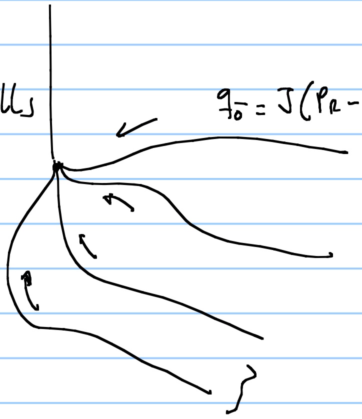
2018 03 19

- downhole networks
- flow of undersaturated oil and water in pipes
- ESP flow design

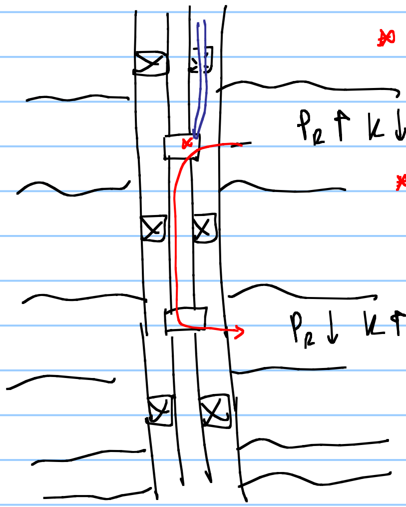
Downhole networks can occur in:

multilateral wells

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

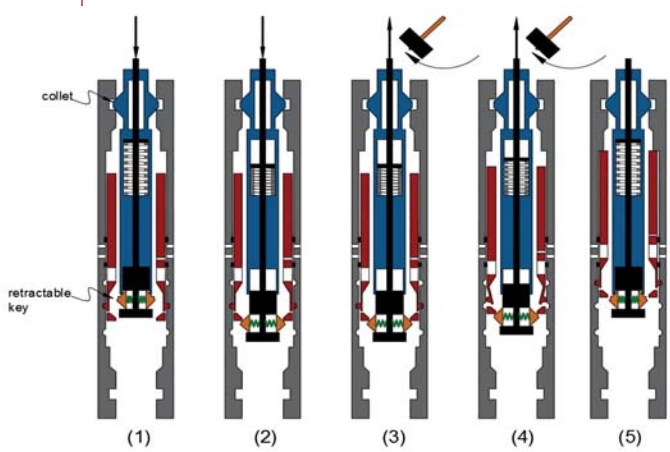


- multilayer

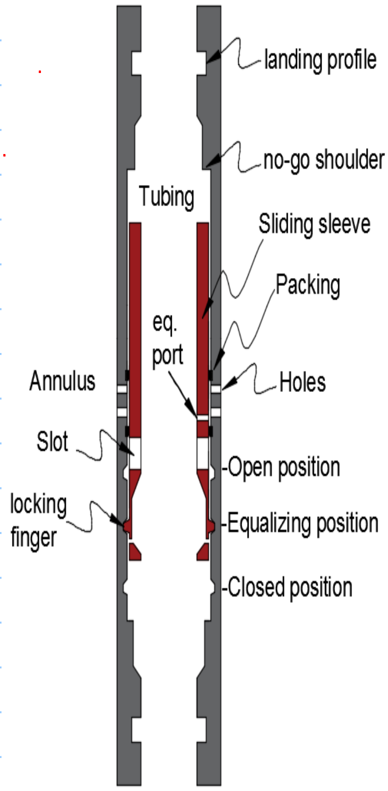


* opening
* sliding sleeve
shift to open or close
* downhole valve
Inflow control valve

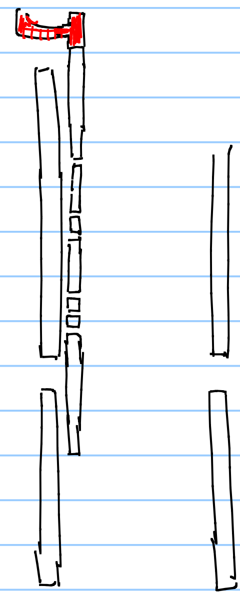
Shifting tool and sequence for sliding sleeve with wireline



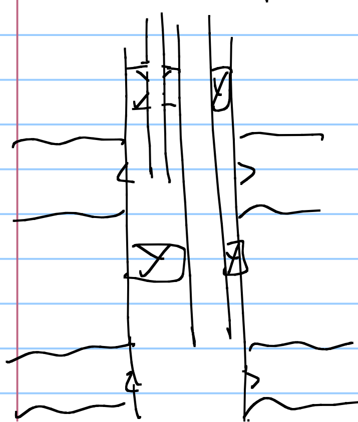
Sliding sleeve



Inflow control Valve (ICV), 4 positions.
I need a hydraulic line to chang the opening without having to run wireline

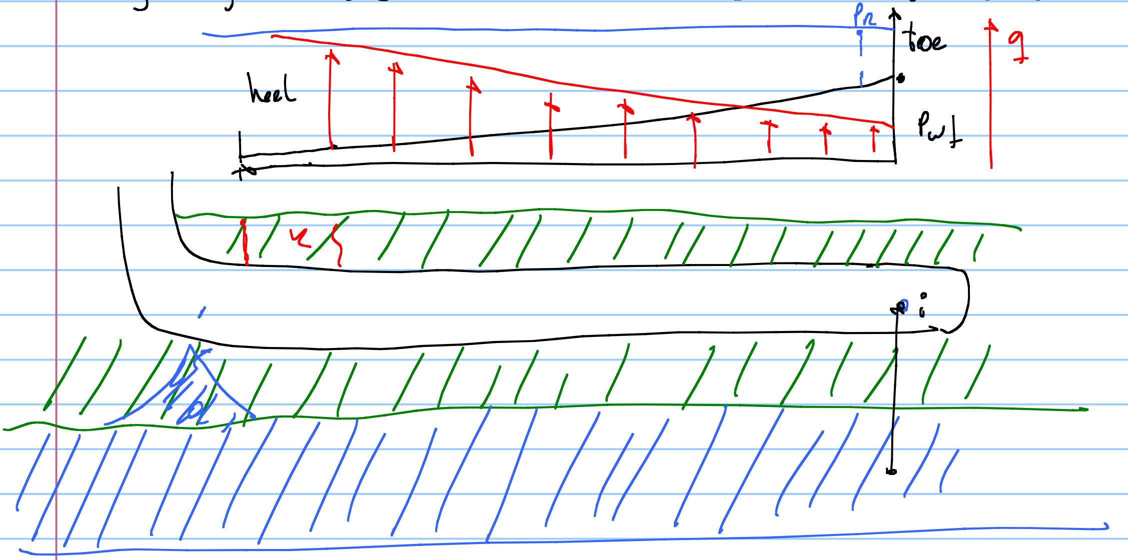


dual-tubing completions are usually not networks !



$\approx$

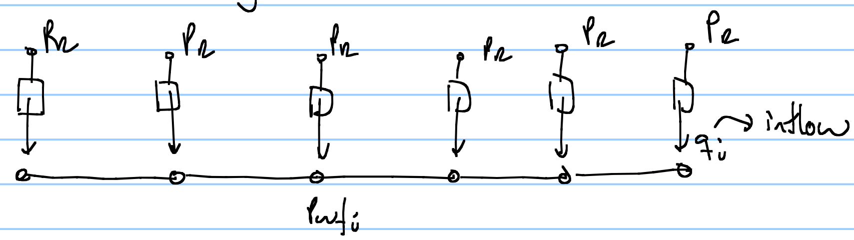
Long horizontal wells sometimes can be treated as a network

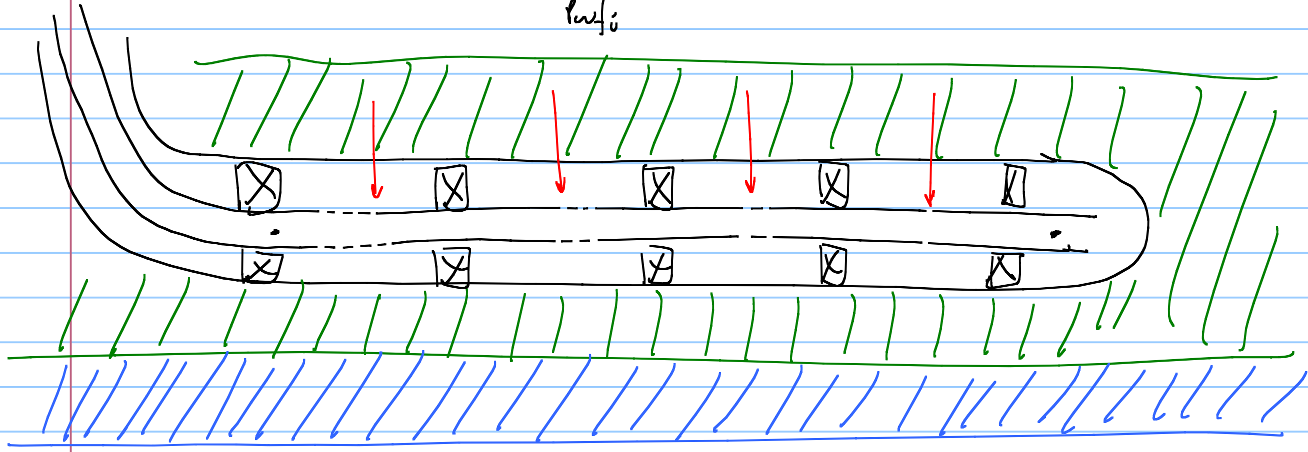


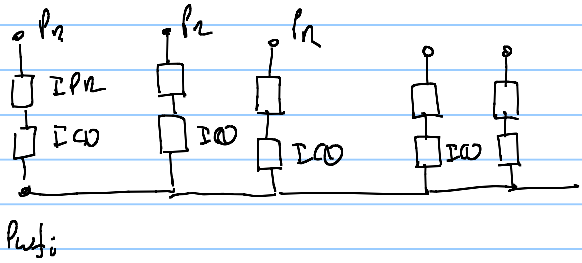
$q_i \propto (p_R - p_{wf_i})\ J$

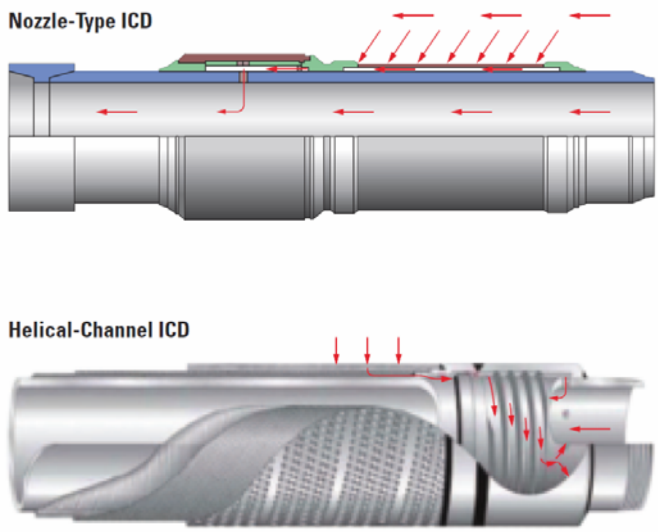
$J\ f(k)$

approximate the well by a network







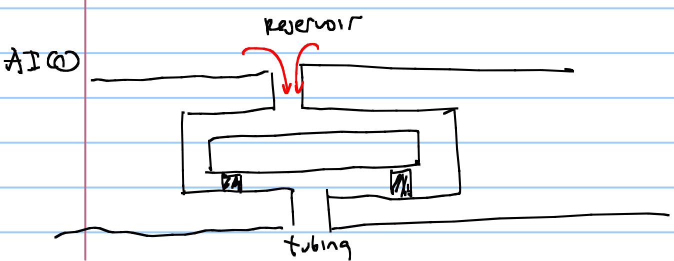


^ Leading ICD types. Fluid from the formation (red arrows) flows through multiple screen layers mounted on an inner jacket, and along the annulus between the solid basepipe and the screens. It then enters the production tubing through a restriction in the case of nozzle- and orifice-based tools (*top*), or through a tortuous pathway in the case of helical- and tube-based devices (*bottom*).

ICD inflow control device

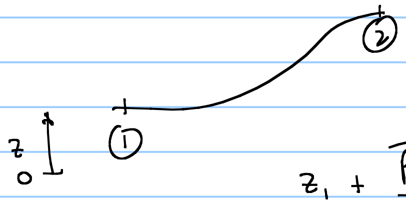
ICV inflow control valve

AICD Autonomous inflow control device



NetTool ⇝ Halliburton for Analizing downhole networks.

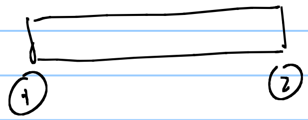
- pressure drop calculations for undersaturated oil + water



$$h_1 = h_2 + \Delta h_L$$

$$z_1 + \frac{p_1}{\rho \cdot g} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\rho \cdot g} + \frac{v_2^2}{2g} + \underbrace{f \frac{L}{\Phi} \frac{v^2}{2g}}_{\text{friction}} + K \frac{v^2}{2g}$$

localized loss coefficient



$V = \frac{q}{\text{Area}}$ ⇝ local volumetric rate @ p, T

$q_{\bar{o}}$ $q_{\bar{w}}$

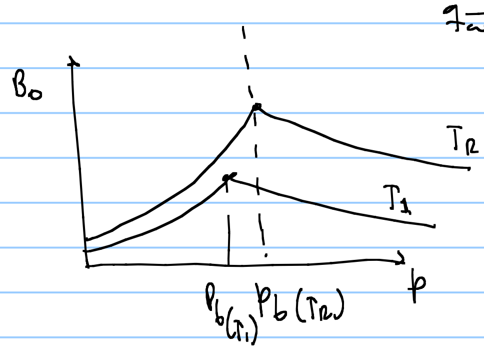
calculation modes:

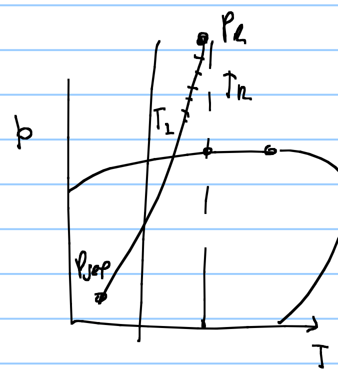
① p_1 fixed ⇝ Calculate p_2
q

② p_2 fixed ⇝ calculate p_1
q

$$B_o(p,T) = \frac{q_{@p,T}}{q_{\bar{o}}}$$

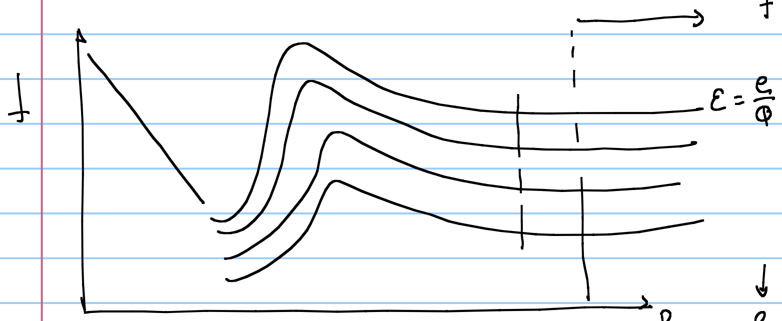
$$B_w(p,T) = \frac{q_{@p,T}}{q_{\bar{w}}}$$





ρ is also a function of p, T

f friction factor



⟶ $f \neq F(Re)$

$f = F(\varepsilon)$

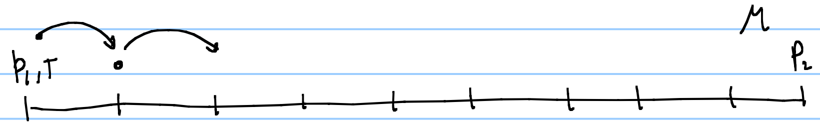
$$Re = \frac{\rho V \Phi}{\mu}$$

Because of changes in p and T along the pipe, $q_{@p,T}$ will change

ρ " "

μ " "

pressure drop calculations in well, in pipes should be done in a stepwise manner.



$\frac{\Delta p}{\frac{1}{2}\rho\frac{v^2}{2}}$

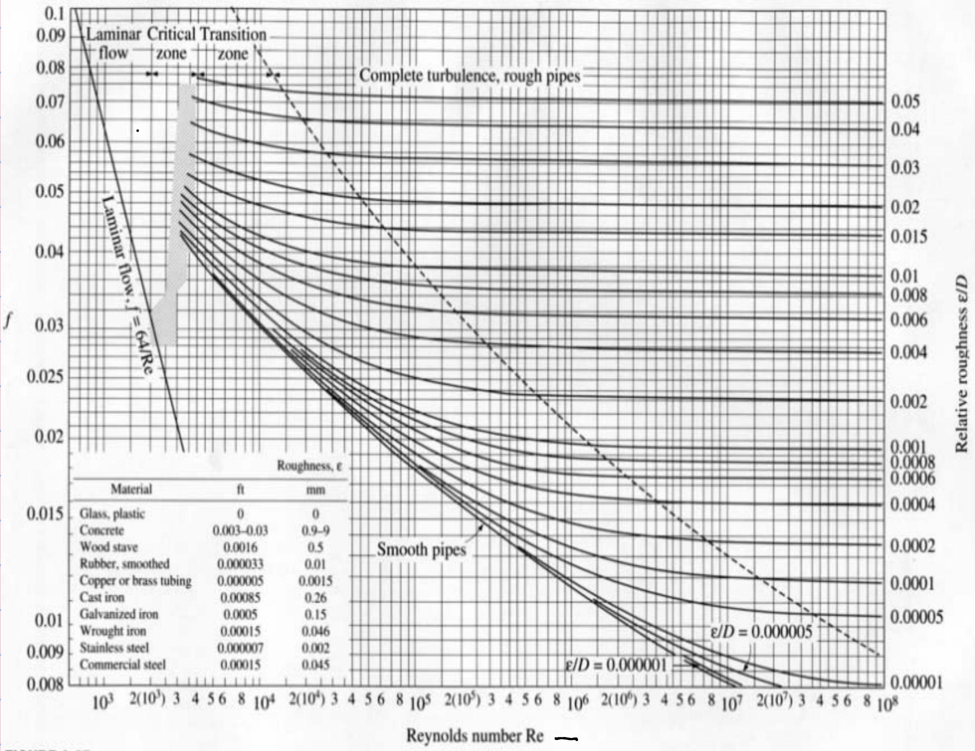


FIGURE A-27
The Moody chart for the friction factor for fully developed flow in circular tubes.

https://en.wikipedia.org/wiki/Darcy_friction_factor_formulae

Table of Colebrook equation approximations

Equation	Author	Year	Range	Ref
$f = .0055\left[1+\left(2\times10^4\cdot\frac{\varepsilon}{D}+\frac{10^6}{Re}\right)^{\frac{1}{3}}\right]$	Moody	1947	$Re = 4000 - 5.10^8$ $\varepsilon/D = 0 - 0.01$	
$f = .094\left(\frac{\varepsilon}{D}\right)^{0.225}+0.53\left(\frac{\varepsilon}{D}\right)+88\left(\frac{\varepsilon}{D}\right)^{0.44}\cdot Re^{-\Psi}$ where $\Psi = 1.62\left(\frac{\varepsilon}{D}\right)^{0.134}$	Wood	1966	$Re = 4000 - 5.10^7$ $\varepsilon/D = 0.00001 - 0.04$	
$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.715}+\frac{15}{Re}\right)$	Eck	1973		
$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.7}+\frac{5.74}{Re^{0.9}}\right)$	Swamee and Jain	1976	$Re = 5000 - 10^8$ $\varepsilon/D = 0.000001 - 0.05$	
$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.71}+\left(\frac{7}{Re}\right)^{0.9}\right)$	Churchill	1973	Not specified	
$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.715}+\left(\frac{6.943}{Re}\right)^{0.9}\right)$	Jain	1976		
$f = 8\left[\left(\frac{8}{Re}\right)^{12}+\frac{1}{(\Theta_1+\Theta_2)^{1.5}}\right]^{\frac{1}{12}}$ where $\Theta_1 = \left[-2.457\ln\left(\left(\frac{7}{Re}\right)^{0.9}+0.27\frac{\varepsilon}{D}\right)\right]^{16}$ $\Theta_2 = \left(\frac{37530}{Re}\right)^{16}$	Churchill	1977		
$\frac{1}{\sqrt{f}} = -2\log\left[\frac{\varepsilon/D}{3.7065}-\frac{5.0452}{Re}\log\left(\frac{1}{2.8257}\left(\frac{\varepsilon}{D}\right)^{1.1098}+\frac{5.8506}{Re^{0.8981}}\right)\right]$	Chen	1979	$Re = 4000 - 4.10^8$	
$\frac{1}{\sqrt{f}} = 1.8\log\left[\frac{Re}{0.135Re(\varepsilon/D)+6.5}\right]$	Round	1980		
$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon/D}{3.7}+\frac{4.518\log\left(\frac{Re}{7}\right)}{Re\left(1+\frac{Re^{0.52}}{29}(\varepsilon/D)^{0.7}\right)}\right)$	Barr	1981		
$\frac{1}{\sqrt{f}} = -2\log\left[\frac{\varepsilon/D}{3.7}-\frac{5.02}{Re}\log\left(\frac{\varepsilon/D}{3.7}-\frac{5.02}{Re}\log\left(\frac{\varepsilon/D}{3.7}+\frac{13}{Re}\right)\right)\right]$ or $\frac{1}{\sqrt{f}} = -2\log\left[\frac{\varepsilon/D}{3.7}-\frac{5.02}{Re}\log\left(\frac{\varepsilon/D}{3.7}+\frac{13}{Re}\right)\right]$	Zigrang and Sylvester	1982		
$\frac{1}{\sqrt{f}} = -1.8\log\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11}+\frac{6.9}{Re}\right]$	Haaland[2]	1983		
$\frac{1}{\sqrt{f}} = \Psi_1-\frac{(\Psi_2-\Psi_1)^2}{\Psi_3-2\Psi_2+\Psi_1}$ or $\frac{1}{\sqrt{f}} = 4.781-\frac{(\Psi_1-4.781)^2}{\Psi_2-2\Psi_1+4.781}$ where $\Psi_1 = -2\log\left(\frac{\varepsilon/D}{3.7}+\frac{12}{Re}\right)$	Serghides	1984		

Haaland (from NTNU) ~ 1983

$$f = \left[-1.8\log\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11}+\left(\frac{6.9}{Re}\right)\right]\right]^{-2}$$

beware !!!

- Moody (Darcy-Weisbach) friction factor

$$f_{DARCY} = \frac{\tau}{\frac{1}{8}\rho v^2}$$

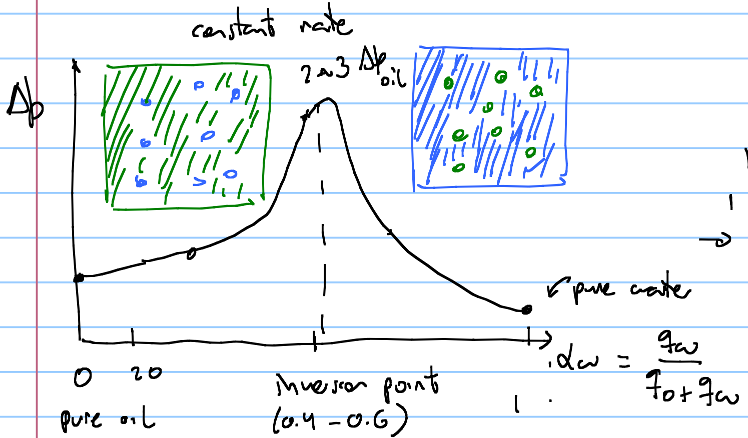
- Fanning friction factor

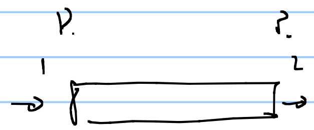
$$f_{FANNING} = \frac{\tau}{\frac{1}{2}\rho v^2}$$

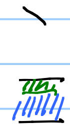
$$f_{DARCY} = 4\, f_{FANNING}$$

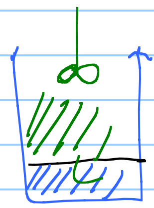
Oil-water flows can be modeled using liquid pressure drop equation

In oil and water flow we have formation of emulsions! fine and stable









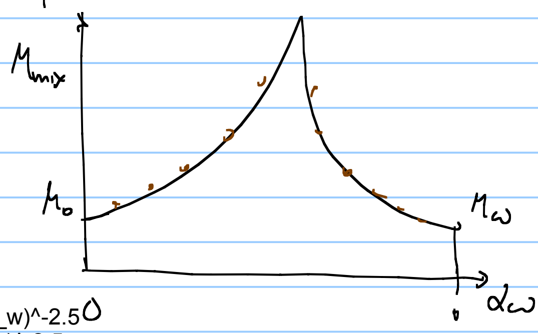
we can apply the same equation that for liquids

$$z_1 + \frac{P_1}{\rho_m g} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{\rho_m g} + \frac{v_2^2}{2g} + f \frac{L}{D} \frac{v^2}{2g}$$

$$\rho_m = \rho_w \cdot \alpha_w + \rho_o \underbrace{(1-\alpha_w)}_{\alpha_o}$$

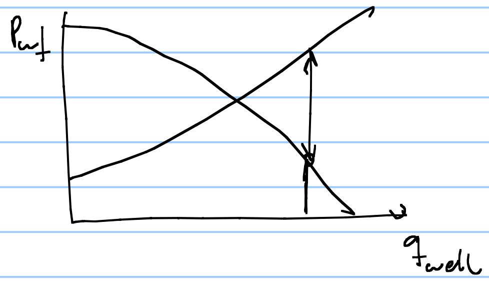
μ

effective viscosity of mixture



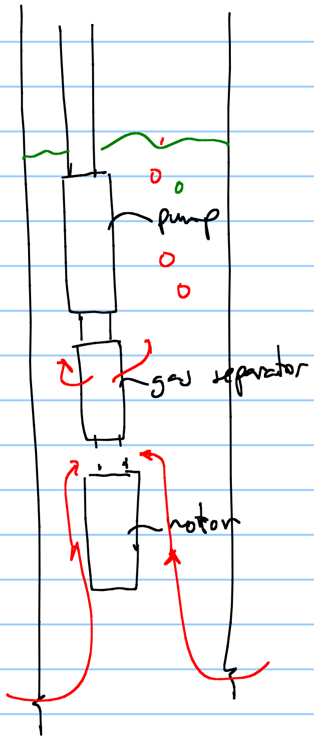
- Some equations used to describe emulsion viscosity are
  - Brinkman mu_m=mu_o*(1-alpha_w)^-2.5
    mu_m=mu_w*(alpha_w)^-2.5
  - Richardson
    in the left
    $$\mu_m = \mu_o \cdot e^{C_w \alpha_w}$$
    to the right
    $$\mu_m = \mu_w \cdot e^{C_o(1-\alpha_w)}$$

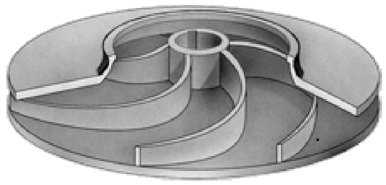

- Electric submersible pump (ESP)

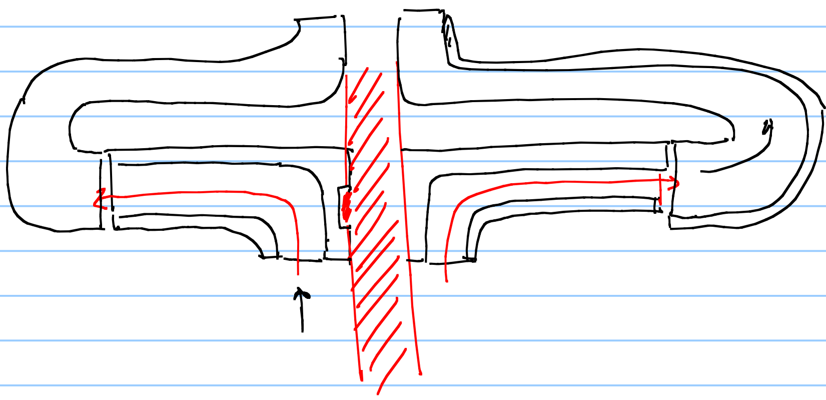


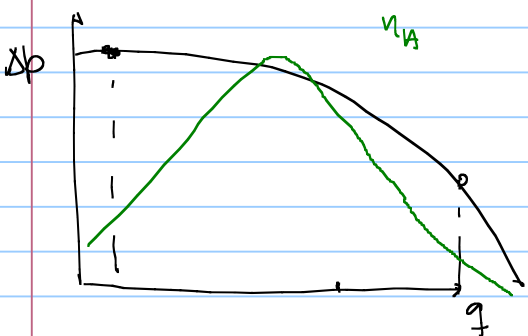
- P_R

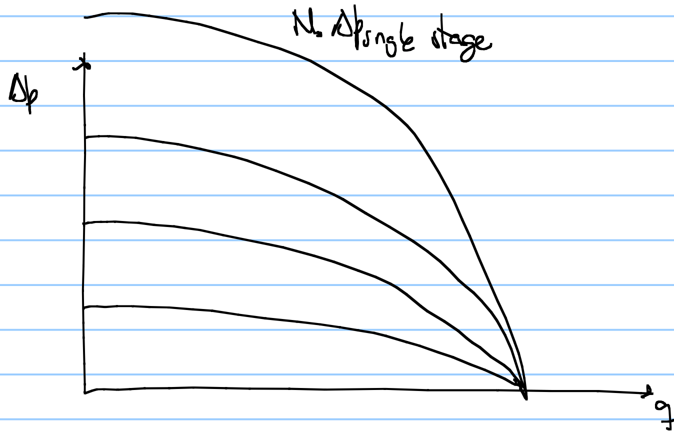
inventor
Armais Arutunoff











$$\underset{power}{\bar{P}} = \frac{\Delta p \cdot q}{\eta_H \cdot \eta_{mech}}$$

$$\Delta p_{required} = \overline{N_{stages}} \; \Delta p_{one\ stage} \cdot F_{pancake\ factor}$$