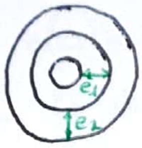
20. GAIA: Erregimen aldakorra hodietan

Energia: $E = \dfrac{\Delta P}{\Delta V / V}$ [kg/cm²]

① → Hodi zurruna: $c = \sqrt{\dfrac{E_F}{\rho} \cdot 9'8}$

→ Hodi elastikoa: $c = \sqrt{\dfrac{E_F \cdot 9'8}{\rho\left(1 + \dfrac{E_F}{E_H} \cdot \dfrac{D}{e}\right)}}$ —ura→ $c = \dfrac{9900}{\sqrt{48'3 + k\dfrac{D}{e}}}$

→ 2 materialeko hodia:



$e_{bal} = e_1 + e_2 \dfrac{E_1}{E_2}$

② → Ixte azkarra $t < \dfrac{2L}{c}$

$\Delta P = \rho c \Delta V$ Joukowsky

$\Delta h = -\dfrac{c \Delta V}{g}$ Allievi

→ Ixte motela $t > \dfrac{2L}{c}$

$\Delta h = k \dfrac{L v}{g\, t_{ixte}}$

→ $k = 2$ → Michaud → HODI ELASTIKOA

→ $k = 1$ → Sauguet

Anulazio denbora:

$t = c + k \dfrac{L v}{g H_m}$ → Mendiluce

($c + k$: ~1)

Gainpresio maximoa:

$L_m = L - \dfrac{ct}{2}$

m = tolerantzia

c = gain lodiera

Barlow: $e = \left(\dfrac{PD}{2\sigma} + c\right)m$

TEMA 20

Cálculo de la velocidad de propagación de una onda en tuberías.

- Tubería rígida

$$c = \sqrt{\frac{E}{\rho}}$$

- Tubería elástica

$$c = \sqrt{\frac{E_F}{\rho \cdot \left[1 + \frac{E_F}{E_T} \cdot \frac{d}{e}\right]}} \quad [m/s]$$

E_F → Módulo de elasticidad volumétrico. Se busca en la tabla 3.
En la tabla lo dan en $\left(\frac{Kg}{cm^2}\right)$, se pasa a $\left(\frac{N}{m^2}\right)$ $(\cdot 98000)$.

E_T → Módulo de elasticidad del material de la tubería.

Si la tubería es elástica y lleva agua se puede usar:

$$c = \frac{9900}{\sqrt{48{,}3 + K \cdot \frac{d}{e}}} \quad [m/s]$$

K → de la tabla de la pág 20-7 del libro según el material.

↳ K liburuko taula

Para saber si el cierre de la válvula es lento o rápido.

$t_{ref} < t_{cierre}$ → Lento

$t_{ref} > t_{cierre}$ → Rápido

$$t_{ref} = \frac{2 \cdot L}{c}$$

Tiempo de cierre con la fórmula de Mendiluce:

$$t = C_c + K \cdot \frac{L \cdot V}{g \cdot H_m}$$

C_c - K → Se buscan en las gráficas de las tablas 41 y 42

H_m → Altura geométrica que da la bomba.

$$H_m = \Delta z + h_R \rightarrow H_m = \Delta z + f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

- Si el cierre es rápido. Allievi

$$\Delta h = \frac{c \cdot v}{g} \quad [mUz]$$

- Si es lento. Michaud

$$\Delta h = \frac{2 \cdot L \cdot v}{g \cdot t_{cierre}} \quad [mUz]$$

Ecuación de Joukowski: para calcular el aumento de presión

$$\Delta p = \rho \cdot c \cdot v = \rho \cdot g \cdot \Delta h \quad [Pa]$$

$\Delta p \rightarrow$ En pascales ($1 m.c.a = 10^5 Pa$)

$\Delta h \rightarrow m.c.a$

$mca = mUz$

Cálculo de la zona de la tubería sometida a presión máxima.

P_{max} non? $\longrightarrow$

$$L_m = L - \frac{c \cdot t_{cierre}}{2}$$

2.2 MAKINA HIDRAULIKOAK. OINARRIZKO PRINTZIPIOAK, TURBOMAKINAK

Reynolds - en Garraioaren Teorema.

$$\sum \vec{F}_{KANPO} = \rho \varphi (\vec{v}_1 - \vec{v}_2)$$

→ Fluidoak jasango duen indarra: $\vec{F} = P_1 \cdot \vec{A}_1 + P_2 \cdot \vec{A}_2 + \rho \varphi (\vec{v}_2 - \vec{v}_1)$

Potentzia fluidoetan. $P_{ot} = \rho g \varphi H_E$

Euler-en teoria / Infinitu alabeen teoria. $P = \rho g \varphi H_E = \rho \varphi (C_{u_1} u_1 - C_{u_2} u_2)$

→ EULER-EN ALTUERA: $H_E = \dfrac{c_1 u_1 \cos\alpha_1 - c_2 u_2 \cos\alpha_2}{g}$

⊕ Turbina (Fluidoak lana eman ardatzari)

⊖ Ponpa (Ardatzak lana eman fluidoari)

Irteerako abiaduren triangeluen teorema & Sarrerako abiadurak

$\vec{w} = \vec{c} - \vec{u}$

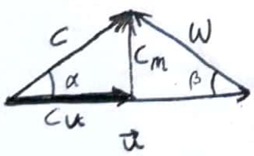
c: Velocidad del fluido

$M = \dot{m}(c_{1u} \cdot r_1 - c_{2u} \cdot r_2)$

$\dot{m}$ [l/s]

$$w^2 = u^2 + c^2 - 2u \cdot c \cdot \cos\alpha$$

$u = \dfrac{2\pi N}{60} \cdot r$



$$H_E = \frac{(c_1^2 - c_2^2) + (u_1^2 - u_2^2) + (w_2^2 - w_1^2)}{2g} \;?$$

M: Indar Parea

c_{m_1}: Sarrerako abiadura absolutua.

$$H_e = \frac{c_{1u} \cdot u_1 - c_{u2} \cdot u_2}{g} \;(m)$$

Euler-en teoria BERNOULLI-n ordezkatuz: $H_E = \dfrac{P_1 - P_2}{\rho g = \gamma} + \dfrac{c_1^2 - c_2^2}{2g}$

$$H_E = h_p + h_z$$

$$\begin{cases} h_z = \dfrac{c_1 - c_2}{2g} \\ h_p = \dfrac{P_1 - P_2}{2g} = \dfrac{u_1^2 - u_2^2}{2g} + \dfrac{w_2^2 - w_1^2}{2g} \end{cases}$$

$h_z \cdot h_d$ = (Presio dinamikoa)

h_p = Presio hazkundea

$$\varphi = C_m \cdot S = C_m \cdot K \cdot \pi \cdot D \cdot b$$

b = Koroaren zabalera

K = Koefiziente laburbiltzailea (~0'95)

C_m = Abiadura meridianoa

↳ okupatutako gainazala %5 → K: 0'95

Antzekotasuna Turbomakinetan. $Re_e = Re_p$ $\lambda = 1 \rightarrow$ Makina berdina denean

→ ANTZEKOTASUN GEOMETRIKOA: $\frac{L_p}{L_e} = \lambda$

→ ANTZEKOTASUN ZINEMATIKA: $\frac{C_p}{C_e} = \frac{u_p}{u_e} = \frac{w_p}{w_e}$

Aurreko bi antzekotasuna bete, Moody: $\frac{1-\eta_e}{1-\eta_m} = \lambda^{1/4}$

→ ALTUEREN ERLAZIOA: $\frac{C_p}{C_e} = \left(\frac{H_p}{H_e}\right)^{1/2} = \frac{\sqrt{2gH_p}}{\sqrt{2gH_e}}$

→ ABIADUREN ETA BIRAKETA-ABIADUREN ERLAZIOA: $\frac{u_p}{u_e} = \lambda \frac{N_p}{N_e}$ $\quad u = \frac{\pi D N}{60}$

→ ALDAGAI NAGUSIEN ARTEKO ERLAZIOA:

$$\frac{\varphi_p}{\varphi_e} = \frac{v_p \cdot A_p}{v_e \cdot A_e} = \left(\frac{H_p}{H_e}\right)^{1/2} \cdot \lambda^2 \qquad \frac{Pot_p}{Pot_e} = \frac{\rho g \varphi_p H_p}{\rho g \varphi_e H_e} = \left(\frac{H_p}{H_e}\right)^{3/2} \cdot \lambda^2$$

$$\frac{N_p}{N_e} = \frac{v_p / L_p}{v_e / L_e} = \left(\frac{H_p}{H_e}\right)^{1/2} \cdot \frac{1}{\lambda}$$

→ COMBES - BERTRAND - RATEAU-ren teorema: $Re = \frac{VD}{\nu}$ $\quad F_e = \frac{V}{\sqrt{Dg}}$ $\quad F_{RO} = Re$

$$\frac{D_p}{D_e} = \lambda = \frac{V_e}{V_p} \cdot \frac{\nu_p}{\nu_e} \qquad \frac{V_e D_e}{\nu_e} = \frac{v_p D_p}{\nu_p}$$ (Normalen fluido berdinean)

$$\frac{L_p}{L_e} = \lambda = \left(\frac{v_p}{v_e}\right)^2 \cdot \frac{g_e}{g_p} \qquad \frac{v_e}{\sqrt{L_e \cdot g}} = \frac{v_p}{\sqrt{L_p \cdot g}}$$

$$\lambda = \frac{1}{\sqrt{\lambda}} \qquad \frac{V_e}{V_p} = \sqrt{\frac{1}{\lambda}}$$

F_{R-z} eta R_{e-z} paso, eskala 1 delako.

Abiadura Espezifikoa Ponpetan eta Turbinetan.

$$\frac{P_p}{P_m} = \frac{\varphi_p \cdot H_p}{\varphi_m \cdot H_m} = \left(\frac{H_p}{H_m}\right)^{3/2} \cdot \lambda^2 \qquad \frac{N_p}{N_m} = \left(\frac{H_p}{H_m}\right)^{1/2} \cdot \frac{1}{\lambda} \qquad \frac{\varphi_p}{\varphi_m} = \left(\frac{H_p}{H_m}\right)^{1/2} \cdot \lambda^2 \Bigg\} \lambda = \frac{D_p}{D_m} = \left(\frac{H_p}{H_m}\right)^{1/2} \cdot \frac{1}{}$$

⇓ λ ordezkatuz ⇓

$$\frac{P_p}{P_m} = \left(\frac{H_p}{H_m}\right)^{5/2} \cdot \left(\frac{N_m}{N_p}\right)^2 \Rightarrow N_m = N_p \sqrt{\frac{P_p}{P_m}} \sqrt[4]{\left(\frac{H_m}{H_p}\right)^5} \qquad N_m^2 = N_p^2 \cdot \frac{\varphi_p}{\varphi_m} \left(\frac{H_p}{H_m}\right)^{3/2}$$

→ Abiadura Espezifikoa. $n_s = \frac{N\sqrt{P}}{H^{5/4}}$ [rpm] $\quad N$ = rpm, P = CV, H = m $\quad$ Camerer-en Zenbakia

→ Abiadura Espezifiko adimentsionala. $n_{so} = \frac{N\sqrt{P}}{\rho^{1/2}(gH)^{5/4}}$

→ Abiadura Espezifikoa (Emariarekin) $\quad N_{s\varphi} = \frac{N\sqrt{\varphi}}{H^{3/4}}$ Bauer-en Zenbakia

→ " adimentsionala $\frac{\delta_R^2}{\mu_R^3} = \frac{N^2 \varphi^2}{(g \cdot H)^3}$

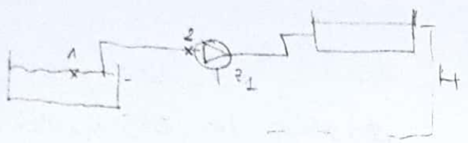
Kabitazioa $\sigma = \frac{P - P_s}{\frac{1}{2}\rho v^2}$ $\sigma = \frac{\rho g h_{AP}}{1/2\, \rho g 2 h_v} = \frac{h_{AP}}{h_v}$ $\sigma = \frac{2}{E_u^2}$ Euler-en zenbi erabiliz

p = presio absolutua
P_s = asetasun-presioa

* $P = P_s$, $\sigma = 0$ Kabitazioa sortu.

→ KABITAZIOA PONPETAN:

$$\frac{P_2 - P_s}{\gamma} + \frac{v_2^2}{2g} = \frac{P_1 - P_3}{\gamma} - z_2 - h_{R_{1\to2}}$$

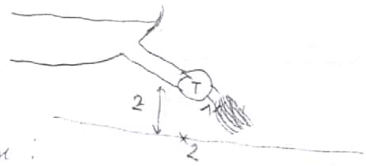


- $\frac{P_1 - P_3}{\gamma} - z_2 - h_{R_{1\to2}}$ → NPSH$_{erabilgarria}$
- $\frac{v_2^2}{2g}$ → NPSH$_{eskaturikoa}$
- $\frac{P_2 - P_s}{\gamma}$ → NPSH$_{segurtasunezkoa}$

* NPSH$_{erabilgarria}$ > 1'3 NPSH$_{eskaturikoa}$ Kabitaziorik gerta ez dadin

- KABITAZIOA TURBINETAN:

$$\frac{P_1 - P_s}{\gamma} + \frac{v_1^2}{2g} = \frac{P_2 - P_s}{\gamma} - z_1 + h_{R_{1\to2}}$$



$\frac{P_2 - P_s}{\gamma} - z_1 + h_{R_{1\to2}}$ → NPSH$_{erabilgarria}$

Ponparen P_{mek}:

$P_{mek} = \frac{\rho g H_m \cdot Q}{\eta}$

$W_{hidraulikoa} = \eta_{Hid}\, \rho \cdot g \cdot Q \cdot H_E$

$W_{elek} = \frac{W_{hid}}{\eta_T}$

Turbinetan:

$W_{elek} = W_H\, \eta$

TEMAS 22-23

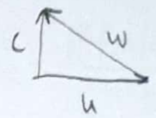
arrastre abiadura
abiadura absolutua

- Velocidad del rodete
  arrastre abiadura

$$u = \frac{2\pi \cdot n}{60} \cdot r \quad [m/s]$$

- Velocidad del fluido respecto al rodete
  abiadura erlatiboa

$$\vec{w} = \vec{c} - \vec{u} \quad [m/s]$$



$u + w = c$

- C: Velocidad del fluido
  abiadura absolutua

$$C = u + w \quad [m/s]$$

- Caudal

→ errodete zabalera

$$Q = 2\pi \cdot r \cdot K \cdot b \cdot C_m \quad [m^3/s]$$

- Potencia

$$Pot_{MAX} = M \cdot \omega$$

$$P = \rho \cdot g \cdot H_m Q$$
$$= \rho g \, He \cdot Q \cdot \eta_H$$
$$= F \cdot d$$

- Par motor

$\dot{m} = \rho \cdot Q$

$$M = \dot{m} \cdot C_{u_1} \cdot r_1 - \dot{m} \cdot C_{u_2} \cdot r_2$$

- Altura de Euler

$$He = \frac{C_{u_1} \cdot u_1 - C_{u_2} \cdot u_2}{g} \quad [m]$$

Bomba $He < 0$
Turbina $He > 0$

$$\eta_H = \frac{H_m = H_{neto}}{H_E} \qquad \eta_T = \frac{P_m}{P_{e}}$$

$u \equiv$ V rodete
$w \equiv$ V relativa
$c \equiv$ V agua

- TRIANGELUAK:
  - Zorrotada besoen mugimenduaren norantzan sartu: $\alpha_1 = 0°$
  - Besoetara marruskadurarik gabe sartu: $W_1 = W_2$
  - Aldagai periferikorik gabe irten errodetetik: $\alpha_2 = 90°$
  - Abiadura osagai tangentzialik gabe irteten da: $\alpha_2 = 90°$
  - Irteera erradialeko turbina: $\alpha_2 = 90°$
  - Pelton $\alpha_1 = 0°$ (Normalean) $U_1 = U_2$ ($\emptyset$ = kte)

Semejanza de turbinas

$$\lambda = \frac{D_2}{D_1}$$

$$\frac{Q_2}{Q_1} = \left(\frac{H_2}{H_1}\right)^{1/2} \cdot \lambda^2 = \frac{V_2 \cdot A_2}{V_1 \cdot A_1}$$

$$\frac{P_2}{P_1} = \left(\frac{H_2}{H_1}\right)^{3/2} \lambda^2 = \frac{Q_2 \cdot H_2}{Q_1 \cdot H_1}$$

$$\frac{N_2}{N_1} = \left(\frac{H_2}{H_1}\right)^{1/2} \cdot \frac{1}{\lambda} = \frac{V_2 / D_2}{V_1 / D_1}$$

Velocidad específica en turbinas

$$N_S = \frac{N_p \cdot \sqrt{P}}{H^{5/4}}$$

$N_S \rightarrow$ rpm; $N_p \rightarrow$ rpm; $P \rightarrow$ CV

$$N_{S0} = \frac{N\sqrt{P}}{\rho^{1/2} \cdot (gH)^{5/4}}$$

Velocidad específica en bombas

$$N_{SQ} = \frac{N \cdot \sqrt{Q}}{H^{3/4}}$$

$N_{SQ} \rightarrow$ rpm; $N \rightarrow$ rpm; $Q \rightarrow m^3/s$

$$N_S = \frac{N \cdot \sqrt{Q}}{(gH)^{3/4}}$$

Cavitación en bombas. Antes de la bomba

$$\underbrace{\frac{P_1 - P_s}{\gamma} - Z_2 - h_{R1\to2}}_{NPSH\ disp.} = \underbrace{\frac{P_2 - P_s}{\gamma}}_{NPSH\ seg.} + \underbrace{\frac{V_2^2}{2g}}_{NPSH\ req.}$$

$$h_R = \frac{8 f \cdot L Q^2}{g \pi^2 D^5} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} \quad \oplus T \quad \ominus B$$

P_s : Tabla 3

Cavitación en turbinas. Después de la turbina

$$\underbrace{\frac{P_1 - P_s}{\gamma}}_{NPSH\ seg.} + \underbrace{\frac{V_1^2}{2g}}_{NPSH\ req.} = \underbrace{\frac{P_2 - P_s}{\gamma} - Z_1 + h_{R1\to2}}_{NPSH\ disp.}$$

$$NPSH_{disp} \geq 1,3\ NPSH_{req}$$ Para evitar la cavitación

BOMBA: $H_1 + H_m = H_2 + h_{R1\to2}$

TURBINA: $H_1 - H_m = H_2 + h_{R1\to2}$

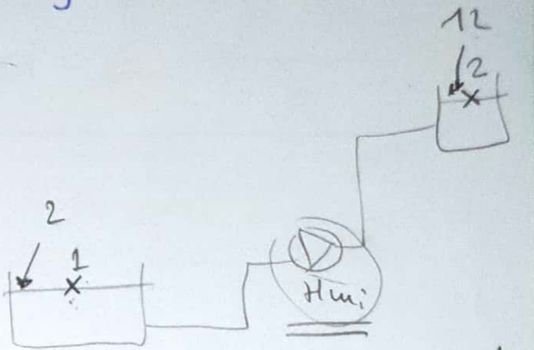
$$h_{R1} = \frac{8 f L Q^2}{g \pi^2 D^5} \qquad h_{R2} = \frac{8 \cdot (\Sigma K) \cdot Q^2}{g \pi^2 \cdot D^5}$$

25. GAIA:

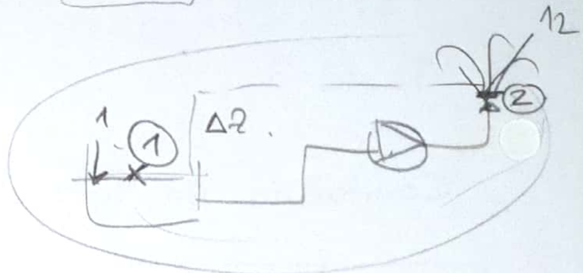
- Funtzionamendu ptua: $H_{mi} = \Delta z + \underbrace{\frac{8 \cdot f \cdot L \cdot Q^2}{g \cdot \pi^2 \cdot D^5}}_{h_{R\,prim}} + \underbrace{\frac{8 \cdot (\Sigma k) \cdot Q^2}{g \cdot \pi^2 \cdot D^4}}_{h_{R\,sek.}}$

$$H_1 + H_{mi} = H_2 + h_{R1\to2}$$ (BOMBA)

$$\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} + H_{mi} = \frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g} + h_{R1\to2}$$



$$1 + H_{mi} = 12 + \frac{V_2^2}{2g} + h_{R1\to2}$$ PRIM+SEK.



$$H_{mi} = 11 + \frac{8Q^2}{\pi^2 g D^4} + \frac{8fLQ^2}{\pi^2 g D^5}$$

$$\frac{V_2^2}{2g} = \frac{(Q/A)^2}{2g} = \frac{\frac{16Q^2}{\pi^2 D^4}}{2g} = \frac{\overset{8}{\cancel{16}} Q^2}{\cancel{2} g \pi^2 D^4} = \frac{8Q^2}{g \pi^2 D^4}$$

$$H_{mi} = 11 + Q^2 \left(\frac{8}{\pi^2 g D^4} + \frac{8fL}{\pi^2 g D^5} \right)$$

Tipo de turbina:

- $5 < n_s < 36$ → Pelton
- $36 < n_s < 50$ → Pelton multiples inyectores
- $50 < n_s < 100$ → Francis motela
- $100 < n_s < 200$ → Francis normala
- $200 < n_s < 400$ → Francis azkarra
- $400 < n_s < 700$ → Helize, kaplan, Dériaz
- $700 < n_s < 1300$ → Kaplan, Deriaz

Presioa:

$1\ atm = 10{,}33\ mUz = 760\ mmHg = 1\ bar$

$10\ mUz = 1\ kg/cm^2$

$1\ bar = 10^5\ Pa = 10\ mUz$

$N/m^2 = Pa \qquad N = \frac{kg \cdot m}{s^2} \qquad N/cm^2 = 10^4\ Pa$

23. GAIA: Turbina hidraulikoak

- **Turbinen sailkapena erreaktio-maila kontuan hartuta**

$$\varepsilon = \frac{h_p}{h_E}$$

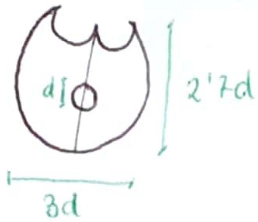
- $\varepsilon = 0 \rightarrow$ Akzio-turbinak
- $\varepsilon > 0 \rightarrow$ Erreaktio-turbina

Pelton turbina:

Altuera handietan lan egiteko. $v_T = \sqrt{2gH}$

Goilara:

$$\frac{D}{d} = 10 \text{ edo } 14 \text{ artean}$$



- **Turbinen sailkapena abiadura espetifikoaren arabera**

$$n_s = \frac{N\sqrt{P_e}}{H^{5/4}} \longrightarrow P_e\,[2P] \qquad N = \frac{60f}{p}$$

Sailkapena 23-25 orrian

25. GAIA:

$$H_{mi} = \Delta z + \Delta\left(\frac{p}{\gamma}\right) + \Delta \frac{v^2}{2g} + h_R$$

Altuera piezometrikoa:

$$H_{io} = z + \Delta\left(\frac{p}{\gamma}\right)$$

$$h_{R\,pri} = \frac{8 f L Q^2}{g \pi^2 D^5}$$

$$h_{R\,sek} = \frac{8 \Sigma k Q^2}{g \pi^2 D^4}$$