7 GAIA

KANPO KONBEKZIO BEHARTUA

7.0 - HELBURUAK

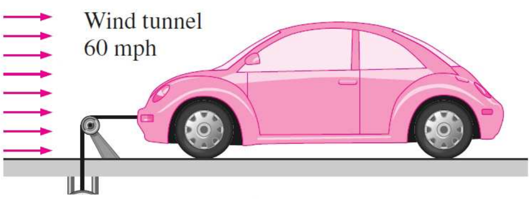
- **Barne-** eta **kanpo-fluxuak** bereizi.
- Marruskadura- eta presio-arrastea era intuitiboan ulertzeko gaitasuna landu, eta kanpo-fluxuen **batez besteko** arraste- eta **konbekzio-koefizienteak** kalkulatu
- **Xafla lauen** gaineko fluxu laminar nahiz turbulentuen arrastea eta bero-transferentzia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

Gorputz solidoen aurkako jariakin fluxua:

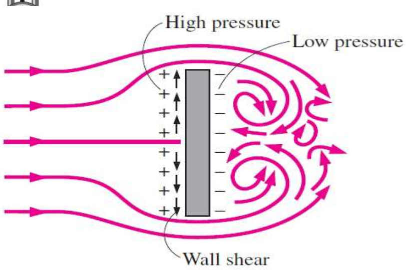
Ebazpen analitiko konplexua

- Zenbakizko metodoak
- Metodo esperimentalak

MARRUSKADURA- ETA PRESIO-ARRASTEA

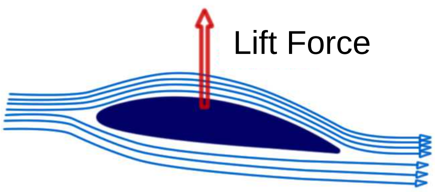


Arraste indarrak
(jariakinarekiko paralelo)



Presio indarrak
(jariakinarekiko paralelo)

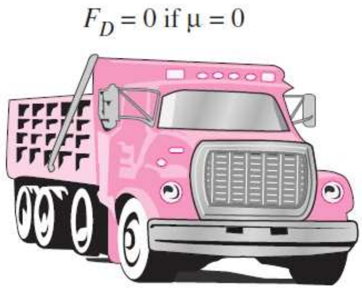
Euste indarrak
(jariakinari elkartzut)



MARRUSKADURA- ETA PRESIO-ARRASTEA

Arraste-koefizientea →

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$$



$$C_D = C_{D,\,friction} + C_{D,\,pressure}$$

Azaleko marruskadura-arrastea (ebakidura tentsioa)

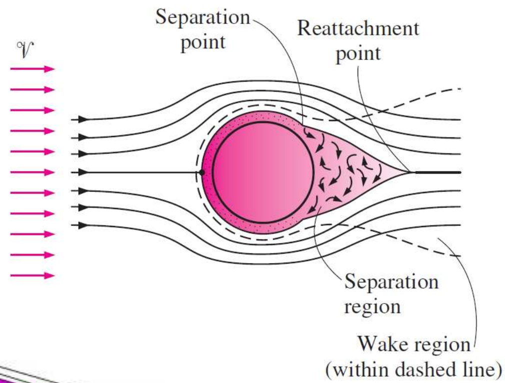
Presio-arrastea (gorputzaren formagatik)

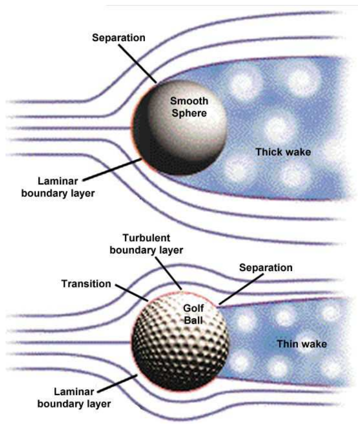
$$C_{D,\text{ pressure}} = 0$$
$$C_D = C_{D,\text{ friction}} = C_f$$

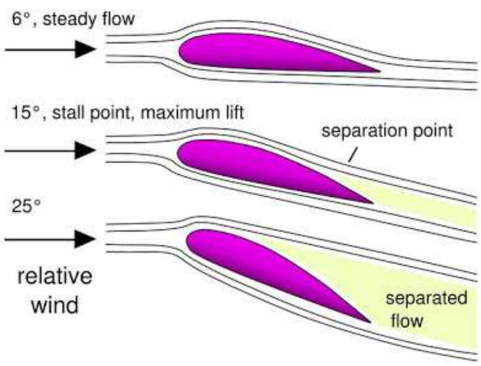
$$F_{D,\text{ pressure}} = 0$$
$$F_D = F_{D,\text{ friction}} = F_f = C_f A \frac{\rho \mathcal{V}^2}{2}$$

MARRUSKADURA- ETA PRESIO-ARRASTEA

Eskualde banatua (ubera)







7.1 – ARRASTEA ETA BERO-TRANSFERENTZIA KANPO-FLUXUETAN

BERO-TRANSFERENTZIA

6. GAIA ⇒ $Nu_x = f_1\left(x^*, \mathrm{Re}_x, \mathrm{Pr}\right)$ ⇒ $Nu = f_2\left(\mathrm{Re}_L, \mathrm{Pr}\right)$

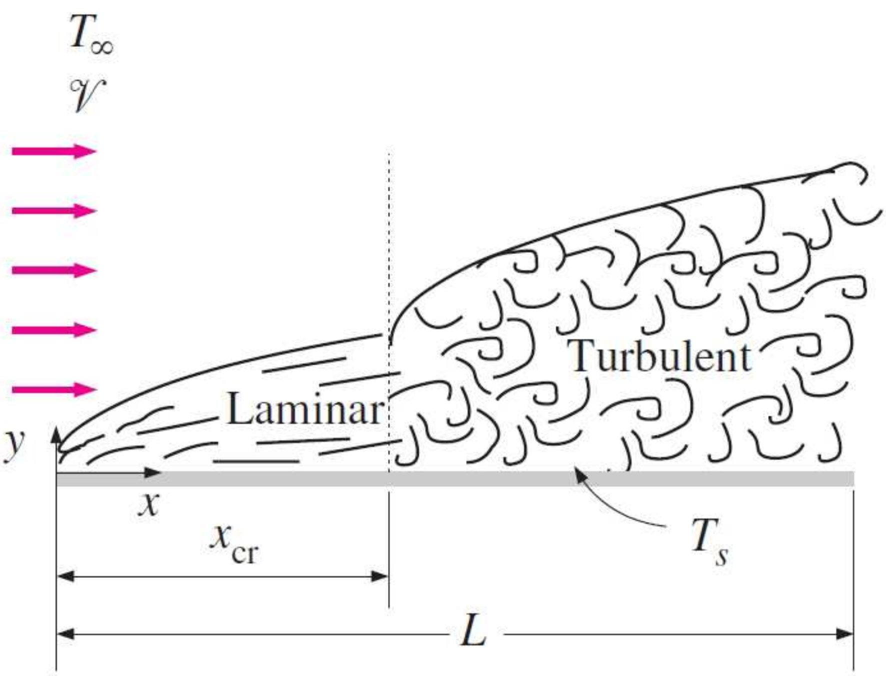
$$Nu = \frac{1}{L}\int_0^L Nu_x dx$$

$$Nu = C\,\mathrm{Re}_L^m\,\mathrm{Pr}^n$$

Jariakinaren propietateak:

- $T_f = \dfrac{T_s + T_\infty}{2}$ → Geruza-tenperatura
- T_∞ → $\left(\dfrac{\mathrm{Pr}_\infty}{\mathrm{Pr}_s}\right)^r$ edo $\left(\dfrac{\mu_\infty}{\mu_s}\right)^r$

7.2 – XAFLA LAUEN GAINEKO FLUXU PARALELOA



$$\mathrm{Re}_x = \frac{Vx}{\nu}$$

$$\mathrm{Re}_{cr} = \frac{Vx_{cr}}{\nu} = 5\cdot 10^5$$

MARRUSKADURA-KOEFIZIENTEA

$$\delta_{v,x} = \frac{4.91x}{\mathrm{Re}_x^{1/2}} \quad \text{eta} \quad C_{f,x} = \frac{0.664}{\mathrm{Re}_x^{1/2}} \qquad \mathrm{Re_x} < 5\cdot10^5$$

$$\delta_{v,x} = \frac{0.38x}{\mathrm{Re}_x^{1/5}} \quad \text{eta} \quad C_{f,x} = \frac{0.059}{\mathrm{Re}_x^{1/5}} \qquad 5\cdot10^5 \le \mathrm{Re_x} < 10^7$$

Balio lokalak

$$C_f = \frac{1}{L}\int_0^L C_{f,x}\,dx = \frac{1}{L}\int_0^L \frac{0.664}{\mathrm{Re}_x^{1/2}}\,dx = \frac{0.664}{L}\int_0^L \left(\frac{\mathcal{V}x}{\nu}\right)^{-1/2} dx = \frac{0.664}{L}\left(\frac{\mathcal{V}}{\nu}\right)^{-1/2} \left.\frac{x^{1/2}}{\frac{1}{2}}\right|_0^L = \frac{2\times0.664}{L}\left(\frac{\mathcal{V}L}{\nu}\right)^{-1/2} = \frac{1.328}{\mathrm{Re}_L^{1/2}}$$

$$C_f = \frac{1.328}{\mathrm{Re}_L^{1/2}} \qquad \mathrm{Re_L} < 5\cdot10^5$$

$$C_f = \frac{0.074}{\mathrm{Re}_L^{1/5}} \qquad 5\cdot10^5 \le \mathrm{Re_L} < 10^7$$

Bataz besteko balioak

MARRUSKADURA-KOEFIZIENTEA

$$C_f = \frac{1}{L}\left(\int_0^{x_{cr}} C_{f,x\,\mathrm{laminar}}\,dx + \int_{x_{cr}}^{L} C_{f,x\,\mathrm{turbulent}}\,dx\right)$$

$$C_f = \frac{0.074}{\mathrm{Re}_L^{1/5}} - \frac{1742}{\mathrm{Re_L}} \qquad 5\cdot10^5 \le \mathrm{Re_L} < 10^7$$

Fluxu mistoa

- Fluxu laminarra (Re ↓) → C_f = f (Re)
- Fluxu guztiz turbulentua (Re ↑↑) → C_f = f (ε)

Zimurtasuna

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 Re = 10^7. Others calculated from Eq. 7-18.

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

⇒ Schlichtingen korrelazioa fluxu turbulentuan dauden gainazal zimurrentzat

BERO-TRANSFERENTZIAREN KOEFIZIENTEA

$$Nu_x = \frac{h_x x}{k} = 0.332 \mathrm{Re}_x^{0.5} \mathrm{Pr}^{1/3} \qquad \mathrm{Pr} > 0.6, \quad \mathrm{Re}_x < 5 \cdot 10^5$$

$$Nu_x = \frac{h_x x}{k} = 0.0296 \mathrm{Re}_x^{0.8} \mathrm{Pr}^{1/3} \qquad 0.6 \le \mathrm{Pr} \le 60, \quad 5 \cdot 10^5 \le \mathrm{Re}_x \le 10^7$$

Balio lokalak (T_s = cte)

$$Nu = \frac{hL}{k} = 0.664 \mathrm{Re}_L^{0.5} \mathrm{Pr}^{1/3} \qquad \mathrm{Pr} > 0.6, \quad \mathrm{Re}_L < 5 \cdot 10^5$$

$$Nu = \frac{hL}{k} = 0.037 \mathrm{Re}_L^{0.8} \mathrm{Pr}^{1/3} \qquad 0.6 \le \mathrm{Pr} \le 60, \quad 5 \cdot 10^5 \le \mathrm{Re}_L \le 10^7$$

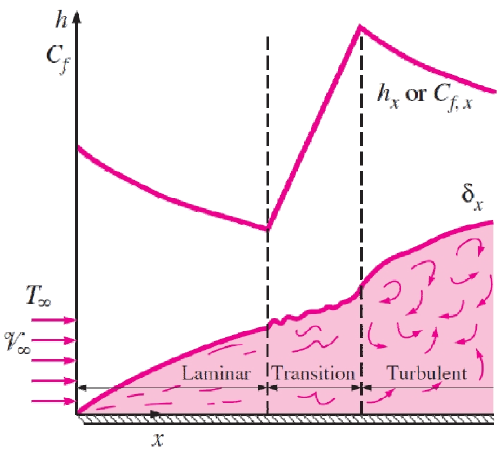
Bataz besteko balioak

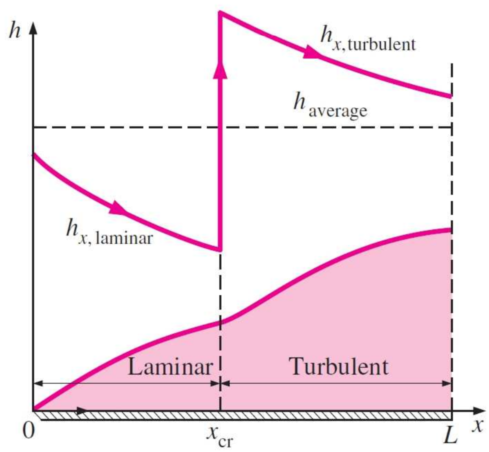
BERO-TRANSFERENTZIAREN KOEFIZIENTEA

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

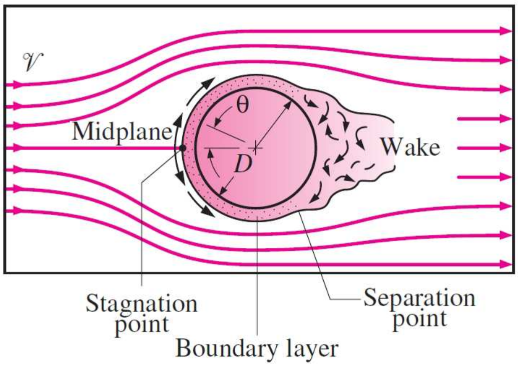
$$Nu = \frac{hL}{k} = \left(0.037 \mathrm{Re}_L^{0.8} - 871\right) \cdot \mathrm{Pr}^{1/3} \qquad 0.6 \le \mathrm{Pr} \le 60, \quad 5 \cdot 10^5 \le \mathrm{Re}_L \le 10^7$$

Fluxu mistoa

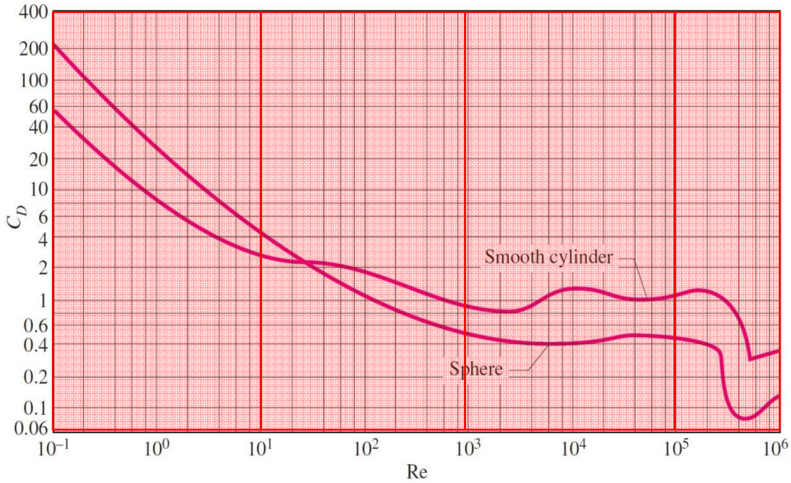




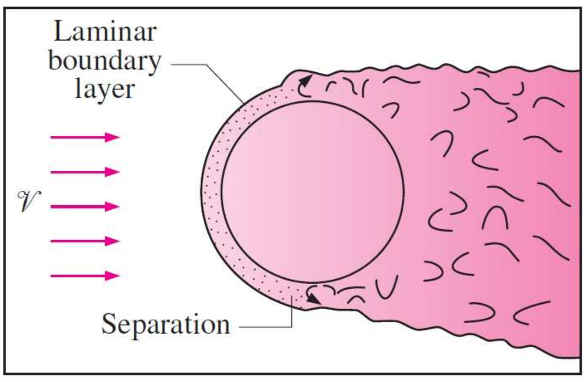
7.3 – ZILINDRO ETA ESFERETAN ZEHARREKO FLUXUA



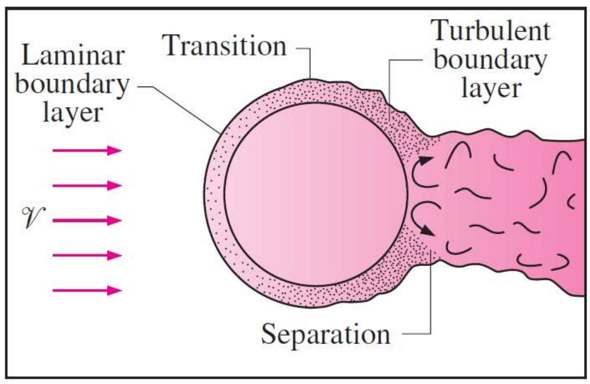
- Re ↓ → Marruskadura indarrak
- Re ↑ → Presio indarrak
- Tarteko Re → Biak



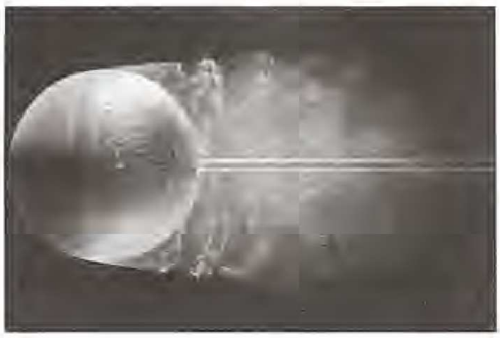
7.3 – ZILINDRO ETA ESFERETAN ZEHARREKO FLUXUA



(*a*) Laminar flow (Re < 2×10^5)

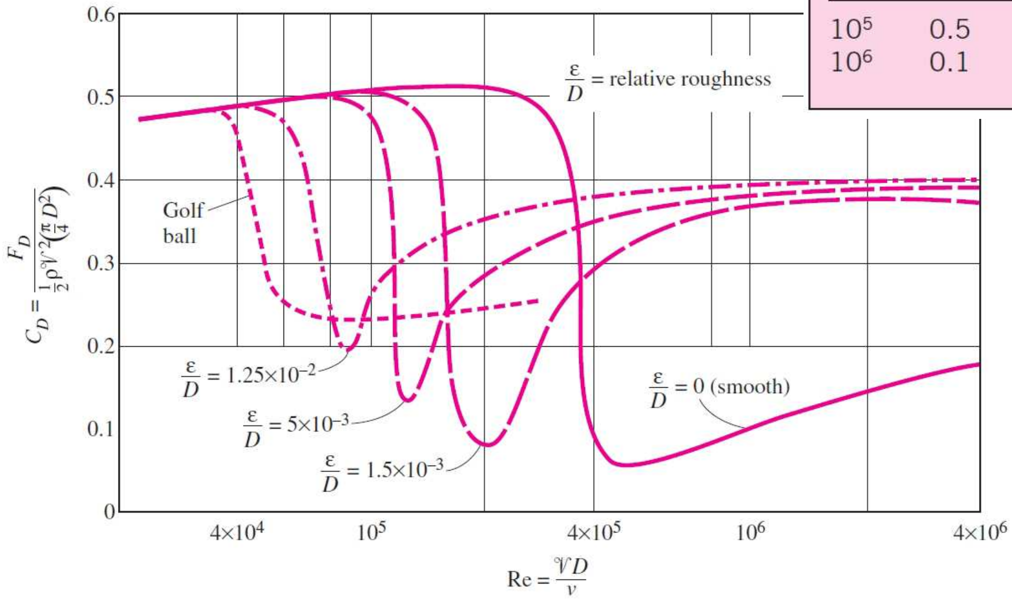


(*b*) Turbulence occurs (Re > 2×10^5)

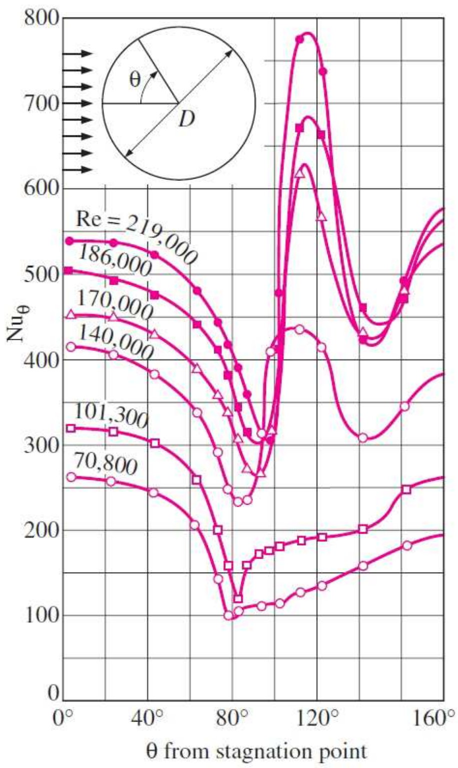


GAINAZAL-ZIMURTASUNAREN ERAGINA

Re	C_D Smooth surface	C_D Rough surface, $\varepsilon/D = 0.0015$
10^5	0.5	0.1
10^6	0.1	0.4



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)

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

$\mathrm{Re}\cdot\mathrm{Pr} > 0.2$

Whitaker
(esferarekiko fluxua)

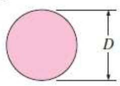
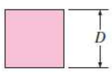
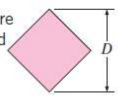
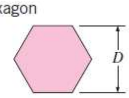
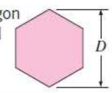
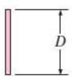
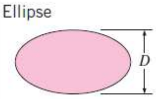
$$Nu_{sph} = \frac{hD}{k} = 2 + \left[0.4\,\mathrm{Re}^{1/2} + 0.06\,\mathrm{Re}^{2/3}\right]\mathrm{Pr}^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

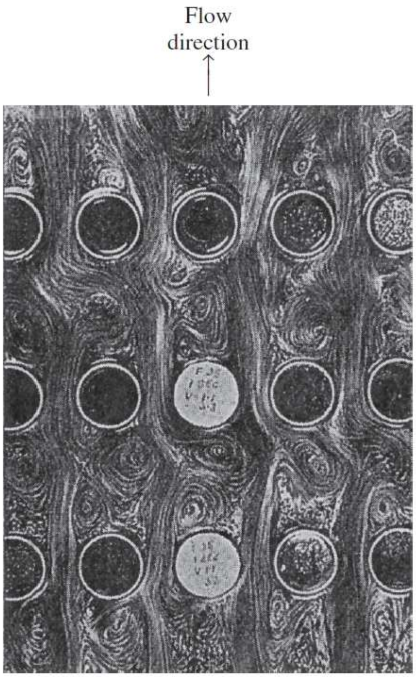
$0.7 \le \mathrm{Pr} \le 380$

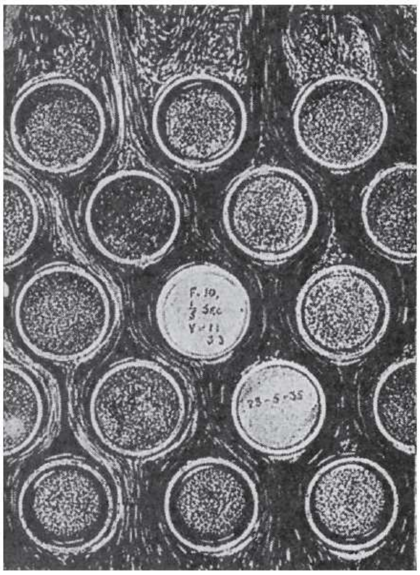
$3.5 \le \mathrm{Re}_D \le 80000$

BERO-TRANSFERENTZIAREN KOEFIZIENTEA

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

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	$Nu = 0.989Re^{0.330}\,Pr^{1/3}$ $Nu = 0.911Re^{0.385}\,Pr^{1/3}$ $Nu = 0.683Re^{0.466}\,Pr^{1/3}$ $Nu = 0.193Re^{0.618}\,Pr^{1/3}$ $Nu = 0.027Re^{0.805}\,Pr^{1/3}$
Square 	Gas	5000–100,000	$Nu = 0.102Re^{0.675}\,Pr^{1/3}$
Square (tilted 45°) 	Gas	5000–100,000	$Nu = 0.246Re^{0.588}\,Pr^{1/3}$
Hexagon 	Gas	5000–100,000	$Nu = 0.153Re^{0.638}\,Pr^{1/3}$
Hexagon (tilted 45°) 	Gas	5000–19,500 19,500–100,000	$Nu = 0.160Re^{0.638}\,Pr^{1/3}$ $Nu = 0.0385Re^{0.782}\,Pr^{1/3}$
Vertical plate 	Gas	4000–15,000	$Nu = 0.228Re^{0.731}\,Pr^{1/3}$
Ellipse 	Gas	2500–15,000	$Nu = 0.248Re^{0.612}\,Pr^{1/3}$



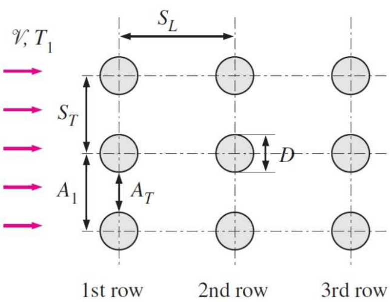


Lerrokatuta

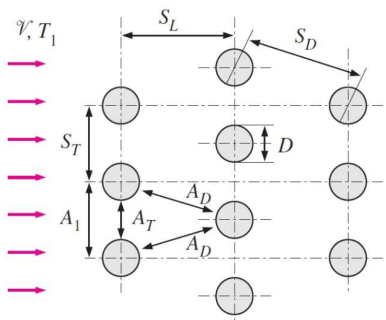
Mailakatuta

Bero-trukagailuak:

- Barne-fluxua
- Kanpo-fluxua



(a) In-line



$A_1 = S_T L$
$A_T = (S_T - D)L$
$A_D = (S_D - D)L$

(b) Staggered

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

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

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

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

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

$$Nu = \frac{hD}{k} = C\,\mathrm{Re}_D^m\,\mathrm{Pr}^n\left(\mathrm{Pr}/\mathrm{Pr}_s\right)^{0.25}$$

$$0.7 \le \mathrm{Pr} \le 500$$

$$0 \le \mathrm{Re}_D \le 2\cdot 10^6$$

Arrangement	Range of Re_D	Correlation
In-line	0–100	$\mathrm{Nu}_D = 0.9\,\mathrm{Re}_D^{0.4}\mathrm{Pr}^{0.36}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$
	100–1000	$\mathrm{Nu}_D = 0.52\,\mathrm{Re}_D^{0.5}\mathrm{Pr}^{0.36}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$
	$1000–2\times10^5$	$\mathrm{Nu}_D = 0.27\,\mathrm{Re}_D^{0.63}\mathrm{Pr}^{0.36}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$
	$2\times10^5–2\times10^6$	$\mathrm{Nu}_D = 0.033\,\mathrm{Re}_D^{0.8}\mathrm{Pr}^{0.4}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$
Staggered	0–500	$\mathrm{Nu}_D = 1.04\,\mathrm{Re}_D^{0.4}\mathrm{Pr}^{0.36}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$
	500–1000	$\mathrm{Nu}_D = 0.71\,\mathrm{Re}_D^{0.5}\mathrm{Pr}^{0.36}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$
	$1000–2\times10^5$	$\mathrm{Nu}_D = 0.35(S_T/S_L)^{0.2}\,\mathrm{Re}_D^{0.6}\mathrm{Pr}^{0.36}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$
	$2\times10^5–2\times10^6$	$\mathrm{Nu}_D = 0.031(S_T/S_L)^{0.2}\,\mathrm{Re}_D^{0.8}\mathrm{Pr}^{0.36}(\mathrm{Pr}/\mathrm{Pr}_s)^{0.25}$

Baldin N_L<16 → $Nu_{D,N_L} = F Nu_D$

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

Bataz besteko tenperatura-diferentzia logaritmikoa:

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

Irteera-tenperatura:

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

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

7.5 – IRAKATSIKO EZ DIREN ATALAK

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