{hA_s}$




- Erradiazioan: $R_{rad} = \frac{1}{h_{rad}A_s}$


$$\dot{Q} = \frac{\Delta T}{\Sigma R} = UA\Delta T$$ ondorioz $$\frac{1}{R_{TOT}} = UA$$

## Zilindro eta esfera

↳ hodia

$$R_{zil} = \frac{\ln(r_2/r_1)}{2\pi L K}$$

$$R_{esf} = \frac{r_2 - r_1}{4\pi r_1 r_2 K}$$

## Hegal infinituko ekuazioa.

$$\dot{Q}_{hegal\infty} = \sqrt{hPKA_c}\,(T_b - T_\infty) \quad [W]$$

non $P \equiv$ perimetroa $[m]$

$T_b \equiv$ hasiako puntuko tenperatura

$$\frac{T(x) - T_\infty}{T_b - T_\infty} = e^{-x \cdot \sqrt{hP/KA_c}}$$

Luzera egokia ($L_c$).

Konbekzioa ere baldin badu, hau da, ez bada adiabatikoa.

$$L_c = L + \frac{A_c}{P} \quad [m]$$

Bero-transferentzia maximoa ($\dot{Q}_{\infty,max}$).

$$\dot{Q}_{\infty,max} = hA\,(T_b - T_\infty) \quad [W]$$

Hegalaren errendimendua ($\eta$)

$$\eta = \frac{\dot{Q}_{hegal,\infty}}{\dot{Q}_{\infty,max}} \quad [\%]$$

Hegal-eraginkortasuna

$$\varepsilon_\infty = \sqrt{\frac{kP}{hA_c}}$$

4.gaia.

# Bero-eroapen iragankorra

↳ $\dot{Q}_1 \neq \dot{Q}_2$

Tenperatura ez da konstantea denboran zehar.

Tenperatura denboran zehar ($T(t)$).

$$\frac{T(t)-T_\infty}{T_i - T_\infty} = e^{-\frac{hA_s}{\rho V c_p} \cdot t}$$

Xafla laua → $A_s/V = 1/L$ ← ez beti, begiratu

zilindroa → $A_s/V = 2/r$

esfera → $A_s/V = 3/r$

$$t = \frac{\ln[(T(t)-T_\infty)/(T_i - T_\infty)]}{-b} \quad [seg]$$

Bero-transferentzia ($Q$)

$Q = m c_p [T(t) - T_i]$ [J]

$Q_{max} = m c_p (T_\infty - T_i)$ [J]

Luzera karakteristikoa ($L_c$).

$L_c = \frac{V}{A_s}$ [m] non $V \equiv$ bolumena [$m^3$]

Biot zenbakia ($Bi$)

$Bi = \frac{h \cdot L_c}{k} = \frac{\text{kondukzio bero}}{\text{eroandako bero}}$ [-] $Bi > 0'1$ sistema ez-kontzentratua

Kondukzio eta eroapen beroen arteko erlazioa adierazten du.

Parametro-kontzentratuen sistemen analisien irizpideak betetzeko $Bi < 0'1$.

Ekuazio diferentziala.

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

Difusibitate termikoa ($\alpha$).

$\alpha = \frac{k}{\rho c_p}$ [$m^2/s$]

Fourieren zenbakia ($\tau$)

$\tau = \frac{\alpha t}{L^2} = \frac{\text{eroandako beroa}}{\text{metatutako beroa}}$

$\tau > 0'2$ bada kurbileta bidezko ebazpidea erabil dezakegu

Ebazpide analitikoa zein grafikoa erabili ahal izango dugu.

Ebazpide analitikoa.

- Horma laua: $\theta_{o,wall} = \dfrac{T_o - T_\infty}{T_i - T_\infty} = A_1 \cdot e^{-\lambda_1^2 \cdot \tau}$

- Zilindroa: $\theta_{o,zi} = \dfrac{T_o - T_\infty}{T_i - T_\infty} = A_1 e^{-\lambda_1^2 \tau}$

- Esfera: $\theta_{o,esf} = \dfrac{T_o - T_\infty}{T_i - T_\infty} = A_1 e^{-\lambda_1^2 \tau}$

$A_1$ eta $\lambda_1$ taulatik

Bi zenbakiaren arabera

Ebazpide grafikoa.

(18/30), (19/30) eta (20/30) diapositibetan daude grafikoak.

Bero-transferentziaren kantitate totala kalkulatzeko (21/30) grafikoa.

6. gaia.

# Konbekzioaren oinarriak

Newton-en hozte-legea:

$\dot{Q}_{konb} = h A_s (T_s - T_\infty)$ [W] non $h \equiv$ konbekzio koef. [W/m²°C]

Nusselt-en zenbakia (Nu).

$Nu = \frac{h \cdot L_c}{k}$ [-] non $k \equiv$ eroankortasun termikoa [W/m°C]

Luzera karakteristikoa ($L_c$).

$L_c = \frac{V}{A_s}$ [m] non $V \equiv$ bolumena [m³]

Biskositate zinematikoa ($\nu$)

$\nu = \frac{\mu}{\rho}$ [m²/s] non $\mu \equiv$ biskositate dinamikoa [kg/ms]

1 stoke = $10^{-4}$ m²/s

1 poise = 0'1 kg/ms

Gainazaleko ebakidura-tentsioa ($\tau_s$).

$\tau_s = C_f \frac{\rho V^2}{2}$ non
$V \equiv$ ebakidura (abiadura) indarra [N] ??
$C_f \equiv$ marruskadura koef

Prandtl-en zenbakia (Pr).

$Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{k} = \frac{\text{Momentuaren difusibitate molekularra}}{\text{beroaren difusibitate molekularra}}$

Difusibitate termikoa ($\alpha$).

$\alpha = \frac{k}{\rho C_p}$ [m²/s]

Reynolds-en zenbakia (Re).

$Re = \frac{V \cdot L}{\nu} = \frac{\rho V L}{\mu}$ non $V \equiv$ abiadura [m/s]

$Re = \frac{\text{Inertzi indarrak}}{\text{biskositate-indarrak}}$

Re ↓ = fluxu laminarra

Re ↑ = fluxu turbulentua

## Reynolds-en analogia.

$\boxed{Pr = 1}$

stantonen zenbakia → $St = \frac{h}{\rho C_p V} = \frac{Nu}{Re} = \frac{C_f}{2}$ non V ≡ abiadura [m/s]

## Reynolds-en analogia eraldatua

$\boxed{Pr \neq 1}$

colburnen j faktorea → $j_H = \frac{h}{\rho C_p V} \cdot Pr^{2/3} = \frac{C_f}{2}$ non V ≡ abiadura [m/s]

# Kanpo konbekzio behartua

Marruskadura-eta presio-arrastea

Arraste-koefizientea → $C_D = \frac{F_D}{1/2\,\rho V^2 A}$

$C_D = C_{D,marrus} + C_{D,presioa}$

ebakidura tentsioa — gorputzaren formagatik

Geruza-tenperatura ($T_f$)

$Re = \frac{V.L}{\nu} \Rightarrow L_c = \frac{Re\,\nu}{V}$

$T_f = \frac{T_s + T_\infty}{2}$

Batazbesteko marruskadura-koefizientea ($C_f$)

$Re_L < 5.10^5 \longrightarrow C_f = \frac{1'328}{Re_L^{1/2}}$

xafla lauean fluxu ez-mistoa

$5.10^5 \leq Re_L < 10^7 \longrightarrow C_f = \frac{0'074}{Re_L^{1/5}}$

Batazbesteko bero-transferentziaren koefizientea (Nu)

$\left.\begin{array}{l} Pr > 0'6 \\ Re_L < 5.10^5 \end{array}\right\} \; Nu = \frac{h.L}{k} = 0'664\, Re_L^{0'5}\, Pr^{1/3}$

$T_f$

xafla laua

fluxu ez-mistoa

$\left.\begin{array}{l} 0'6 \leq Pr \leq 60 \\ 5.10^5 \leq Re_L \leq 10^7 \end{array}\right\} \; Nu = \frac{h.L}{k} = 0'037\, Re_L^{0'8}\, Pr^{1/3}$

Zilindro eta esferetan bero-transferentziaren koef. (Nu)

$T_f$

Churchill eta Berstein → $Nu_{cyl} = \frac{hD}{k} = 0'3 + \frac{0'62\, Re^{1/2}\, Pr^{1/3}}{[1+(0'4/Pr)^{2/3}]^{1/4}} \left[1 + \left(\frac{Re}{282000}\right)^{5/8}\right]^{4/5}$

$Pr > 0'2$

$T_\infty$

$0'7 \leq Pr \leq 380$

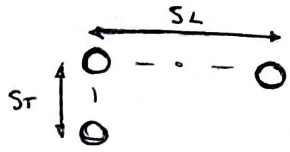
$3'5 \leq Re_D \leq 80000$

Whitaker

$\longrightarrow Nu_{sph} = \frac{hD}{k} = 2 + [0'4\, Re^{1/2} + 0'06\, Re^{2/3}]\, Pr^{0'4} \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$

## Hodi multzoetan zeharreko fluxua

$$Re_D = \frac{V_{max} D}{\nu} \Rightarrow V_{max} = \frac{S_T}{S_T - D} V$$




$0'7 \le Pr \le 500$
$0 \le Re_D \le 2 \cdot 10^6$

$$Nu = \frac{hD}{k} = C Re_D^m Pr^n (Pr/Pr_s)^{0'25}$$

## Batazbesteko tenperatura-diferentzia logaritmikoa ($\Delta T_{en}$)

gai honetan ez

$$\Delta T_{en} = \frac{\Delta T_e - \Delta T_i}{\ln[\Delta T_e / \Delta T_i]}$$

non

$\Delta T_e = T_s - T_e$, $\Delta T_i = T_s - T_i$ } berotketan

$\Delta T_e = T_e - T_s$, $\Delta T_i = T_i - T_s$ } hozketan

$i \to \infty$ hasieran
$e \to \infty$ irteeran

## Irteera tenperatura ($T_e$)

$$T_e = T_s - (T_s - T_i) \cdot e^{-\frac{A_s h}{\dot{m} C_p}}$$

## Konbekzio bidezko bero-fluxua ($\dot{Q}_{konb}$)

ez

$$\dot{Q}_{konb} = h A_s \Delta T_{en} = \dot{m} C_p (T_e - T_i)$$

edo

bai $\rightarrow$ $\dot{Q}_{konb} = h A_s (T_s - T_\infty)$

8.gaia.

# Barneko konbekzio behartua

Masaren kontserbazio printzipioa

$\dot{m} = \rho V_{bb} A_c$ [kg/s]  $\dot{V} = V A_c$ [$m^3/s$] non $V \equiv$ abiadura (m/s)

gas ideala → $\rho = P/[R(T_i + 273)]$ [$kg/m^3$] non $R = 0'287$ [kPa $m^3$/kg K]
(P: kPa)

Fluxu laminarra eta turbulentua

$$Re = \frac{\rho V_{bb} D}{\mu} = \frac{V_{bb} D}{\nu} \quad [-]$$

$Re < 2300$ fluxu laminarra

$Re > 10\ 000$ fluxu turbulentoa

Diametro hidraulikoa → $D_h = \dfrac{4A_c}{\text{Perimetroa}}$ [m]

Gainazaleko bero-fluxua ($\dot{q}$).

$\dot{q} = \dot{q}_s = h(T_s - T_f)$ [$W/m^2$]  $T_f = \dfrac{T_e + T_i}{2}$ [°C edo K]

Sarrera-luzera (L)

Fluxu laminarra → $L_h \approx 0'05\, Re \cdot D$ [m]  $L_h \equiv$ luzera hidrodinamikoa

→ $L_t \approx 0'05\, Re\, Pr\, D$ [m]  $L_t \equiv$ luzera termikoa

Fluxu turbulentua → $L_h \approx L_t \approx 10D$ [m]

Fluxu geldikorraren energia-kontserbazioaren ekuazioa.

$\dot{Q} = \dot{m} C_p (T_e - T_i) = \dot{q}_s A_s$ ($\Delta T_{ln}$ edo)

$$\Delta T_{ln} = \frac{\Delta T_e - \Delta T_i}{\ln[\Delta T_e / \Delta T_i]}$$

non $\left.\begin{array}{l}\Delta T_e = T_s - T_e \\ \Delta T_i = T_s - T_i\end{array}\right\}$ berotu

$\left.\begin{array}{l}\Delta T_e = T_e - T_s \\ \Delta T_i = T_i - T_s\end{array}\right\}$ hoztu

Gainazal-tenperatura konst. ($T_s$ = konst)

$\dot{Q} = h A_s \Delta T = h A_s (T_s - T_f)$ [W]

$T_e = T_s - (T_s - T_i) \cdot e^{\frac{-hA_s}{\dot{m} C_p}}$ [°C]

Presio galera ($\Delta P$).

$\Delta P = f \dfrac{L}{D} \cdot \dfrac{\rho V_{bb}^2}{2}$ [Pa]  hodietan → $f = 64/Re$

Karga-galera ($h_L$)

$$\Delta P = \rho g h_L \Rightarrow \boxed{h_L = \frac{\Delta P}{\rho g}} \quad [m]$$

Ponpatze-potentzia ($W$)

$$\boxed{W = \dot{V}\Delta P} = VA \cdot \Delta P = \dot{m} g h_L \quad [W]$$

Nu fluxu laminarretan

$$T_s = \text{cste} \rightarrow Nu = 3'66 + \frac{0'0065\,(D/L)\,RePr}{1 + 0'04\,[D/L \cdot RePr]^{2/3}}$$

$$T_s \neq \text{cste} \rightarrow \boxed{Nu = 1'86\left(\frac{RePrD}{L}\right)^{1/3}\left(\frac{\mu_b}{\mu_s}\right)^{0'14}}$$

Nu fluxu turbolentuetan

$$3000 < Re < 5 \cdot 10^6 \longrightarrow f = [0'79 \cdot \ln(Re) - 1'64]^{-2}$$

$$\boxed{Nu = 0'023\,Re^{0'8}\,Pr^n} \quad \begin{cases} \boxed{n = 0'4} \text{ heating} \\ \boxed{n = 0'3} \text{ cooling} \end{cases}$$

Gainazal zimurrak.

$$\text{Moody} \rightarrow \boxed{\frac{1}{\sqrt{f}} = -1'8 \log\left(\frac{6'9}{Re} + \left(\frac{\varepsilon/D}{3'7}\right)^{1'11}\right)}$$

9. gaia.

# Konbekzio naturala

Newton-en hozte-legea:

$\dot{Q}_{konb} = hA_s(T_s - T_\infty)$ [W]   $h \equiv$ konbekzio koef. [W/m²°C]

Dilatazio koef. bolumetrikoa ($\beta$).

gas idealetan → $\beta = \frac{1}{T_f}$ [K⁻¹]

Batazbesteko tenperatura ($T_f$).

$$T_f = \frac{T_s + T_\infty}{2} \quad [\text{K edo °C}]$$

Grashofen zenbakia ($Gr$)

$$Gr = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu^2} \quad [-]$$

$g = 9'81 [m/s^2] \equiv$ grabitate azelerazioa

Konbekzio naturalaren fluxua laminarra edo turbulentua den adierazteko balio du.

Luzera karakteristikoa ($L_c$).

$L_c = \frac{V}{A_s}$ [m]   non   $V \equiv$ bolumena [m³]

Rayleigh-en zenbakia ($Ra$)

$$Ra = Gr\,Pr = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu^2} \cdot Pr \quad [-]$$

Prandtl-en zenbakia ($Pr$)

$$Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{k} \quad [-]$$

Itxitura angeluzuzen horizontala

Nusselt-en zenbakia ($Nu$).

$Ra < 10^8$

$$Nu = \frac{h \cdot L_c}{k} = 1 + 1'44\left[1 - \frac{1708}{Ra}\right]^+ + \left[\frac{Ra^{1/3}}{18} - 1\right]^+$$

$[\,]^+$ notazioak adierazten du kortxete arteko kantitatea negatiboa bada, zero jarri beharko litzatekeela.

10. gaia.

# Irakite eta kondentsazioa

## Irakitea

Gainazalarekin kontaktuan dagoen likidoa $T_s > T_{sat}$ denean.

$$q_{irakite} = h(T_s - T_{sat}) = h \Delta T_{excess} \quad [W/m^2]$$

## Gainberoketa ($\Delta T_{excess}$)

Gainberoketaren arabera lau irakite-erregimen izango ditugu:

1. Konbekzio naturala: gainberoketa txikia, $\Delta T_{excess} = [2-6]$°C
2. Irakite nukleatua: lehen burbuilak, $\Delta T_{excess} = [6-30]$°C, $\dot{q}_{max}$ du.
3. Trantsizio-irakitea: lurrun-geruza batek gainazalaren parte bat estaltzen du.
   $\Delta T_{excess} = [30-120]$°C
4. Geruza-erako irakitea: lurrun geruza jarraitu eta egonkorra du, $\dot{q}_{min}$, $\Delta T > 120$°C

## Irakite nukleatua ($\dot{q}_{nucleate}$)

$$q_{nucleate} = \mu_L h_{fg} \left[\frac{g(\rho_L - \rho_v)}{\sigma}\right]^{1/2} \left[\frac{c_{PL}(T_s - T_{sat})}{C_{sf}\, h_{fg}\, Pr_L^n}\right]^3$$

non $n \equiv$ konst. esperimentala (11/28) taula $n=1$

## Puntako bero-fluxua ($\dot{q}_{max}$)

$$q_{max} = C_{cr} \cdot h_{fg} \left[\sigma g \rho_v^2 (\rho_L - \rho_v)\right]^{1/4} \quad [W/m^2]$$

(12/28) taulan

- Xafla luze horizontala → $C_{cr} = 0'149$
- Zilindro luze horizontala → $C_{cr} = 0'12$
- Esfera luzea → $C_{cr} = 0'11$

## Bero-fluxu minimoa ($\dot{q}_{min}$)

Xafla handi horizontalean:

$$\dot{q}_{min} = 0'09\, \rho_v\, h_{fg} \left[\frac{\sigma g (\rho_L - \rho_v)}{(\rho_L - \rho_v)^2}\right]^{1/4} \quad [W/m^2]$$

## Batazbesteko tenperatura ($T_f$)

$$T_f = \frac{T_s + T_{sat}}{2} \quad [°C \text{ edo } K]$$

## Kondentsazioa

$$\dot{Q}_{kondents} = h A_s (T_{sat} - T_s) = \dot{m} h_{fg}^* \quad [W]$$

$$h_{fg}^* = h_{fg} + 0'68\, c_{PL} (T_{sat} - T_s) \quad [W/m^2 °C]$$

Xala bertikala - fluxu laminar izurtua

$$h_{bert} = \frac{K_L \, Re}{1'08 \, Re^{1'22} - 5'2} \left(\frac{g}{\nu_L^2}\right)^{1/3}$$

$$Re = \left[4'81 + \frac{3'70 \, L \, K_L (T_{sat} - T_s)}{\mu_L \, h_{fg}^*} \left(\frac{g}{\nu_L^2}\right)^{1/3}\right]^{0'82}$$

Hodi multzo horizontalak

$$h_{horiz,N} = 0'729 \left[\frac{g \, \rho_L (\rho_L - \rho_v) \, h_{fg}^* \, K_L^3}{\mu_L (T_{sat} - T_s) \, N \, D}\right] = \frac{1}{N^{1/4}} \cdot h_{horiz,\,1\,tubo}$$

11. gaia.

# Bero-trukagailuak

Bero-fluxua ($\dot{Q}$)

$\dot{Q} = \dot{m} C_p (T_{out} - T_{in})$ [W]

$\dot{Q} = U A_s F \Delta T_{ln}$ [W] non

F ≡ zuzenketa faktorea (karkasa eta hodietan) (17/27) tauletan

U ≡ bero-trukagailuaren transferentzi koef. [W/m²°C]

Batazbesteko tenperatura-diferentzia logaritmikoa ($\Delta T_{ln}$)

$$\Delta T_{ln} = \frac{\Delta T_{in} - \Delta T_{out}}{\ln[\Delta T_{in} / \Delta T_{out}]}$$

non

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

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

Jariakin hotzak hartutako bero-fluxua ($\dot{Q}$) / Bero erabilgarria/efektiboa

$\dot{Q}_{cold} = \dot{m}_c C_{pc} (T_{c,out} - T_{c,in})$ [W]

Jariakin beroak emandako bero-fluxua ($\dot{Q}$)

$\dot{Q}_{hot} = \dot{m}_h \cdot C_{ph} \cdot (T_{h,in} - T_{h,out})$ [W]

Bero-transferentziaren koefiziente orokorra (U).

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

Bero-transferentzia abiadura maximoa ($\dot{Q}_{max}$)

$\dot{Q}_{max} = C_{min} (T_{h,in} - T_{c,in})$ non $C_{min}$ [W/°C] { $C_c = \dot{m}_c C_{pc}$ ; $C_h = \dot{m}_c C_{ph}$ }

Eraginkortasuna ($\varepsilon$).

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} \quad [\%]$$

NTU erlazioa.

$$NTU = \frac{U A_s}{C_{min}} \quad [-]$$

c erlazioa.

$$c = \frac{C_{min}}{C_{max}} \quad [-]$$

} $\varepsilon = \varepsilon(NTU, c)$ (20/27) taulan

12. gaia.

# Erradiazio termikoaren oinarriak

Stefan - Boltzmann-en legea:

$\dot{Q}_{rad} = \varepsilon \sigma A_s T_s^4$ [W] $\varepsilon$ = emisibitatea [-]

$\dot{Q}_{rad\,max} = \sigma A_s T_s^4$ [W] $\sigma = 5'67 \cdot 10^{-8}$ [W/m²K⁴]

Wien-en desplazamendu legea:

$(\lambda T)_{max} = 2897'8$ [μm K]

Stefan - Boltzmann-en legea:

$E_b(T) = \sigma T^4$ [W/m²] $E_b$ ≡ emisio ahalmena

Erradiazio propietateak.

$\alpha + \rho + \tau = 1$

Absortibitatea ($\alpha$).

$\alpha = \frac{G_{abs}}{G}$ [-] $0 \leq \alpha \leq 1$ G ≡ incident radiation [W/m²]

Erreflektibitatea ($\rho$)

$\rho = \frac{G_{ref}}{G}$ [-] $0 \leq \rho \leq 1$

Transmisibitatea ($\tau$)

$\tau = \frac{G_{tr}}{G}$ [-] $0 \leq \tau \leq 1$

Gainazal beltza → $\alpha = 1$ ; $\rho = \tau = 0$
Gainazal ispilua → $\rho = 1$ ; $\alpha = \tau = 0$
Gainazal gardena → $\tau = 1$ ; $\alpha = \rho = 0$
Gainazal opakoa → $\tau = 0$ ; $\alpha + \rho = 1$
Gainazal matea → $\rho = 0$ ; $\alpha + \tau = 1$

Kirchoff-en legea

$$\left.\begin{array}{l} G_{abs} = \alpha G = \alpha \sigma T^4 \\ E_{emit} = \varepsilon \sigma T^4 \end{array}\right\} \quad \varepsilon(T) = \alpha(T)$$

Solar incident radiation ($G_{solar}$)

$G_{solar} = G_0 \cdot \cos\theta + G_d$ [W/m²] $\theta$ ≡ intzidentzia angelua

Atmosferako igorpena ($G_{sky}$)

$G_{sky} = \sigma T_{sky}^4$ [W/m²]

$q_{net,rad} = \alpha_s G_{solar} + \varepsilon \sigma (T_{sky}^4 - T_s^4)$ [W/m²] ← kasuaren arabera, energia balantzea

18. gaia.

# Erradiazio bidezko bero-transferentzia

Stefan-Boltzmann-en legea:

$\dot{Q}_{rad,emit} = \varepsilon \sigma A_s (T_s^4)$ [W] $\sigma = 5'67 \cdot 10^{-8}$ [W/m²K⁴]

Elkarreikuskotasun-erlazioa

$A_i F_{ij} = A_j F_{ji}$ non $F \equiv$ ikuspen-faktorea [-]

Batuketa araua.

$\sum_{i=1}^{N} F_{i \to j} = 1$ adibidez, $F_{11} + F_{12} + \dots + F_{1N} = 1$

Simetria-araua

j eta k gainazalak i-rekiko simetrikoak badira.

$F_{i \to j} = F_{i \to k}$ eta $F_{j \to i} = F_{k \to i}$

Gainazal bateko kanpoko bero-transferentzia.

$\dot{Q}_{1 \to 2} = A_1 F_{1 \to 2} \sigma (T_1^4 - T_2^4)$ [W] ← Gorputz beltza

$Q_{i \to j} = \dfrac{J_i - J_j}{R_{i \to j}}$ [W] ← gainazal difuso grisak

Erradiositatea ($J_i$)

gorputz beltza → $J_{bi} = E_{bi} = \sigma T_i^4$ [W/m²]

gainazal grisa → $J_i = \varepsilon_i E_{bi} + (1 - \varepsilon_i) G_i$ [W/m²]

Bero transferentzia garbia ($\dot{Q}_i$)

$\dot{Q}_i = \dfrac{E_{bi} - J_i}{R_i}$ [W]

Erradiazio gainazal erresistentzia ($R_i$)

$R_i = \dfrac{1 - \varepsilon_i}{A_i \varepsilon_i}$ [1/m²] eta $R_{i \to j} = \dfrac{1}{A_i F_{i \to j}}$ [1/m²]

espazio erresistentzia