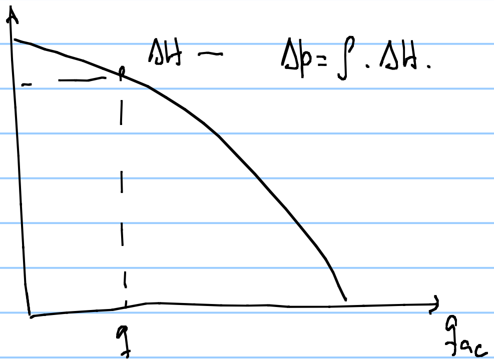
ESP { performance curve

head

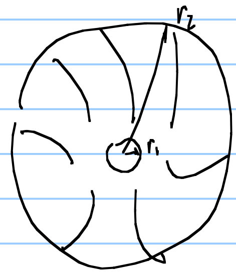
$\Delta H = \frac{\Delta p}{\rho \cdot g}$



$\Delta H - \Delta p = \rho \cdot \Delta H.$

- water → $\Delta p / (\rho \cdot g)$
- single stage

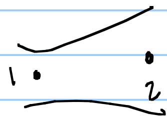
- impeller : increase the fluid energy by increasing the speed



$$\Delta H = \left(a_4 \cdot q^4 + a_3 \cdot q^3 + a_2 \cdot q^2 + a_1 \cdot q + a_0\right) N$$

2nd order → 5th order polynomial

- diffusor



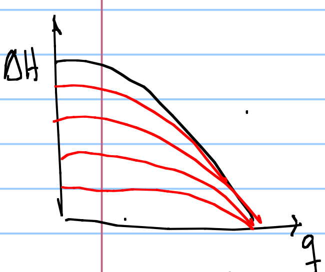
convert kinetic energy to potential energy

$$\frac{P_1}{\rho \cdot g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho \cdot g} + \frac{v_2^2}{2g}$$

$\uparrow \quad \uparrow \quad \uparrow \quad \uparrow$

modifications

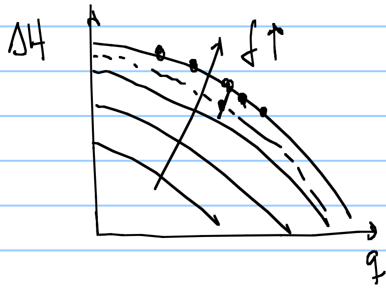
Number of stages



N number of stages

$\Delta H_{\text{single stage}} \cdot N = \Delta H_{ESP}$

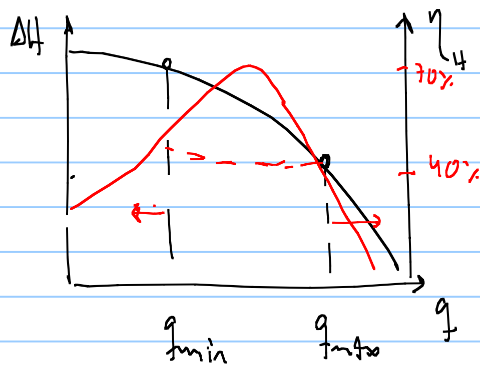
changes with rotational speed
$f_{ref} = 60\ hz$



$f_{min} \leq f \leq f_{max}$

30-40 hz ↓ 60-70 hz

- operational limits

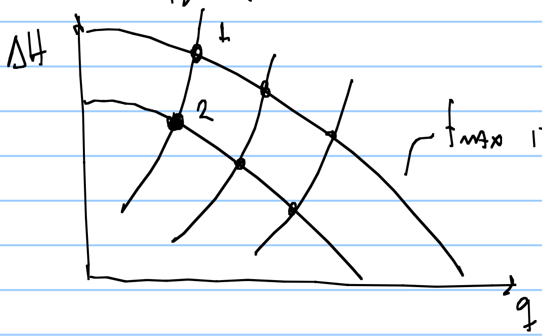


- upthrust
- downthrust

*

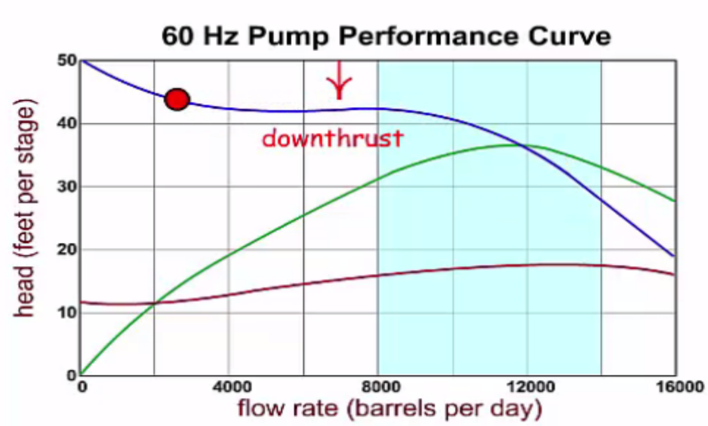
$$\frac{\Delta H_1}{\Delta H_2} = \left(\frac{f_1}{f_2}\right)^2$$

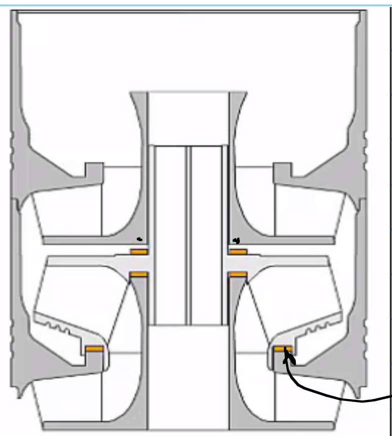
$$\frac{q_1}{q_2} = \left(\frac{f_1}{f_2}\right)$$



f_{max} is given by the maximum power capacity of the motor

$$\Delta H = \left(a_4 \cdot \left(\frac{60\,hz}{f}\right)^4 \cdot q^4 + a_3 \cdot \left(\frac{60\,hz}{f}\right)^3 \cdot q^3 + a_2 \cdot \left(\frac{60\,hz}{f}\right)^2 \cdot q^2 + a_1 \cdot \left(\frac{60\,hz}{f}\right) \cdot q + a_0 \right) \cdot \left(\frac{f}{60\,hz}\right)^2 \cdot N_{stages}$$



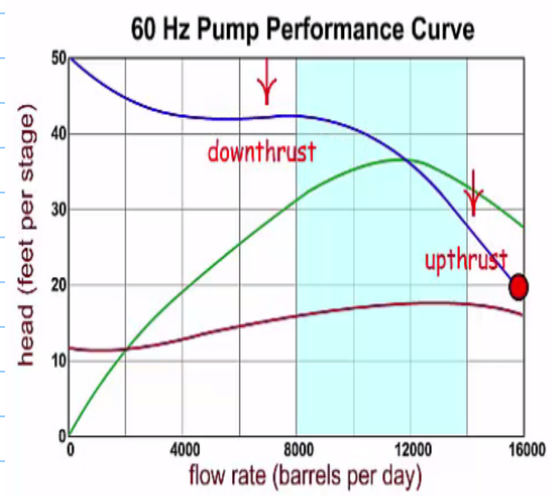


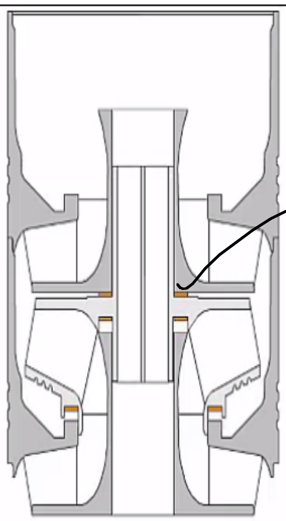
Until it reaches a certain point on the curve where it goes in to downthrust.

downthrust

too much weight in the washer area

↳ failure



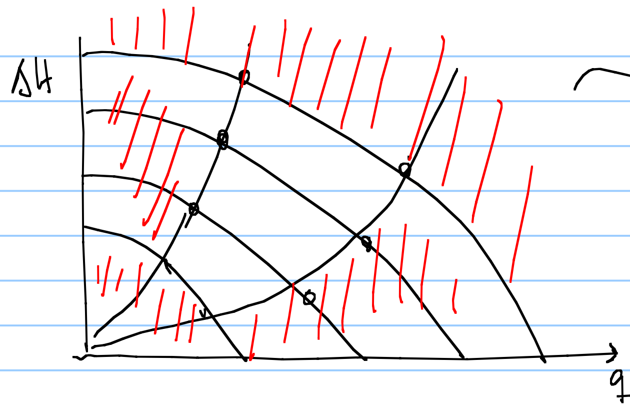


It will not go into upthrust at the same point it went into downthrust.

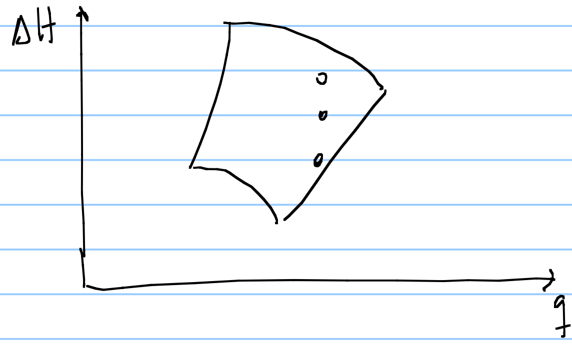
upthrust → wear, heating

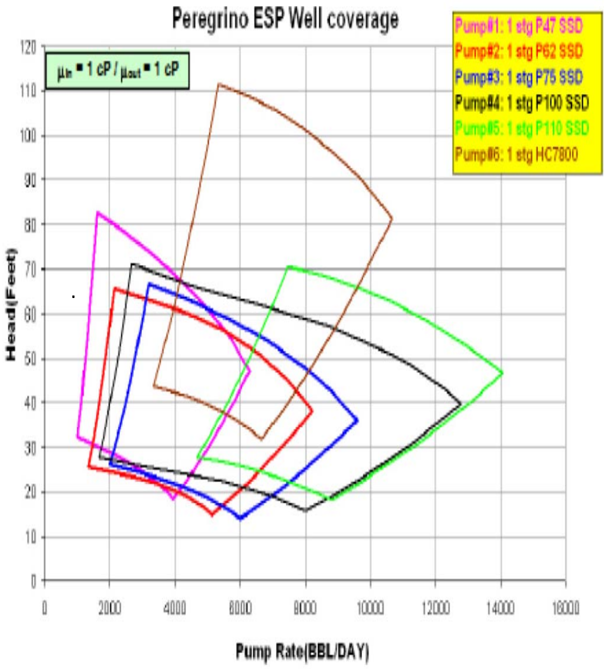
detrimental for the life of the ESP

q_{min} and q_{max} change with the rotational speed of the pump

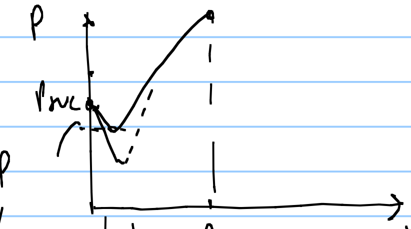


$$\frac{q_1}{q_2} = \frac{f_1}{f_2}$$





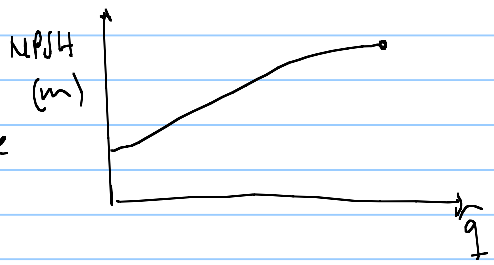
• $P_{suc} \geq P_{minimum}$ → avoid gas coming out of solution
→ avoid cavitation



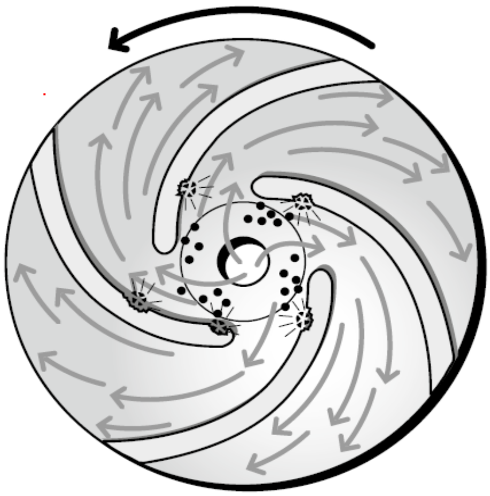
x → fluid path along the pump

p has to be larger than P_b of the fluid at that temperature

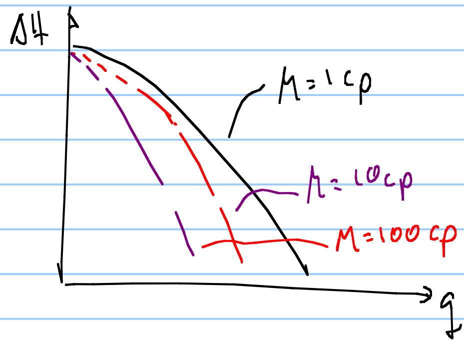
NPSH for each rate
(Net positive suction pressure

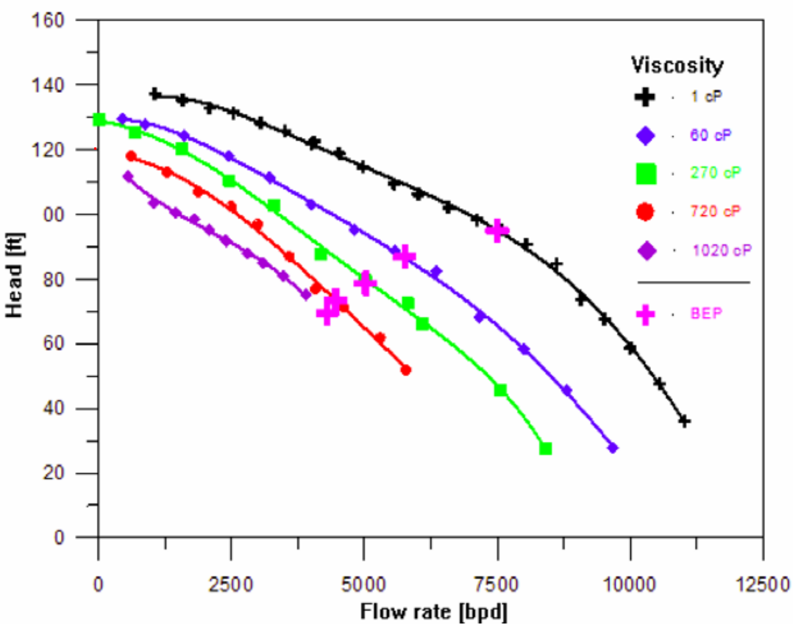


$$\left.\begin{matrix} q_{min}(t) \\ q_{max}(t) \\ f_{min} \\ f_{max} \\ \underbrace{P_{suc} \geq P_{min}} \end{matrix}\right\}$$ vaporization and cavitation



Performance of the pump for different viscosit





 ANSI/HI 9.6.7-2010

American National Standard (Guideline) for

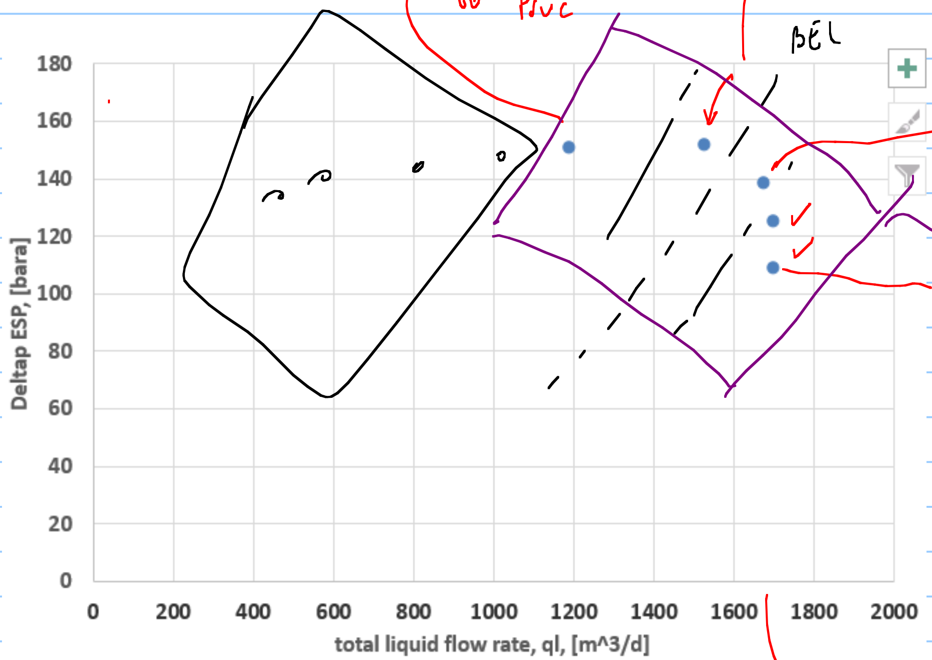
Effects of Liquid Viscosity on Rotodynamic (Centrifugal and Vertical) Pump Performance class examples → $P \le 600\,hp$

$P_{suc} \ge 31.5$ bara

rate reduction due to P_{suc}

rate reduction due to : power constraint
P_{suc}

rate reduction due to power constraint

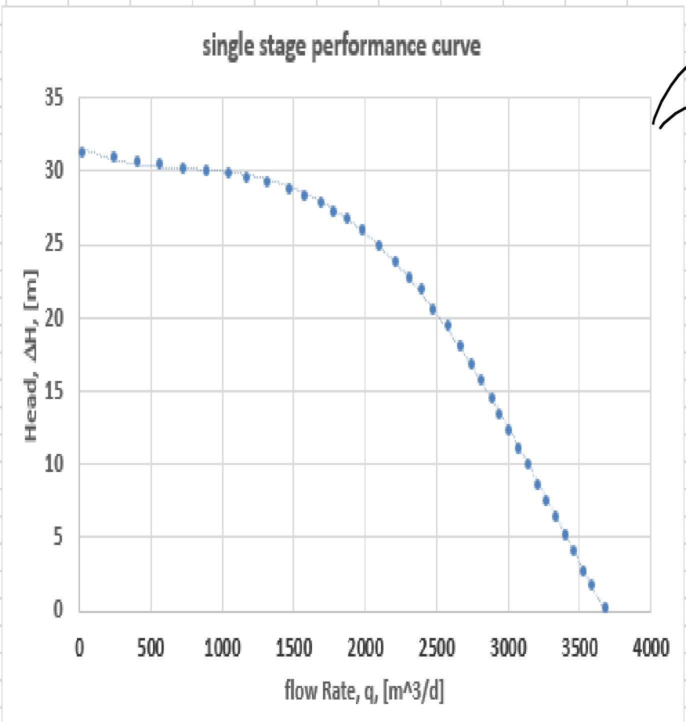


find a pump envelope such as all points fall inside the feasible area.

1700 m³/d

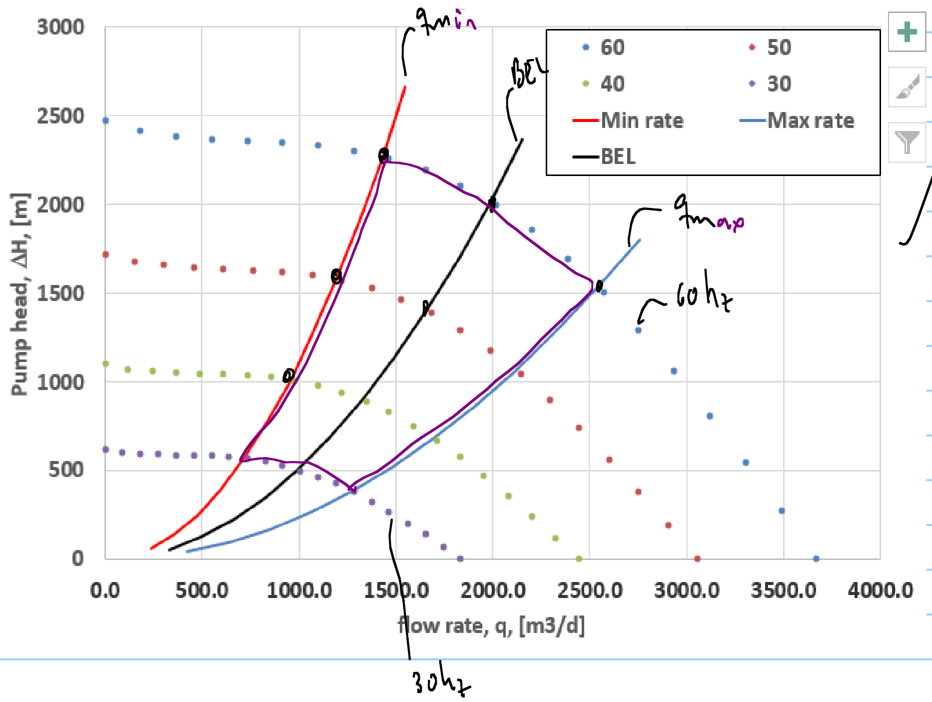
ESP model:

flowrate [bbl/d]	flowrate [m^3/d]	head [ft]	head [m]
107	17	103	31
1524	242	102	31
2566	408	101	31
3524	560	100	31
4524	719	99	30
5608	892	99	30
6545	1041	98	30
7358	1170	97	30
8254	1312	96	29
9213	1465	95	29
9921	1577	93	28
10630	1690	91	28
11193	1780	90	27
11756	1869	88	27
12464	1982	85	26
13194	2098	82	25
13903	2210	78	24
14529	2310	75	23
15050	2393	72	22
15572	2476	68	21
16197	2575	64	19
16761	2665	59	18
17220	2738	55	17
17679	2811	52	16
18138	2884	48	15
18492	2940	44	13
18910	3006	41	12
19327	3073	37	11
19744	3139	33	10
20183	3209	29	9
20537	3265	25	8
20934	3328	21	6
21351	3395	17	5
21727	3454	13	4
[illegible]	[illegible]	[illegible]	[illegible]



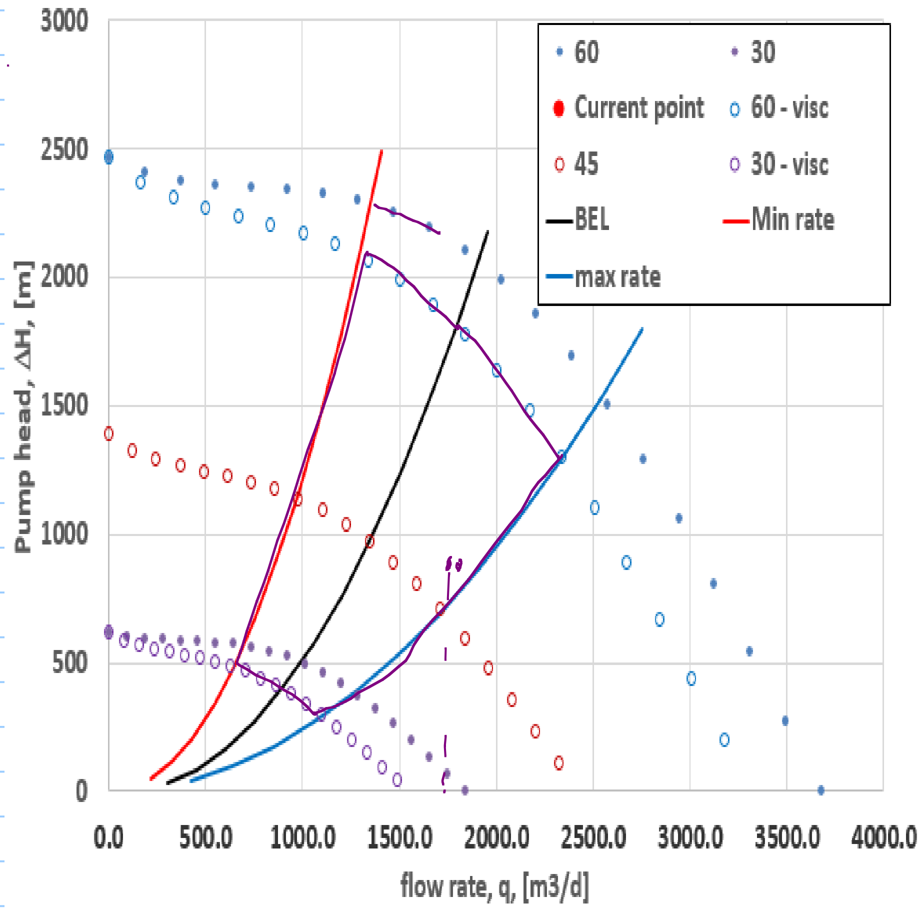
water
single stage.
f=60hz

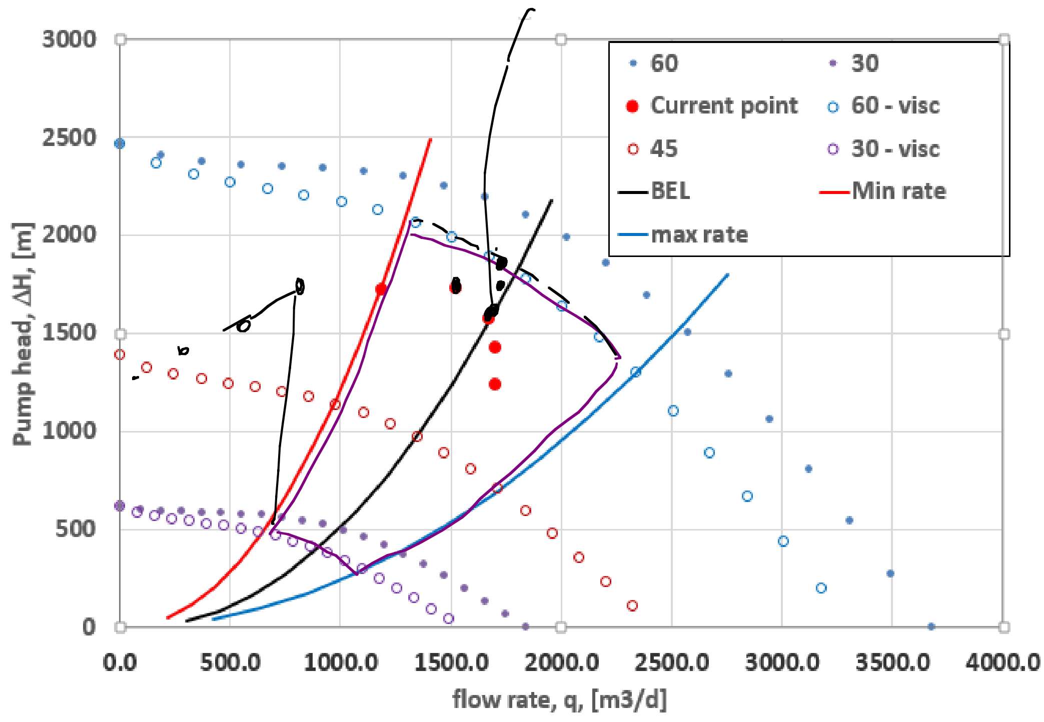
$$y = \underbrace{4.24658E\text{-}13x^4}_{a_4} \underbrace{- 3.62657E\text{-}09x^3}_{a_3} + \underbrace{6.64204E\text{-}06x^2}_{a_2} \underbrace{- 5.13919E\text{-}03x}_{a_1} + \underbrace{3.16938E{+}01}_{a_0}$$

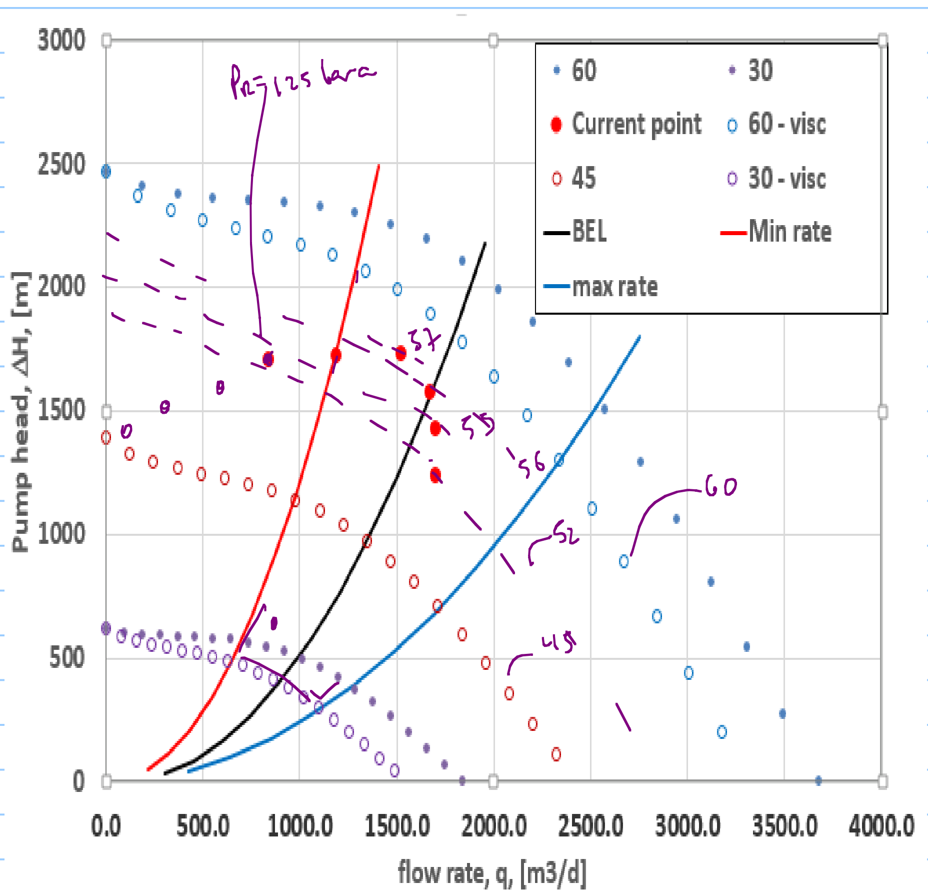


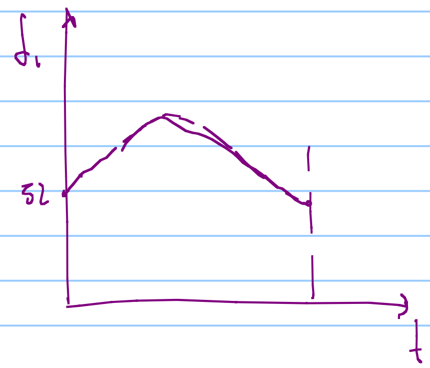
water, 78 stages

performance curves corrected by viscosity = 100 cp









NOTE: $P_{wh} \leq P_b$ probably gas coming out of solution at some position in the tubing. We are neglecting this gas!

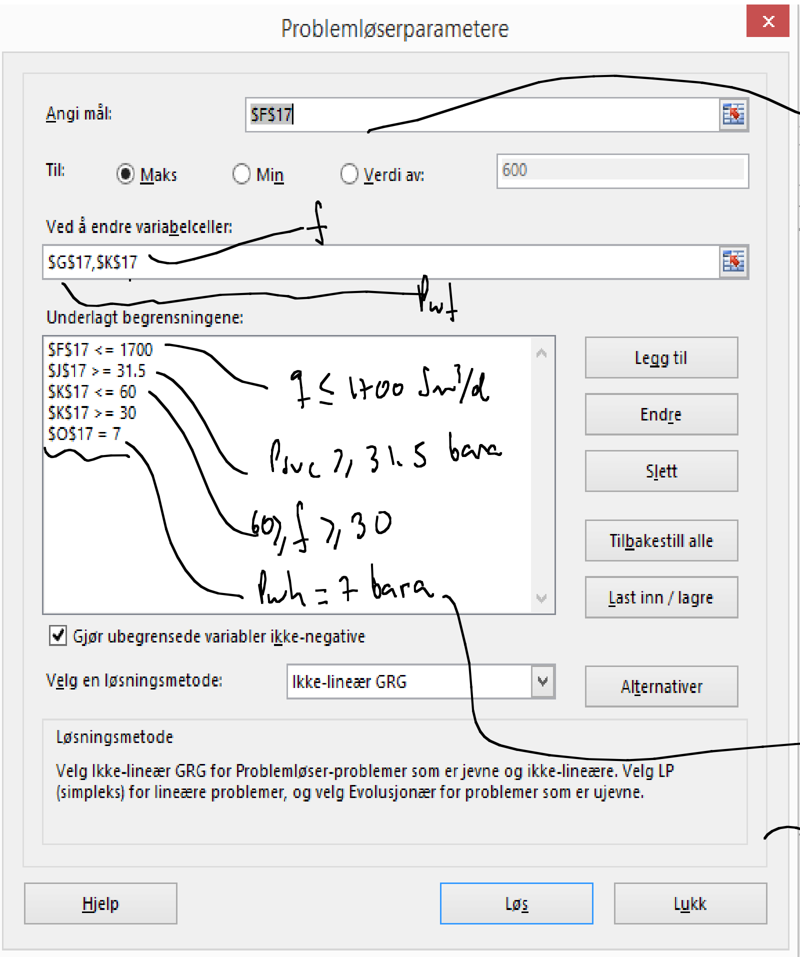
2nd approach: include the pump model in my hydraulic calculator

Calculation proposal co-current from bottom-hole to wellhead

check is $P_{wh,cal} = 7$ bara? if not → try new rate

if yes → stop calculation

Case 1 : finding f to get a certain rate and honouring operational constraints



max liquid rate

f

P_{wf}

$q \leq 1700$ Sm³/d

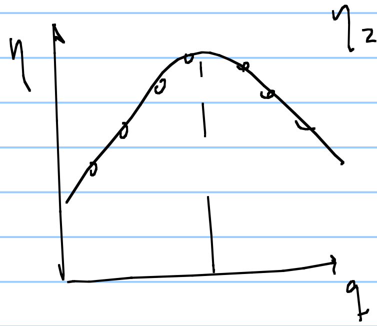
$P_{suc} \geq 31.5$ bara

$60 \geq f \geq 30$

$P_{wh} = 7$ bara

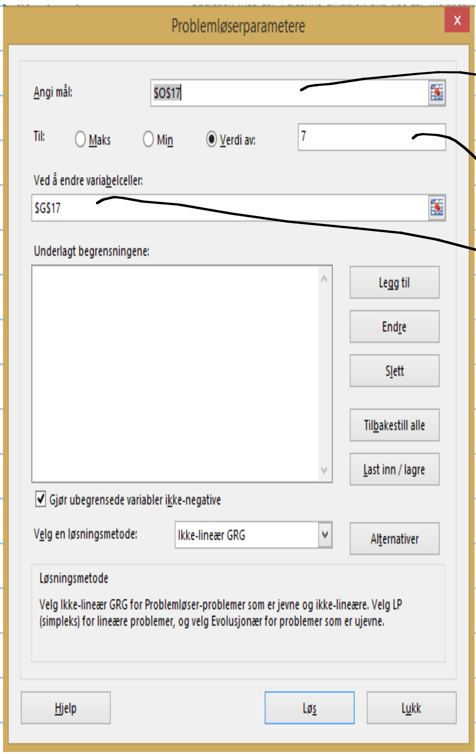
closes the hydraulic equilibrium

solving the hydraulic equilibrium.



$\eta = a_4 q^4 + a_3 q^3$

Case 2 fixing f, find equilibrium rate



P_{wh}

7 bara

P_{wf}

Summarizing

1: approach : without pump ESP out of the system.

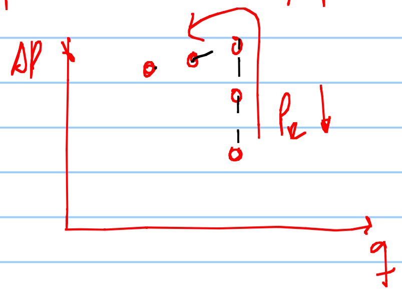
q_L given by reservoir engineer

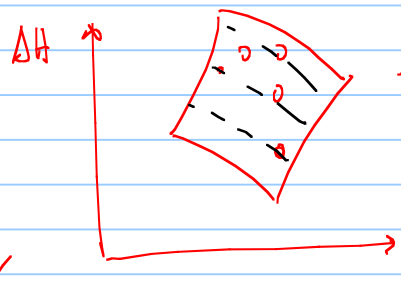
calculated P_{DIS}, P_{SUC}

$\left\{ \begin{array}{l} \frac{q \cdot \Delta P}{\eta} \leq P_{max} \sim \text{power} \\ P_{suc} \geq P_b \cdot F_s \quad \text{cavitation} \end{array} \right.$

OBS❗ we made a mistake, P should have been a bit higher than 600 hp

found that rate had to be reduced due to power limitations, P_{suc} limitations





pump plot given by ESP specialist

↳ correction by Nstages

by frequency

by viscosity

the pump can provide the operational conditions that were estimated ✓ !!

2nd approach: there is an ESP model built in in the production simulator.

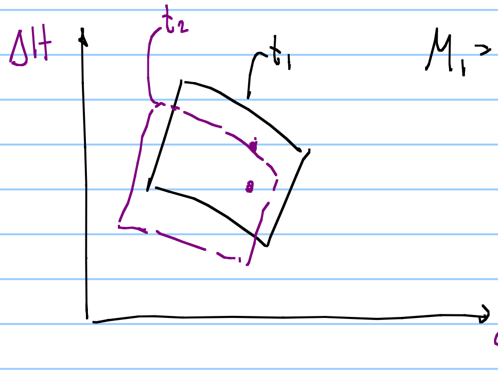
find f such as P_{wf} ⟶
$\left\{ \begin{array}{l} q = 1700\ Sm^3/d \\ P_{suc} \geq 31.5 \text{ bara} \\ P_{wh} = 7 \text{ bara} \\ q_{min} \leq q \leq q_{max} \\ 30 \leq f \leq 60 \text{ hz} \end{array} \right\}$ we have to use the solver

Operational limits	
Frequency [Hz]	60
Min rate [m3/d]	1302
Max rate [m3/d]	2314

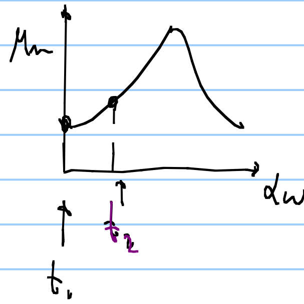
for a $\mu = 100\,cp$

$$\frac{q_{min@f}}{1302} = \frac{f}{60} \qquad q_{max@f} = \left(\frac{f}{60\,Hz}\right) \cdot 2314$$

Problems with the graphical method : pump operational envelope changes with viscosity

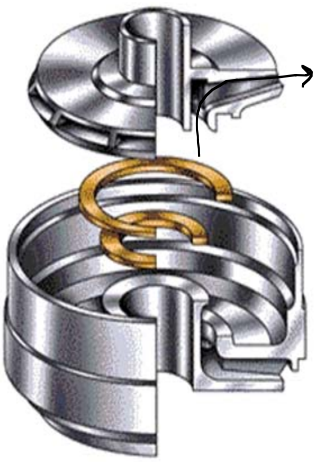


$\mu_1 > 100\,cp$

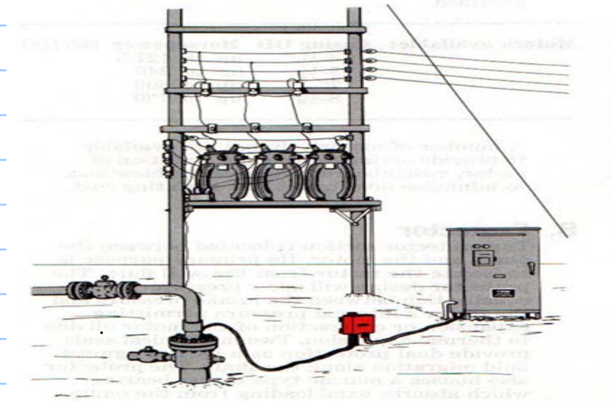


Problem with the analytical methods : it might be difficult for solver to find a feasible solution with all the constraints

mixed impeller
axial and radial

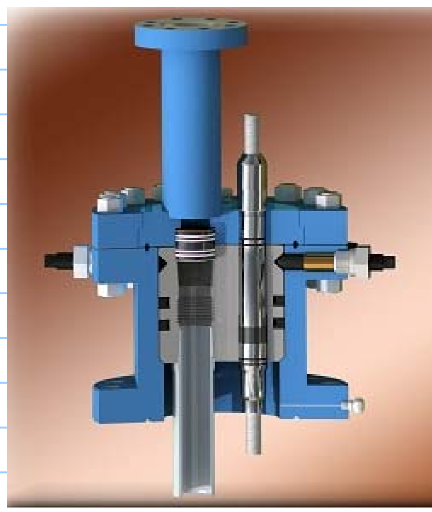


radial



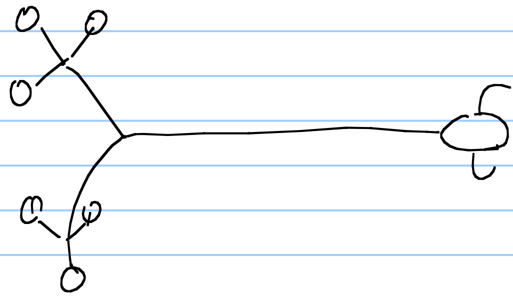
high GVF application
$GVF \lesssim 30\%$

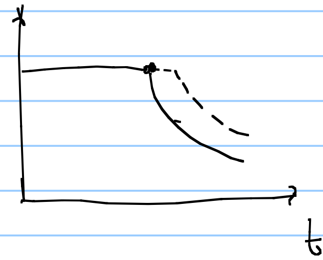
low GVF application
$GVF \lesssim 10\%$



ways to prolong plateau :

- use methods increase the available pressure. ⇝ P_{wh}
- decrease the required pressure ⇝ P_{wh}





methods to increase the available pressure :

- Pressure support methods : maintain reservoir pressure
  - injection of water \$
  - injection of gas \$
- Improve reservoir deliverability ⇝
  - acidizing
  - injecting chemical to improve permeability of near wellbore region

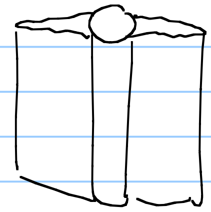
\$

$$q = J\,(P_R - P_{wf})$$

$$q = C_R\,(P_R^2 - P_{wf}^2)^n$$

↑ increase J, C_R

- fracturing



$

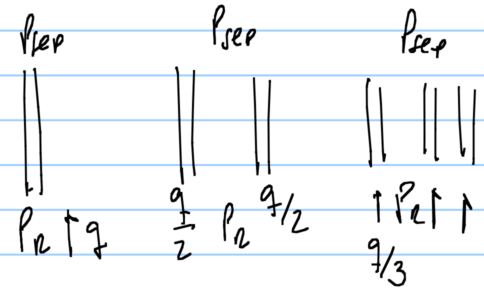
- well completion, ◦ multilateral well
  - ICV
  - ICD

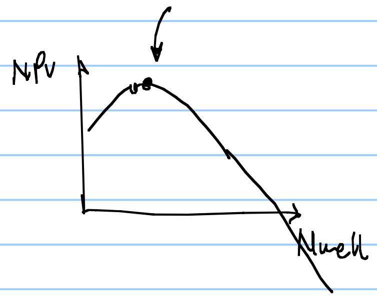
- tubing : increase the size of the tubing

  install artificial lift : ESP , foam sticks
  gas lift , plunger lift ,
  rod pump ,
  jet pump ,
  PCP ,

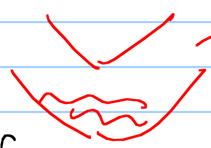
  - inject diluent ⇝ High API crude to reduce the viscosity of the formation oil.

  - increase the number of wells ⇝

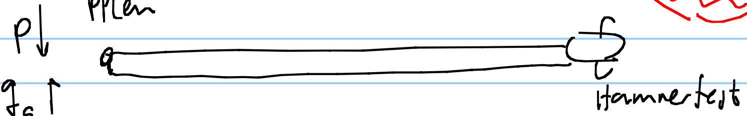




- seabed: bigger flowlines and pipelines
  parallel flowline and pipeline
  OBS ⚠ gas and liquid production, if I increase the diameter of flowline

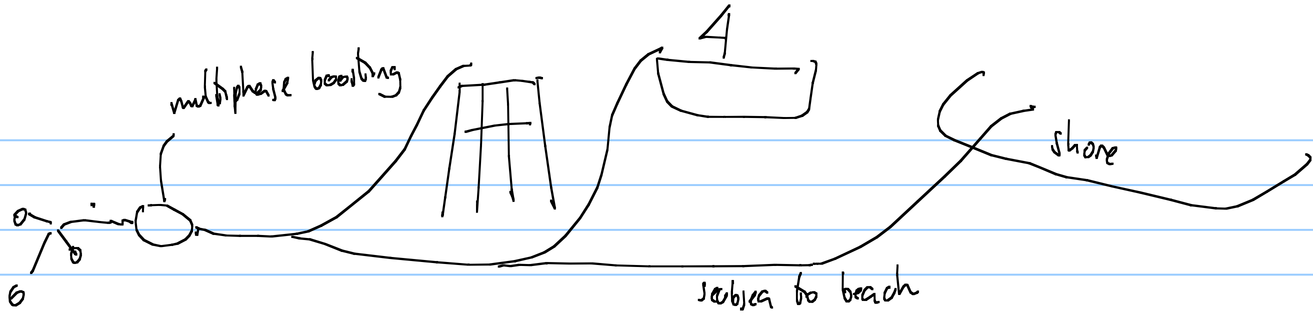


— bigger pipe ⇝ less gas velocity
↳ accumulation of liquid

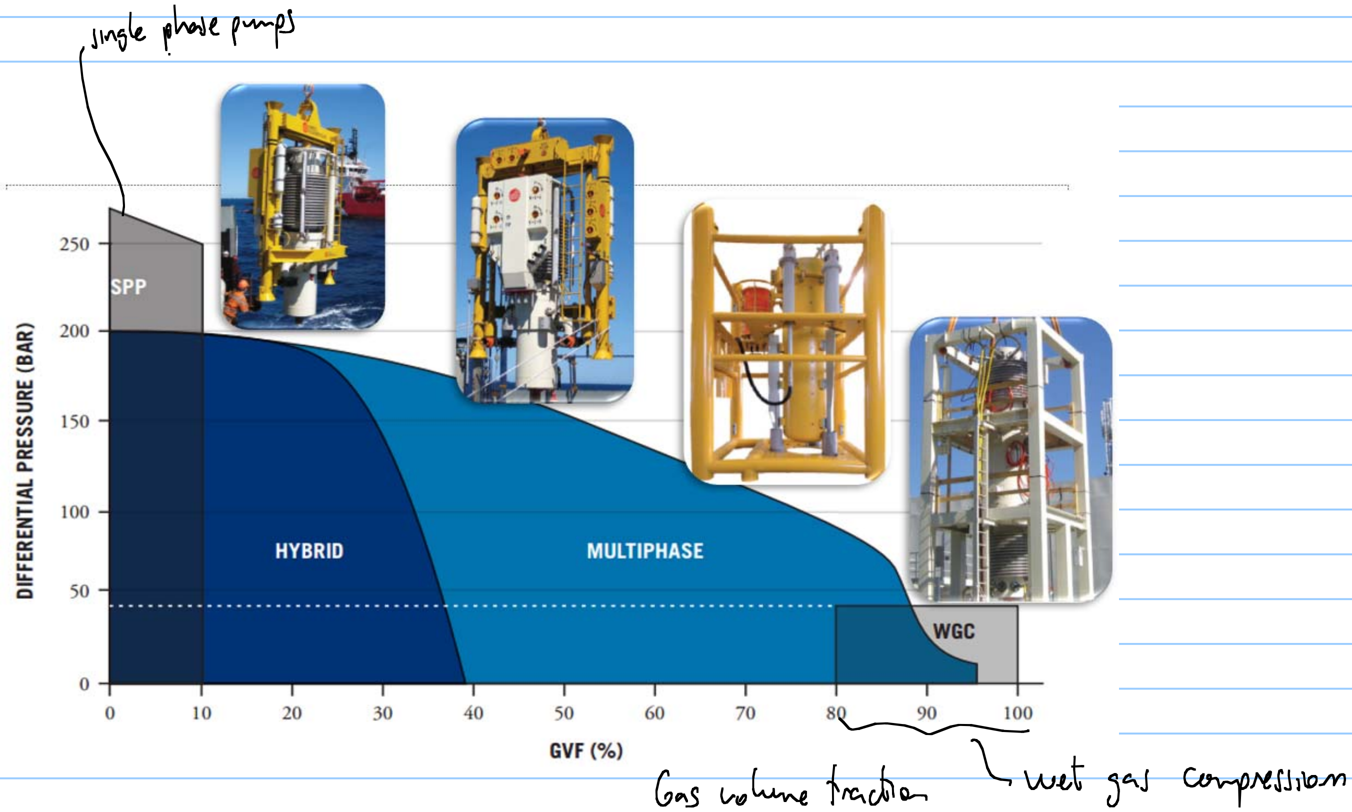


V_g ↑ — friction ↑ ⇝ Δp friction ↑

- subsea boosting and compression



one limitation is power transportation.



subsea separation + single phase boosting.