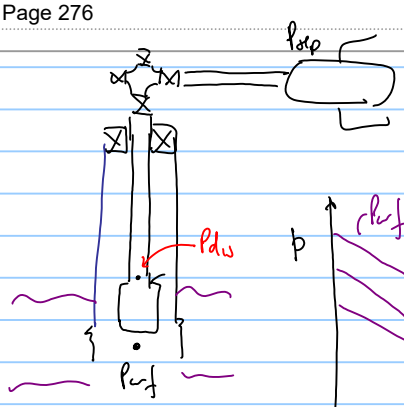
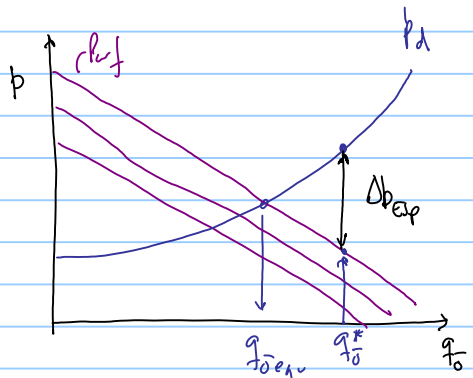
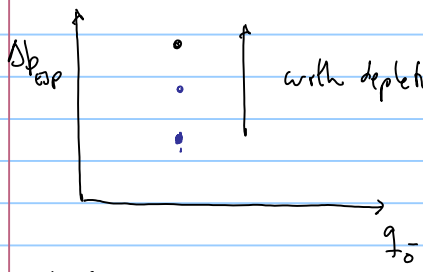
ESP electric submersible pump





↳ no ESP

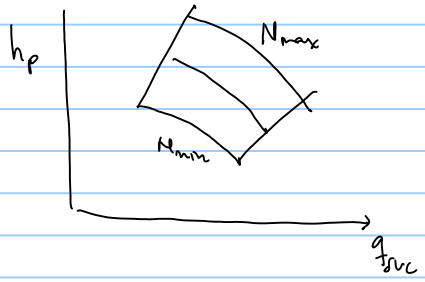


with depletion Δp_{esp} is increasing

the pump also has operational constraints

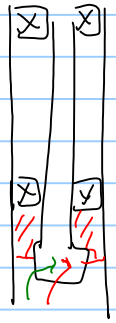
- limited available (maximum power) capacity
- operational map (envelope)
- $p_{suc} \geq p_b(T_R)$
  ↳ bubble point pressure (no gas is allowed in the pump)

for compressor:



onshore

offshore



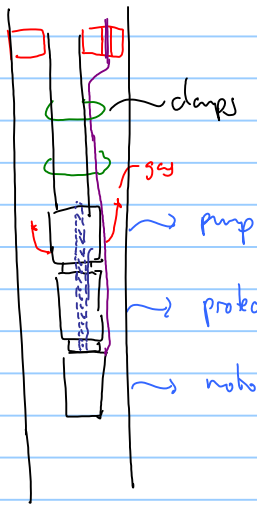
typical gas tolerance in ESP is GVF = 10%

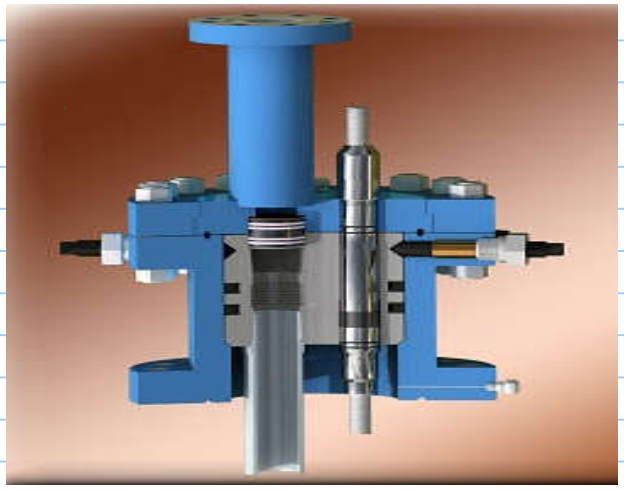
gas volume fraction

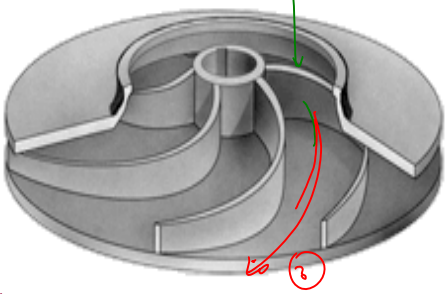
$$GVF = \frac{q_g}{q_L + q_g} \times 100\%$$

$q_L = q_o + q_w$

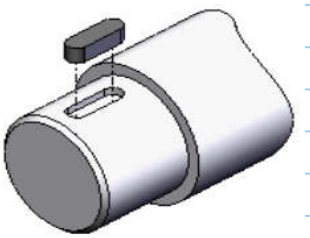
Armais Arutunoff

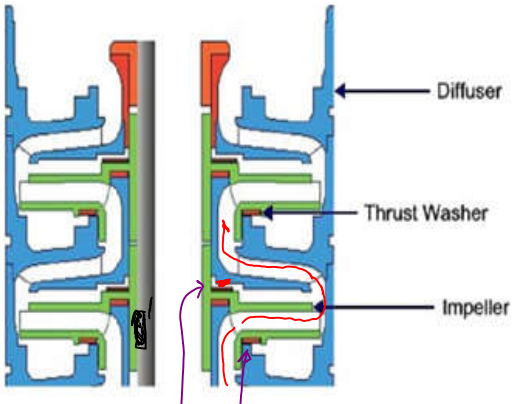






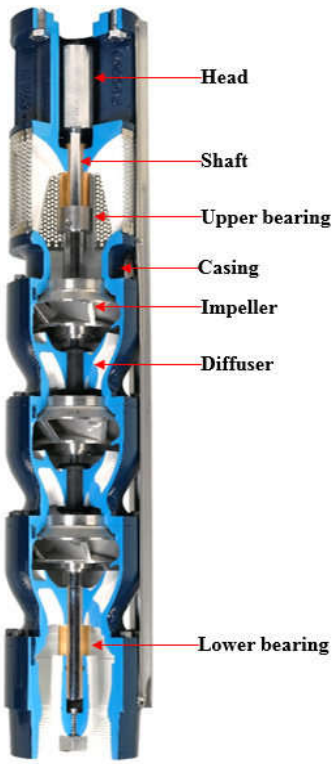
stage : impeller (rotor) + diffuser

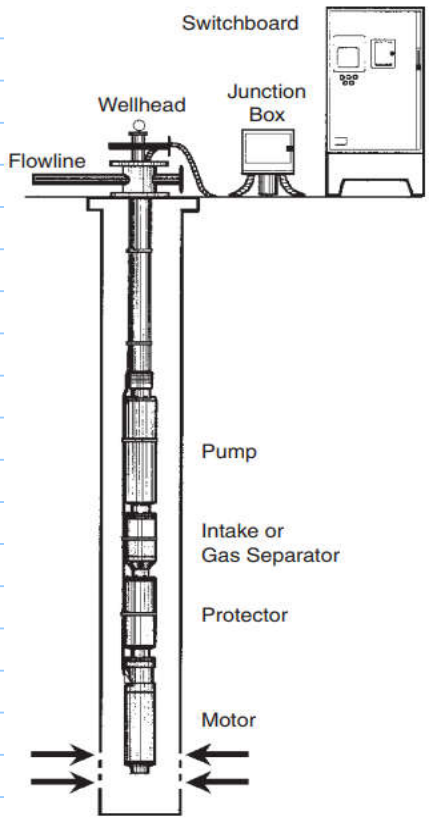


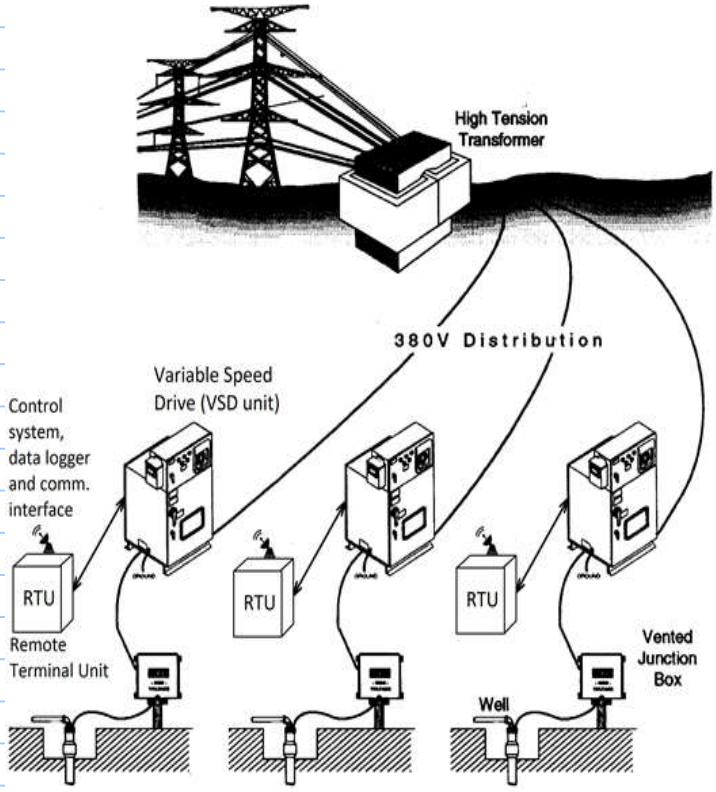


upthrust

downthrust





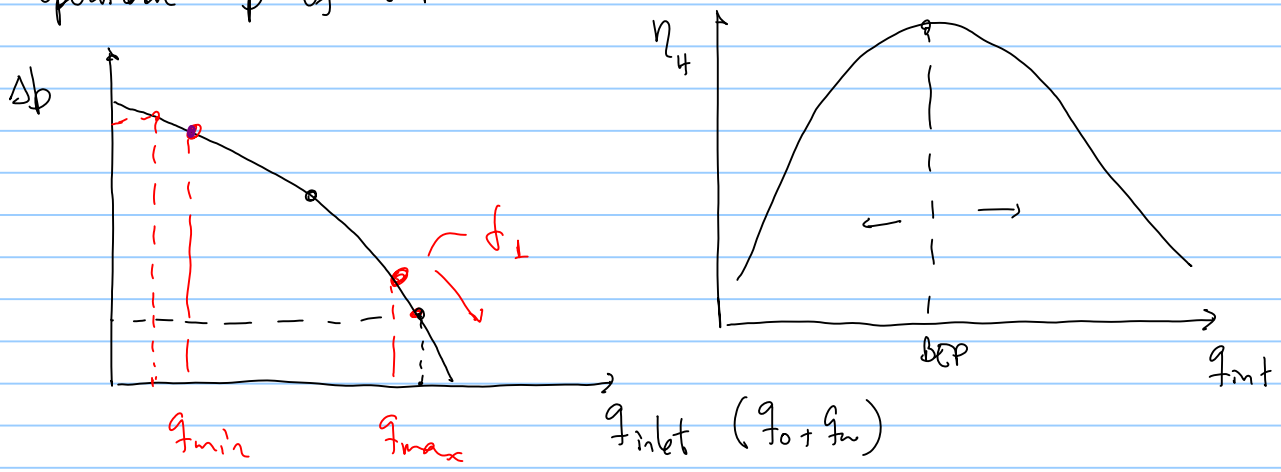


pump frequency

$f = 30 - 70\ hz$

gas impeller and diffuser more tolerant to gas

operational map of ESP



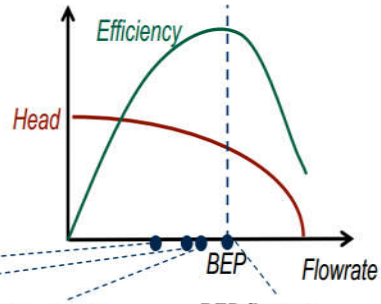
downthrust

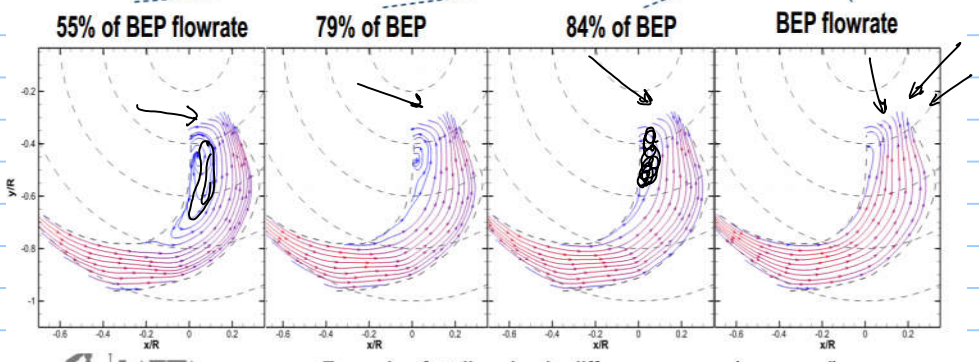
if $q > q_{max}$ then upthrust but also low efficiency

pump hydraulic power $P_H = \frac{\Delta p \cdot q_{inlet}}{\eta_H}$

PIV measurement in a radial flow stage

- Flow features in diffuser and impeller may be identified from measurements
- Flow misalignment and recirculations reduce efficiency





Example of stall region in diffuser passage (measured)

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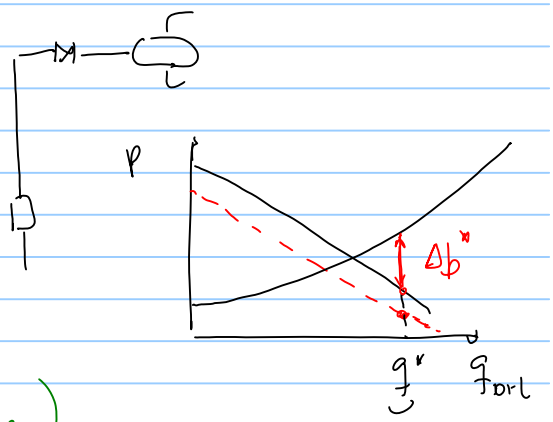
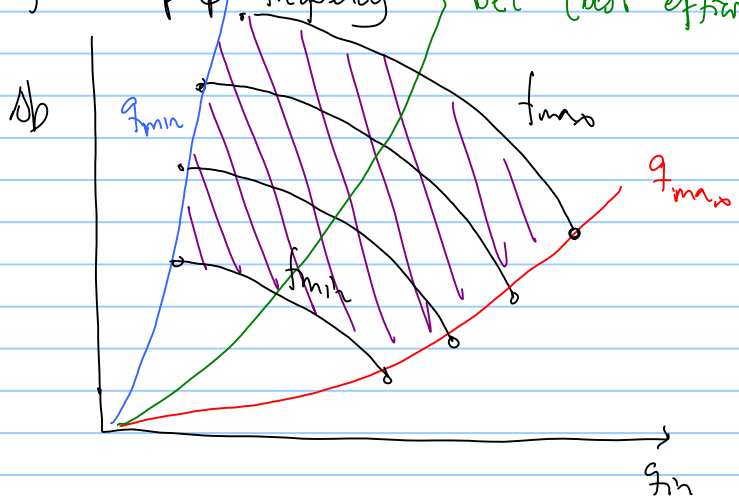
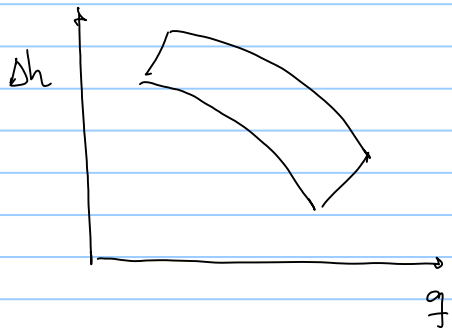
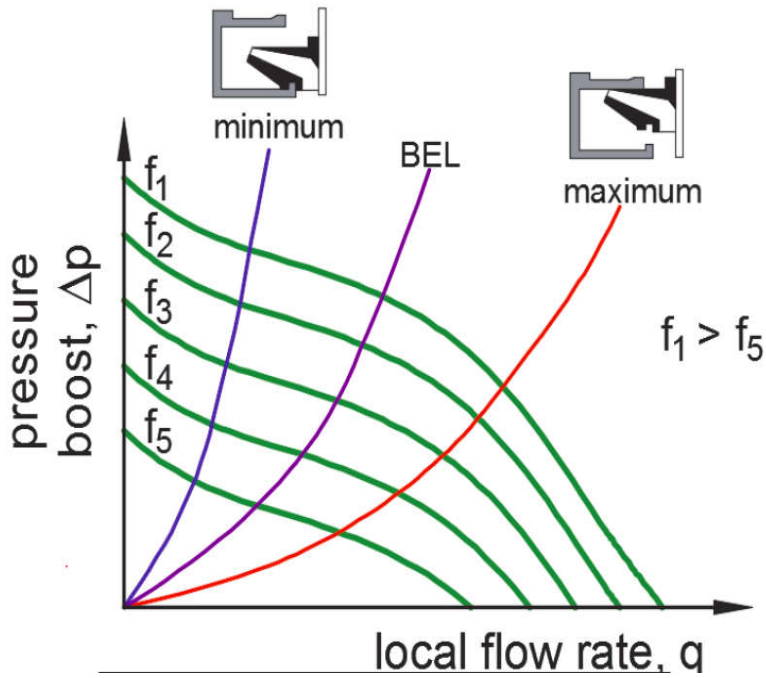


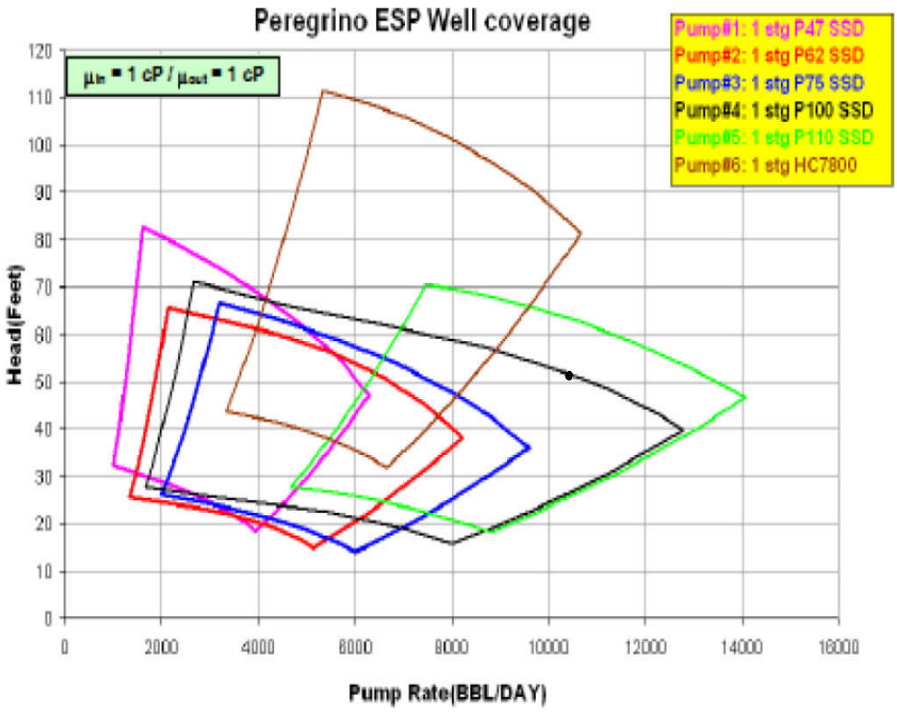
changes in pump frequency, BEL (best efficiency line)



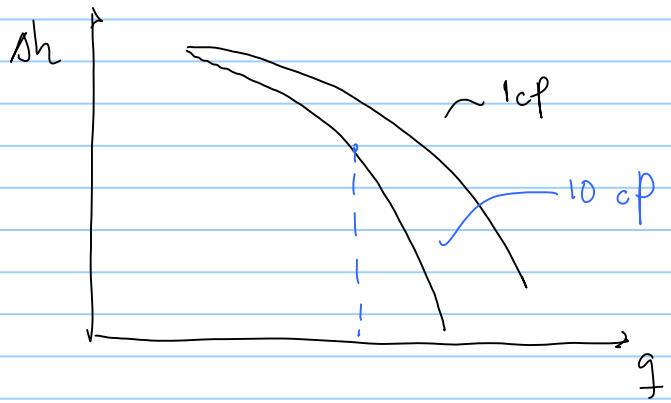
Δh = head = $\frac{\Delta p}{\rho_{mix}}$



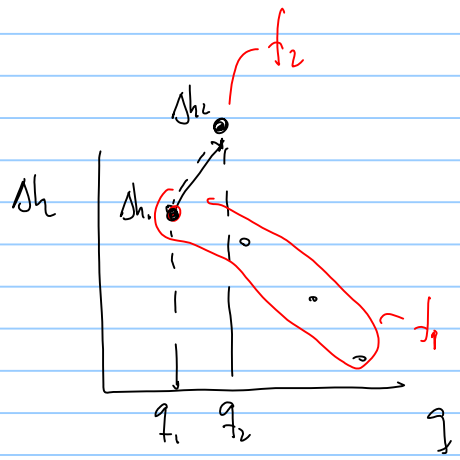




the viscosity of fluid also affects the performance of pump



for a given frequency



$$\Delta h = a q^4 + b q^3 + c q^2 + d q + e$$

$$\frac{\Delta h_{@f_1}}{\Delta h_{@f_2}} = \left(\frac{f_1}{f_2}\right)^2 \qquad \frac{q_1}{q_2} = \frac{f_1}{f_2} \quad \text{similarity law}$$

$$\frac{q_{ref}}{q} = \frac{f_{ref}}{f}$$

$$\Delta h(f) = \frac{f^2}{f_{ref}^2}\left[a\left(\frac{f_{ref}}{f}q\right)^4 + b\left(\frac{f_{ref}}{f}q\right)^3 + c\left(\frac{f_{ref}}{f}q\right)^2 + d\,\frac{f_{ref}}{f}q + e\right]$$