



Univerzitet u Beogradu – Građevinski fakultet
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Studijski program: **Građevinarstvo**
Modul: **HVE**
Godina/Semestar: **III godina / V semestar**

Naziv predmeta (šifra): **Hidraulika 1 (B2H3H1)**

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doc. dr Robert Ljubičić **doc. dr Anja Ranđelović**

Naslov predavanja: **Vežba 2: pumpe (i turbine)**

Datum : 25.10.2022.

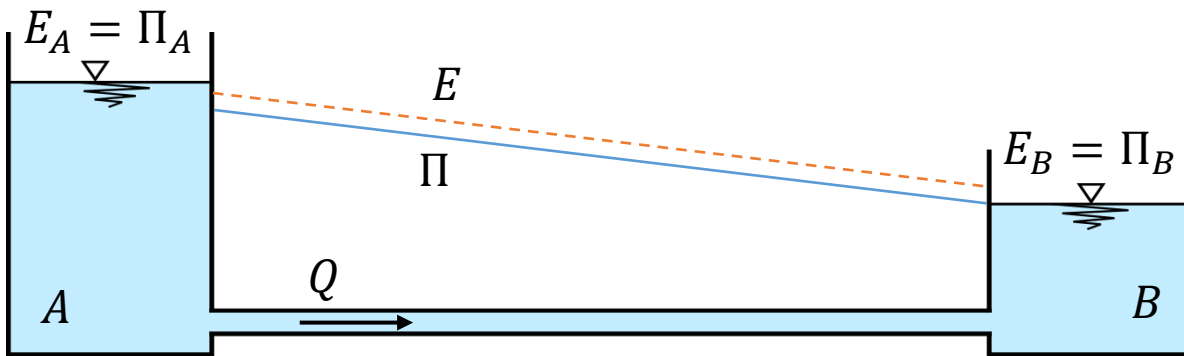
Beograd, 2022.

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PUMPE

Uloga pumpi u sistemima pod pritiskom

- Fluid se uvek kreće od mesta više energije ka mestu niže energije
→ tečenje izazvano gravitacijom; **gravitaciono oticanje vode** iz rez. A u rez. B
- Postoji samo **jedna vrednost protoka** Q koja zadovoljava energetska jednačinu



$$E_A = E_B + \Delta E_{A-B}$$

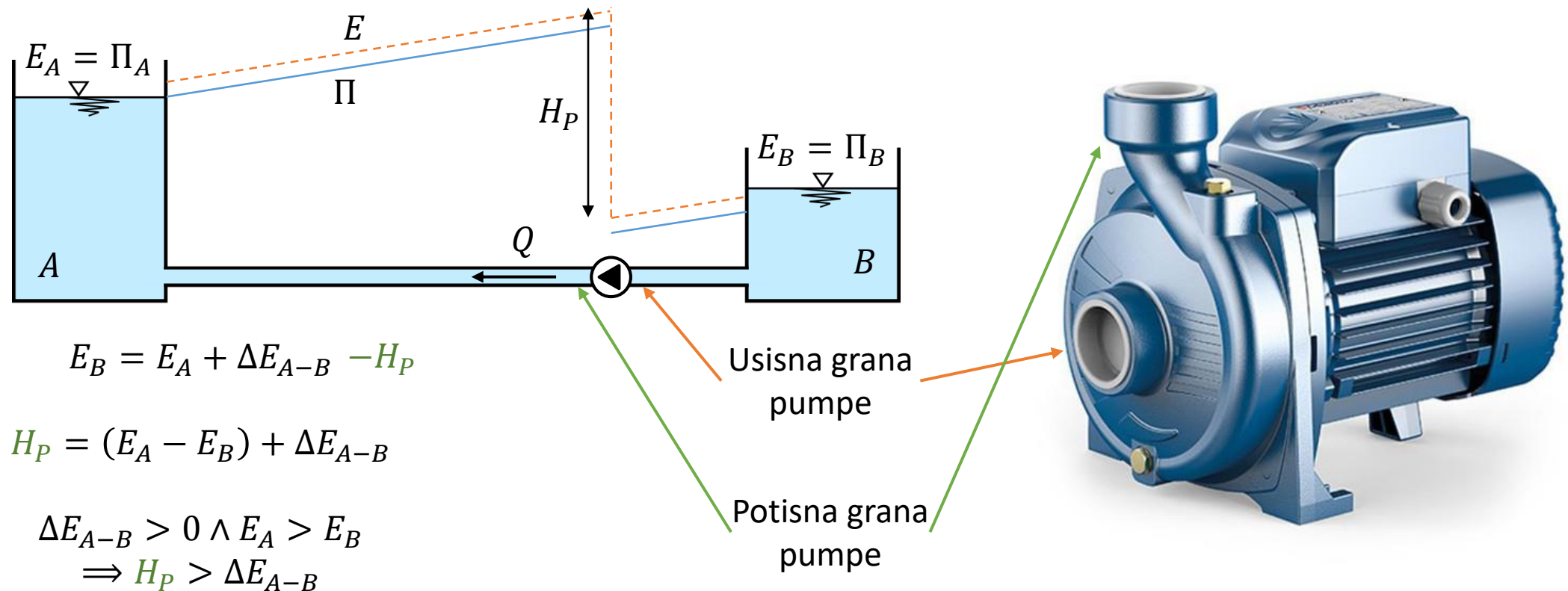
$$\Delta E_{A-B} > 0$$

$$E_A > E_B$$

Prevod energetske jednačine: **razlika energija u rezervoarima „troši“ se na savladavanje gubitaka**

Uloga pumpi u sistemima pod pritiskom

- Šta ako želimo da vodu pošaljemo u suprotnom smeru?
- **Pumpe “dodaju” mehaničku energiju fluidu**
- H_P - „**visina dizanja pumpe**“ (engl. *pump head*); količina mehaničke energije koju pumpa preda fluidu [m]



Vrste pumpi

- **Centrifugalna pumpa** (engl. *centrifugal pump, radial-flow pump*)
- Uobičajena u vodovodnim sistemima
- Visoke visine dizanja pri niskim i srednjim protocima

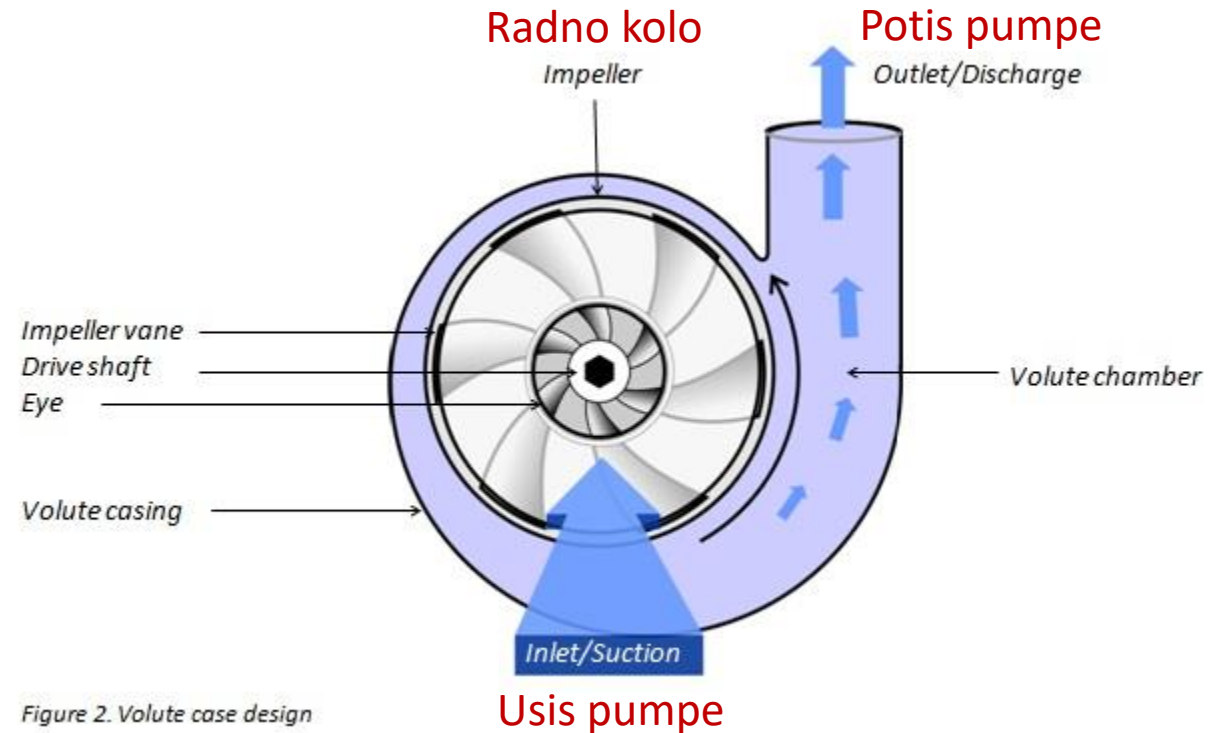
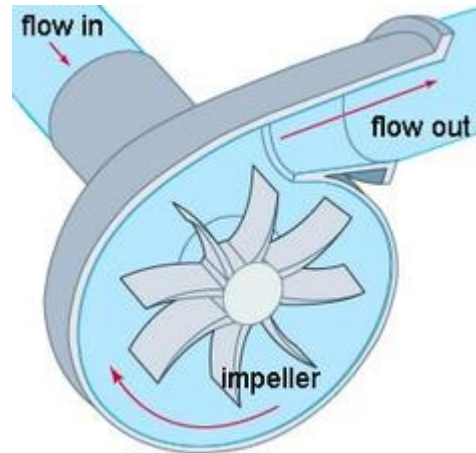
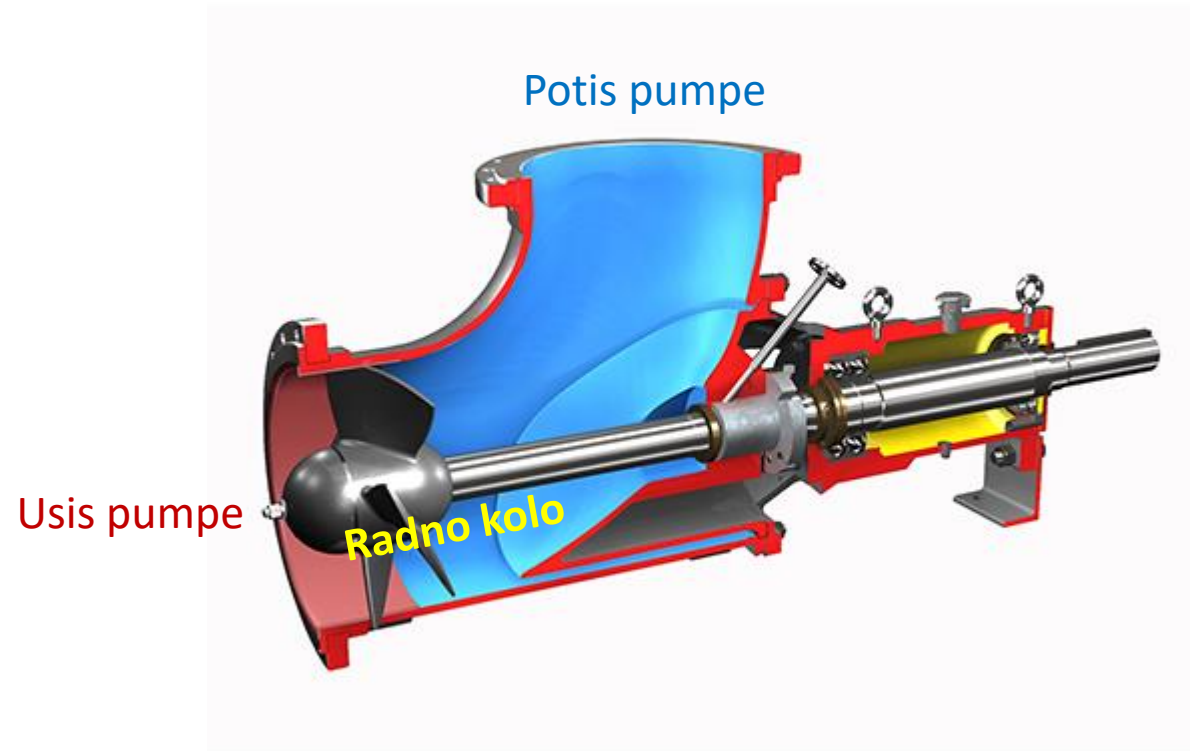


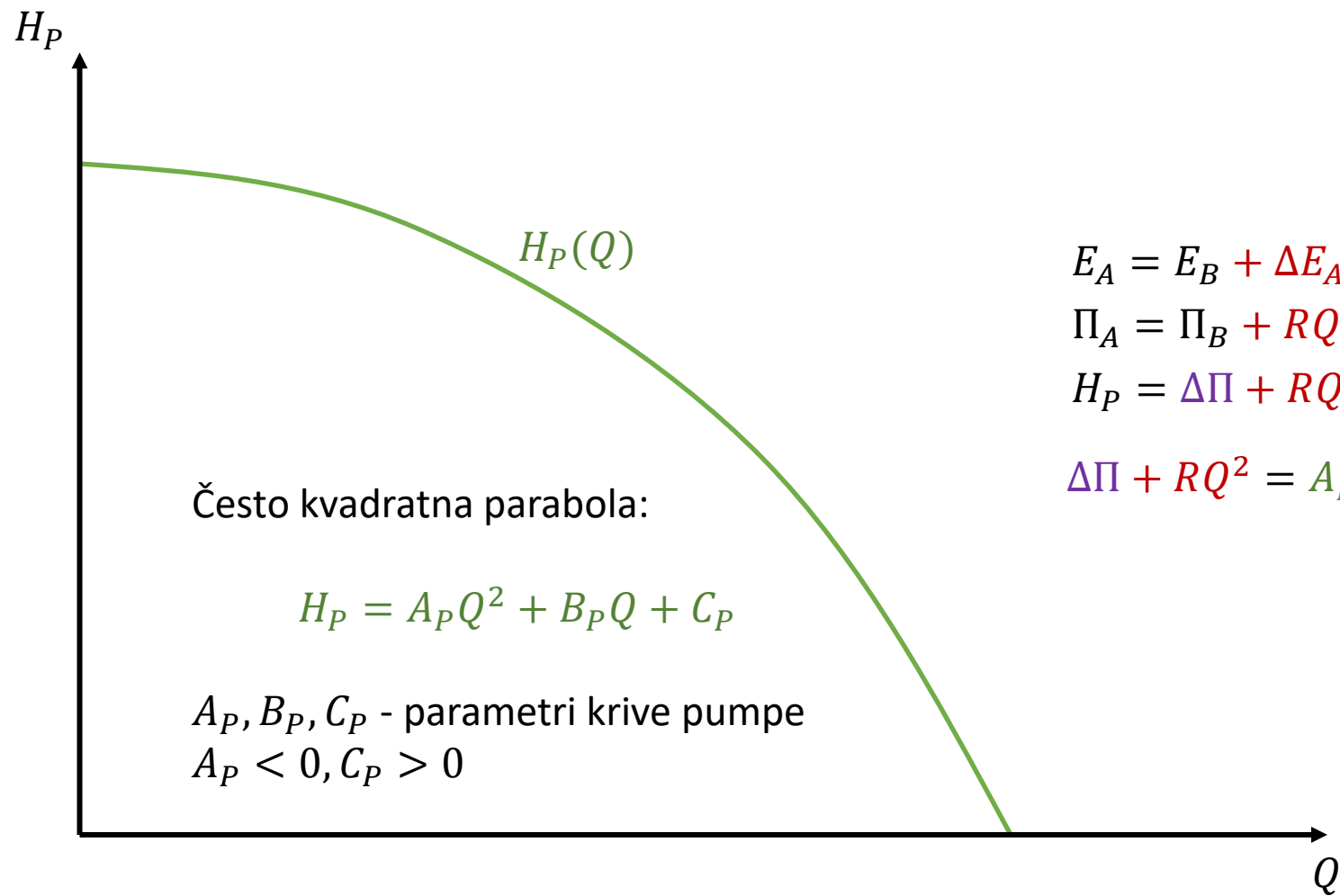
Figure 2. Volute case design

Vrste pumpi

- **Aksijalna pumpa** (engl. *axial-flow pump*)
- Industrijska primena
- Visok protok vode za relativno malu visinu dizanja



Radni dijagram pumpe, kriva pumpe



Često kvadratna parabola:

$$H_P = A_P Q^2 + B_P Q + C_P$$

A_P, B_P, C_P - parametri krive pumpe

$A_P < 0, C_P > 0$

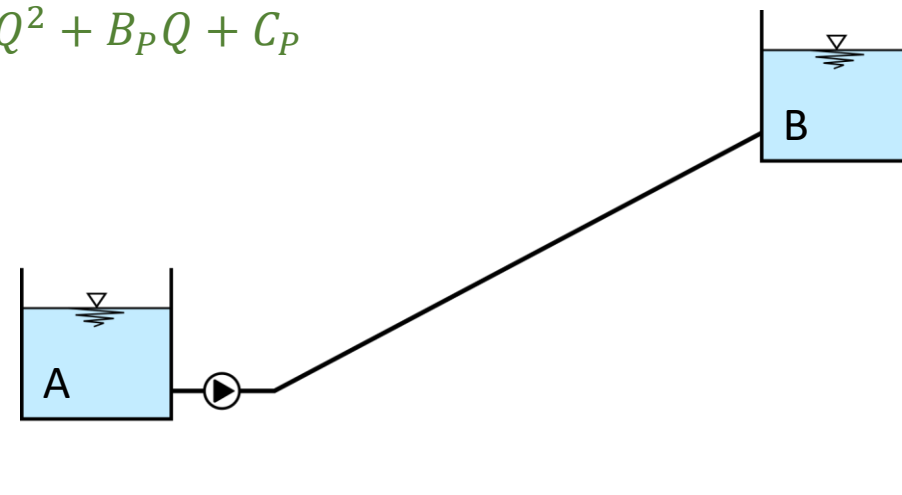
$$E_A = E_B + \Delta E_{A-B} - H_P$$

$$\Pi_A = \Pi_B + RQ^2 - H_P$$

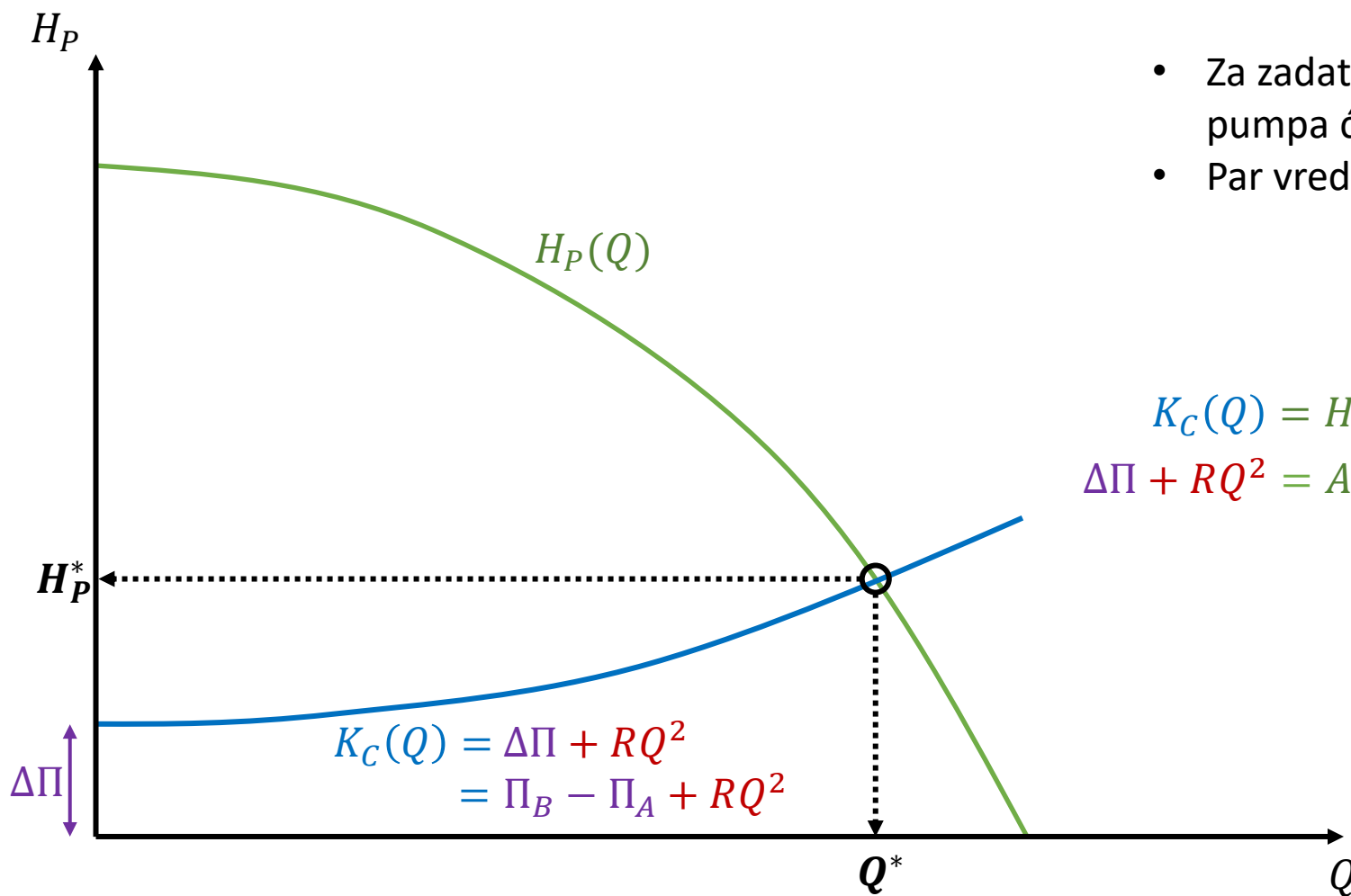
$$H_P = \Delta \Pi + RQ^2$$

$$\Delta \Pi + RQ^2 = A_P Q^2 + B_P Q + C_P$$

$$R = \frac{(\sum \xi + \sum \lambda \frac{L}{D})}{2gA^2}$$



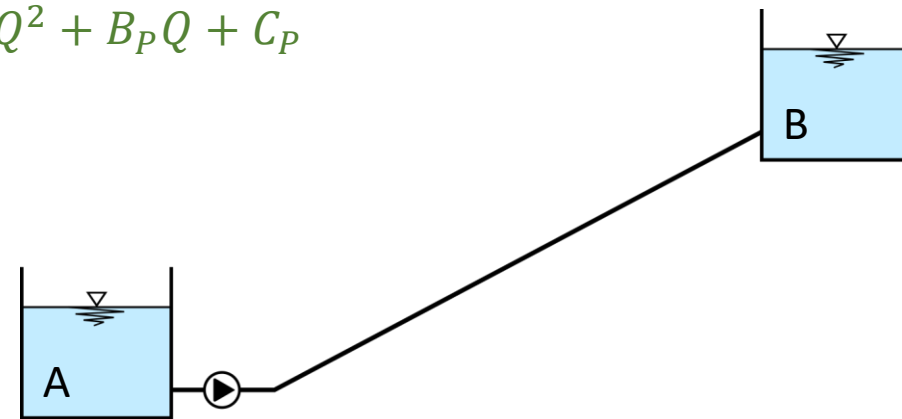
Kriva sistema (cevovoda), radna tačka pumpe



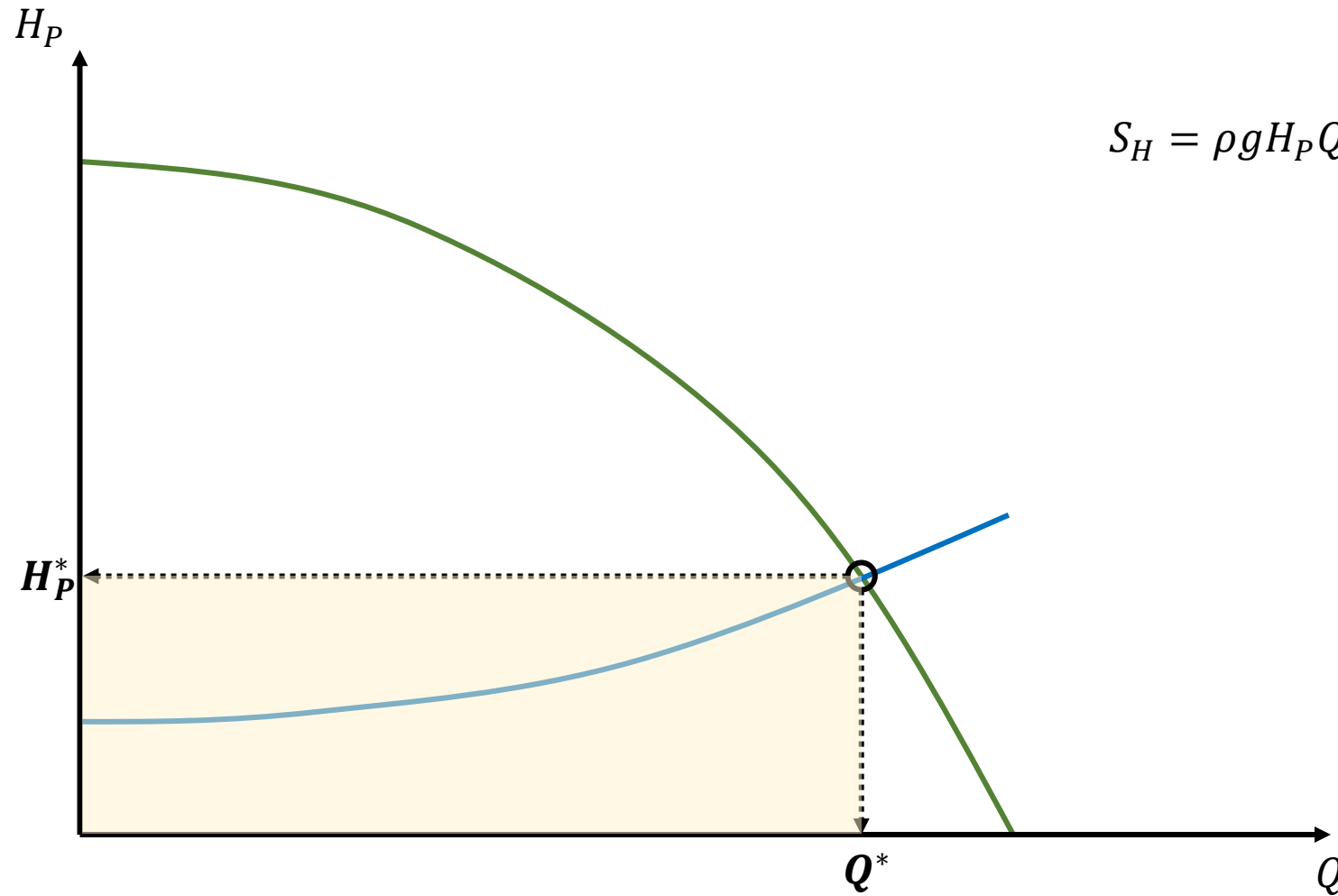
- Za zadate kote u rezervoarima i na datom cevovodu pumpa će imati visinu dizanja H_p^* pri protoku Q^*
- Par vrednosti (H_p^*, Q^*) predstavlja radnu tačku pumpe

$$K_C(Q) = H_p(Q) \text{ za } Q^* \text{ i } H_p^*$$

$$\Delta\Pi + RQ^2 = A_p Q^2 + B_p Q + C_p$$

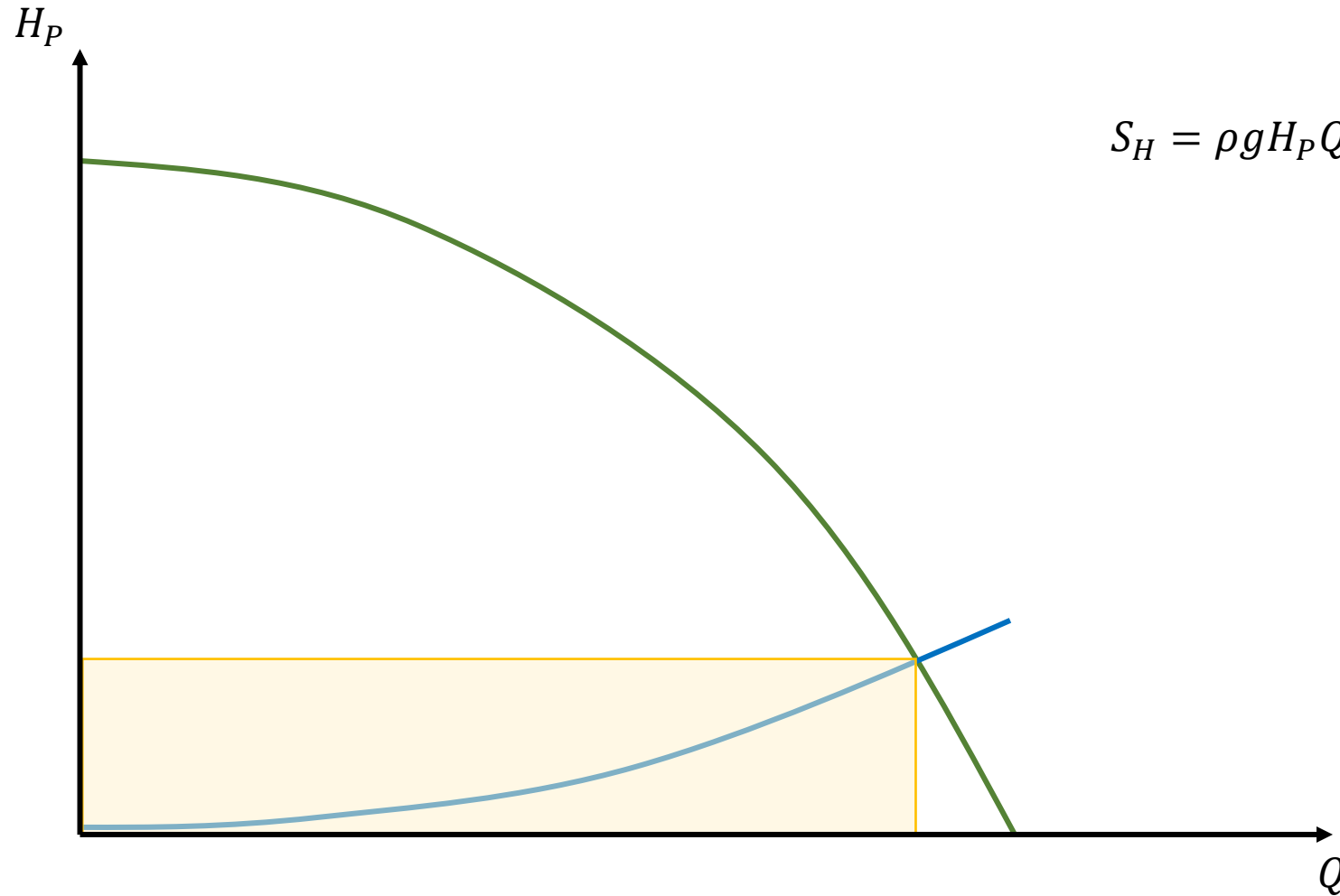


Hidraulička snaga



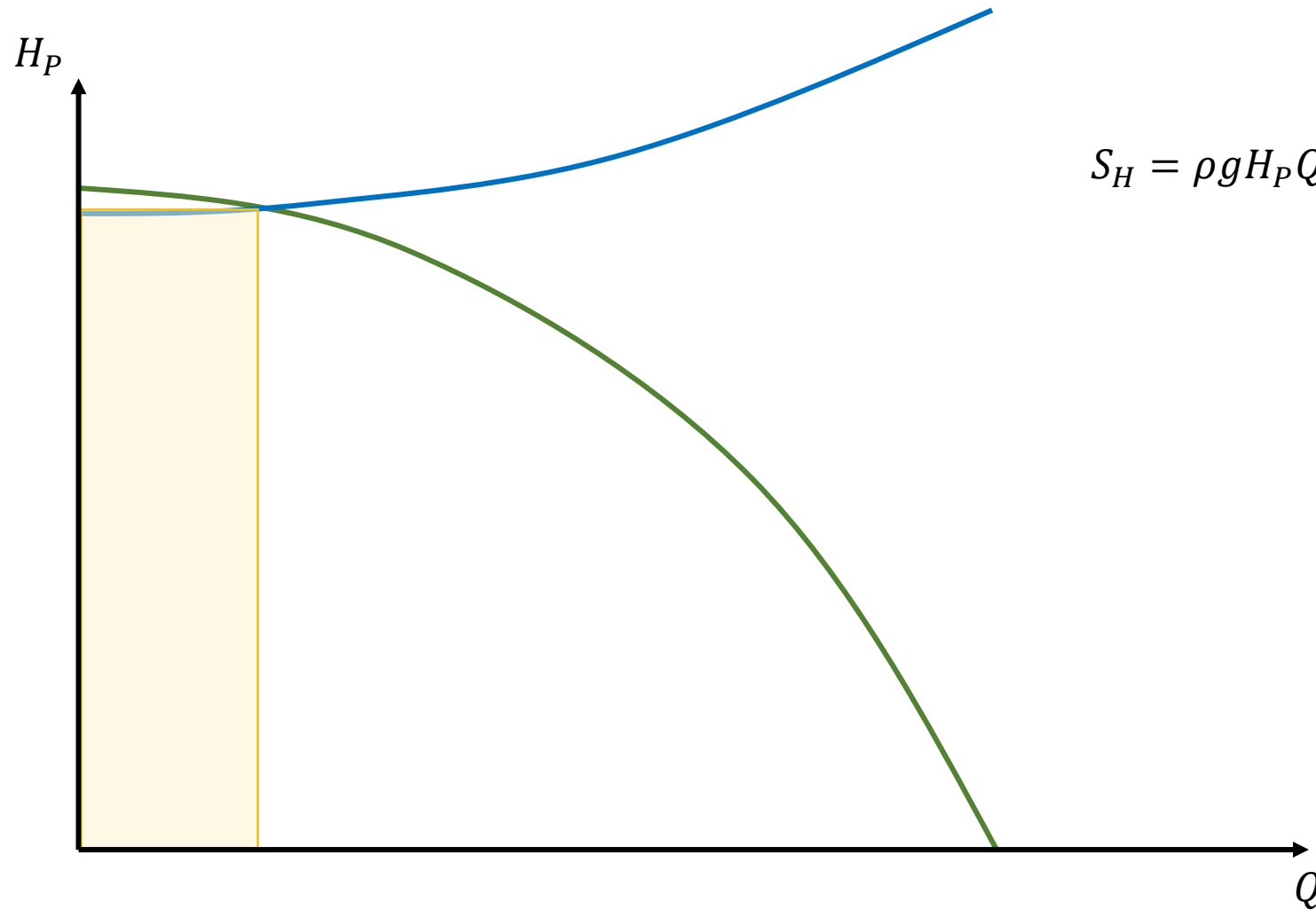
$$S_H = \rho g H_P Q \quad - \quad \text{hidraulička snaga predata fluidu [W]}$$

Hidraulička snaga



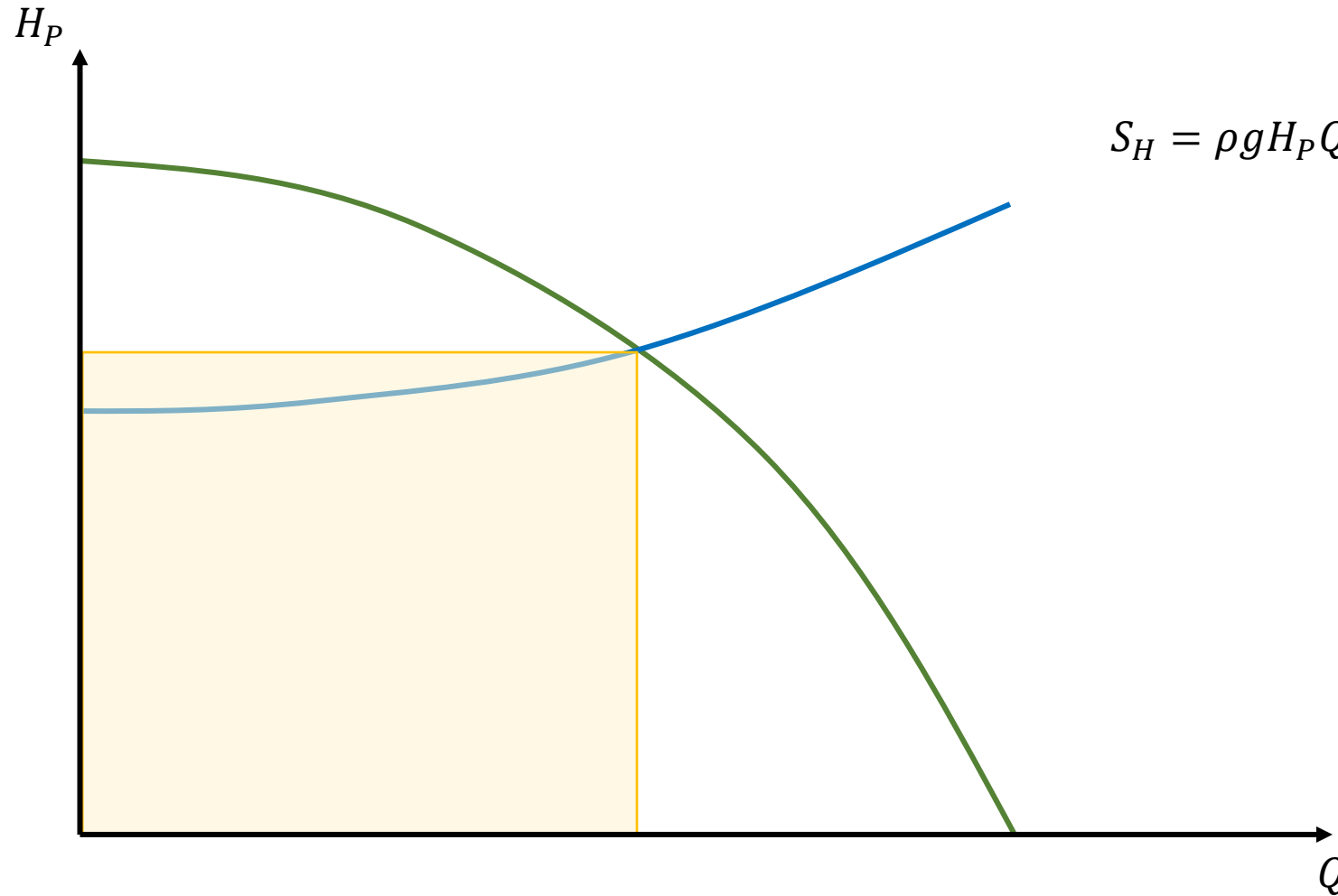
$$S_H = \rho g H_P Q \quad - \quad \text{hidraulička snaga predata fluidu [W]}$$

Hidraulička snaga



$$S_H = \rho g H_P Q \quad - \quad \text{hidraulička snaga predata fluidu [W]}$$

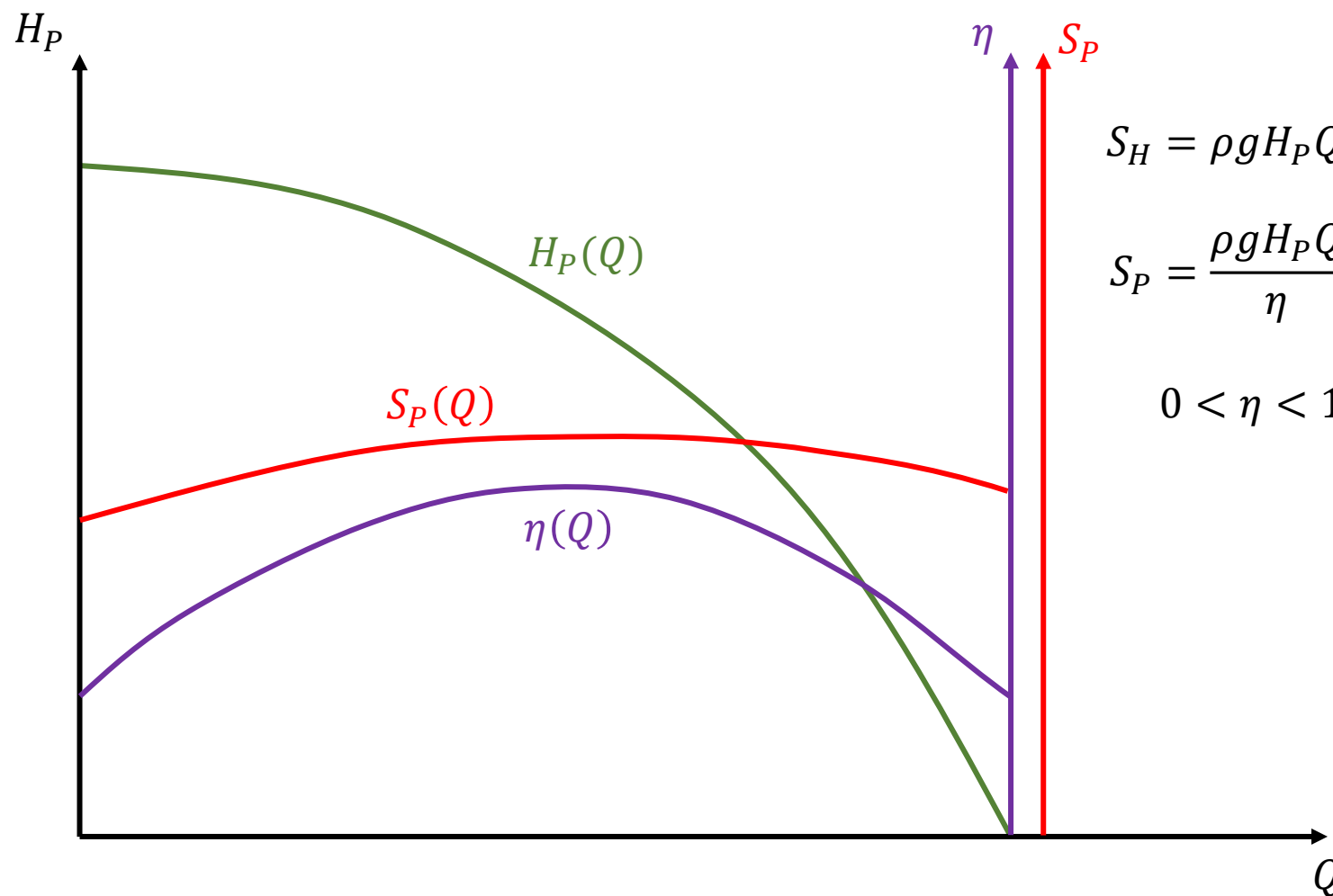
Hidraulička snaga



$$S_H = \rho g H_P Q \quad - \quad \text{hidraulička snaga predata fluidu [W]}$$

Snaga pumpe

- Pumpa ne poseduje istu **snagu**, a ni **efikasnost** rada pri svim protocima i visinama dizanja



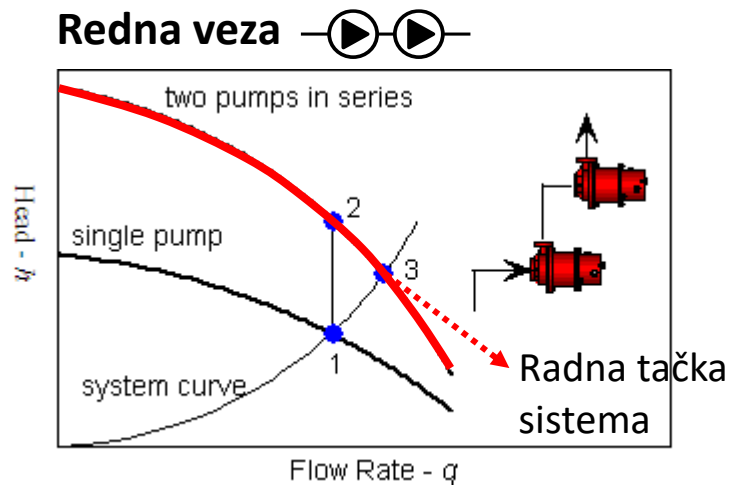
$S_H = \rho g H_P Q$ - hidraulička snaga predata fluidu [W]

$S_P = \frac{\rho g H_P Q}{\eta}$ - angažovana snaga pumpe [W]

$0 < \eta < 1$ - koeficijent korisnog dejstva, koeficijent efikasnosti pumpe [-]

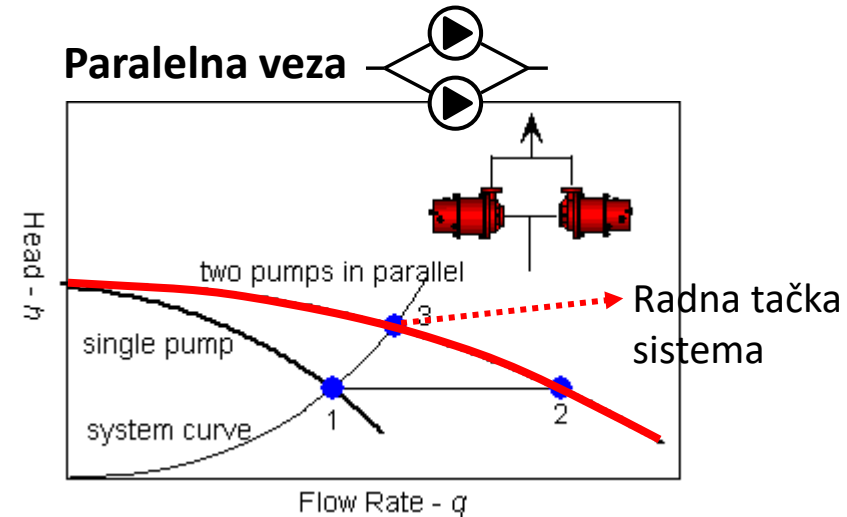
Pumpna postrojenja

- Nekad jedna pumpa nije dovoljna – **nedovoljan** protok Q , **nedovoljna** visina dizanja H_P
- **Povezivanje pumpi u sisteme** radi savladavanja tih ograničenja
- Dva osnovna načina povezivanja pumpi:
 1. Redno (serijska veza)
 2. Paralelno



$$H_{P,ukupno} = H_{P1} + H_{P2} = 2H_P$$

$$Q_{P1} = Q_{P2} = Q$$



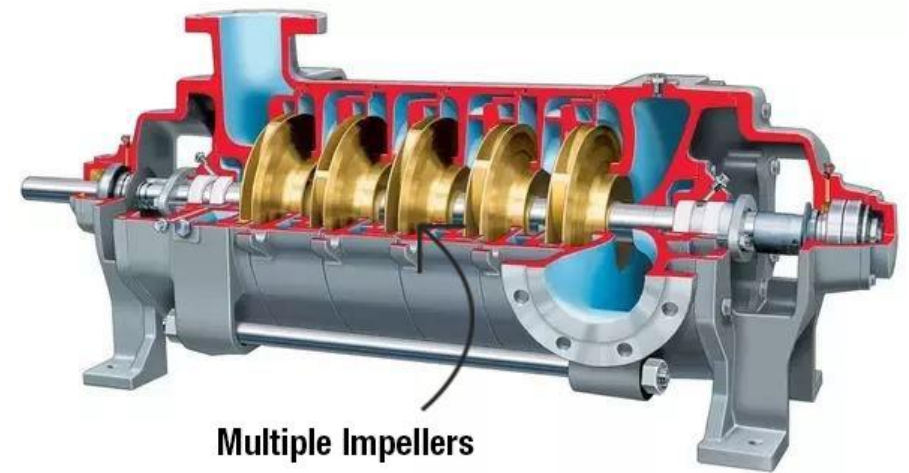
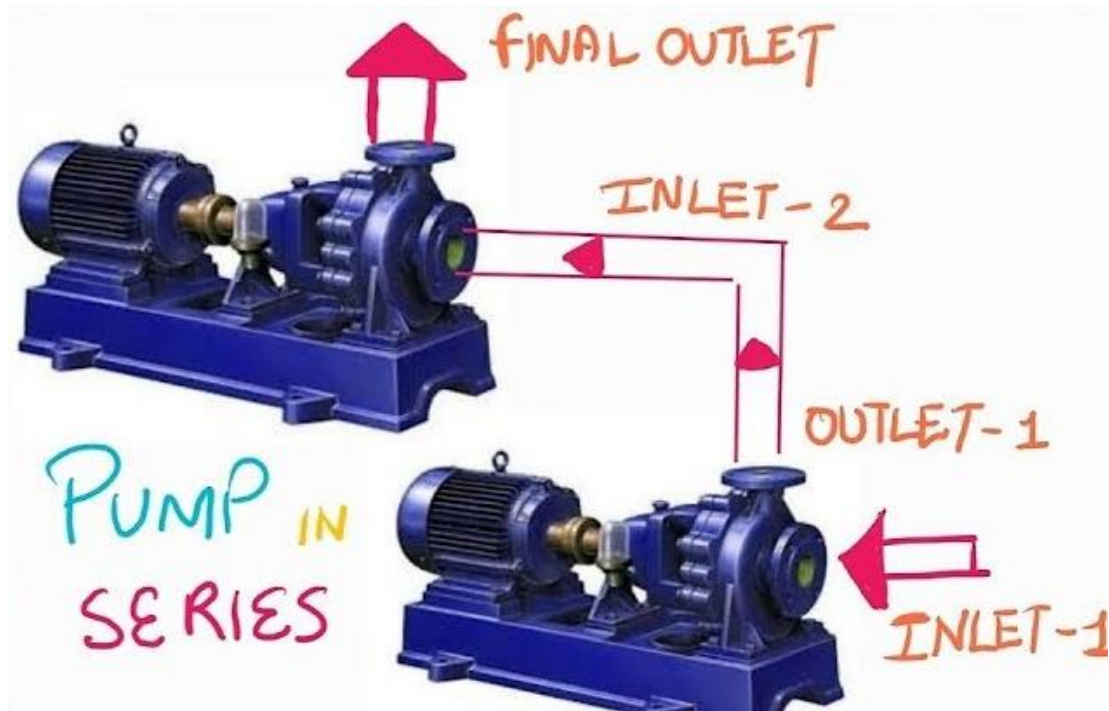
$$H_{P1} = H_{P2} = H_P$$

$$Q_{P,ukupno} = Q_{P1} + Q_{P2} = 2Q_P$$



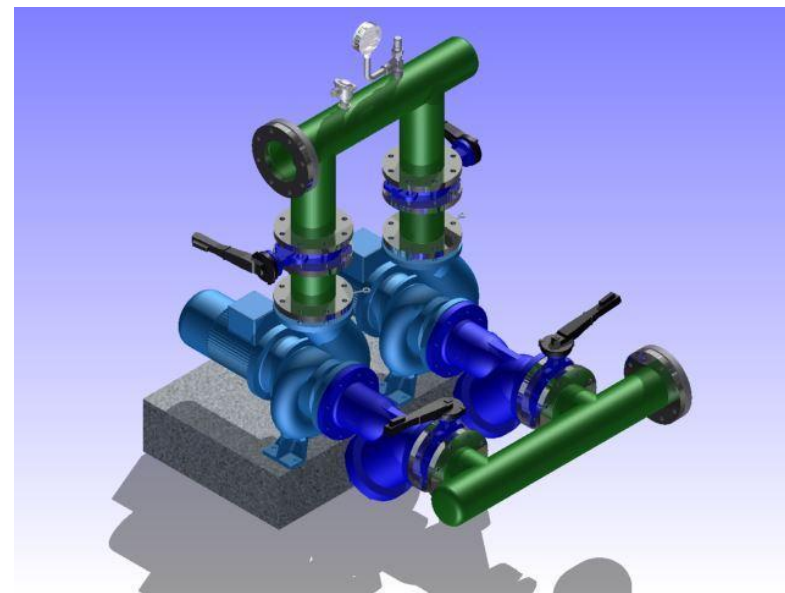
Redna veza pumpi, višestepene pumpe —▶▶—

- Povećanje učinka pojedinačnih pumpi
- Više radnih kola u istom kućištu – višestepena pumpa



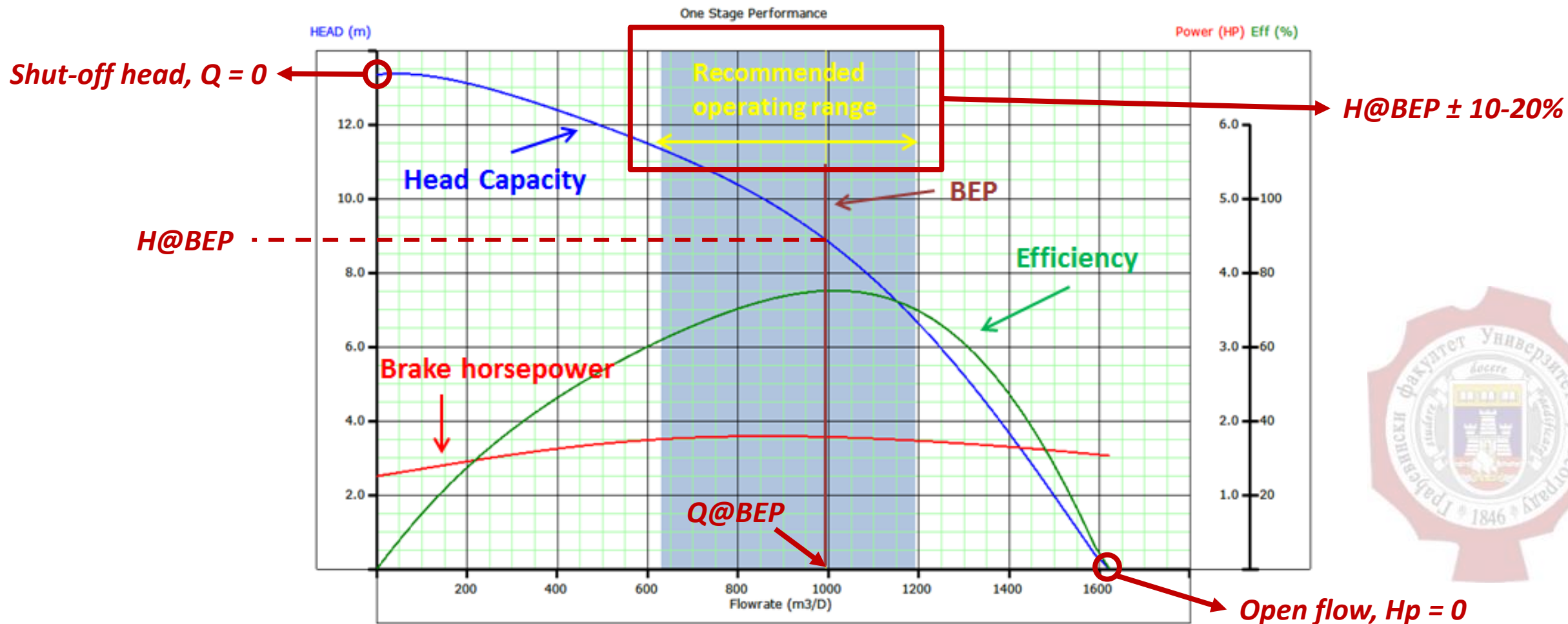
Paralelna veza pumpi

- Povećanje sigurnosti sistema u pogledu otkaza pojedinačnih pumpi
- Po potrebi se mogu paliti i gasiti pumpe



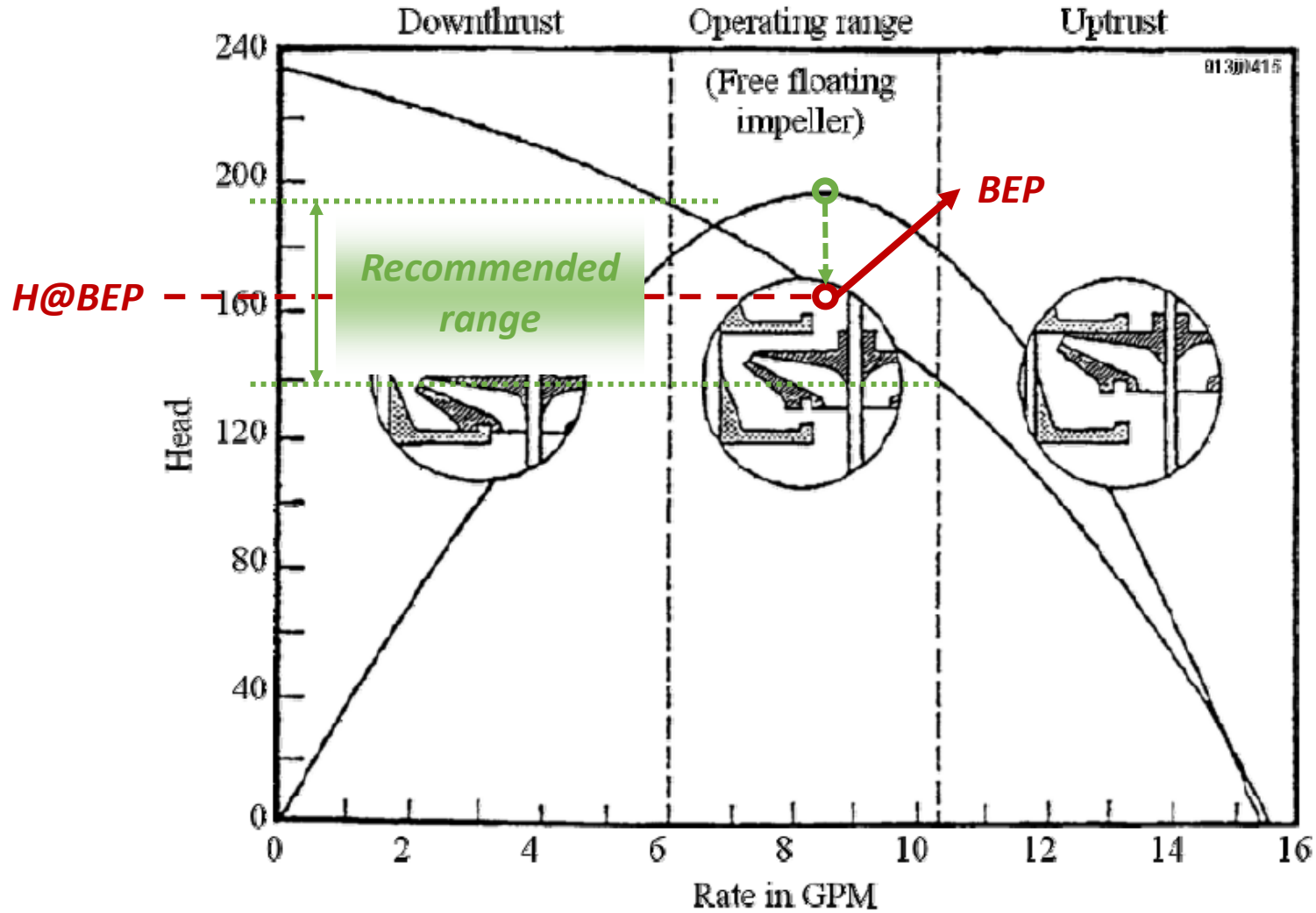
Kako odabrati pumpu?

- *Best efficiency point (BEP)* – tačka najveće efikasnosti pumpe
- *Best efficiency range (BER)* – opseg najveće efikasnosti pumpe



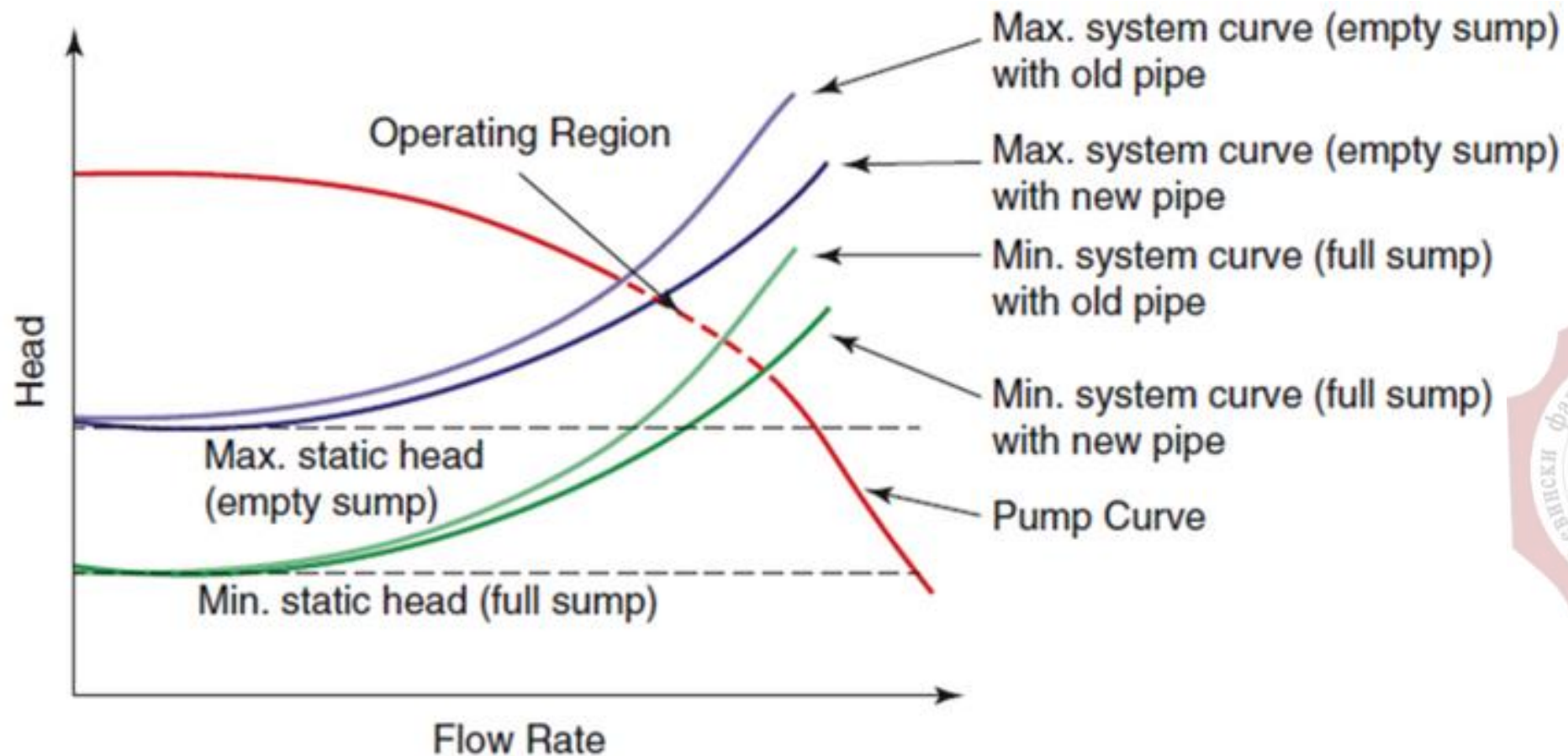
Dodatno o pumpama

- Rad pumpe (centrifugalne) izvan optimalnog radnog opsega: opterećenje na konstrukciju pumpe



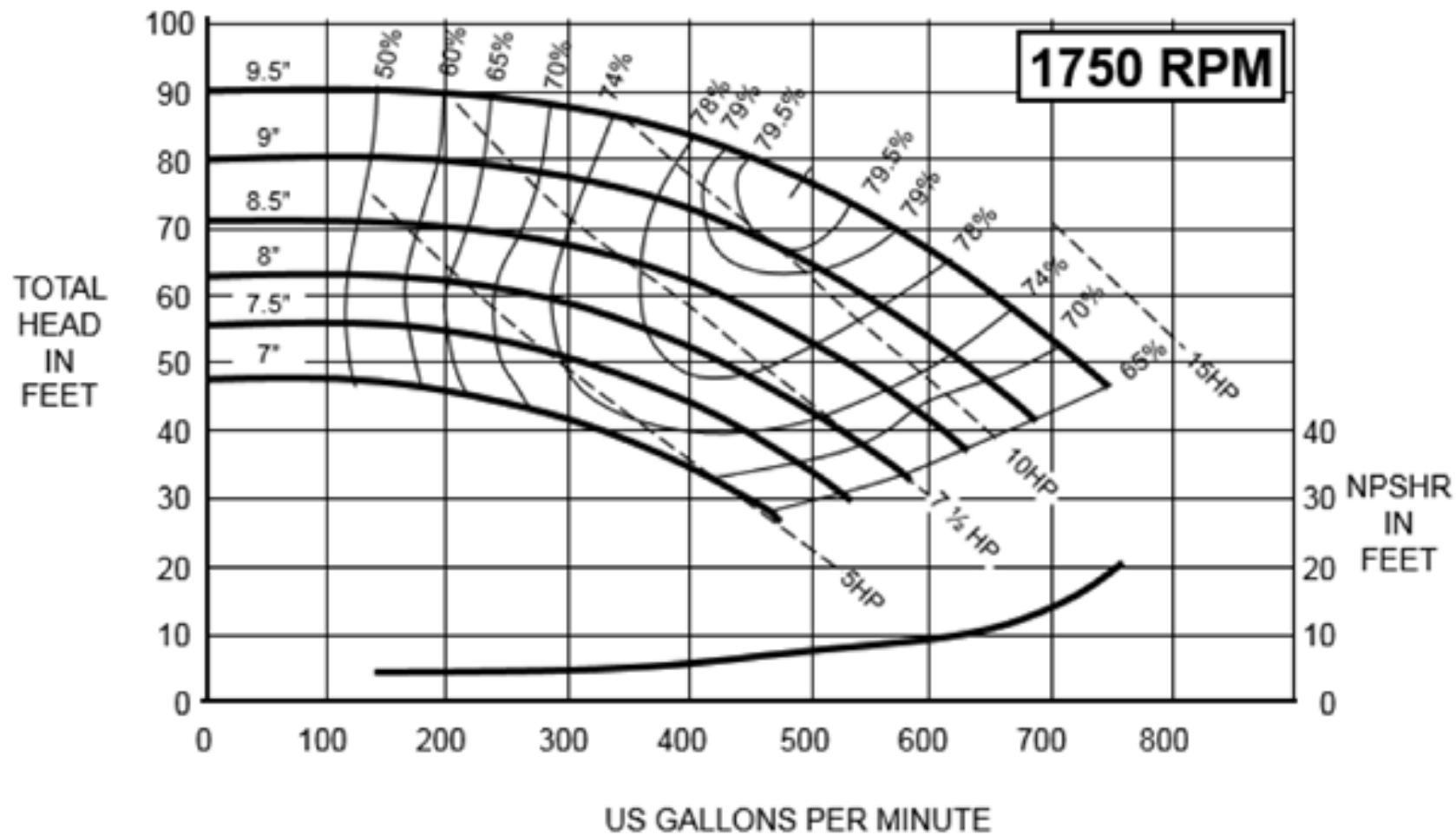
Dodatno o pumpama

- **U obzir uzeti pun opseg rada pumpe**
 - Uzeti u obzir sve moguće geodetske razlike (usled promena nivoa u rezervoarima)
 - Uzeti u obzir sve moguće karakteristike cevovoda (usled položaja zatvarača, promenama u potrošnji vode, starenja cevi, ...)



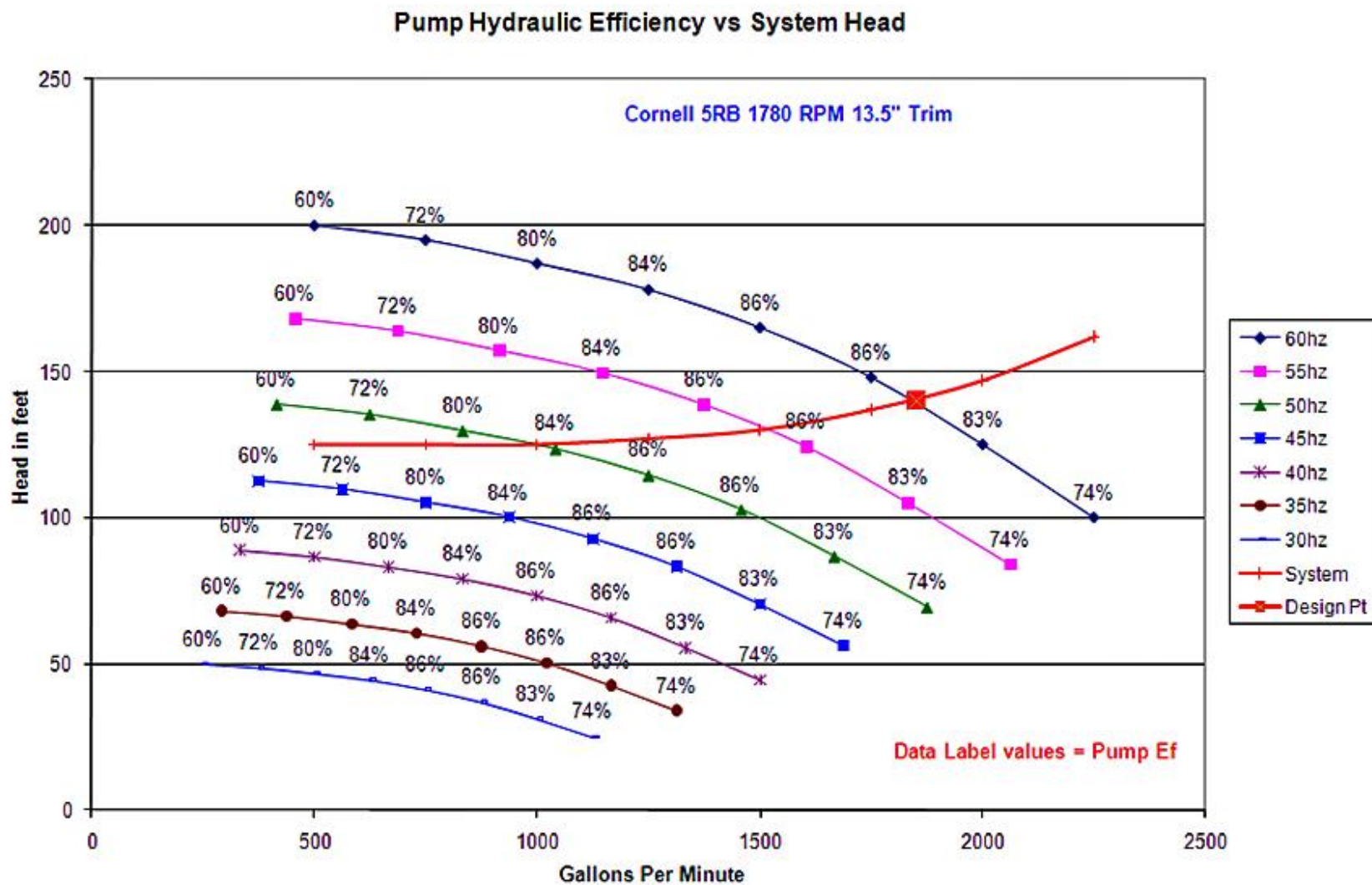
Dodatno o pumpama

- Školjka dijagram: kombinovani prikaz $H_p(Q)$ za različite veličine radnog kola, zajedno sa efikasnošću, snagom, NPSH (*net positive suction head*), i dr.



Dodatno o pumpama

- Školjka dijagram: frekventna regulacija = regulacija broja obrtaja pumpe



Dodatno o pumpama

- **Korisne skraćenice i jedinice:**

- | | |
|---|--|
| ▪ Pump curve | = kriva pumpe, radni dijagram pumpe |
| ▪ Series/parallel pump operation | = redno/paralelno vezane pumpe |
| ▪ System (resistance) curve | = karakteristika sistema/cevovoda |
| ▪ (B)HP – (brake) horsepower | = konjska snaga $\approx 0.7457 \text{ kW}$ |
| ▪ USG – US (liquid) gallon | $\approx 3.785 \text{ L}$ |
| ▪ GPM – (US) gallons per minute | $\approx 3.785 \text{ L/min}$ |
| ▪ CFS/CFM – cubic feet per second/minute | $\approx 28.32 \text{ L/s}, 0.472 \text{ L/s}$ |
| ▪ RPM – revolutions per minute | = obrtaja/min |
| ▪ Discharge, flow rate | = protok |
| ▪ Pressure/Pump/Total head | = visina pritiska/visina dizanja/pijezometarska kota |
| ▪ Static head | = geodetska razlika nivoa |
| ▪ Shut-off head | = visina dizanja pri $Q = 0$ |
| ▪ Open flow | = rad pumpe pri $H_p = 0$ |
| ▪ Impeler | = radno (obrtno) kolo |
| ▪ Vane | = lopatica (radnog) kola |
| ▪ Suction side/pipe | = usis pumpe |
| ▪ Discharge side/pipe | = potis pumpe |



Poznati proizvođači pumpi (različitih namena)

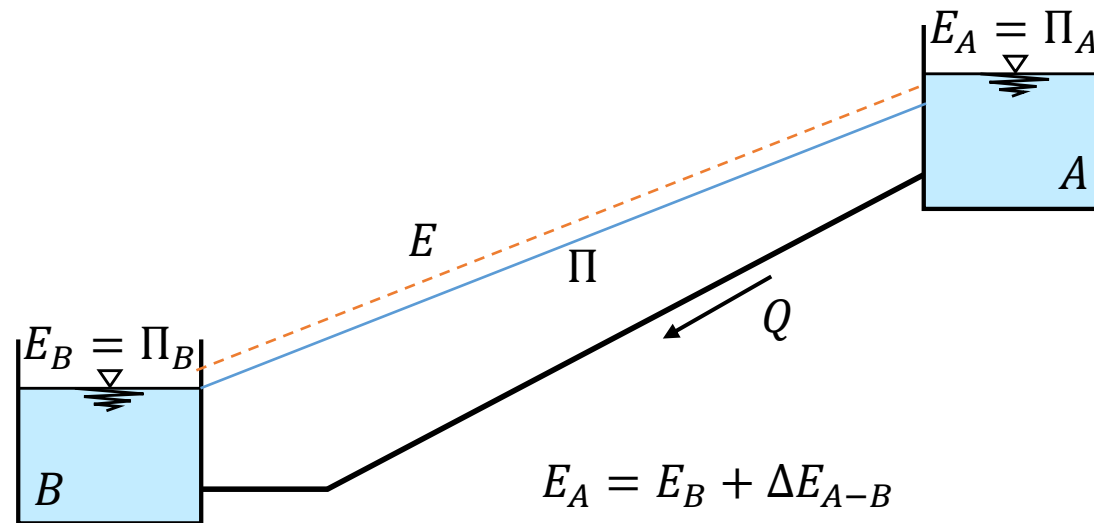
- Sulzer
- Grundfos
- Calpeda
- Lowara
- Ebara
- Wilo
- KSB
- Xylem/Flygt
- Pedrollo
- Verder
- Schmitt



TURBINE

Uloga turbina

- Obrnut proces u odnosu na pumpe:
→ vodi se oduzima mehanička energija u cilju „proizvodnje“ energije



$$E_A = E_B + \Delta E_{A-B}$$

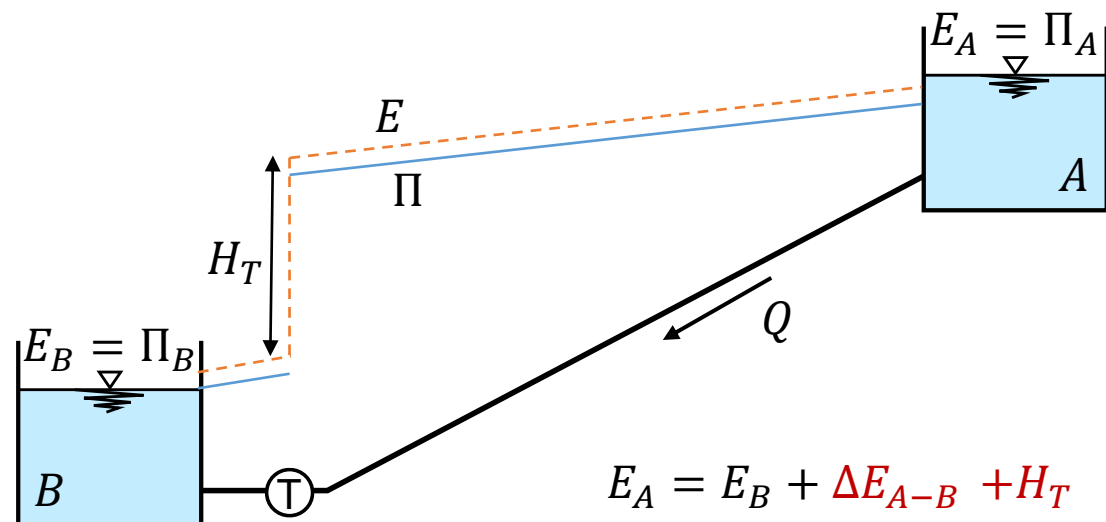
$$\Delta E_{A-B} > 0$$

$$E_A > E_B$$



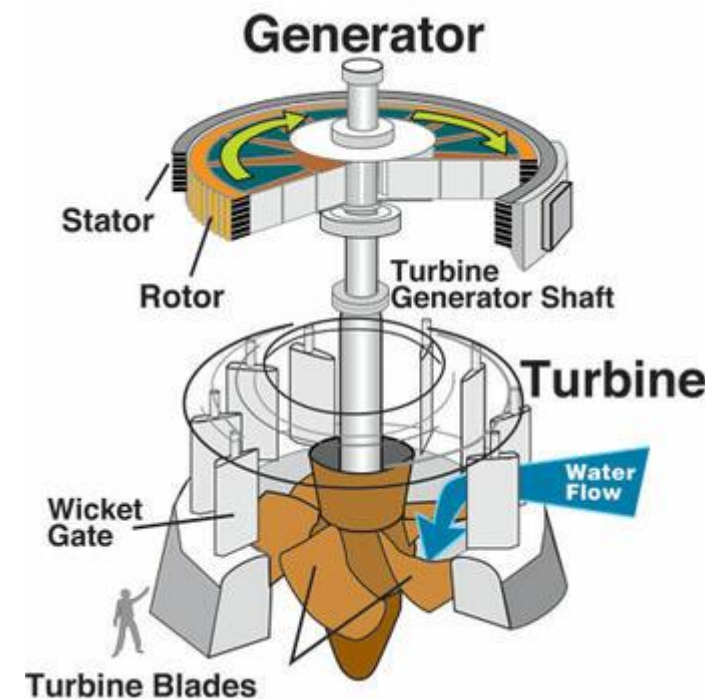
Uloga turbina

- Obrnut proces u odnosu na pumpe:
 - vodi se oduzima mehanička energija u cilju „proizvodnje“ energije
- H_T = „pad“ turbine, oduzeta mehanička energije po jedinici težine [m]



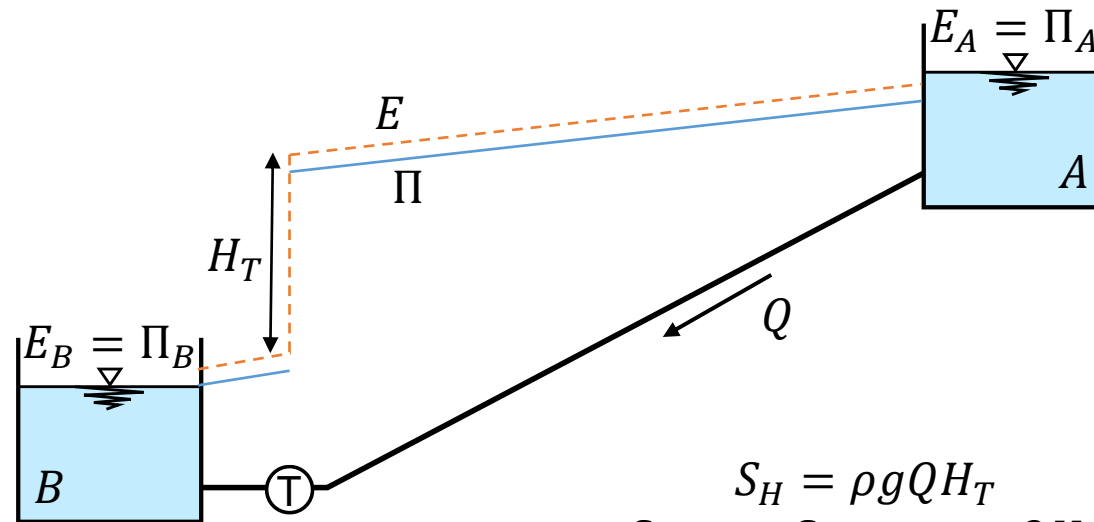
$$E_A = E_B + \Delta E_{A-B} + H_T$$

$$\begin{aligned} E_A &> E_B \\ \Delta E_{A-B} &> 0 \\ H_T &> 0 \end{aligned}$$



Snaga turbinskog postrojenja

- Obrnut proces u odnosu na pumpe:
→ vodi se oduzima mehanička energija u cilju „proizvodnje“ energije
- H_T = „pad“ pumpe, oduzeta mehanička energije po jedinici težine
- Gubici prilikom prenosa **hidrauličke snage na turbinu i sa turbine na generator**, itd.



$$S_H = \rho g Q H_T$$

$$S_T = \eta_T S_H = \eta_T \rho g Q H_T$$

$$S_{TP} = \eta_G S_T = \eta_G \eta_T \rho g Q H_T$$

$$S_{TP} = \eta \rho g Q H_T$$

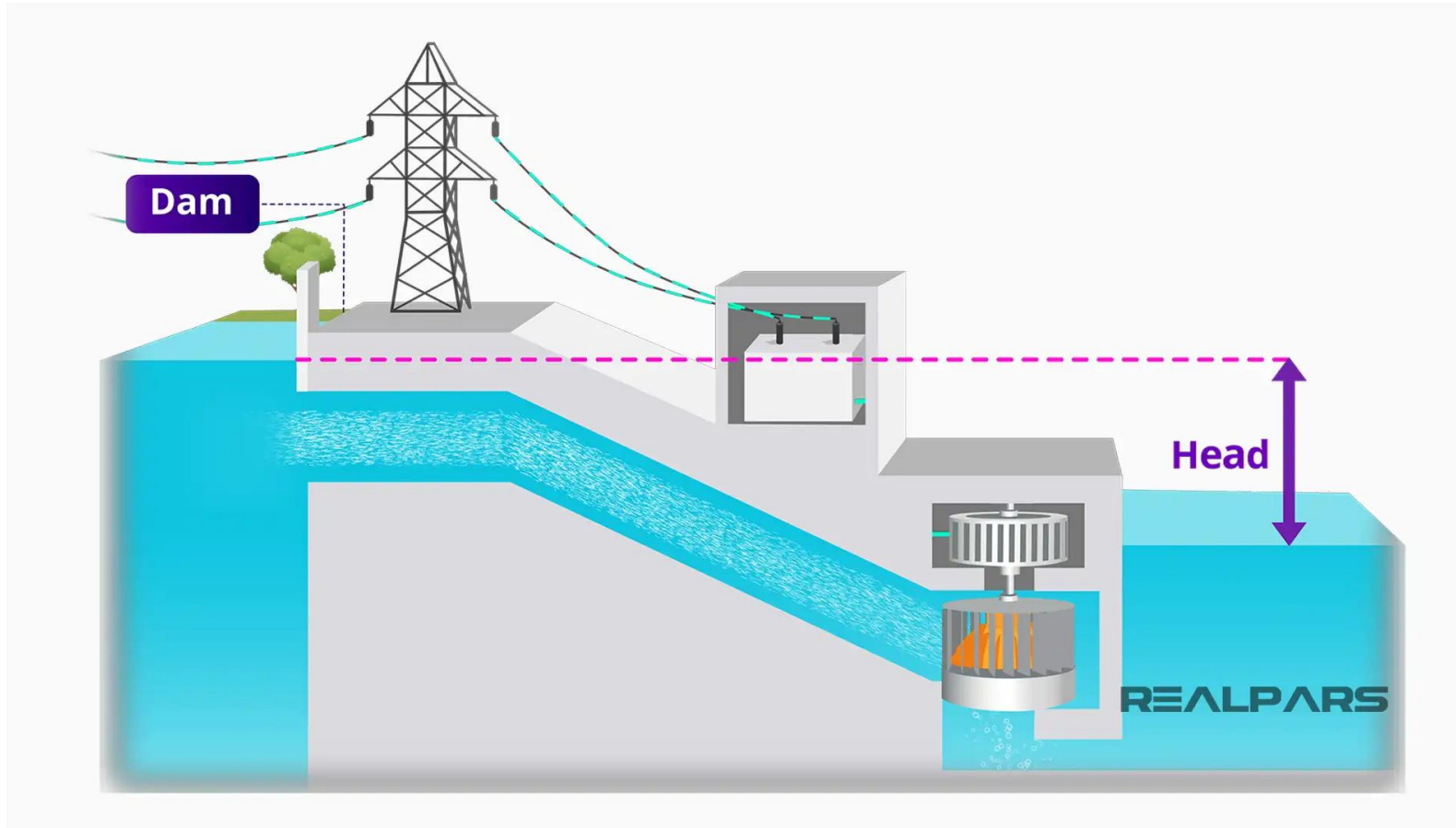
$$\eta = \eta_G \eta_T$$

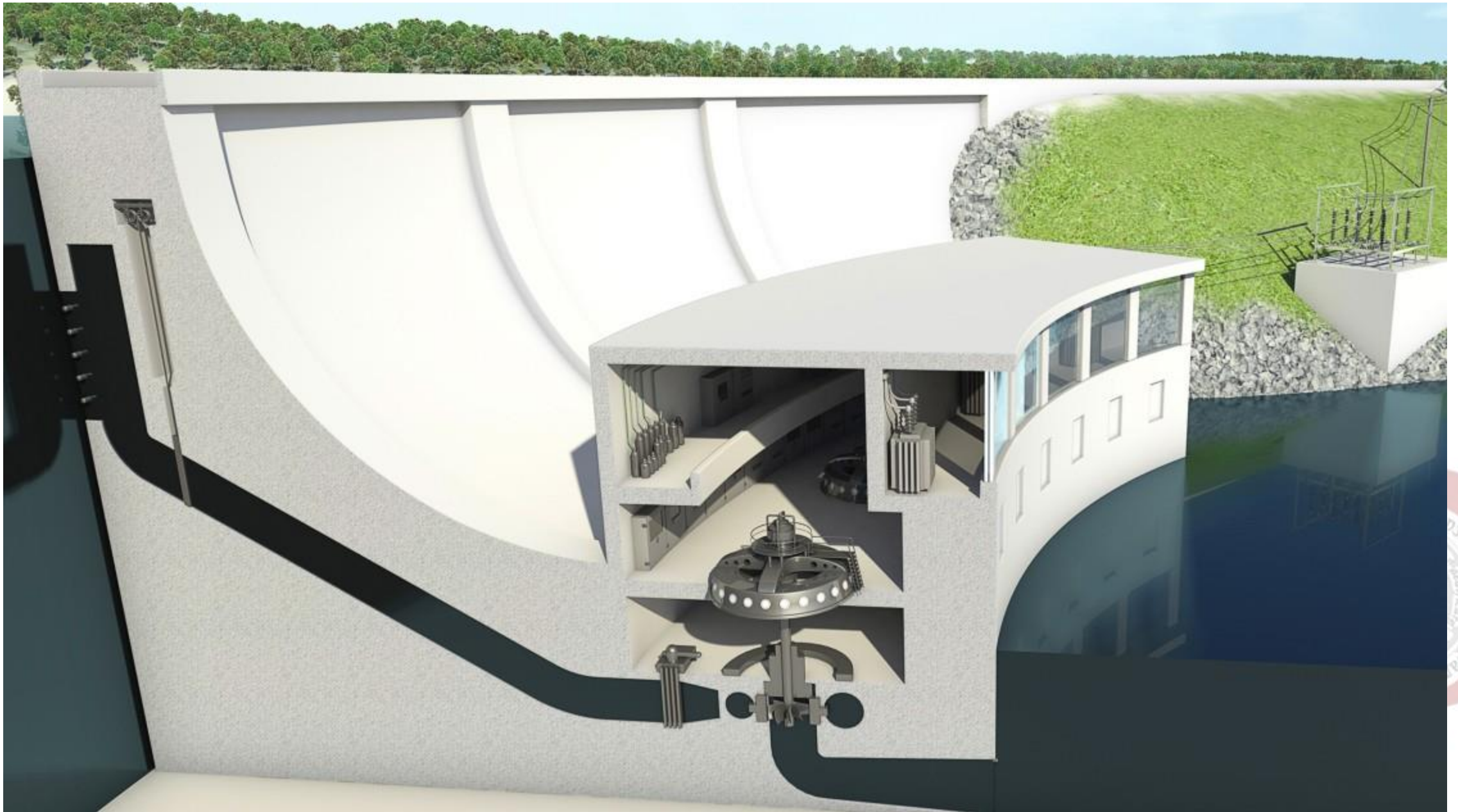
- snaga turbine
- snaga turbinskog postrojenja
- snaga turbinskog postrojenja
- koeficijent korisnog dejstva

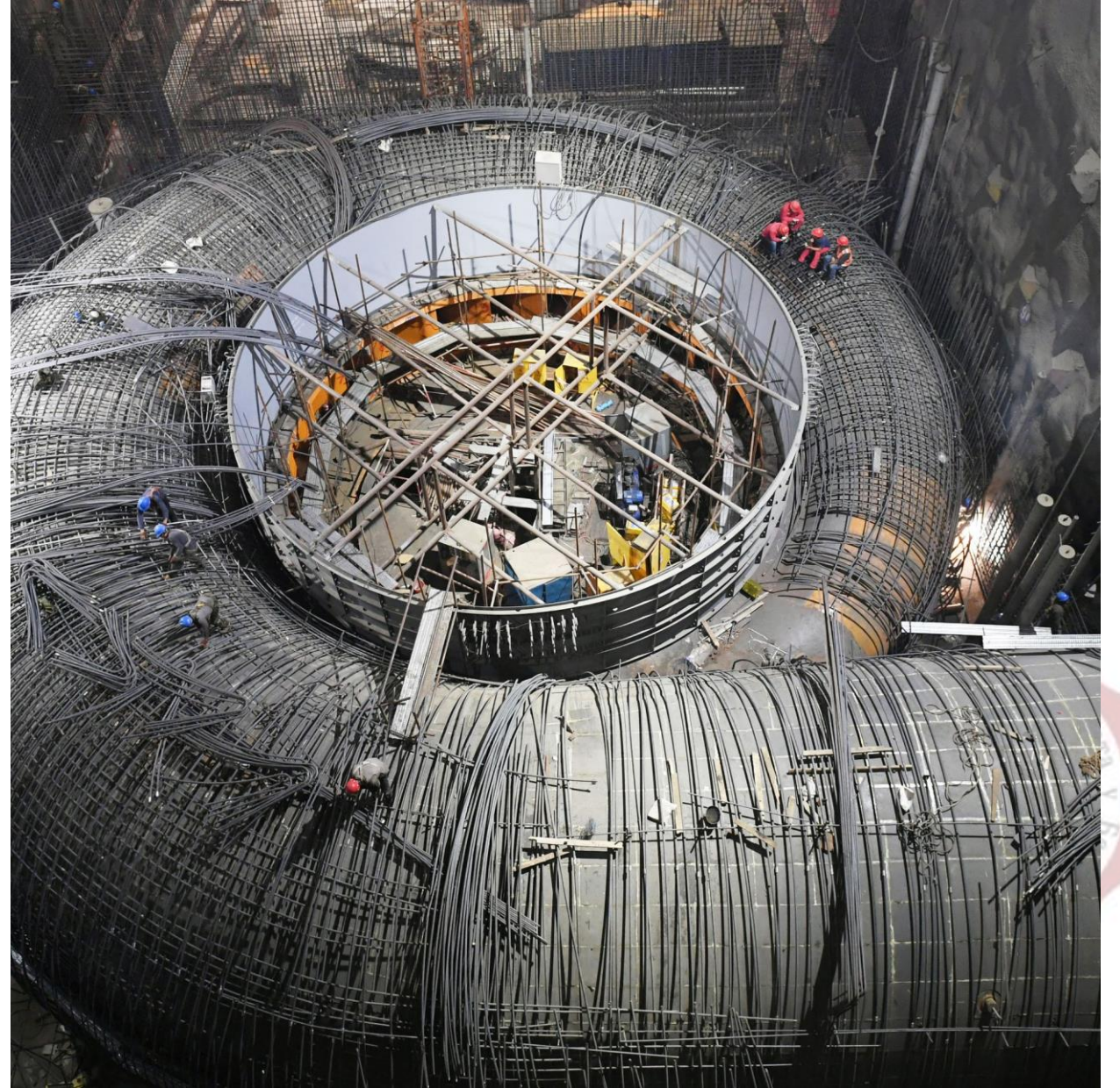


Turbinsko postrojenje u sklopu brane

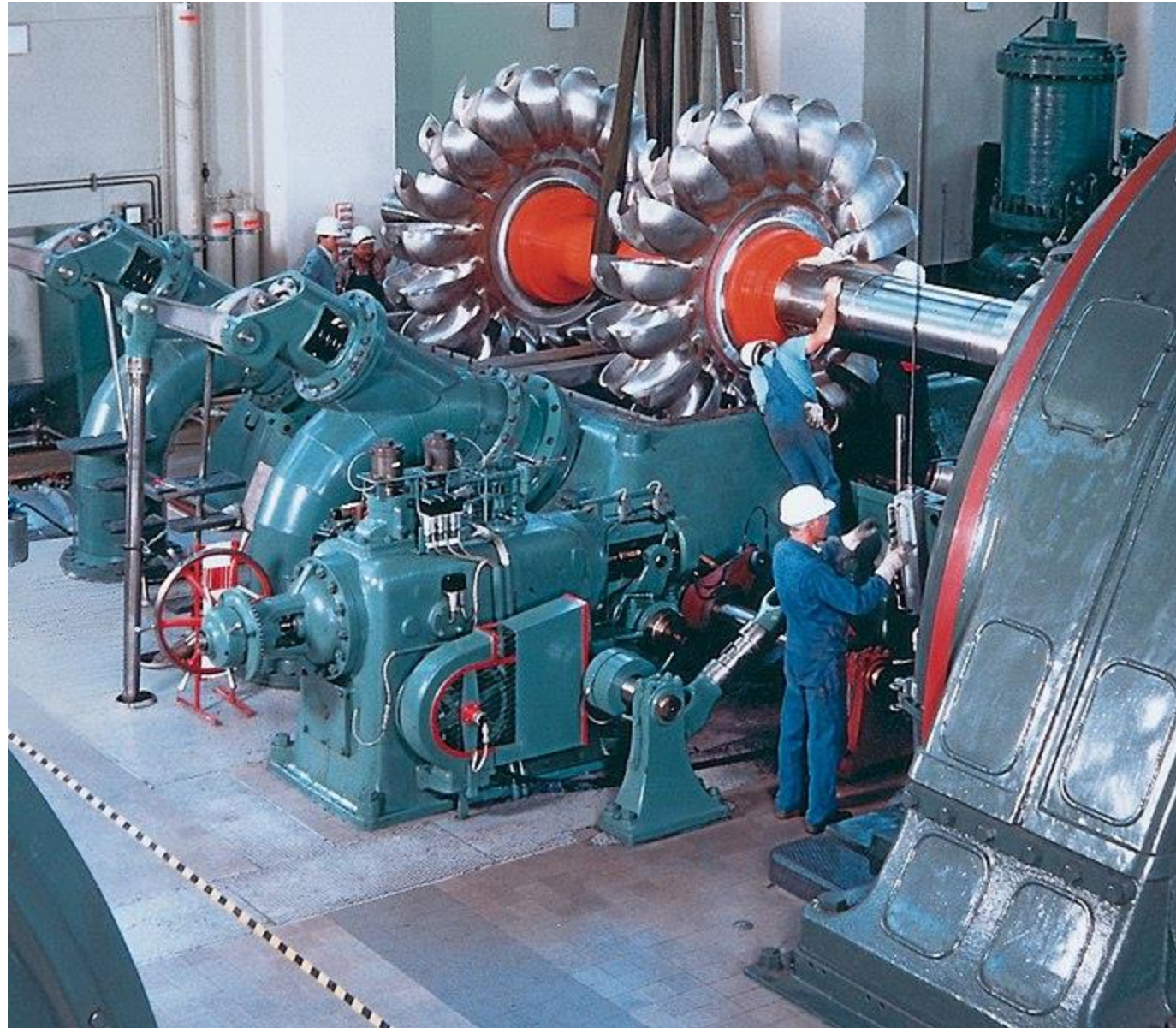
- Najčešće u sklopu brana
- Uzvodno od brane – akumulacija vode
- Po potrebi se akumulirana voda turbinira i proizvodi se električna energija











Interesantni klipovi

• Pumpe

- <https://www.youtube.com/watch?v=BaEHVpKc-1Q> – animacija rada centrifugalne pumpe
- <https://www.youtube.com/watch?v=lmjIQqo8mX4> – “
- <https://www.youtube.com/watch?v=spmj4FplQ5o> – princip rada višestepenih pumpi
- <https://www.youtube.com/watch?v=Qy1iV6EzNHg> – različiti tipovi pumpi

• Turbine

- <https://www.youtube.com/watch?v=3BCiFeykRzo> – Fransisove turbine, širok opseg Q i H
- <https://www.youtube.com/watch?v=0p03UTgpnDU> – Kaplanove turbine, mali pad H i veliki protok Q
- <https://www.youtube.com/watch?v=Jd5BN7SPkqI> – Peltonove turbine, veliki pad H i mali protok Q
- <https://www.youtube.com/watch?v=k0BLOKEZ3KU> – poređenje Fransis/Kaplan/Pelton

