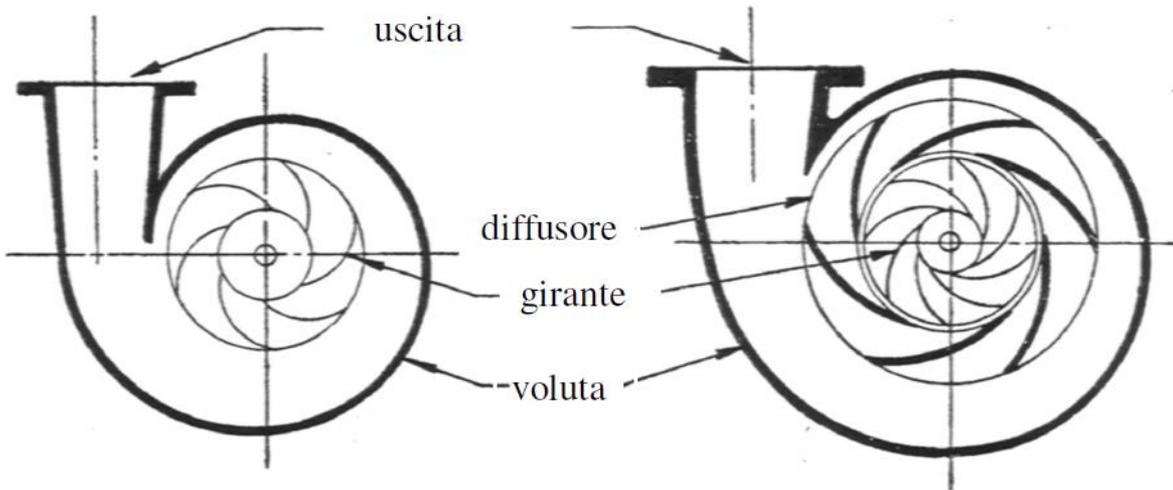
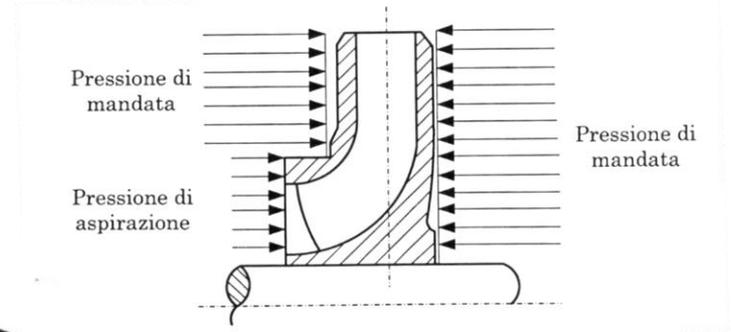
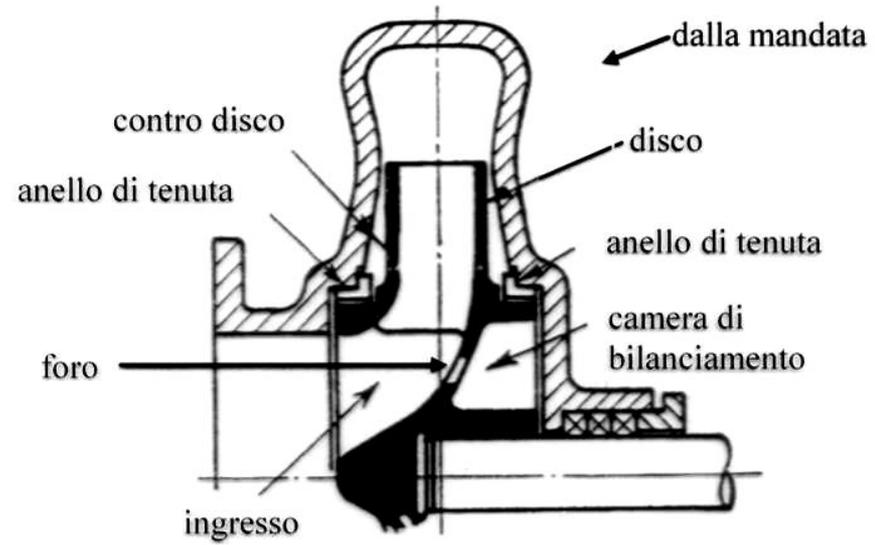
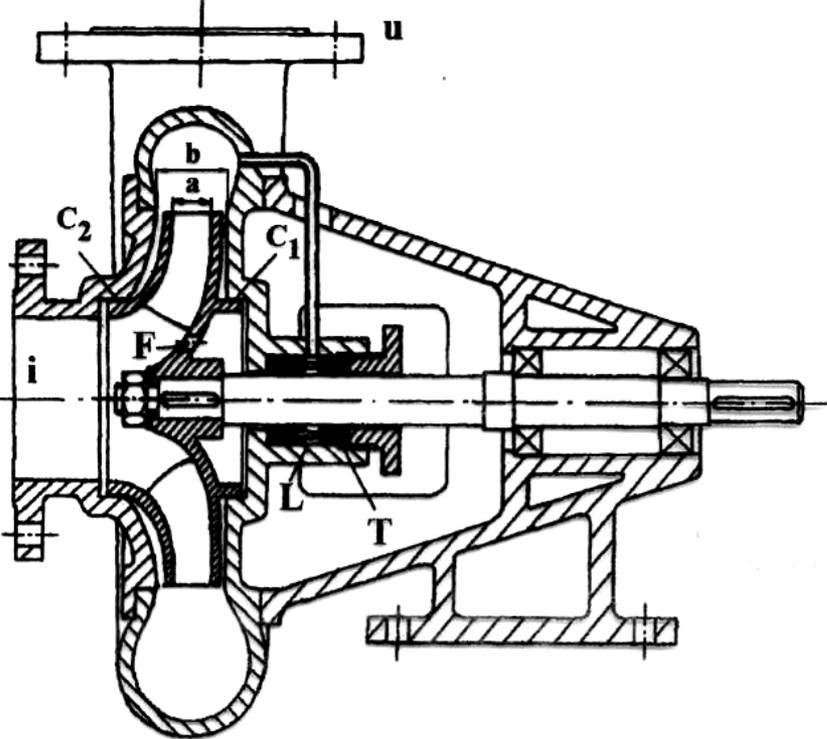
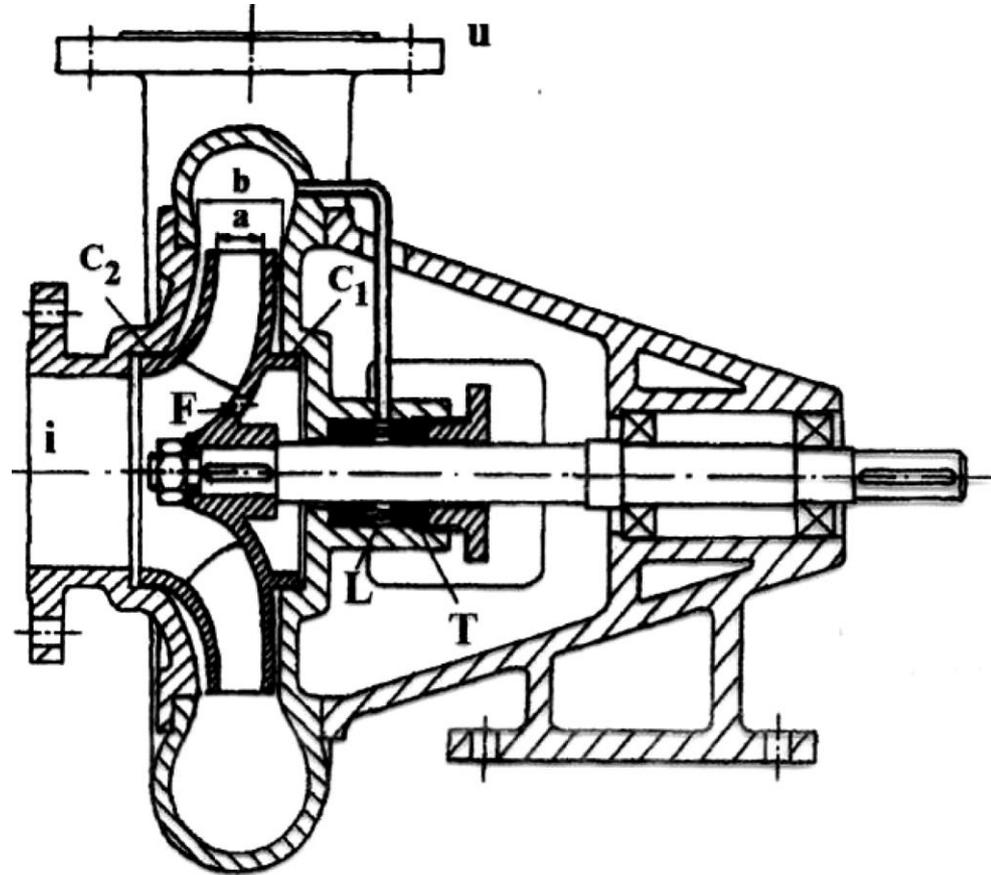
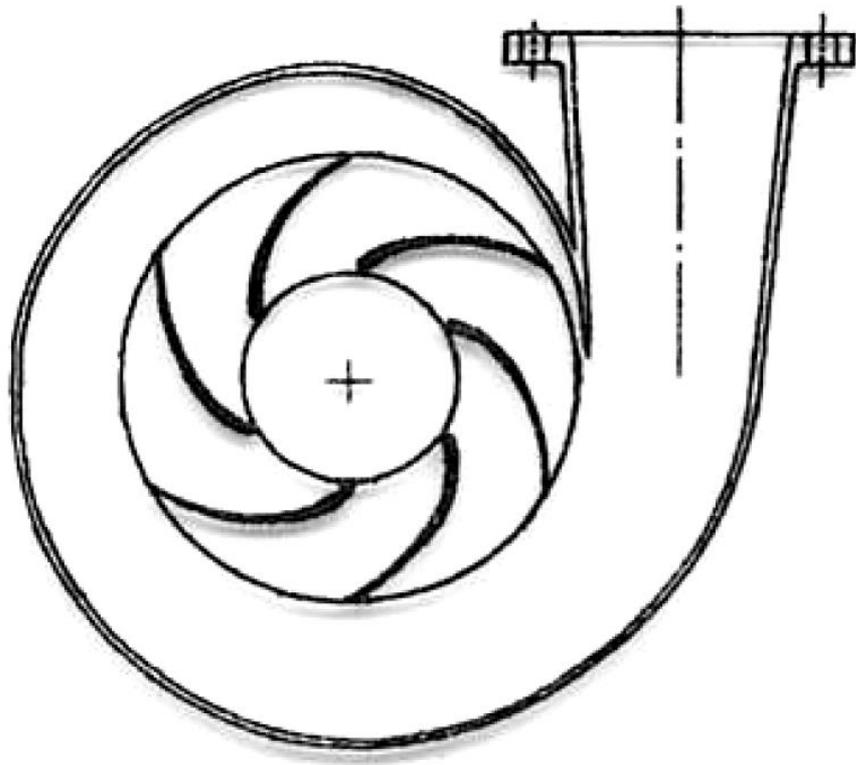
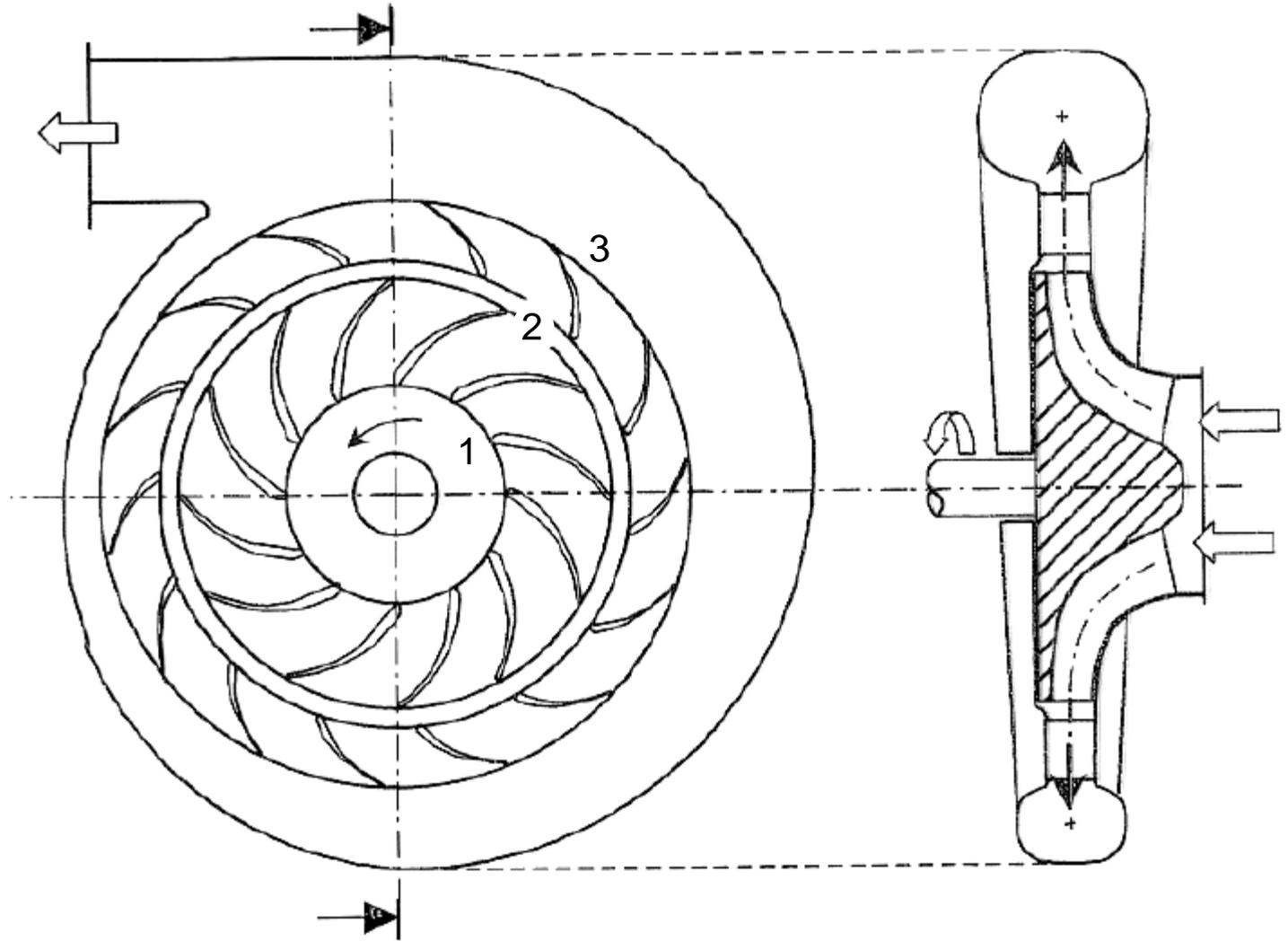
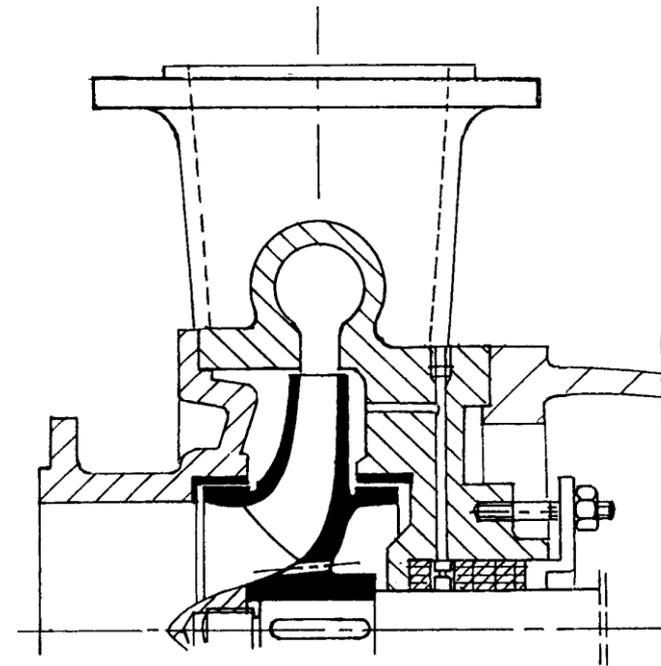
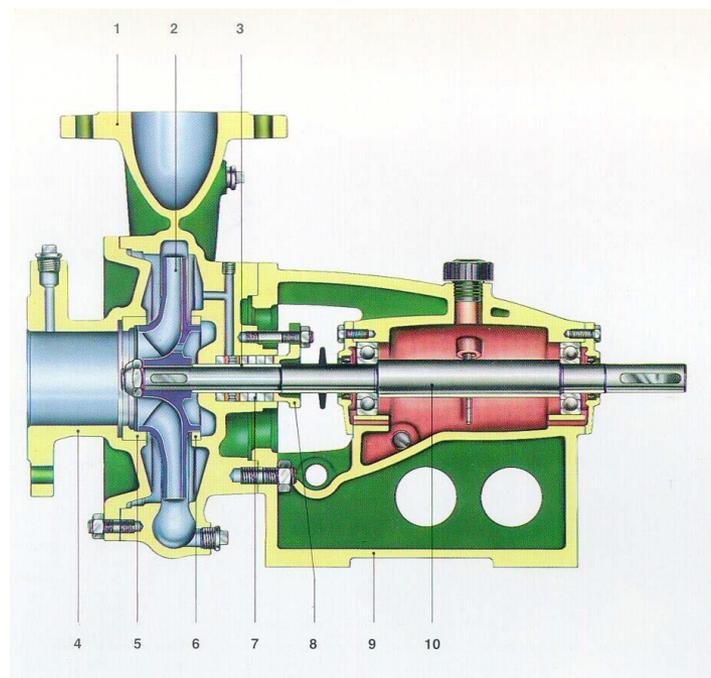
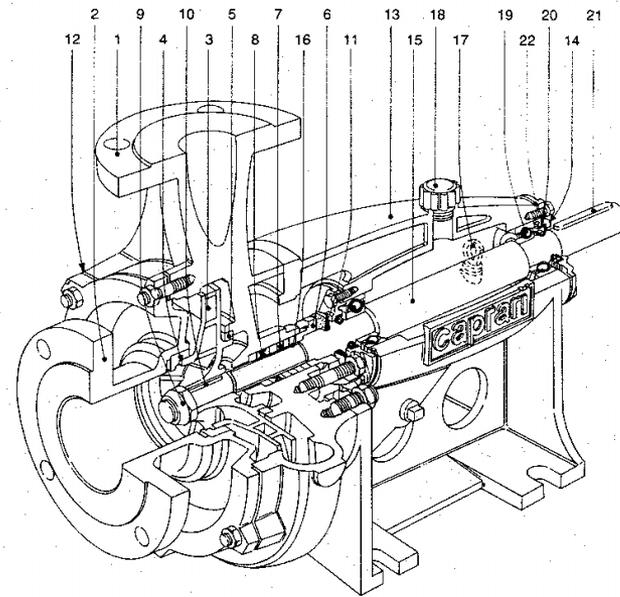


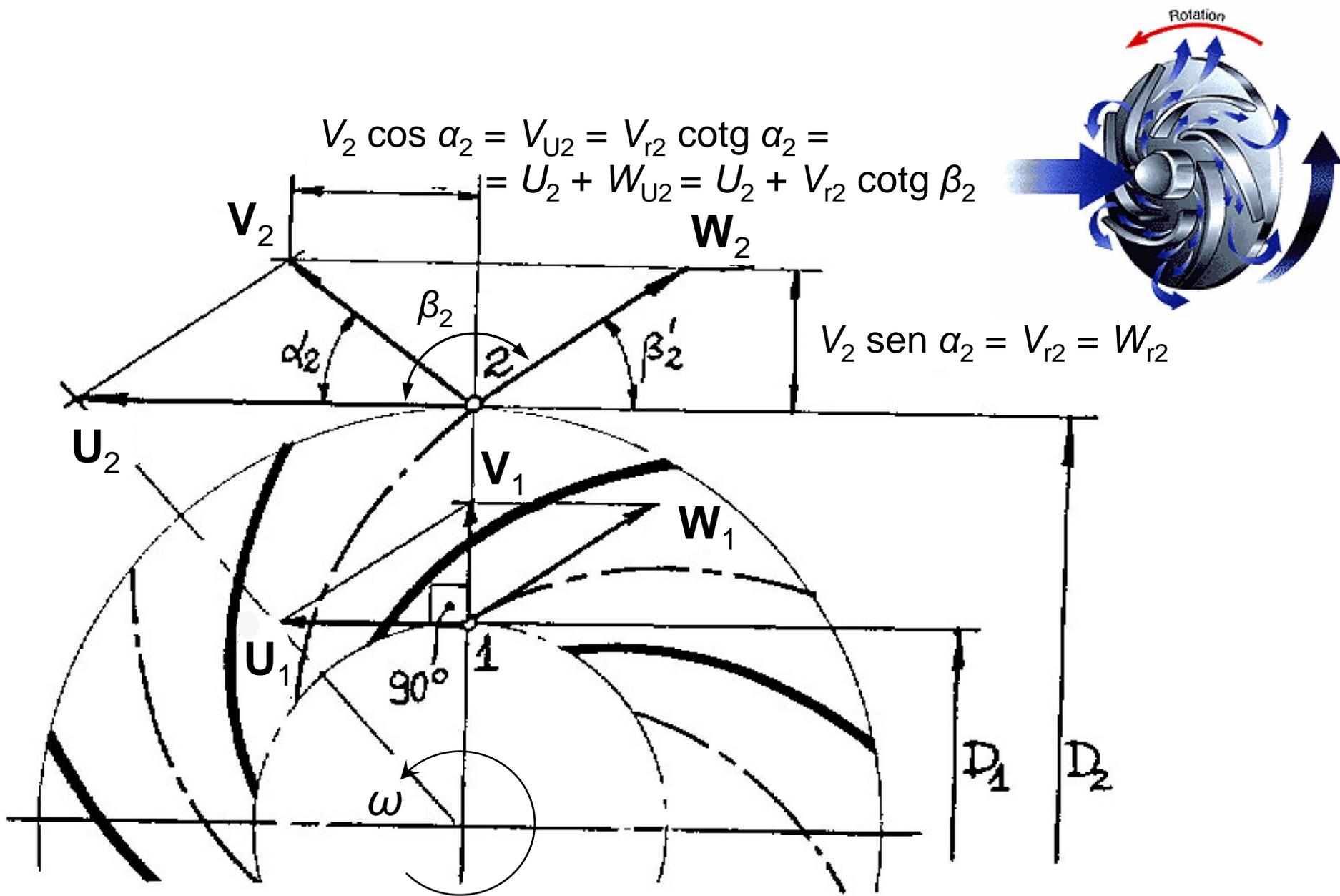
Pompe dinamiche

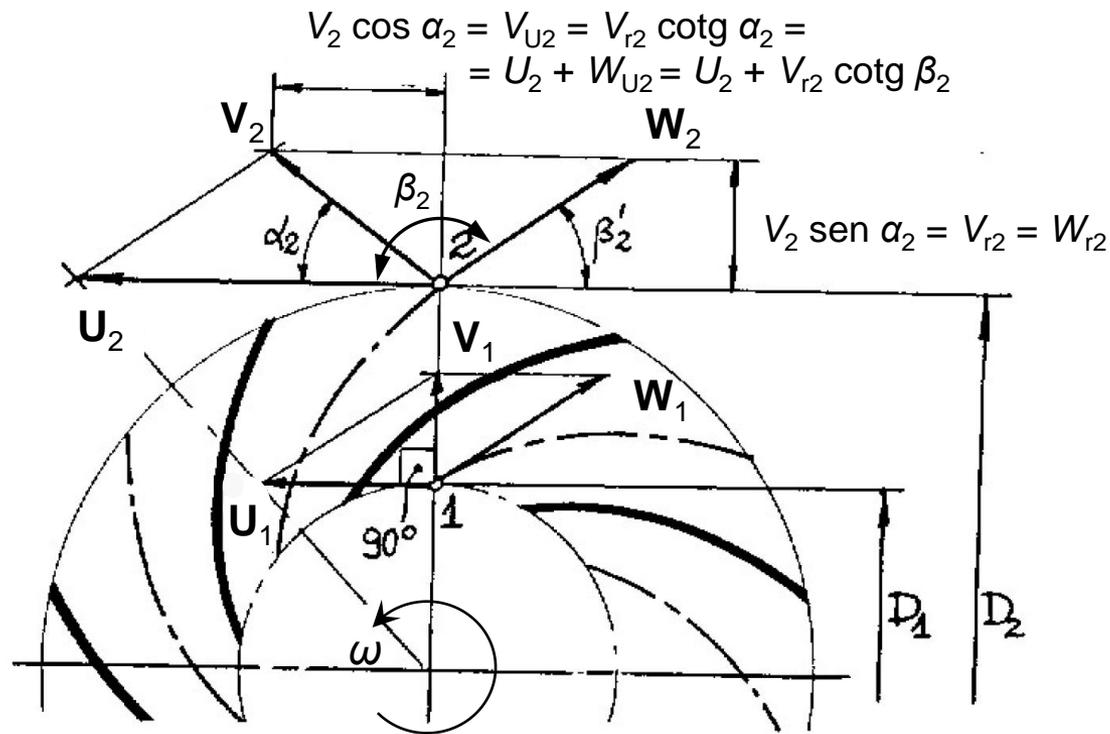








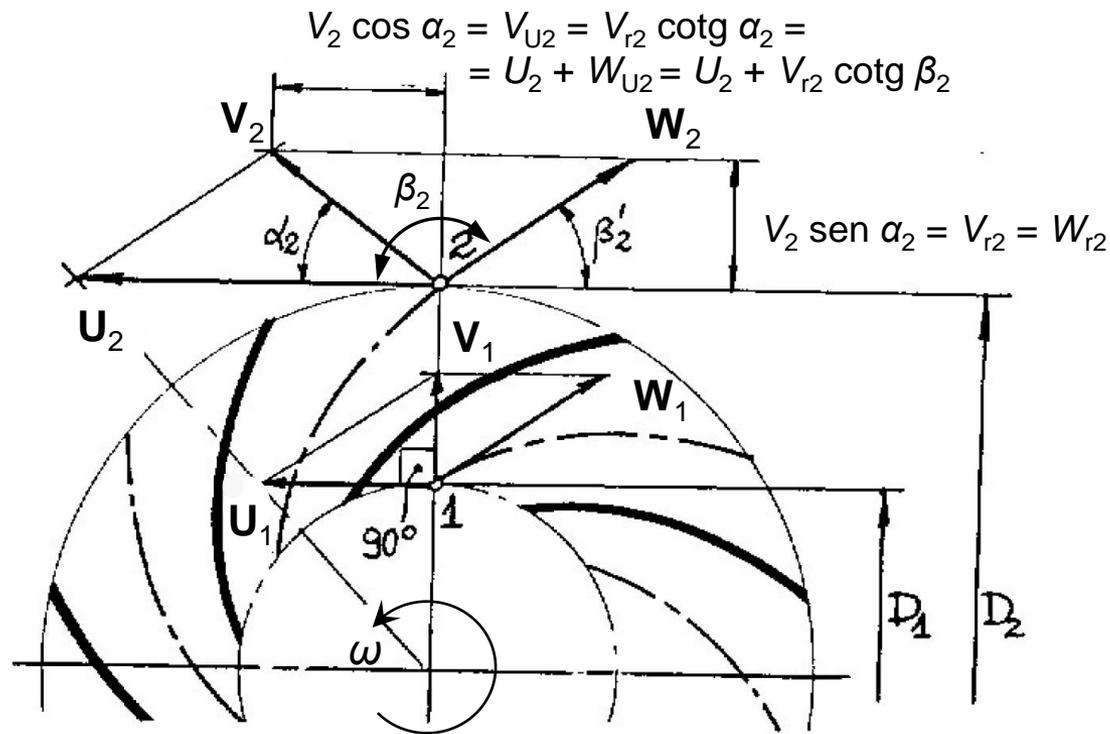




$$l_g = \frac{V_2^2 - V_1^2}{2} + \frac{W_1^2 - W_2^2}{2} + \frac{U_2^2 - U_1^2}{2} = U_2 V_2 \cos \alpha_2 - U_1 V_1 \cos \alpha_1 = U_2 V_{U2} - U_1 V_{U1}$$

Nel caso $\alpha_1 = 90^\circ$:

$$l_g = U_2 V_2 \cos \alpha_2 = U_2 V_{U2} = U_2 (U_2 + V_{r2} \cotg \beta_2)$$

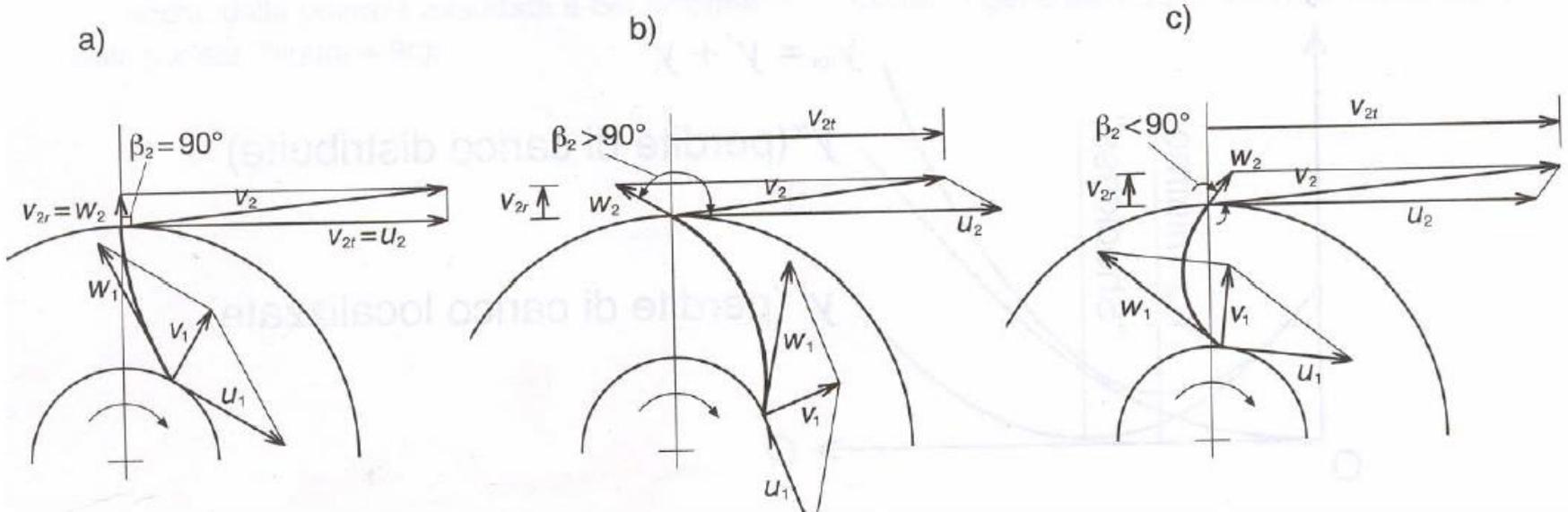
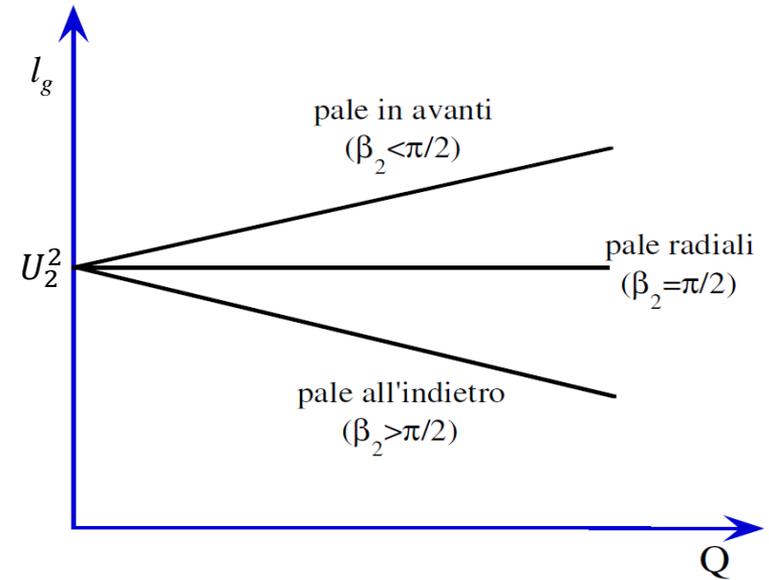


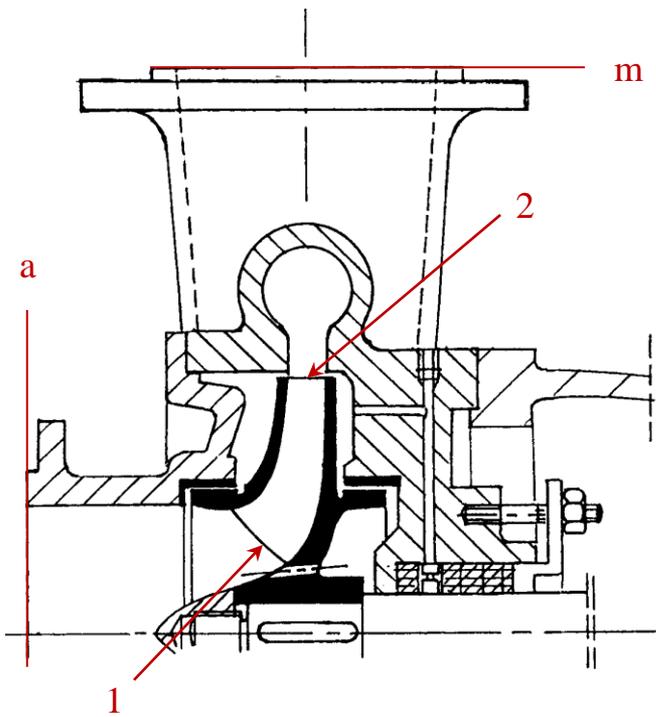
$$l_g = U_2(U_2 + V_{r2} \cotg \beta_2) = U_2 \left(U_2 + \frac{Q}{A_2} \cotg \beta_2 \right)$$

$$l_g = U_2 \left(U_2 + \frac{Q}{A_2} \cotg \beta_2 \right)$$

Forma della girante centrifuga:

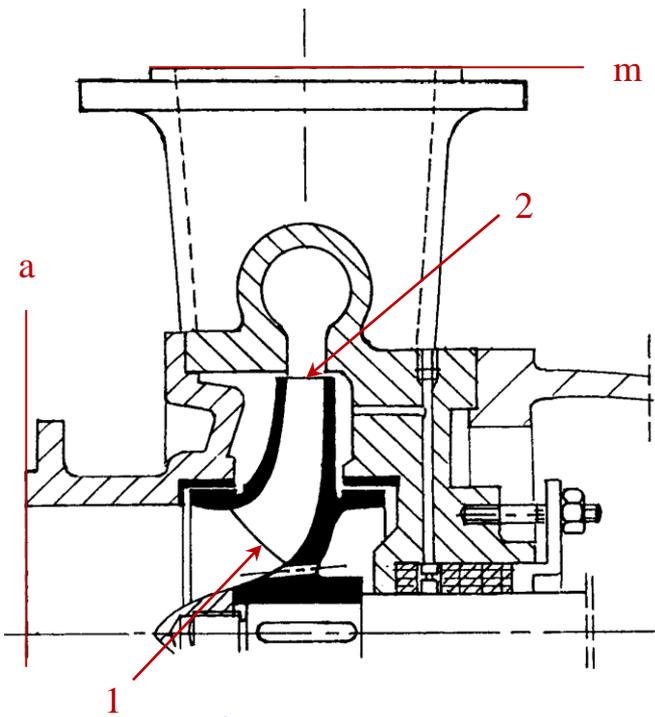
- a) a scarico "radiale",
- b) a scarico "all'indietro" ($\beta_2 > 90^\circ$),
- c) a scarico "in avanti" ($\beta_2 < 90^\circ$).





$$l_g = l_{1-2} = U_2 \left(U_2 + \frac{Q}{A_2} \cot g \beta_2 \right)$$

$$l_p = l_{a-m} = gH = \frac{V_m^2 - V_a^2}{2} + g(z_m - z_a) + \frac{p_m - p_a}{\rho} = l_g - R_{a-m}$$

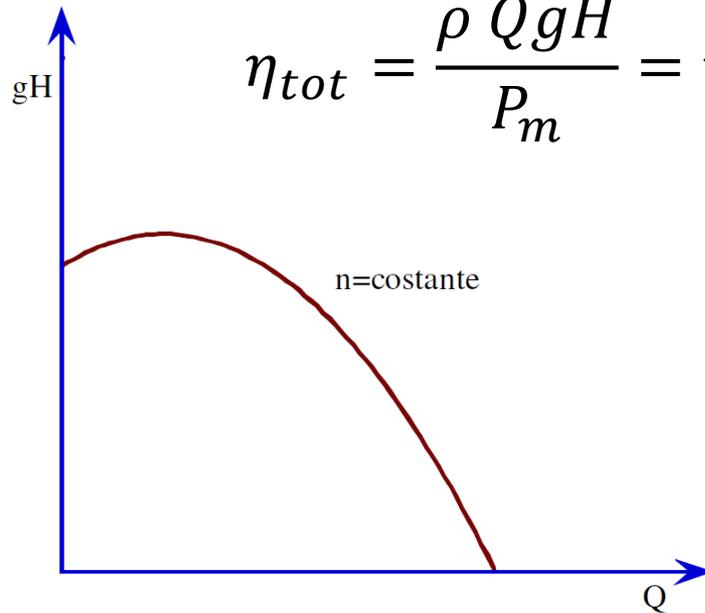
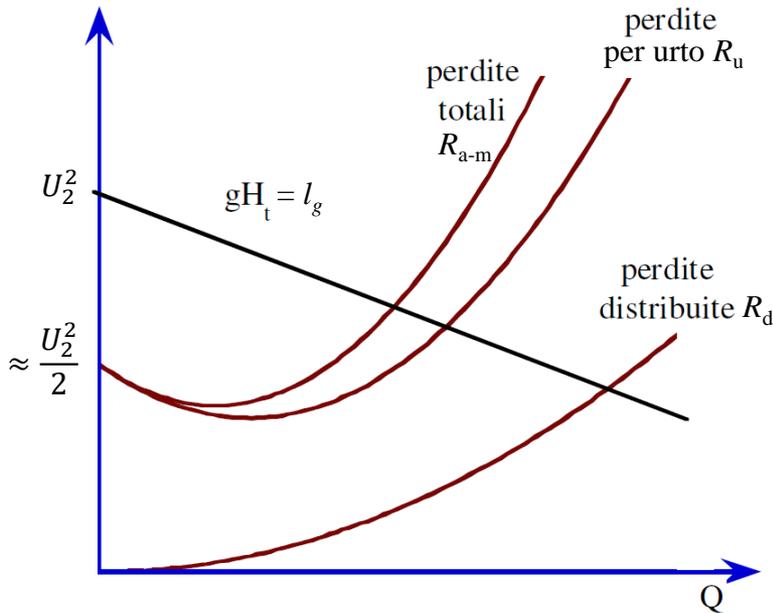


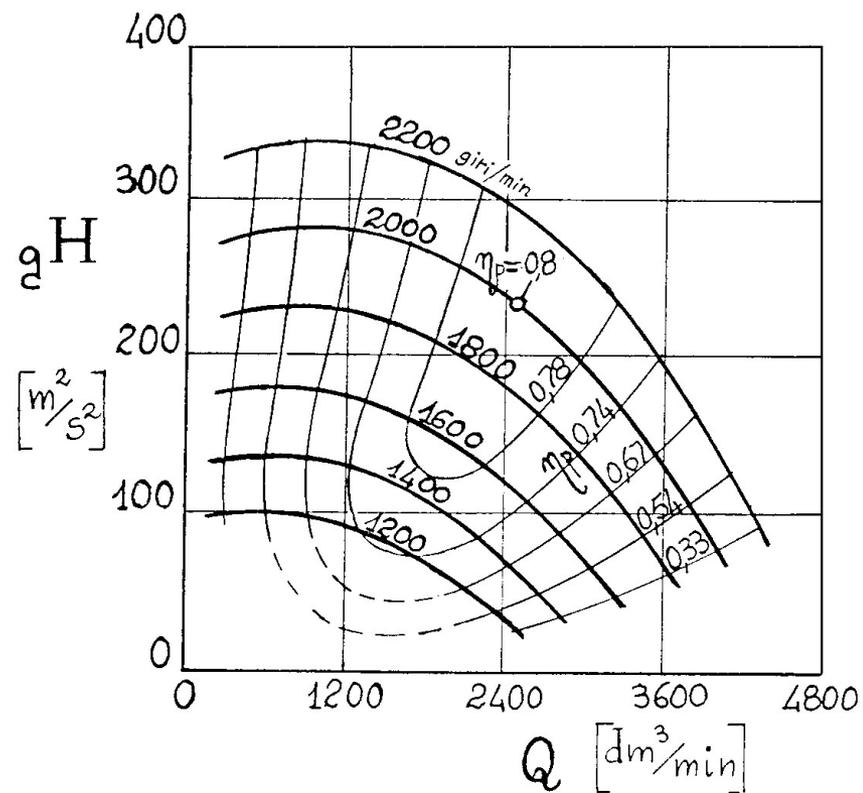
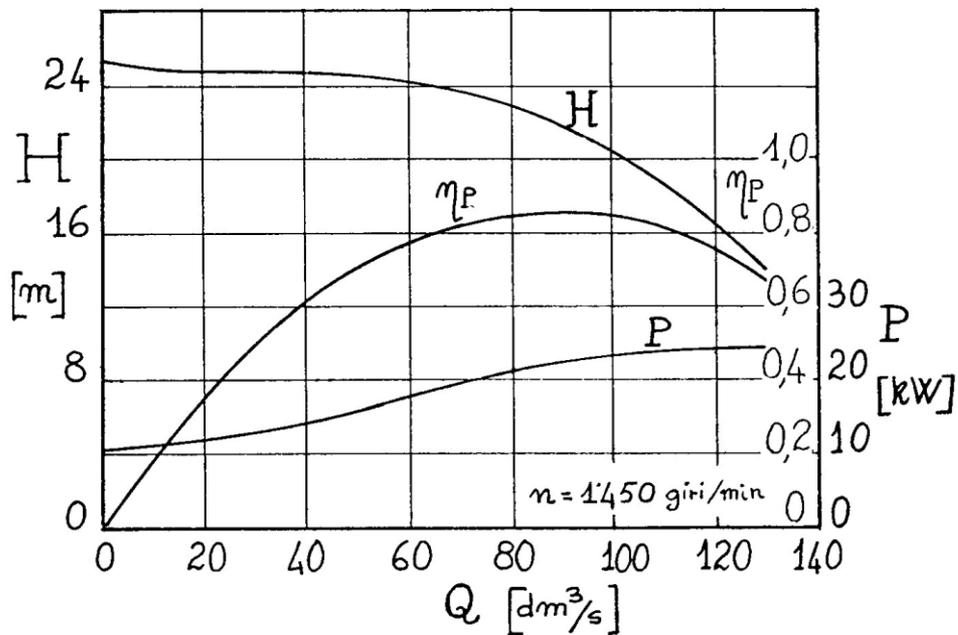
$$l_p = gH = l_g - R_{a-m} = l_g - R_d - R_u$$

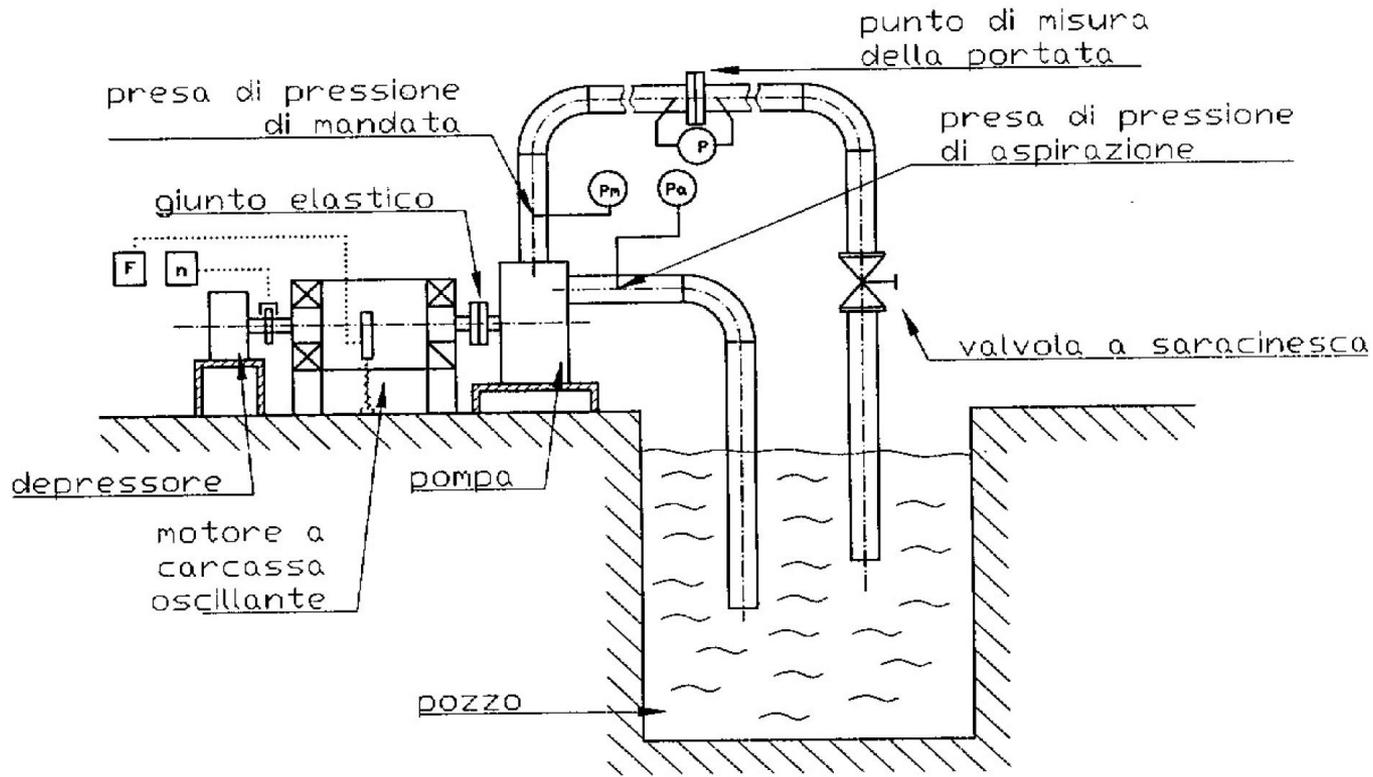
$$\eta_i = \frac{gH}{l_g} = \frac{l_g - R_{a-m}}{l_g}$$

$$\eta_m = \frac{\rho Q l_g}{P_m}$$

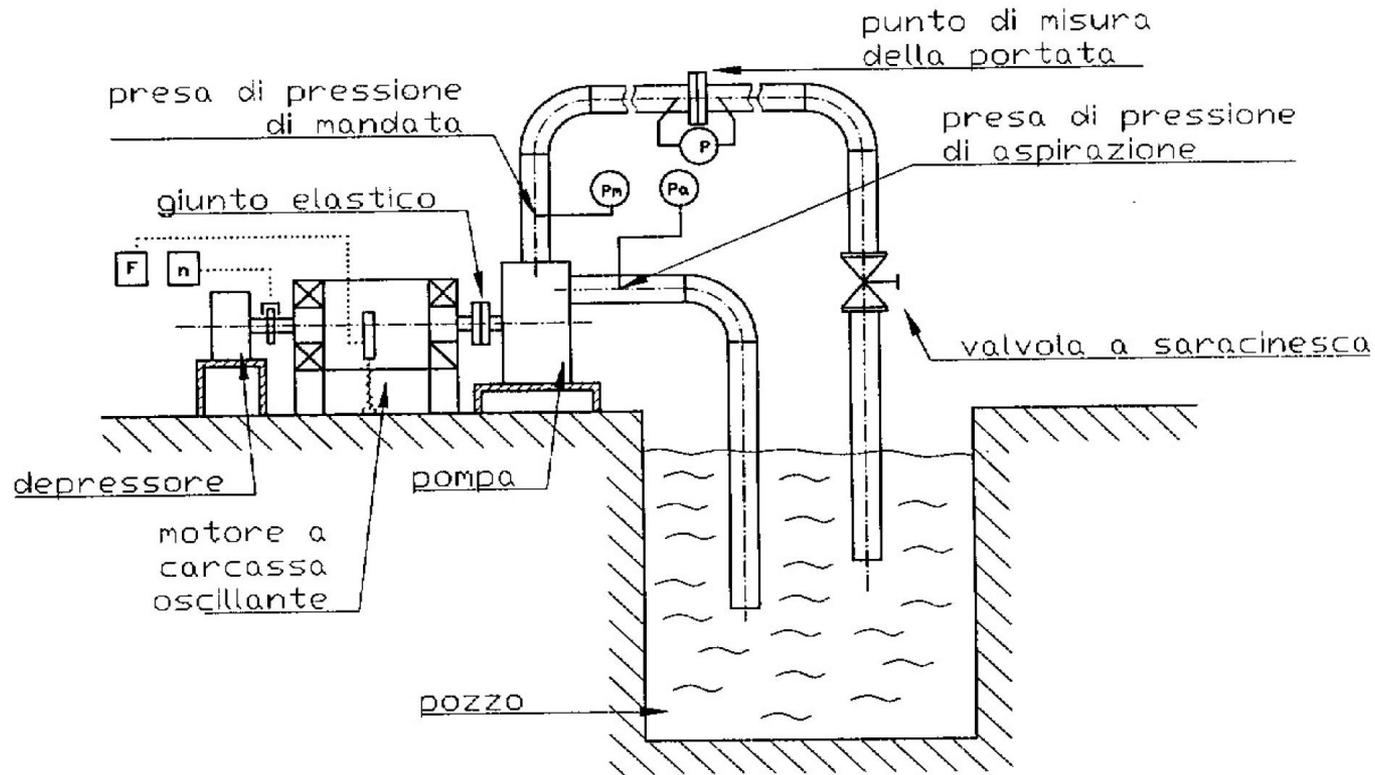
$$\eta_{tot} = \frac{\rho Q gH}{P_m} = \eta_i \eta_m$$







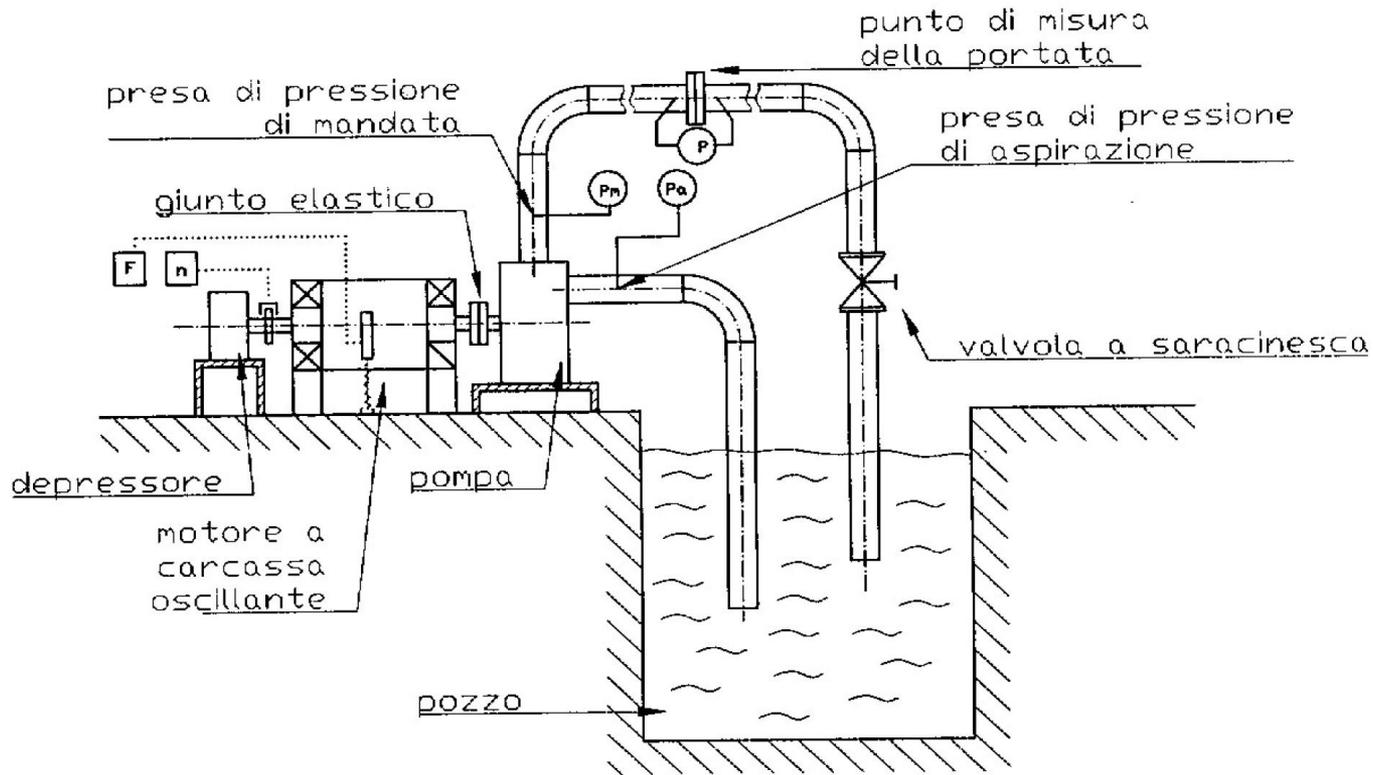
$$l_p = l_{a-m} = gH = \frac{V_m^2 - V_a^2}{2} + g(z_m - z_a) + \frac{p_m - p_a}{\rho}$$



Nel caso di:

- bocche di aspirazione e mandata di ugual diametro $V_m = V_a$

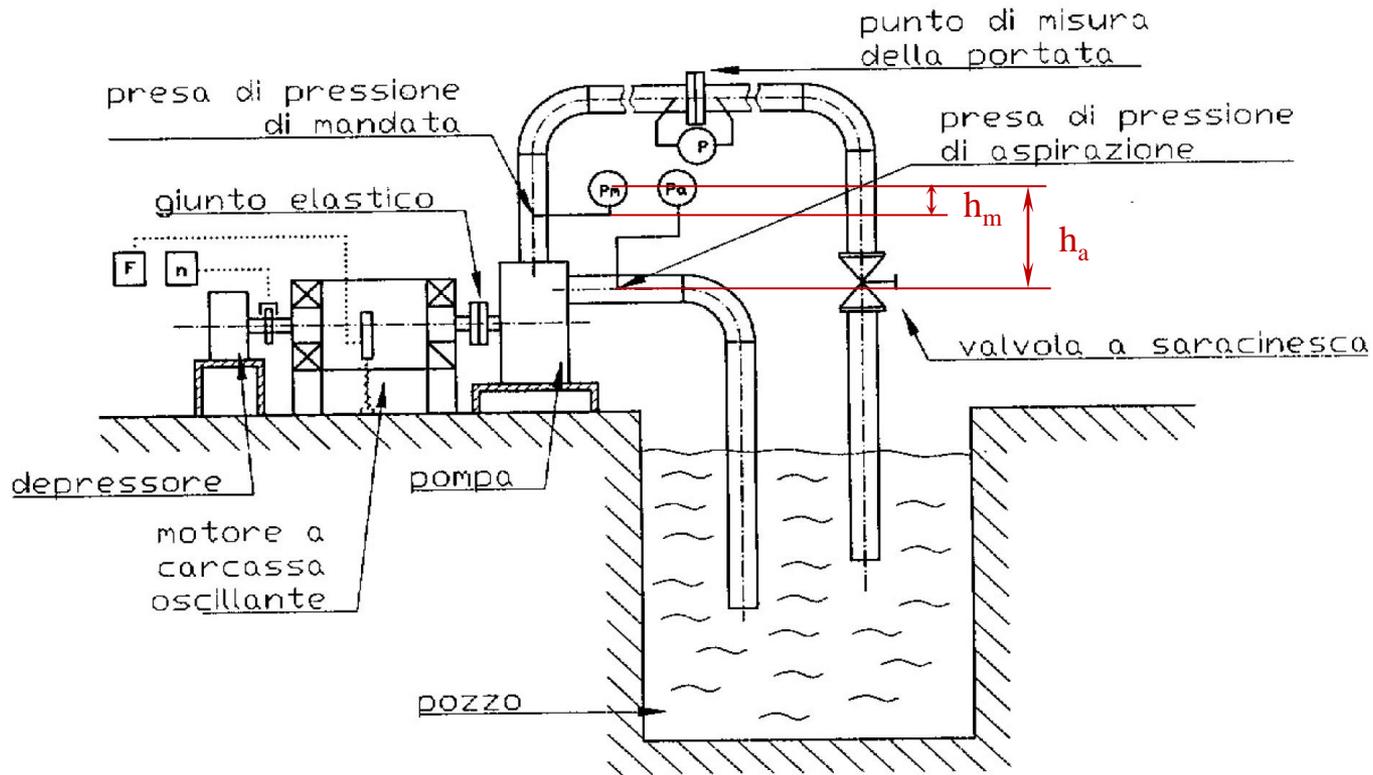
$$l_p = l_{a-m} = gH = \frac{V_m^2 - V_a^2}{2} + g(z_m - z_a) + \frac{p_m - p_a}{\rho}$$



Nel caso di:

- bocche di aspirazione e mandata di ugual diametro $V_m = V_a$

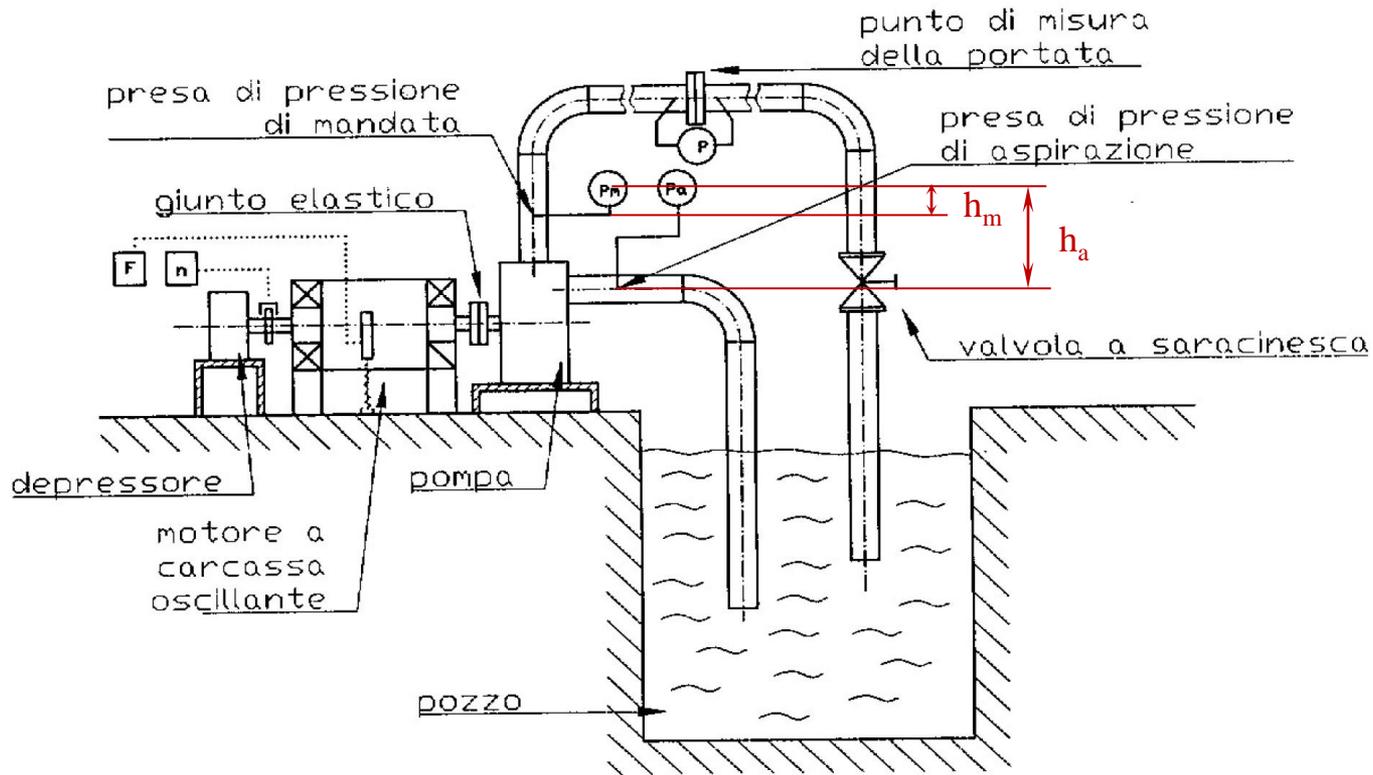
$$l_p = l_{a-m} = gH = g(z_m - z_a) + \frac{p_m - p_a}{\rho}$$



Nel caso di:

- bocche di aspirazione e mandata di ugual diametro
- elementi sensibili dei manometri per la misura di p_a e p_m posti alla stessa quota

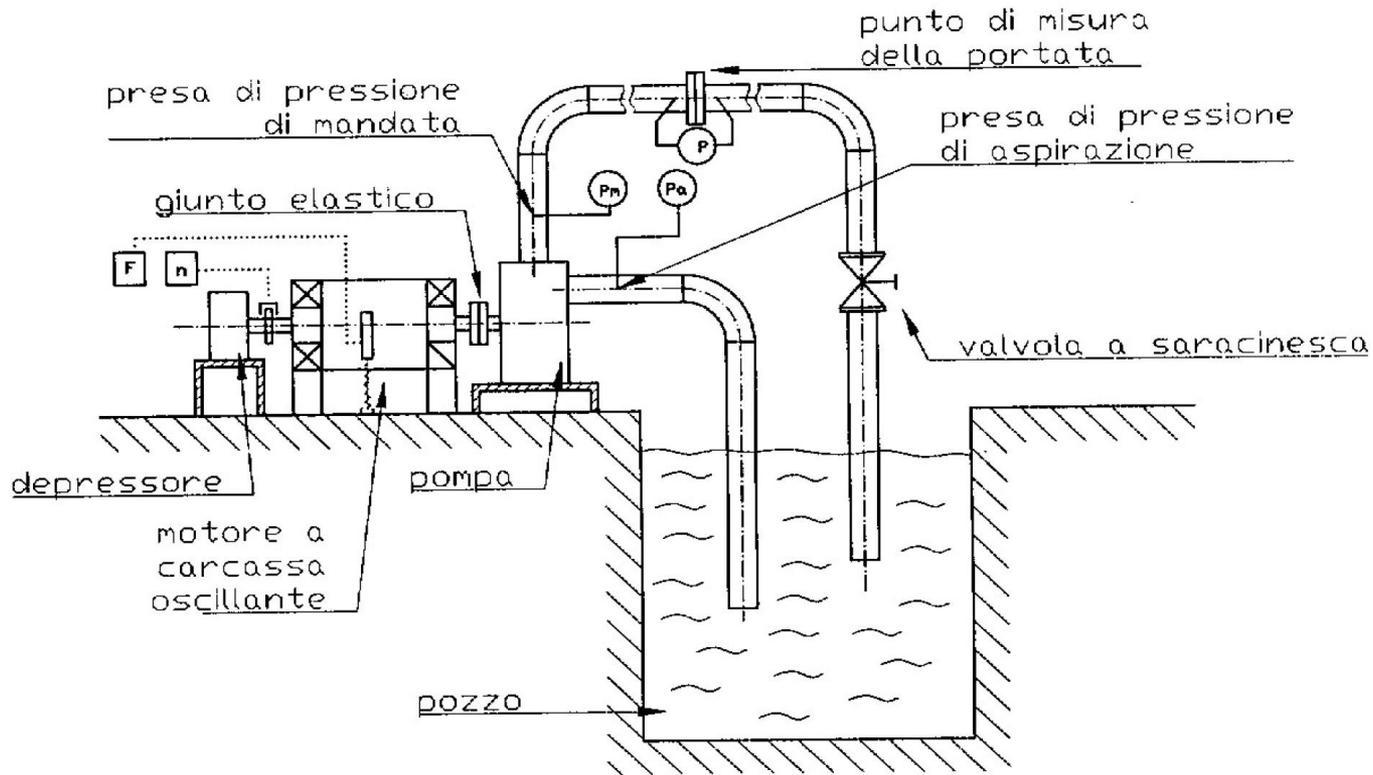
$$l_p = l_{a-m} = gH = g(z_m - z_a) + \frac{p_m - p_a}{\rho}$$



Nel caso di:

- bocche di aspirazione e mandata di ugual diametro
- elementi sensibili dei manometri per la misura di p_a e p_m posti alla stessa quota

$$\left. \begin{aligned} (p_m)_{mis} &= p_m - \rho g h_m \\ (p_a)_{mis} &= p_a - \rho g h_a \end{aligned} \right\} \rightarrow (p_m - p_a)_{mis} = p_m - p_a + \rho g (h_a - h_m) = \\
 &= p_m - p_a + \rho g (z_m - z_a)$$



Nel caso di:

- bocche di aspirazione e mandata di ugual diametro
- elementi sensibili dei manometri per la misura di p_a e p_m posti alla stessa quota

$$l_p = gH = \frac{(p_m - p_a)_{mis}}{\rho}$$

Similitudine geometrica:

$$\frac{l_{1A}}{l_{1B}} = \dots = \frac{l_{nA}}{l_{nB}} = \frac{\varepsilon_{1A}}{\varepsilon_{1B}} = \dots = \frac{\varepsilon_{mA}}{\varepsilon_{mB}} = \lambda$$

↓

$$\frac{l_{iA}}{D_{refA}} = \frac{l_{iB}}{D_{refB}} \quad , \quad i = 1, \dots, n$$

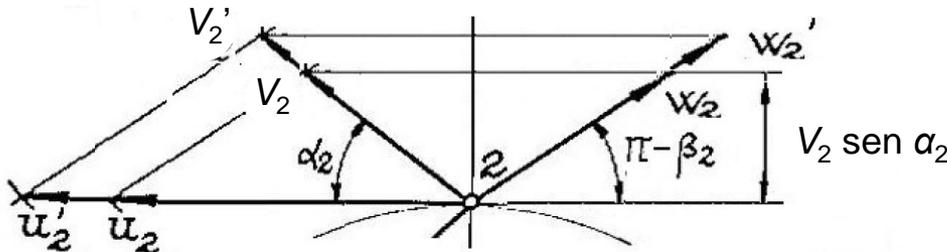
$$\frac{\varepsilon_{jA}}{D_{refA}} = \frac{\varepsilon_{jB}}{D_{refB}} \quad , \quad j = 1, \dots, m$$

Similitudine cinematica:

$$\frac{V_{1A}}{V_{1B}} = \dots = \frac{V_{nA}}{V_{nB}} = \nu$$

↓

$$\frac{V_{iA}}{V_{refA}} = \frac{V_{iB}}{V_{refB}} \quad , \quad i = 1, \dots, n$$



similitudine triangoli di velocità

Macchine geometricamente simili, funzionanti in condizioni di similitudine cinematica con Re elevati (moto turbolento completamente sviluppato), presentano gli stessi valori dei seguenti raggruppamenti adimensionali di variabili:

$$\eta_{iA} = \eta_{iB}$$

rendimento idraulico

$$\phi_A = \frac{Q_A}{\omega_A D_A^3} = \phi_B = \frac{Q_B}{\omega_B D_B^3}$$

coefficiente di flusso o di portata

$$\psi_A = \frac{gH_A}{\omega_A^2 D_A^2} = \psi_B = \frac{gH_B}{\omega_B^2 D_B^2}$$

coefficiente di carico

$$\hat{P}_A = \frac{P_A}{\rho_A \omega_A^3 D_A^5} = \hat{P}_B = \frac{P_B}{\rho_B \omega_B^3 D_B^5}$$

coefficiente di potenza

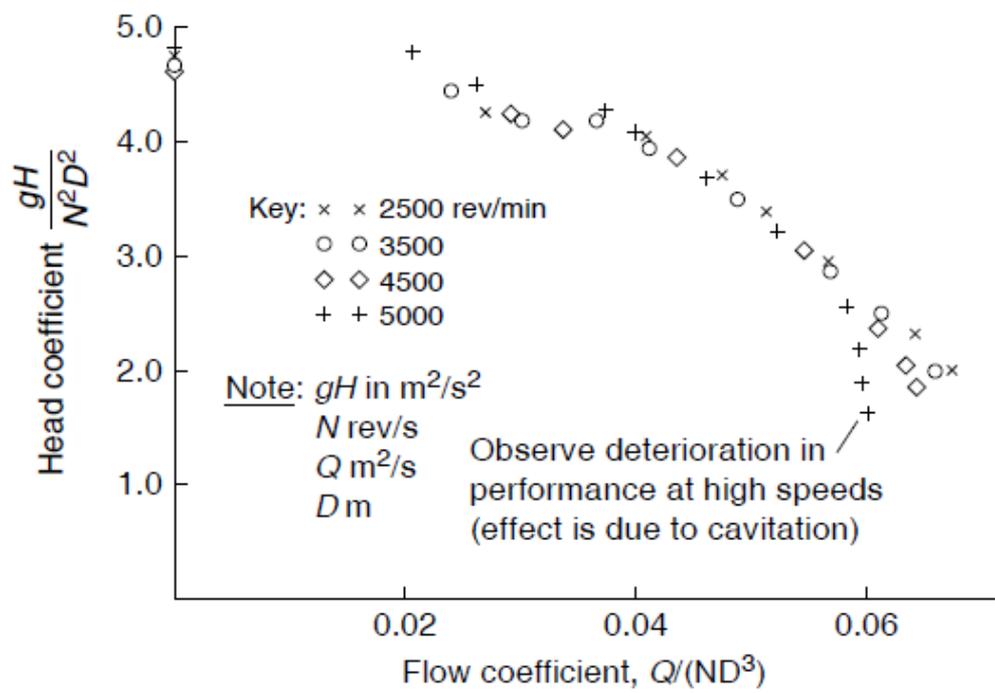
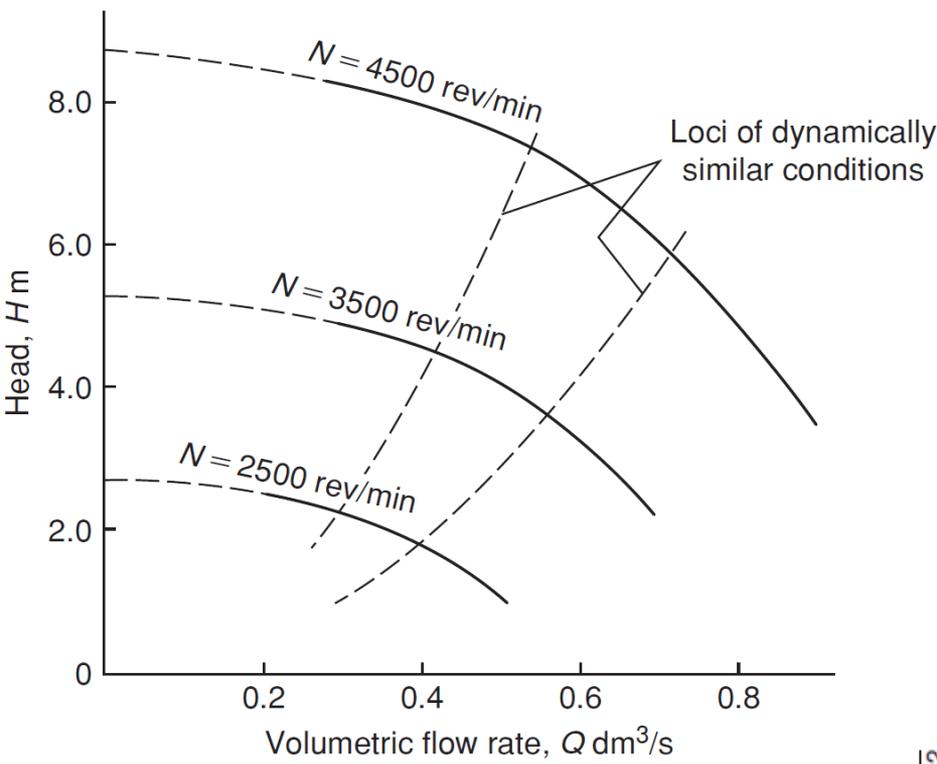
Macchine geometricamente simili, funzionanti in condizioni di similitudine cinematica con Re elevati (moto turbolento completamente sviluppato), presentano pertanto:

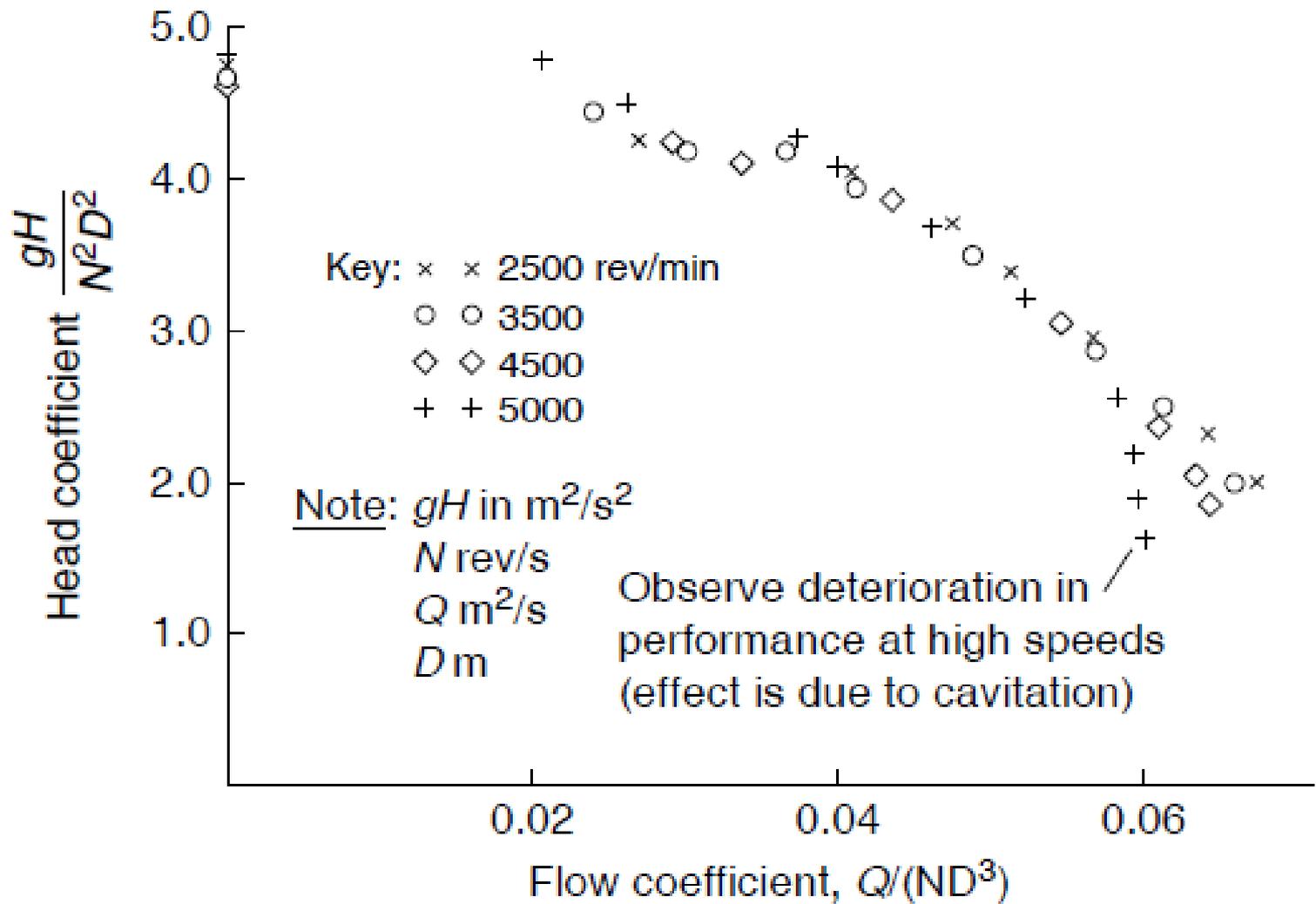
$$\eta_{iA} = \eta_{iB}$$

$$\frac{Q_A}{Q_B} = \frac{\omega_A D_A^3}{\omega_B D_B^3}$$

$$\frac{gH_A}{gH_B} = \frac{\omega_A^2 D_A^2}{\omega_B^2 D_B^2}$$

$$\frac{P_A}{P_B} = \frac{\rho_A \omega_A^3 D_A^5}{\rho_B \omega_B^3 D_B^5}$$





Per una famiglia di macchine simili è possibile individuare una coppia di valori di $\phi_{\eta_{max}}$ e $\psi_{\eta_{max}}$ per cui il rendimento idraulico risulta massimo:

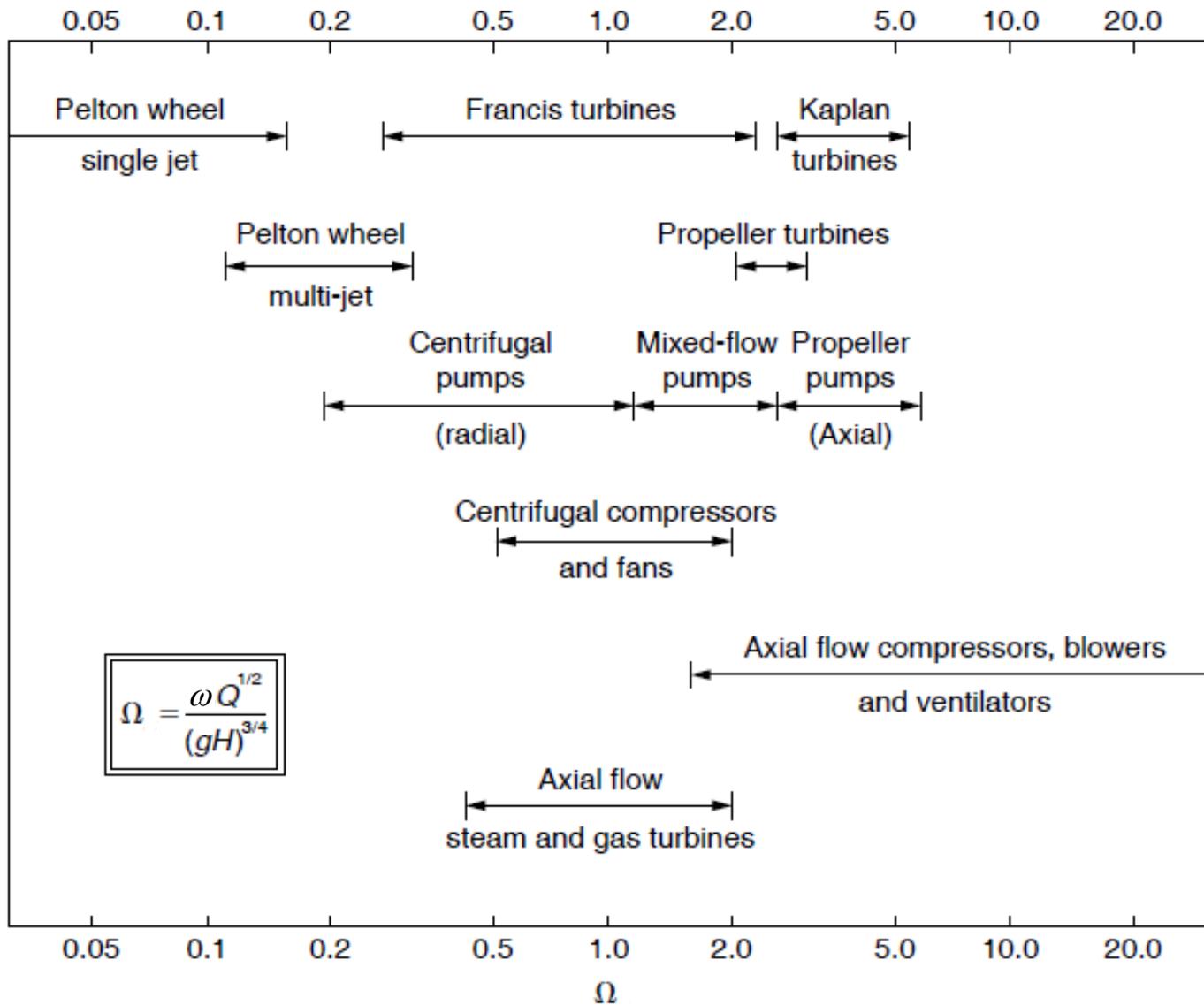
$$\phi_{\eta_{max}} = \left(\frac{Q}{\omega D^3} \right)_{\eta_{max}} \quad \psi_{\eta_{max}} = \left(\frac{gH}{\omega^2 D^2} \right)_{\eta_{max}}$$

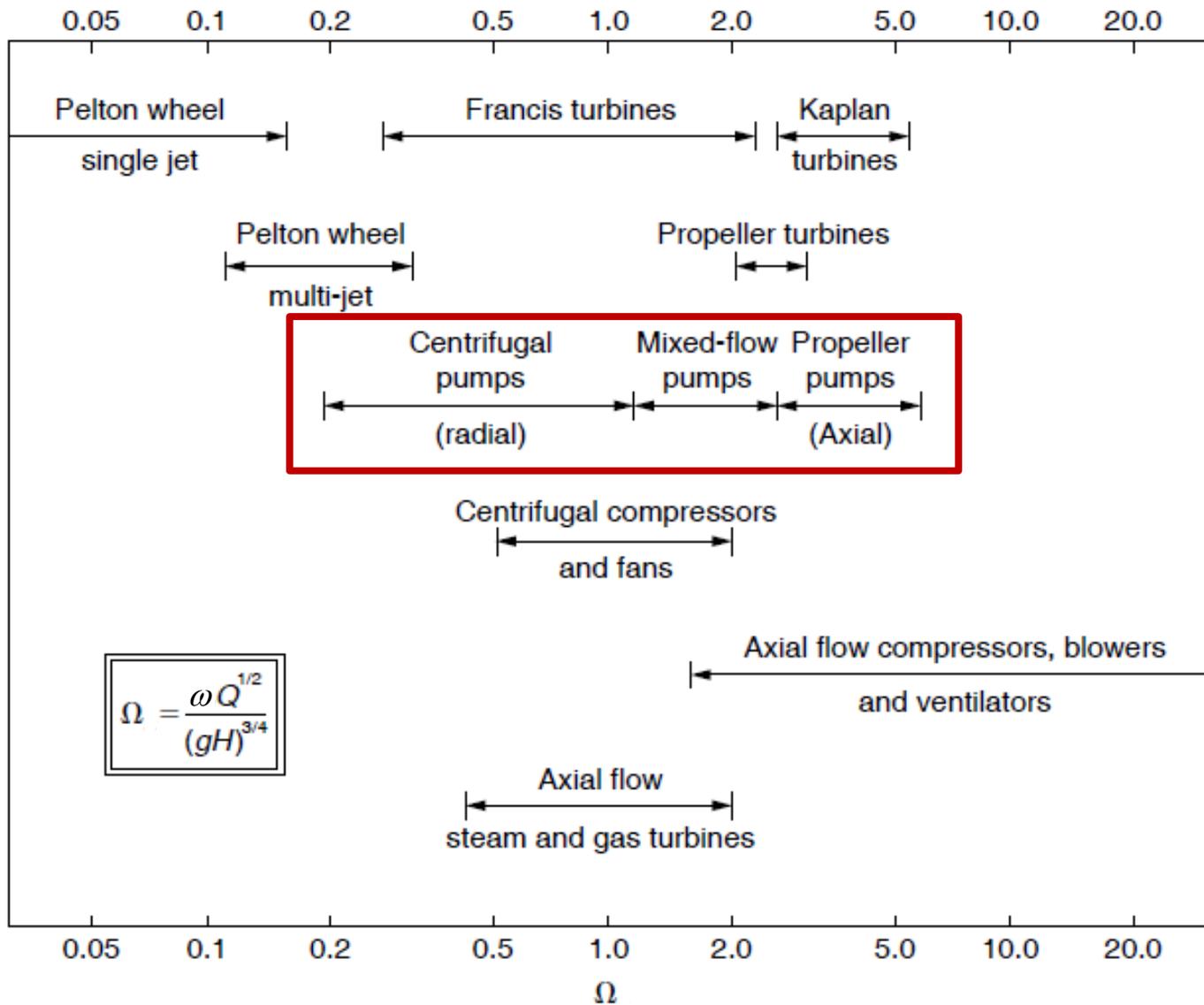
Combinando opportunamente ϕ e ψ si può ottenere un raggruppamento adimensionale di variabili che non contiene D , che prende il nome di **velocità specifica**:

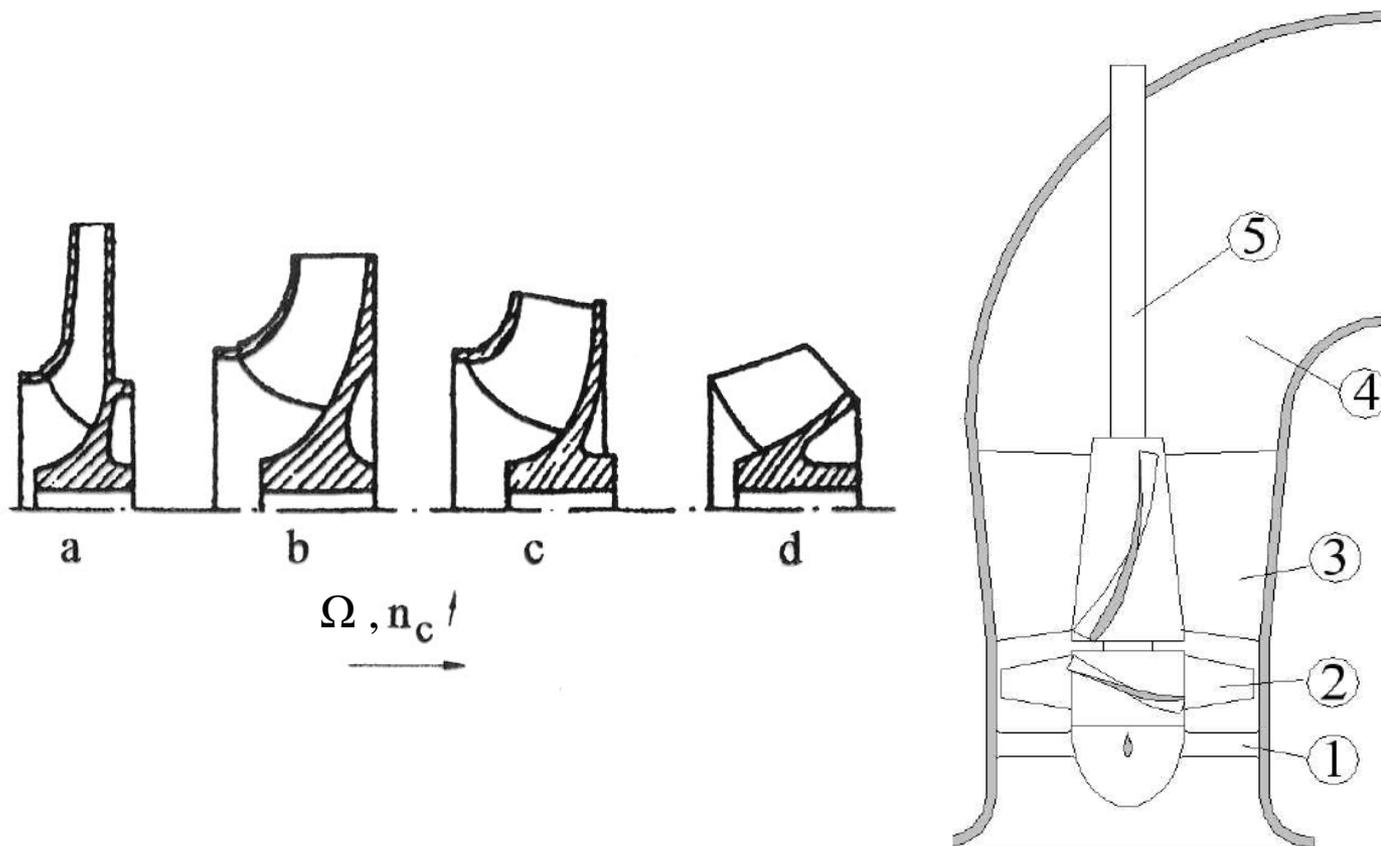
$$\Omega = \frac{\phi^{1/2}}{\psi^{3/4}} = \omega \frac{Q^{1/2}}{(gH)^{3/4}}$$

Un numero dimensionale equivalente alla velocità specifica è l'**indice caratteristico** :

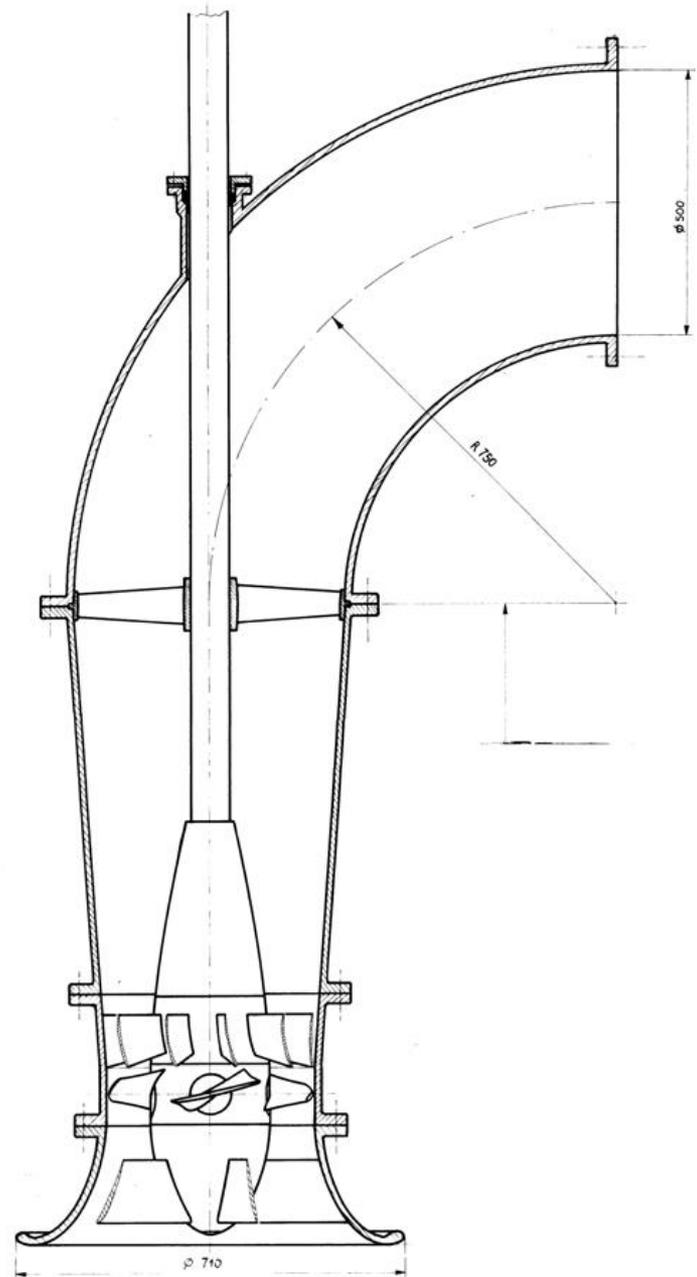
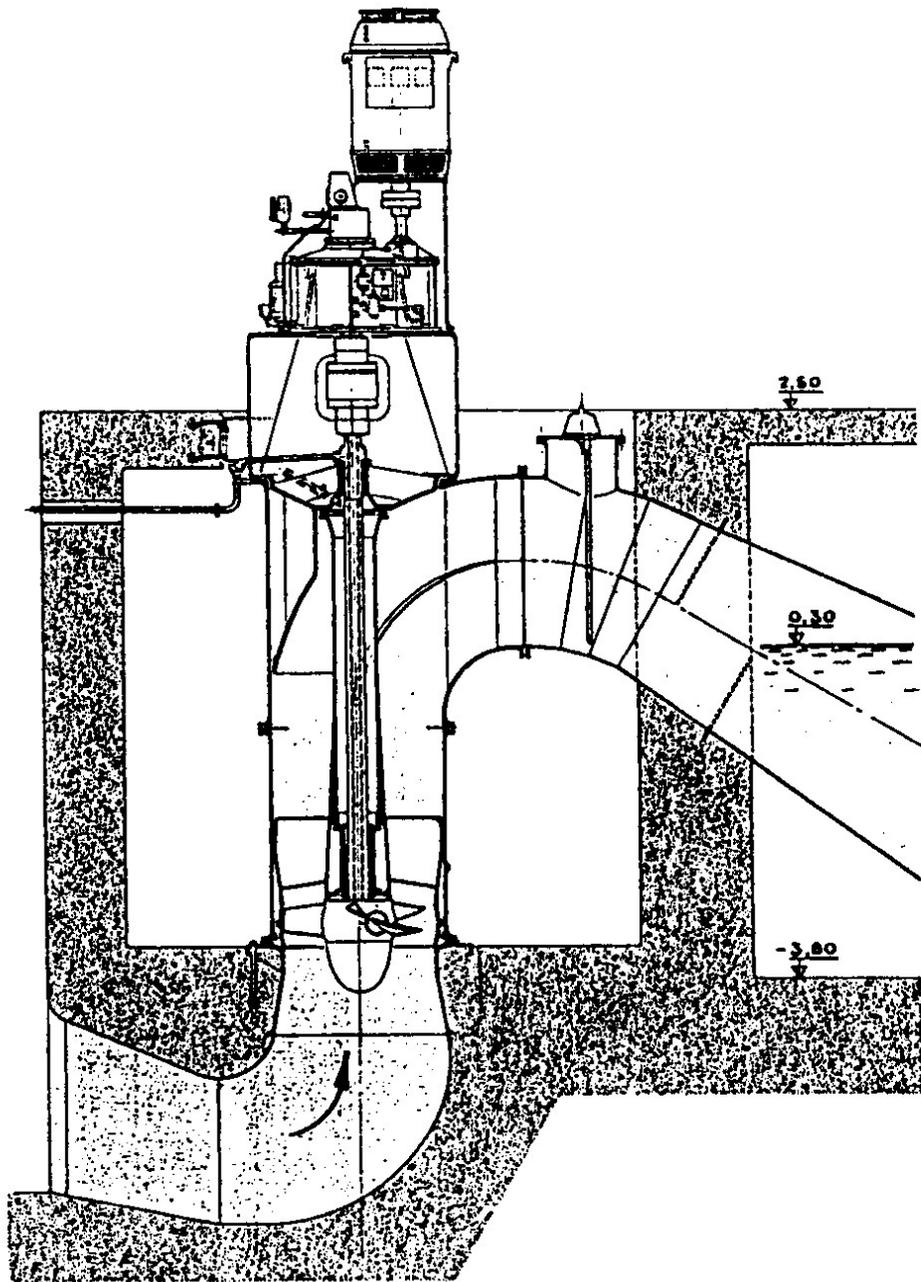
$$n_c = n_q = N \frac{Q^{1/2}}{H^{3/4}}$$

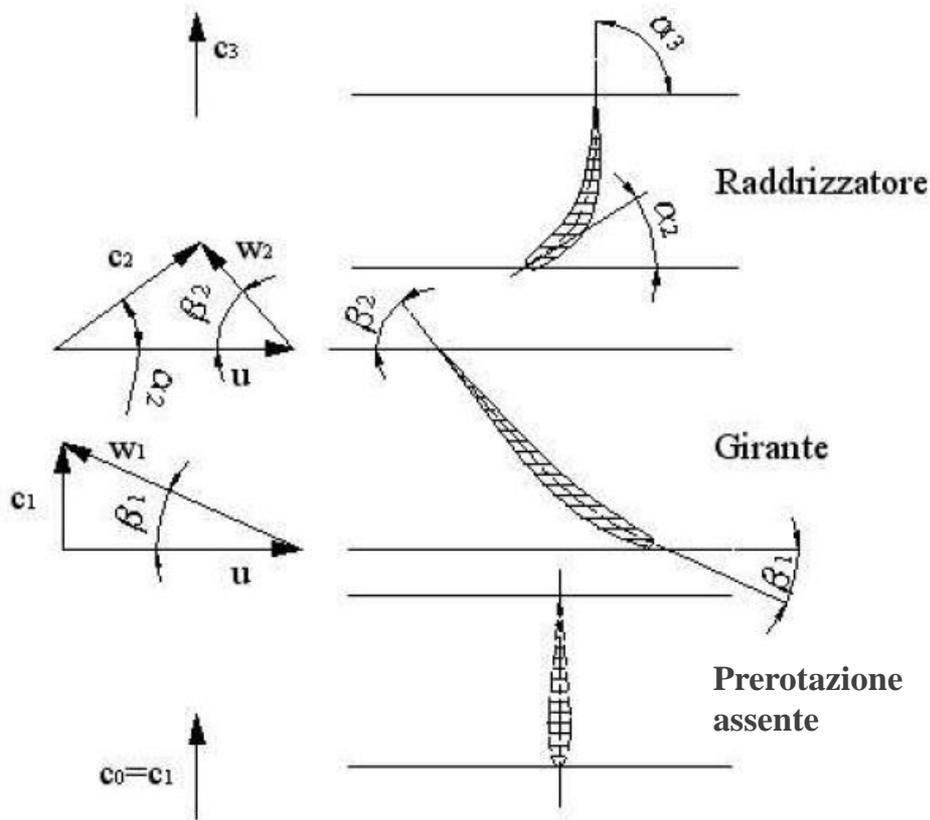




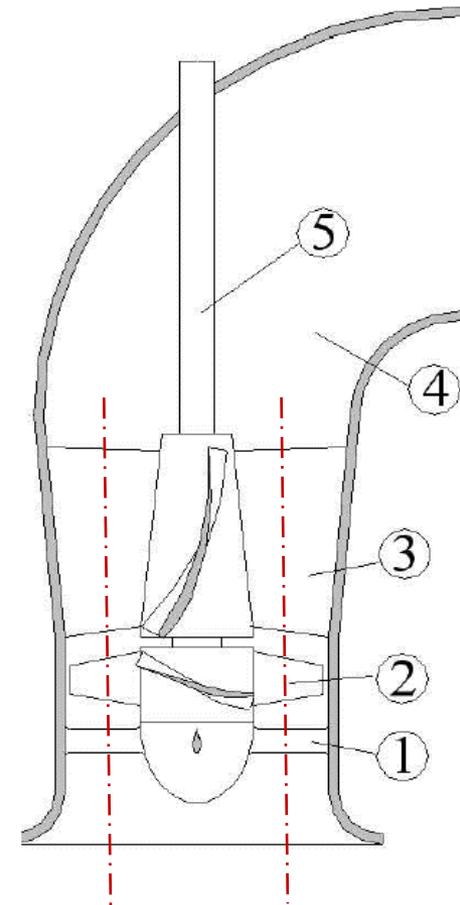


Schema di una pompa assiale: 1-predistributore, 2-girante, 3-raddrizzatore, 4-diffusore, 5-albero



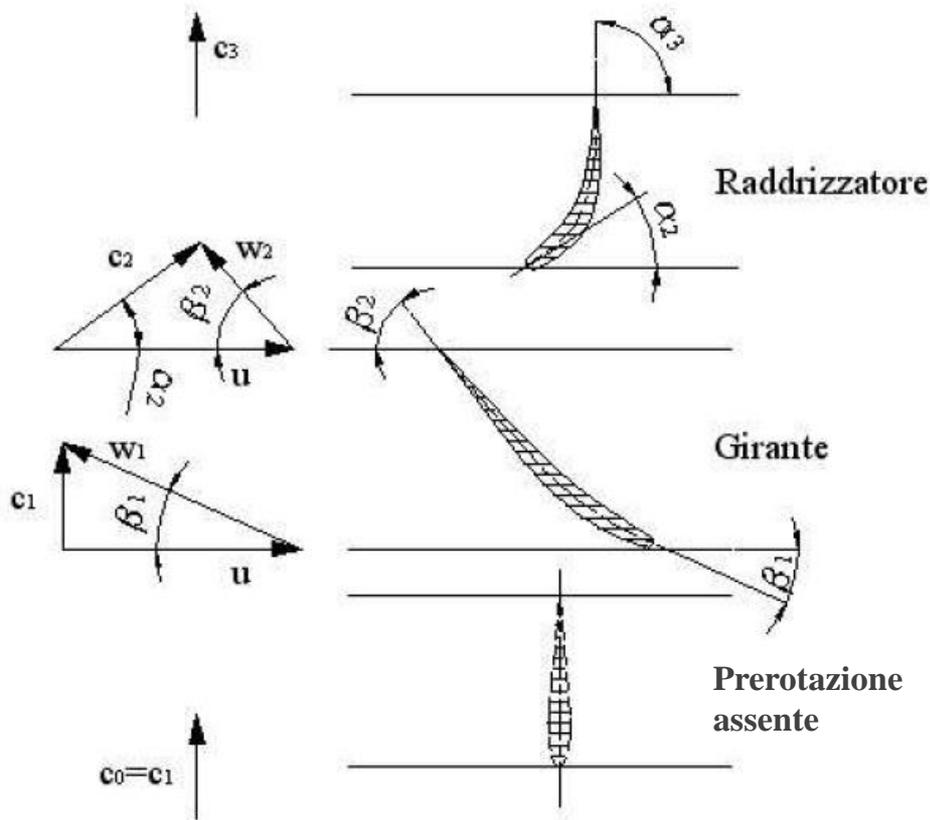


Sezioni dei profili palari e triangoli di velocità sulla superficie di corrente cilindrica al raggio medio sviluppata su un piano

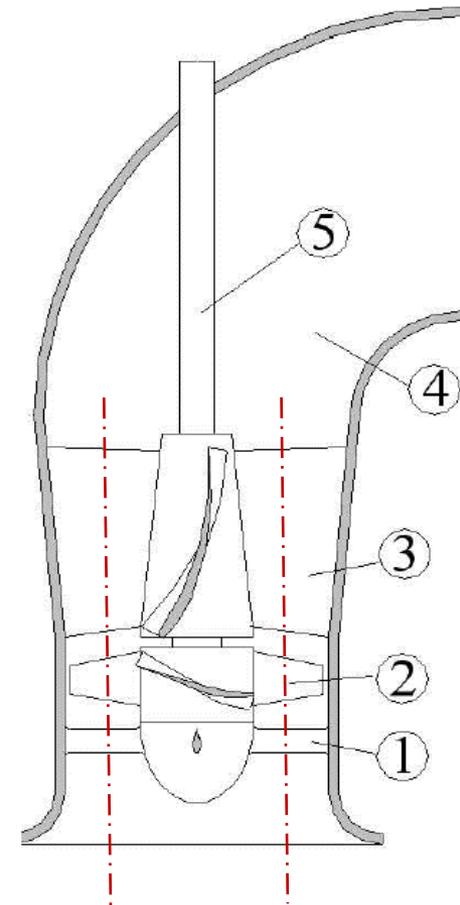


Traccia superficie di corrente cilindrica al raggio medio

$$l_g = \frac{c_2^2 - c_1^2}{2} + \frac{w_1^2 - w_2^2}{2} = u(c_2 \cos \alpha_2 - c_1 \cos \alpha_1)$$

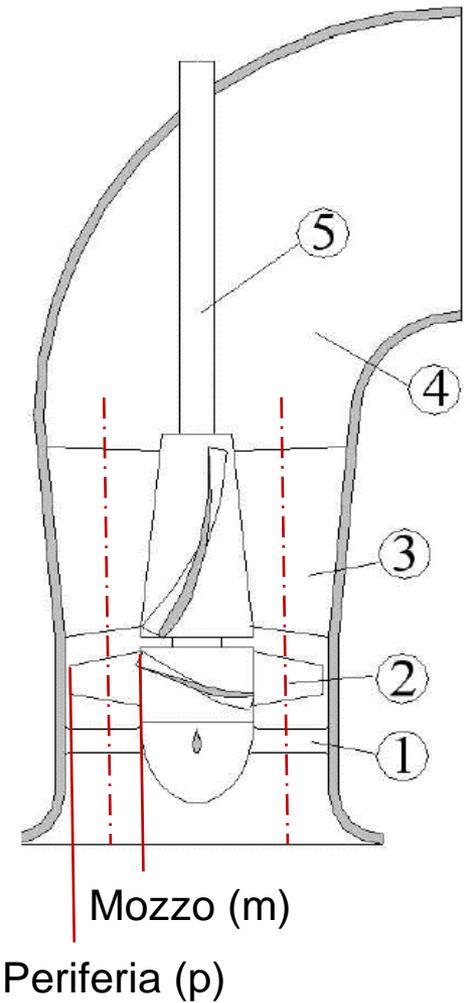
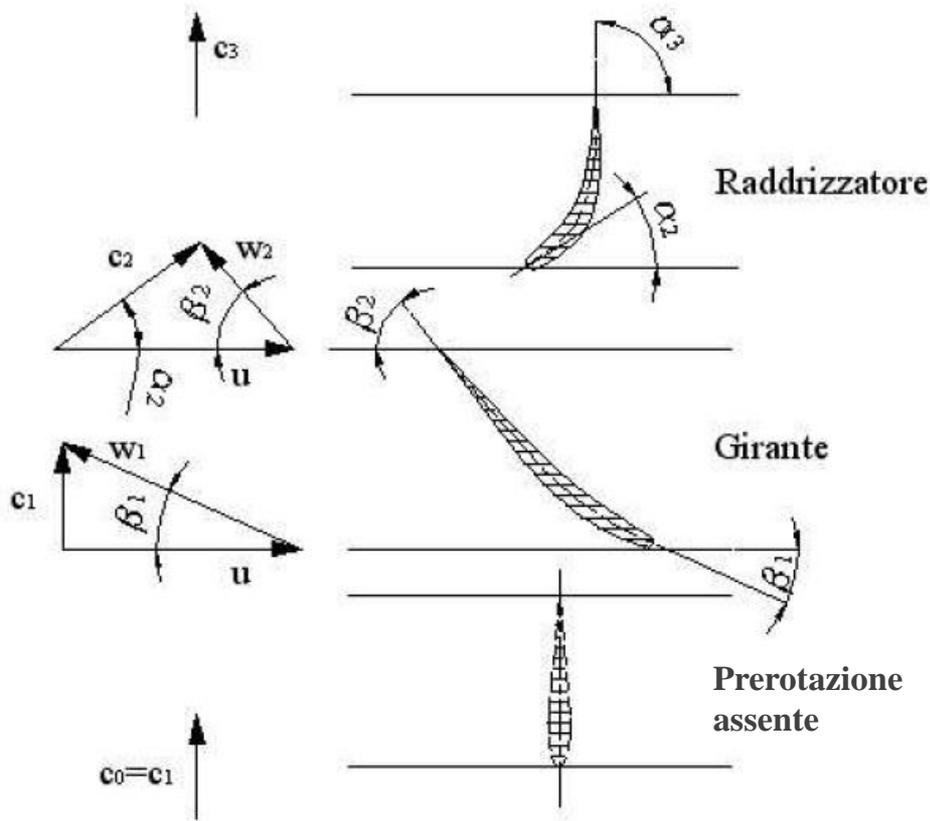


Sezioni dei profili palari e triangoli di velocità sulla superficie di corrente cilindrica al raggio medio sviluppata su un piano



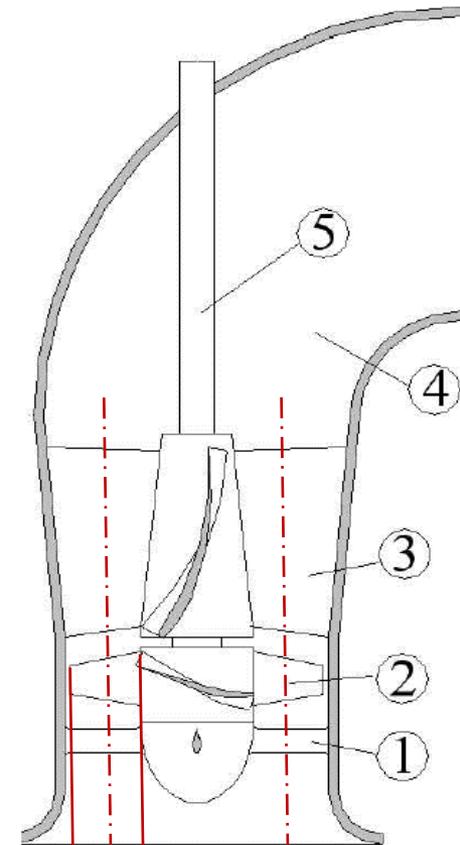
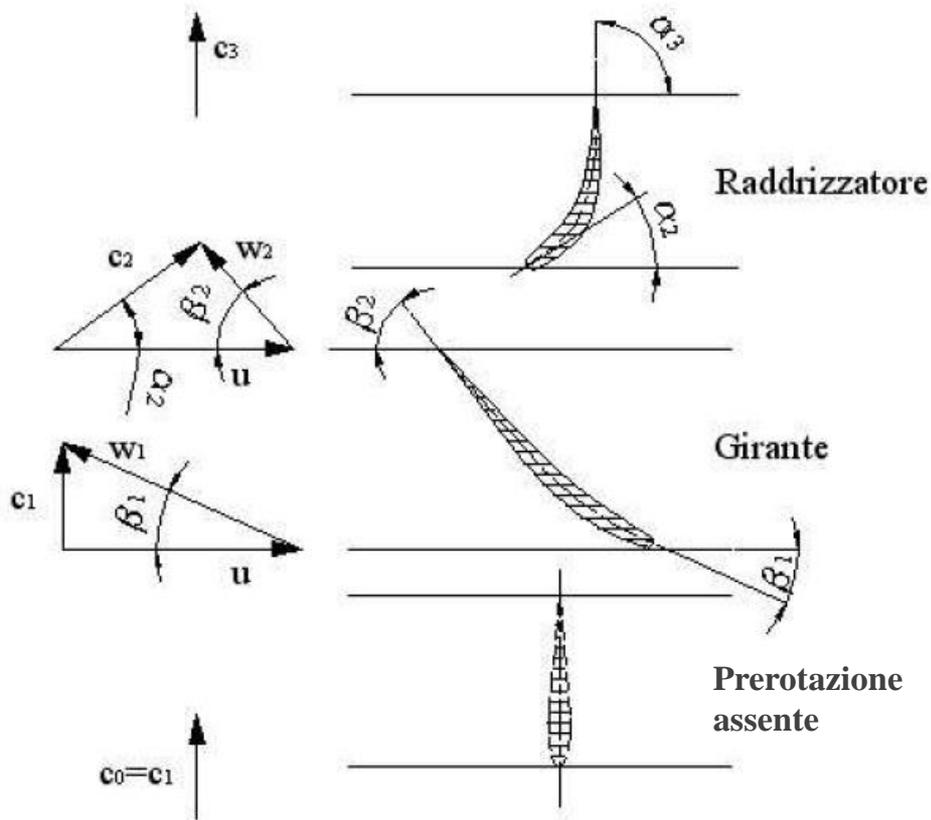
Traccia superficie di corrente cilindrica al raggio medio

$$\alpha_1 = 90^\circ \rightarrow l_g = \frac{c_2^2 - c_1^2}{2} + \frac{w_1^2 - w_2^2}{2} = u c_2 \cos \alpha_2 = \omega r c_{u2}$$



$$l_{g,m} = \omega r_m c_{u2,m} = l_{g,p} = \omega r_p c_{u2,p} \rightarrow r_m c_{u2,m} = r_p c_{u2,p}$$

$$\frac{u_m}{r_m} = \frac{u_p}{r_p} = \omega$$

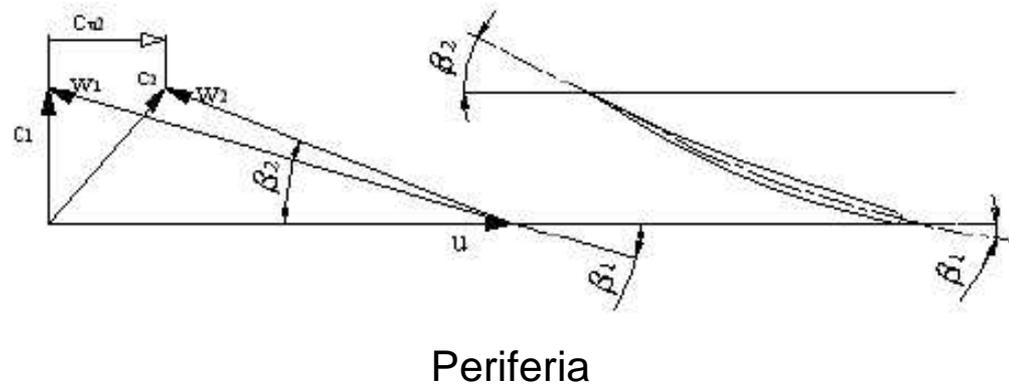
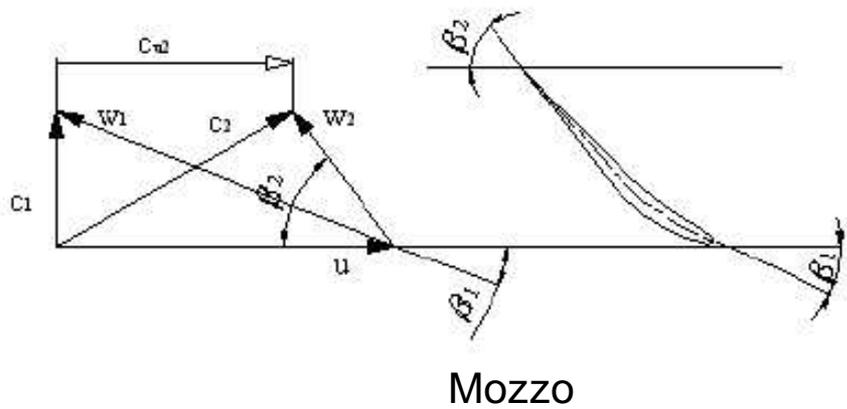
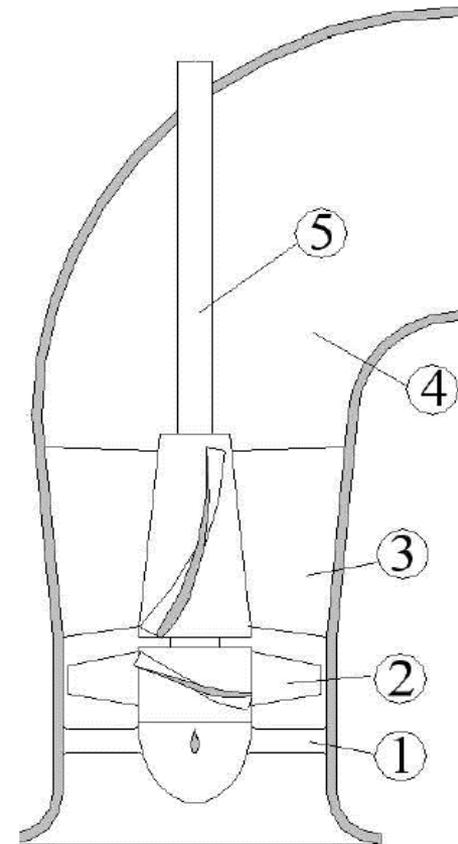
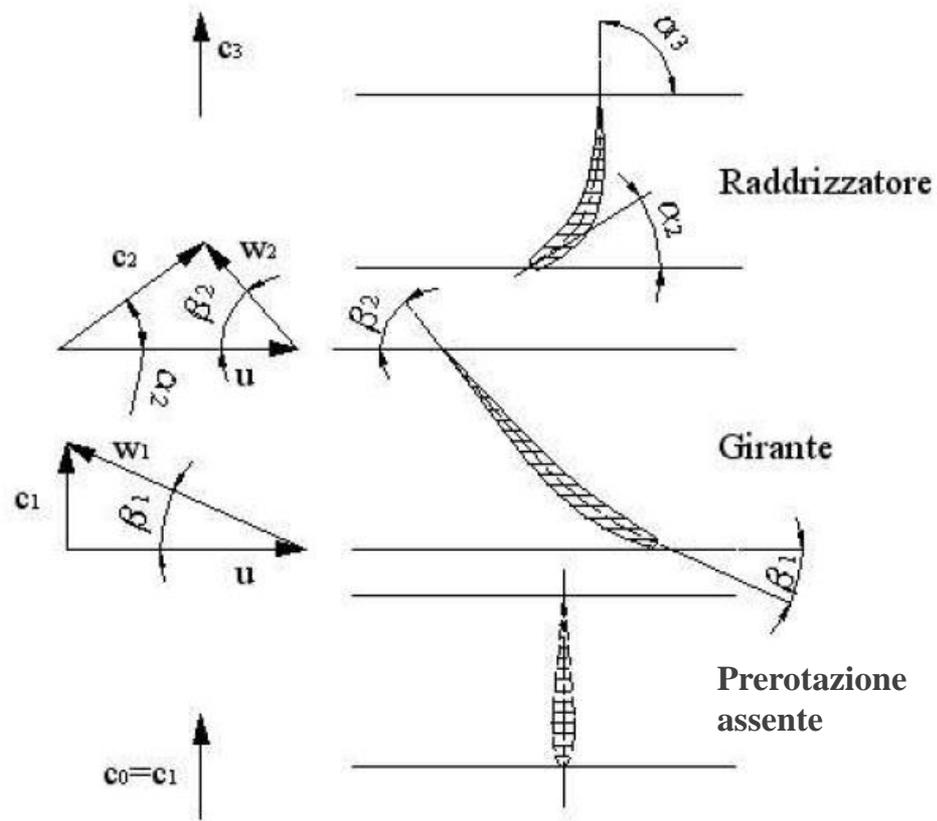


Mozzo (m)

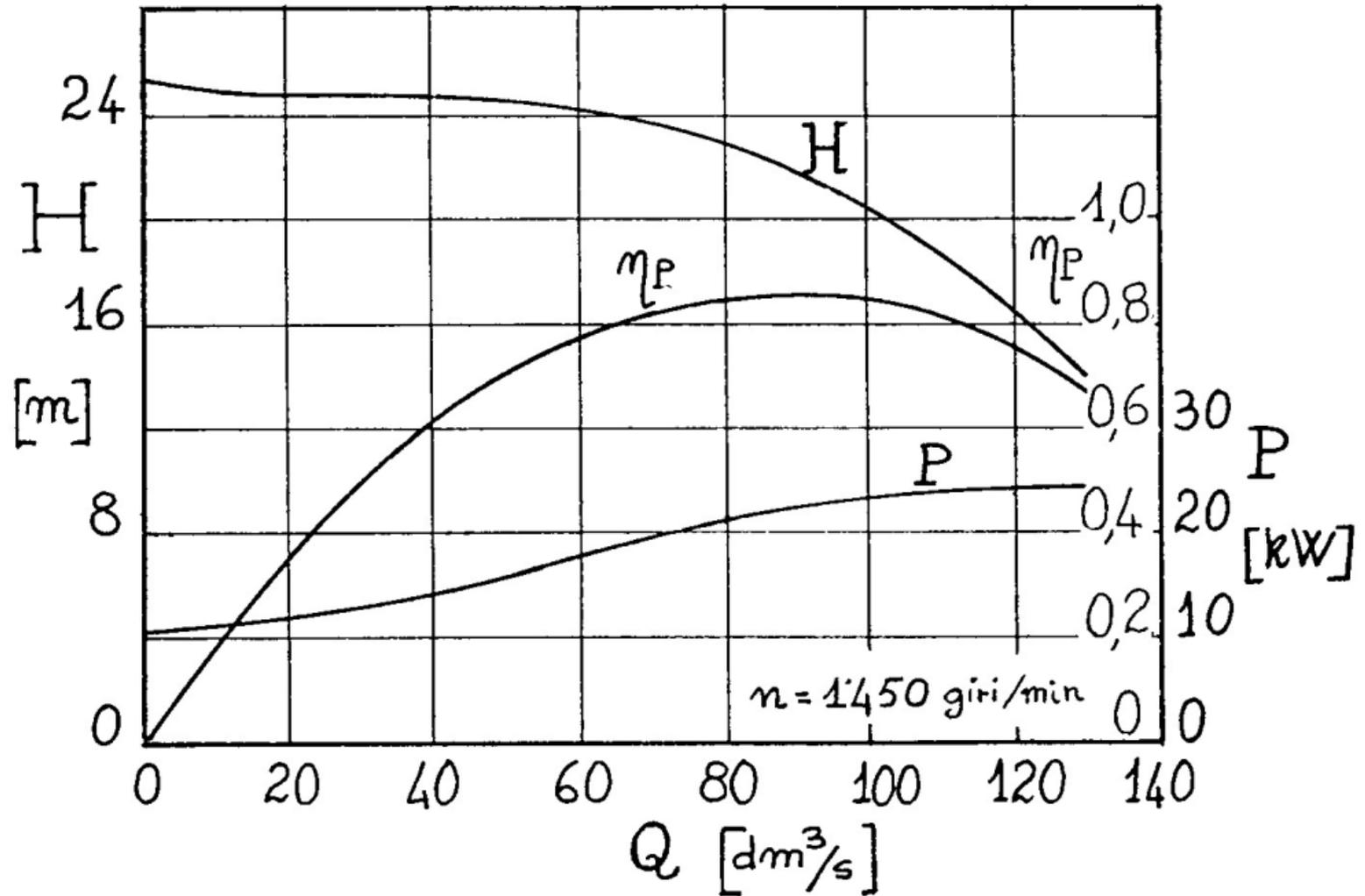
Periferia (p)

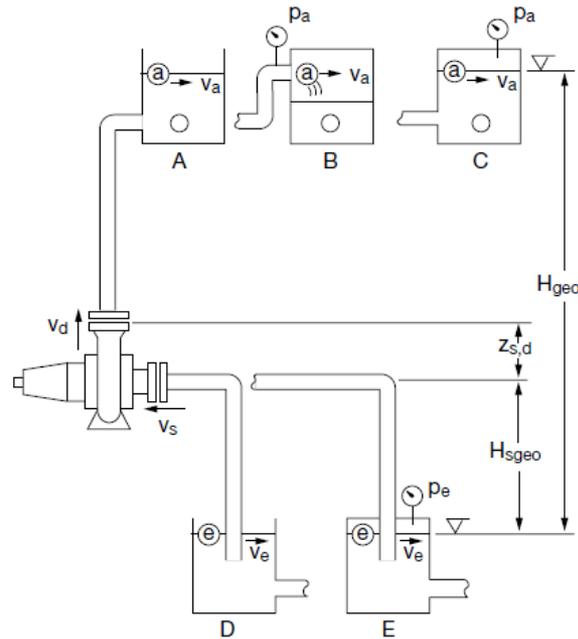
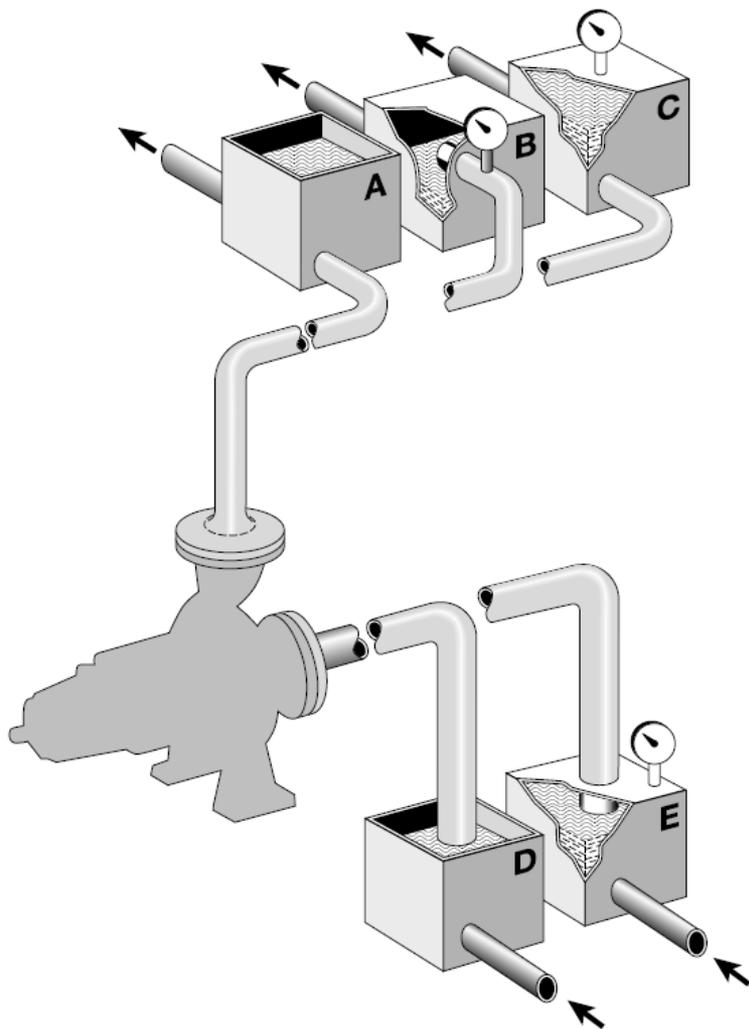
$$r c_{u2} = \text{const.} \rightarrow c_{u2} = \frac{\text{const.}}{r}$$

$$u = \omega r$$



Punto di funzionamento della pompa





Impianti di pompaggio funzionanti in aspirazione, con serbatoi in esecuzioni diverse

A = Serbatoio di mandata aperto con sbocco del tubo sotto il livello dell'acqua

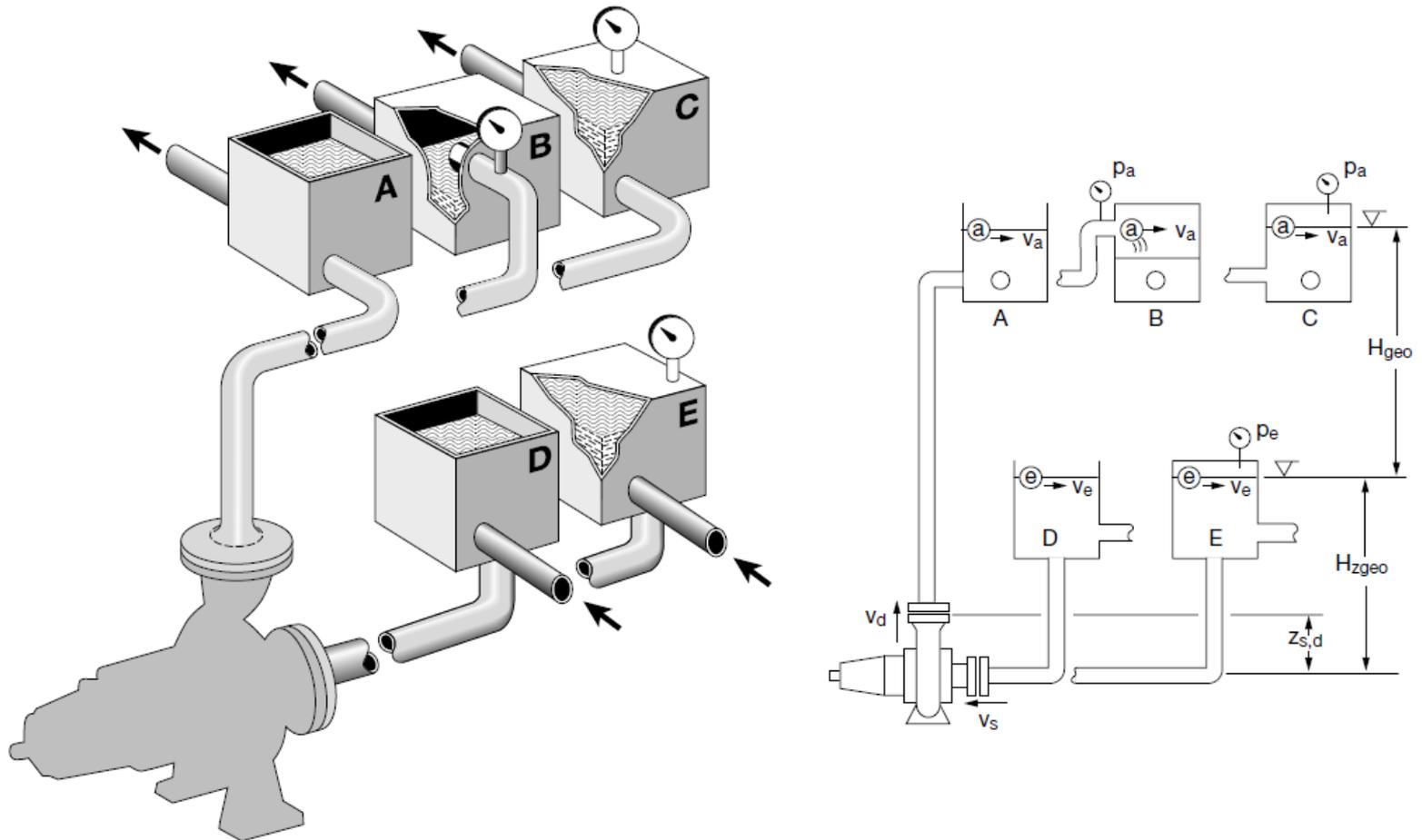
B = Serbatoio di mandata chiuso con uscita libera dal tubo

C = Serbatoio di mandata chiuso con sbocco del tubo sotto il livello del liquido

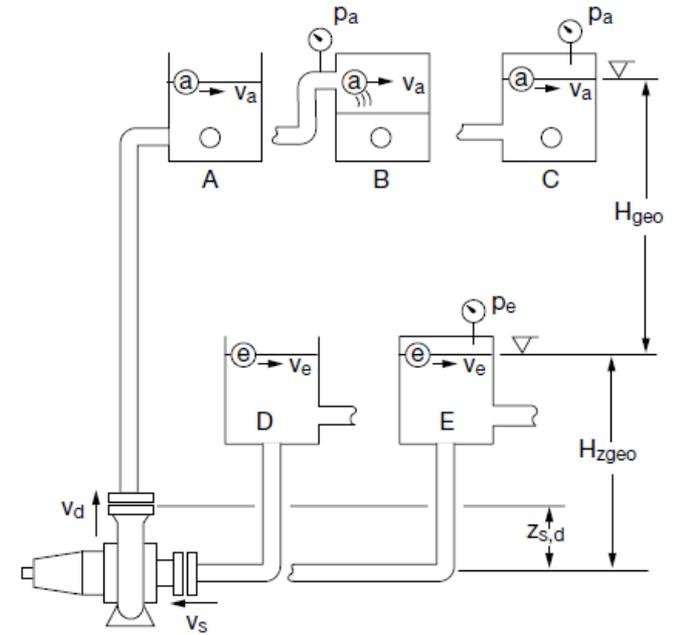
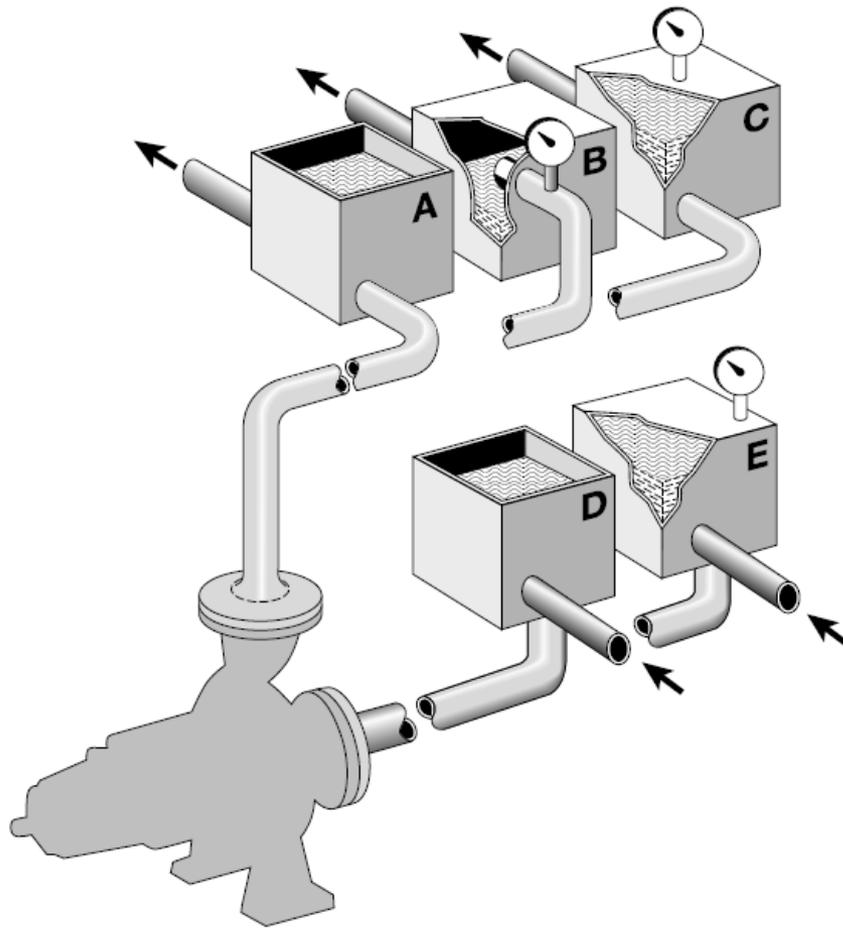
D = Serbatoio di aspirazione o serbatoio di carico aperti

E = Serbatoio di aspirazione o serbatoio di carico chiusi

v_a e v_e sono rispettivamente le velocità del fluido (per lo più piccole da trascurare) nei serbatoi A e C nei punti @ e nei serbatoi D ed E nei punti ⊕, nel caso B invece v_a è la velocità non trascurabile di efflusso dalla sezione di tubo @.

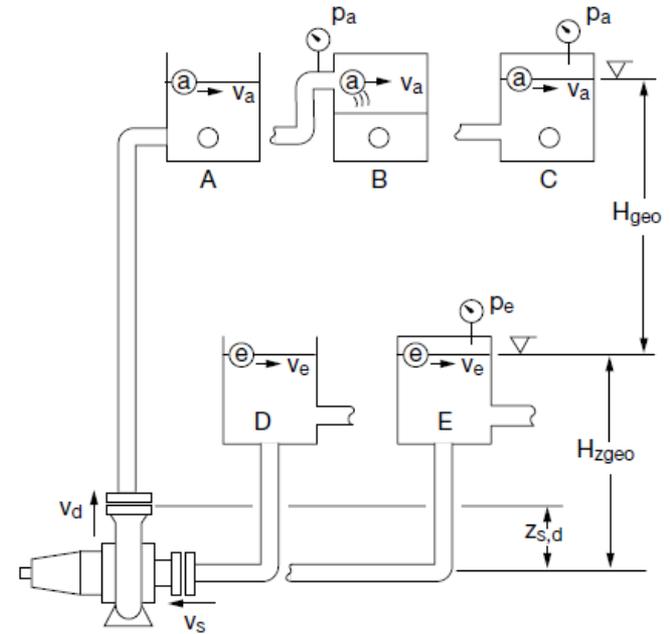
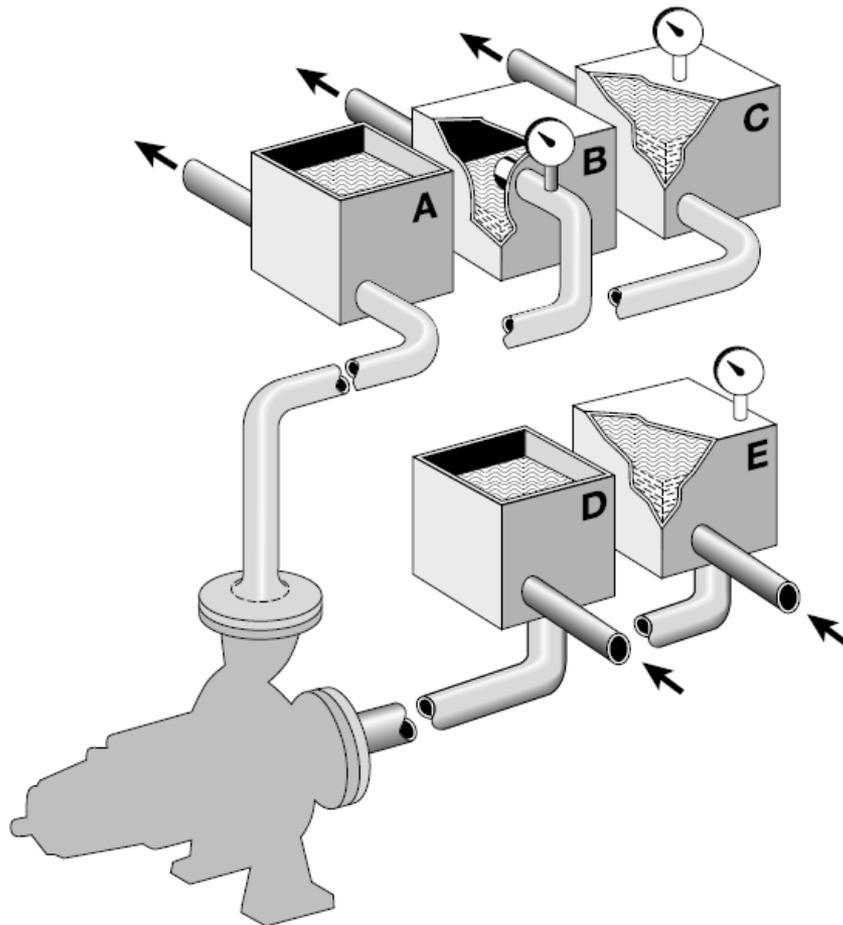


Impianti di pompaggio funzionanti sotto battente, con serbatoi in esecuzioni diverse



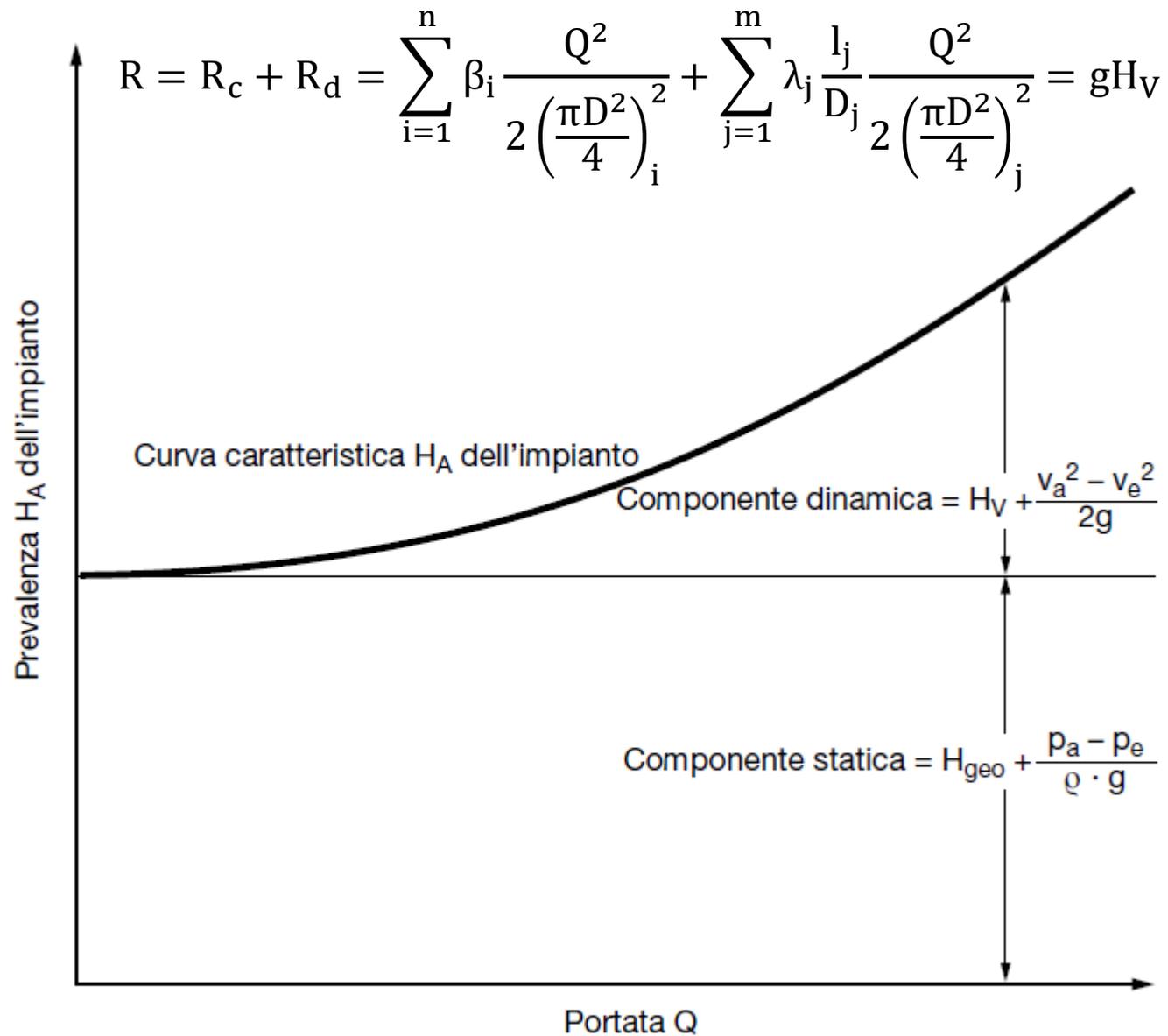
$$l_p = gH = R + \frac{V_a^2 - V_e^2}{2} + g(z_a - z_e) + \frac{p_a - p_e}{\rho}$$

Impianti di pompaggio funzionanti sotto battente, con serbatoi in esecuzioni diverse

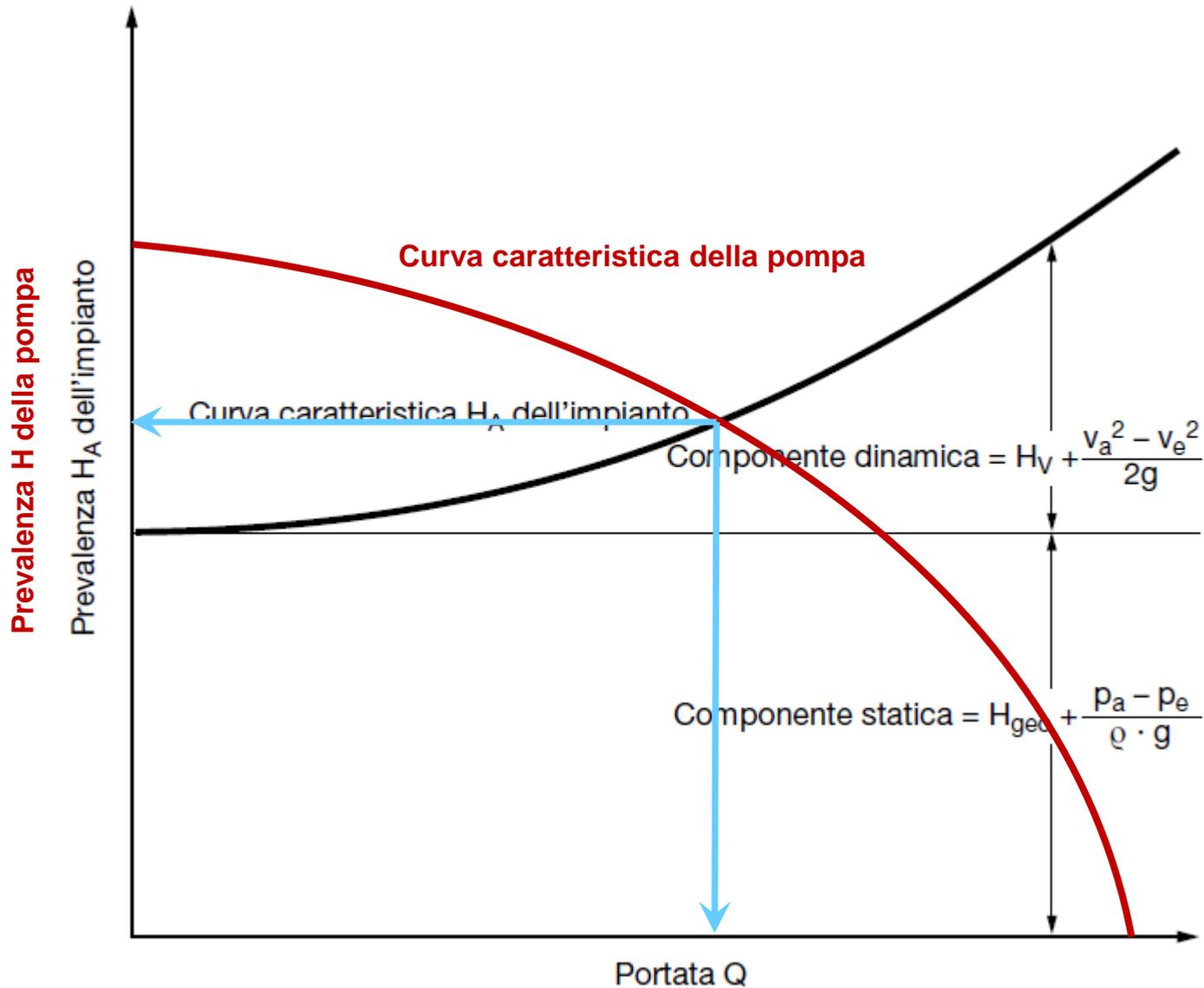


$$l_p = gH = gH_v + \frac{V_a^2 - V_e^2}{2} + gH_{geo} + \frac{p_a - p_e}{\rho} = gH_A$$

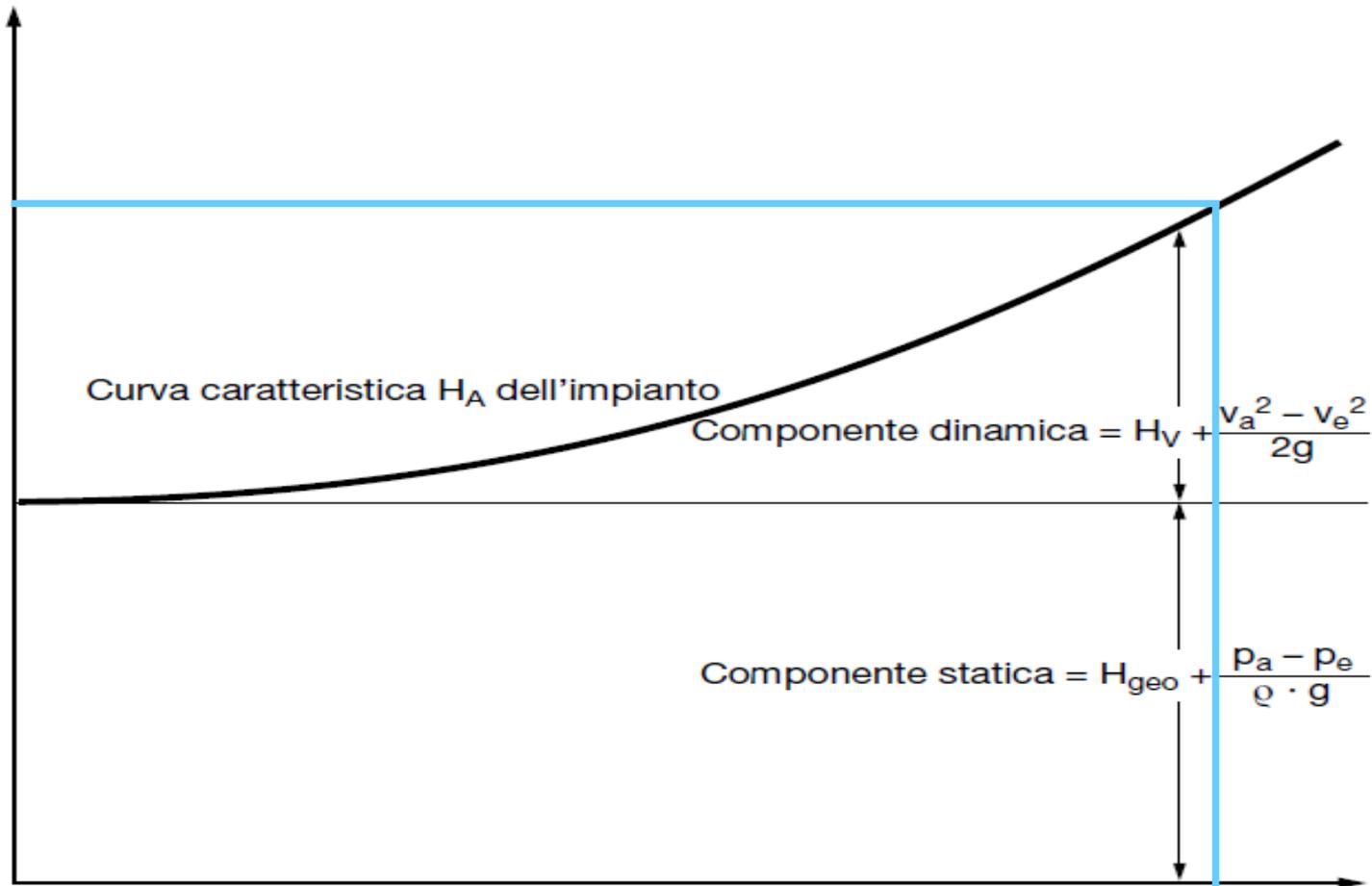
Impianti di pompaggio funzionanti sotto battente, con serbatoi in esecuzioni diverse

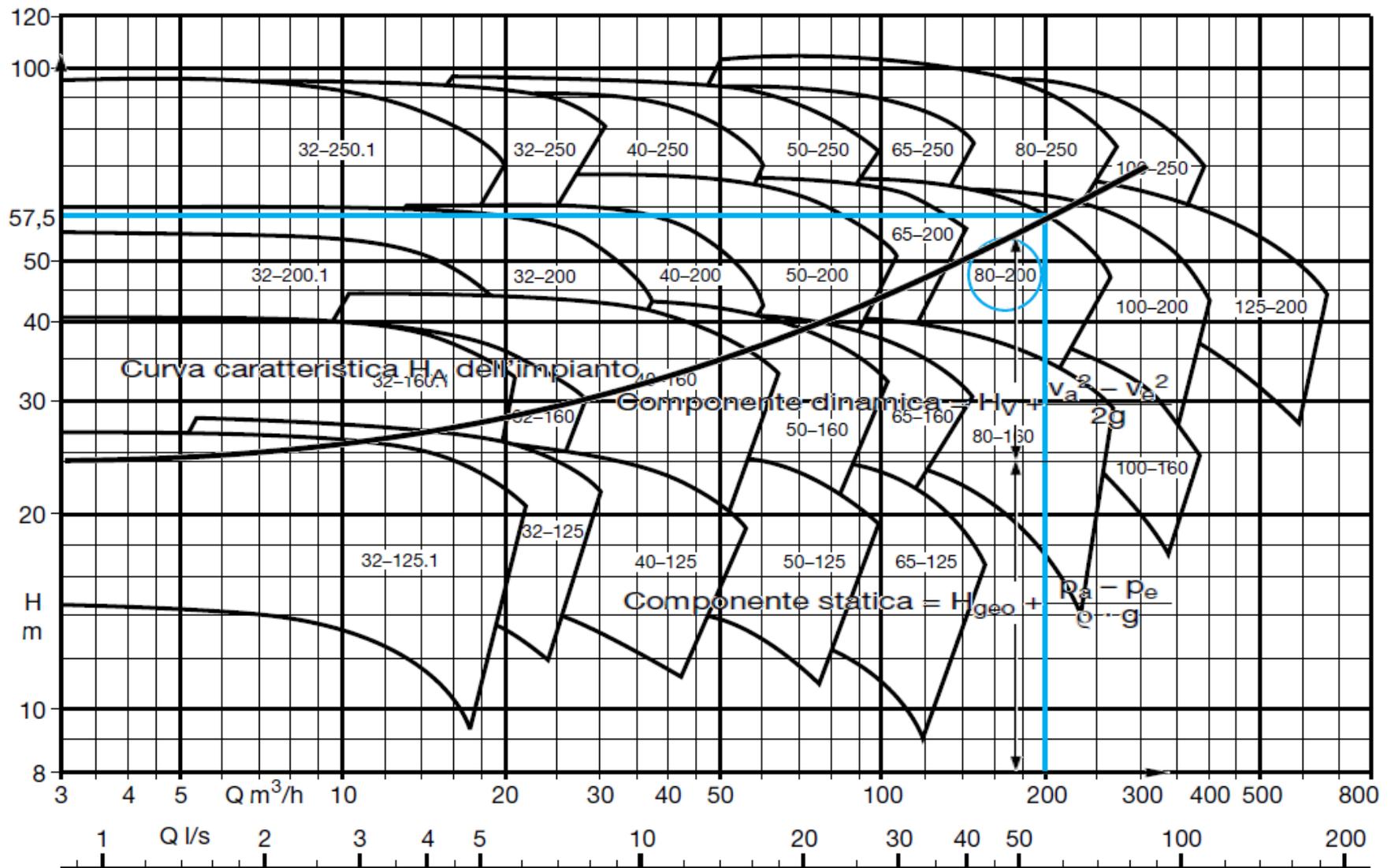


Punto di funzionamento della pompa ($H = H_A$)

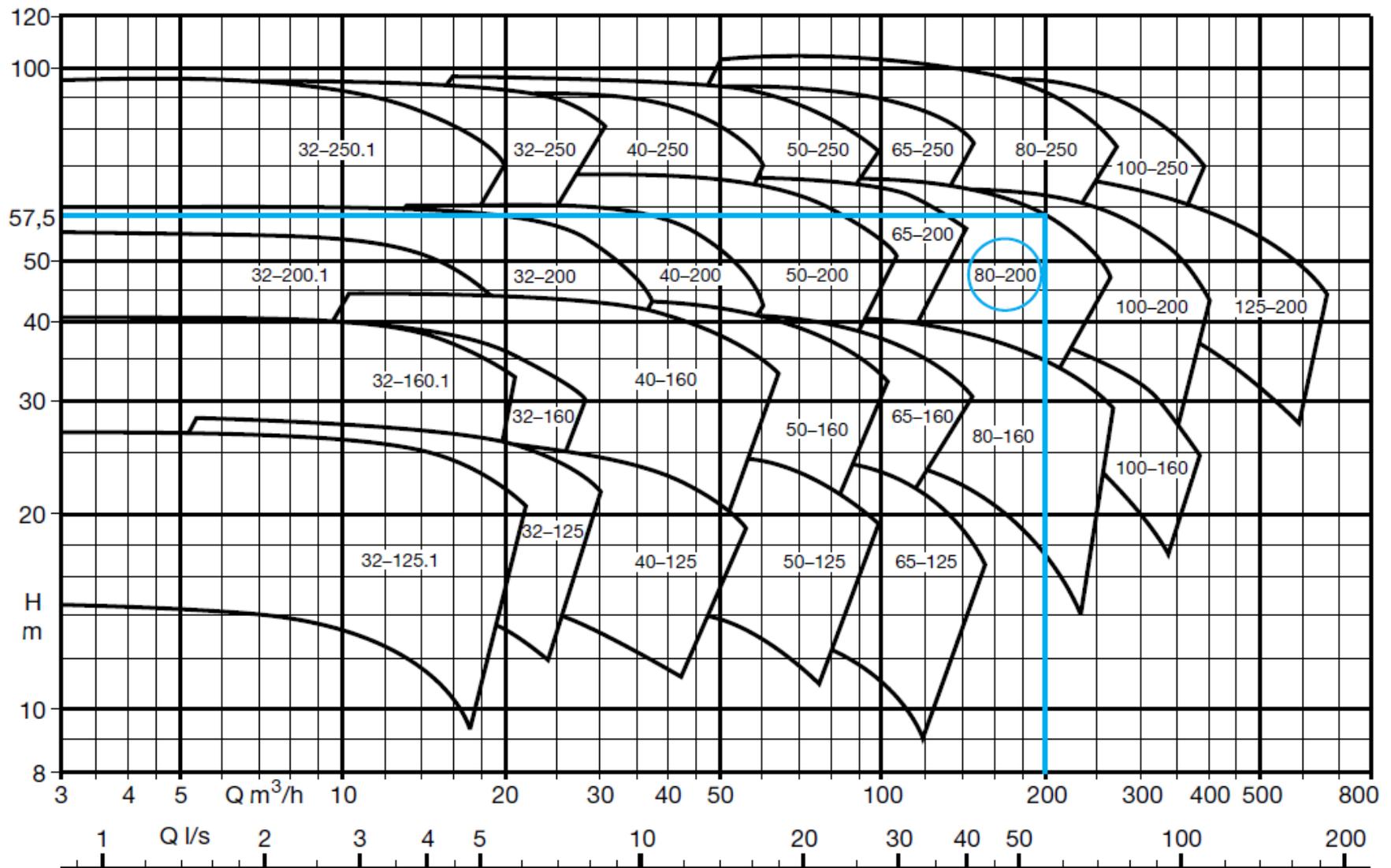


Scelta della pompa

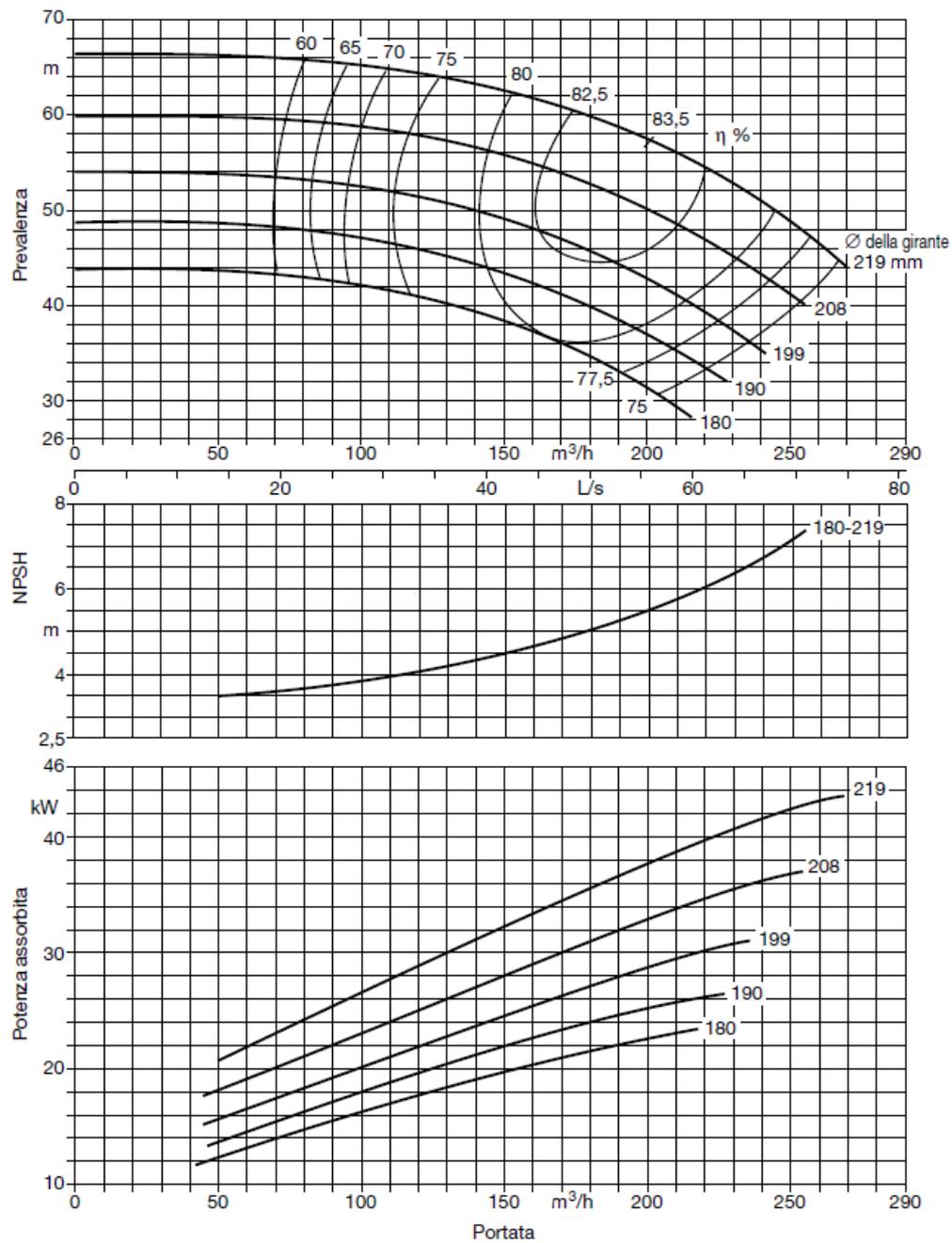




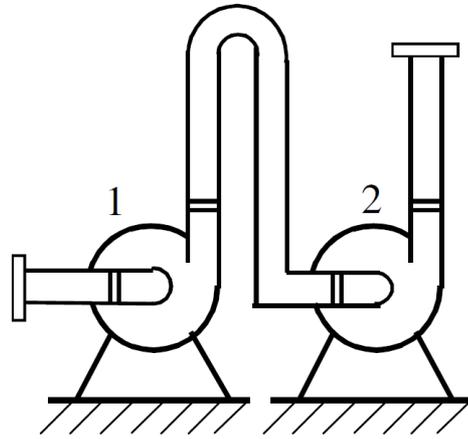
Campo caratteristico complessivo di una serie costruttiva di pompe con corpo a spirale a $n = 2900 \text{ min}^{-1}$ (1° numero = diametro nominale della bocca premente, 2° numero = diametro nominale della girante)



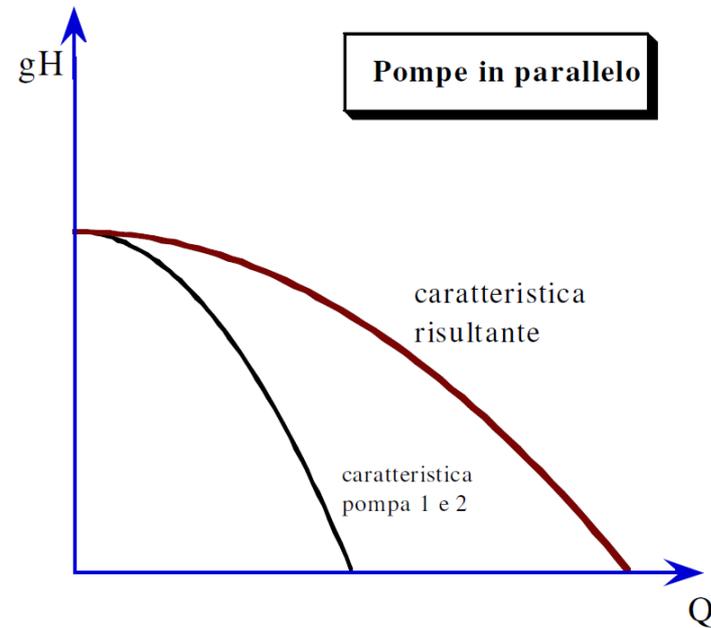
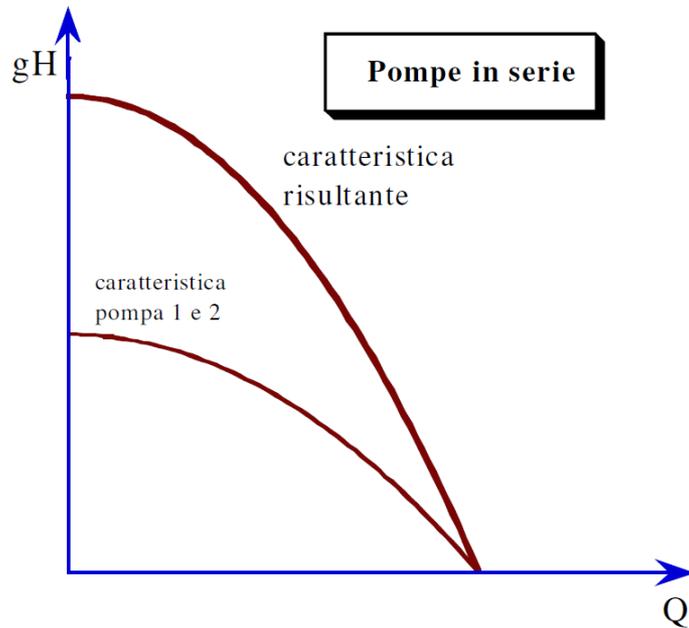
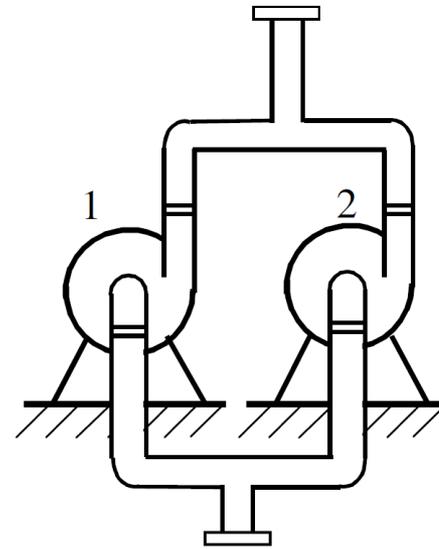
Campo caratteristico complessivo di una serie costruttiva di pompe con corpo a spirale a $n = 2900 \text{ min}^{-1}$ (1° numero = diametro nominale della bocca premente, 2° numero = diametro nominale della girante)

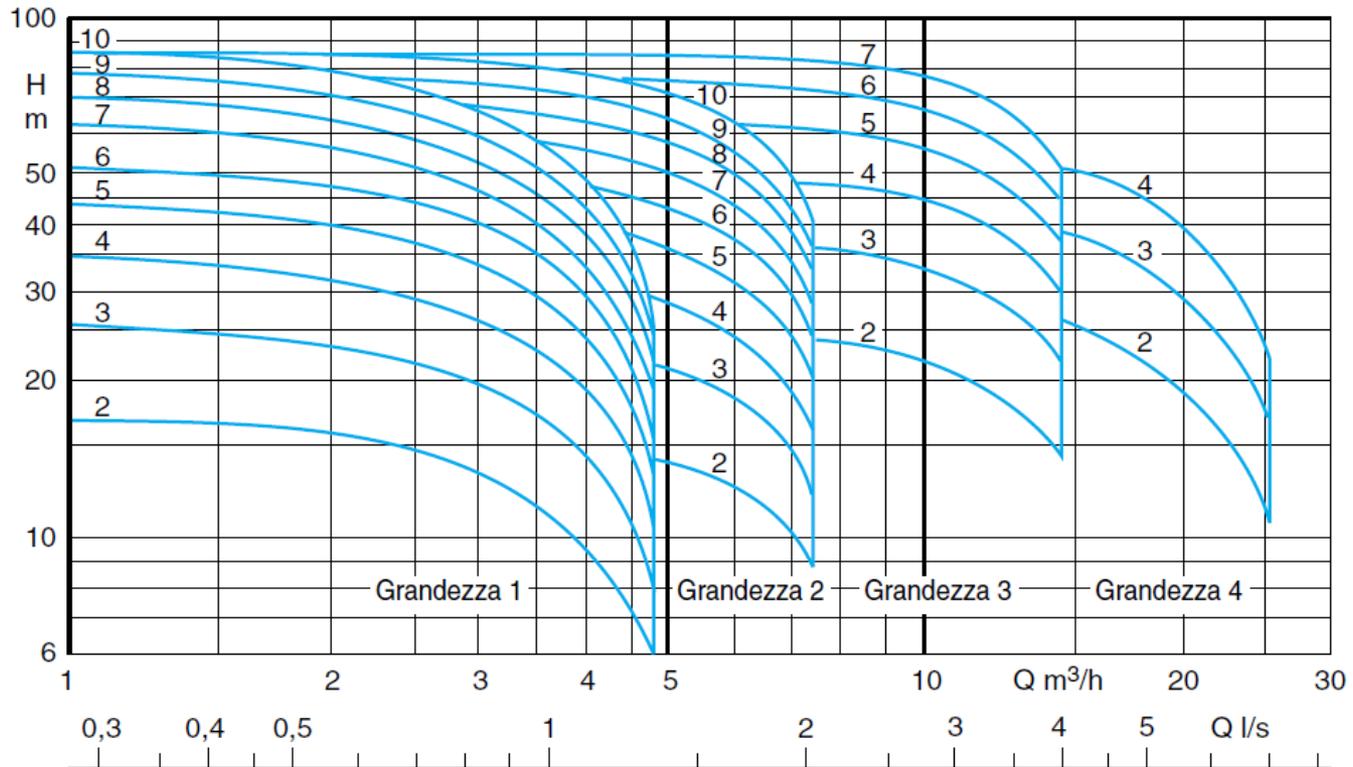
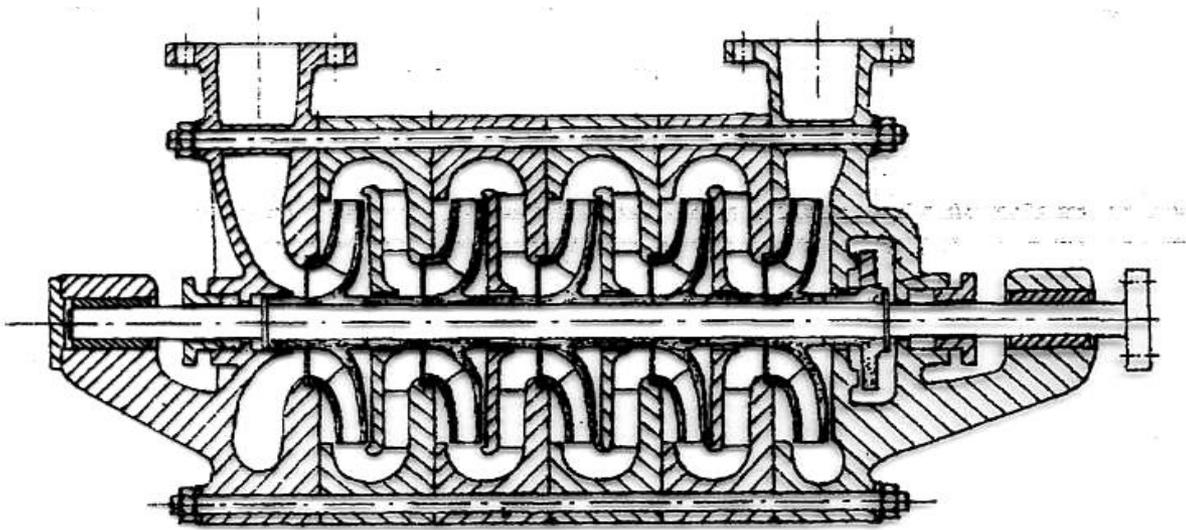


Pompe in serie

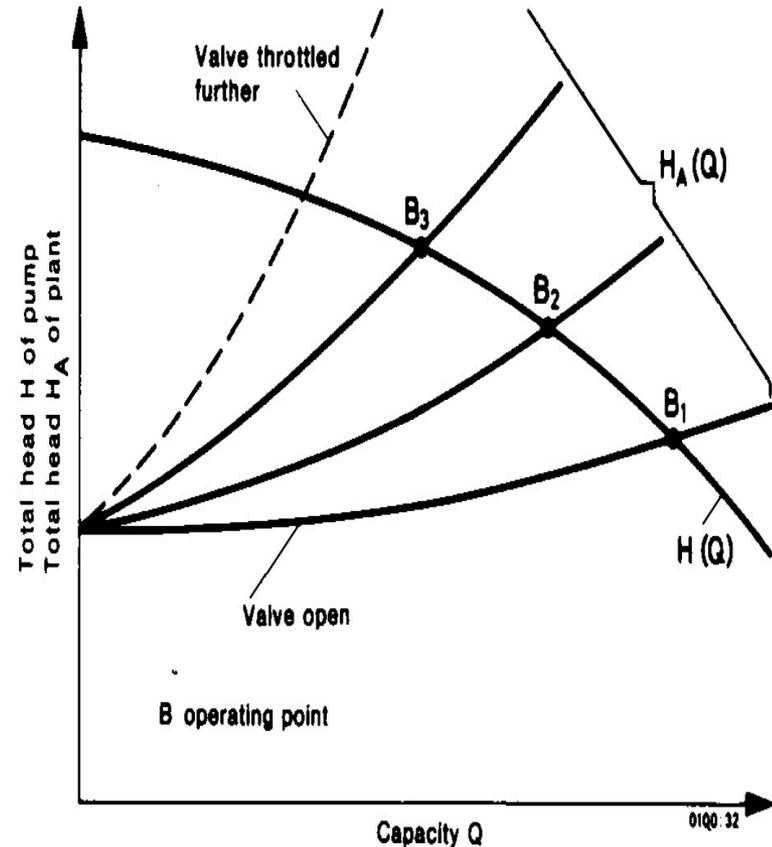
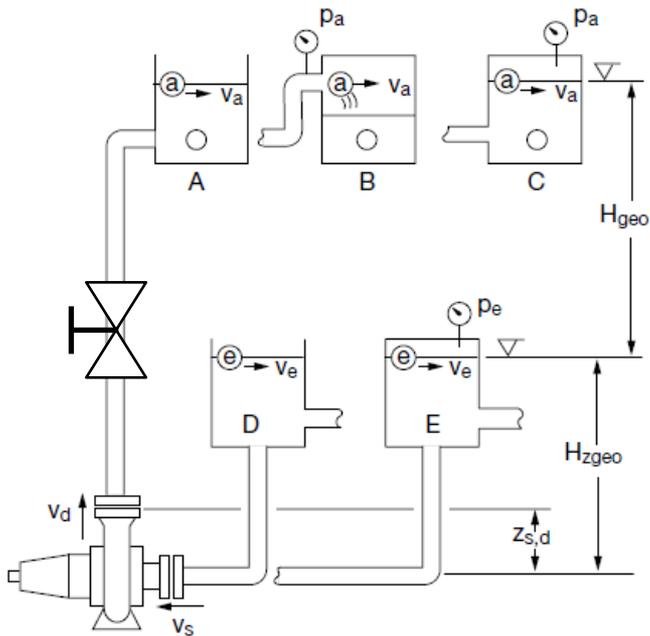


Pompe in parallelo



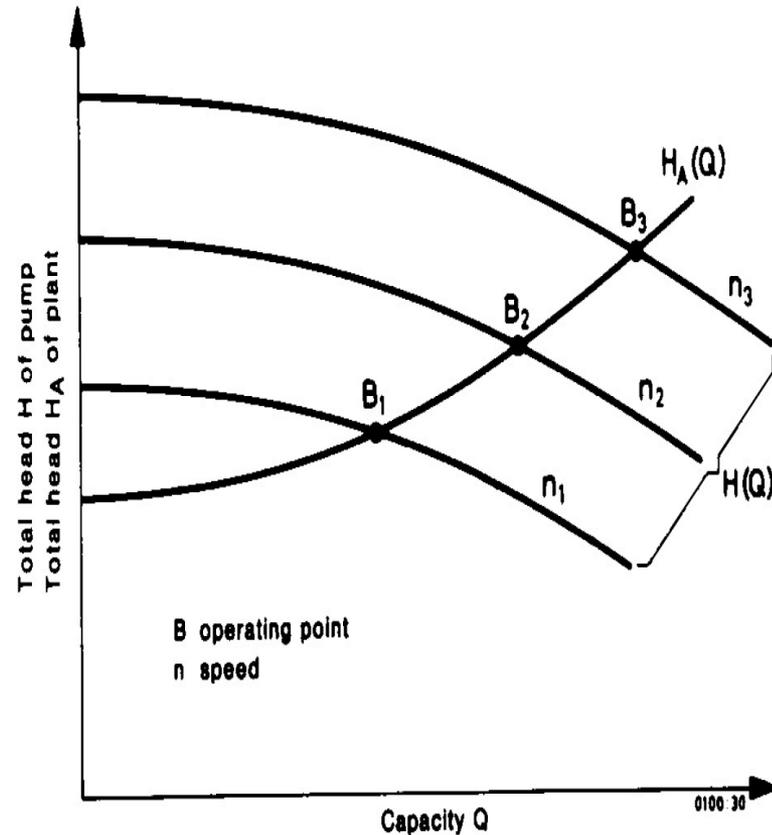
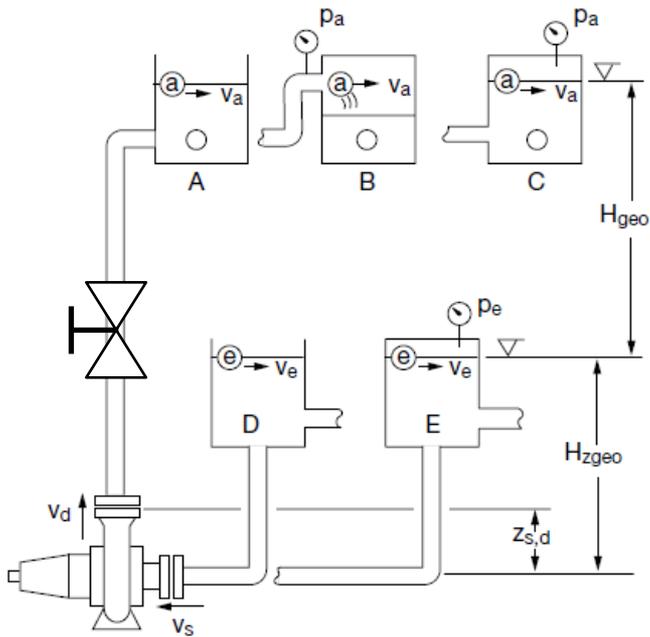


$$l_p = gH = gH_A = R + \frac{V_a^2 - V_e^2}{2} + g(z_a - z_e) + \frac{p_a - p_e}{\rho}$$



Regolazione della portata mediante chiusura della valvola alla mandata

$$l_p = gH = gH_A = R + \frac{V_a^2 - V_e^2}{2} + g(z_a - z_e) + \frac{p_a - p_e}{\rho}$$



Regolazione della portata mediante variazione della velocità di rotazione

Cavitazione: *galleria*

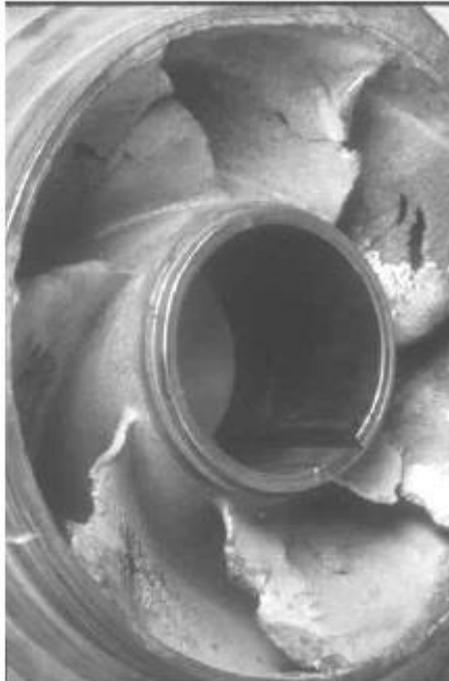
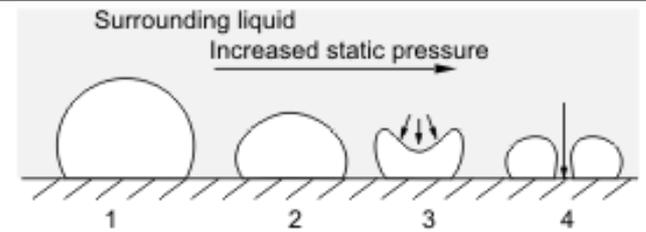
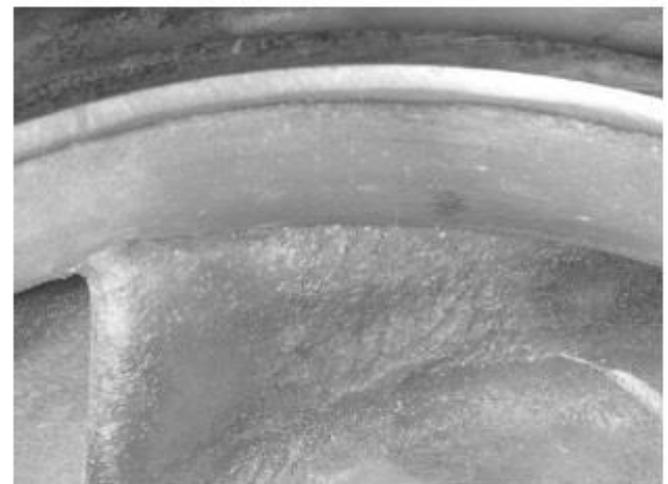
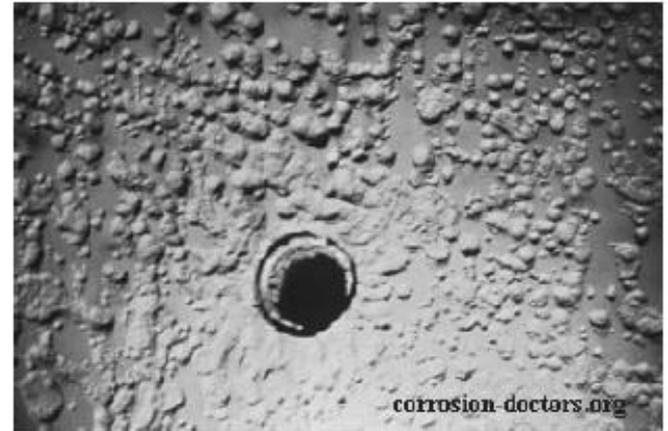
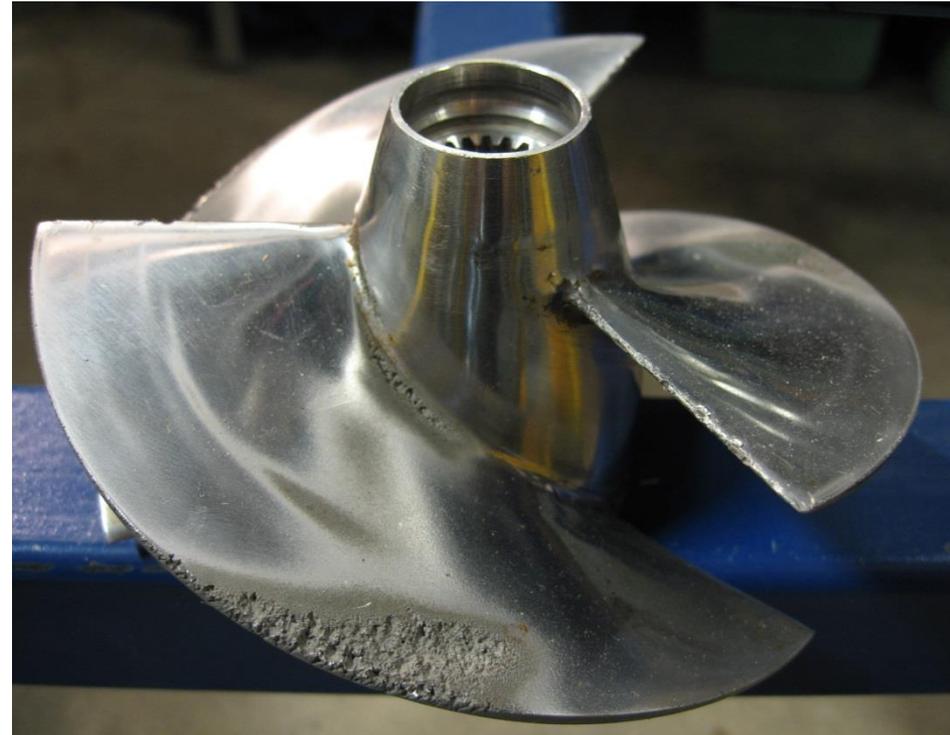
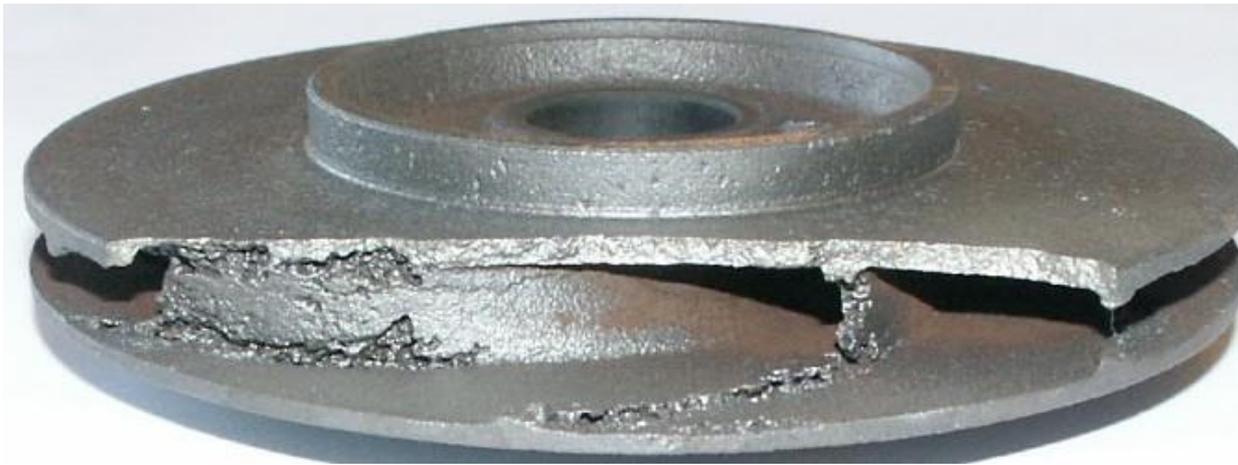


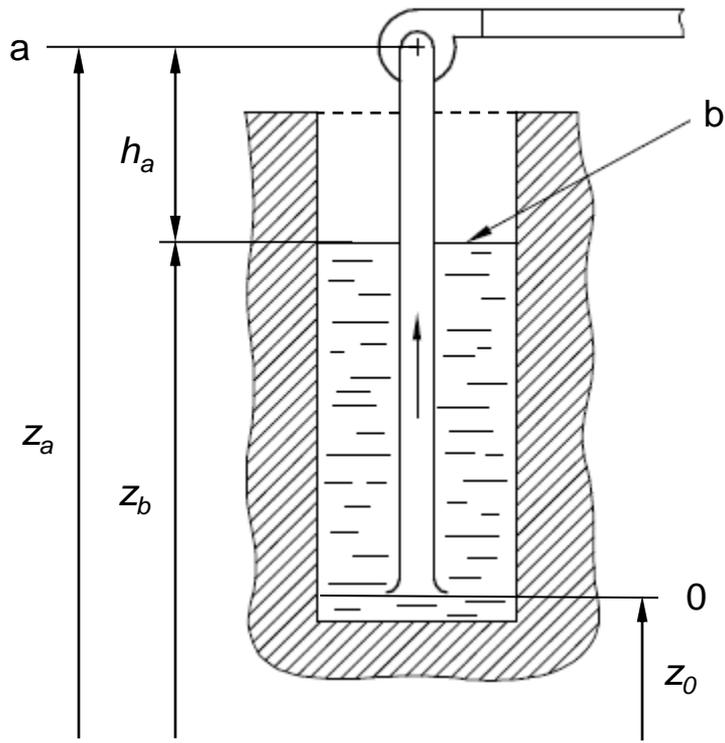
Figure 34 Cavitation on the leading edge, suction side of a runner
Muller, Parker Durr, *Archives*. Bureau of Engineering photo.



Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.







$$\frac{V_0^2}{2} + \frac{p_0}{\rho} + g z_0 = \frac{V_a^2}{2} + \frac{p_a}{\rho} + g z_a + R_{0-a}$$

$$V_0 \ll V_a$$

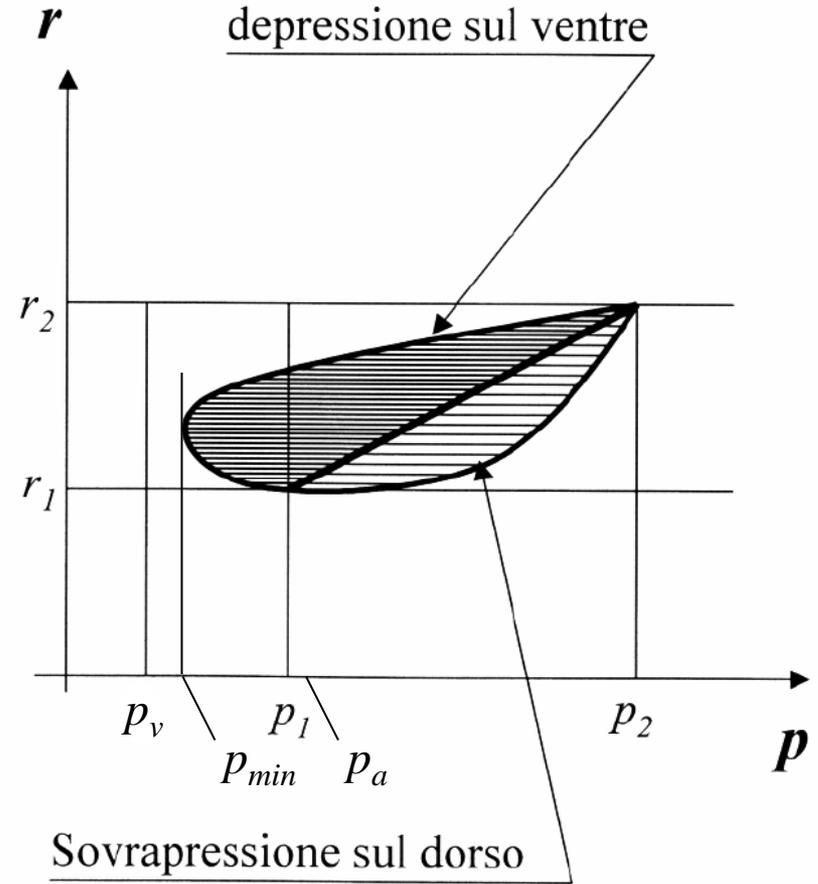
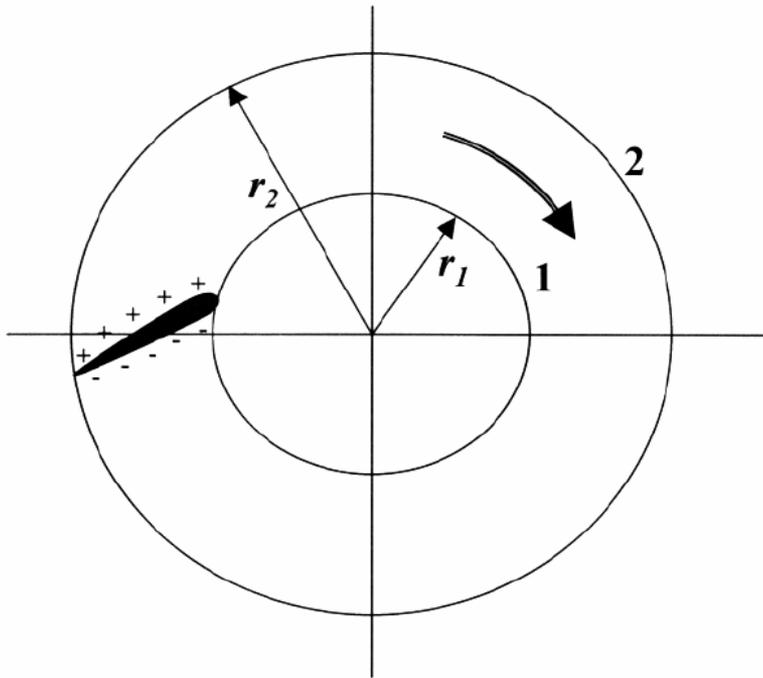


$$\frac{p_0}{\rho} + g z_0 = \frac{V_a^2}{2} + \frac{p_a}{\rho} + g z_a + R_{0-a}$$

$$\frac{p_0}{\rho} + g z_0 = \frac{p_b}{\rho} + g z_b \quad \rightarrow \quad \frac{p_a}{\rho} = \frac{p_b}{\rho} - g(z_a - z_b) - \frac{V_a^2}{2} - R_{0-a}$$

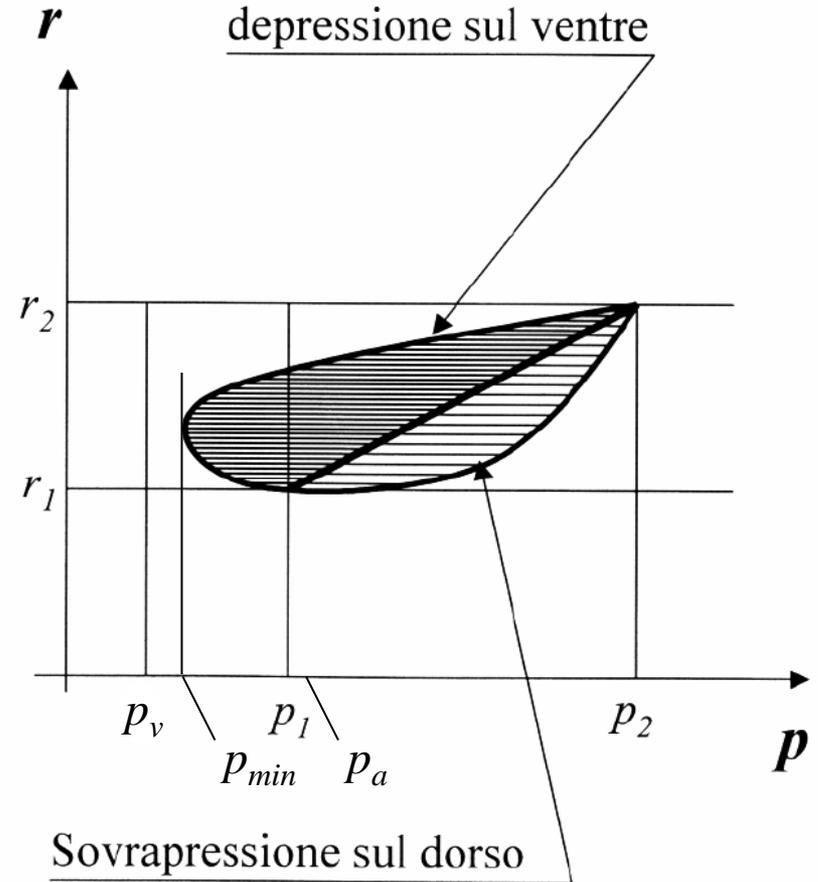
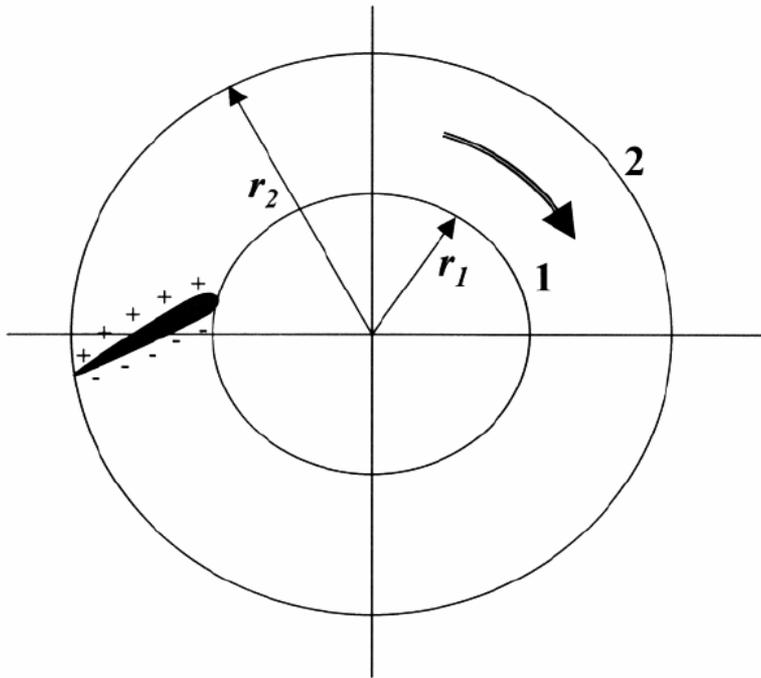


$$\frac{p_a}{\rho g} = \frac{p_b}{\rho g} - \left(h_a + \frac{V_a^2}{2g} + \frac{R_{0-a}}{g} \right)$$



$$\frac{p_{min}}{\rho g} + \frac{V_{p_{min}}^2}{2g} + \frac{R_{a-p_{min}}}{g} = \frac{p_a}{\rho g} + \frac{V_a^2}{2g}$$

Condizione al limite della cavitazione



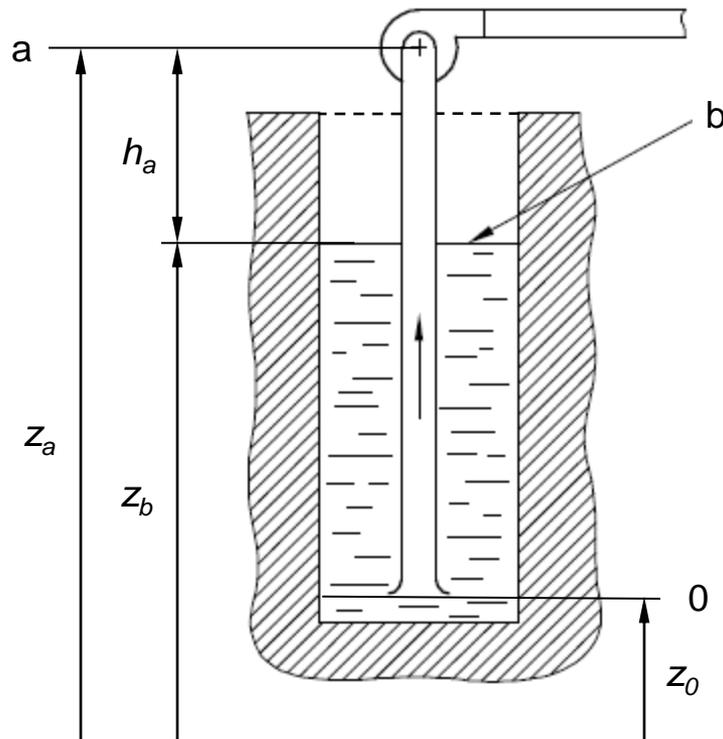
$$p_{min} = p_v \rightarrow \left(\frac{p_a}{\rho g} + \frac{V_a^2}{2g} \right)_{lim} = \frac{p_v}{\rho g} + \left(\frac{V_{p_{min}}^2}{2g} + \frac{R_{a-p_{min}}}{g} \right)_{lim}$$

NPSH_r – Net Positive Suction Head *required*

$$p_{min} = p_v \rightarrow \left(\frac{p_a}{\rho g} + \frac{V_a^2}{2g} \right)_{lim} = \frac{p_v}{\rho g} + \left(\frac{V_{p_{min}}^2}{2g} + \frac{R_{a-p_{min}}}{g} \right)_{lim}$$

$$NPSH_r = NPSH_{lim} = \left(\frac{p_a - p_v}{\rho g} + \frac{V_a^2}{2g} \right)_{lim} = \left(\frac{V_{p_{min}}^2}{2g} + \frac{R_{a-p_{min}}}{g} \right)_{lim}$$

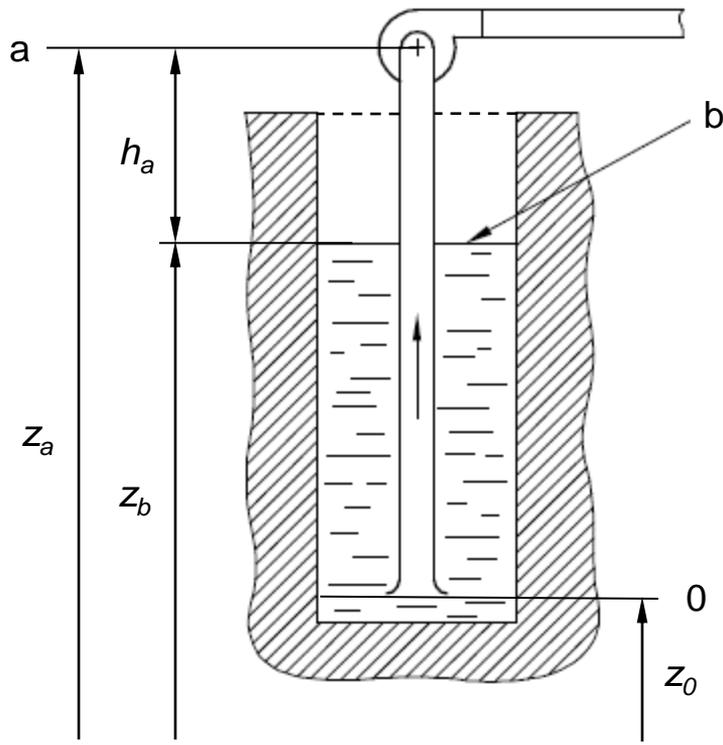
$NPSH_a$ – Net Positive Suction Head *available*



$$\frac{p_a}{\rho g} = \frac{p_b}{\rho g} - (z_a - z_b) - \frac{V_a^2}{2g} - \frac{R_{0-a}}{g}$$

$$NPSH_a = \frac{p_a - p_v}{\rho g} + \frac{V_a^2}{2g} = \frac{p_b - p_v}{\rho g} - (z_a - z_b) - \frac{R_{0-a}}{g}$$

Condizione affinché la pompa non cavi



$$\frac{p_a}{\rho g} = \frac{p_b}{\rho g} - (z_a - z_b) - \frac{V_a^2}{2g} - \frac{R_{0-a}}{g}$$

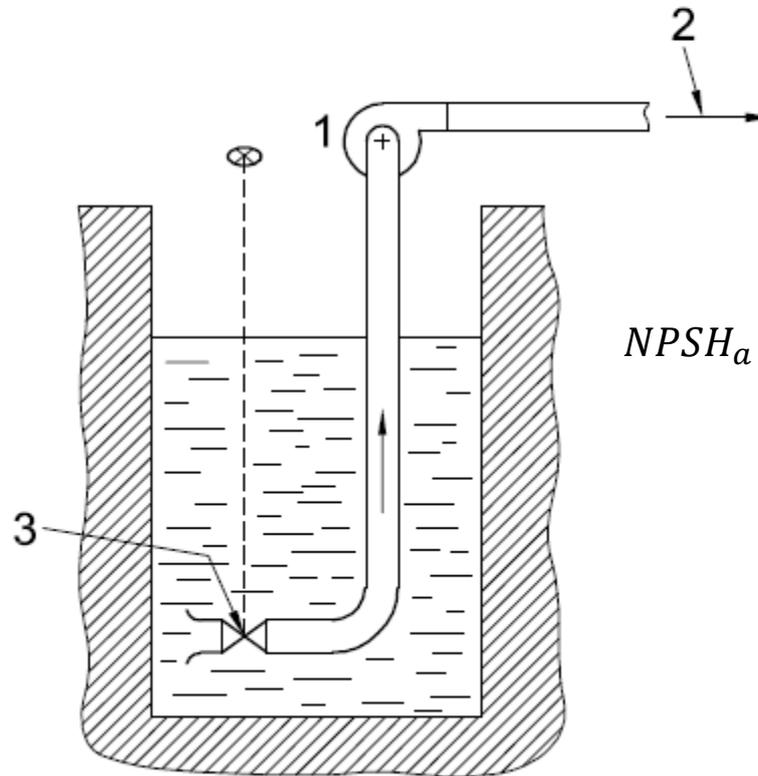
$$NPSH_a = \frac{p_b - p_v}{\rho g} - (z_a - z_b) - \frac{R_{0-a}}{g} > NPSH_r$$

Norma UNI EN ISO 9906 - 2002

Prove di cavitazione: Variazione dell'NPSH mediante una valvola di regolazione della pressione di aspirazione

Legenda

- 1 Pompa di prova
- 2 Alla valvola di regolazione del flusso e al flussometro
- 3 Valvola di regolazione della pressione di aspirazione



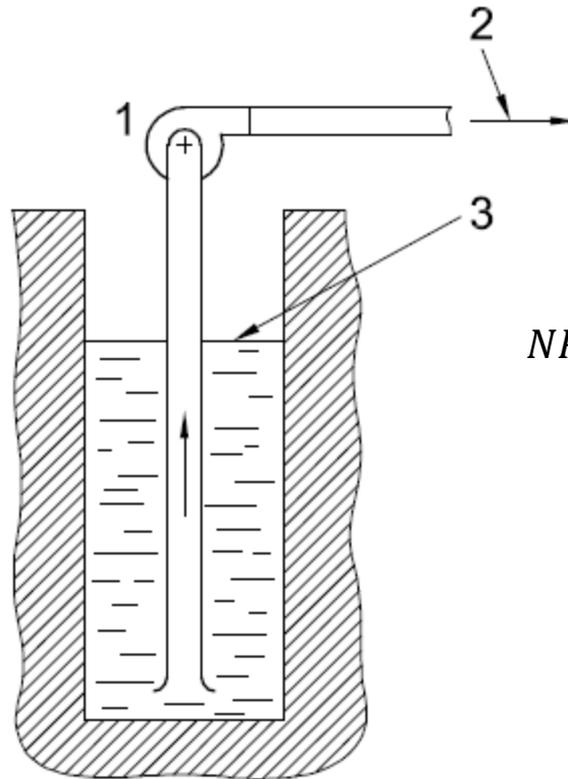
$$NPSH_a = \frac{p_b - p_v}{\rho g} - (z_a - z_b) - \frac{R_{0-a}}{g}$$

Norma UNI EN ISO 9906 - 2002

Prove di cavitazione: Variazione dell'NPSH mediante regolazione del livello del liquido nella vasca di aspirazione

Legenda

- 1 Pompa di prova
- 2 Alla valvola di regolazione del flusso e al flussometro
- 3 Livello dell'acqua regolabile



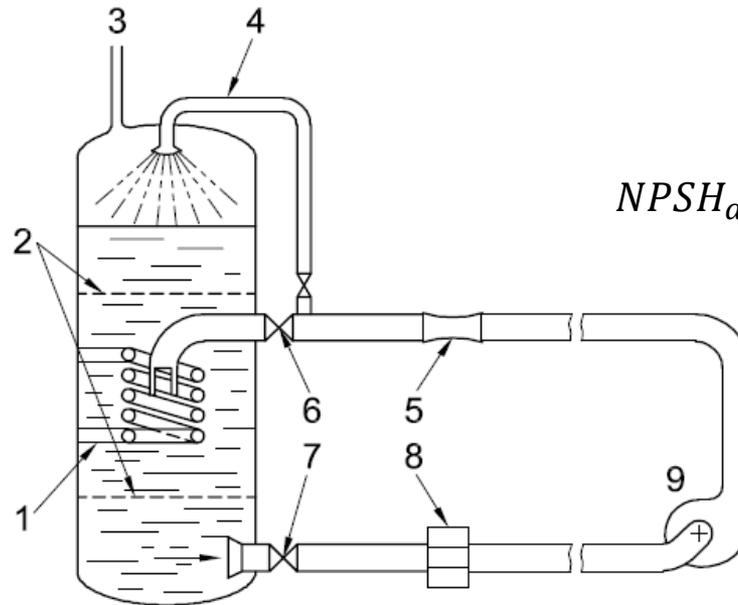
$$NPSH_a = \frac{p_b - p_v}{\rho g} - (z_a - z_b) - \frac{R_{0-a}}{g}$$

Norma UNI EN ISO 9906 - 2002

Prove di cavitazione: Variazione dell'NPSH in circuito chiuso con regolazione della pressione e/o della temperatura

Legenda

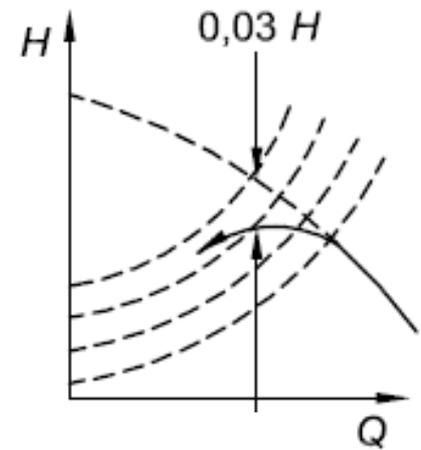
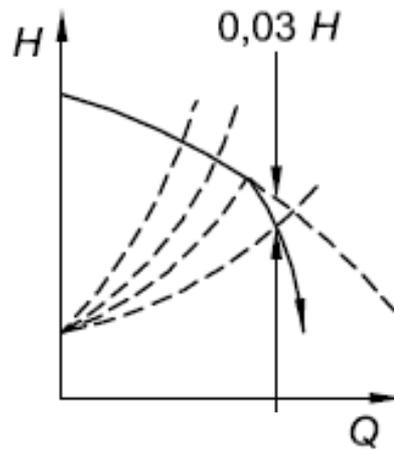
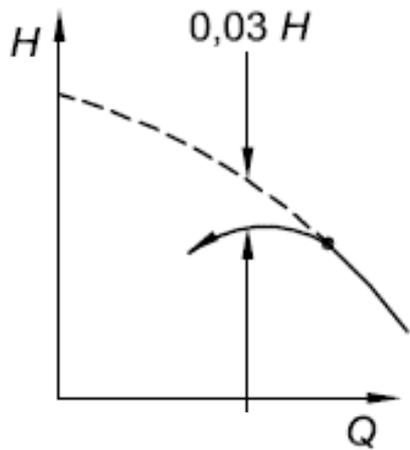
- 1 Serpentini di raffreddamento o di riscaldamento
- 2 Schermi di calma
- 3 Al vuoto o alla regolazione della pressione
- 4 Spruzzatore per la disaerazione del liquido
- 5 Flussometro
- 6 Valvola di regolazione del flusso
- 7 Valvola di intercettazione
- 8 Punto di misura per il contenuto di gas
- 9 Pompa di prova



$$NPSH_a = \frac{p_b - p_v}{\rho g} - (z_a - z_b) - \frac{R_{0-a}}{g}$$

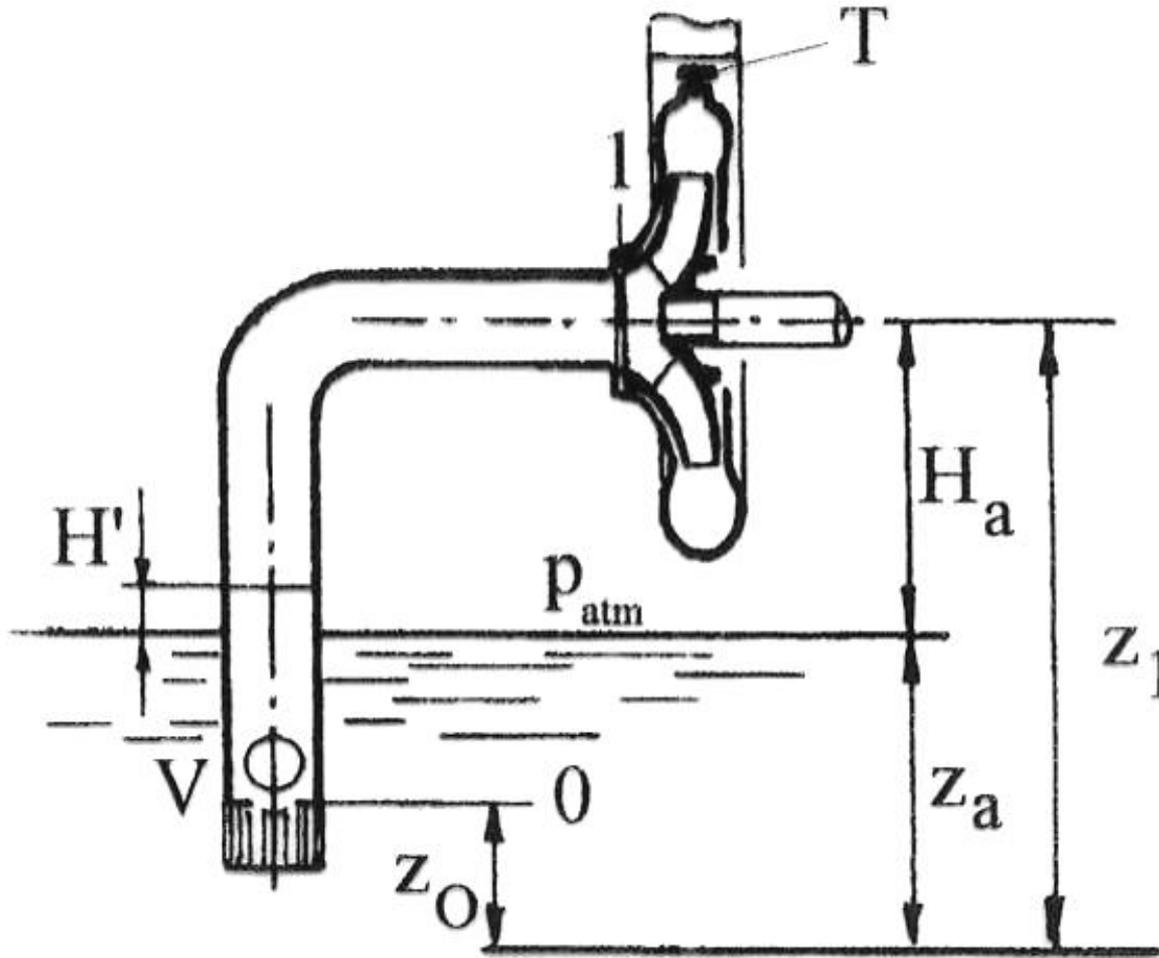
Nota Il raffreddamento mediante serpentino può essere sostituito da un'iniezione di acqua fresca sopra la superficie libera del liquido e dall'estrazione dell'acqua riscaldata.

Norma UNI EN ISO 9906 - 2002



Variabile indipendente	Valvola di strozzamento di entrata	Valvola di strozzamento di uscita	Livello dell'acqua
Costante	Valvola di strozzamento di uscita	Valvola di strozzamento di entrata	Valvole di strozzamento di entrata e di uscita
Grandezze la cui variazione dipende dalla regolazione	Altezza totale, portata, NPSHA, livello dell'acqua	Altezza totale, portata, NPSHA, livello dell'acqua	Altezza totale, portata, NPSHA

Adescamento



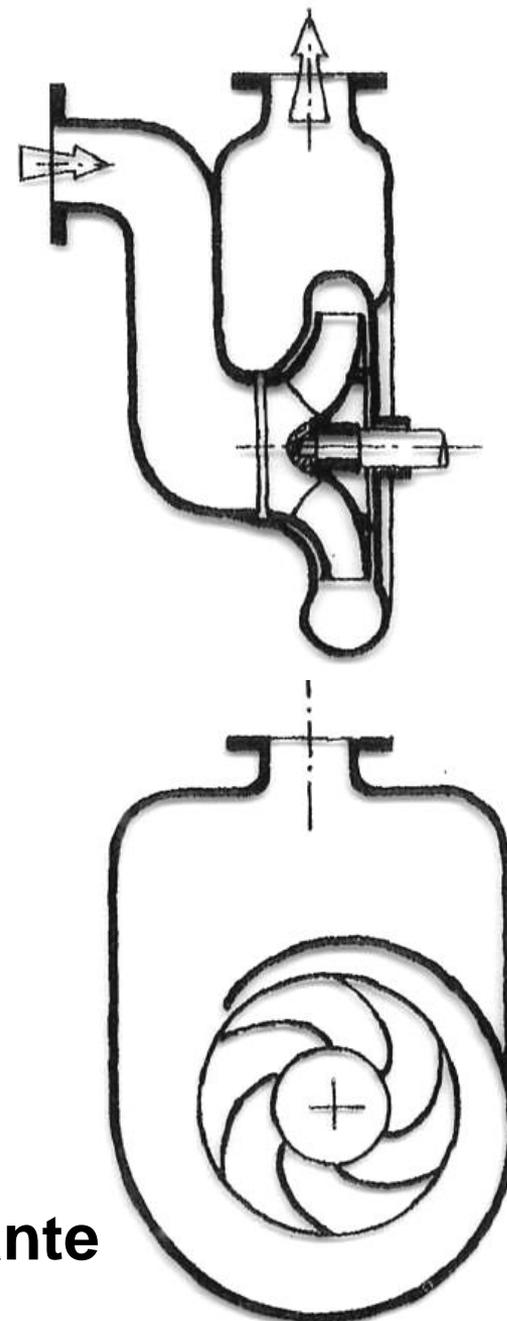
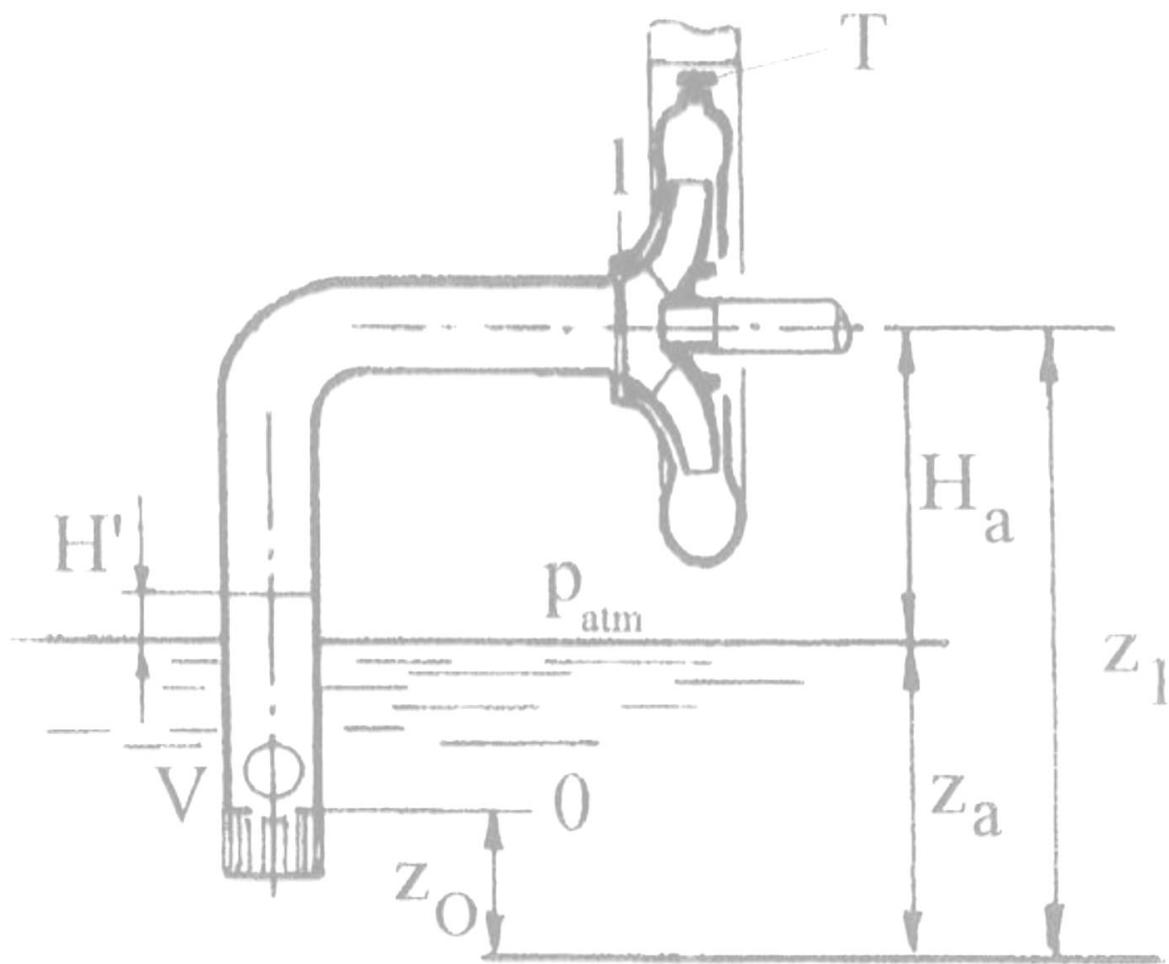
$$gH = \frac{\Delta p_{acqua}}{\rho_{acqua}} \cong \frac{\Delta p_{aria}}{\rho_{aria}}$$

$$\Delta p_{aria} = \frac{\rho_{aria}}{\rho_{acqua}} \Delta p_{acqua}$$

$$\Delta p_{aria} = \rho_{aria} gH = \rho_{acqua} gH'$$

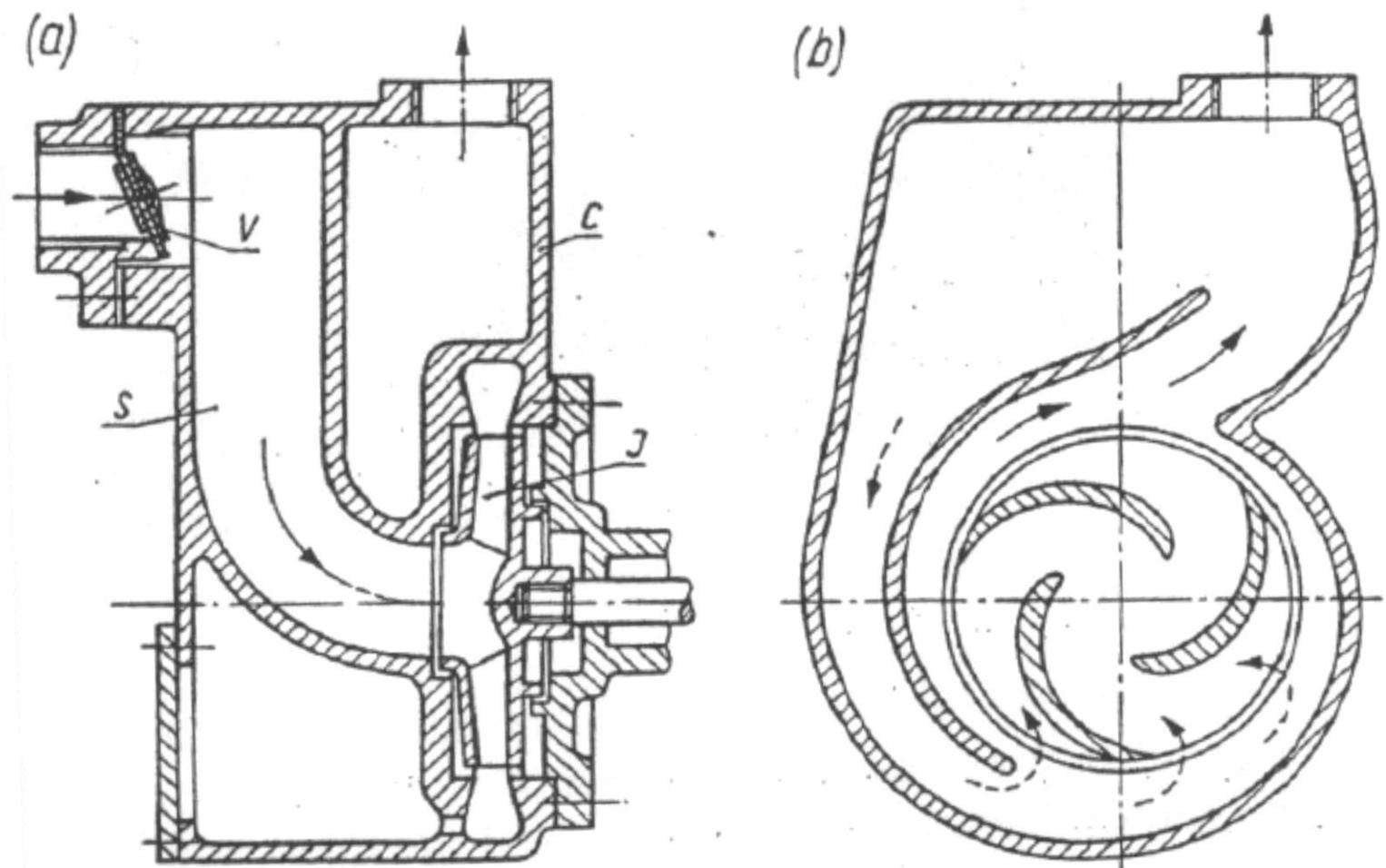
$$H' = \frac{\rho_{aria}}{\rho_{acqua}} H$$

Adescamento



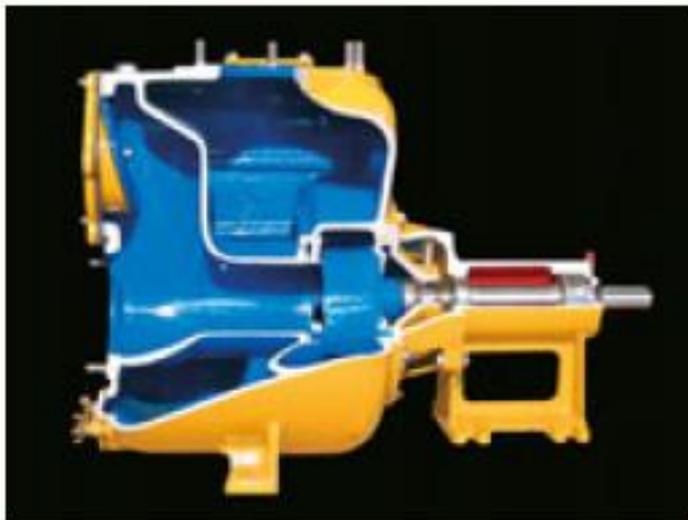
Pompa centrifuga autoadescante

Pompa centrifuga autoadescante "solid handling"



Self-priming centrifugal pump with double volute: (a) longitudinal section, (b) cross-section (INGERSOLL-RAND);
C — casing, J — impeller, S — suction chamber, V — non-return valve.

Pompa centrifuga autoadescante "solid handling"



Pompa centrifuga autoadescante "solid handling"

