8. GAIA

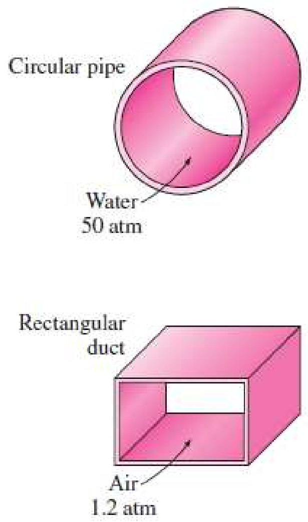
BARNEKO KONBEKZIO BEHARTUA

8.0 - HELBURUAK

- Barne-fluxuaren **batez besteko abiadura** lortu, abiadura-profilean oinarrituta, eta **batez besteko tenperatura** lortu, tenperatura-profilean oinarrituta
- Barne-fluxuko **fluxu-eskualdeen ulermen** bisuala eduki, hala nola sarrera-eskualdearena eta erabat garatutako fluxu-eskualdearena, eta sarrera-luzera hidrodinamikoa eta termikoa kalkulatu
- Gainazal-tenperatura konstantea eta gainazaleko bero-fluxuaren baldintza konstanteak dituen hodi batean doan fluido bat **berotzeko eta hozteko prozesua aztertu**, eta **batez besteko tenperatura-diferentzia logaritmikoarekin** lan egin
- **Fluxu laminar** erabat garatuen abiadura-profilaren, presio-jaitsieraren, marruskadura-faktorearen eta Nusselten zenbakiaren **erlazio analitikoa lortu**
- **Fluxu turbulentu** erabat garatuen marruskadura-faktorea eta Nusselten zenbakia kalkulatu, erlazio enpirikoez baliatuta, eta presio-jaitsiera eta bero-transferentziaren abiadura kalkulatu

8.1 - SARRERA

Barne-fluxuan, fluidoa hodiaren barne-gainazalek inguratua dago

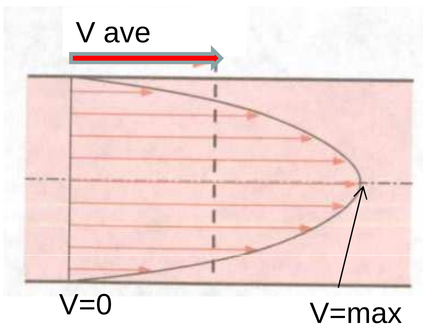


Fluidoa LIKIADOA denean

Fluidoa GASA denean

8.2 – BATEZ BESTEKO ABIADURA ETA TENPERATURA

BATEZ BESTEKO ABIADURA (V_{AVE})



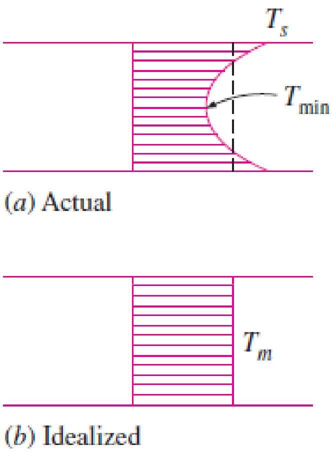
MASAREN kontserbazio-printzipioa

$$\dot{m} = \rho V_{prom} A_c = \int_{Ac} \rho u(r) dA_c$$

$$V_{prom} = \frac{2}{R^2} \int_0^R u(r) r dr$$

$$u(r): \text{abiadura-profila}$$

BATEZ BESTEKO TENPERATURA (T_M)



<u>ENERGIAREN kontserbazio-printzipioa</u>

$$\dot{E}_{fluido} = \dot{m} c_p T_m = \int_{A_c} \rho C_p T(r) u(r) dA_c$$

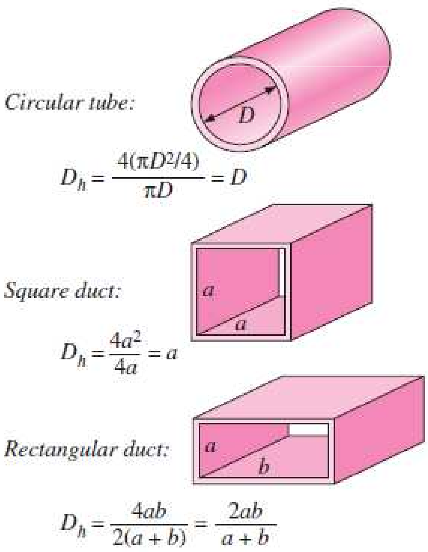
$$T_m = \frac{2}{V_{prom} R^2} \int_0^R T(r) u(r) r dr$$

FLUXU LAMINARRAK ETA TURBULENTUAK HODIETAN

$$\boxed{\mathrm{Re} = \frac{\rho V_{prom} D}{\mu} = \frac{V_{prom} D}{\upsilon}}$$

$$\upsilon = \mu / \rho$$ Biskositate zinematikoa

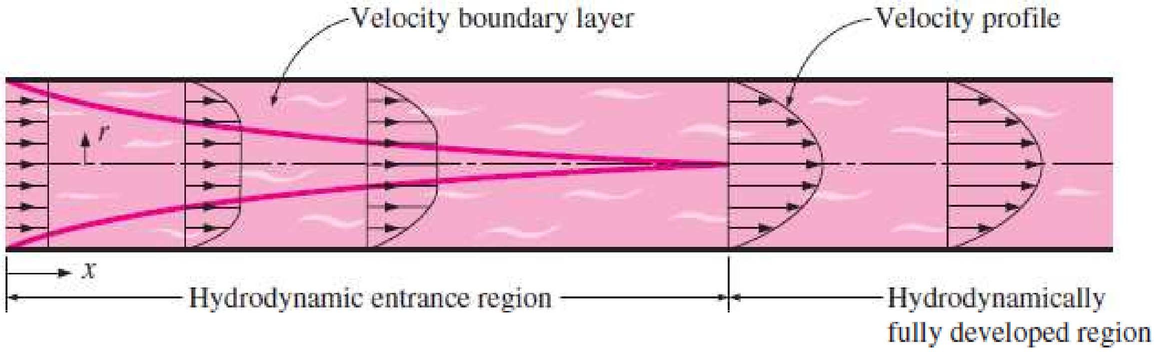
- **Re < 2.300 fluxu laminarra**: fluido oso biskosoak edo abiadura bajuak
- **Re > 10.000 fluxu turbulentoa**



Diametro Hidraulikoa

$$\boxed{D_h = \frac{4A_c}{p}}$$

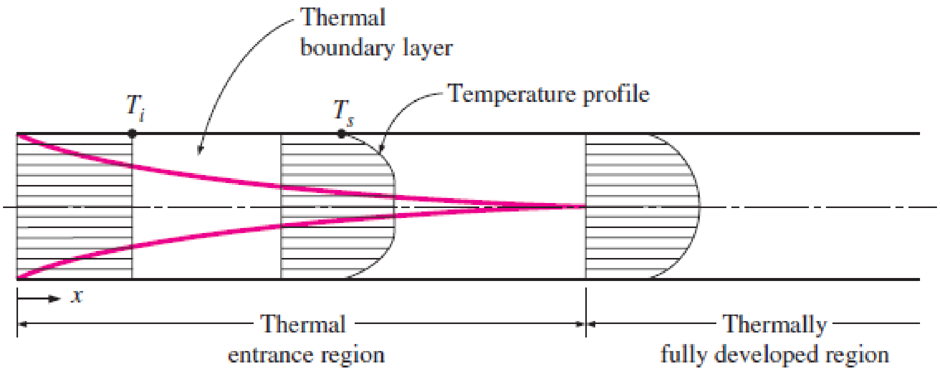
HODI BATEKO MUGALDE-GERUZA ABIADURAREN GARAPENA



Hidrodinamikoki erabat garatutako eskualdea

$$\frac{\partial u(r,x)}{\partial x} = 0 \rightarrow \mathrm{u} = \mathrm{u(r)}$$

HODI BATEKO MUGALDE-GERUZA TERMIKOAREN GARAPENA

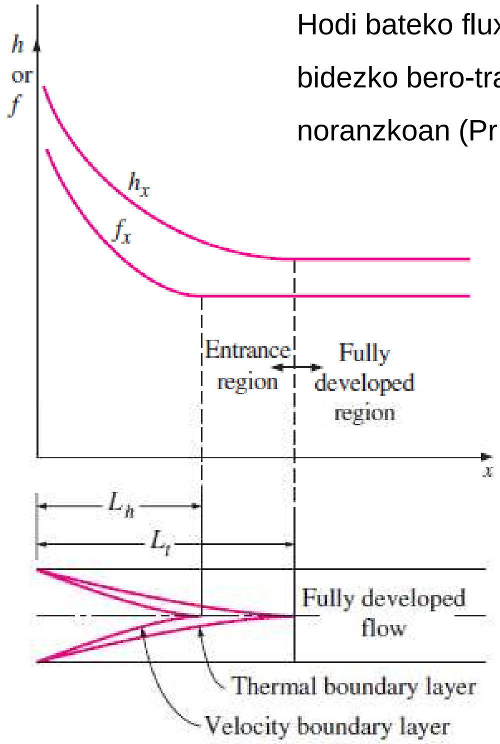


Termikoki erabat garatutako eskualdea

$$\frac{\partial}{\partial x}\left[\frac{T_s(x)-T(r,x)}{T_s(x)-T_m(x)}\right] = 0$$

Gainazaleko bero-fluxua

$$\dot{q} = \dot{q}_s A = h_x (T_s - T_m) = k \left.\frac{\partial T}{\partial r}\right|_{r=R}$$



Hodi bateko fluxuaren marruskadura-faktorearen eta konbekzio bidezko bero-transferentziaren koefizientearen aldaketa fluxuaren noranzkoan (Pr > 1)

L_h luzera hidrodinamikoa

L_t luzera termikoa

SARRERA-LUZERAK EXPERIMENTALAK

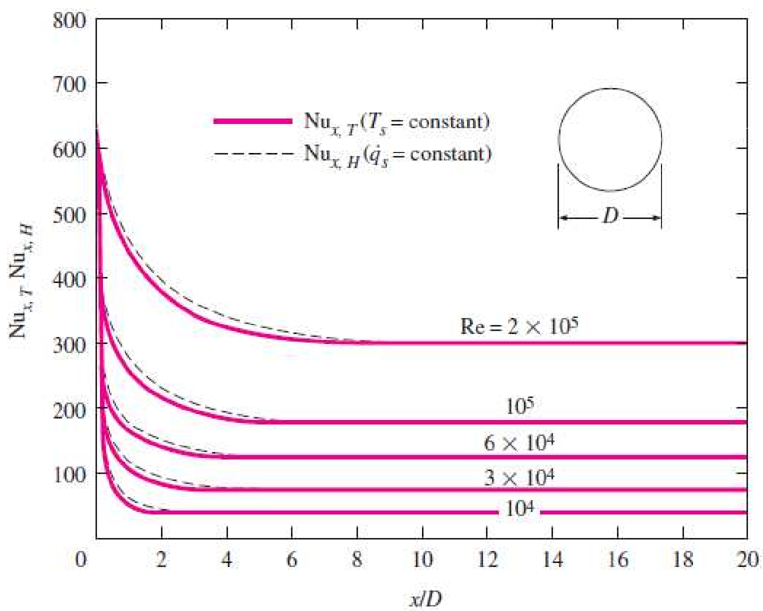
Fluxu Laminarra

$$L_{h,\mathrm{laminar}} \approx 0{,}05\,\mathrm{ReD}$$

$$L_{t,\mathrm{laminar}} \approx 0{,}05\ \mathrm{Re}\,\mathrm{Pr}\,D = \mathrm{Pr}\,L_{h,\mathrm{laminar}}$$

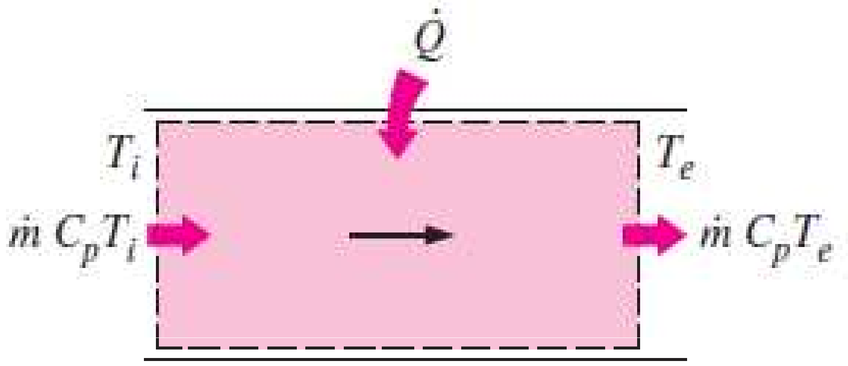
Fluxu turbulentua

$$L_{h,\mathrm{turbulent}} \approx L_{t,\mathrm{turbulent}} \approx 10\mathrm{D}$$



Fluxu turbulentua duen hodi batean zeharreko Nusselten zenbaki lokalaren aldaketa

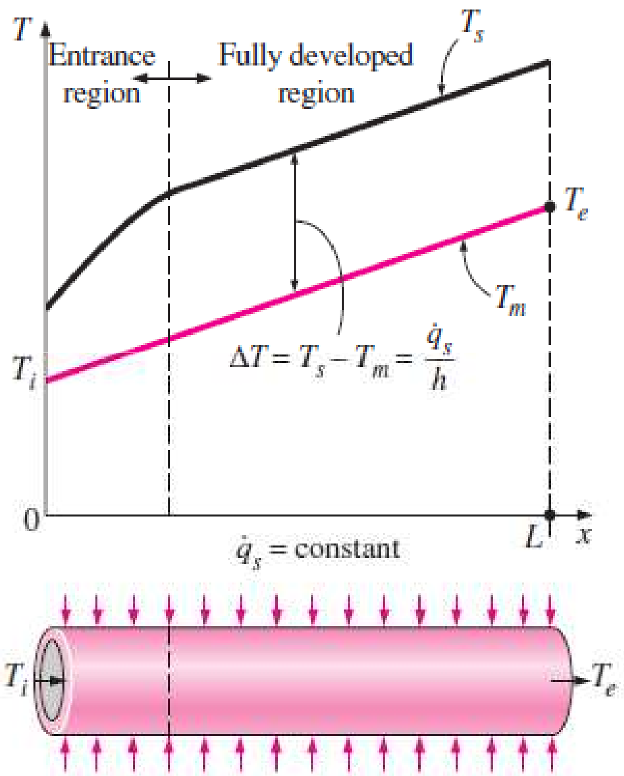
Hodi bateko fluido baten fluxu geldikorraren energia-kontserbazioaren ekuazioa



$$\dot{Q} = \dot{m}c_p(T_e - T_i) \quad \text{(W)}$$

$$\dot{q}_s = h_x(T_s - T_m) \quad (\text{W/m}^2)$$

GAINAZALEKO BERO-FLUXU KONSTANTEA (Q_S= CONSTANTE)



$$\boxed{\dot{Q} = \dot{q}_s A_s = \dot{m}c_p(T_e - T_i) \quad \text{(W)}}$$

$$T_e = T_i + \frac{\dot{q}_s A_s}{\dot{m}C_p}$$

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

$$T_s - T_m = cte$$

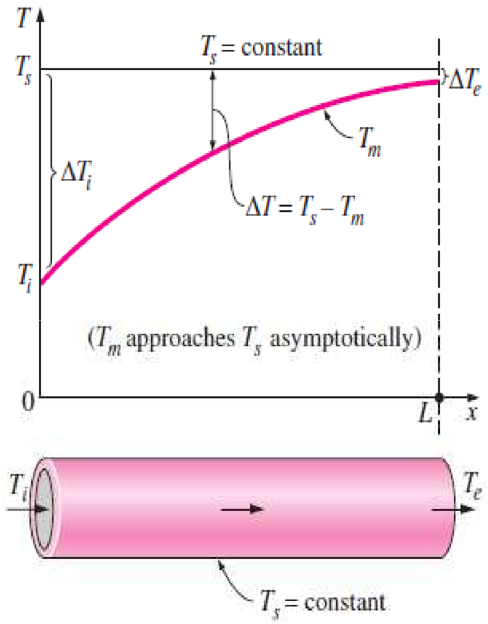
$$\frac{\partial T}{\partial x} = \frac{dT_s}{dx} = \frac{dT_m}{dx} = \frac{2\dot{q}_s p}{\rho V_{prom} C_p R} = cte$$

Tutu zirkularra:

$$p = 2\pi R \ \text{ y } \ \dot{m} = \rho V_{prom} A_c$$

8.4 – ANALISI TERMIKO OROKORRA

GAINAZAL-TENPERATURA KONSTANTEA (T_S= CONSTANTE)



$$\dot{Q} = hA_s \Delta T_{prom} = hA_s (T_s - T_m)_{prom} \quad \text{(W)}$$

$$\Delta T_{prom} \approx \Delta T_{ma} = \frac{\Delta T_i - \Delta T_e}{2} = \frac{(T_s - T_i) + (T_s - T_e)}{2}$$

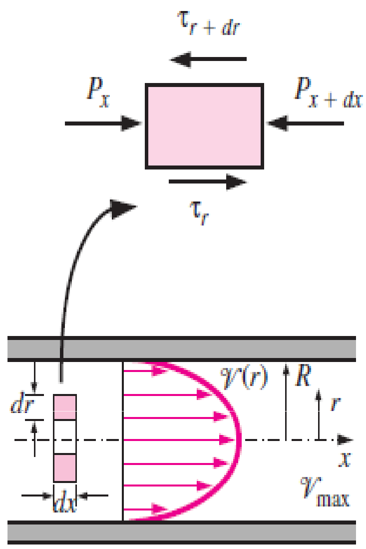
Energia Balantzea:

$$\dot{m} c_p dT_m = h(T_s - T_m) dA_s$$

$$\boxed{T_e = T_s - (T_s - T_i)\exp(-hA_s / \dot{m} c_p)}$$

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

8.5 – FLUXU LAMINARRA HODIETAN



Indar-balantzeak:

$$(2\pi r dr P)_x - (2\pi r dr P)_{x+dx} + (2\pi r dx \tau)_r - (2\pi r dx \tau)_{r+dr} = 0$$

Lim dr, dx→ 0 , ordezkapena $\tau = -\mu(du/dr)$

$$\frac{dP}{dx} = -\frac{2\tau_w}{R}$$ berrantolatuz eta bi aldiz integratuz

$$u(r) = \frac{1}{4\mu}\left(\frac{dP}{dx}\right) + C_1 \ln r + C_2$$

$$u(r) = -\frac{R^2}{4\mu}\left(\frac{dP}{dx}\right)\left(1 - \frac{r^2}{R^2}\right)$$

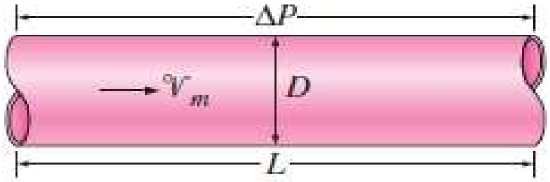
$$V_{prom} = \frac{2}{R^2}\int_0^R u(r) r dr = -\frac{R^2}{8\mu}\left(\frac{dP}{dx}\right)$$

$$u(r) = 2V_{prom}\left(1 - \frac{r^2}{R^2}\right)$$

non r=0 → $u_{\max} = 2V_{prom}$

PRESIO-GALERA (ΔP)

$$\frac{dP}{dx} = \frac{P_2 - P_1}{L}$$



Fluxu Laminarra →

$$\Delta P = P_1 - P_2 = \frac{8\mu L V_{prom}}{R^2} = \frac{32\mu L V_{prom}}{D^2}$$

Presio Galera →

$$\Delta P_L = f\,\frac{L}{D}\,\frac{\rho V^2{}_{prom}}{2}$$

f= Darcy-ren marruskadure faktorea →

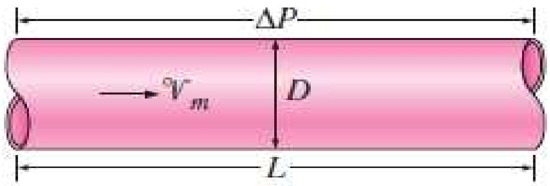
$$f = \frac{8\tau_w}{\rho V^2{}_{ave}}$$

Hodi zirkularra, Laminarra →

$$f = \frac{64\mu}{\rho D V_{ave}} = \frac{64}{\mathrm{Re}}$$

KARGA-GALERA (h_L)

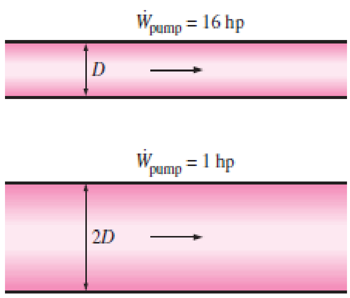
$$\Delta P = \rho g h$$



Karga Galera →

$$h_L = \frac{\Delta P_L}{\rho g} = f\,\frac{L}{D}\,\frac{\rho V^2{}_{prom}}{2g}$$

PONPATZE-POTENTZIA



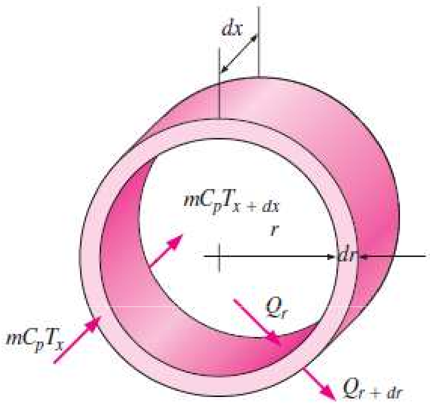
$$W_{bomba,L} = \dot{V}\Delta P_L = \dot{V}\rho g h_L = \dot{m} g h_L$$

$$V_{prom} = \frac{(P_1 - P_2)R^2}{8\mu L} = \frac{\Delta P D^2}{32\mu L}$$

Poiseville-ren Legea →

$$\dot{V} = V_{prom} A_c = \frac{(P_1 - P_2)R^2}{8\mu L}\pi R^2 = \frac{\Delta P \pi D^4}{128\mu L}$$

TENPERATURA-PROFILA ETA NUSSELTEN ZENBAKIA



Fluxu Laminarra,geldikorra,u=u(r)

Energia Balantzea

$$\dot{m}c_pT_x - \dot{m}c_pT_{x+dx} + \dot{Q}_r - \dot{Q}_{r+dr} = 0$$

$$u\frac{\partial T}{\partial x} = -\frac{1}{2\rho c_p \pi r \mathrm{dx}}\frac{\partial \dot{Q}}{\partial r}$$

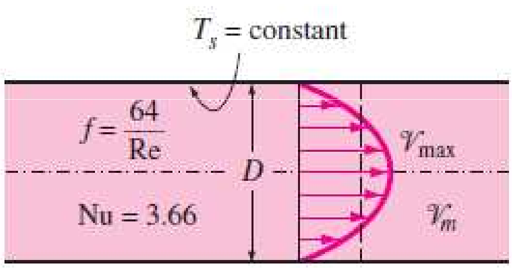
$$u\frac{\partial T}{\partial x} = \frac{\alpha}{r}\frac{\partial}{dr}\left(r\frac{\partial T}{\partial r}\right)$$

GAINAZALEKO BERO-FLUXU KONSTANTEA (QS=CTE)

$$Nu = \frac{hD}{k} = 4{,}36$$

GAINAZAL-TENPERATURA KONSTANTEA (TS=CTE)

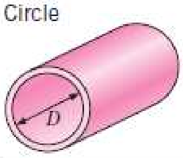
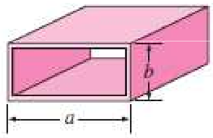
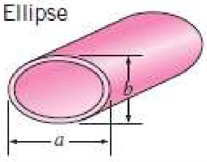
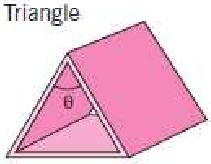
$$Nu = \frac{hD}{k} = 3{,}66$$



Fully developed laminar flow

FLUXU LAMINARRA HODI EZ-ZIRKULARRETAN

$$Nu = \frac{hD}{k} \Rightarrow$$

Tube Geometry	a/b or $\theta°$	Nusselt Number		Friction Factor f
		T_s = Const.	$\dot{q}_s$ = Const.	
Circle 	—	3.66	4.36	64.00/Re
Rectangle 	a/b			
	1	2.98	3.61	56.92/Re
	2	3.39	4.12	62.20/Re
	3	3.96	4.79	68.36/Re
	4	4.44	5.33	72.92/Re
	6	5.14	6.05	78.80/Re
	8	5.60	6.49	82.32/Re
	∞	7.54	8.24	96.00/Re
Ellipse 	a/b			
	1	3.66	4.36	64.00/Re
	2	3.74	4.56	67.28/Re
	4	3.79	4.88	72.96/Re
	8	3.72	5.09	76.60/Re
	16	3.65	5.18	78.16/Re
Triangle 	θ			
	10°	1.61	2.45	50.80/Re
	30°	2.26	2.91	52.28/Re
	60°	2.47	3.11	53.32/Re
	90°	2.34	2.98	52.60/Re
	120°	2.00	2.68	50.96/Re

GARAPEN-FASEKO FLUXU LAMINARRA SARRERA-ESKUALDEAN

Hodi zirkularra, L, Ts=cte

$$Nu = 3{,}66 + \frac{0{,}0065(D/L)\,\mathrm{Re}\,\mathrm{Pr}}{1 + 0{,}04[(D/L)\,\mathrm{Re}\,\mathrm{Pr}]^{2/3}}$$

Hodi zirkularra, L, Ts ≠T fluidoa

$$Nu = 1{,}86 + \left(\frac{\mathrm{Re}\,\mathrm{Pr}\,D}{L}\right)^{1/3}\left(\frac{\mu_b}{\mu s}\right)^{0{,}14}$$

Hodi zirkularra, L, fluxua plaka paralelo isotermoen artean Re≤ 2800

$$Nu = 7{,}54 + \frac{0{,}03(D_h/L)\,\mathrm{Re}\,\mathrm{Pr}}{1 + 0{,}016[(D_h/L)\,\mathrm{Re}\,\mathrm{Pr}]^{2/3}}$$

HODI LEUNA

Petukhov →

$$f = (0.790 \ln \mathrm{Re} - 1.64)^{-2} \qquad 3000 < \mathrm{Re} < 5\mathrm{x}10^6$$

Chilton-Colburn →

$$\mathrm{Nu} = 0.125 f \,\mathrm{Re}\,\mathrm{Pr}^{1/3}$$

$$\mathrm{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3} \qquad \begin{pmatrix} 0.7 \le \mathrm{Pr} \le 160 \\ \mathrm{Re} > 10\,000 \end{pmatrix}$$

$$\mathrm{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{n} \qquad \begin{pmatrix} \mathrm{n} = 0.4\ \text{heating} \\ \mathrm{n} = 0.3\ \text{cooling} \end{pmatrix}$$

Sieder-Tate →

$$\mathrm{Nu} = 0.027\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3}\left(\frac{\mu}{\mu_s}\right)^{0.14} \qquad \begin{pmatrix} 0.7 \le \mathrm{Pr} \le 17\,600 \\ \mathrm{Re} \ge 10\,000 \end{pmatrix}$$

Re > 10 000 Y HODI LEUNA ETA ZIMURRAK

2ª-Petukhov →

$$\mathrm{Nu} = \frac{(f/8)\mathrm{Re}\,\mathrm{Pr}}{1.07 + 12.7(f/8)^{0.5}\left(\mathrm{Pr}^{2/3} - 1\right)} \qquad \begin{pmatrix} 0.5 \le \mathrm{Pr} \le 2\,000 \\ 10^4 < \mathrm{Re} < 5\mathrm{x}10^6 \end{pmatrix}$$

Gnielinski →

$$\mathrm{Nu} = \frac{(f/8)(\mathrm{Re} - 1000)\mathrm{Pr}}{1 + 12.7(f/8)^{0.5}\left(\mathrm{Pr}^{2/3} - 1\right)} \qquad \begin{pmatrix} 0.5 \le \mathrm{Pr} \le 2\,000 \\ 3\mathrm{x}10^3 < \mathrm{Re} < 5\mathrm{x}10^6 \end{pmatrix}$$

GAINAZAL ZIMURRAK

Colebrook →

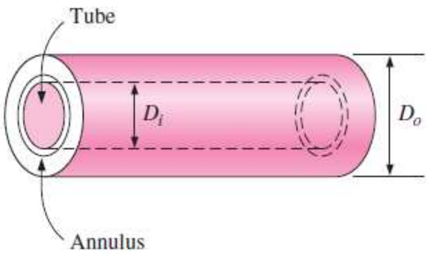
$$\frac{1}{\sqrt{\mathrm{f}}} = -2.0\log\left(\frac{\varepsilon/\mathrm{D}}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{\mathrm{f}}}\right)$$

Moody →

$$\frac{1}{\sqrt{\mathrm{f}}} = -1.8\log\left(\frac{6.9}{\mathrm{Re}} + \left(\frac{\varepsilon/\mathrm{D}}{3.7}\right)^{1.11}\right)$$

8.6 – FLUXU TURBULENTUA HODIETAN

FLUXUA HODI ZENTROKIDEEN ARTEKO ERAZTUN-FORMAKO ESPAZIOAN



$$D_h = \frac{4A_c}{p} = D_o - D_i$$

$$Nu_i = \frac{h_i D_h}{k} \qquad Nu_o = \frac{h_o D_h}{k}$$

Gnielinski

Erabat garatutako fluxu turbulentuetan

Gnielinski ekuazioaren obezpena

$$Fi = 0.86\left(\frac{Di}{Do}\right)^{-0.16}$$ horma adiabatikoa, kanpokoa

$$Fo = 0.86\left(\frac{Di}{Do}\right)^{-0.16}$$ horma adiabatikoa, barnekoa

8.7 – IRAKATSIKO EZ DIREN ATALAK