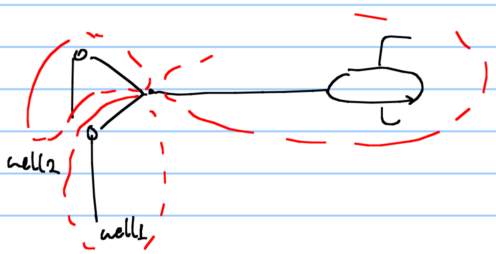
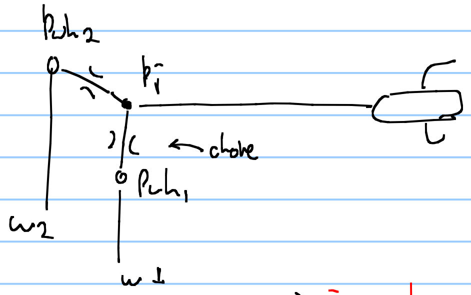
- Networks
- Boosting → liquid pumping in well (ESP)





1st approach (more general, computationally expensive) → set q_1^*, q_2^*

Equations	Unknowns	equations
IPR_1		
IPR_2		
TPR_1		
TPR_2		
FPR		
→ $\Delta p_{\text{choke}_1} = f_1(q_1, Co_1)$		
$\Delta p_{\text{choke}_2} = f_2(q_2, Co_2)$		

FPR flowline performance relationship

Co: choke opening

you need two layer iterative process.

assume Co_1, Co_2

↓

solve network

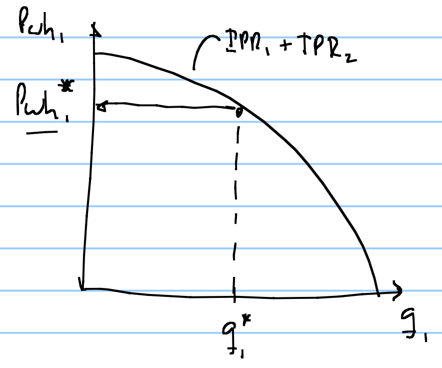
↓

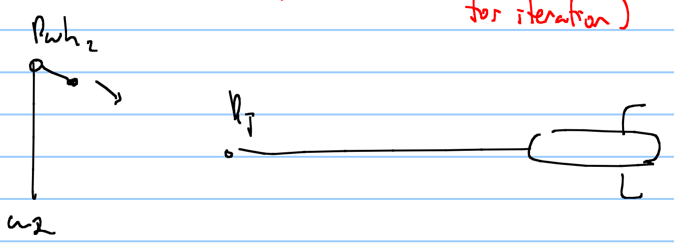
calculate q_1, q_2

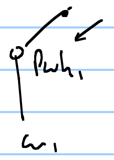
↓ same q_1^*, q_2^* (not → back to assume Co_1, Co_2)

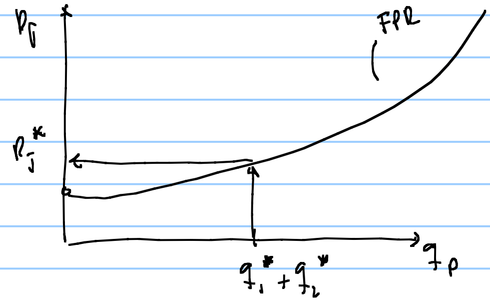
solution

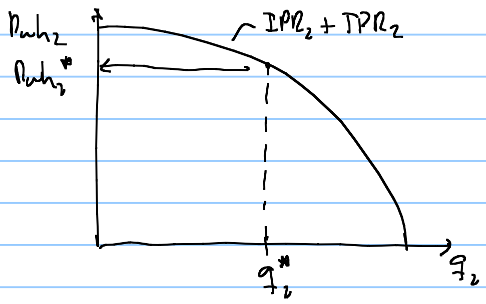
2nd approach (smarter, no need for iteration)







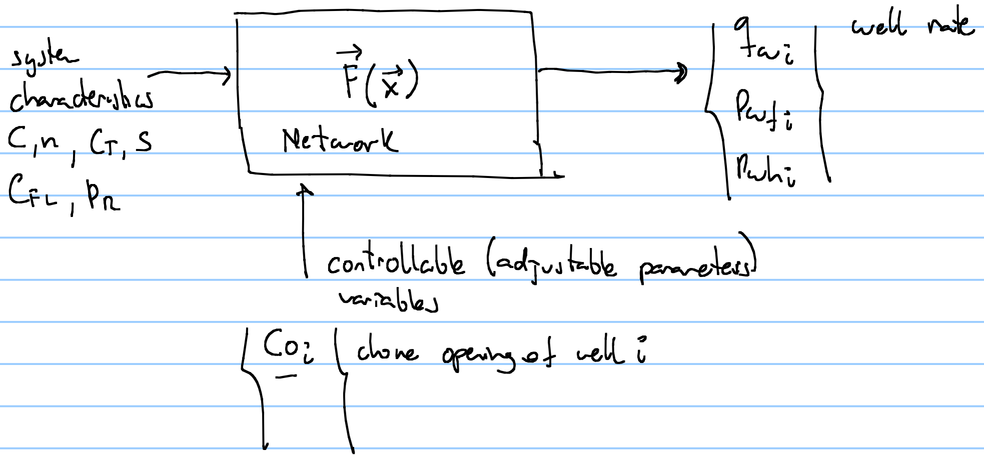




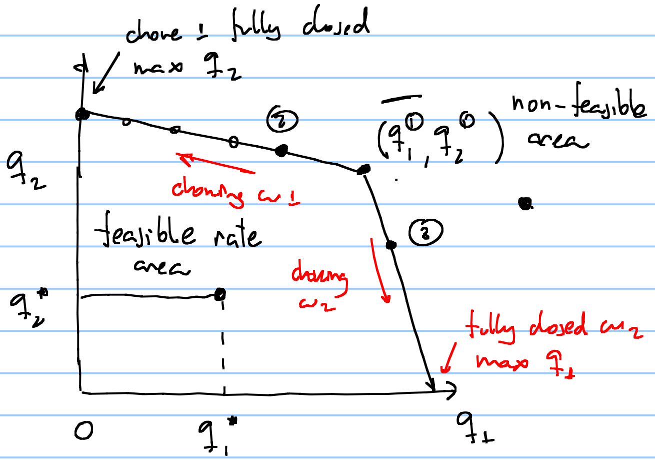
q_1^* is feasible only if $Pwh_1^* > P_J^*$

q_2^* is feasible ONLY if $Pwh_2^* > P_J^*$

for q^{rit} approach, it is sometimes useful to visualize the network as a function



Co_i has an effect on the results. for our two well system:

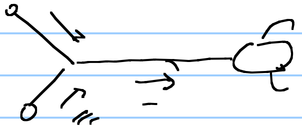


① $Co_1 = 100\%$ $Co_2 = 100\%$ (open)

$q_1^{①}$ $q_2^{①}$

② $Co_1 = 80\%$ $Co_2 = 100\%$

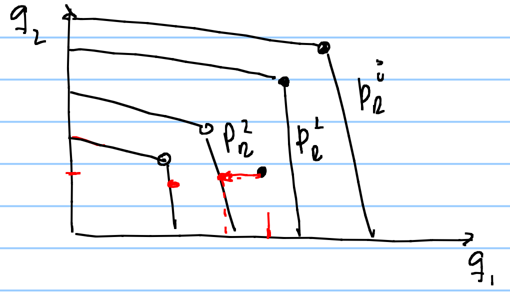
$q_2^{②}$ $\bar{q}_1^{②}$



③ $Co_1 = 100\%$ $Co_2 = 80\%$)

$q_1 \uparrow$ $q_2 \downarrow$

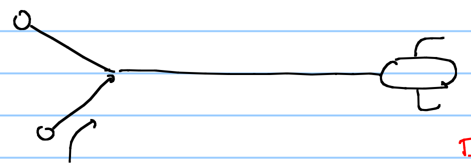
what happens with the when $p_R \downarrow$



initial reservoir pressure

$p_R^i > p_R^1 > p_R^2$

example of solution using excel



no chokes

☐ input ☐ calculated ▨ decision variable

	P_R	C	n	P_{wf}	q	C_T	S	P_j	C_{FL}	P_{sep}	Error
well 1	☐	☐	☐	▨	☐	☐	☐	▨			$(P_j - P_{av})^2$
well 2	☐	☐	☐	▨	☐	☐	☐	▨			$(P_j - P_{av})^2$
flowline					$q_1 + q_2$	☐	☐	▨	▨	▨	$(P_j - P_{av})^2$
							P_{av}	▨			$\Sigma(\quad)$

use this as the objective function

If iterating with q the following could happen

$$q = C\left(P_R^2 - \underset{\sim}{P_{wf}^2}\right)^n$$

$$P_{wf} = \underline{\sqrt{P_R^2 - \left(\frac{q}{C}\right)^{1/n}}}$$

P_{wf} on the other hand, i know the bounds

$$P_{sep} \le P_{wf} \le P_R$$

Solver Parameters

Set Objective: \$A\$1

To: ○ Max ○ Min ● Value Of: 0

By Changing Variable Cells: P_{wf_1} , P_{wf_2}

Subject to the Constraints:

☑ Make Unconstrained Variables Non-Negative

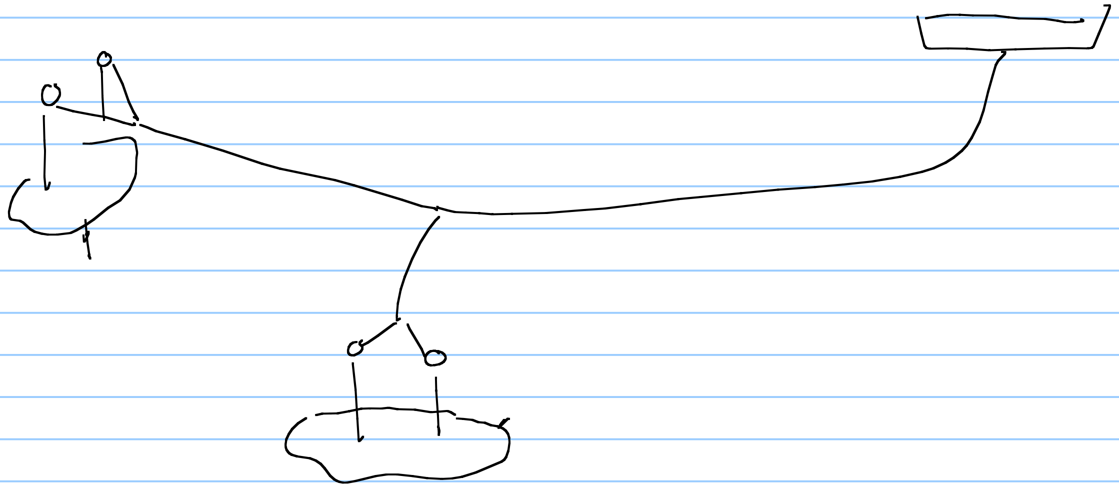
Select a Solving Method: GRG Nonlinear

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

in solver, i cannot make 3 cell equal, only maximize, minimize or "have equal to" one cell

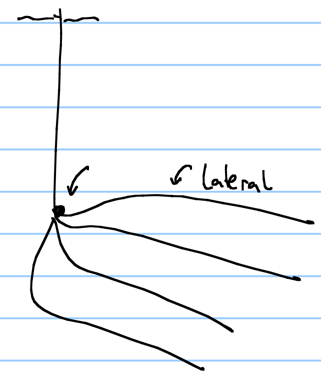
Another complexity is having well in the same network that are producing from different reservoirs

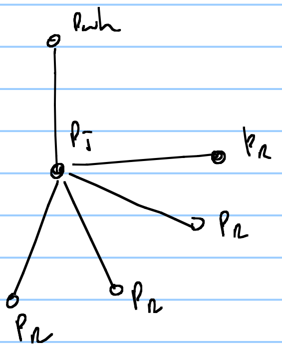


time	P_{R_1}	z_1	G_{p_1}	P_{R_2},	z_2,	G_{p_2}
0	0	0	0	0	0	0
1						
2						

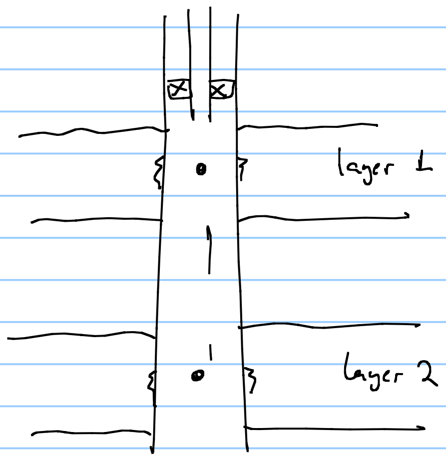
Network solving can also be used for downhole networks

multi-lateral wells

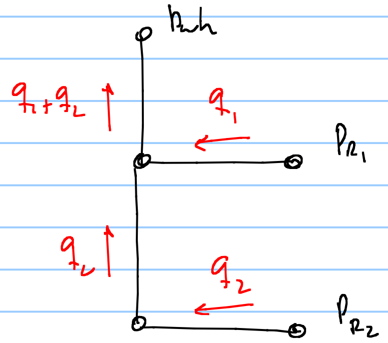


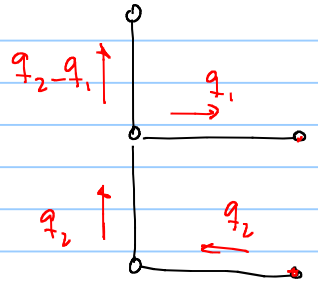


multi-layer wells

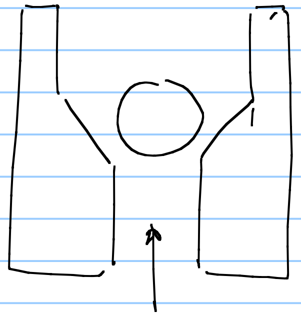


if layer deplete very differently

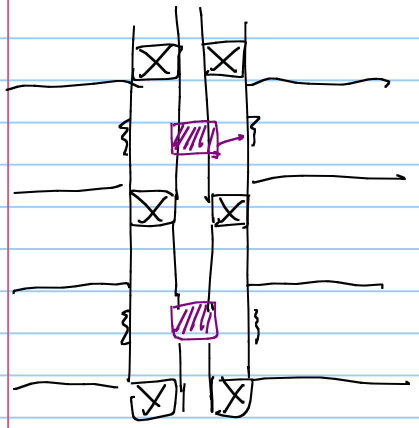




in well, a check valve is typically placed at X-mas tree to avoid back flow



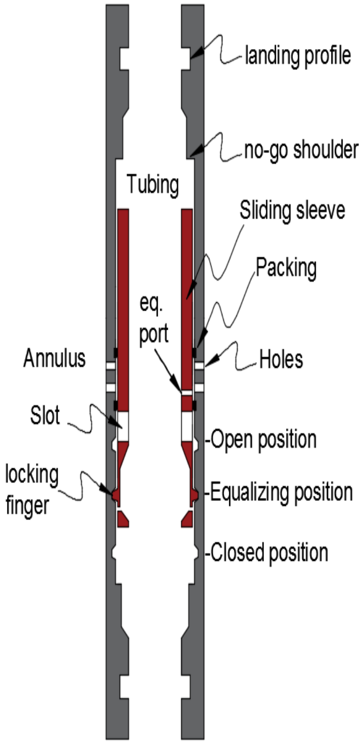
in well sometimes we use sliding sleeves



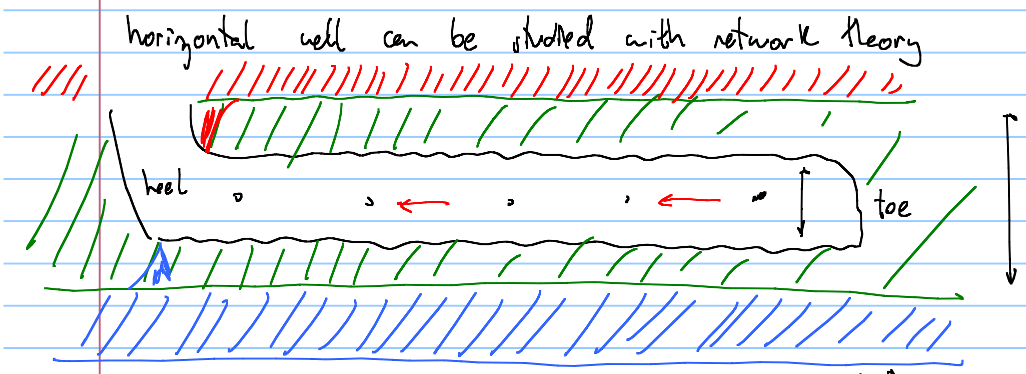
▨ sliding sleeve

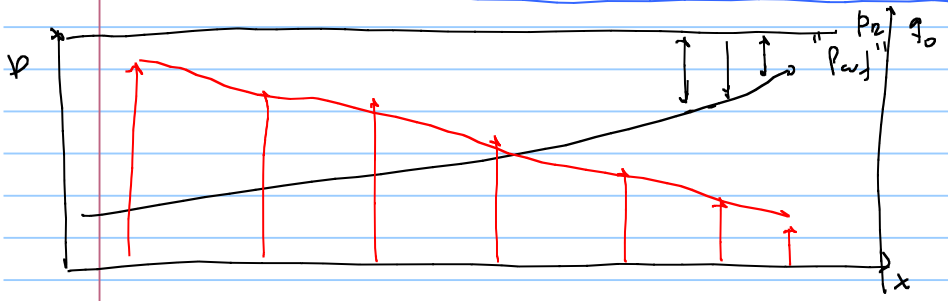
Inflow control device ICD

Inlow control valve (choke) ICV

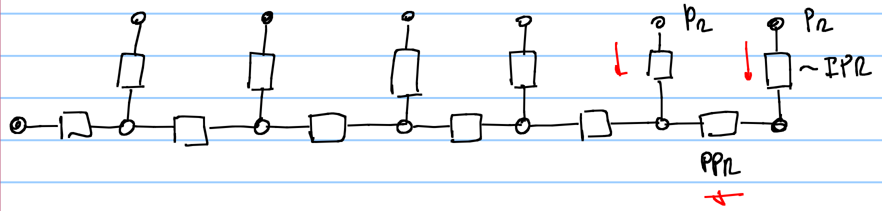


horizontal well can be studied with network theory

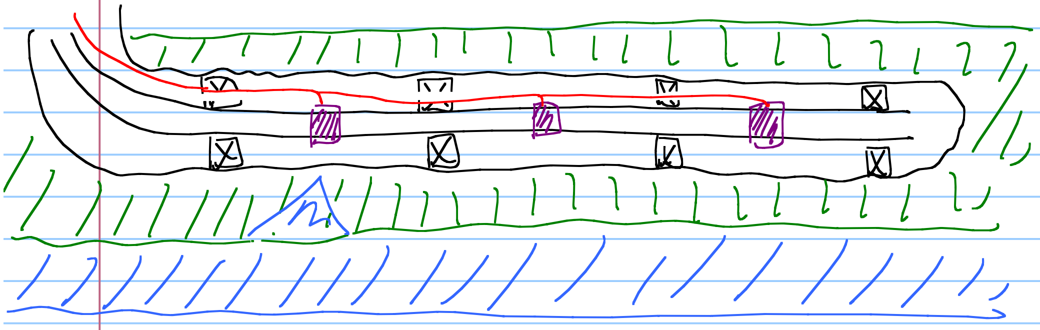


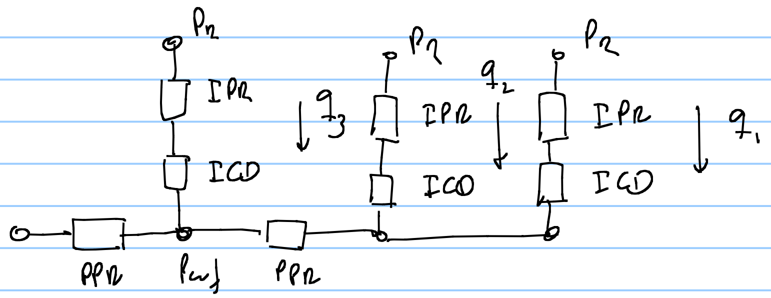


$$q_o = J(P_R - P_{wf})$$



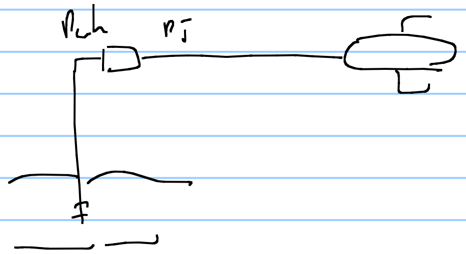
to improve drainage

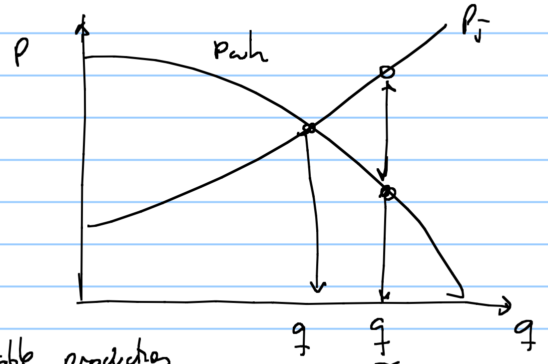




change Δp accross each ICD to get $q_1 \simeq q_2 \simeq q_3$

Boosting : adding energy to fluid (pressure increase)





\ low $ (low API, high viscosity)

- from the beggining (to get profitable production rates)
- later while production (to prolong plateau)

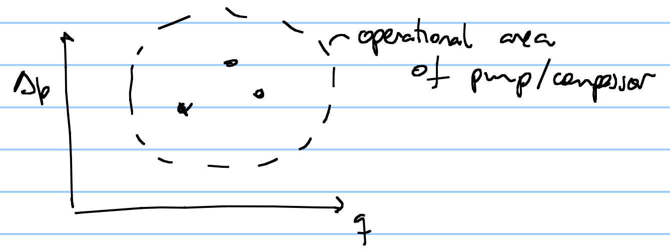
q^* Δp^*

two different types

well level
Artificial lift

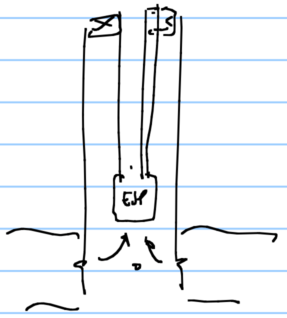
system level (group of wells)
boosting is typically
- two-phase gas + liquid flowing through pump
- gas compression
- separate and pump gas and liquid separatedly

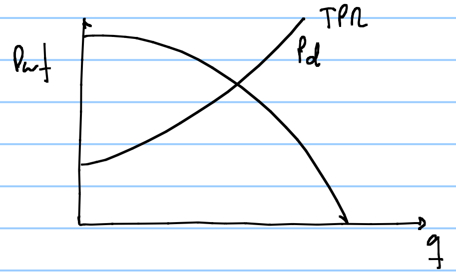
q^* Δp^* is this combination feasible

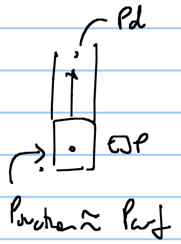


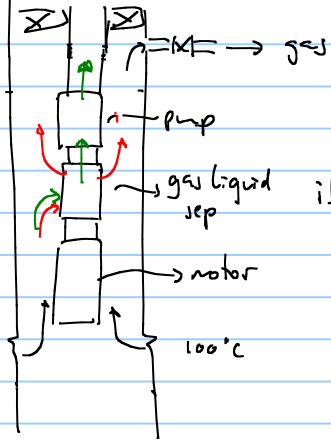
Artificial lift, electric submersible pump (ESP) pump for mainly liquid.

typically installed as close as possible to formation

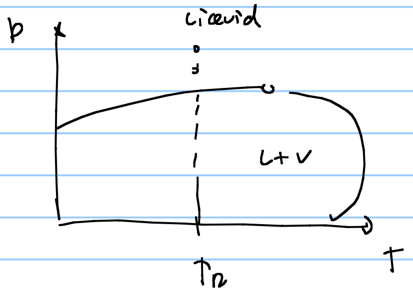


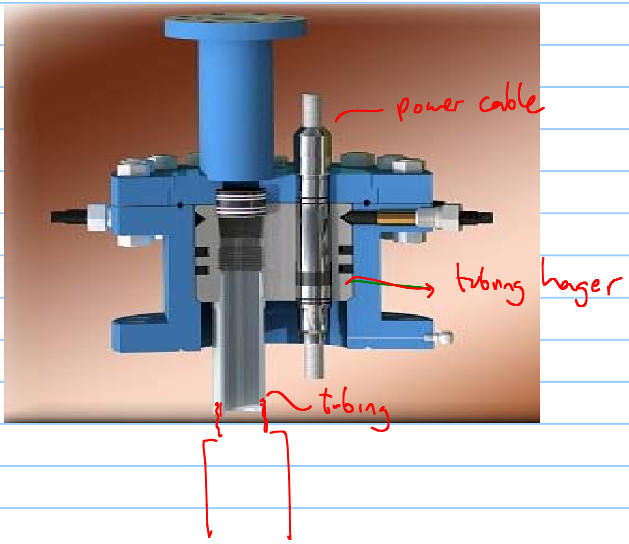


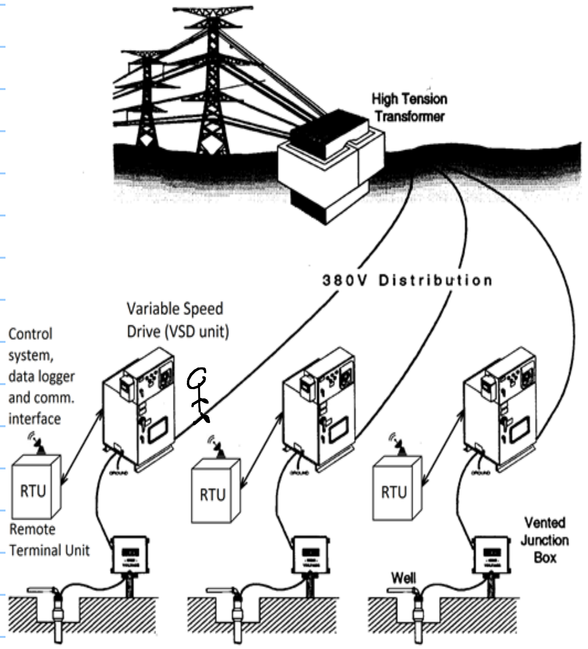


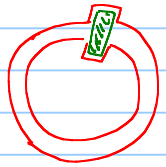


if $P_{wc} < P_{bubble\ point}$ → there will be gas



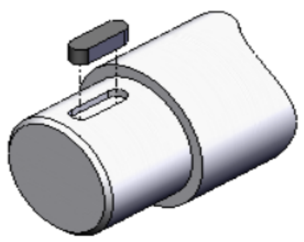


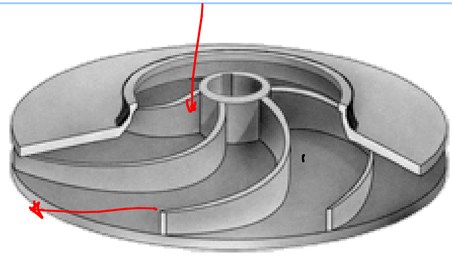




down

Armais Arutunoff

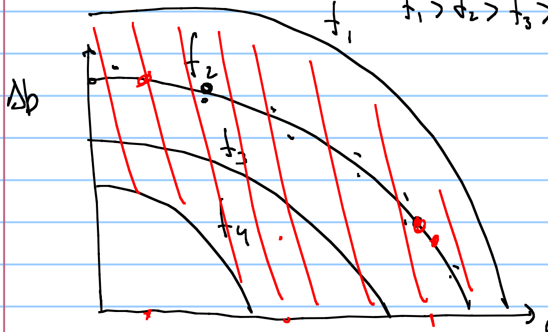




up

$f_1 > f_2 > f_3 > f_4$

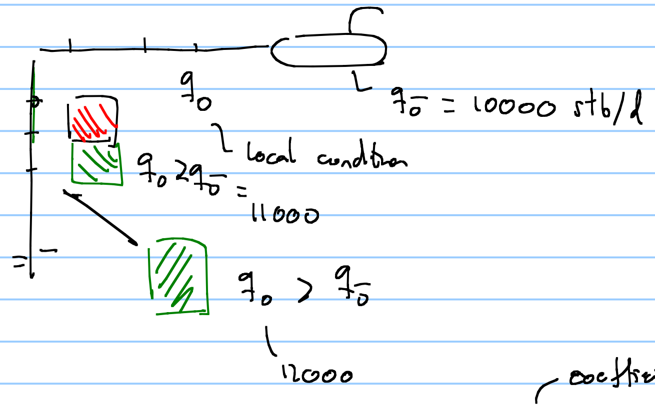
$30 hz \leq f \leq 70 hz$



$$\underset{fixed}{\underline{P_{ower}}} = \frac{\Delta p \cdot q}{\eta_H}$$

for a collection of stages (pumps in series)

$q \sim [\cancel{Sm^3/d}]$ $[m^3/d]$ at inlet conditions

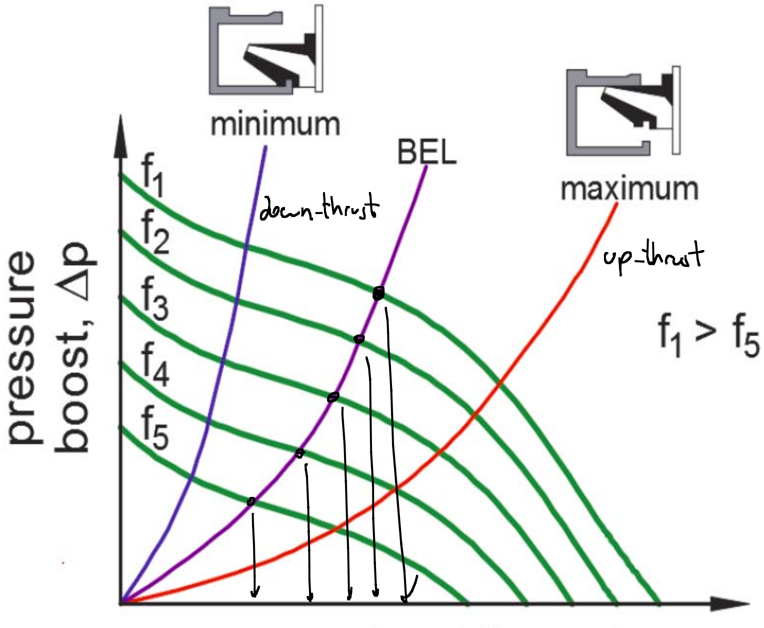


coefficient calculated @ fref = 60 Hz
50 Hz

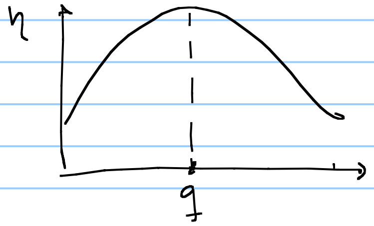
pump equation $$\Delta p = \rho_{mix} \cdot \left(a\, q^4 + b\, q^3 + c\, q^2 + d\, q + e \right)$$

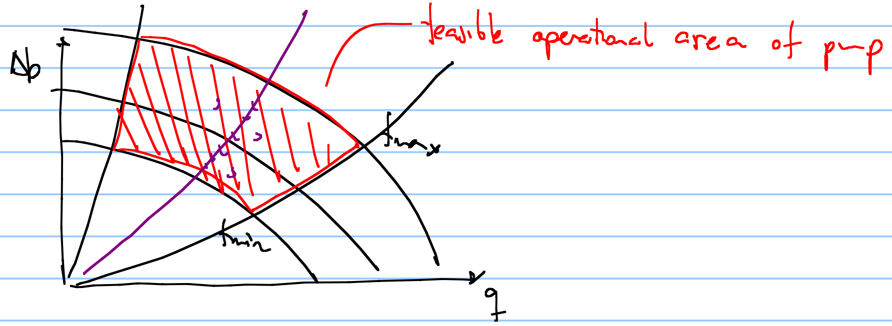
for another frequency $$\Delta p = \rho_{mix} \left(a \left(q \frac{f_{ref}}{f} \right)^4 + b \left(q \left(\frac{f_{ref}}{f} \right)^3 \right) + c \left(\frac{q\, f_{ref}}{f} \right)^2 + d \frac{f_{ref}}{f} q + e \right]$$

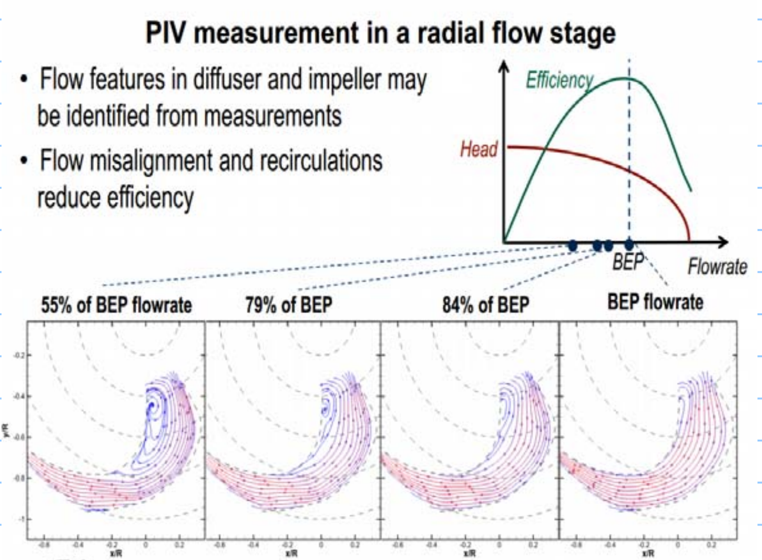
there is another constraint to the pump map: upthrust - down-thrust region (floating impeller)



$$P = \frac{\Delta p \cdot q}{\eta_H}$$





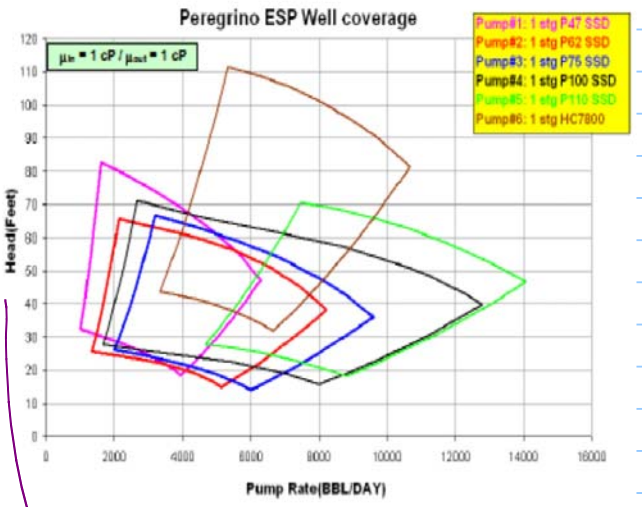


PIV measurement in a radial flow stage

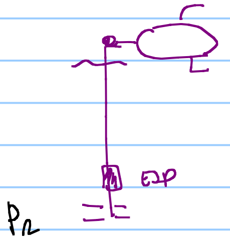
- Flow features in diffuser and impeller may be identified from measurements
- Flow misalignment and recirculations reduce efficiency

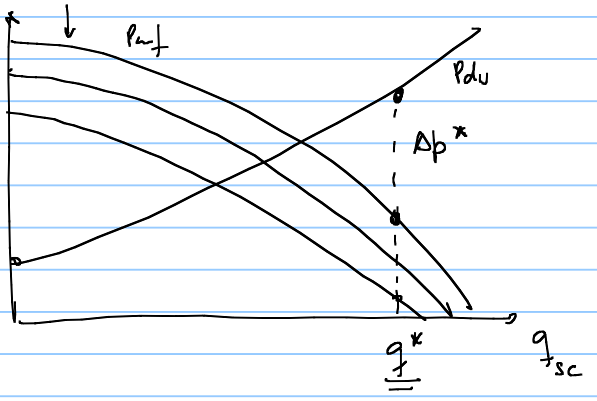
Example of stall region in diffuser passage (measured)

SPE-14MEAL-14017-PP-MS • Measurement and Unsteady Simulation of Internal Flows within Stages • J Dusting



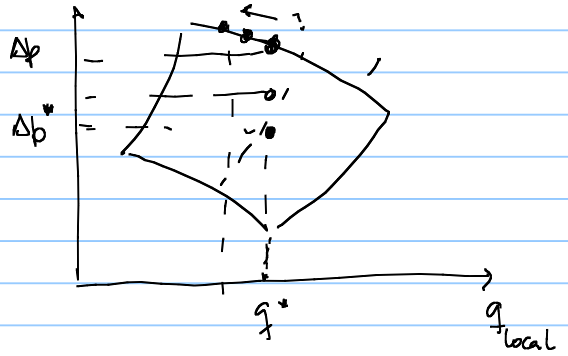
$\frac{\Delta p}{\rho} = \Delta h$ head





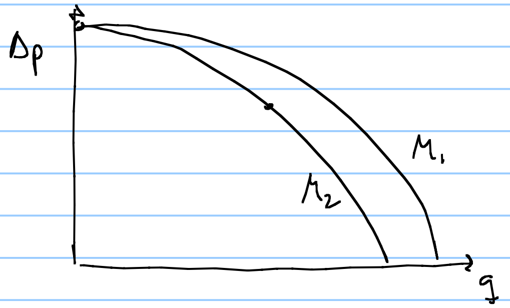
with time, $P_R \downarrow$

$\Delta p^* \uparrow$



$q_{local} \approx q_{sc}$ no gas is coming out of solution

viscosity affect the curve of pump



$\mu_2 > \mu_1$