Flow Assurance and Multiphase flow

- Multiphase flow
- Offshore
- Subsea
- Deepwater
- Long transportation
- (Near) Arctic

Prof. Rune W. Time

Department of Petroleum Engineering
University of Stavanger

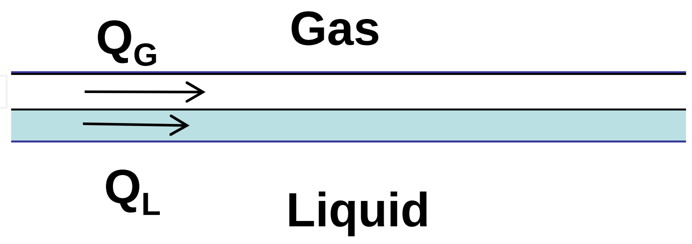
Seminar at Aker Solutions, Stavanger – May 31st, 2011

Outline and time schedule

8.30 – 9.15	**Flow regimes and impact on phase slippage, fluid concentrations and pressure drop in pipelines**
9.25 – 10.15	Hydrates, wax and asphaltenes
10.25 -11.00	Multiphase flow – influence from interfaces, compression effects and waves

Flow regimes and impact on phase slippage, fluid concentrations and pressure drop in pipelines

Transparent pipe



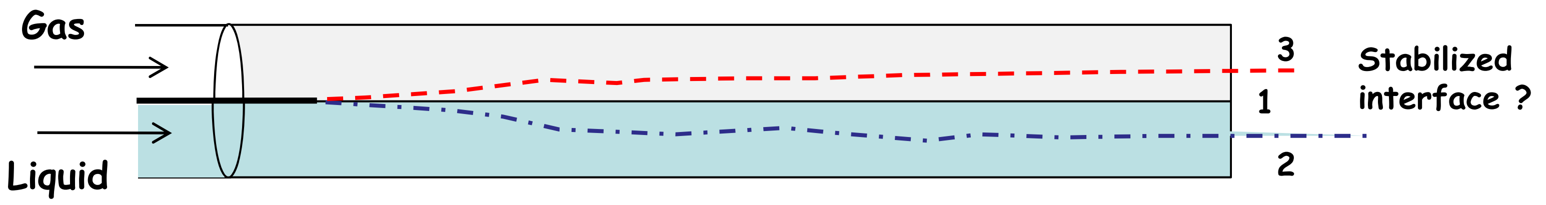
- Stratified liquid and gas – is there a flow? How to decide?
- Some concepts are needed:
  - Flow speeds
  - Fluid fractions
  - Flow patterns (”regimes”)

QUIZ:
A simple(st) case of two-phase flow

Equal inflow

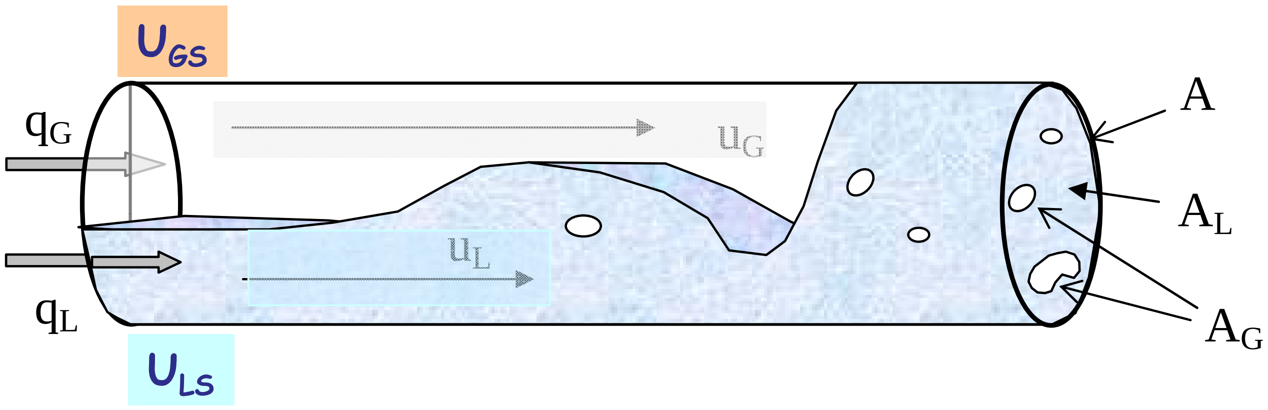
$Q_L = Q_G$

Horizontal pipeline



- How to decide?
- Any guideline principles?

Basic quantities and definitions:
- Superficial velocities and fluid fractions



Superficial velocities :

$$U_{LS} = \frac{q_L}{A}$$

$$U_{GS} = \frac{q_G}{A}$$

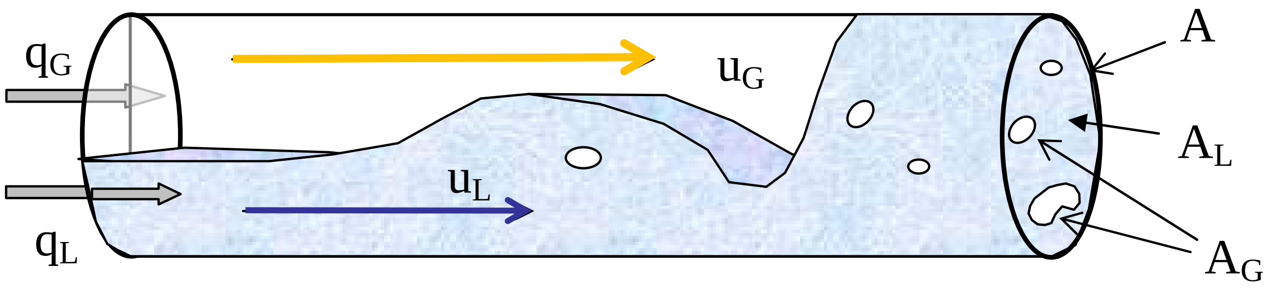
Mixture velocity :

$$U_{mix} = U_{LS} + U_{GS}$$

Apparent liquid fraction ("noslip"):

$$\lambda_L = \frac{q_L}{q_L + q_G} = \frac{U_{LS}}{U_{LS} + U_{GS}}$$

Basic quantities and definitions:
- True velocities and Slip



True (phase) velocities :

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

$$u_G = \frac{q_G}{A_G}$$

Slip velocity : $u_S = |u_G - u_L|$

and

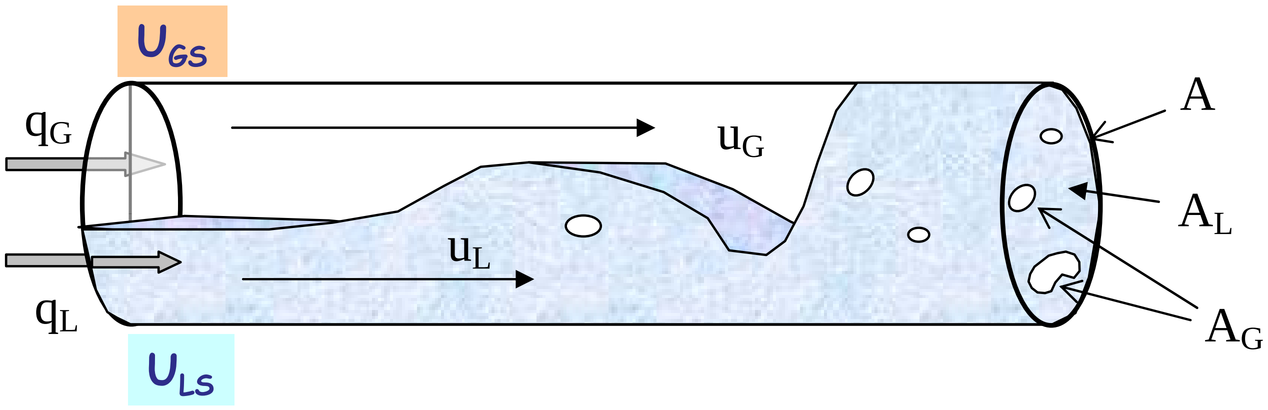
Slip ratio : $S = \frac{u_G}{u_L}$

NOSLIP condition:

$u_L = u_G = U_{mix}$

$S=1$

Basic quantities and definitions:
- True liquid fraction versus noslip fraction



True (real) volume fraction

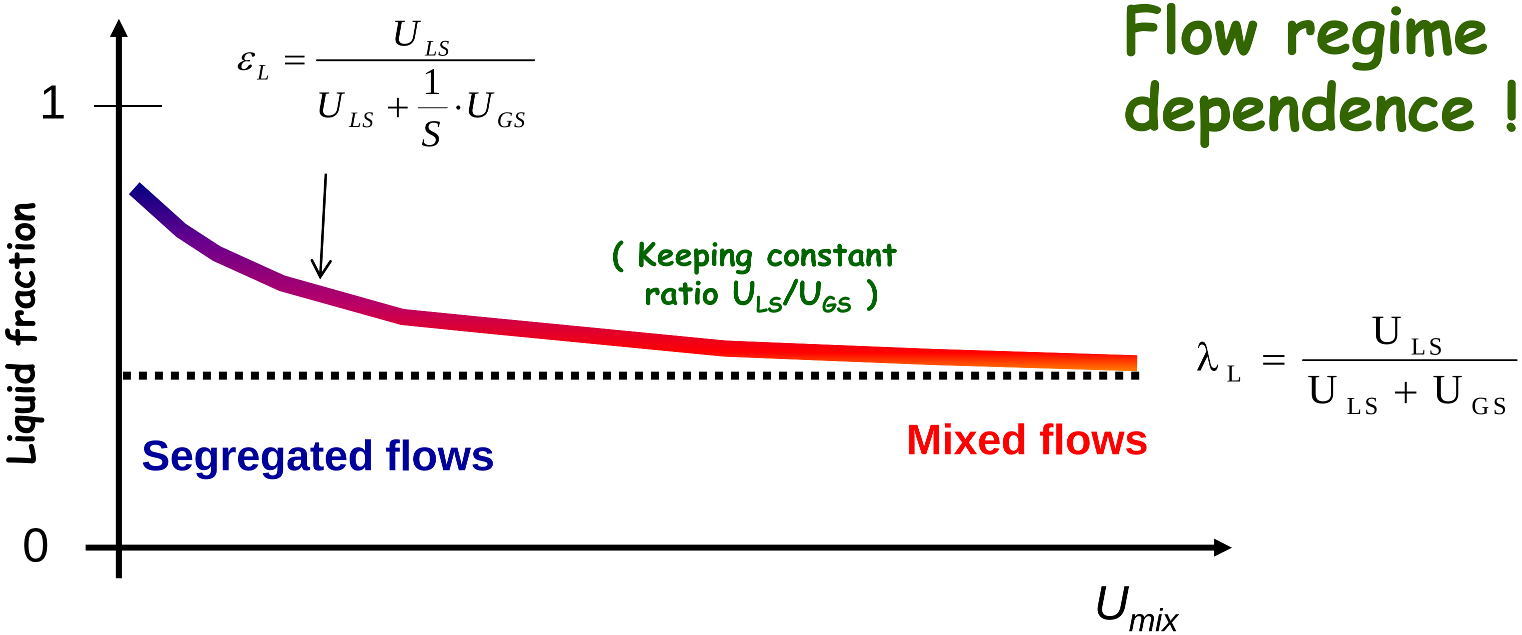
$$\varepsilon_L \equiv \frac{A_L}{A_L + A_G} = \frac{U_{LS}}{U_{LS} + \frac{1}{S} \cdot U_{GS}}$$

S = Slip ratio

Apparent ("noslip"):
$$\lambda_L = \frac{q_L}{q_L + q_G} = \frac{U_{LS}}{U_{LS} + U_{GS}}$$

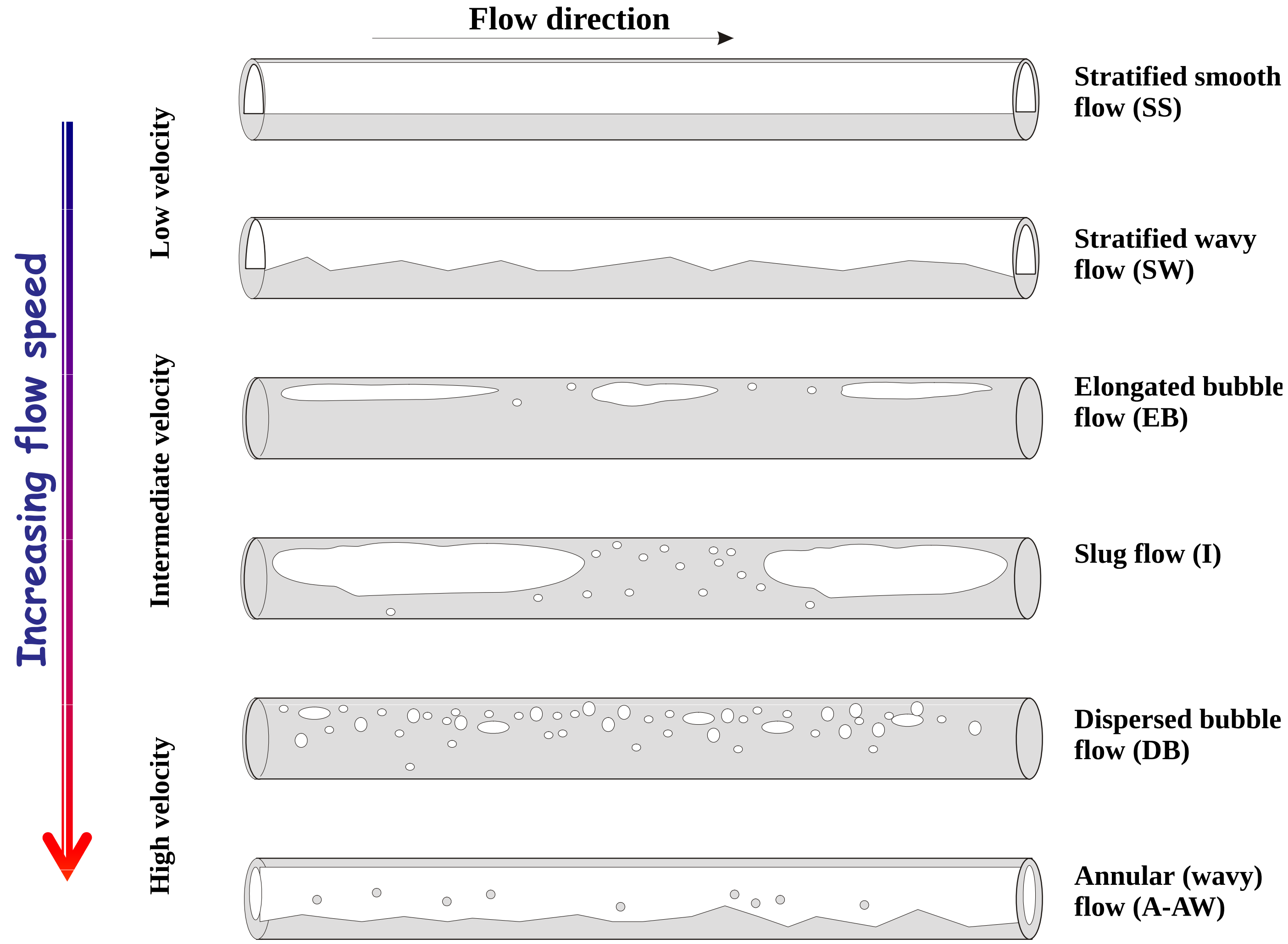
True fraction versus mixture velocity

True fraction → noslip fraction (S = 1)
as mixture velocity increases

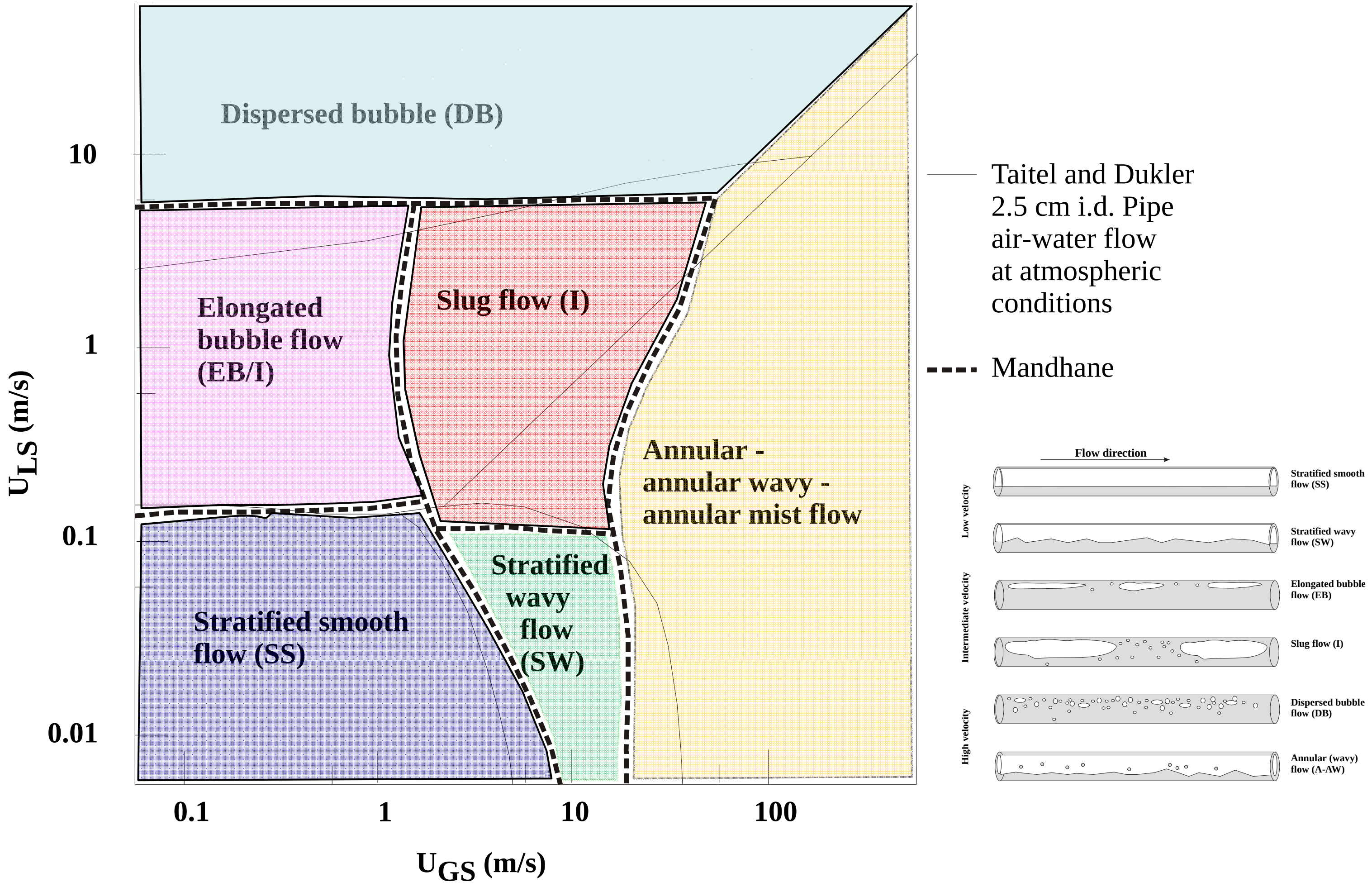


Flow regime dependence !

Flow regimes in horizontal pipes

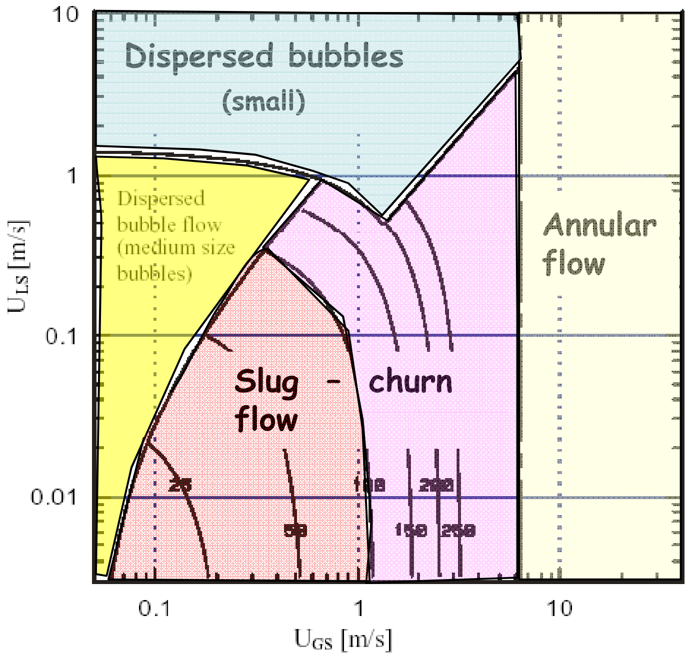


Flow regime map - horizontal pipes

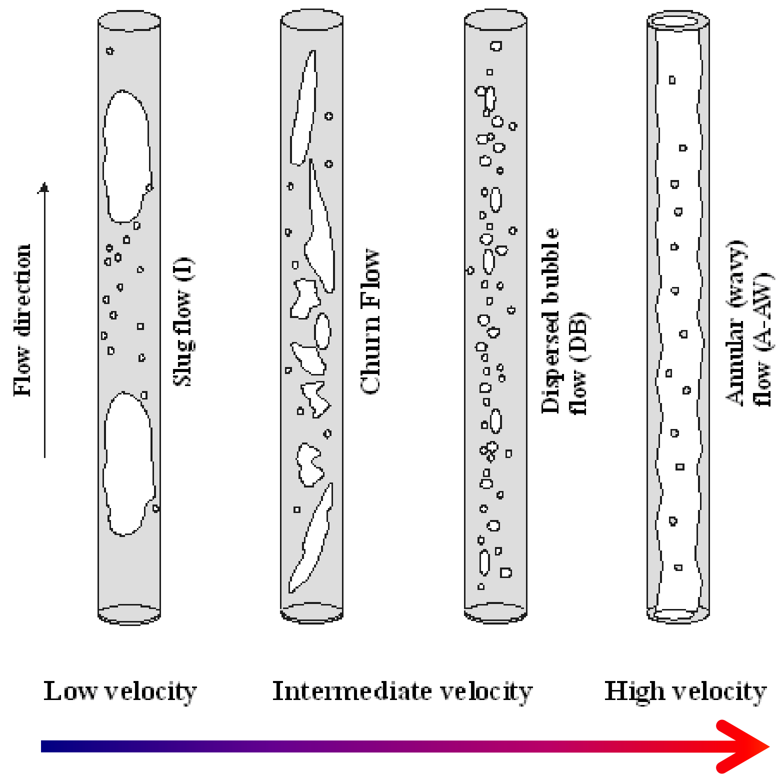


Flow regimes and map – vertical pipes

Flow regime map

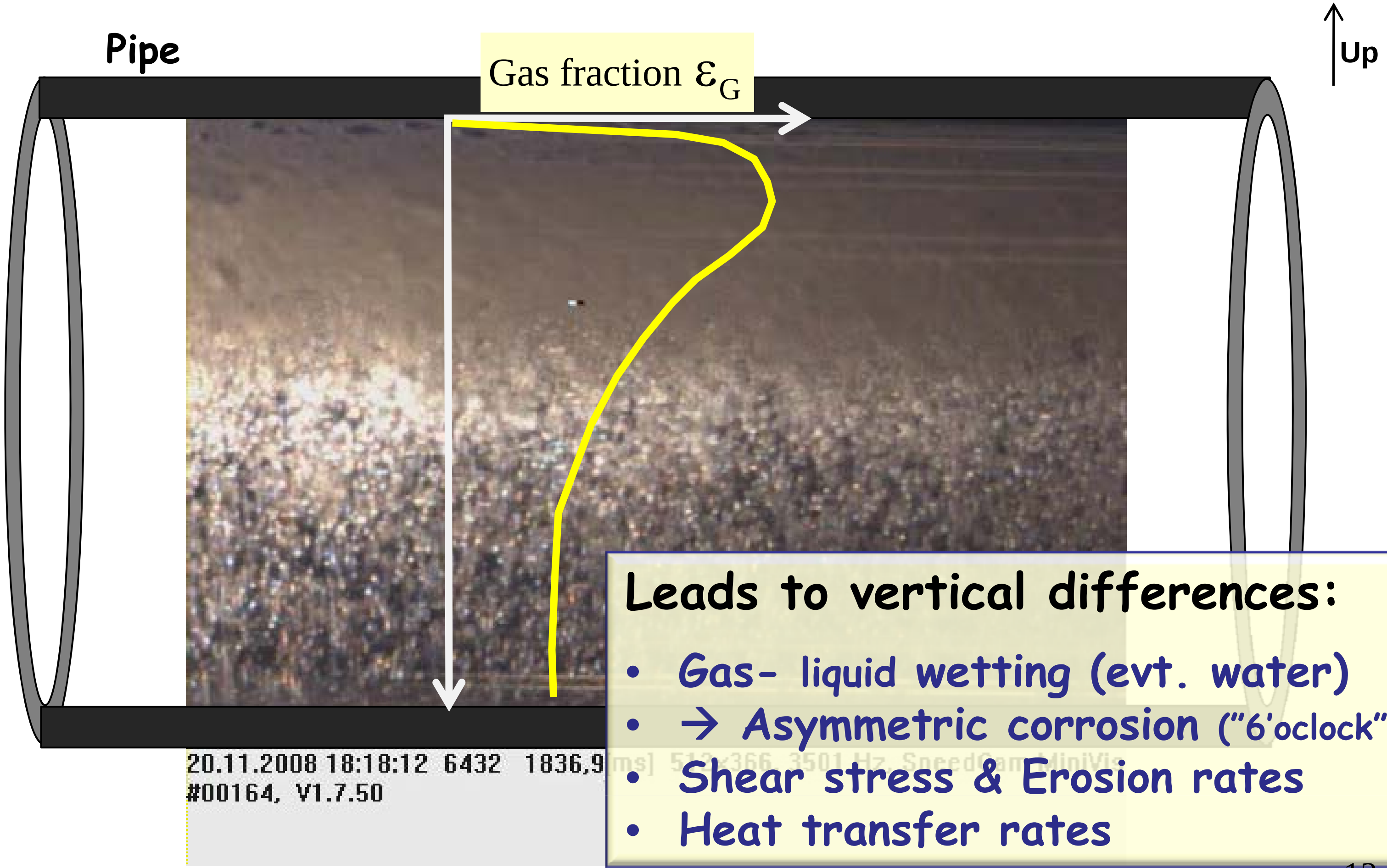


Flow regimes - types



Gas - concentration profiles

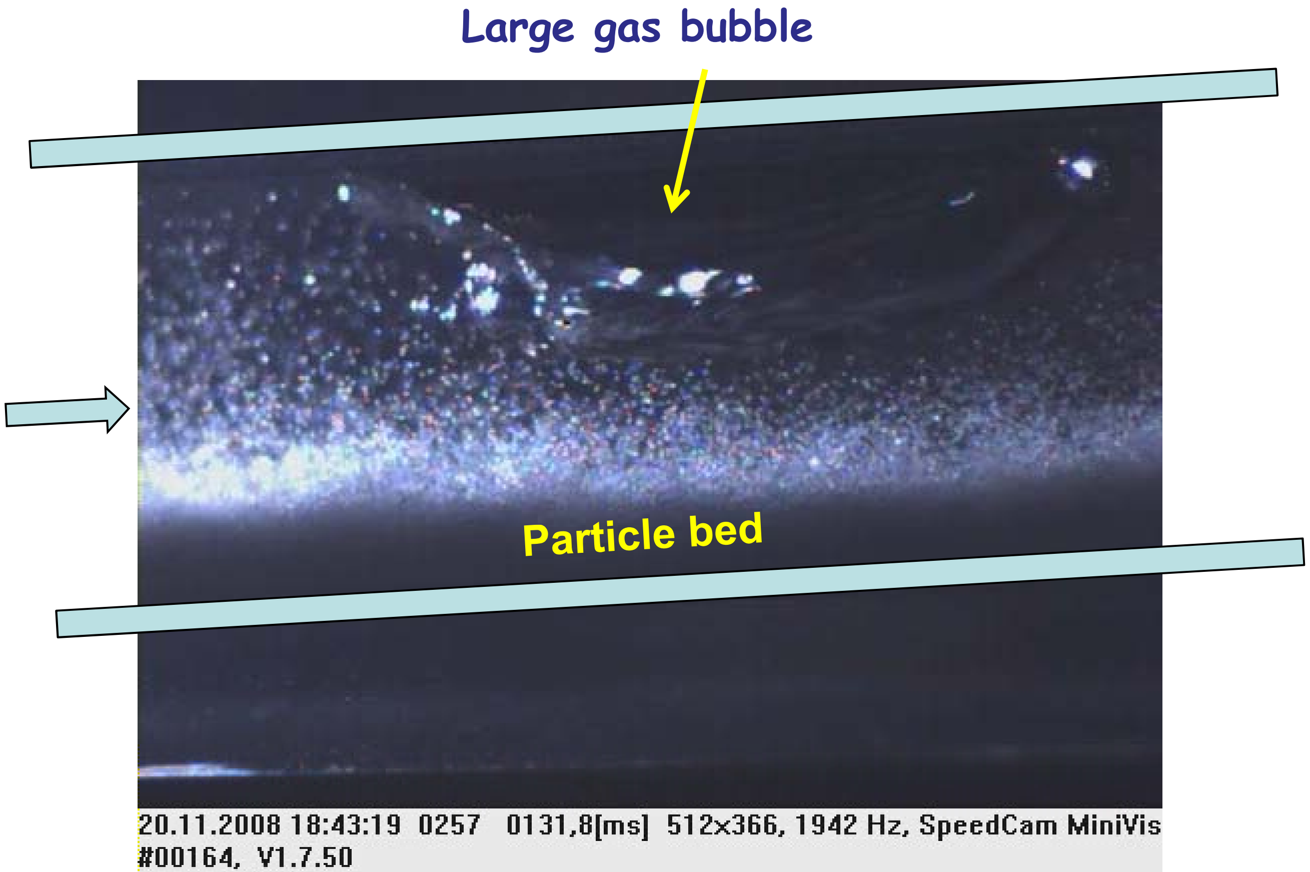
Snapshot of dispersed bubble flow



Leads to vertical differences:

- Gas- liquid wetting (evt. water)
- → Asymmetric corrosion ("6'oclock")
- Shear stress & Erosion rates
- Heat transfer rates

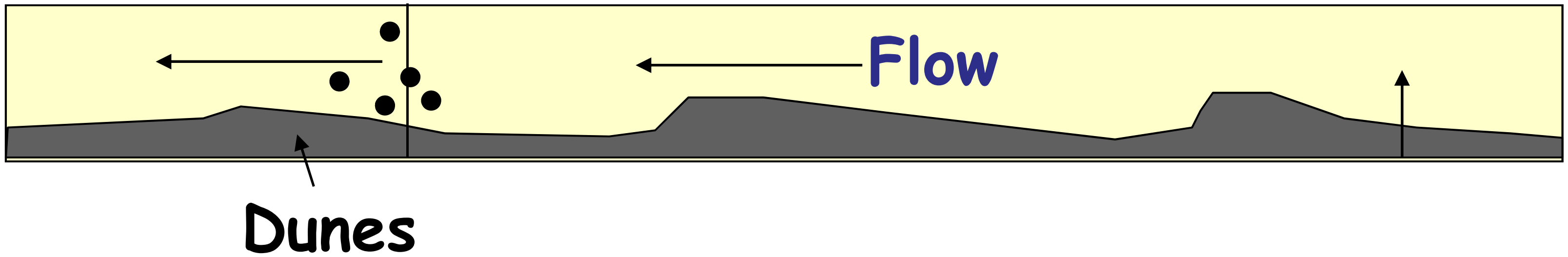
Particle slurries in multiphase flow

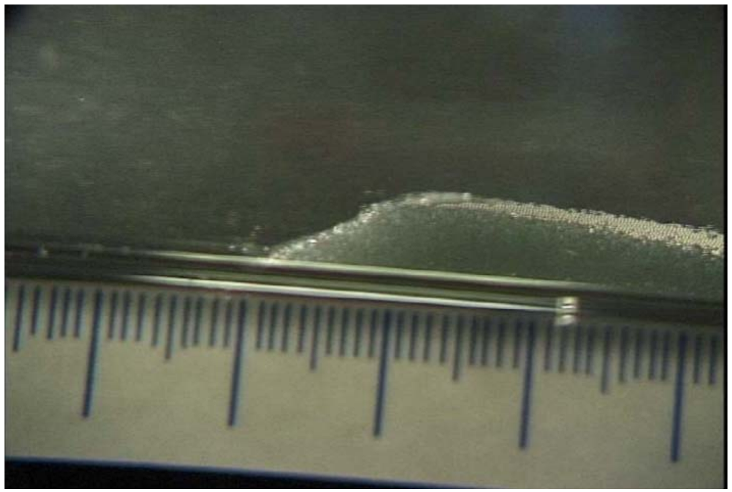


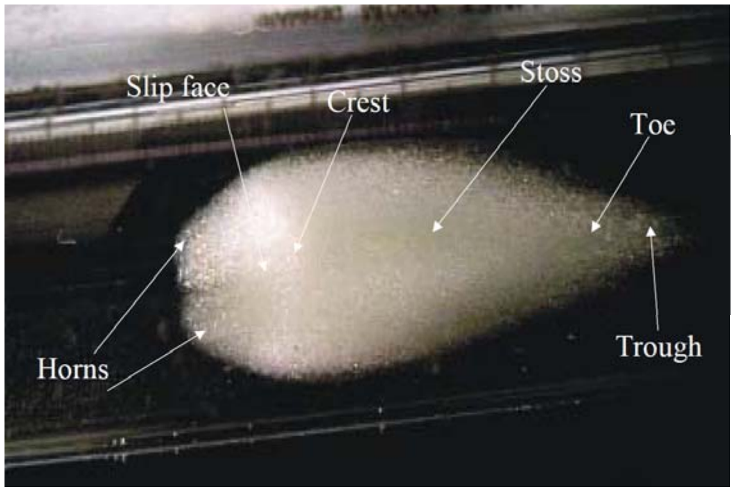
D:\BACKUP 2009 - DET ASTRONOMISKE ÅRET 2009\Åpent Hus 17mars09\Utvalgte high-speed videoer\ Water speed 1

Particle slurry regimes - dunes

Suspended particles in liqud

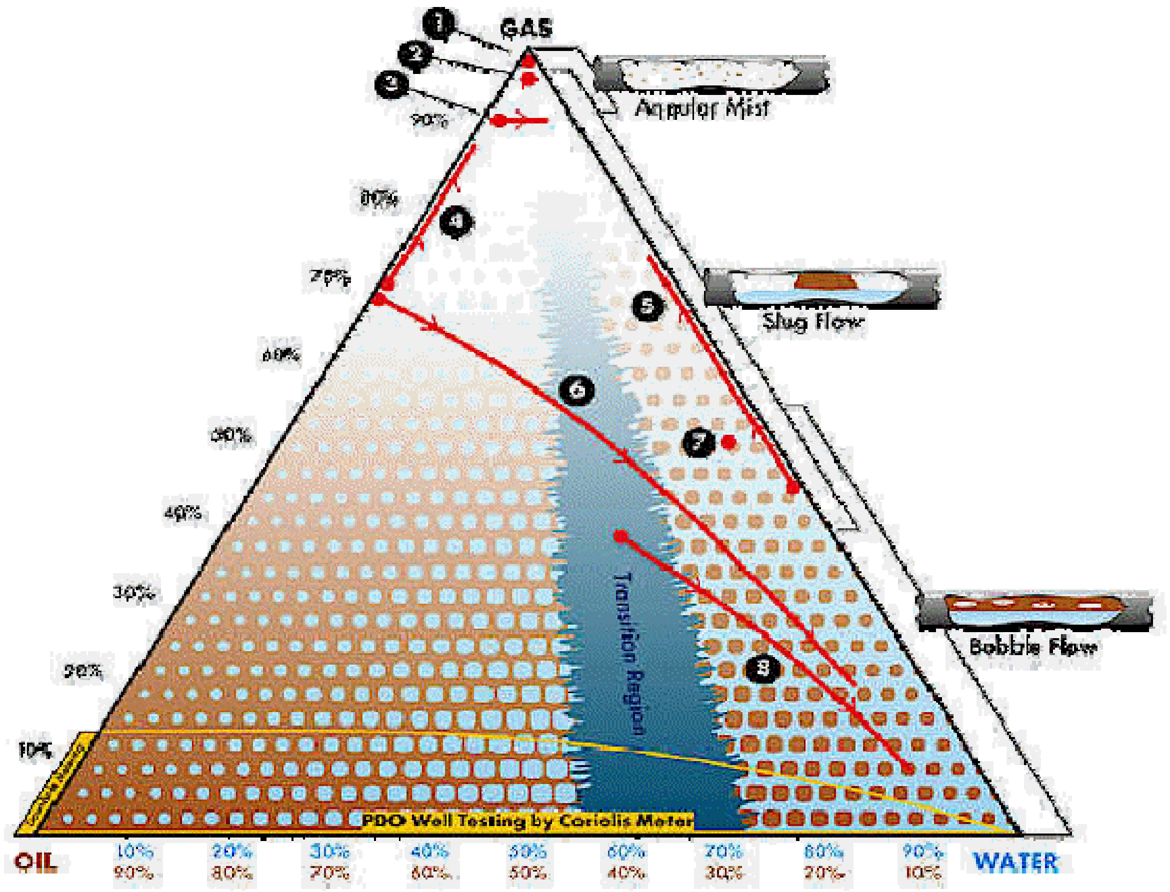






Rabenjafimantsoa and Time (UIS) - project with Statoil 2000-2005

Oil-water-gas flow regime map



REF:
http://www.iceweb.com.au
/Flow/multiphase_1.htm

MULTIPHASE COMPOSITION TRIANGLE

Importance of flow regimes

Much more than just "flow appearance":

Field plan and development

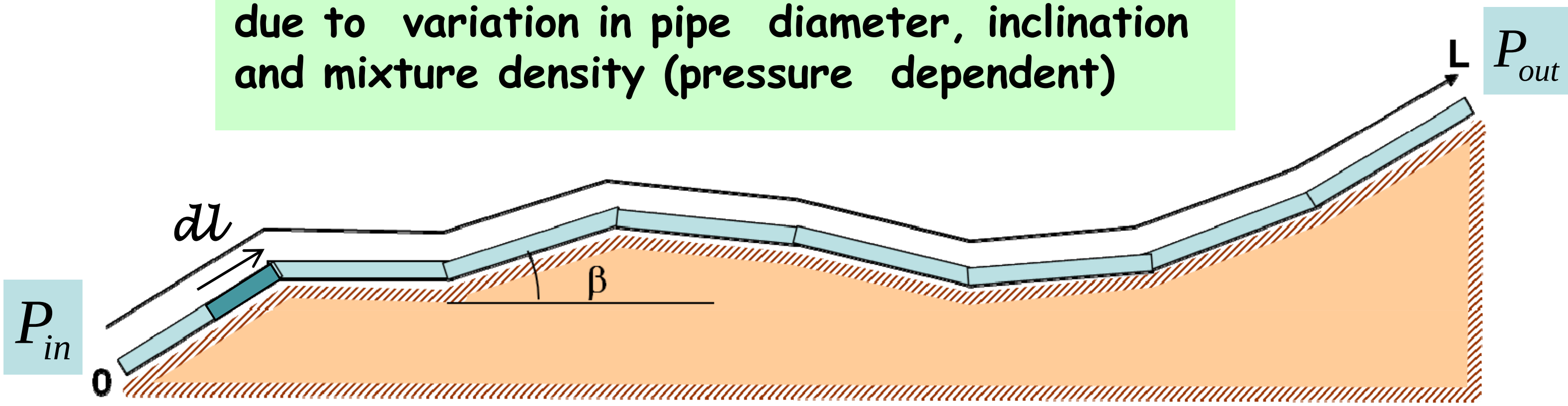
- Multiphase simulation, pressure and fluid fraction determination
- Slip ratio and fluid transport rates in long pipelines
- Multiphase pumping
- Decisive for quality of multiphase metering

Flow assurance, safety

- Process stability and control
- Pipeline and equipment vibration and fatigue
- Erosion
- Corrosion

The challenge of calculating pressure drop in long traverses

The pressure gradient varies along the pipe due to variation in pipe diameter, inclination and mixture density (pressure dependent)



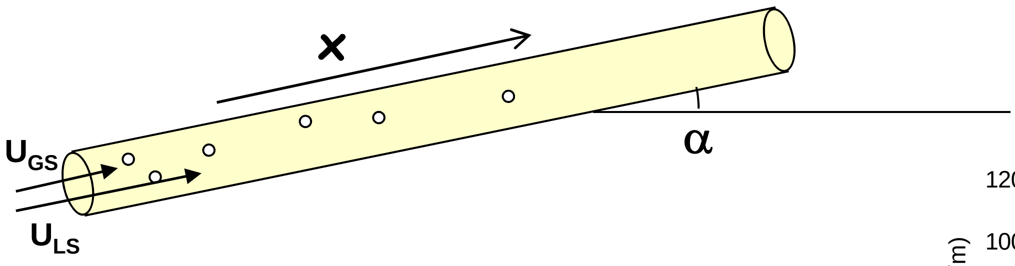
Pressure at exit: $P_{out} = P_{in} + \Delta P$

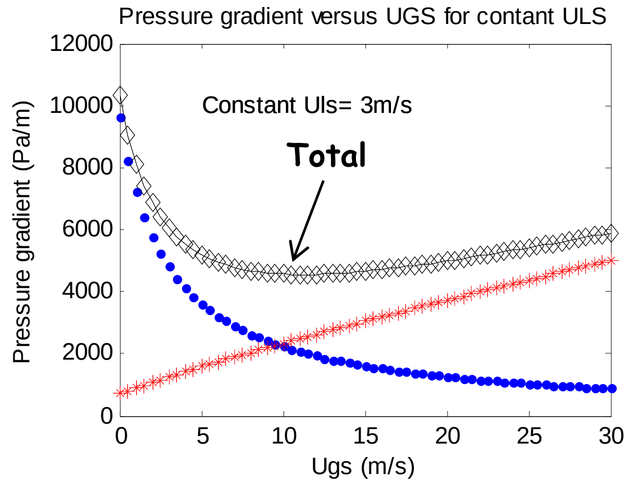
Sum of pressure drop in all pipe segment

Challenge in multiphase flow:

- *The pressure profile depends on the pressure!*
- *Requires iterative numerical solver*

Robust – "homogeneous" pressure drop model for two-phase flow





Friction factor

Friction : $$\left(\frac{dp}{dx}\right)_f = \frac{4}{D}\cdot f(\mathrm{Re})\cdot\frac{1}{2}\rho_{m}\cdot U_{mix}^{2}$$ *

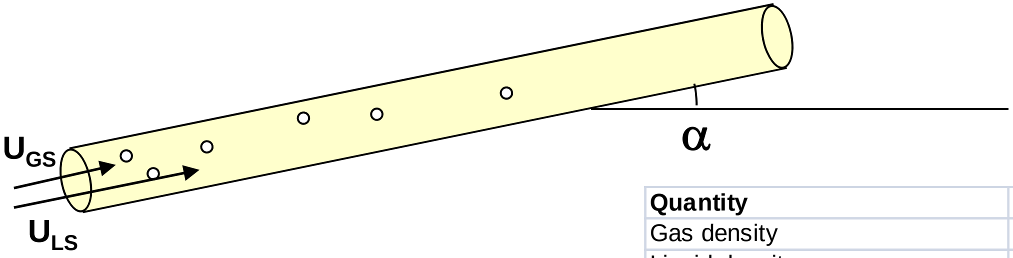
Hydrostatic: $$\left(\frac{dp}{dx}\right)_h = \rho_m \cdot g \cdot \sin\alpha$$ •

Acceleration: $$\left(\frac{dp}{dx}\right)_a = -\rho_m \cdot U_{mix} \cdot \frac{dU_{mix}}{dx}$$

EXCEL

version

Two-phase pressure drop model – Excel version



$$\left(\frac{dp}{dx}\right)_f = \frac{4}{D} \cdot C \cdot \left(\mathrm{Re}_m\right)^{-n} \cdot \frac{1}{2} \rho_m U_{mix}^{\ 2}$$

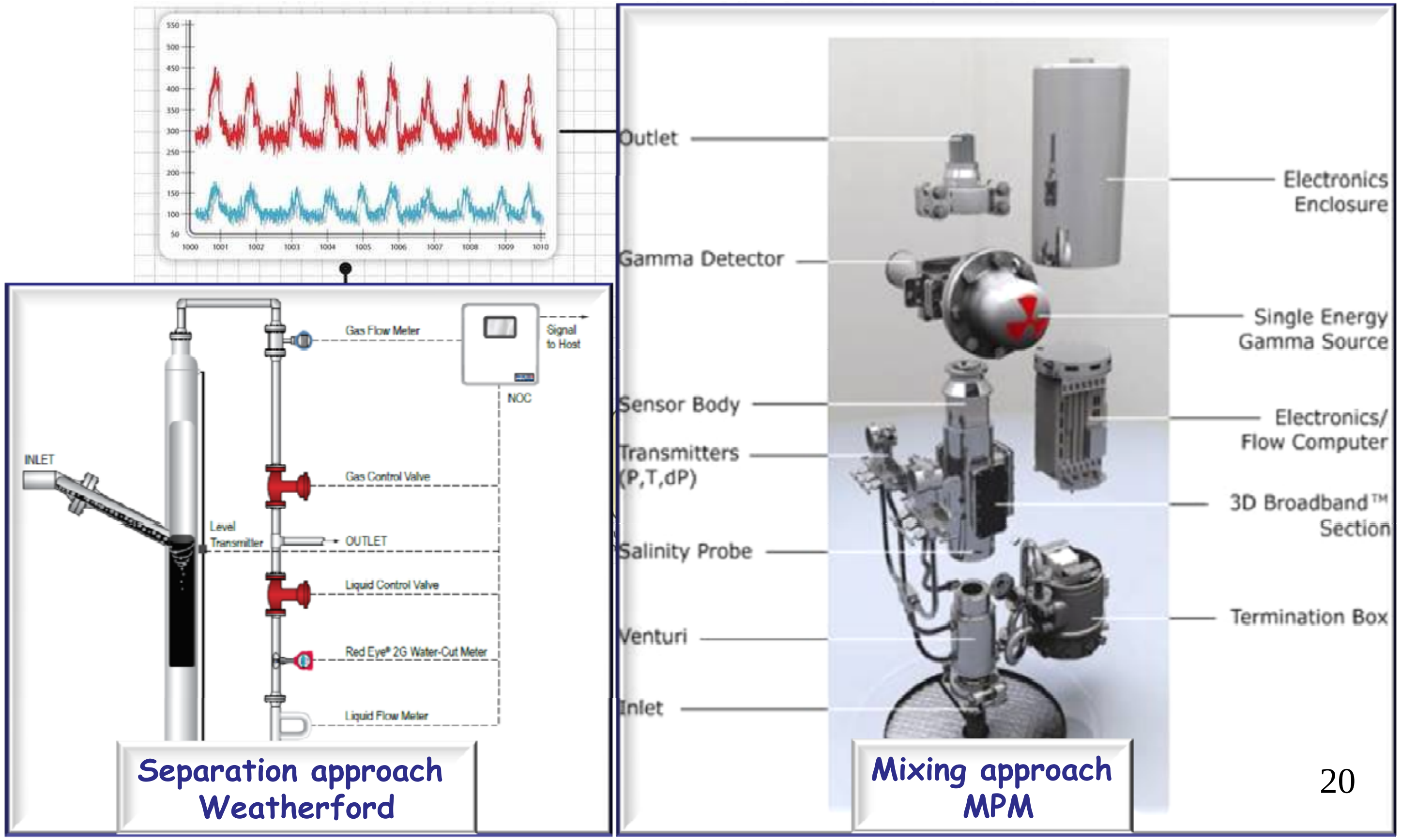
$$\left(\frac{dp}{dx}\right)_h = \rho_m \ g \sin\alpha$$

$$\left(\frac{dp}{dx}\right)_a = -\rho_m \cdot U_{mix} \cdot \frac{dU_{mix}}{dx}$$

Quantity	Symbol	Value	Unit		
Gas density	rog	10	kg/m^3		
Liquid density	rol	1000	kg/m^3		
Kinematisk gas viscosity	nyg	1,50E-06	m^2/s		
Dynamic gas viscosity	myg	1,50E-05	Pa*s		
Liquid viscosity	myl	3,00E-03	Pa*s		
Pipe diameter	D	1,50E-01	m		
Pipe inclination	α	20,0	deg	3,49E-01	rad
Acceleration of gravity	g	9,81E+00	m/s^2		
Slip ratio	S	1,2			
Superficial liquid velocity	ULS	3,5	m/s		
Superficial gas velocity	UGS	1,3	m/s		
Mixture velocity	Umix	4,8	m/s		
Gas fraction	epsg	0,236363636			
Liquid fraction	epsl	0,763636364			
Mixture density	rom	766	kg/m^3		
Mixture viscosity	mym	2,29E-03	Pa*s		
Reynolds number	Re	2,40E+05			
Friction factor	f	3,86E-03			
Friction pressure drop	dPdx_f	9,08E+02	Pa/m		
Hydrostatic pressure drop	dPdx_h	2,57E+03	Pa/m		
Accelerational pressure drop	dPdx_a		Pa/m		
Total pressure drop	dPdx	3,48E+03	Pa/m		

The World is Dynamic! – need for Measurement and Control

- Even constant inflow of multiphase flow mixtures into pipeline does not mean that the individual flowrates (G,L) are constant !
- Need for multiphase metering for survey and control !



Separation approach Weatherford

Mixing approach MPM