

The calculation of frictional pressure loss for two phase gas-liquid flow is complex. The coexistent flow of two phases complicates the theoretical and empirical approaches which are available; this means that a complete analytical solution is not possible. After 60 years of extensive research it is rare to find two correlations with exact predictions. In an effort to overcome these shortcomings THE *FluidFlow3* two-phase module provides six choices of correlations that represent some of the most successful approaches to this complex problem. These are detailed at the end of this note.

### Method of Solution

The pressure gradient ( $\Delta P/L$ ) for two phase flow is not constant but varies along the pipe as a function of temperature and pressure. This means that the pressure drop must be calculated by integrating the pressure gradient along the pipe. The calculation approach used by *FluidFlow3* is similar to that used in compressible flow calculation. The following steps are made:

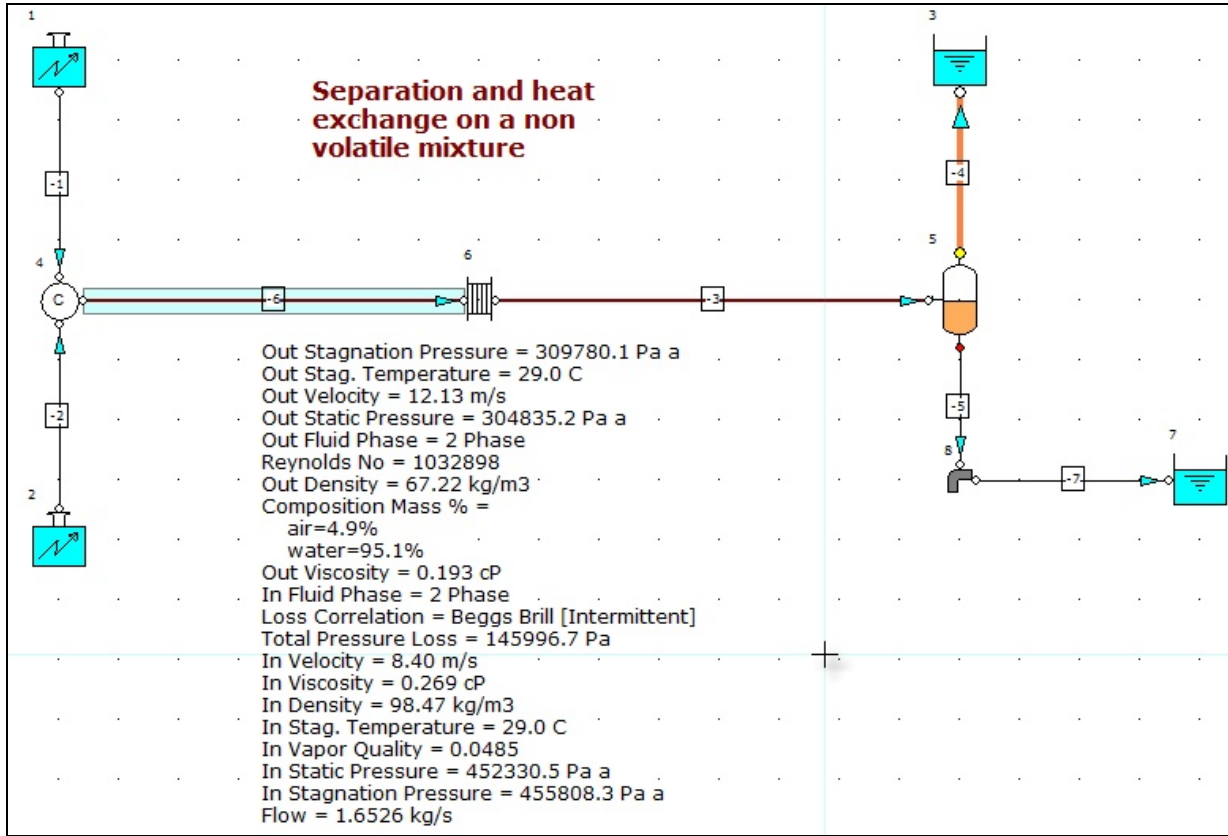
1. A pipe increment is selected based on a small change in pressure  $P_1$  and  $P_2$ . The length of this increment is not yet known.
2. Upstream temperature, pressure, quality and physical properties are determined. Physical properties for each phase and the mixture physical properties are needed. Crucial here is *FluidFlow3's* fluids database containing the thermophysical properties of more than 900 pure fluids.
3. A flash calculation is then performed to determine the downstream quality.

$$X_2 = X_1 + C_p(T_1 - T_b)/H_v$$

4. From the downstream properties, *FluidFlow3* determines the flow regime and then determines the incremental length of this segment. Determination of the incremental length depends on the friction loss calculation method used.
5. Steps 1 to 4 are repeated until the end of the pipe is reached. The incremental length step size therefore shortens as the calculation moves down the pipe. For the last segment, which will never be the exact length required, we use interpolating functions based on results from previous segments.

**Example 1. An air water two phase model. Constant quality.**

Two-phase can be specified at a boundary, for a single fluid, or we can mix gas and liquid streams in order to make a two phase mixture. We will use the second method in this example.



The model shows two known flows (one fluid air(2), one fluid water(1)) combining and being heated via a plate exchanger, then flowing to a separation vessel (5). The red dot on the Knock Out Pot (separator) represents the liquid outlet and the yellow dot represents the vapour outlet.

Node 1 (water inlet) conditions are		Node 2 (air inlet) conditions are		Node 6 (the plate exchanger) conditions are	
Unique Name		Unique Name		Unique Name	
Status	On	Status	On	Status	On
Elevation	0	Elevation	0	Elevation	0
Elevation Unit	m	Elevation Unit	m	Elevation Unit	m
Flow Direction	Into Network	Flow Direction	Into Network	Pressure Loss Model	Standard Relationships
Flow	25	Flow	0.08023	Number Of Plates	20
Flow Unit	usgpm	Flow Unit	kg/s	Plate Width	0.5
Temperature	29	Temperature	29	Plate Height	1
Temperature Unit	C	Temperature Unit	C	Width/Height Unit	m
Fluid	water	Fluid	air	Distance between Plates	3
Fluid Type	Newtonian/NN-NonSettling	Fluid Type	Newtonian/NN-NonSettling	Plate Distance Unit	mm
Properties on Flowsheet	Hide	Properties on Flowsheet	Hide	Heat Loss Model	Fixed Temperature Change
				Heat Transfer Direction	Into Network
				Temperature Change	30
				Temperature Unit	C
				Properties on Flowsheet	Hide

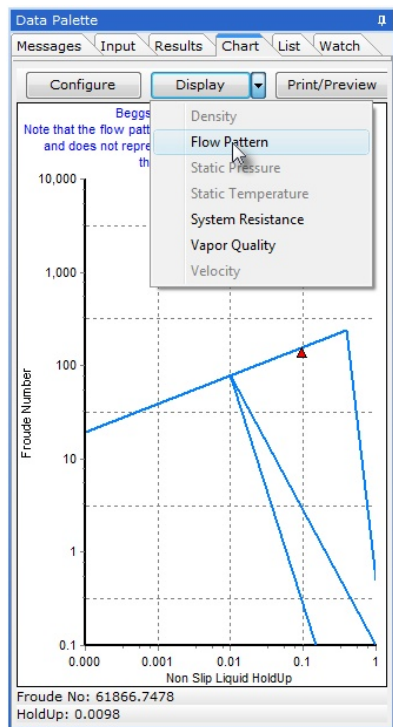
Pipe information is:

- Pipes (-1 and -2 connecting the known flows to the connector) 0.5 m in length 2" sch 40 pipe.
- Pipe (-6 from the connector to the plate exchanger) 60 m in length and an inside diameter of 50.8 mm
- Pipe (-3 connecting the plate exchanger to the KO Pot) 60m in length and an inside diameter of 50.8 mm.
- Pipe (-4 vapour outlet from KO Pot) 5m and 6" sch 40 pipe. Pipes (-5 and -7 liquid outlet from the KO Pot) 10m and 2" sch 40 pipe.

Calculation method - Beggs Brill.

### Overview of Results:

This is an example of two phase flow with constant quality. This means that the vapor mass fraction is constant and there is no mass transfer between the phases. It does **not** mean that the pressure loss per unit length is constant or that the velocity between the two phases is constant. In the first pipe section after mixing (pipe -6) you can see that the gas superficial velocity increases from the start to the end of pipe -6. For 60m of pipe -6, the total pressure loss is 145997 Pa, but the friction loss is 144529 Pa. Since the pipe is horizontal the difference is the acceleration loss. After the exchanger the mixture has experienced a temperature increase of 30 °C. The total pressure loss in the pipe after the exchanger (-3) is 198502 Pa (pipe -3 is identical in length and diameter to -6). This is because gas volume and velocity as well as other fluid properties have changed with the increase in temperature in the outlet pipe. You can get a feel for the differences by displaying the Beggs Brill flow pattern map.



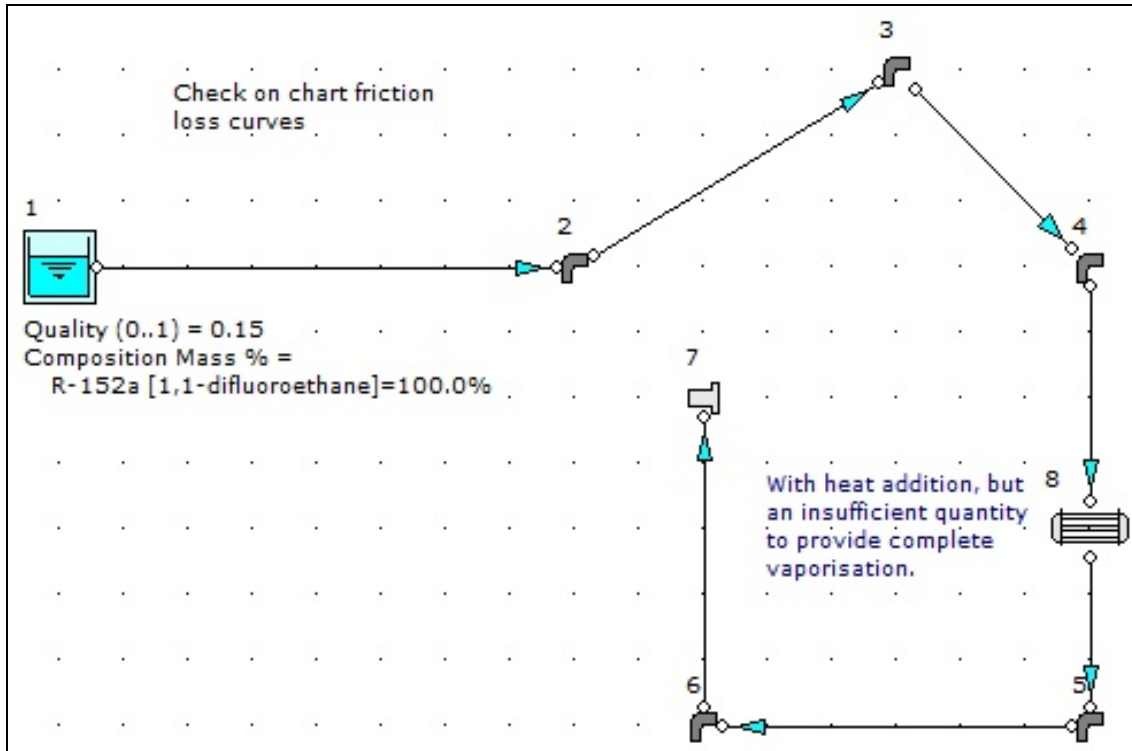
If you use the Whalley criteria, FluidFlow selects the Friedel method and in this case total system pressure losses reduce by 17.5%.

For this example MSH, Whalley and Beggs Brill are probably the most appropriate methods. You can see the total system pressure loss estimation can vary considerably.

## Example 2. A Refrigerant system with changing quality.

In this example we have a single fluid, R-152a flowing through the system shown below, from a known pressure (node 1) at 1.18 atm and the fluid is at its saturation temperature of  $-18^{\circ}\text{C}$ .

We have specified a vapour quality (vapour mass fraction of 0.15) at the inlet and we are carrying out the calculation using the Whalley criteria.



### Overview of Results:

This is an example of two phase flow with changing quality. This means that the vapour mass fraction is not constant and there is mass transfer between the phases. You can see this in the results of all flowsheet elements, examine the vapour quality entering and leaving each node or pipe, and you will see that quality is increasing as we flow through the system. This is because the pressure falls as the fluid flows down a pipe (or across a bend) and so some of the liquid boils to form more vapour. This is called flashing, and FluidFlow assumes that instantaneous isenthalpic flashing occurs. You should also notice that velocities are increasing and that mixture densities are decreasing.

At the heat exchanger we are adding some 10000 Watts of heat and this has the effect of vaporising additional liquid. Across this element the quality increases from 0.158 to 0.2697.

As an exercise change the heat loss model at the exchanger from "Fixed Transfer Rate" to "Ignore Heat Loss". What do you expect to happen to the vapour quality leaving the exchanger? It should decrease. You should also note that system flow will increase because of this.

## Friction Loss Correlations available in FluidFlow3

### Friedel

$$\Delta L_{\text{segment}} = (P_1 - P_2)D^5 \rho_L / (C_C f_L F m^2)$$

where

- $C_C$  is a constant
- $\rho_L$  is the average liquid density over the increment
- $f_L$  is the liquid phase friction factor
- $F$  is the Friedel correction factor. Ref (2)
- $m$  is the mass flow

### Beggs Brill

$$\Delta L_{\text{segment}} = (P_1 - P_2)D^5 \rho_{\text{mix}} / (C_C f_{\text{TP}} m^2)$$

where

- $C_C$  is a constant
- $\rho_{\text{mix}}$  is the two phase mixture density over the increment. Ref (1)
- $f_{\text{TP}}$  is the two phase friction factor. Ref (3)
- $m$  is the mass flow

### Drift Flux

$$\Delta L_{\text{segment}} = (P_1 - P_2)D^5 \rho_{\text{mix}} / (C_C f_{\text{TP}} m^2)$$

where

- $C_C$  is a constant
- $\rho_{\text{mix}}$  is the two phase mixture density over the increment. (Ref 3)
- $f_{\text{TP}}$  is the two phase friction factor. (Ref 3)
- $m$  is the mass flow

### Muller Steinberg Heck

$$\Delta L_{\text{segment}} = (P_1 - P_2) / (\Delta P_L + 2(\Delta P_G - \Delta P_L)X_{\text{av}}(1 - X_{\text{av}})^{0.3333}) + \Delta P_G X_{\text{av}}^3$$

where

- $\Delta P_G$  is the gas phase pressure loss over the increment. Ref (4)
- $\Delta P_L$  is the liquid phase pressure loss over the increment. Ref (4)
- $X_{\text{av}}$  is the average vapour quality for the segment.

For both **Lockhart Martinelli** and **Chisholm Baroczy** correlations the equations are identical to the Beggs Brill equation with the addition of a two phase multiplier. Ref (2).

### **Which equation?**

Until recently, the "literature consensus" indicated that a mechanistic approach could be used for all gas liquid ratios and all pipe inclinations. Great in theory, but in practice, you need to make simplifying assumptions to solve/close the equations. FluidFlow3 implements a simple mechanistic model according to Beggs-Brill. There are more complex mechanistic models in the literature (Shoham or Aziz - in a future release), but these are not trivial to implement successfully.

Recently, the "literature consensus" appears to agree that mechanistic modelling has gone as far as it can go and researchers are now favouring a drift flux approach. FluidFlow3 implements also this type of relationship, but this model is best suited for vertical and inclined pipes.

As a general purpose model for single component two phase flow the MSH relationship is considered to be the most accurate, but the method loses accuracy at high vapour qualities.

Perhaps the most comprehensive literature summary was carried out by Whalley. The recommendations of this study use gas/liquid ratios and gas/liquid viscosities to determine the best correlation to use. This is the default calculation method used by FluidFlow3.

If you are dealing with steam/condensate systems the recommendation is to use either use MSH or Whalley.

### References

- 1 Mechanistic Modeling of Gas-Liquid Two-Phase Flow in Pipes - O. Shoham ISBN 978 1 55563 107 9
- 2 Fluid Flow Handbook - J. Saleh - ISBN 0 07 136372 6
- 3 A Basic Approach to Wellbore Two Phase Flow Modelling - AR Hasan, CS Kabir and M Sayarpour - SPE 109868
- 4 Process Heat Transfer Principles and Applications - R Serth - ISBN 978 0 12 373588 1
- 5 Stromung und Druckverlust - Walter Wagner - ISBN 3 8023 1879 X
- 6 Two-Phase Flow in Complex Systems - S Levy ISBN 0 471 32967 3
- 8 Friedel L. Improved friction pressure drop correlations for horizontal and vertical two phase pipe flow. Ispra European Two Phase Flow Group meet, Paper F2 (1979).
- 9 A Simple Mechanistic Model for Void Fraction and Pressure Gradient Prediction in Vertical and Inclined Gas/Liquid Flow Khasanov et al SPE

*The 2-phase Gas/Liquid module requires that both the Liquid and Gas modules are activated. Cost is \$9,500.00 plus GST per seat.*

Accutech 2000 Pty Ltd PO Box 65, Applecross Western Australia 6953	T: 08 9364 2211 F: 08 9316 1364 E: info@accutech2000.com.au	ABN: 40 062 194 580
--	---	---------------------