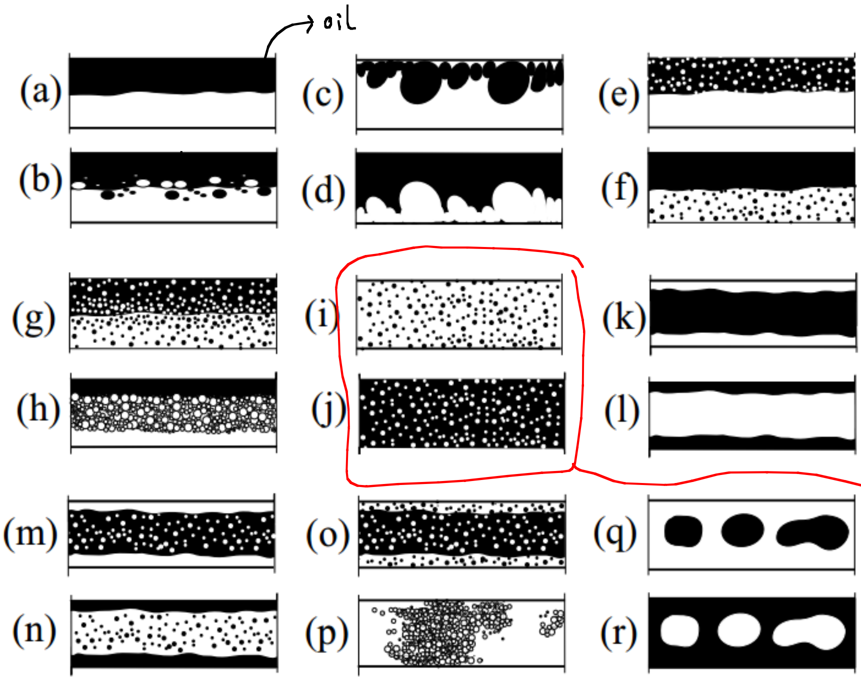
Note Title 23.02.2016

Water + oil flow



flow patterns. Spatial arrangement/configuration of phases in the pipe while flowing.

fine dispersion

droplets of oil in water

droplets of water in oil

behave "almost" like a single fluid.

It is possible to use modified version pressure drop for liquid flow

① ⟶ ②

$$P_2 = \rho \cdot g \left[(z_1 - z_2) + \frac{P_1}{\rho g} - f \frac{L}{\phi} \frac{V^2}{2g} \right]$$

ρ, μ

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

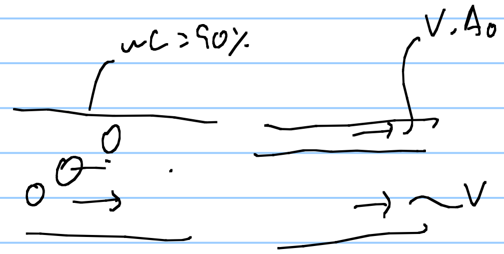
$$V = \frac{q}{A} = \frac{\dot{m}/\rho}{A}$$

for oil and water $\rho_m = \alpha_o \rho_o + \alpha_w \cdot \rho_w$

volume fraction $\alpha_o = \frac{q_o}{q_o + q_w}$ $\alpha_w = \frac{q_w}{q_o + q_w}$ $\alpha_o + \alpha_w = 1$

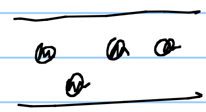
$$V_m = \frac{q_o + q_w}{A}$$

what to do with viscosity?



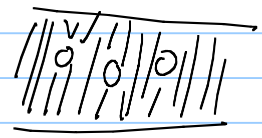
we use the mixture viscosity $\mu_m = (\alpha_o)\mu_o + \alpha_w \mu_w$ usually not a good approximation

use the viscosity of the fluid that is wetting the wall (continuous fluid) $\rightsquigarrow$ water continuous $\sim \mu = \mu_w$

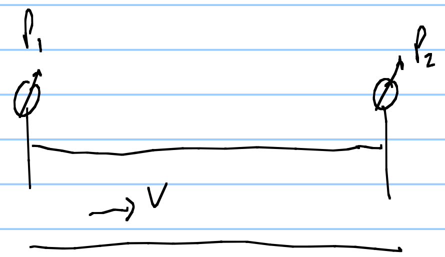


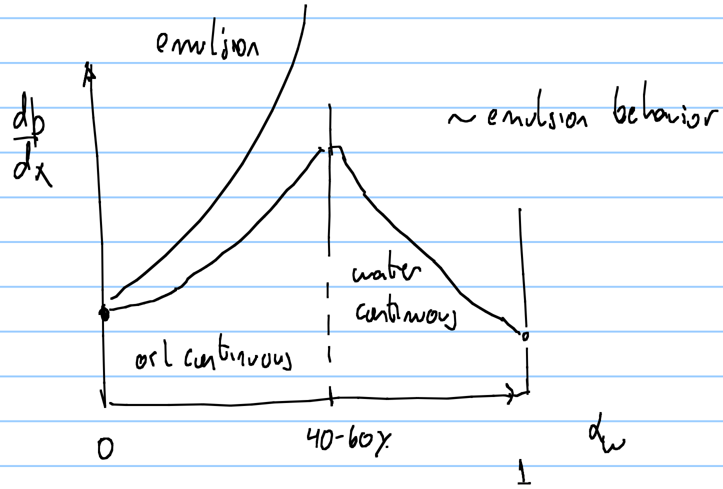
$\alpha_o \uparrow$ or $\alpha_w \uparrow$

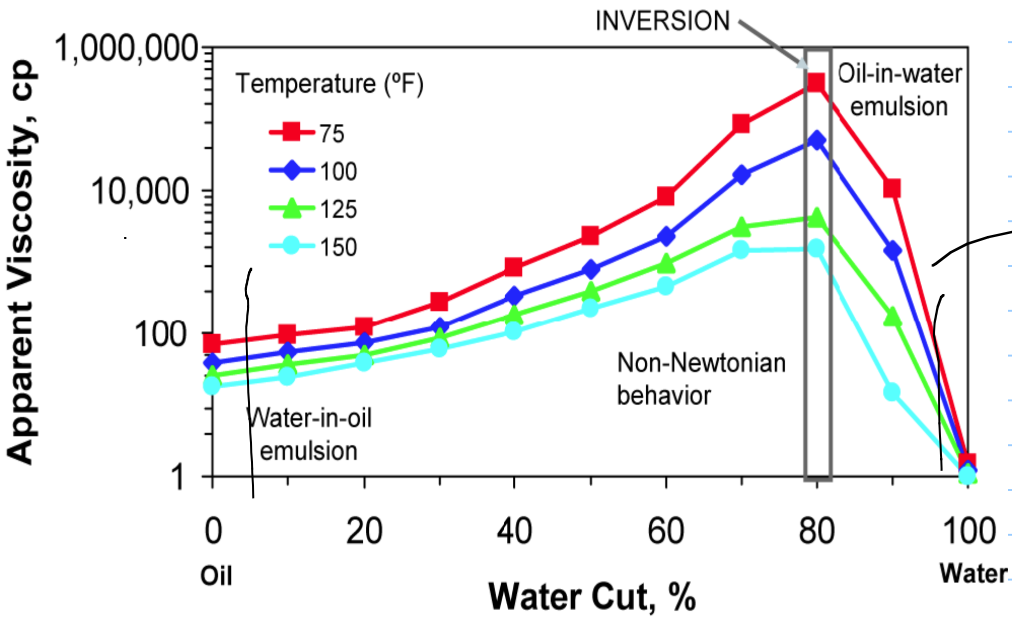
oil continuous

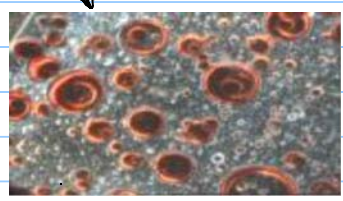


$\sim \mu = \mu_o$









perform experimental measurements

Richardson formula

- Valle (2000)

$$\mu_{rel} = \mu_{rel}\left(\Phi_d / (\Phi)_{\mu=\mu_{rel0}}\right) = \frac{1}{(1-K_0K_F(\gamma)\cdot\Phi_d)} = \left[1+\frac{\frac{\Phi_d}{(\Phi)_{\mu=\mu_0}}}{\frac{\mu_0^{0.4}}{\mu_0^{0.4}-1}-\frac{\Phi_d}{(\Phi)_{\mu=\mu_0}}}\right]^{2.5}$$

$$\mu_m = \mu_o \cdot e^{\cancel{3.215}\, C_o \frac{WC}{100}}$$

$$\mu_m = \mu_w \cdot e^{\cancel{3.089}\, C_w \left(100 - \frac{WC}{100}\right)}$$

- Brinkmann (1956)

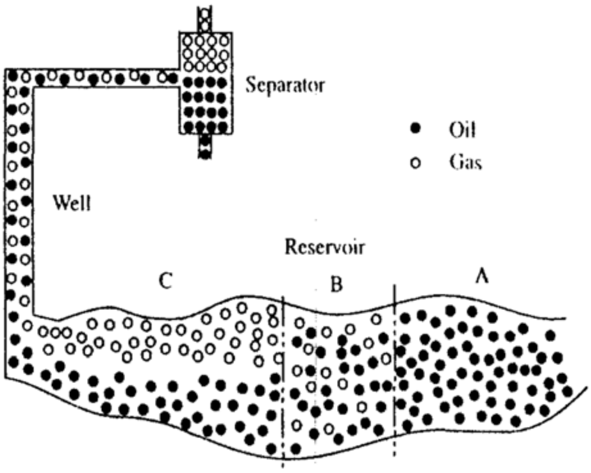
$$\mu_{rel} = (1-\Phi_d)^{-2.5}$$

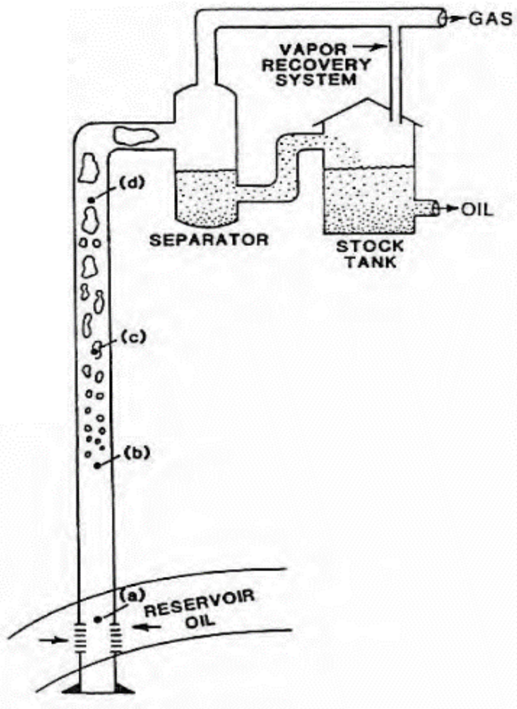
volume fraction of the dispersed phase

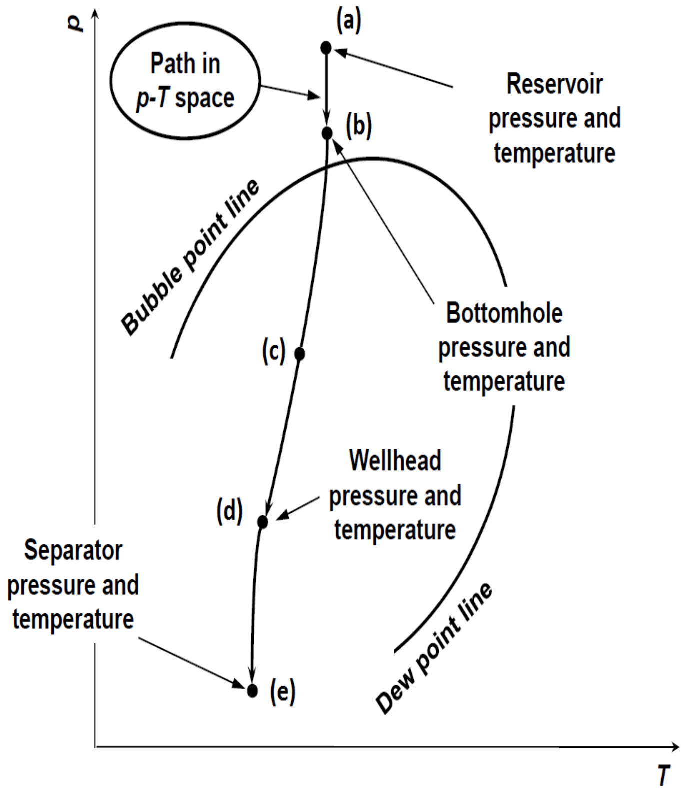
$$\frac{\mu_{mix}}{\mu_o} = (1-\alpha_w)^{-2.3} \qquad \mu_m = \mu_w \cdot (1-\alpha_o)^{-2.5}$$

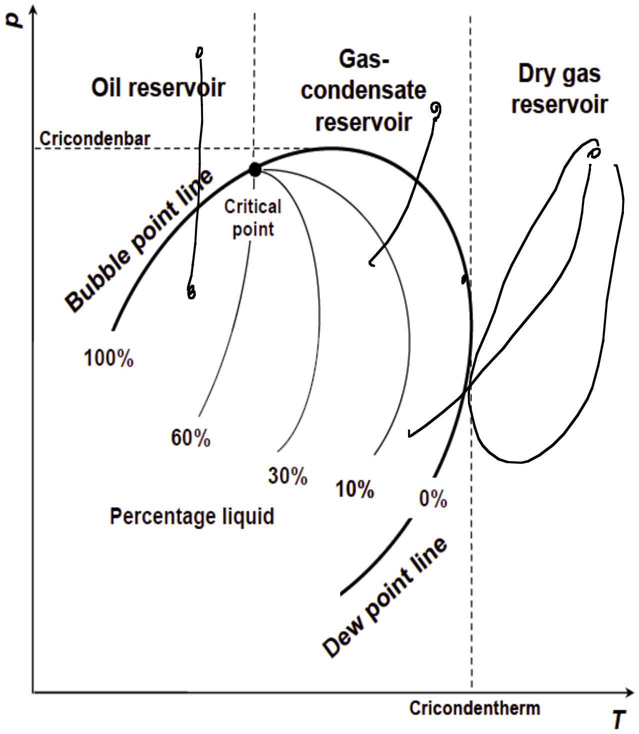
- Multiphase flow ~ simultaneous flow of
  - gas ~ vapour phase
  - oil ~ liquid phase
  - water ~ liquid phase

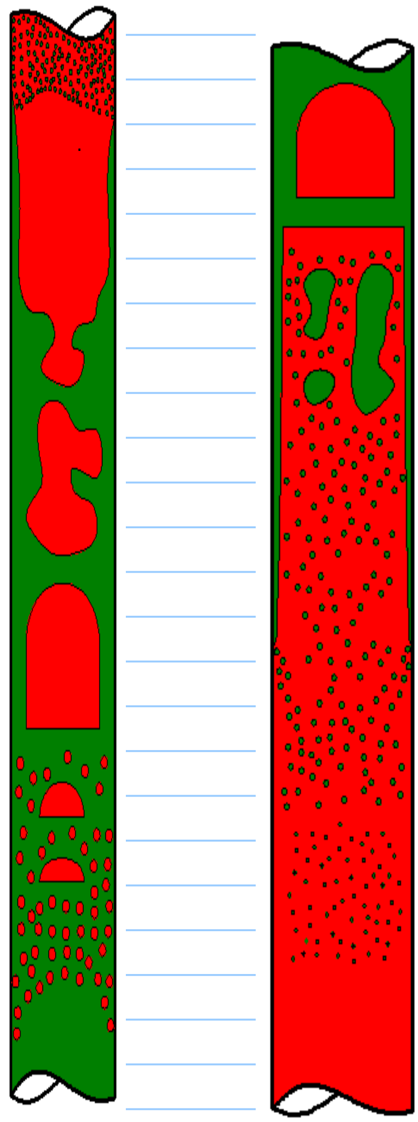
  } very frequently they are treated as single liquid phase with equivalent properties

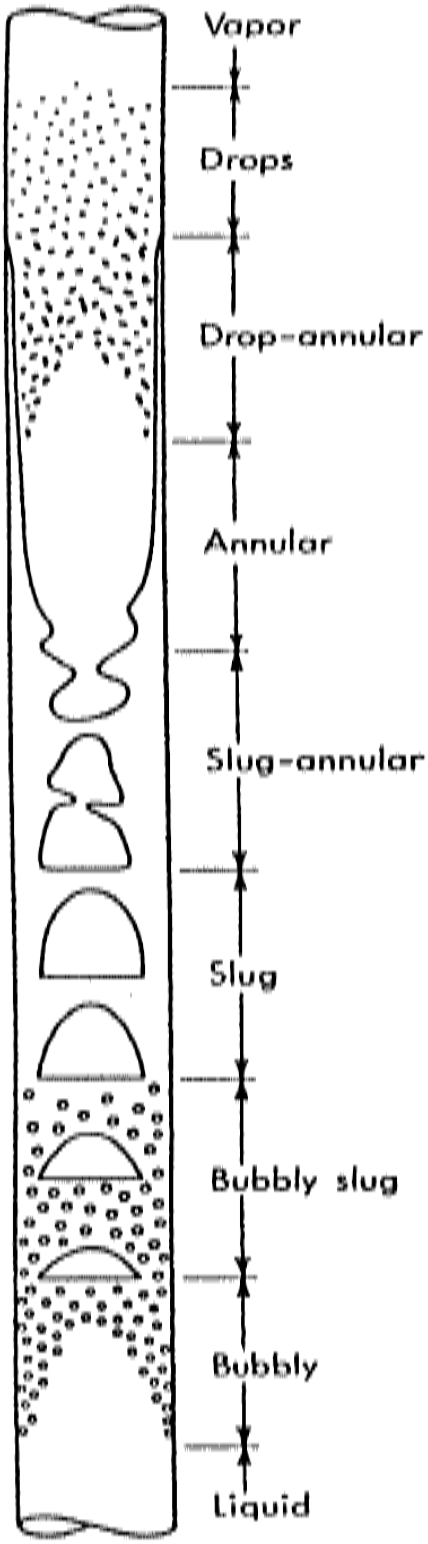



GAS
VAPOR RECOVERY SYSTEM
SEPARATOR
STOCK TANK
OIL
(d)
(c)
(b)
(a)
RESERVOIR OIL


p
(a)
Path in p-T space
Reservoir pressure and temperature
(b)
Bubble point line
Bottomhole pressure and temperature
(c)
Wellhead pressure and temperature
(d)
Separator pressure and temperature
(e)
Dew point line
T


p
Oil reservoir
Gas-condensate reservoir
Dry gas reservoir
Cricondenbar
Critical point
Bubble point line
100%
60%
30%
10%
0%
Percentage liquid
Dew point line
Cricondentherm
T





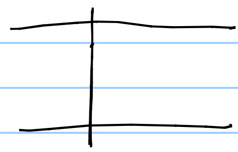
flow pattern identification is not all the time black and white

→ EPT ~> Multiphase flow ~> prof. Ole Jørgen Nydal

TEP4250

classification

- Steady state $\frac{\partial}{\partial t} = 0$



$\frac{\partial \alpha_o}{\partial t} = 0$

- transient $\frac{\partial}{\partial t} \neq 0$

→ pipesim, gap, prosper, wellflow, olga, leda

→ olga, leda

$$f = \frac{\Delta p}{\frac{v^2}{2g}} \left(\frac{D}{L}\right) \qquad Re = \quad \Bigg\} \text{ Moody diagram}$$

why not use the same approach as for single phase flow in multiphase flow (adimensional number)?

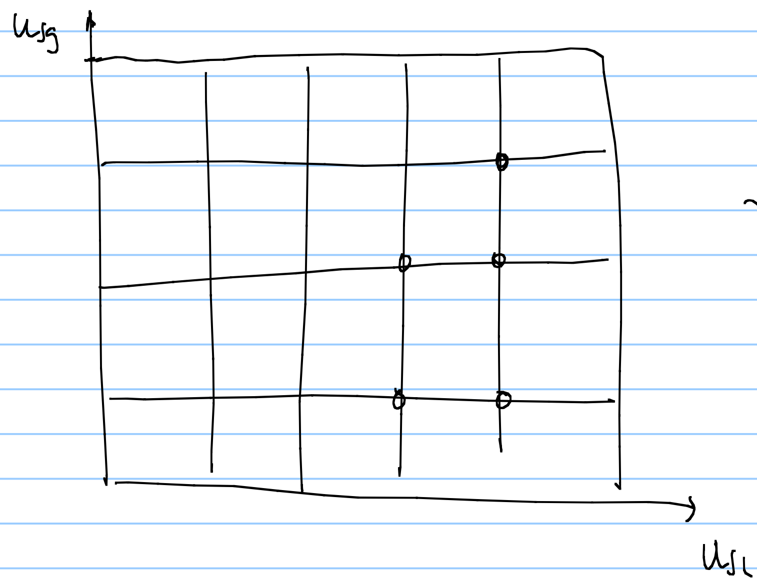
A large number of adimensional numbers (to cover all posible pipe configurations, fluid properties, flow conditions) and it is very difficult to find a correlation between them.

- Gas-liquid flows

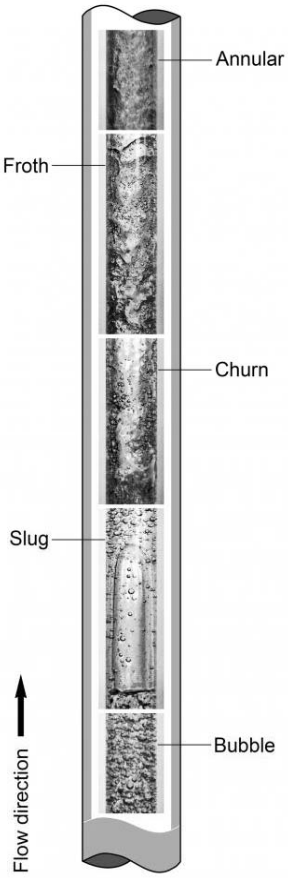
Use sort of an adimensional number: Superficial velocities $\underset{\text{liquid}}{u_{sL}} = \frac{q_L}{A}$ ↳ cross section area of pipe

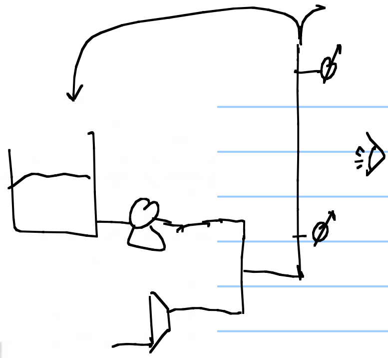
$$u_{sg} = \frac{q_g}{A}$$

flow pattern map

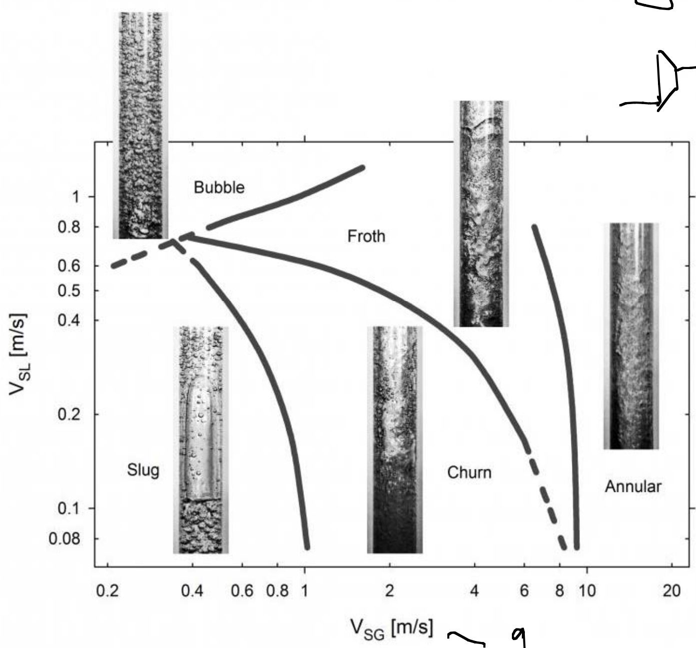


↳ for a given inclination, fluid properties, pipe diameter, ε, wall material

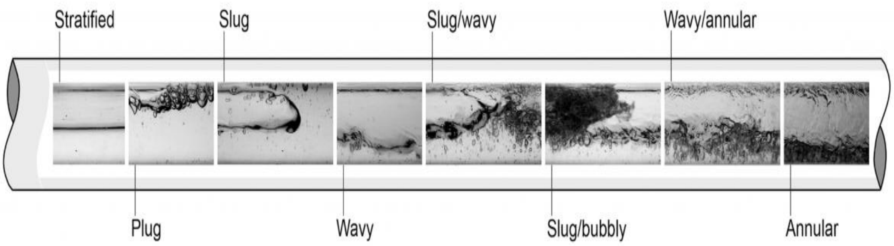


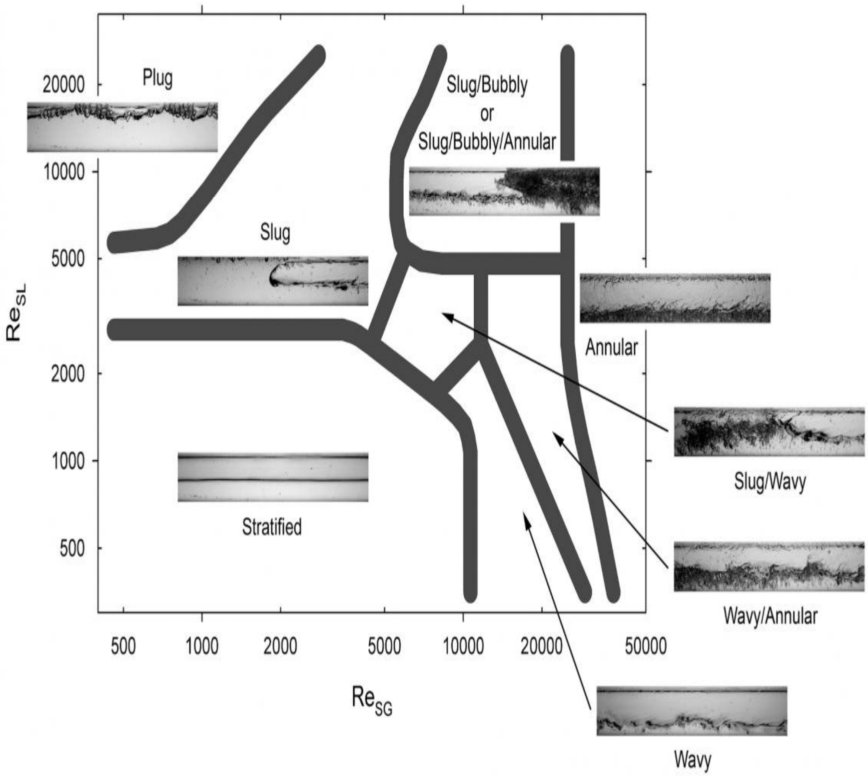


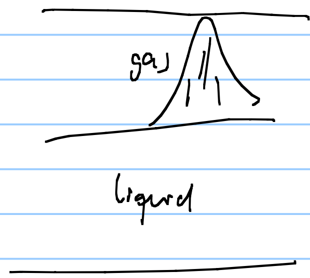
$\frac{q_L}{A}$



$\sim \frac{q_g}{A}$







multiphase flow pattern and pressure drop is dictated by a balance between forces:

- mixing forces
- segregation forces

{ turbulence
inertia (velocity)
gravitational acceleration
viscosity
surface tension

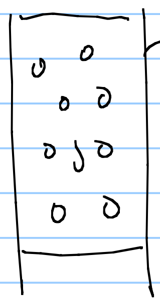
Ways to compute multiphase flow in production engineering:

- Correlation-based, equation based on tuning with experimental data

- mechanistic modeling: applying continuity equation
momentum equation
energy equation
⇓
solve the system of equations.

correlations derived from experiments

the number of equations used depend on the flow pattern



1 momentum equation

2 mass conservation equation

1- Identification of flow patterns

2- Computation using the appropriate model.

2 mass conservation equation

2 momentum conservation equation

two phases gas-liquid

~ homogeneous flow

$$\lambda_L = \frac{A_L}{A}$$

$$\lambda_g = \frac{A_g}{A}$$

q_L, q_g

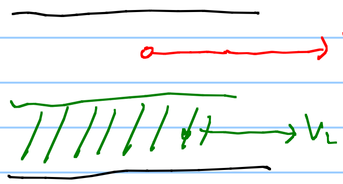
non slip volume fraction

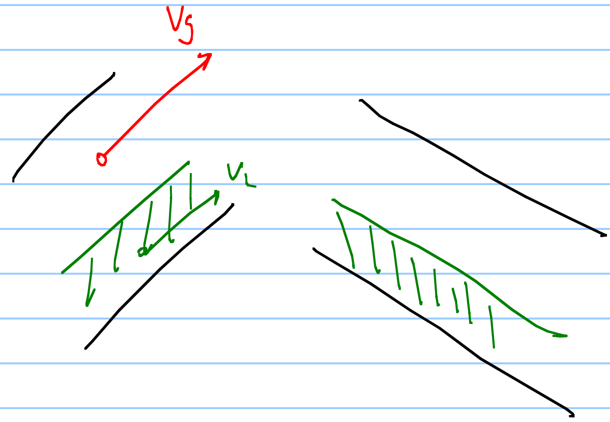
$$A_L = \frac{q_L}{V_m}$$

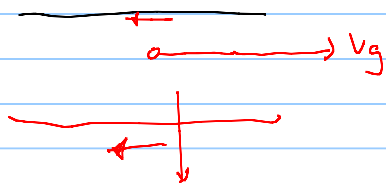
$$A_g = \frac{q_g}{V_m}$$

$$\lambda_L = \frac{q_L/\cancel{V_m}}{\frac{q_L}{\cancel{V_m}} + \frac{q_g}{\cancel{V_m}}} = \frac{q_L}{q_L + q_g}$$

in the general case $V_L \neq V_g$







$$H_L = \frac{A_L}{A}$$ ~ Holdup

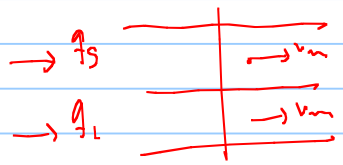
if $V_g > V_L$ q_L, q_g

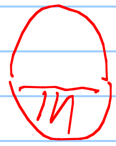
H_L λ_L

$q_g = V_g \cdot A'_g$ $q_g = V_m \cdot A_g$

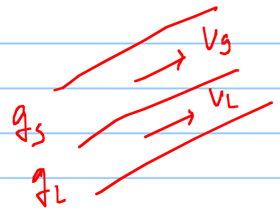
$$u_g = \frac{q_g}{A(1-H_L)} \qquad u_g = \frac{u_{sg}}{(1-H_L)}$$

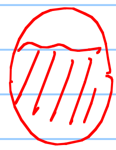
$$u_L = \frac{q_L}{A(H_L)} \qquad u_L = \frac{u_{sL}}{H_L}$$





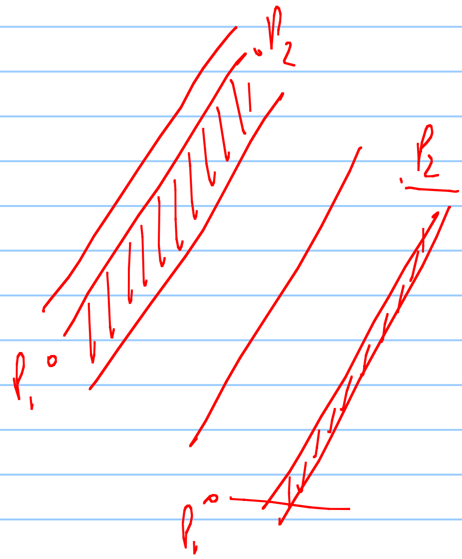
$\lambda_L = \frac{q_L}{q_g + q_L}$

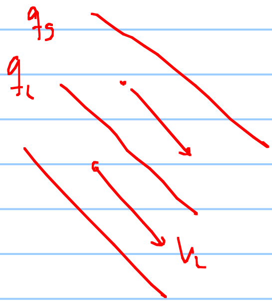




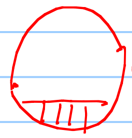
$\sim H_L = \frac{A_L}{A}$ $\quad v_g > v_L$

$H_L > \lambda_L$





$v_L > v_g$



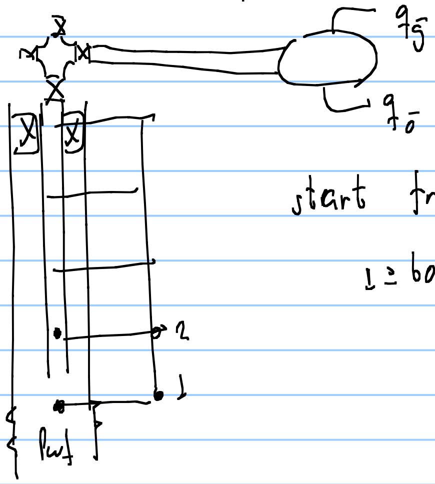
$\sim H_L = \frac{A_L}{A}$

$H_L < \lambda_L$

$v_s = v_g - v_L$

↳ slip velocity

Multiphase flow pressure drop in conduits



start from a point of known pressure and known temperature

1: bottom-hole $\quad P_{wf}, T_R$

$q_{\bar{o}} \longrightarrow q_o$ $\quad$ calculate local flow rates | BO tables

$q_{\bar{g}} \longrightarrow q_g$ @ P, T $\quad$ BO correl.

EOS (z_G)

2: Calculate fluid properties @ P, T conditions | BO table

$\rho_o, \rho_g, \rho_w, \sigma_{og}, \sigma_{ow}, \sigma_{wg}, \mu_o, \mu_g, \mu_w$ $\quad$ BO correlation

EOS (z_i)

↳ composition

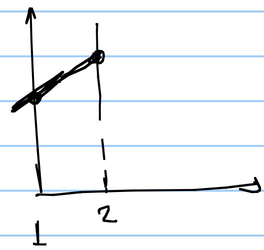
3. System properties: $\overset{\text{diameter}}{\phi}$, $\overset{\text{roughness}}{\varepsilon}$, θ inclination, entry effects

4. Go to our multiphase flow expert
- software: olga, leda
- correlation
- expert

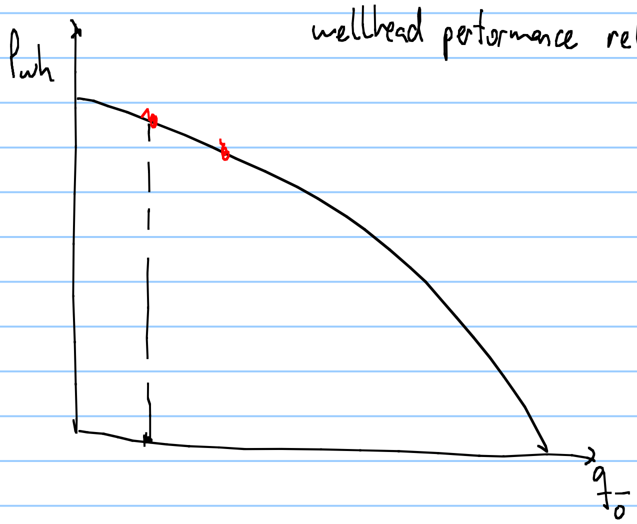
with information gathered in 2, 3, 4 → $\frac{dp}{dL}$ → along the direction of the conduit

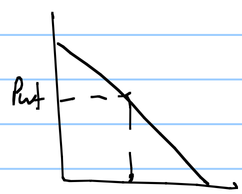
$\left.\frac{dp}{dL}\right|_{\substack{x = \text{bottomhole} \\ p = p_{wf}}}$, $P_0 = P_{wf}$ } numerical integration
- euler's method
- Runge-Kutta → $\boxed{\text{RK4, explicit}}$

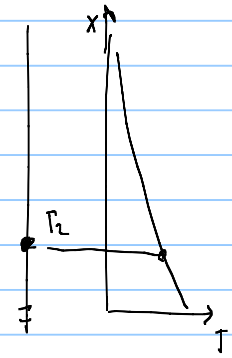
$$P_2 = P_1 + \Delta L \cdot \left.\frac{dP}{dL}\right|_{\substack{L = L_0 \\ P = P_0}}$$



e.g. to calculate wellhead performance relationship



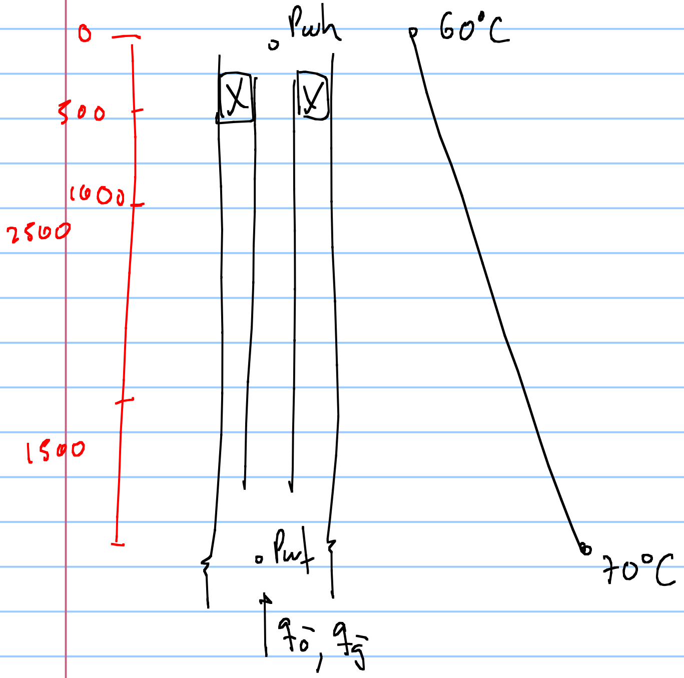




for point 2, I repeat the steps, but I am missing T_2.
- assume a temperature distribution
- need a model that tells me $\frac{dT}{dL}$

$\frac{dT}{dL}, \left.\frac{dP}{dL}\right|_{T_1, P_{wf}}$

Class exercise, Calculate WPR, we want to calculate P_{wh} award for a given rate $q_{\bar{o}}, q_{\bar{g}}$



	Mole %	Mole frac		
Nitrogen	0.4	0.004	qo [Sm^3/d]	1000
CO2	0.1	0.001	qg [E03 Sm^3/d]	200
Methane	43.2	0.432	pwf [bara]	147
Ethane	4.7	0.047	TR [C]	70
Propane	3.0	0.03	ID [m]	0.12
i-butane	1.5	0.015	Well TVD Depth [m]	2500
n-butane	0.9	0.009	Twh [C]	60
neo-pentane	0.0	0	Sc oil density [Kg/m^3]	850
i-pentane	0.8	0.008	Sc gas density [Kg/m^3]	0.91
n-pentane	0.5	0.005		
Hexanes	1.8	0.018		
Heptanes	4.1	0.041	mosc [kg/s]	
Octanes	5.0	0.05	mgsc [kg/s]	
Nonanes	3.8	0.038	mt [kg/s]	
Decanes	30.1	0.301		

1: q_o, q_g from $q_{\bar{o}}, q_{\bar{g}}$ $\qquad$ $\dot{m}_o$, $\dot{m}_g$

$$\dot{m}_o = q_{\bar{o}} \cdot \rho_{\bar{o}}$$

one method: Calculate total mass flow rate

$$\dot{m} = \underbrace{q_{\bar{o}} \cdot \rho_{\bar{o}}} + \underbrace{q_{\bar{g}} \cdot \rho_{\bar{g}}}$$

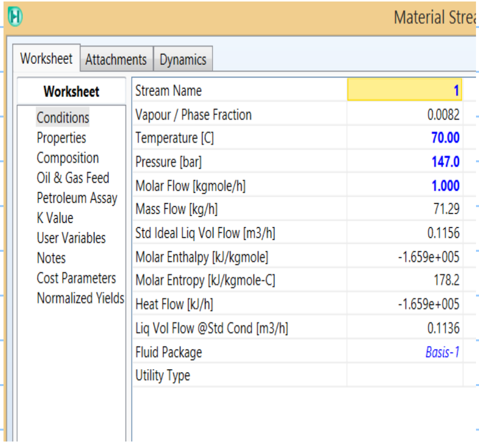
$\dot{m} = 11.9$ kg/s $\rightarrow$ total mass flow rate circulating in the tubing

$$q_o @ P_{wf}, T_{wf} = \dot{m}_o @ P_{wf}, T_{wf} / \rho_o @ P_{wf}, T_{wf}$$

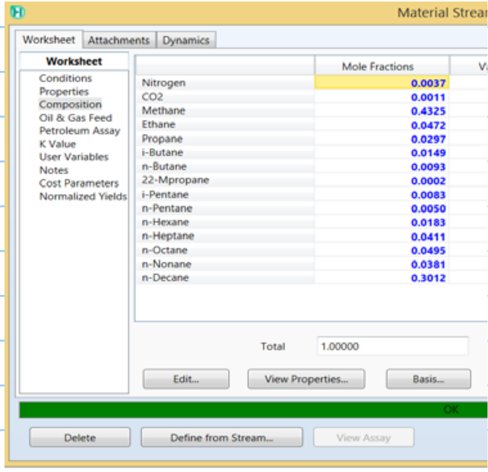
$$q_g @ P_{wf}, T_{wf} = \dot{m}_g @ P_{wf}, T_{wf} / \rho_g @ P_{wf}, T_{wf}$$

it is necessary to estimate $\dot{m}_o$ and $\dot{m}_g$ @ P_{wf}, T_{wf}.

we are going to use HYSYS as a fluid properties generator



Worksheet	Stream Name	1
Conditions	Vapour / Phase Fraction	0.0082
Properties	Temperature [C]	70.00
Composition	Pressure [bar]	147.0
Oil & Gas Feed	Molar Flow [kgmole/h]	1.000
Petroleum Assay	Mass Flow [kg/h]	71.29
K Value	Std Ideal Liq Vol Flow [m3/h]	0.1156
User Variables	Molar Enthalpy [kJ/kgmole]	-1.659e+005
Notes	Molar Entropy [kJ/kgmole-C]	178.2
Cost Parameters	Heat Flow [kJ/h]	-1.659e+005
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	0.1136
	Fluid Package	Basis-1
	Utility Type	

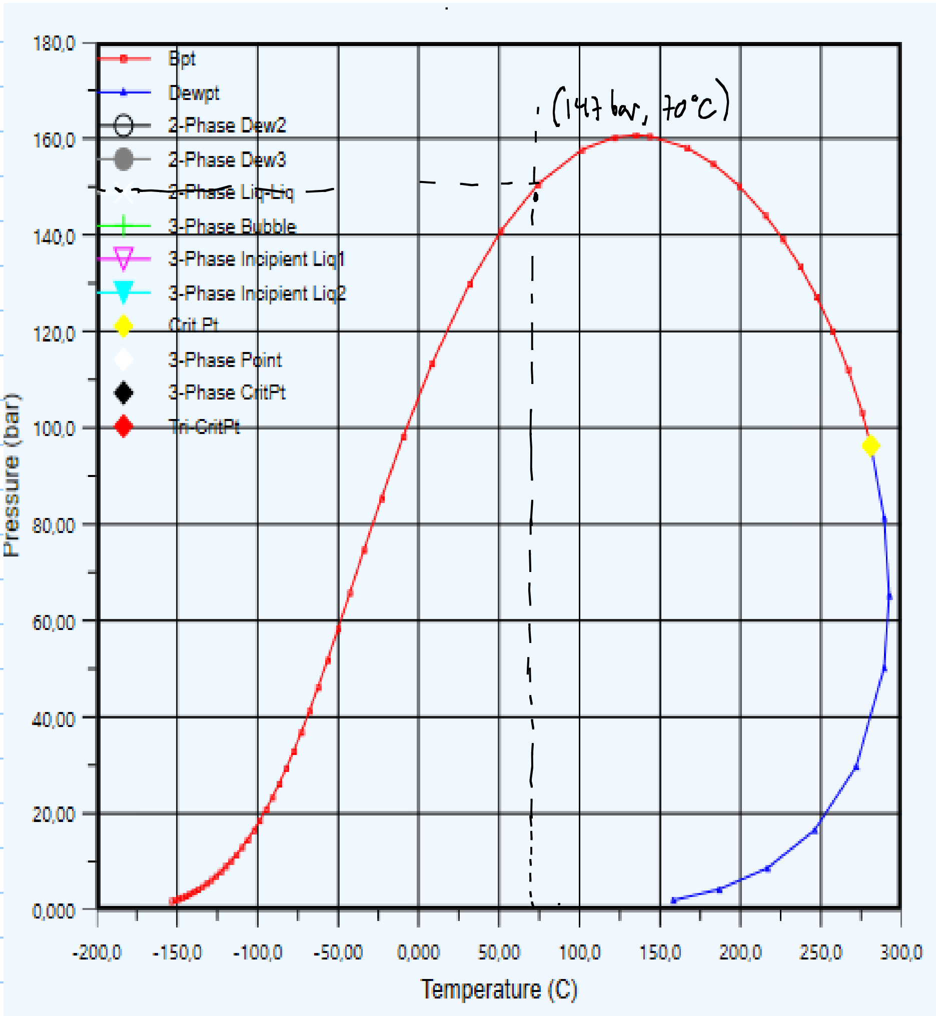


Worksheet		Mole Fractions
Conditions	Nitrogen	0.0037
Properties	CO2	0.0011
Composition	Methane	0.4325
Oil & Gas Feed	Ethane	0.0472
Petroleum Assay	Propane	0.0297
K Value	i-Butane	0.0149
User Variables	n-Butane	0.0093
Notes	22-Mpropane	0.0002
Cost Parameters	i-Pentane	0.0083
Normalized Yields	n-Pentane	0.0050
	n-Hexane	0.0183
	n-Heptane	0.0411
	n-Octane	0.0495
	n-Nonane	0.0381
	n-Decane	0.3012
	Total	1.00000

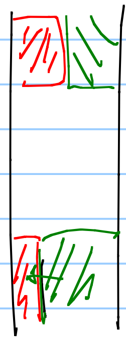
Edit... View Properties... Basis...

OK

Delete Define from Stream... View Assay



mosc [kg/s]	9.8
mgsc [kg/s]	2.1
mt [kg/s]	11.9



from hysy @ Pwt, TR

mass raction

$$X_{Liquid} = \frac{\dot m_{liquid}}{\dot m_T}$$

$$\dot m_o = 11.9(0.9975) =$$

	TVD	p	T	Liquid Mass fraction	mo	mg	deno	deng	qo	qg	vso	vsg
	[m]	[bara]	[C]	[-]	[kg/s]	[kg/s]	[kg/m^3]	[kg/m^3]	[m^3/s]	[m^3/s]	[m/s]	[m/s]
1	2500	147	70	0.9978	11.9203	0.02628	569	116	0.0209	0.00023	1.851	0.020

go to your multiphase expert (multiphase calculator public_xslm)

FLUID PROPERTIES				
μ_o	[Pa s]	2.095E-04		
μ_g	[Pa s]	1.787E-05		
σ_{og}	[N/m]	0.009		
ρ_o	[kg/m^3]	569		
ρ_g	[kg/m^3]	116	dp/dx	Flow pattern
			[Pa/m]	[-]
OPERATING CONDITIONS			5659.60	Bubble
Usl	[m/s]	1.851		
Usg	[m/s]	0.020		
PIPING CHARACTERISTICS				
Angle (from hor.)	[rad]	1.571		
Diameter	[m]	0.12		
Roughness	[m]	1.50E-05		

$$P\Big|_{1500m} = P\Big|_{2500m} - \frac{dP}{dL}\Big|_{2500m} \cdot (1500\,m) = 147\text{ bara} - 0.05657\ \text{bara}/m \cdot 1500\,m$$

$$P_{@1000m} = 62\text{ bara.}$$

find $T_{@1000m}$ by interpolating between 60°C → 70°C

repeat !!