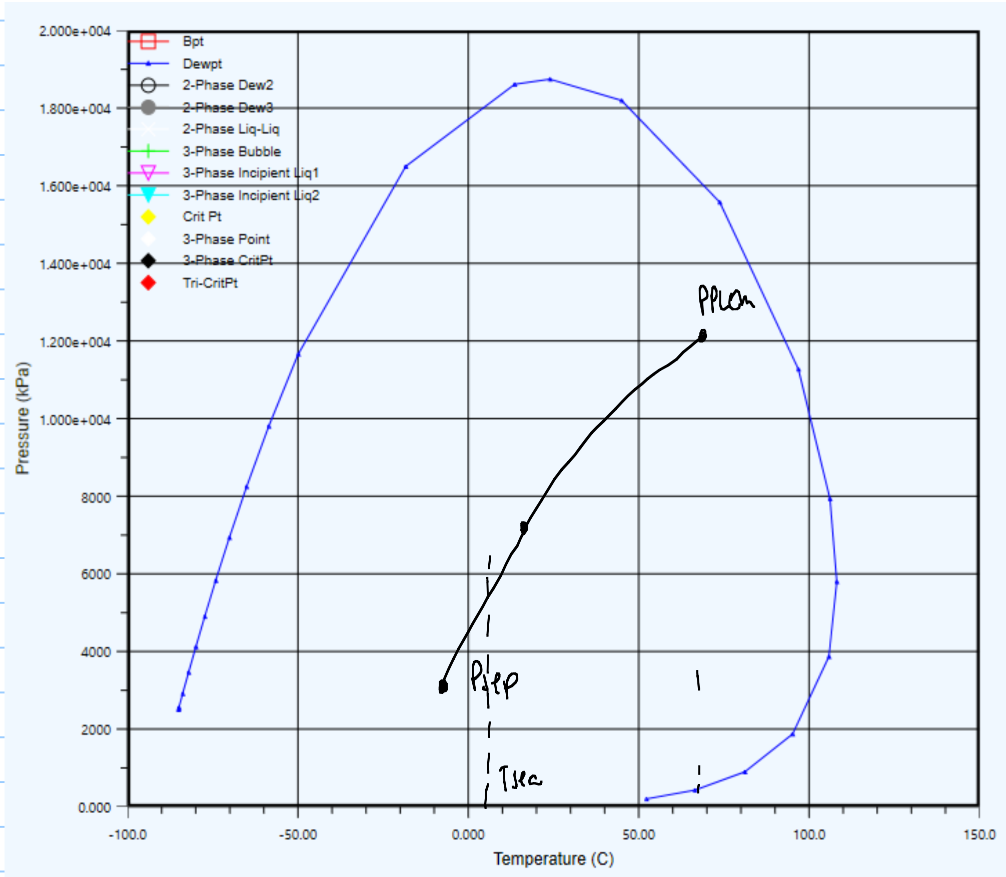
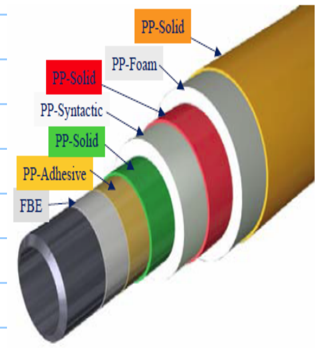
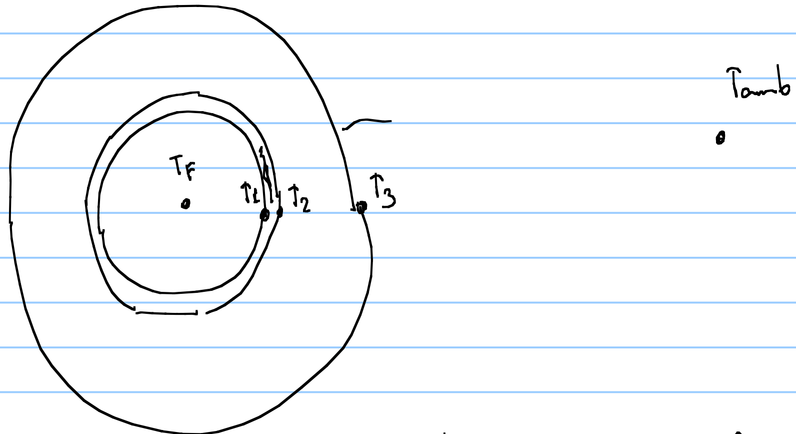
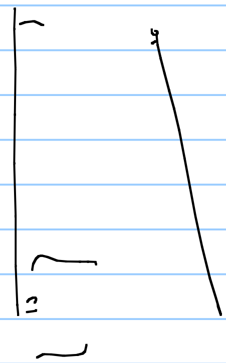








$\dot{Q}$ heat flowing from fluid to ambient.

heat transfer in solids conduction

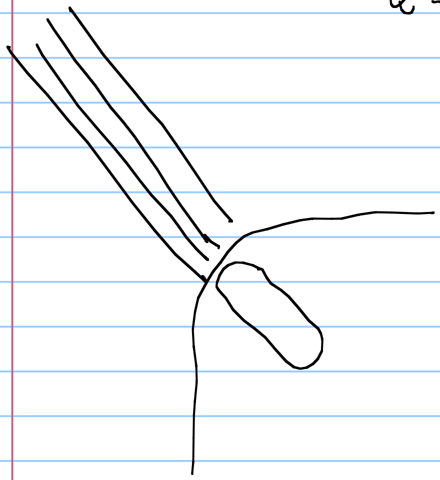
heat transfer in fluids ~ convection → forced convection; → natural convection

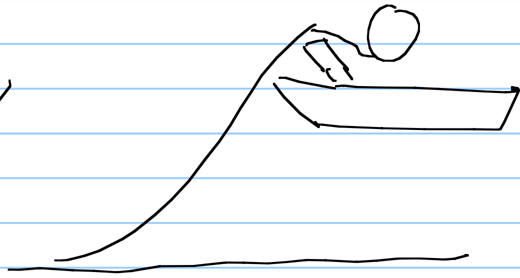
$$\dot{Q} = \underbrace{h_i}_{\left[\frac{W}{m^2 \cdot K}\right]} A_i \left(T_f - T_1\right)$$

↳ internal convection coefficient

↳ $\pi D_1 . L$

$$\dot{Q} = 2\pi \overset{\text{conductivity}}{K}\, L \,(T_1 - T_2)\,\frac{1}{\ln\left(\frac{r_2}{r_1}\right)}$$





$$\dot{Q} = h_{out}\, A_{out}\,(T_3 - T_{amb})$$

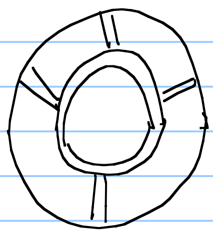
Sum all the equations

$$(T_f - T_{amb}) = \dot{Q}\left[\frac{1}{h_i A_i} + \frac{1}{h_o A_o} + \frac{\ln(r_2/r_1)}{2\pi k_m L} + \frac{\ln(r_3/r_2)}{2\pi K_{insu} . L}\right]$$

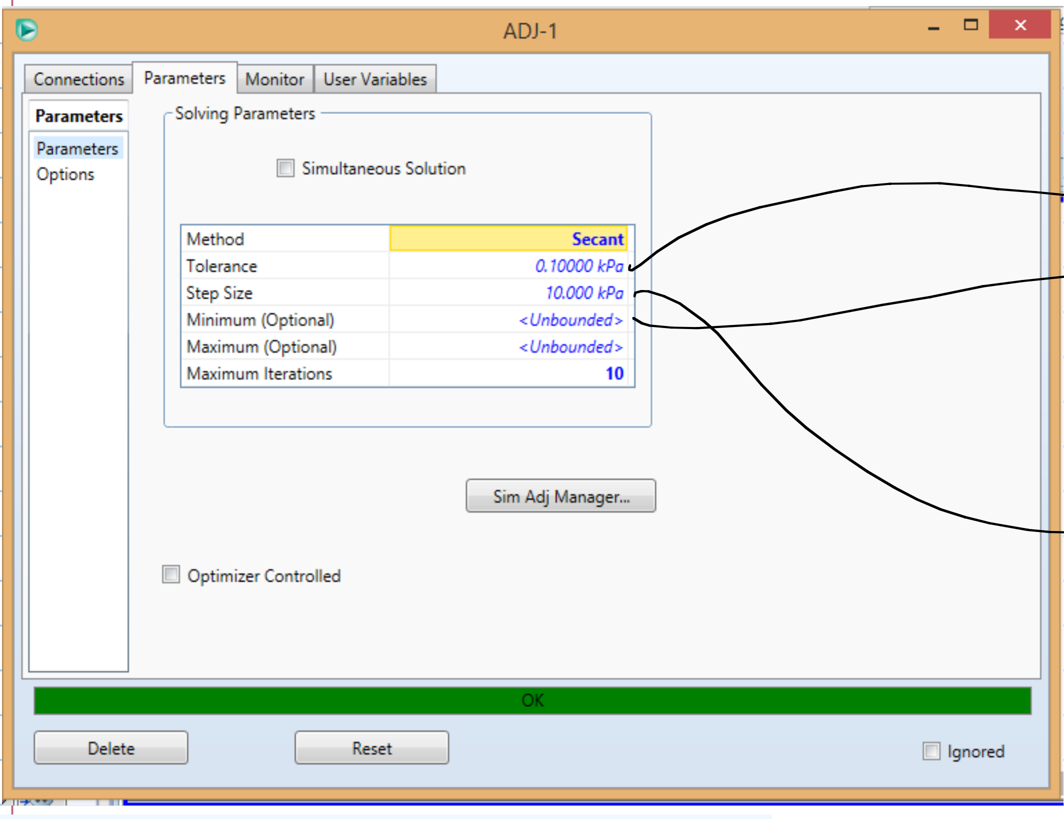
$$(T_f - T_{amb}) = \dot{Q}\,\frac{1}{\underbrace{U}_{\text{universal heat transfer coefficient}} . A_o}$$

$$\frac{1}{U . A_o} = \left[\frac{1}{h_i A_i} + \frac{1}{h_o A_o} + \frac{\ln(r_2/r_1)}{2\pi k_m L} + \frac{\ln(r_3/r_2)}{2\pi K_{insu} . L}\right]$$

$$U = A_o^{-1} \cdot \left[\frac{1}{h_i A_i} + \frac{1}{h_o A_o} + \frac{\ln(r_2/r_1)}{2\pi k_m L} + \frac{\ln(r_3/r_2)}{2\pi K_{insu} . L}\right]^{-1}$$



$h \neq f(x)$ $\quad x$ distance.



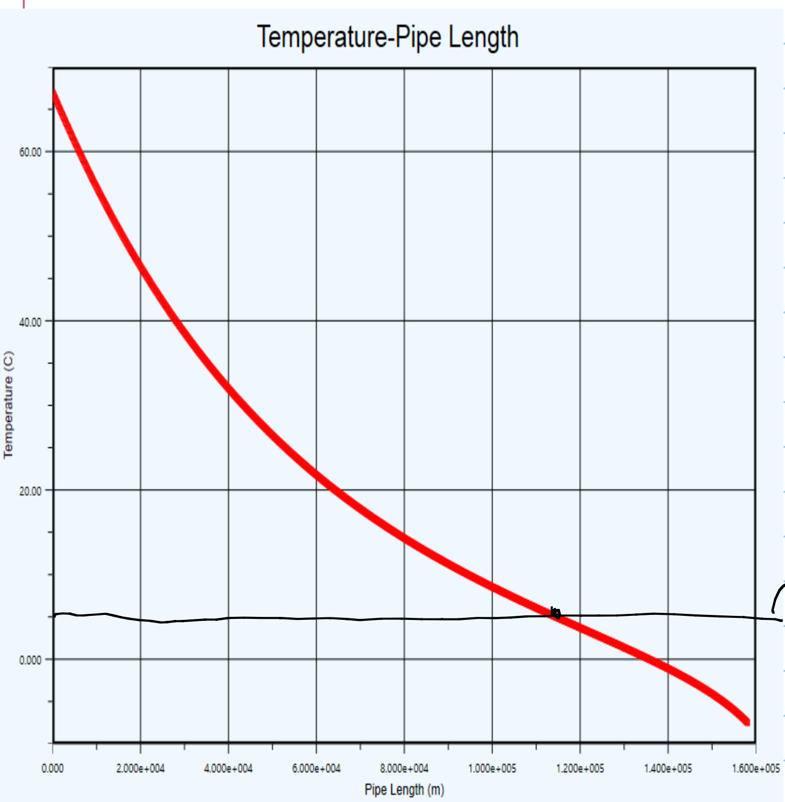
$p = 30$ bar $\pm$ 0.001 bar

P_{plem} min

P_{plem} max ~>

P_{plem} 120 bar

120.01 bar

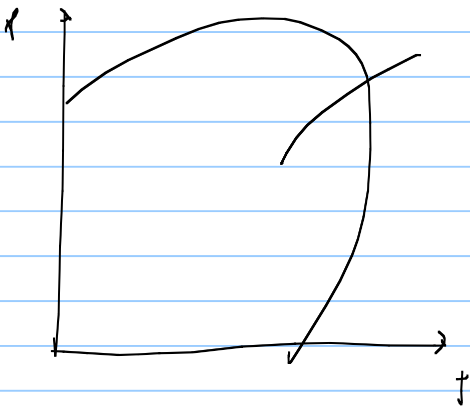


T_{sea}

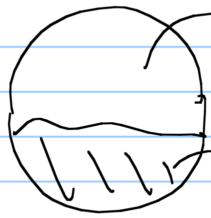
below sea temperature Joule-thompson effect

Δp ~> ΔT

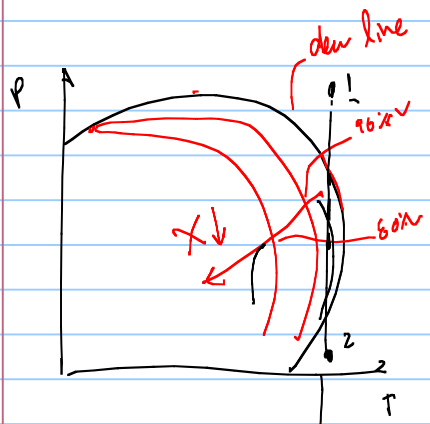
joule-thompson coefficient

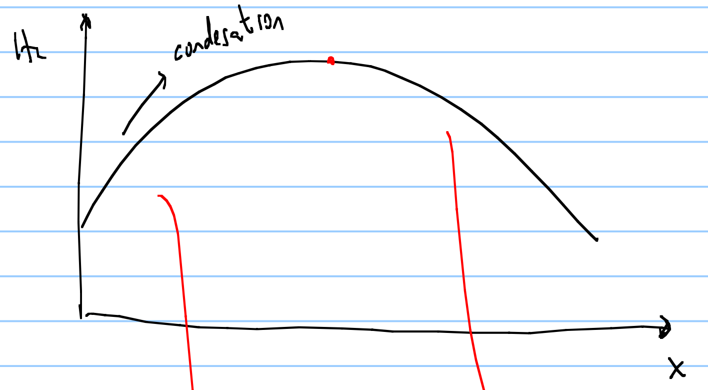


$$\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H$$



$$\frac{A_L}{A_T} = H_L$$





$$X = \frac{m_g}{m_L + m_g}$$

• condensation

evaporation

retrograde condensation

condensation → evaporation.

• multiphase flow dynamics $V_L \downarrow$ $V_g \uparrow$

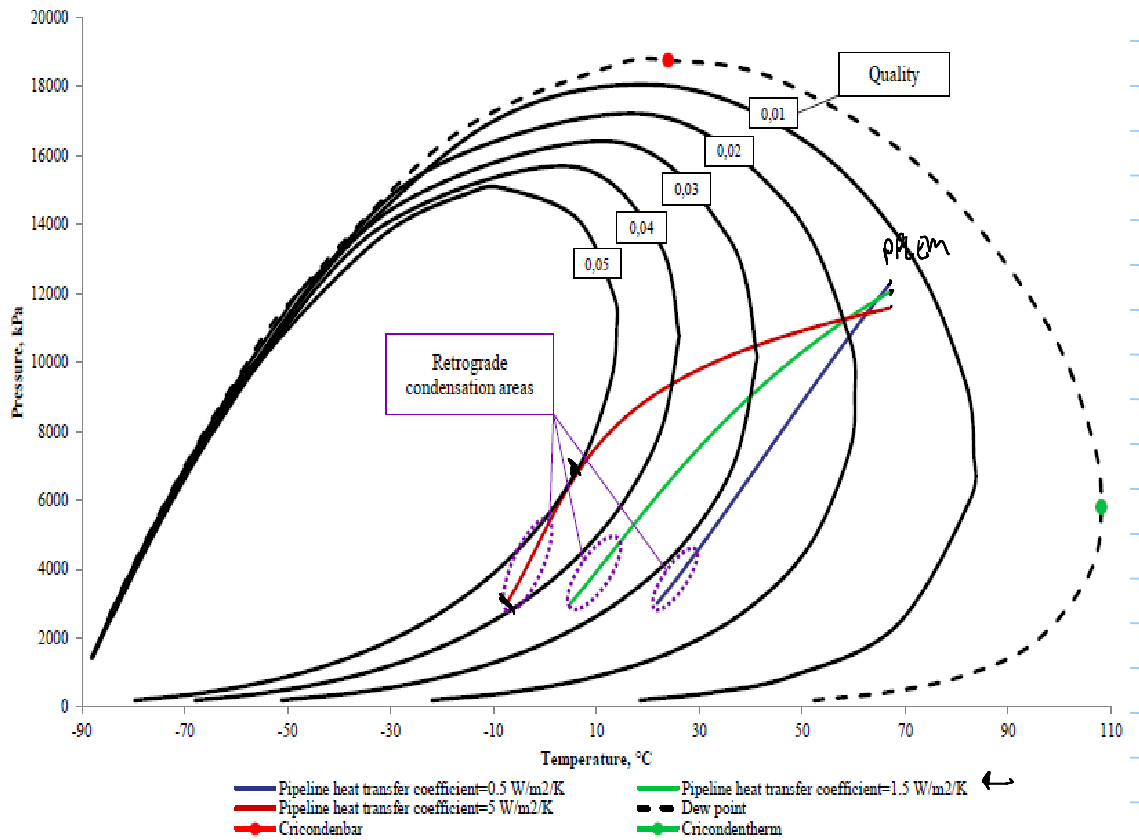
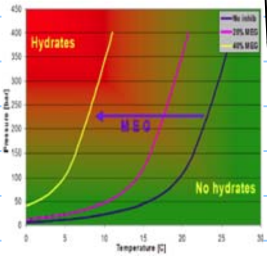
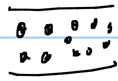
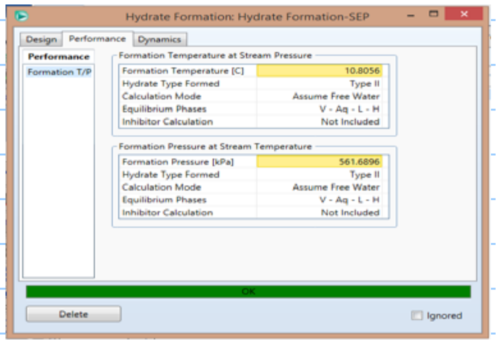
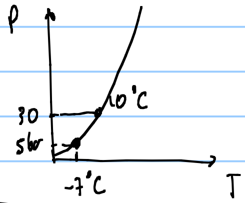
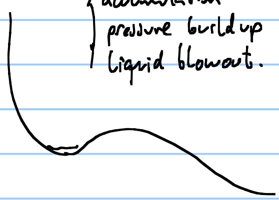
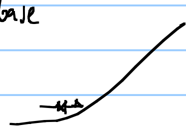
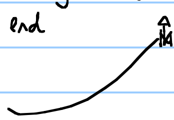
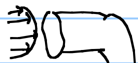
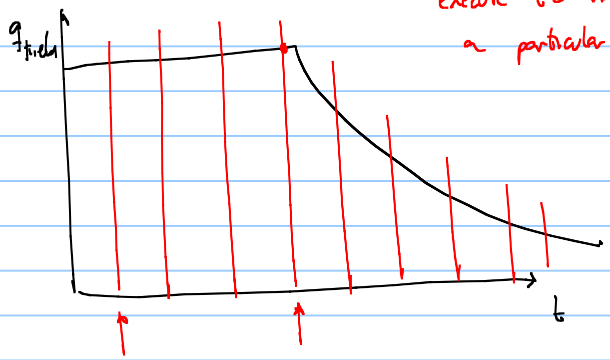


Figure 10. Phase envelope of the gas mixture and P-T distribution along the pipeline (zero-elevation case).

$$\Delta p = \Delta p_g + \Delta p_f$$

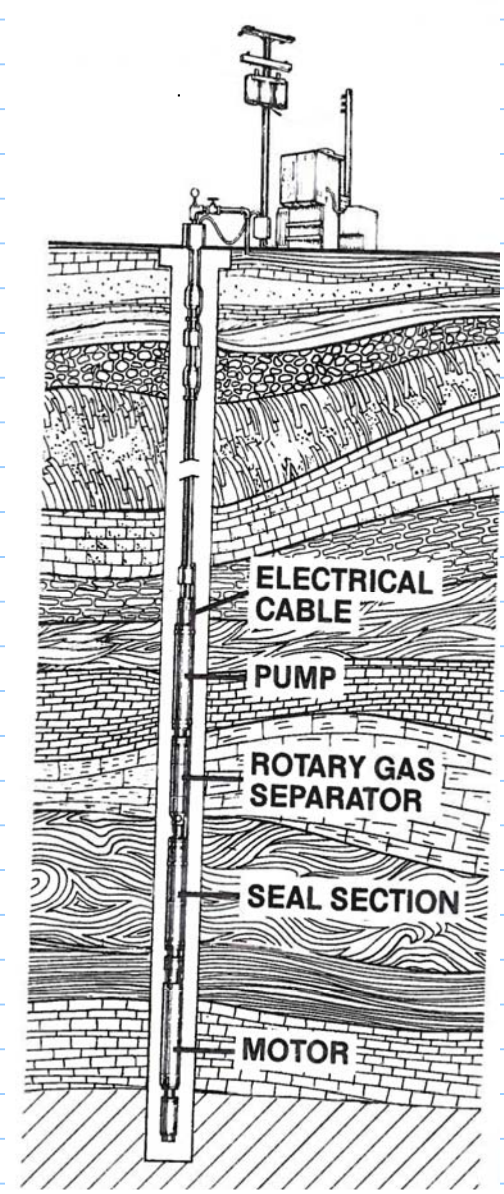
$$\rho = f(P,T)$$

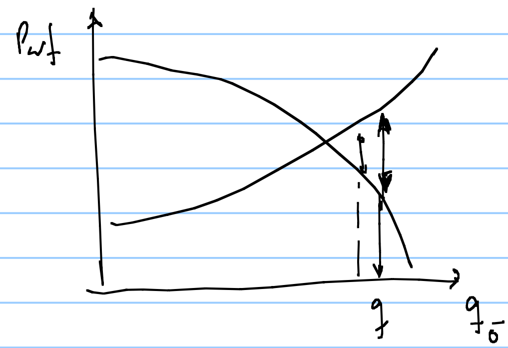
Flow assurance issue	Cause	Consequences	industrial Preventive measures	Tool to analyze
Hydrates 	• water free water • light HC molecules • Begin to form at P,T according to hydrate equilibrium  • precipitation, agglomeration.	• blockage of pipe production loss • flowlines and pipelines	• pipe insulation • electric heating • hydrate inhibitor acting on the free water avoid inhibitor evaporation !! 150°C • cold flow. SINTEF  • water separation • pipe coating	• correlations • compositional and multiphase simulator Hydrate formation module in HYSYS  
Wax 'slug' in pig trap at Statfjord B  Wax	• precipitation of heavy chains as a solid phase. • Crudes with tendency to produce wax • Begin to form at given P, T • cold wall • precipitation, agglomeration, deposition	↑ pressure drop • roughness ↑ • reduce cross section area of pipe • gelling ↳ startup of pipe.	• pigging (3 months) • stay away from wax region - pipe insulation - electrical heating • chemical inhibitors • chemical dissolvers • pipe coating • Cold flow	• laboratory experiments tune to correlations or expressions • deposition rates $\dot{m}$ vs T
Slugging intermittent flow 	• multiphase flow dynamics • transients liquid accumulation accumulation pressure buildup liquid blowout. 	• unstable operation • added pressure drop • vibration ↳ structural damage ↳ leaks	• gas lift in riser base  • choking at riser end  • subsea separation	• transient multiphase flow simulator (OLGA, LEDA) slug frequency slug length ↳ forces on structures ↳ riflex ↳ Fisana ↳ FEA Finite element analysis.
Scaling	Deposition of mineral from produced water • Begin to deposit at P,T conditions • mixing of incompatible waters • occurs in well with associated water production.	• reduction of pipe cross section • malfunctioning of well equipment. SSSV	• chemical inhibitors • chemical dissolvers • mechanical removal • pipe coating.	laboratory tests deposition rates
erosion	• Liquid droplets in the gas • gas bubbles in liquid • Sand production	• structural problem • leaks • vibration	• high resistance pipe coating • modify geometry • reduce flow rate • sand separation subsea	• Computational fluid dynamics (CFD), 

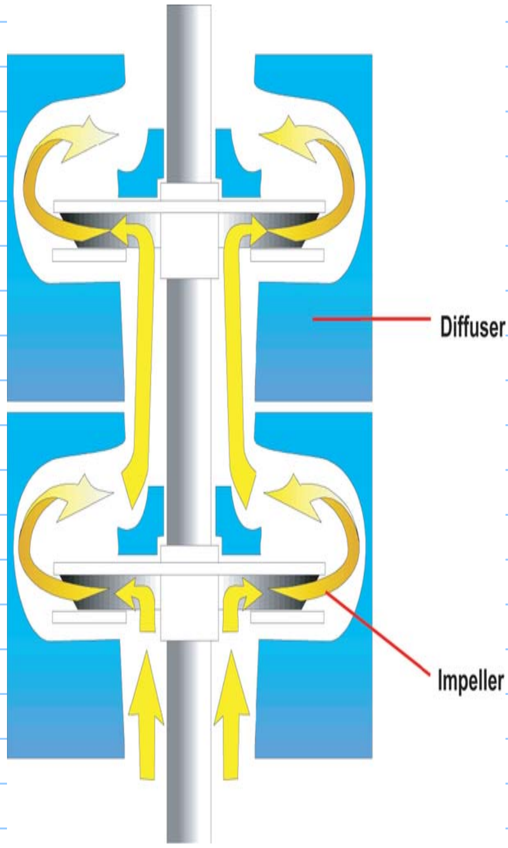


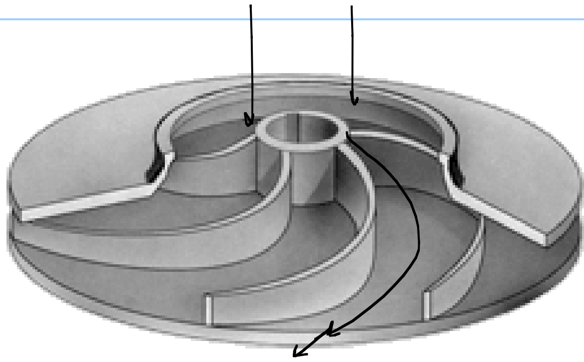
execute the analysis with fixed rate at a particular point in time
- design phase
- operational phase

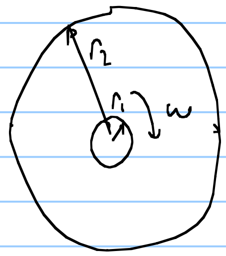
Production enhancement techniques: ESP: (Electric submersible pump).







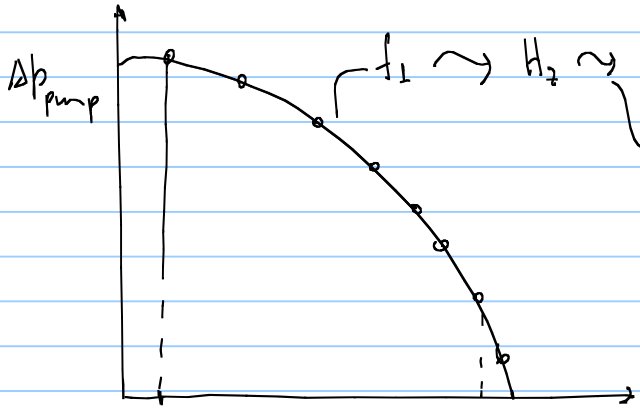




$U_1 = r_1 \vec{\omega}$

$U_2 = r_2 \vec{\omega}$

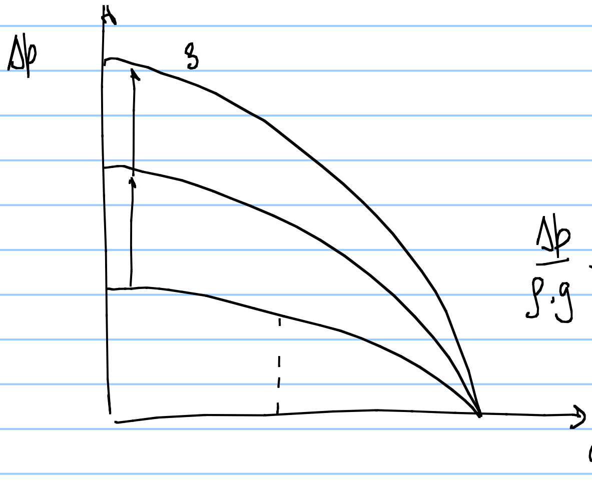
hydraulic performance of ESP = IPR



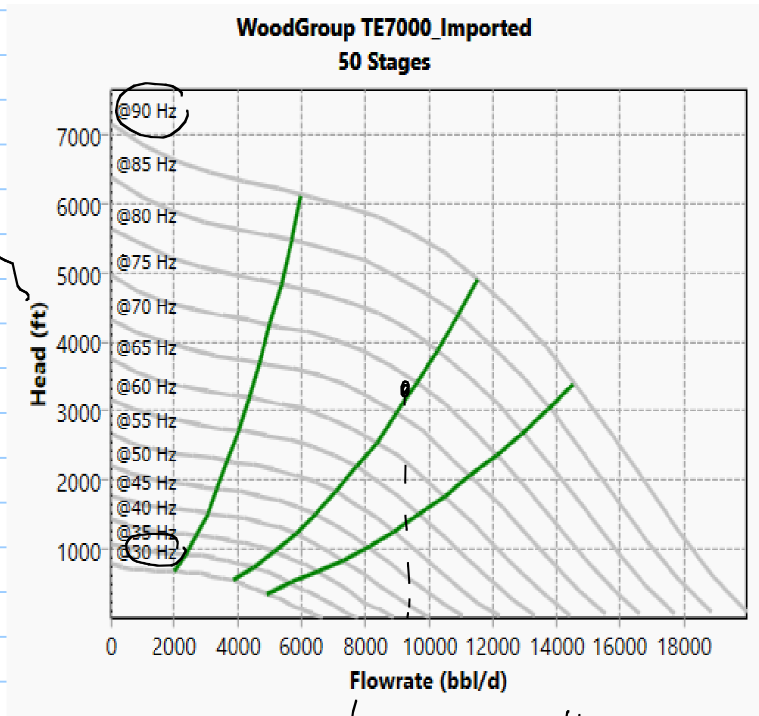
$f_1 \sim Hz \sim 90\ Hz$

$\hookrightarrow 30\ Hz$

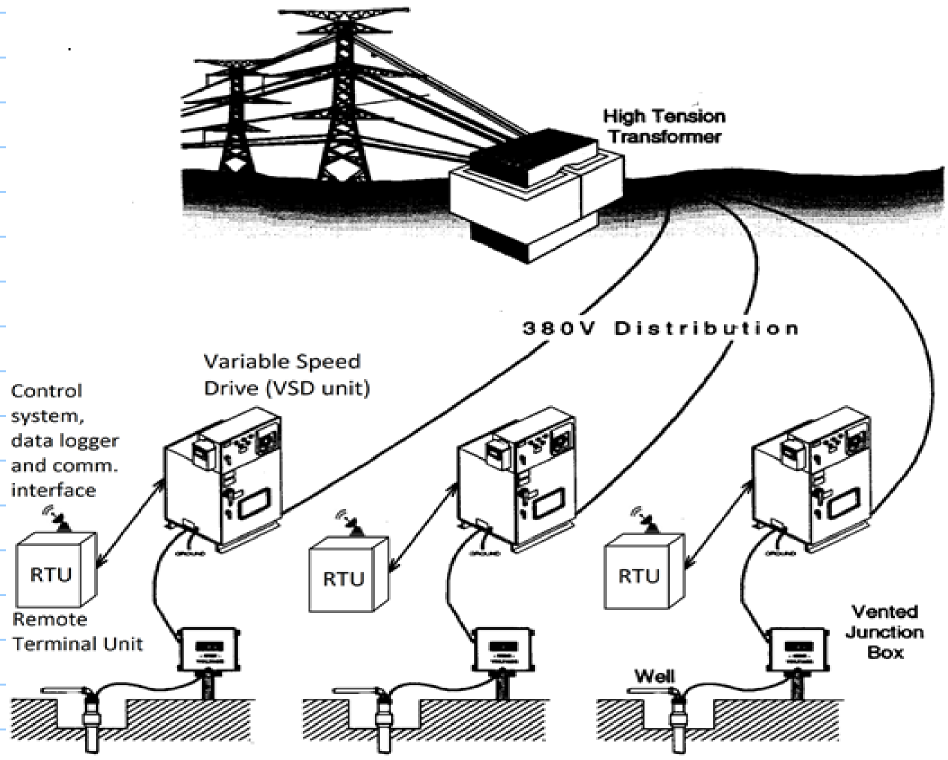
q_{actual} liquid rate at pump outlet



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



local liquid flow rate


High Tension
Transformer
380V Distribution
Variable Speed
Drive (VSD unit)
Control
system,
data logger
and comm.
interface
RTU
Remote
Terminal Unit
RTU
RTU
Vented
Junction
Box
Well