Interpretation of Production Logs

KAPPA

INTERPRETATION THEORY

Module #10

Multiple Phase Conditions

Two phase flow:

Oil plus water	- liquid + liquid
Oil plus gas	- liquid + gas
Water plus gas	- liquid + gas

The questions are:

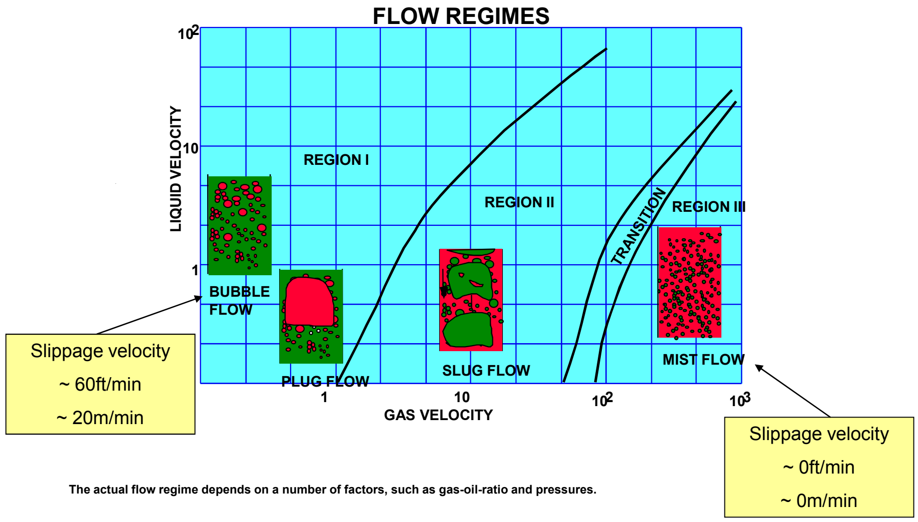
- what is flowing from which perforations
- is there any flow behind casing and if so which fluid
- is free gas being produced

Three phase flow there is:

Oil and gas plus water - liquid + liquid + gas

The questions are the same but the problem has an added unknown.

Flow In the Well - 2 Phase



The actual flow regime depends on a number of factors, such as gas-oil-ratio and pressures.

Definitions

Slip velocity, v_{slip}:

This is the absolute velocity difference between phases flowing together. No tool currently available to directly measure slip velocity.

Vslip = Vlight - Vheavy

Emeraude uses “Correlations” to assist in providing slip velocity.

Hold-up, Y:

This is fraction of the pipe cross-sectional area occupied by the phase of interest. The hold-ups must sum to unity

Yw + Yo + Yg = 1

Cut:

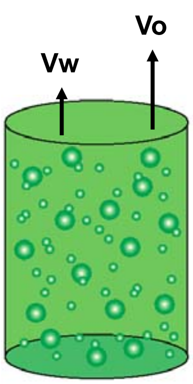
This is the ratio of the flowrate of the phase to the total flowrate. If there is no slip, then cut and hold-up are equal.

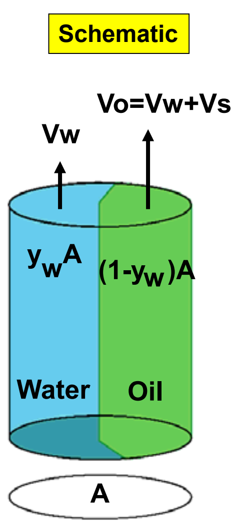
Water Cut = Qwater / Qtotal

Multiphase Solutions

- As with the single phase case the spinner will give an average total velocity, which will give an average total flow rate.
- Additional measurements are need to differentiate between the fluids.
- Here the fluid density and/or hold-up is used.
- In 3 phase both the density and hold-up are needed.
- An interpretation scheme making some assumptions can also be used, which is provided within Emeraude, with Flow Models and Correlations.

Bubble Model





The bubble flow model used to be assumed in order to simplify the calculations as a quick look. A single slippage velocity Vs was required.

In computer based solutions a correlation is used to derive the flow regime and calculate a slippage velocity.

Hold Up From Density

The solution for the rates needs an input of the hold up of any phase or the density

$\rho_M = \rho_H.Y_H + \rho_L.Y_L$

But $Y_L + Y_H = 1$ Therefore $Y_L = 1 - Y_H$

$\rho_M = \rho_H.Y_H + \rho_L.(1-Y_H)$

$$Y_H = \frac{(\rho_M - \rho_L)}{(\rho_H - \rho_L)}$$

ρ_L = light phase density
ρ_H = heavy phase density
ρ_M = mixture density

2-Phase equal velocities

With the two phases flowing at the same velocity it would be sufficient to have a bulk rate and a way of measuring the holdups.

$$Q_t = 1.4 \times \left[0.83 \times V_{app}\right] \times D^2$$

(Units - Q [bbl/d]; V_{app}, V_m [ft/min]; D [inch])

$$\rho = Y_h \times \rho_h + Y_l \times \rho_l \quad \rightarrow \quad Y_h = \frac{\rho - \rho_l}{\rho_h - \rho_l}$$

$$Q_h = Y_h \times Q_t \quad ; \quad Q_l = Q_t - Q_h$$

NB: Vpcf and the friction correction (gradio) would require an iterative solution method

2-Phase unequal velocities

Holdups: $Y_h + Y_l = 1$

Rates:

$$Q_h = V_h \times A \times Y_h \;;\; Q_l = V_l \times A \times Y_l$$

$$Q_h + Q_l = Q_t$$

Slippage:

$$Vs = V_l - V_h = \frac{Q_l}{A \times Y_l} - \frac{Q_h}{A \times Y_h} \Rightarrow Vs = \frac{Q_t - Q_h}{A \times (1 - Y_h)} - \frac{Q_h}{A \times Y_h}$$

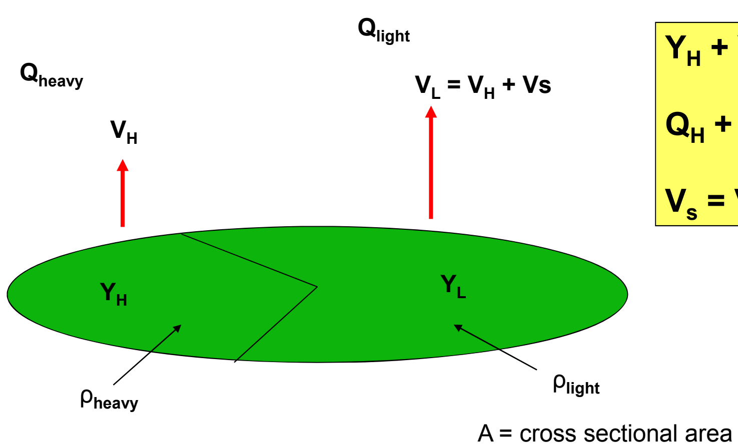
Rearranging:

$$Q_h = Y_h \times Q_t - Y_h \times (1 - Y_h) \times V_s \times A$$

$$Q_h = Y_h \times \left[Q_t - (1 - Y_h) \times V_s \times 1.4 \times D^2 \right]$$

(Units - Q [bbl/d]; V_{app}, V_m [ft/min]; D [inch])

2-Phase Model

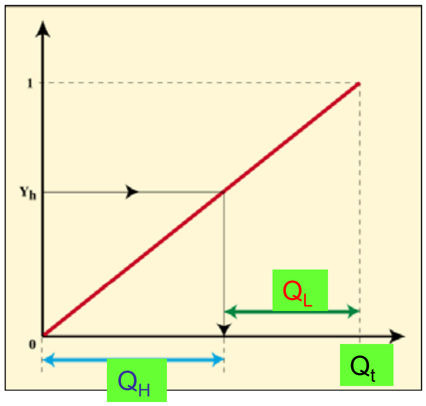


$Y_H + Y_L = 1$

$Q_H + Q_L = Q_t$

$V_s = V_L - V_H$

Superficial Velocities

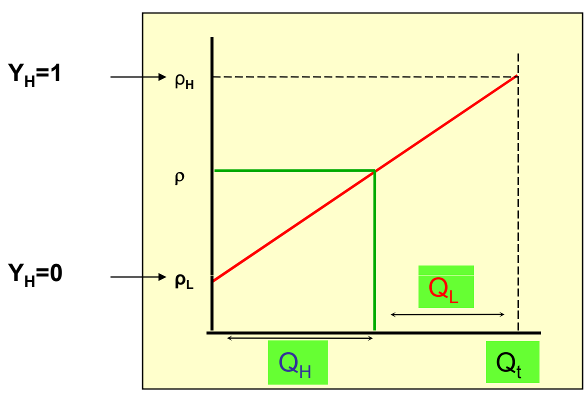


From the equations:

$Y_H + Y_L = 1$
$Q_H + Q_L = Q_t$

NOTE:
(No slippage velocity or flow regimes considered on this plot)

Densities



A similar solution is possible for the density, instead of holdups

Slippage Velocities

In the general case there is a difference between the two phases.

This term is called the Slippage Velocity, and will vary depending on the flow regime

The Slippage Velocity is the difference in velocities between the two phases.

Vslippage = Vlight - Vheavy

The light phase generally rises faster than the heavy phase.

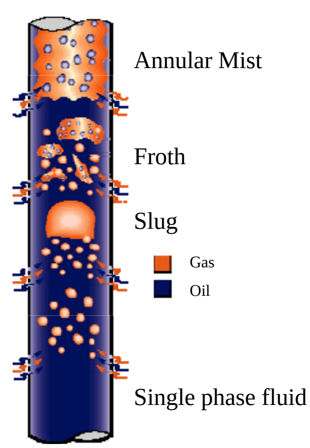
Slippage velocity correlations

Slippage velocity depends on the type of flow regime.

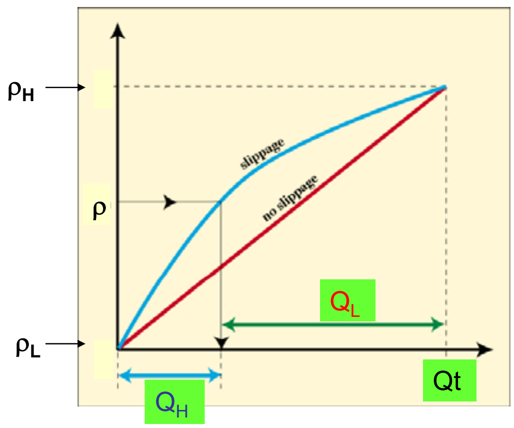
In Liquid-Gas a wide variety of regimes can occur

In Liquid-Liquid bubble flow is usually encountered (not near horizontal …)

A number of correlations exist, empirical or mechanistic, to determine the flow regime and calculate the slippage velocity Vs



Slippage Velocities

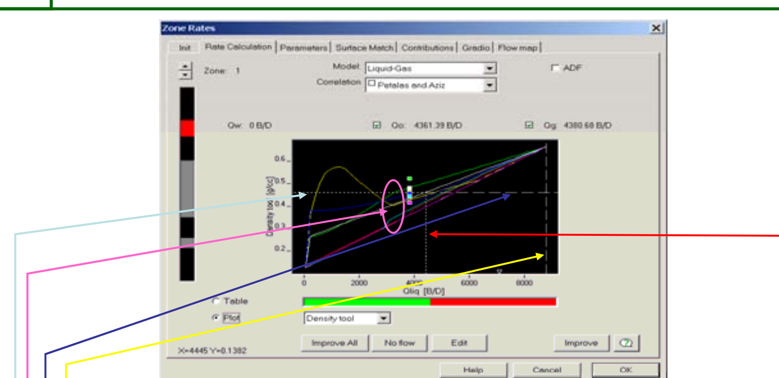


The slippage velocity implies that there will be less of the light phase seen in the pipe

The heavy phase hold up (Y_H) is larger, than would be predicted with no slip between the light and heavy phases.

The relationship becomes non-linear due to slippage and the changing nature of the flow regimes between the phases.

Zone Rates Calculation - 1

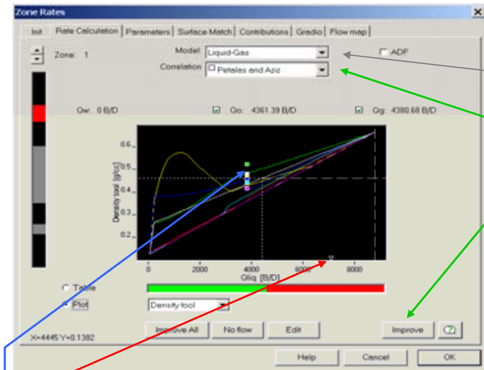


The default plot shows the density tool response vs possible values of Qh for the current Qt.

Values on the X-axis are between 0 and Qt. The value Qt - Qh represents Ql (light)

- vertical dashed line: current value of Qt
- horizontal dashed line: measured density tool response for the zone
- coloured curves: simulated density tool responses for the applicable flow correlations
- vertical dotted line: Qh for the current solution
- horizontal dotted line : simulated density tool response for the current solution

Zone Rates Calculation - 2



- **Change Model** – Auto Improve
- **Change Correlation** – User must perform a "Manual Improve"

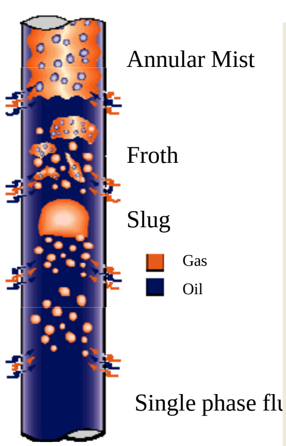
If the surface rates have been entered, (and the zone in view is the top calculation zone):

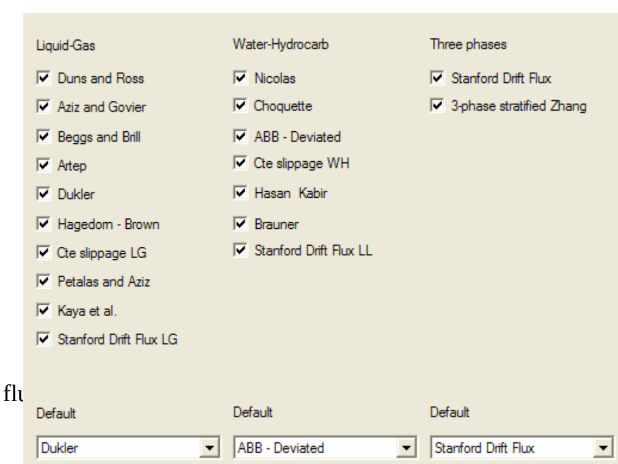
- white triangle pointing down on the X-axis:… downhole mixture rate as computed from the entered surface rates (and the PVT model Volume factors etc).
- colored squares:…. the density tool response the correlations would predict if the downhole rates were those corresponding to the entered surface conditions.

When a water holdup or a gas holdup measurement is available, it is possible to change the plot to a display of Water holdup or Gas holdup vs Qh. …replacing "density tool response" by "water holdup" or "gas holdup".

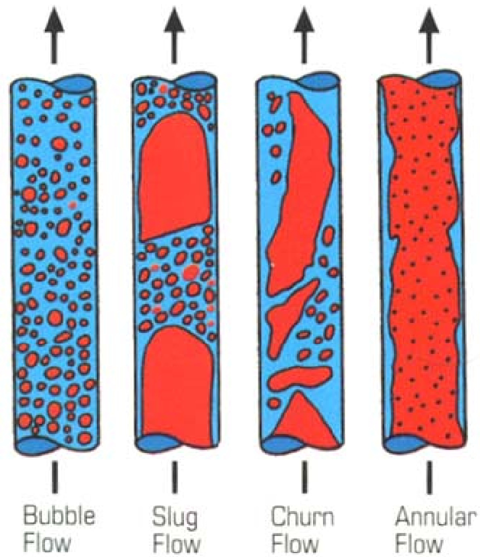
Flow Correlations

Flow Correlations

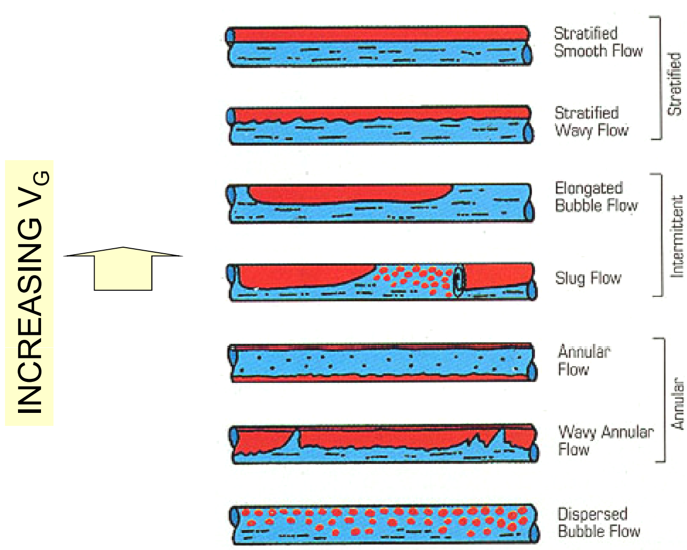




Flow Regimes in Vertical Pipes

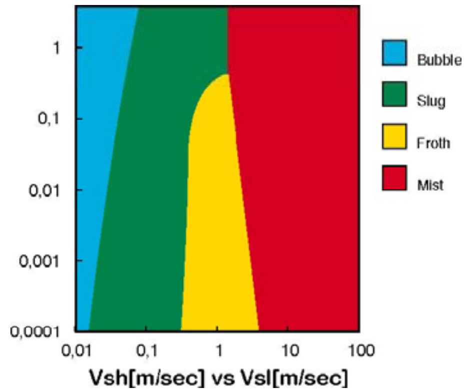


Flow Regimes in Horizontal Pipes

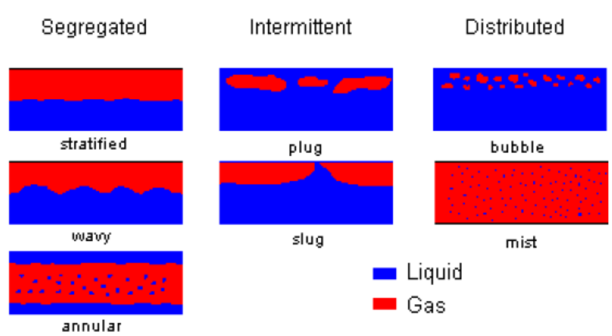


Aziz and Govier

- Mechanistic correlation for Liquid-gas flows.
- Only vertical flow is considered by the correlation
- Determination of the flow regimes is made using a single flow map plotted in terms of modified superficial velocities Y.Vsh vs X.Vsl, where X and Y are functions of the densities and interfacial tensions.



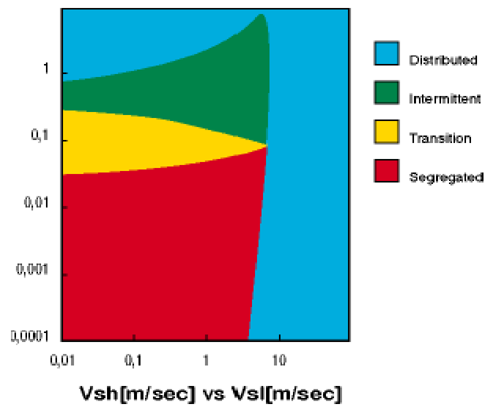
Beggs and Brill - 1



Correlation based on experiments with air-water flow for various pipe inclinations. The correlation distinguishes the flow regimes shown.

Beggs and Brill - 2

- Developed for tubing strings in inclined wells, and pipelines for hilly terrain, (but no negative Vs)
- From experiments using air and water over a wide range of parameters.
- Wide range of oil gravity
- Large errors for GOR>5000
- Accurate up to 10% water cut
- Not good in vertical oil flow
- Deviations 45 - 90deg

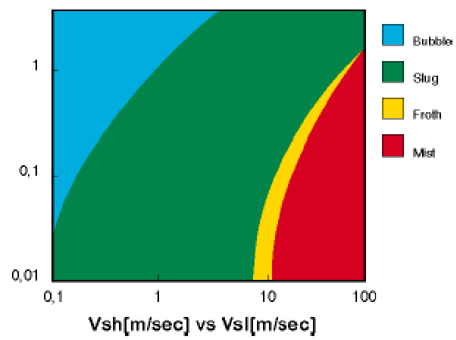


Artep

- No Flow Map
- Correlation for Liquid-Gas flow coupling a mechanistic derivation with a physical basis provided by experiments.
- The experiments were conducted in a flow loop at deviation between 0 and 90 degrees.
- The correlation does not handle a deviation of 90°.

Duns and Ross

- Only vertical upward flow is considered by the correlation.
- Handles mist better than slug flow.
- 1000 < GLR < 5000
- Wide range of oil gravity (13-56 API)
- Not suitable for wells with water cut
- Experimental correlation derived from laboratory data for vertical Liquid-Gas flow
- Good for Condensate wells
- Good for gas lift wells

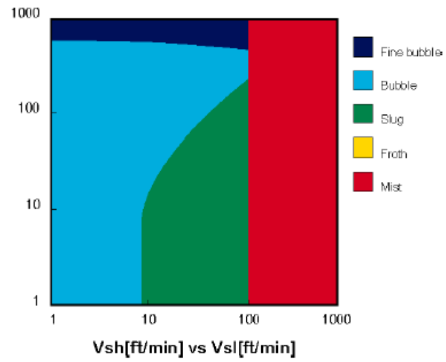


Hagedorn and Brown

- Experiment realised in a 1,500 ft vertical well.
- Tubing I.D: 1 in, 1¼ in, 1½ in.
- Oil viscosities between 10 and 110 cp (@ 80°F)
- Oil gravity from 25-40 °API
- GOR<5000
- Only vertical upward flow is considered by the model.
- No flow map.
- Single Holdup correlation provided for all conditions.
- Best choice for vertical wells with or without water cut.
- Poor in low rates
- Good in slug flows and high rate oil wells

Dukler - 1

- Based on experiments with air and water in 2.5 cm and 5.0 cm pipes.
- Mechanistic approach for the flow map determination.
- Only vertical flow is considered by the flow map, but slip deviation correction is applied in bubble flow (see next slide).



Dukler - 2

- Slug flow: The slippage correlation is given in the reference.
- Bubble flow: Slippage is based on (in ft/min)

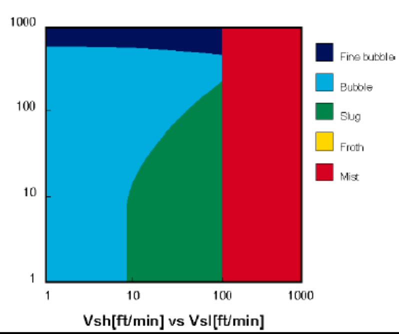
$$Vs = 60 \times \sqrt{(0.95 - (1 - Y_H)*(1 - Y_H))} + 1.50$$

- Pipe deviation: Taken into account by correcting the slippage velocity with a factor defined in the Interpretation Settings dialog as either linear for all angles:

$$Vs = Vs \times (1 + 0.04 \times \text{deviation}) \ldots \text{ in bubble flow only.}$$

Or identical to the above until 45° and decreasing above this value (Ding et al.)

- The default setting is the linear correction.
- Probably the most widely-used flow correlation, although more-recent authors have questioned the physics of the correlation.



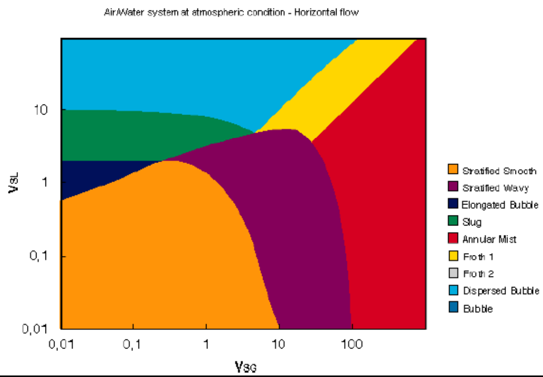
Petalas & Aziz

Mechanistic correlation for all pipe inclinations, geometries, and fluid properties. Empirical correlations involved in the model were developed based on the Multiphase Flow Database of Stanford University gathering 20,000 laboratory measurements and 1800 measurements from actual wells.

This correlation distinguishes the following regimes:

- Froth (transition between dispersed bubble and annular-mist).
- Froth II (transition between slug flow and annular-mist).
- Elongated bubbles
- Bubble
- Stratified smooth
- Stratified wavy
- Slug
- Annular-Mist
- Dispersed bubble

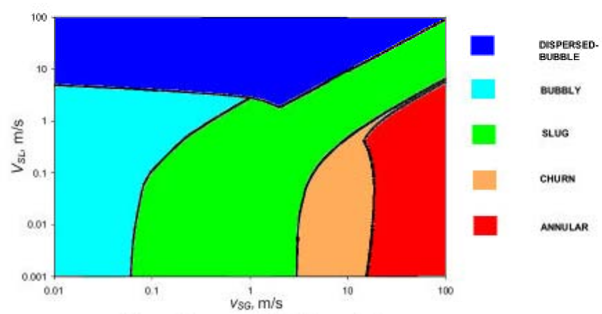
Stratified flow regimes are restricted to horizontal flow.



Kaya et Al

A separate hydrodynamic mechanistic correlation is proposed for the different flow patterns.

The correlation includes five flow patterns: bubbly, dispersed-bubble, slug, churn, and annular flows in vertical and deviated wells



Flow-pattern map (90°, 5.08-cm pipe).

<u>Reference</u>: SPE 72998 : Mechanistic Modeling of Two-Phase Flow in Deviated Wells, A.S. Kaya, C. Sarica, and J.P. Brill

Stanford Drift Flux LG

Stanford Drift Flux Reference: SPE 89836 Drift-Flux Parameters for Three-Phase Steady-State Flow in Wellbores; H. Shi, J.A. Holmes, L.R. Diaz, L.J. Durlofsky, K. Aziz

The Drift-flux correlations represent multiphase flow in wellbores or pipes in terms of a number of empirically determined parameters. The great advantage of this correlation is that there is a continuity between the various flow regime type.

Two-phase correlation and parameter determination
i.e. The drift-flux correlation for two-phase **gas-liquid** flow is given by:
Vg = Co . Vm + Vd
Where Vg is the average gas in situ velocity, Co is the profile parameter, Vm is the mixture velocity and Vd is the drift velocity.
The parameters determining Co, Vm, and Vd are experimentally determined.

Three-phase parameter determination
To model three-phase flow, a two-stage approach is first applied based purely on the two-phase flow correlations. The system is first treated as a gas-liquid flow to determine the gas hold up and then model the liquid as an oil-water system to determine the liquid hold ups.

Data used for the calibration were coming from cases with deviations from 0° to 88°.
The correlation should not be used outside this range.

Liquid-gas Correlations

Correlation	Year	Type	Application
Duns & Ross	1963	Emprical	Vertical flow, High GLR, Mist flows, Condensates, gas lift
Hagedorn & Brown	1965	Emprical	Vertical flow, slug flows
Aziz & Govier	1972	Mechanistic	Vertical flows
Beggs & Brill	1973	Emprical	All deviations
Duckler	1980	Mechanistic	Vertical flow
Artep	1988	Mechanistic	All deviations
Petalas & Aziz	1996	Mechanistic	All deviations (negative slippage)
Stanford Drift Flux LG	2004		0-88deg
Kaya et Al	2001	Mechanistic	Deviated & vertical flows (latest)

Nicolas

Nicolas, Choquette, and “ABB-deviated” are experimental correlations for Liquid-Liquid bubble flow. They all relate the slippage velocity to the bubble rise velocity in a static column.

Nicolas

Slip deviation correction in Emeraude:

Pipe deviation is taken into account by correcting the slippage velocity with a factor defined in the Interpretation Settings dialog as either linear for all angles:

$$Vs = Vs \times (1 + 0.04 \times \text{deviation})$$

Or identical to the above until 45° and decreasing above this value (Ding et al.)

Note that changing the deviation correction mode in the Interpretation Settings will potentially affect all existing interpretations using the Nicolas correlation. It is left to the user to update calculations for zones/logs that are affected by the change.

Choquette, ABB-Deviated, Constant slippage

Choquette

This is a conventional slip velocity corelation in Water-Oil flow, represented as a chart giving the slippage versus the density difference for several values of water holdup .. (See next slide)

Slip deviation correction in Emeraude: as for Nicolas

ABB – Deviated

Variation of the Choquette correlation specifically derived from deviated wells data. Recommended for Liquid-Liquid calculations in deviated wells.

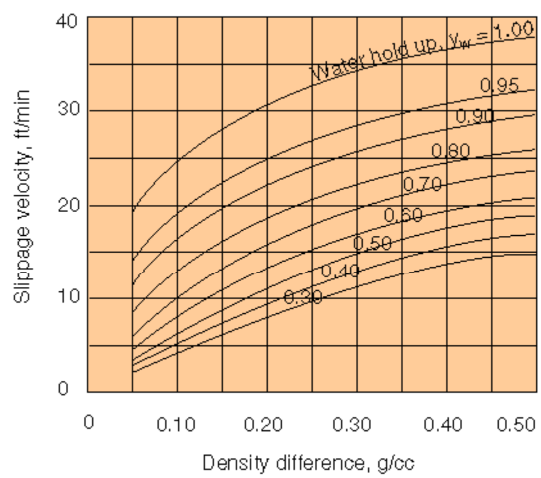
Constant slippage

The slippage value is entered manually on each zone.

When calculations are made using a differential pressure density tool, the pipe friction for all the above models is estimated using a Moody friction factor based for an Reynolds number representative of the mixture.

Choquette

The slippage velocity can be found using this chart. (Choquette)



Hassan & Kabir

SPE 49163:" A Simplified Model for Oil-Water Flow in Vertical and Deviated Wellbores", A. R. Hasan, SPE, U. of North Dakota, and C. S. Kabir, SPE, Chevron Overseas Petroleum Technology Company

The study focuses on water- dominated flow regimes, close to bubbly flow, pseudo-slug flow, and chum flow.

A drift-flux approach is taken to analyze the flow behavior of oil-water systems. Although simplistic, the proposed model appears to be quite robust in that it has reproduced a wide range of laboratory data from various sources.

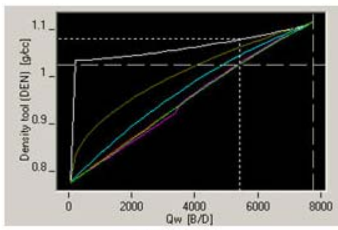
The model was validated versus different pipe sizes(1 to 8 in.), oil viscosity(1 to 150 cp) and production values(500 to 10,000 bpd).

Brauner

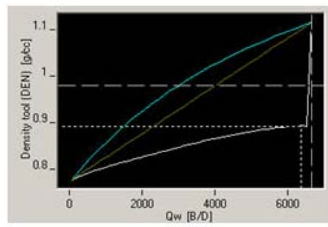
Reference: Modeling and Control of Two-Phase Flow Phenomena" Neima Brauner Ed. V Bertola, CISM Center, Udine, Italy, 2004.

Brauner is a combination of the Brauner stratified water-oil model, with the mechanistic model of Hasan & Kabir.
The option is given to force stratified flow (in the Edit dialog).

It is possible to force "on All" zones at once. Below are examples of the stratified flow predictions for upward and downward flows.



80 degrees



93 degrees

QAQC – Choice of correlations

Correlations can be selected based on a number of justifications:

- Based on a correlation used in pipe lift calculations.. Eg. PROSPER
- Chosen on local empirical experience – it worked for us in the past
- Whether the well is deviated or not.
- Based on the scientific principles the correlation was founded on.
- Used to match rate ratios of the surface rate measurements. (Choice of correlations does not change the total flowrate.. Only the ratio of the heavy and light flowrates)
- A particular correlation may be chosen because of failure of certain other correlations, say for example in low velocity regions where some correlations break down, predicting Vs > Vm
- A constant slippage correlation option can be selected where the slippage velocity is known in certain situations.

NOTE: Correlations were not designed specifically for PL intepretation

Superficial Velocities

The following slides are to introduce the concept of SUPERFICIAL VELOCITY and the relevance in the multiphase calculation process.

SUPERFICIAL VELOCITY is also referred to in the following topics in the online help:

- Apparent Downflow equation
- Viewing Correlation Flow Maps
- Mass weighted Spinner response equation
- Discussion of Multiphase Interpretation Theory

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Superficial Velocities

The actual heavy phase velocity, $V_H = q_H / (Y_H.A)$
And actual light phase velocity, $V_L = q_L / (Y_L.A)$

The superficial velocity of a given phase is the rate of the phase divided by the pipe area. (as if flowing in 100% of the pipe area!)

Superficial heavy phase velocity, $Vs_H = q_H/A$
Superficial light phase velocity, $Vs_L = q_L/A$

The total of the superficial velocities is the mixture velocity;

$$Vs_H + Vs_L = V_M$$

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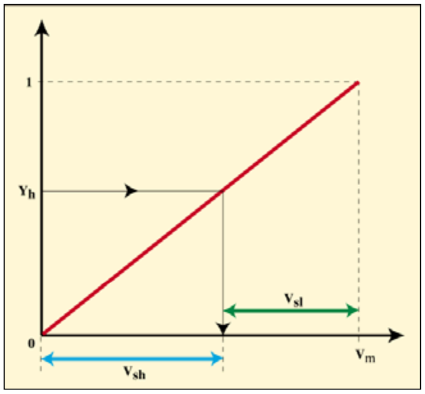
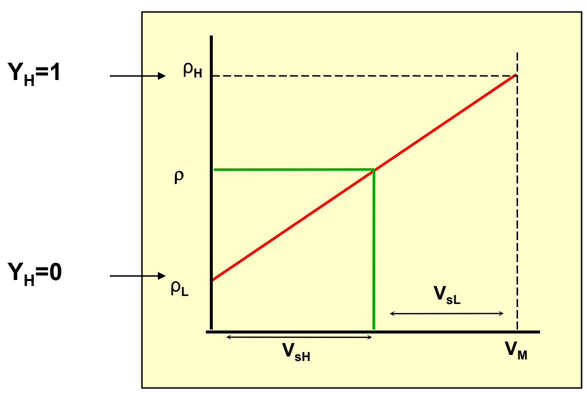
Superficial Velocities



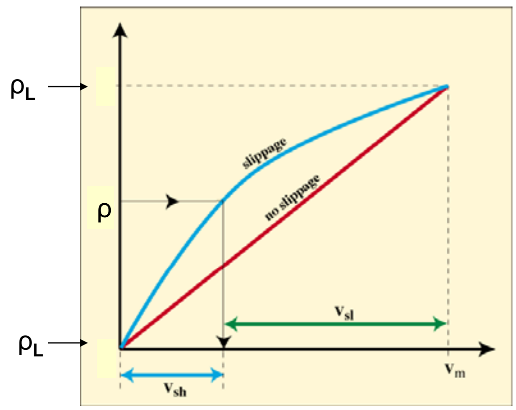
From this relation, if the hold up (e.g. Yh) is known, the superficial velocity can be found from the intercept on the line from 0,0 to 1, Vm

Densities

A similar solution is possible for the density



Slippage Velocities



The slippage velocity implies that there will be less of the light phase seen in the pipe

The heavy phase hold up (Y_H) is larger, than would be predicted with no slip between the light and heavy phases.

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Slippage Velocities