TERMOTEKNIA

1. GAIA: OINARRIZKO KONTZEPTUAK

- [DEF]: BERO TRANSFERENTZIA Q (J)

  BERO TRANSFERENTZIA ABIADURA $\dot{Q}$ (W)

  BERO-FLUXUA $\dot{q}$ (W/m^2)

- TERMODINAMIKAREN 1º LEGEA: $\boxed{Q_{in} - Q_{out} + E_{gen} = E_{mgt}}$

- BERO TRANSFERENTZIAKO MEKANISMOAK:

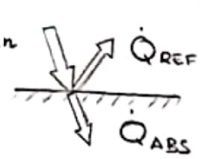
1) EROAPENA: $\boxed{\dot{Q} = -kA\frac{dT}{dx} = -kA\frac{\Delta T}{\Delta x} \quad (W)}$ — FOURIER

- [DEF]: EROANKORTASUN TERMIKOA k $\left(\frac{W}{m°C}\right)$
- [DEF]: DIFUSIBITATE TERMIKOA $\boxed{\alpha = \frac{k}{\rho C_p} \quad (m^2/s)}$

2) KONBEKZIOA: $\boxed{\dot{Q} = h A_s (T_s - T_\infty) \quad (W)}$ — NEWTON

- [DEF]: KONBEKZIO KOEFIZIENTEA h $\left(\frac{W}{m^2 °C}\right)$

3) ERRADIAZIOA: $\boxed{\dot{Q} = \varepsilon \sigma A_s (T_s^4 - T_{surr}^4) \quad (W)}$ — KIRCHOFF



$\boxed{\dot{Q}_{REF} = (1-\alpha)\dot{Q}_{in}}$

$\boxed{\dot{Q}_{ABS} = \alpha \dot{Q}_{in}}$

2. GAIA: BERO EROAPENAREN EKUAZIOA

- [DEF]: GRADIENTE TERMIKOA $\boxed{\vec{\nabla} T = \frac{\partial T}{\partial x}\vec{i} - \frac{\partial T}{\partial y}\vec{j} + \frac{\partial T}{\partial z}\vec{k} \quad (K/m)}$

- $\dot{Q} \rightleftharpoons \vec{\nabla} T$ · $\dot{Q} \perp$ ISOTERMA

• [DEF] : BERO EROAPENAREN EKUAZIO OROKORRA (3D)

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{e}_{gen}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}$$

• [DEF] : BERO EROAPENAREN EKUAZIO UNIDIMENTSIONALA (1D)

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

[n = 0 HORMA LAUA
n = 1 HORMA ZILINDRIKOA
n = 2 HORMA ESFERIKOA]

• HUSTUGAILU GABE $\dot{e}_{gen} = 0$ • 2 MB
• EGOERA EGONKORRA $\frac{\partial T}{\partial \tau} = 0$

• [PROZ.] : EK. DIF. → INTEGRATU → M.B. → $T = T(x, y, z, \tau)$

(GOMENDAGARRIA : EGONKORRA + $e_{gen} \neq 0$ DENEAN)

• MUGALDE BALDINTZAK : ① $T(x=i) = T\,°C$ ② $Q_i = Q_j$

3 GAIA : BERO EROAPEN GELDIKORRA

• [DEF] : ANALOGIA TERMOELEKTRIKOA $I = \frac{\Delta V}{R} \iff \dot{Q} = \frac{T_1 - T_2}{R}$

• [PROZ] : $\frac{dT}{d\tau} = 0 \cap \dot{e}_{gen} = 0$

- EROAPENEKO ERRESISTENTZIA:

1) HORMA LAUA : $R = \frac{L}{k\,A}$ (K/W)

2) ZILINDROA : $R = \frac{\ln(r_2/r_1)}{2\pi L \cdot k}$ (K/W)

3) ESFERA : $R = \frac{r_2 - r_1}{4\pi \cdot r_1 \cdot r_2 \cdot k}$ (K/W)

- KONBEKZIO BIDEZKO ERRESISTENTZIA : $R = \frac{1}{h\,A}$ (K/W)

- ERRADIAZIO BIDEZKO ERRESISTENTZIA : $R = \frac{1}{A \cdot \varepsilon \cdot \sigma (T_S^2 + T_{SURR}^2)(T_S + T_{SURR})}$

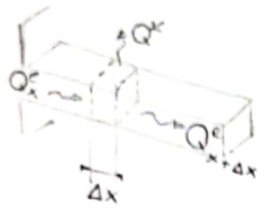
• ERRESISTENTZIA KONBINAZIOAK : • PARALELO : $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

• SERIE : $R_T = R_1 + R_2$

• ERRADIO KRITIKOA $r_{zil} = \frac{K_{isol}}{h}$ — ZILINDROA

$r_{esf} = \frac{2 \cdot K_{isol}}{h}$ — ESFERA $(r < 1cm)$

• GAINAZAL HEGALDUNAK:



- HEGAL EKUAZIOAK:

1) $\dot{Q}_{e,x} = \dot{Q}_{e,x+x} + \dot{Q}_k$

2) $\dot{Q}_k = h p \Delta x (T_{(x)} - T_\infty)$

3) $\dot{Q}_{e,x} = -k A_c \frac{d T(x)}{dx}$

4) $\frac{d}{dx}\left(k A_c \frac{dT(x)}{dx}\right) - hp(T_{(x)} - T_\infty) = 0$

5) $\frac{d^2\theta}{dx^2} - m^2\theta = 0$ [E.D.A]

6) $\theta(x) = C_1 e^{mx} + C_2 e^{-mx}$

$\theta(x) = T(x) - T_\infty$

$m^2 = \frac{hp}{kAc}$

- BERO TRANSFERENTZIA MAXIMOA: $\dot{Q}_{FIN,MAX} = h A_{FIN} (T_b - T_\infty)$

- ERRENDIMENDUA: $\eta = \frac{\dot{Q}_{FIN}}{\dot{Q}_{FIN,MAX}}$ $\quad A_{FIN} = p \cdot L_c$ $\quad L_c = L + \frac{Ac}{p}$

$Q_{FIN} = N\left(-kAc \frac{dT(x)}{dx}\Big|_{x=0}\right)$

$Q_{NOFIN} = h \cdot A_{NO_{FIN}} (T_b - T_\infty)$

$Q_{BARE} = h A_{BARE} (T_b - T_\infty)$

- ERAGINKORTASUNA: $\varepsilon = \frac{N Q_{FIN} + Q_{NO_{FIN}}}{Q_{BARE}}$

• $\varepsilon < 1$ ISOLATZAILEA

• $\varepsilon = 1$ ERAGINIK EZ

• $\varepsilon > 1$ GALERA HANDITU

4. GAIA: BERO EROAPEN IRAGANKORRA

• PARAMETRO KONTZENTRATUAK: $T(r,t) \rightsquigarrow T(t)$

$Bi = \frac{h L_c}{k}$ — BIOT $\quad L_c = \frac{V}{As}$ — LUZERA KARAKTERISTIKO

- BALDINTZA: $Bi \leq 0,1$

$\frac{T(t) - T_\infty}{T_i - T_\infty} = exp - \left(\frac{h As}{\rho V C_p}\right)$

- EKUAZIOAK:

$Q = mC_p(T_{(t)} - T_i)$ — BT TOT

$Q = mC_p(T_\infty - T_i)$ — BT. MAX

• 1D-KO PROBLEMAK DIMENTSIOGABETUAK (IRAGANKORRA)

- T(°C) DIMENTSIOGABEA: $\theta(\bar{X}, \tau) = \frac{T(x,t) - T_m}{T_i - T_m} = \frac{Q(x,t)}{Q_{max}}$
- DISTANTZIA DIMENTSIOGABEA: $\bar{X} = x/L$
- BIOT: $Bi = \frac{h L}{k}$ (B.T. KOEFIZIENTEA)
- FOURIER (TAU): $\tau = \frac{\alpha \cdot t}{r_0^2}$ $\left(\tau = \frac{Q_{KOND}}{Q_{MET.}} \right)$

5 GAIA: ZENBAKIZKO METODOAK BERO-EROAPENEAN

• EKUAZIO DIFERENTZIALEN DIFERENTZIA FINITUKO FORMULAZIOA:

- 1D: $\frac{T_{m-1} - 2T_m + T_{m+1}}{\Delta x^2} + \frac{\dot{e}_m}{k} = 0$
- 2D: $\frac{T_{m+1,n} - 2T_{m,n} + T_{m-1,n}}{\Delta x^2} + \frac{T_{m,n+1} - 2T_{m,n} + T_{m,n-1}}{\Delta y^2} + \frac{\dot{e}_{m,n}}{k} = 0$

• ADI! BEI ERREXAGO

• EGOERA IRAGANKORRA:

- METODO ESPLIZITUA: (ERRAZA, $\Delta\tau$ MUGATUA) $\sum_{\text{All sides}} \dot{Q}^i + \dot{E}^i_{gen,elemnt} = \rho V_{elemnt} \cdot c_p \frac{T_m^{i+1} - T_m^i}{\Delta\tau}$
- METODO INPLIZITUA: (ZAILA, $\Delta\tau$ EZ-MUGATUA) $\sum_{\text{All sides}} \dot{Q}^{i+1} + \dot{E}^{i+1}_{gen,elemnt} = \rho V_{elemnt} \cdot c_p \frac{T_m^{i+1} - T_m^i}{\Delta\tau}$

NODO GUZTIAK BATERA EBATZI

• EGONKORTASUN IRIZPIDEA:

- 1D: $\tau = \frac{\alpha \Delta\tau}{\Delta x^2} \leq \frac{1}{2}$
- 2D: $\tau = \frac{\alpha \Delta\tau}{\ell^2} \leq \frac{1}{4}$

6 GAIA KONBEKZIOAREN OINARRIAK

- BATAZ BESTEKO KONBEKZIO KOEFIZIENTEA: $$h = \frac{-k_{fluid} \cdot (\partial T/\partial y)_{y=0}}{T_s - T_\infty}$$

- NUSSELTEN ZENBAKIA: $$Nu = \frac{h \cdot L_c}{k} \quad \left(Nu = \frac{q_{konb}}{q_{kond}} \right)$$

- GAINAZALEZKO ERAKIDURA-TENTSIOA: $$\tau_s = C_f \cdot \rho \frac{V^2}{2} \quad [N/m^2]$$

- BISKOSITATE ZINEMATIKOA: $$\nu = \frac{\mu}{\rho} \quad [m^2/s] \qquad (\mu \ [kg/m \cdot s])$$

- PRANDTLEN ZBK: $$Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{k}$$ (MOMENTUAREN DIFUSIBITATE MOLEKULARRA / BEROAREN DIFUSIBITATE MOLEKULARRA)

- REYNOLDS ZBK: $$Re = \frac{V \cdot L_c}{\nu} = \frac{\rho V \cdot L_c}{\mu}$$

- STANTONEN ZBK: $$St = \frac{h}{\rho C_p \cdot V} = \frac{Nu}{Re_L \cdot Pr}$$

- CHILTON-COLBURNEN ZBK: $$\frac{C_{f,x}}{2} = \frac{h_x}{\rho C_p \cdot V} \cdot Pr^{2/3} \equiv j_H$$

BALIOGARRIA
$0,6 < Pr < 60$
- FLUXU TURBULENTO PRESIO ∇ BALIOUPE ERE
- FLUXU LAMINARRA BALDIN $\partial P/\partial x = 0$

1) EKUAZIO DIMENTSIOGABEAK:

JARRAITUTASUNA: $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

MOMENTUA: $$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{1}{Re_L} \frac{\partial^2 u}{\partial y^2} - \frac{\partial P}{\partial x}$$

ENERGIA: $$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{1}{Re_L \cdot Pr} \left(\frac{\partial^2 T}{\partial y^2} \right)$$

7 GAIA : KANPO KONBEZIO BEHARTUA

· PROZEDURA :

1) E.B. PLANTEATU

2) h? (T_s?...)

2.1) [SUPOSATU T_s] : $T_f = \frac{T_s + T_\infty}{2}$ T? KARAKTERISTIKOA

2.2) TAULETAN : FLUIDOAREN PROP.

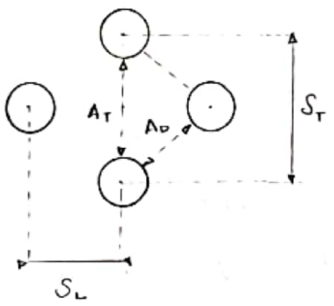
2.3) Re KALKULATU

2.4) Nu KORRELAZIO BAT AUKERATU ETA KALKULATU

2.5) h KALKULATU

3) BERO TRANSFERENTZIA KALKULATU.

· HODI MULTZOETAN ZEHARREKO FLUXUA :



$$\cdot Re = \frac{V_{max} \cdot D}{\nu}$$

$$\cdot S_D = \sqrt{S_L^2 + (S_T/2)^2}$$

$2A_D > A_T$

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

$2A_D < A_T$

$$V_{max} = \frac{S_T}{2(S_D - D)} V$$

· FLUXUA: $\dot{Q} = h A_S \cdot \Delta T_{ln} = \dot{m} c_p (T_e - T_i)$

· $\Delta T_{ln} = \frac{(T_s - T_e) - (T_s - T_i)}{\ln[(T_s - T_e)/(T_s - T_i)]}$ · $T_e = T_s - (T_s - T_i) \cdot e^{-\frac{A_s h}{\dot{m} c_p}}$

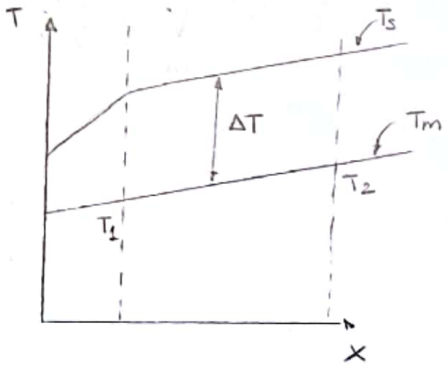
8 GAIA : BARNEKO KONBEKZIO BEHARTUA

· ANALISI TERMIKO OROKORRA:

1) q_s KONSTANTE :

$$\dot{Q} = \dot{q}_s A_s = \dot{m} c_p (T_2 - T_1)$$

$$\dot{q}_s = h (T_s - T_m)$$



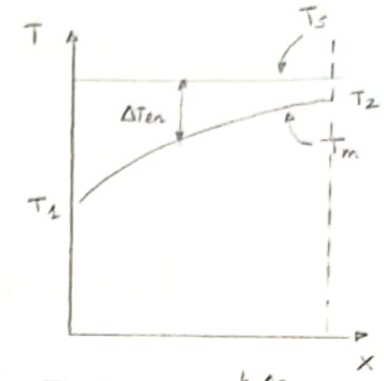
[LAMINAR] $Nu = 4{,}36$ // q_s = kte ΔT = kte h = kte

↳ $T_s - T_m$ = kte

2) T_s KONSTANTE:

$$\dot{Q} = h A_s \Delta T_{en} = \dot{m} c_p (T_2 - T_1)$$

$$\Delta T_{en} = \frac{(T_s - T_2) - (T_s - T_1)}{\ln[(T_s - T_2)/(T_s - T_1)]}$$



[LAMINAR]: $N_u = 3,66$

$$\frac{T_2 - T_s}{T_1 - T_s} = e^{-\frac{h A_s}{\dot{m} c_p}}$$

· PRESIO GALERAK:

- FLUXU LAMINARRA: $\Delta P = \frac{32 \mu L V_{AVG}}{D^2} = f \frac{L}{D} \rho \frac{V_{AVG}^2}{2}$

$$\left[f = \frac{64}{Re} = \frac{8 \tau_w}{\rho V_{AVG}^2} \right]$$

· KARGA GALERAK:

- FLUXU LAMINARRA: $h_L = f \frac{L}{D} \frac{V_{AVG}^2}{2g}$ $\quad W = \dot{V} \Delta P = \dot{m} h_L$

· KORRELAZIOAK:

- LAMINAR: $L_h = 0,05 Re D$ // $L_t = Pr L_h$
- TURBULENTO: $L_h \simeq L_t \simeq 10 D$

9. GAIA: KONBEKZIO NATURALA

· KONBEKZIO BEHARTUA (Pr, Re) ⟶ KONBEKZIO NATURALA (Gr, Pr)

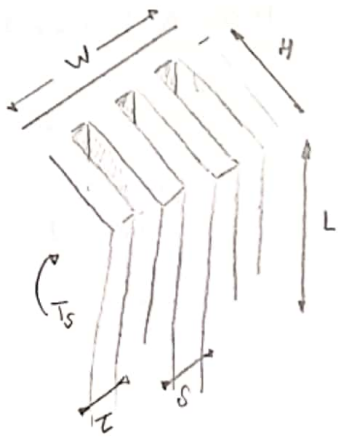
$$Ra = Gr \cdot Pr = \frac{g \beta (T_s - T_\infty) L_c^3}{\nu^2} Pr$$

· GAINAZAL HEGALDUNAK (T_s = kte):

$$S_{opt} = 2,714 \frac{L}{Ra^{0,25}}$$

$$\dot{Q} = h (2 n L H)(T_s - T_\infty)$$

$$n = \frac{W}{S}$$

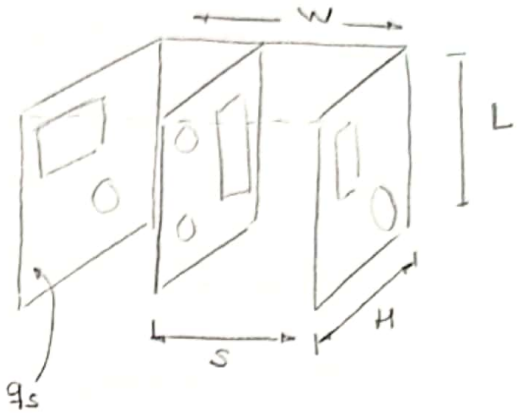


· ZIRKUITU INPRIMATU BERTIKALEAN (q_s = kte)

$$S_{opt} = 2,12 \left(\frac{S^4 L}{Ra_S} \right)^{0,2}$$

$$\dot{Q} = \dot{q}_s A_s = \dot{q}_s (2nLH)$$

$$n = \frac{W}{S} \quad // \quad \dot{q}_s = h (T_L - T_\infty)$$



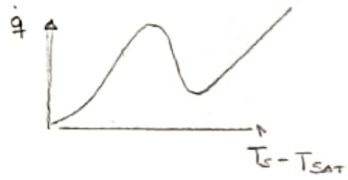
· EROANKORTASUN TERMIKO ERAGINKORRA:

$$\dot{Q} = h A_s (T_1 - T_2) = k Nu A_s \frac{(T_1 - T_2)}{L_c}$$

$$k_{eff} = k Nu$$

10. GAIA: IRAKITEA ETA KONDENTSAZIOA

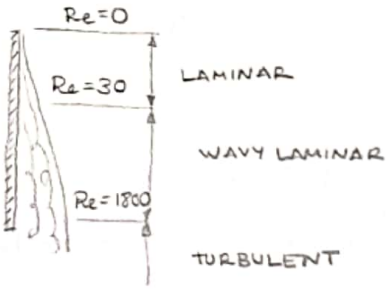
1) IRAKITEA: $\dot{q}_{BOIL} = h (T_s - T_{SAT})$



2) · GERUZA ERAKO KONDENTSAZIOA:

$$h_{fg}^* = h_{fg} + 0,68 C_{pl} (T_{SAT} - T_s)$$

$$\dot{Q}_{COND} = h A_s (T_{SAT} - T_s) = \dot{m} h_{fg}$$



· TANTA ERAKO KONDENTSAZIOA

· HODI HORIZONTALAK

11. GAIA: BERO TRUKAGAILUAK

· BERO-TRANSFERENTZIAREN KOEFIZIENTE OROKORRA:

$$\dot{Q} = U A_s \Delta T_{ln} \qquad U = \frac{1}{\frac{1}{h_0} + \frac{1}{h_1}}$$

· METODO LOGARITMIKOA :

1) $\dot{Q} = mc_p(T_2 - T_1)$

$\dot{Q} = UAF\Delta T_{ln}$

2) ΔT_{ln} : $\Delta T_{ln} = \frac{\Delta T_1 - \Delta T_2}{ln(\Delta T_1/\Delta T_2)}$

$A = \pi D \cdot L \, n_{TUB} \cdot n_{FASES}$

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

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

3) F : ZUZENTZEA (TAULAK)

FASE TUBO 1 → F = 1

· ε - NTU METODOA :

1) $\dot{Q}$: $\dot{Q} = mc_p(T_2 - T_1)$

$\dot{Q}_{max} = C_{min}(T_{h,in} - T_1)$

2) ε : $\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}}$

3). KORRELAZIOA $\varepsilon \propto NTU = \frac{UA}{C_{min}}$

12. GAIA : ERRADIAZIO TERMIKOEN OINARRIAK

· $\lambda T \xrightarrow{\text{TAULAK}} f_\lambda$

· $\varepsilon(T) = f\varepsilon_1 + (1-f)\varepsilon_2$

· $\alpha + \rho + \tau = 1$

· MB : $\dot{q}_{in} = \dot{q}_{out}$ $G_S = G_{S_D} \cdot \cos\alpha + G_{S_{dif.}}$

· KIRCHOFF $\varepsilon = \alpha$

· $F_{i-j} = \frac{\Sigma \text{HARI. GUR.} - \Sigma \text{HARI EZ. GUR.}}{2 \cdot L_i}$

$\varepsilon_g = \varepsilon_{g_1} + \varepsilon_{g_2} - \Delta\varepsilon$

$Q_{TRASM} = q_{SOLAR} \cdot \alpha \cdot A (f_{\lambda 2} - f_{\lambda 1})$