

7 GAIA

KANPO KONBEKZIO BEHARTUA

7.0 - HELBURUAK

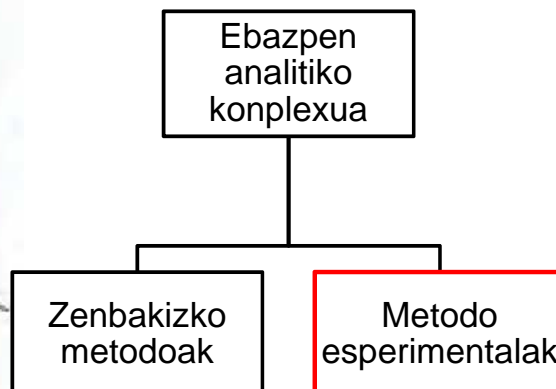
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- **Barne-** eta **kanpo-fluxuak** bereizi.
- Marruskadura- eta presio-arrastea era intuitiboan ulertzeko gaitasuna landu, eta kanpo-fluxuen **batez besteko** arraste- eta **konbekzio-koefizienteak** kalkulatu
- **Xafla lauen** gaineko fluxu laminar nahiz turbulentuen arrastea eta bero-transferentzia kalkulatu.
- Fluxu gurutzatuetan **zilindroei** eragiten zaien arraste-indarra kalkulatu, eta orobat batez besteko bero-transferentziaren koefizientea.
- **Hodi multzoetan** zeharreko fluxuen presio-jaitsiera eta batez besteko bero-transferentziaren koefizientea kalkulatu, konfigurazio lerrokatuan nahiz mailakatuan.

7.1 – ARRASTEA ETA BERO-TRANSFERENTZIA KANPO-FLUXUETAN

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Gorputz solidoen aurkako jariakin fluxua:



7.1 – ARRASTEA ETA BERO-TRANSFERENTZIA KANPO-FLUXUETAN

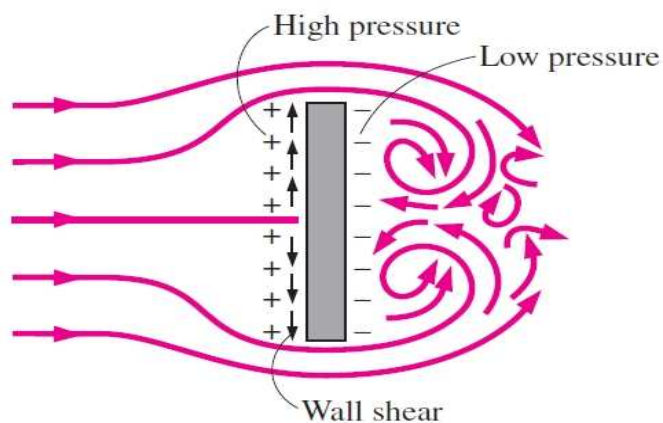
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MARRUSKADURA- ETA PRESIO-ARRASTEAK



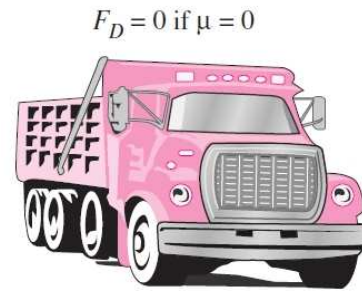
Arraste indarrak
(jariakinarekiko paralelo)

Euste indarrak
(jariakinari elkartut)



MARRUSKADURA- ETA PRESIO-ARRASTEAK

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



$$C_D = C_{D, \text{marruskadura}} + C_{D, \text{presioa}}$$

Azaleko marruskadura-arrastea
(ebakidura tentsioa)

Presio-arrastea
(gorputzaren formagatik)

$$C_{D, \text{pressure}} = 0$$

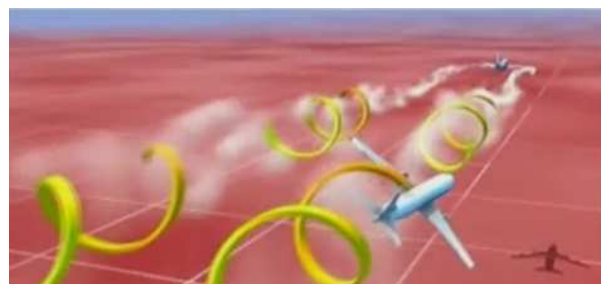
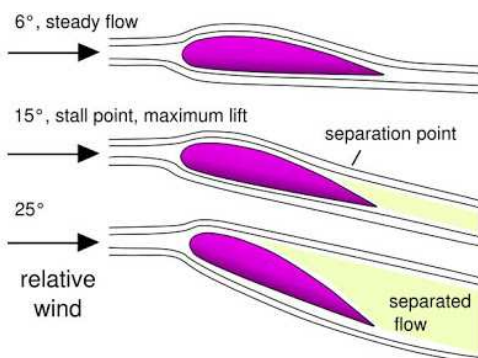
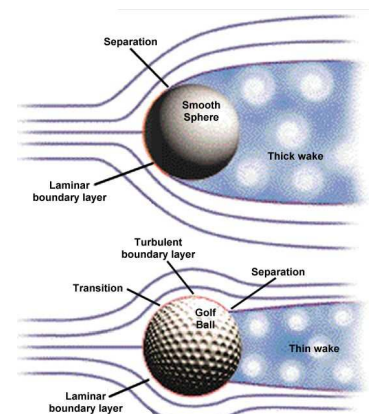
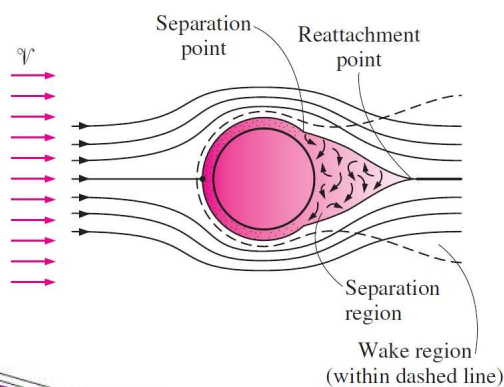
$$C_D = C_{D, \text{friction}} = C_f$$

$$F_{D, \text{pressure}} = 0$$

$$F_D = F_{D, \text{friction}} = F_f = C_f A \frac{\rho V^2}{2}$$

MARRUSKADURA- ETA PRESIO-ARRASTEAK

Eskualde banatua
(ubera)



BERO-TRANSFERENTZIA

6. GAIA

$$\Rightarrow Nu_x = f_1(x^*, Re_x, Pr) \Rightarrow Nu = f_2(Re_L, Pr)$$

$$Nu = \frac{1}{L} \int_0^L Nu_x dx$$

$$Nu = C Re_L^m Pr^n$$

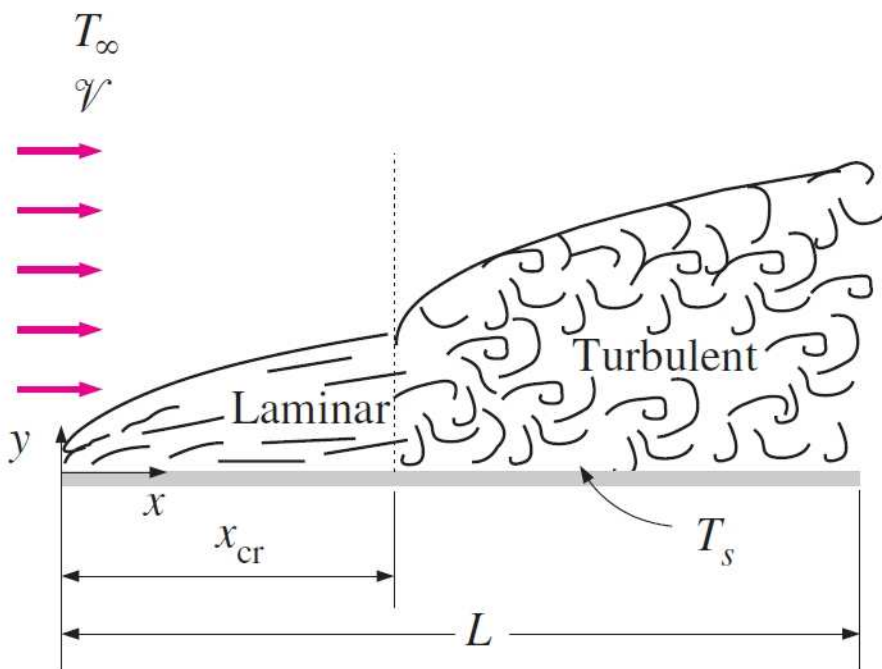
Jariakinaren propietateak

$$T_f = \frac{T_s + T_\infty}{2} \rightarrow \text{Geruza-tenperatura}$$

$$T_\infty \rightarrow \left(\frac{Pr_\infty}{Pr_s} \right)^r \text{ edo } \left(\frac{\mu_\infty}{\mu_s} \right)^r$$

TERMOTEKANIA

7.2 – XAFLA LAUEN GAINEKO FLUXU PARALELOA



$$Re_x = \frac{Vx}{\nu}$$

$$Re_{cr} = \frac{Vx_{cr}}{\nu} = 5 \cdot 10^5$$

MARRUSKADURA-KOEFIZIENTEA

$$\left. \begin{array}{l} \delta_{v,x} = \frac{4.91x}{\text{Re}_x^{1/2}} \quad y \quad C_{f,x} = \frac{0.664}{\text{Re}_x^{1/2}} \quad \text{Re}_x < 5 \cdot 10^5 \\ \delta_{v,x} = \frac{0.38x}{\text{Re}_x^{1/5}} \quad y \quad C_{f,x} = \frac{0.059}{\text{Re}_x^{1/5}} \quad 5 \cdot 10^5 \leq \text{Re}_x < 10^7 \end{array} \right\} \text{Balio lokalak}$$

$$\begin{aligned} C_f &= \frac{1}{L} \int_0^L C_{f,x} dx \\ &= \frac{1}{L} \int_0^L \frac{0.664}{\text{Re}_x^{1/2}} dx \\ &= \frac{0.664}{L} \int_0^L \left(\frac{\gamma x}{\nu} \right)^{-1/2} dx \\ &= \frac{0.664}{L} \left(\frac{\gamma}{\nu} \right)^{-1/2} \frac{x^{1/2}}{\frac{1}{2}} \Big|_0^L \\ &= \frac{2 \times 0.664}{L} \left(\frac{\gamma L}{\nu} \right)^{-1/2} \\ &= \frac{1.328}{\text{Re}_L^{1/2}} \end{aligned}$$

$$\left. \begin{array}{l} C_f = \frac{1.328}{\text{Re}_L^{1/2}} \quad \text{Re}_L < 5 \cdot 10^5 \\ C_f = \frac{0.074}{\text{Re}_L^{1/5}} \quad 5 \cdot 10^5 \leq \text{Re}_L < 10^7 \end{array} \right\} \text{Bataz besteko balioak}$$



7.2 – XAFLA LAUEN GAINEKO FLUXU PARALELOA

MARRUSKADURA-KOEFIZIENTEA

$$\left. \begin{array}{l} C_f = \frac{1}{L} \left(\int_0^{x_{cr}} C_{f,x \text{ laminar}} dx + \int_{x_{cr}}^L C_{f,x \text{ turbulent}} dx \right) \\ C_f = \frac{0.074}{\text{Re}_L^{1/5}} - \frac{1742}{\text{Re}_L} \quad 5 \cdot 10^5 \leq \text{Re}_L < 10^7 \end{array} \right\} \text{Fluxu mistoa}$$

- Fluxu laminarra ($\text{Re} \downarrow$) $\rightarrow C_f = f(\text{Re})$
- Fluxu guztiz turbulentua ($\text{Re} \uparrow \uparrow$) $\rightarrow C_f = f(\epsilon)$

Zimurtasuna \leftarrow

Relative roughness, ϵ/L	Friction coefficient C_f
0.0*	0.0029
1×10^{-5}	0.0032
1×10^{-4}	0.0049
1×10^{-3}	0.0084

*Smooth surface for $\text{Re} = 10^7$. Others calculated from Eq. 7-18.

$$C_f = \left(1.89 - 1.62 \log \frac{\epsilon}{L} \right)^{-2.5}$$

Schlichtingen korrelazioa
fluxu turbulentuan dauden
gainazal zimurrentzat



BERO-TRANSFERENTZIAREN KOEFIZIENTEA

$$Nu_x = \frac{h_x x}{k} = 0.332 Re_x^{0.5} Pr^{\frac{1}{3}}$$

$$Pr > 0.6$$

$$Re_x < 5 \cdot 10^5$$

$$Nu_x = \frac{h_x x}{k} = 0.0296 Re_x^{0.8} Pr^{\frac{1}{3}}$$

$$0.6 \leq Pr \leq 60$$

$$5 \cdot 10^5 \leq Re_x \leq 10^7$$

Balio
lokalak
($T_s = cte$)

$$Nu = \frac{hL}{k} = 0.664 Re_L^{0.5} Pr^{\frac{1}{3}}$$

$$Pr > 0.6$$

$$Re_L < 5 \cdot 10^5$$

$$Nu = \frac{hL}{k} = 0.037 Re_L^{0.8} Pr^{\frac{1}{3}}$$

$$0.6 \leq Pr \leq 60$$

$$5 \cdot 10^5 \leq Re_L \leq 10^7$$

Bataz besteko
balioak

7.2 – XAFLA LAUEN GAINEKO FLUXU PARALELOA

BERO-TRANSFERENTZIAREN KOEFIZIENTEA

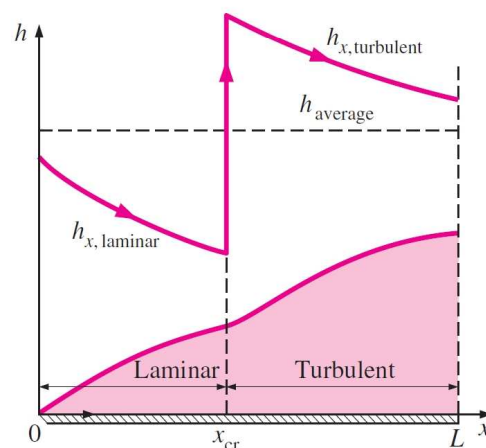
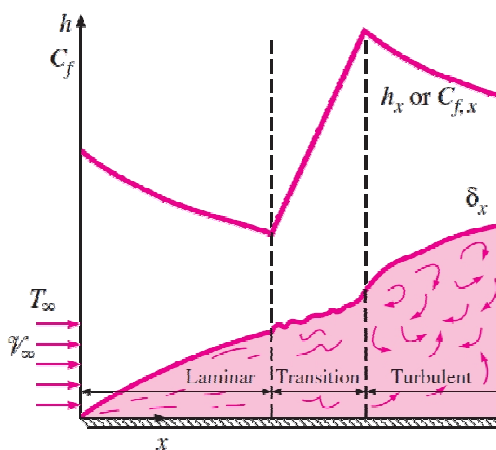
$$h = \frac{1}{L} \left(\int_0^{x_{cr}} h_{x, \text{laminar}} dx + \int_{x_{cr}}^L h_{x, \text{turbulent}} dx \right)$$

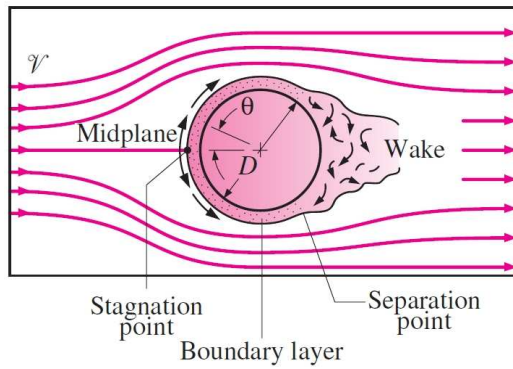
$$Nu = \frac{hL}{k} = (0.037 Re_L^{0.8} - 871) \cdot Pr^{\frac{1}{3}}$$

$$0.6 \leq Pr \leq 60$$

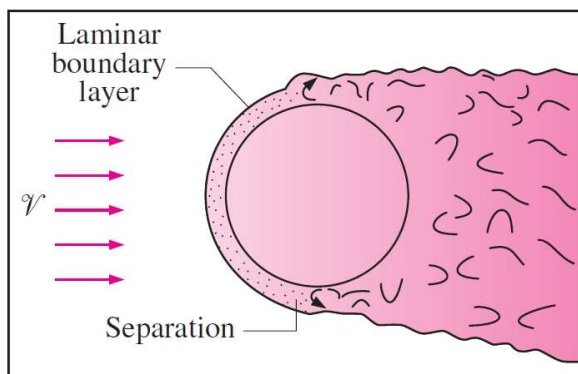
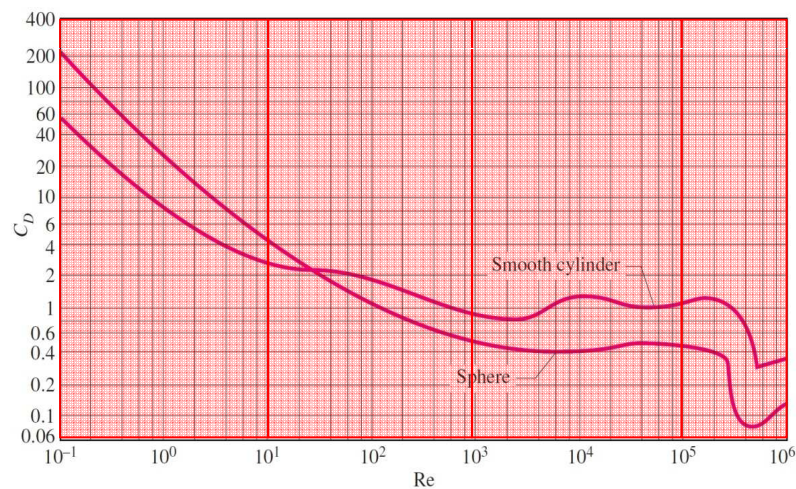
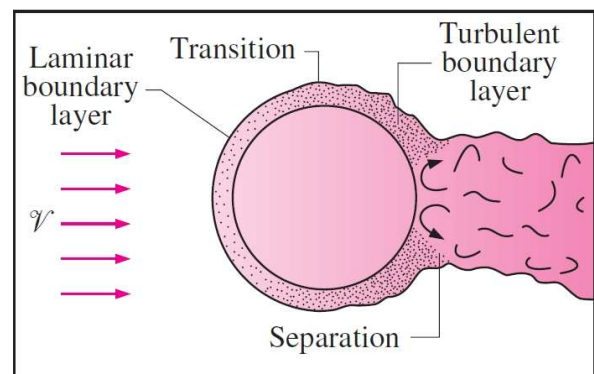
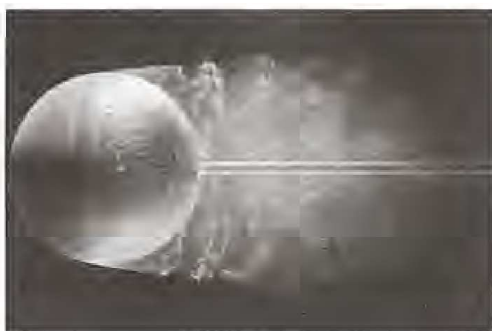
$$5 \cdot 10^5 \leq Re_L \leq 10^7$$

Fluxu
mistoa

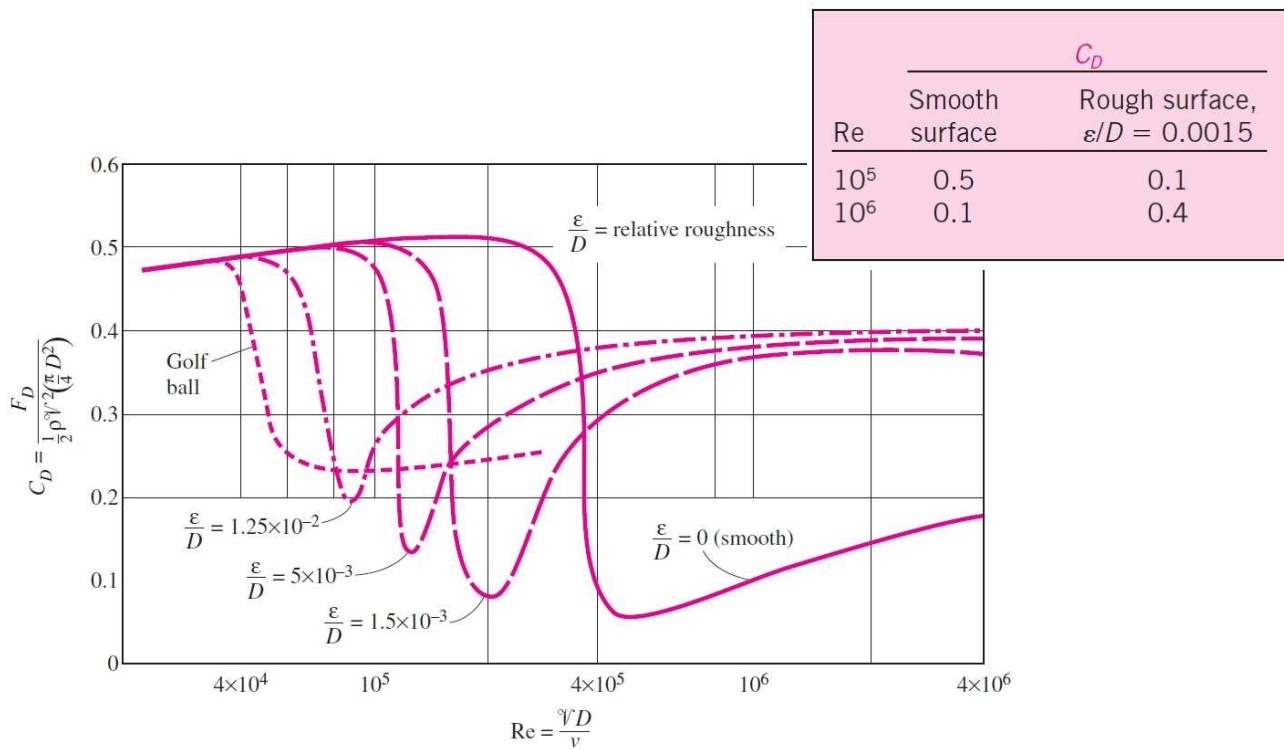




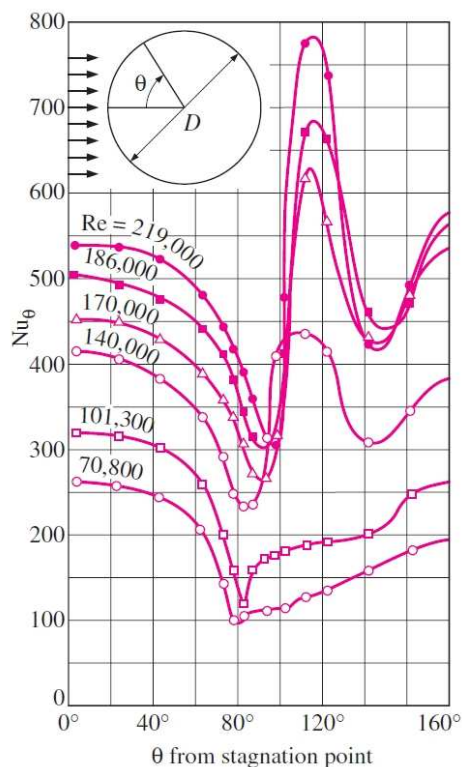
- $Re \downarrow \rightarrow$ Marruskadura indarrak
- $Re \uparrow \rightarrow$ Presio indarrak
- Tarteko $Re \rightarrow$ Biak

(a) Laminar flow ($Re < 2 \times 10^5$)(b) Turbulence occurs ($Re > 2 \times 10^5$)

GAINAZAL-ZIMURTASUNAREN ERAGINA



BERO-TRANSFERENTZIAREN KOEFIZIENTEA



- Fluxu konplexua
- Zenbakizko ebazpena edo esperimentala
- Re-en araberako portaera
- Bataz besteko balioen erabilera

BERO-TRANSFERENTZIAREN KOEFIZIENTEA

Churchill eta Berstein
(zilindroarekiko
zeharkako fluxua)

$$Nu_{cyl} = \frac{hD}{k} = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1 + (0.4/Pr)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{282000}\right)^{5/8}\right]^{4/5}$$

$$Pr > 0.2$$

Whitaker
(esferarekiko fluxua)

$$Nu_{sph} = \frac{hD}{k} = 2 + \left[0.4 Re^{1/2} + 0.06 Re^{2/3}\right] Pr^{0.4} \left(\frac{\mu_{\infty}}{\mu_s}\right)^{1/4}$$

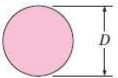
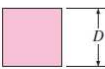
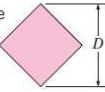
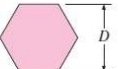
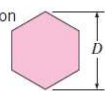

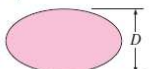
$$0.7 \leq Pr \leq 380$$

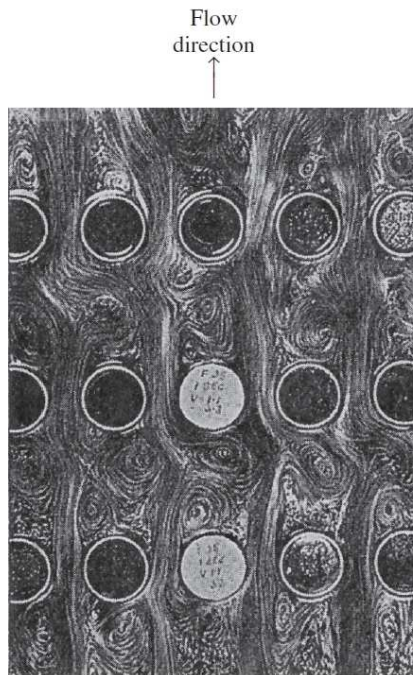
$$3.5 \leq Re_D \leq 80000$$

7.3 – ZILINDRO ETA ESFERETAN ZEHARREKO FLUXUA

BERO-TRANSFERENTZIAREN KOEFIZIENTEA

$$Nu = \frac{hD}{k} = C Re^m Pr^{1/3} \Rightarrow$$

Cross-section of the cylinder	Fluid	Range of Re	Nusselt number
Circle 	Gas or liquid	0.4–4 4–40 40–4000 4000–40,000 40,000–400,000	$Nu = 0.989 Re^{0.330} Pr^{1/3}$ $Nu = 0.911 Re^{0.385} Pr^{1/3}$ $Nu = 0.683 Re^{0.466} Pr^{1/3}$ $Nu = 0.193 Re^{0.618} Pr^{1/3}$ $Nu = 0.027 Re^{0.805} Pr^{1/3}$
Square 	Gas	5000–100,000	$Nu = 0.102 Re^{0.675} Pr^{1/3}$
Square (tilted 45°) 	Gas	5000–100,000	$Nu = 0.246 Re^{0.588} Pr^{1/3}$
Hexagon 	Gas	5000–100,000	$Nu = 0.153 Re^{0.638} Pr^{1/3}$
Hexagon (tilted 45°) 	Gas	5000–19,500 19,500–100,000	$Nu = 0.160 Re^{0.638} Pr^{1/3}$ $Nu = 0.0385 Re^{0.782} Pr^{1/3}$
Vertical plate 	Gas	4000–15,000	$Nu = 0.228 Re^{0.731} Pr^{1/3}$
Ellipse 	Gas	2500–15,000	$Nu = 0.248 Re^{0.612} Pr^{1/3}$



Lerrokatuta

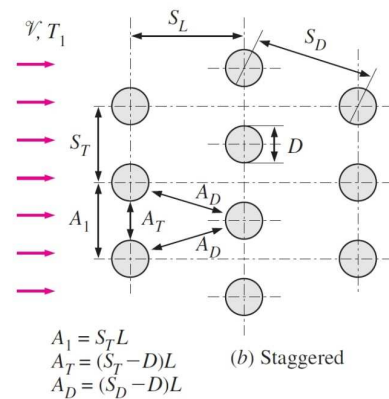
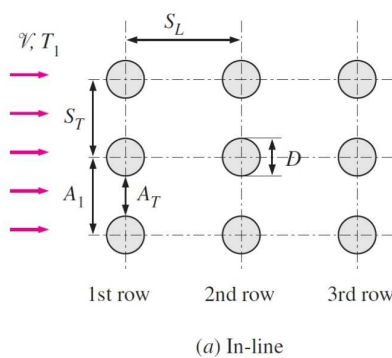


Mailakatuta

Bero-trukagailuak:

- Barne-fluxua
- Kanpo-fluxua

7.4 – HODI MULTZOETAN ZEHARREKO FLUXUA



$$Re_D = \frac{V_{\max} D}{\nu}$$

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

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

Si $2 \cdot A_D > A_T \rightarrow V_{\max} = \frac{S_T}{S_T - D} V$

Si $2 \cdot A_D < A_T \rightarrow V_{\max} = \frac{S_T}{2(S_D - D)} V$

$$Nu = \frac{hD}{k} = C Re_D^m Pr^n (Pr/Pr_s)^{0.25} \quad \begin{array}{l} 0.7 \leq Pr \leq 500 \\ 0 \leq Re_D \leq 2 \cdot 10^6 \end{array}$$

Arrangement	Range of Re_D	Correlation
In-line	0–100	$Nu_D = 0.9 Re_D^{0.4} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	100–1000	$Nu_D = 0.52 Re_D^{0.5} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	1000– 2×10^5	$Nu_D = 0.27 Re_D^{0.63} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	2×10^5 – 2×10^6	$Nu_D = 0.033 Re_D^{0.8} Pr^{0.4} (Pr/Pr_s)^{0.25}$
Staggered	0–500	$Nu_D = 1.04 Re_D^{0.4} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	500–1000	$Nu_D = 0.71 Re_D^{0.5} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	1000– 2×10^5	$Nu_D = 0.35 (S_T/S_L)^{0.2} Re_D^{0.6} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	2×10^5 – 2×10^6	$Nu_D = 0.031 (S_T/S_L)^{0.2} Re_D^{0.8} Pr^{0.36} (Pr/Pr_s)^{0.25}$

Baldin $N_L < 16 \rightarrow Nu_{D, N_L} = F Nu_D$

N_L	1	2	3	4	5	7	10	13
In-line	0.70	0.80	0.86	0.90	0.93	0.96	0.98	0.99
Staggered	0.64	0.76	0.84	0.89	0.93	0.96	0.98	0.99

7.4 – HODI MULTZOETAN ZEHARREKO FLUXUA

Bataz besteko temperatura-diferentzia logaritmikoa:

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

Irteera-tenperatura:

$$T_e = T_s - (T_s - T_i) \exp\left(\pm \frac{A_s h}{\dot{m} c_p}\right)$$

$$\dot{Q} = h A_s \Delta T_{\ln} = \dot{m} c_p (T_e - T_i)$$

- 7.2ko azpiatala: BEROTU GABEKO HASIERA ZATIA DUEN XAFLA LAUA
- 7.2ko azpiatala: BERO-FLUXU UNIFORMEA
- 7.4ko azpiatala: PRESIO-JAITSIERA

Erabilitako irudien iturria:

ÇENCEL, Y.A. TRANSFERENCIA DE CALOR Y MASA, Un enfoque práctico. McGraw-Hil.3 Edición. 2007