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Two-phase flow pressure losses in pipeline fittings

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the following Working Party on behalf of the Internal Flow Panel:

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TWO-PHASE FLOW PRESSURE LOSSES IN PIPELINE FITTINGS

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TWO-PHASE FLOW PRESSURE LOSSES IN PIPELINE FITTINGS

1. NOTATION AND UNITS

		Units	
		SI	British
A	cross-sectional area of flow	m^2	ft^2
B	coefficient, see Equation (7.3)	—	—
C_c	single-phase contraction coefficient, see Figure 1	—	—
C_k	single-phase pressure-loss coefficient	—	—
D	pipe internal diameter	m	ft
G	mass flux, $(\dot{m}_L + \dot{m}_G)/A$	kg/s m^2	lb/s ft^2
h_f	specific enthalpy of saturated liquid	kJ/kg	BTU/lb
h_g	specific enthalpy of saturated vapour	kJ/kg	BTU/lb
K	slip ratio, gas velocity/liquid velocity	—	—
$\dot{m}$	mass flow rate	kg/s	lb/s
p	static pressure	N/m^2	lbf/ft^2
Δp	change in static pressure	N/m^2	lbf/ft^2
R	radius of bend	m	ft
Re	Reynolds number, GD/μ	—	—
t	thickness of orifice plate	m	ft
x	mass dryness fraction, $\dot{m}_G/(\dot{m}_G + \dot{m}_L)$	—	—
δ	degree of opening of valve: number of handle turns from fully closed/number of handle turns from fully closed to fully open	—	—
μ	dynamic viscosity	N s/m^2	lbf s/ft^2
ρ	density	kg/m^3	lb/ft^3
σ	area ratio	—	—
ϕ_{LO}^2	two-phase multiplier	—	—

Subscripts

<i>exp</i>	experimental values
<i>G</i>	gas flowing alone at same mass flow rate as gas component of two-phase mixture
<i>L</i>	liquid flowing alone at same mass flow rate as liquid component of two-phase mixture
<i>LO</i>	liquid flowing alone at same mass flow rate as complete two-phase mixture
<i>pred</i>	predicted values
<i>TP</i>	two-phase
1	conditions upstream of fitting
2	conditions downstream of fitting

2. INTRODUCTION

This Item provides information on two-phase pressure losses for various pipeline fittings. The information is presented in terms of a two-phase multiplier which, when applied to the single-phase pressure loss, gives the two-phase pressure loss. Sections 3 to 7 give semi-empirical methods for calculating these multipliers for a number of pipeline fittings. Effects of flow regime*, pipe orientation and other factors influencing pressure loss are discussed.

2.1 Scope and Applicability

This Item provides methods for calculating two-phase pressure losses for sudden expansions, sudden contractions, orifice plates, valves and bends. The methods are based on the following assumptions:

- (i) the gas phase is incompressible,
- (ii) phase velocities are well below sonic (critical),
- (iii) there is no mass transfer between the phases, and
- (iv) there is no interaction between adjacent fittings.

The data given in this Item are taken from isolated fittings where the flow is fully developed both upstream and downstream of the fitting. Flow disturbances upstream can either increase or decrease the pressure loss in a fitting depending on the fluid properties and flow regime. Measurements taken too close to a fitting can give a considerably larger pressure loss than would be obtained by assuming fully-developed flow (see Sketch 2.1).

2.2 Flashing

Flashing occurs when the pressure loss through a fitting is sufficiently large to cause a degree of vaporisation of the liquid phase. A simple approximate method of allowing for flashing is given below and is illustrated in Example 2.

- (1) Obtain h_g and h_f from physical properties tables at inlet pressure, p_1 .
- (2) Calculate the pressure loss, Δp , through the fitting using this Item.
- (3) Obtain h_g and h_f from physical properties tables at pressure, $p_2 = (p_1 - \Delta p)$.
- (4) Calculate the average dryness fraction, $(x_1 + x_2)/2$, where the exit dryness fraction, x_2 , is given by

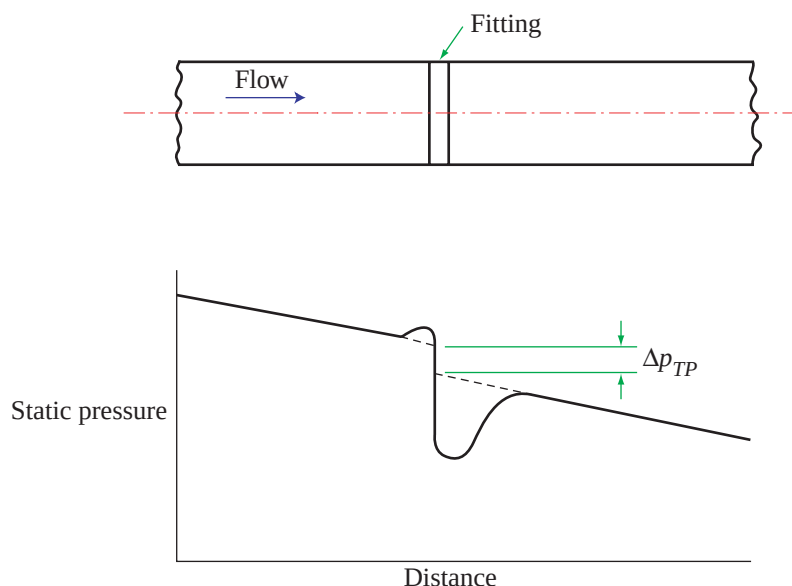
$$x_2 = \frac{x_1 h_{g1} + h_{f1}(1 - x_1) - h_{f2}}{h_{g2} - h_{f2}}. \quad (2.1)$$

- (5) Obtain ρ_G and ρ_L from physical properties tables at average pressure, $(p_1 + p_2)/2$.
- (6) Repeat step (2) using the average dryness fraction and densities.
- (7) Compare the calculated pressure losses based on step (2) and step (6). If a large difference exists repeat steps (2) to (6) until the difference is within acceptable limits.

* For a study of flow regimes and their identification see References 1 and 2.

2.3 Calculation of Two-phase Pressure Loss

The two-phase pressure loss is the difference between the pipe losses incurred with and without the fitting present, and is obtained by extrapolating the upstream and downstream static-pressure gradients to the fitting. The two-phase pressure loss for a typical fitting is shown in Sketch 2.1.



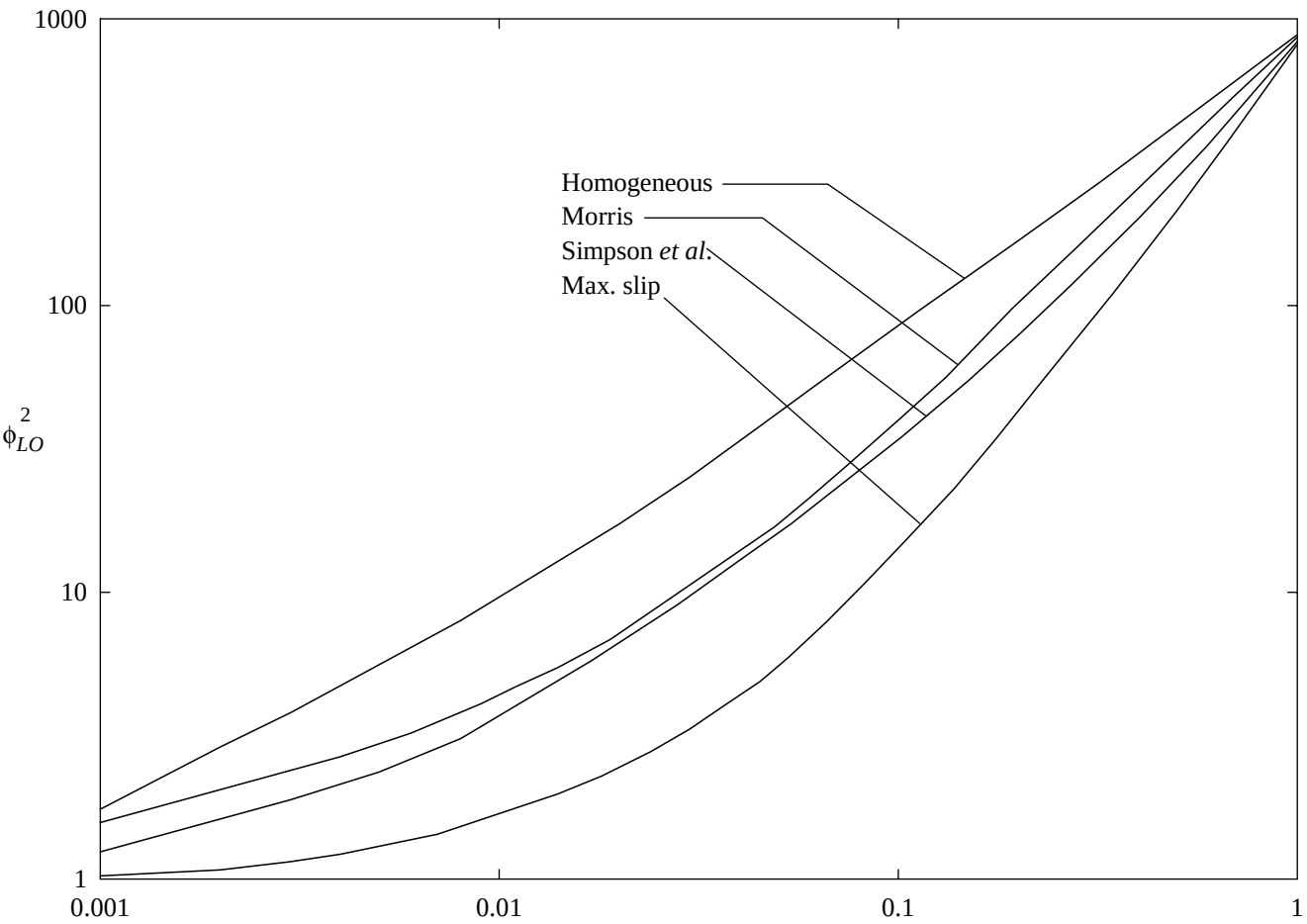
Sketch 2.1 Definition of two-phase pressure loss

The two-phase pressure loss, Δp_{TP} , is given by

$$\Delta p_{TP} = \phi_{LO}^2 \times \Delta p_{LO}, \quad (2.2)$$

where ϕ_{LO}^2 is the two-phase multiplier and Δp_{LO} is the single-phase pressure loss for the liquid phase flowing alone at the same mass flow rate as the complete two-phase mixture.

The methods of calculating ϕ_{LO}^2 presented in this Item accommodate various degrees of slip ratio, K , between the phases. The Simpson *et al.*¹⁹ and Morris²¹ methods lie between the two extremes of assuming either no slip (homogeneous model, $K = 1$) or maximum slip ($K = \sqrt{\rho_L / \rho_G}$, see Reference 20). The effects of slip ratio on the value of the multipliers can be seen in Sketch 2.2 for air/water flow at atmospheric conditions.

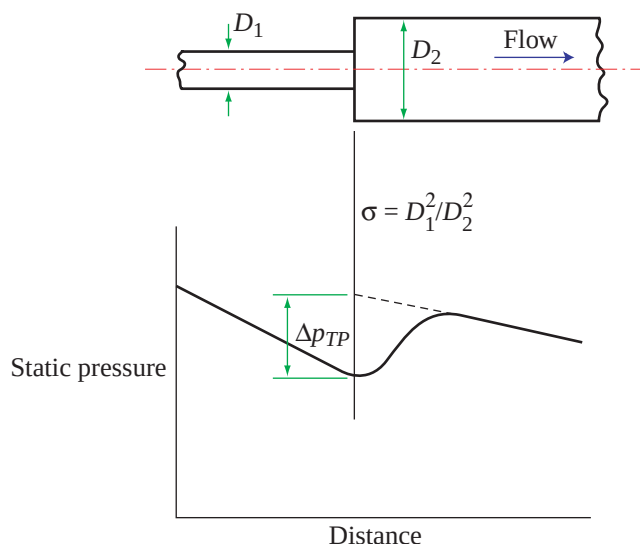


Sketch 2.2 Comparison of various two-phase multiplier models against dryness fraction, x , for air/water flow at atmospheric conditions

3. SUDDEN EXPANSIONS

3.1 Geometry

Sketch 3.1 shows a typical static-pressure recovery along a duct with a sudden enlargement of area.



Sketch 3.1 Typical static-pressure distribution along a duct with a sudden enlargement of area

3.2 Pressure Recovery Calculation Procedure

The two-phase pressure recovery for a sudden enlargement is given by

$$\Delta p_{TP} = \phi_{LO}^2 \times \Delta p_{LO}, \quad (3.1)$$

where the two-phase multiplier, ϕ_{LO}^2 , is given by the method of Simpson *et al.*¹⁹ as

$$\phi_{LO}^2 = [1 + x\{(\rho_L/\rho_G)^{1/6} - 1\}][1 + x\{(\rho_L/\rho_G)^{5/6} - 1\}] \quad (3.2)$$

and the single-phase pressure recovery, Δp_{LO} , is given by

$$\Delta p_{LO} = -\frac{G_1^2}{2\rho_L} \{ \sigma^2 - 1 + (1 - \sigma)^2 \}. \quad (3.3)$$

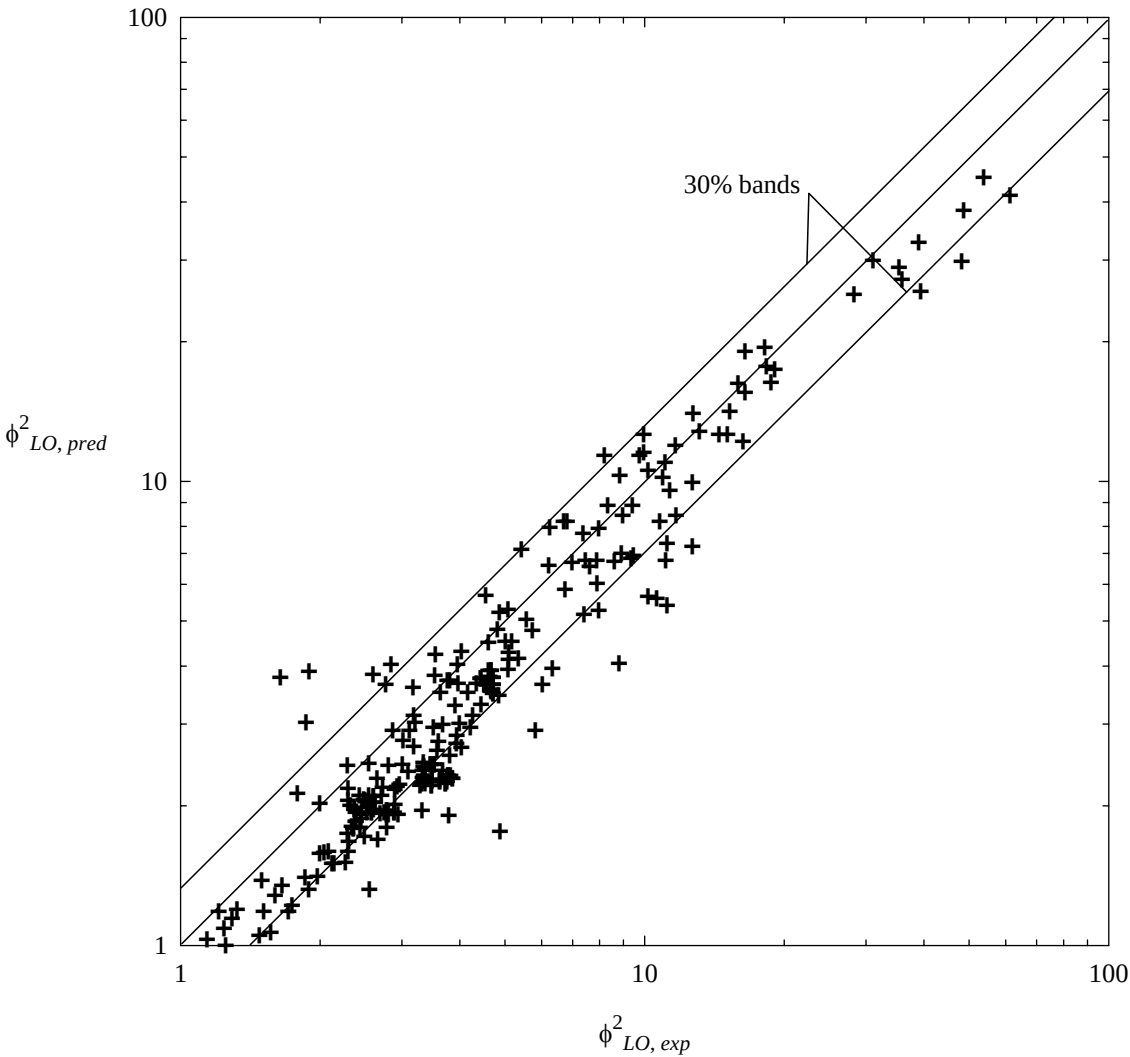
The selection of Equation (3.2) for the two-phase multiplier is based on data from Derivations 4, 5, 6 and 8. Table 3.1 shows the range of the parameters covered in these Derivations and Sketch 3.2 shows predicted values of ϕ_{LO}^2 from Equation (3.2) against experimental values.

Over the range of data given in Derivations 4, 5, 6 and 8 there are no apparent effects of inlet diameter, area ratio or mass velocity on the accuracy of Equation (3.2).

Although the majority of the data are in the annular flow regime, the method was also found to apply to the limited data in both slug and churn flow. However, in slug and churn flow there is a tendency for Equation (3.2) to underpredict the value of the two-phase multiplier.

TABLE 3.1 Range of Parameters from Derivations 4, 5, 6 and 8

Derivation	Upstream diameter, D_1 , (mm)	Area ratio, σ	Flow orientation and direction	Fluids	Inlet pressure, (bar)
4	9.55, 12.9, 17.6	0.14, 0.26, 0.49	Vertical (upwards)	Steam/water	13.8, 27.6, 41.4
5	38.1, 50.8	0.44, 0.56	Horizontal	Steam/water	82.7
6	17	0.5	Horizontal	Steam/water	68.9
8	8.64, 11.7	0.33, 0.55, 0.61	Vertical (upwards)	Steam/water	4.14, 8.27, 16.3



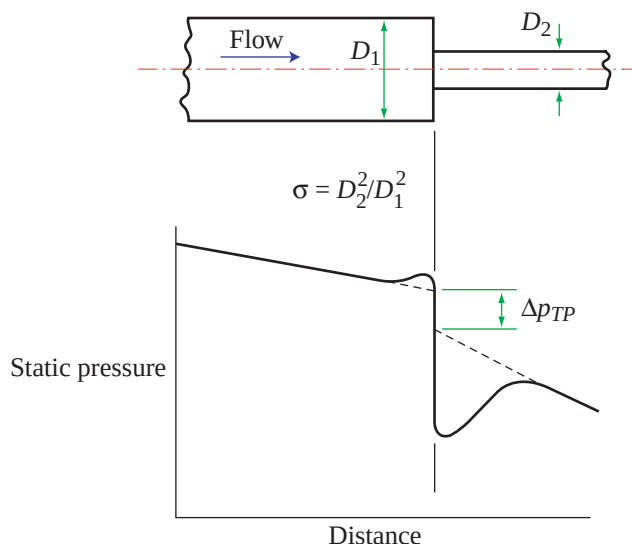
Sketch 3.2 Predicted against experimental values of ϕ_{LO}^2 for sudden expansions

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4. SUDDEN CONTRACTIONS

4.1 Geometry

Sketch 4.1 shows a typical static-pressure distribution along a duct with a sudden contraction of area.



Sketch 4.1 Typical static-pressure distribution along a duct with a sudden contraction of area

4.2 Pressure Loss Calculation Procedure

The two-phase pressure loss for a sudden contraction is given by

$$\Delta p_{TP} = \phi_{LO}^2 \times \Delta p_{LO} \quad , \quad (4.1)$$

where the two-phase multiplier, ϕ_{LO}^2 , is given by the homogeneous model as

$$\phi_{LO}^2 = 1 + x \left(\frac{\rho_L}{\rho_G} - 1 \right) \quad (4.2)$$

and the single-phase pressure loss, Δp_{LO} , is given by

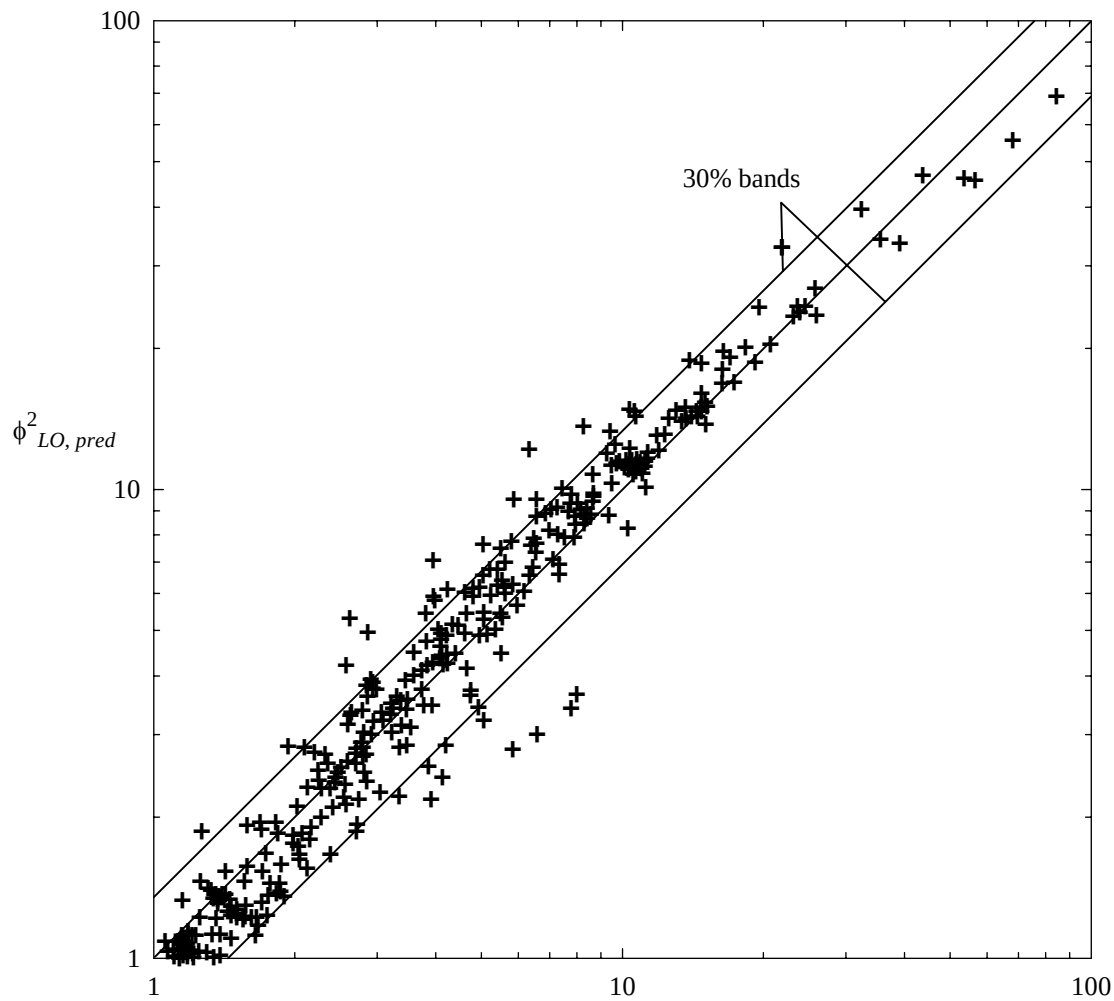
$$\Delta p_{LO} = \frac{G_2^2}{2\rho_L} \left\{ 1 - \sigma^2 + \left(\frac{1}{C_c} - 1 \right)^2 \right\}, \quad (4.3)$$

where C_c is the single-phase contraction coefficient given in Figure 1.

The selection of Equation (4.2) for the two-phase multiplier is based on data from Derivations 5, 7 and 8. Table 4.1 shows the range of the parameters covered in these Derivations and Sketch 4.2 shows predicted values of ϕ_{LO}^2 from Equation (4.2) against experimental values.

TABLE 4.1 Range of Parameters from Derivations 5, 7 and 8

Derivation	Upstream diameter, D_1 , (mm)	Area ratio, σ	Flow orientation and direction	Fluids	Inlet pressure, (bar)
5	50.8, 76.2	0.25, 0.44, 0.56	Horizontal	Steam/water	82.7
7	25.4	0.14, 0.25, 0.4	Vertical (upwards)	Steam/water	13.8, 20.7, 27.6, 34.5
8	11.7, 15	0.55, 0.61	Vertical (upwards)	Steam/water	4.14, 8.27, 16.5



Sketch 4.2 Predicted against experimental values of ϕ_{LO}^2 for sudden contractions

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