NTNU – Trondheim
Norwegian University of
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Two-phase flow in a down-hole shut-in valve

by
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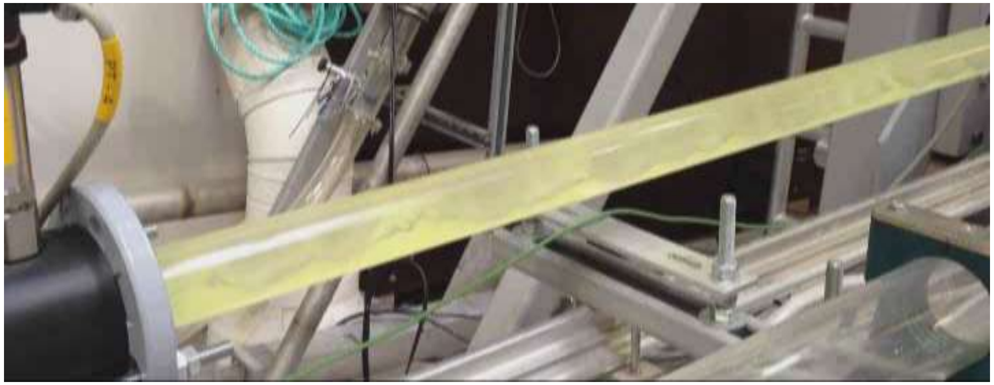

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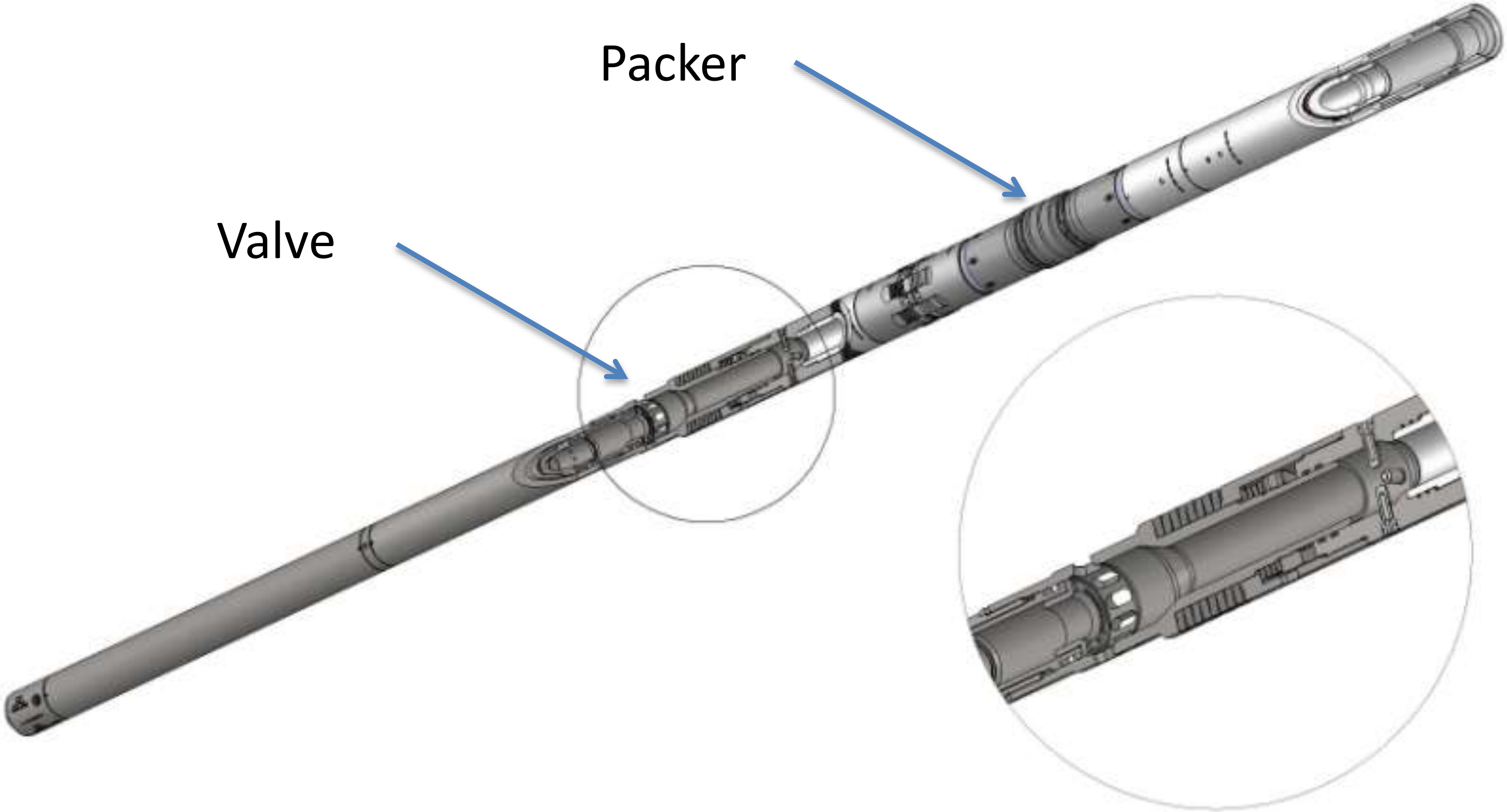
Research question:

- How accurate can the single phase/two-phase pressure drop in a complex geometry be quantified?

Objective:

- 3-dimensional CFD simulation for liquid pressure drop
- Make 1-D model from CFD data
- Simulate 2-phase flow with Least Squares Spectral Element Method (LSSEM)

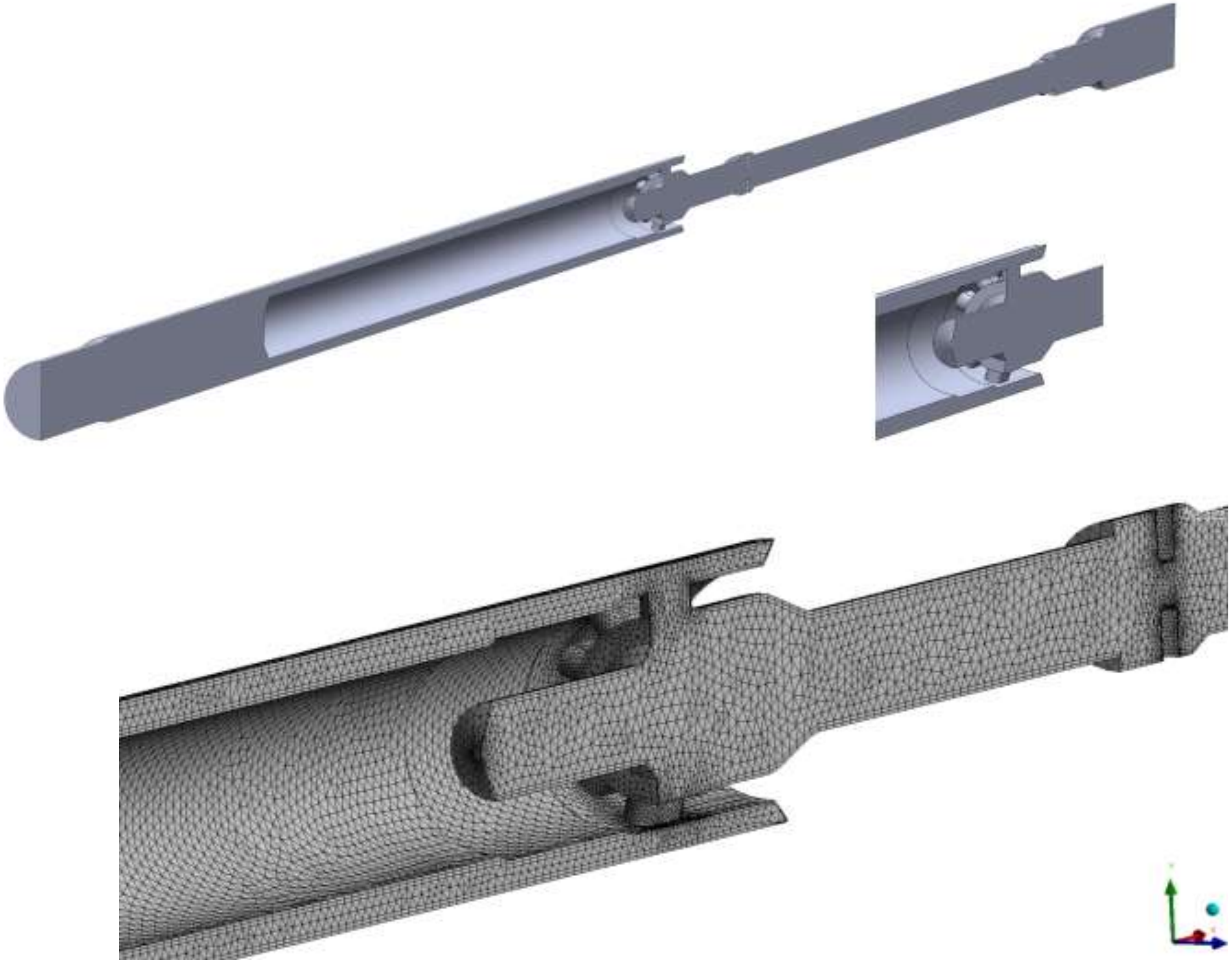
Down-hole shut-in valve



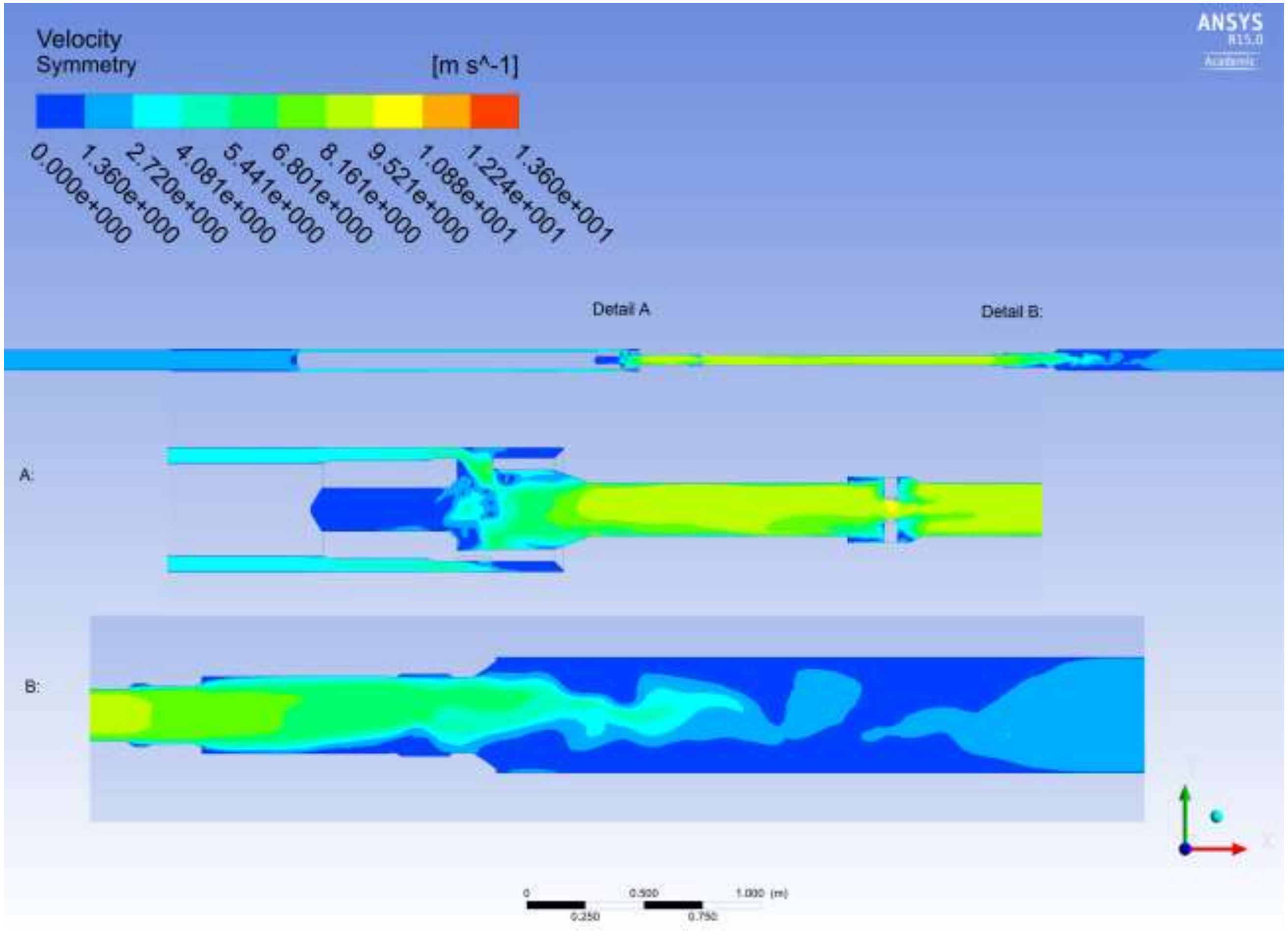
Packer

Valve

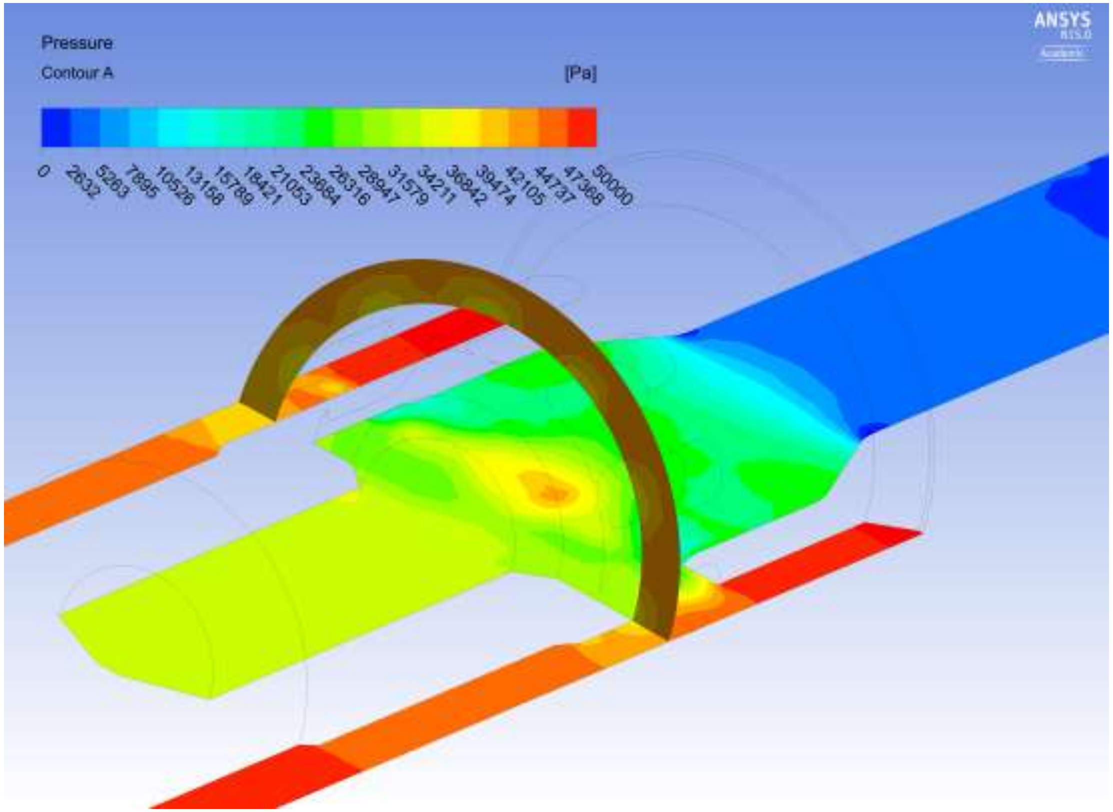
CFD-model



CFD simulation



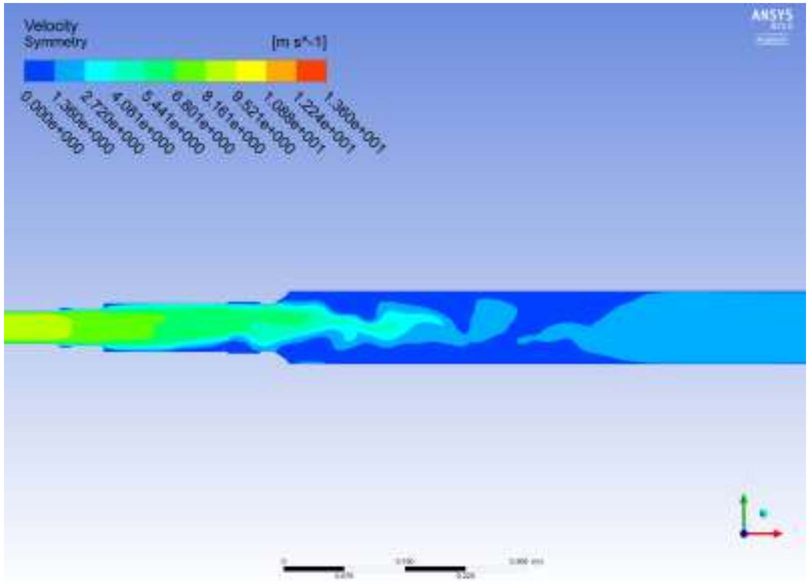
Pressure drop

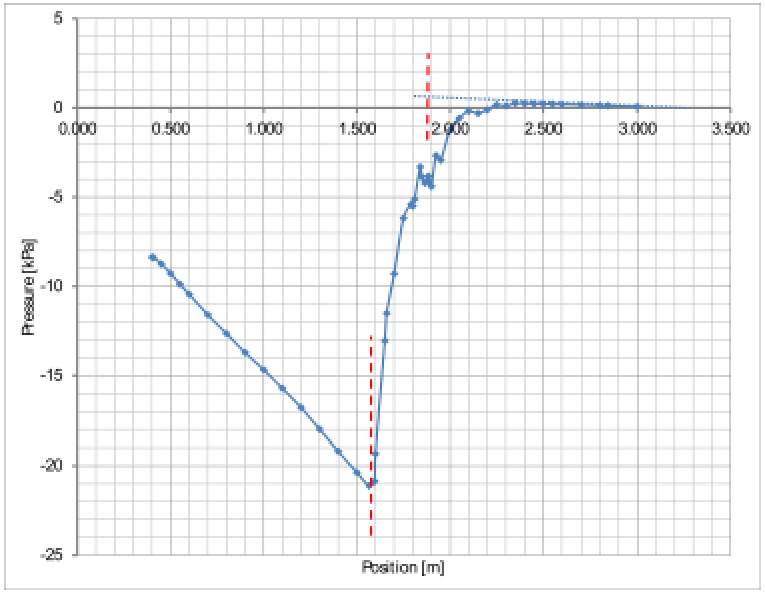


Pressure calculated as average over cross-section

$$P_1 + \rho\frac{v_1^2}{2} - K_L\rho\frac{v_1^2}{2} = P_2 + \rho\frac{v_2^2}{2}$$

Axial pressure profile

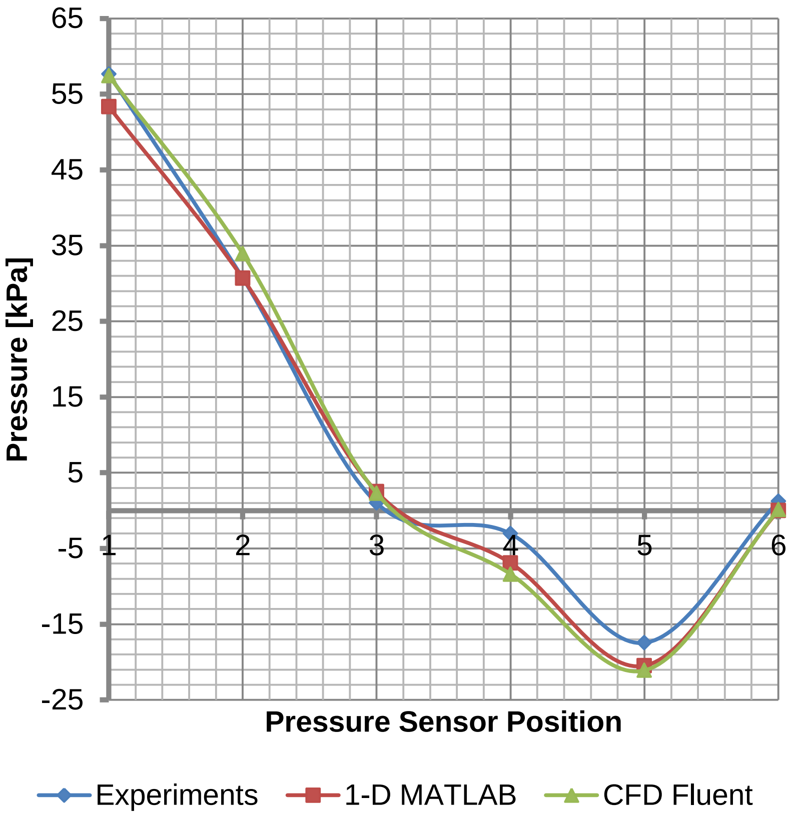


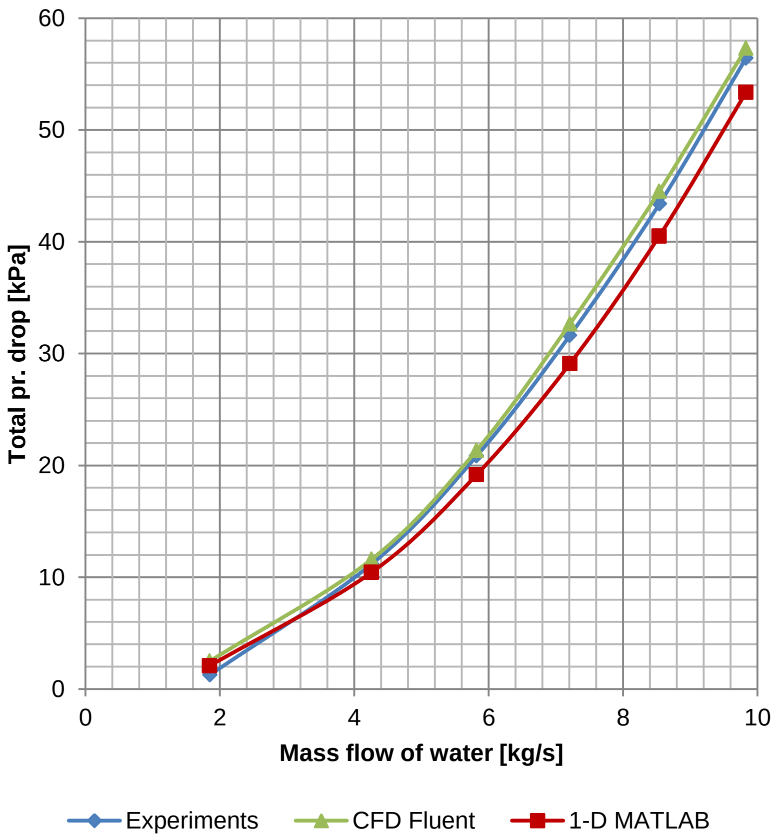


Minor losses

No.	Description	Length S	Minor loss	Diameter (perimeter)	Hydraulic diameter
		[m]	coeff.	[m]	[m]
1	Circular	0.100		0.0849	0.0849
2	Diffuser, 16°	0.030	0.036	0.0849 < 0.094	
3	Circular, at inlet	0.525		0.094	0.094
4	Annular contraction, 90°	0.015	0.366	0.094 >	0.024
5	Annular	1.259		0.094 x 0.070	0.024
6	Annular contraction, 90°	0.004	0.095		0.024 > 0.020
7	Annular	0.075		0.094 x 0.074	0.02
8	Annular contraction, 90°	0.006	0.071		0.020 > 0.016
9	Annular	0.020		0.094 x 0.078	0.016
10	Valve opning	0.075	1.759		0.016 > 0.060
11	Contraction, 40°	0.030	0	0.060 < 0.040	
12	Circular	0.192		0.04	0.04
13	Equalizing central	0.058	0.284		
14	Circular, through packer	1.220		0.04	0.04
15	Expansion	0.288	0.255	0.040 < 0.090	
16	Circular	0.958		0.09	0.09

CFD and 1D model – Liquid flow





Least squares method

- $L\mathbf{u} = \mathbf{g}$ in Ω
- $B\mathbf{u} = \mathbf{h}$ on $\boldsymbol{\partial}\Omega$

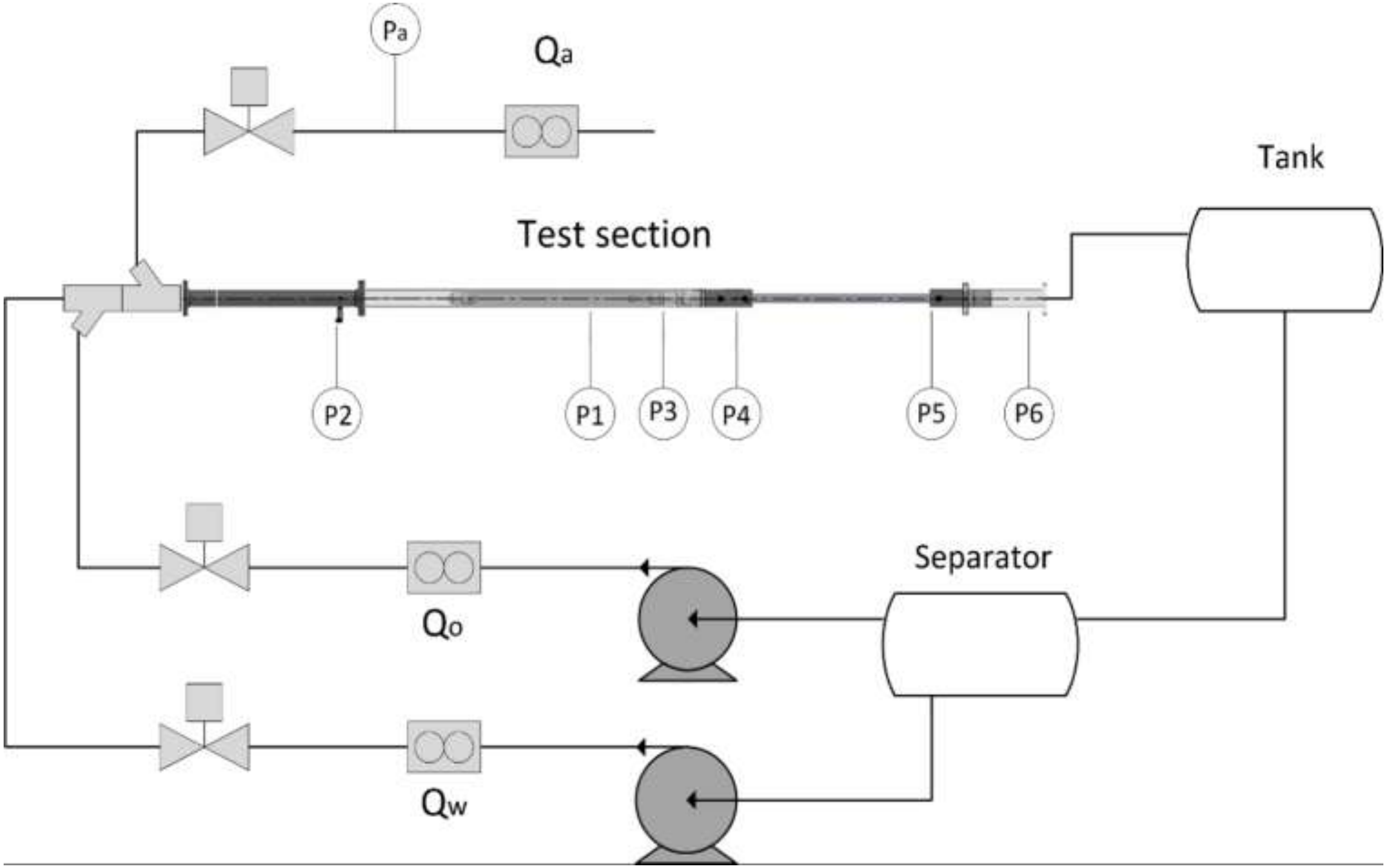
- $$\left\{\begin{matrix} \frac{\partial}{\partial x} & 0 & 0 \\ 0 & \frac{\partial}{\partial x} & 0 \\ v_G^* \frac{\partial}{\partial x} + \frac{\partial v_G^*}{\partial x} & v_L^* \frac{\partial}{\partial x} + \frac{\partial v_L^*}{\partial x} & \frac{\partial}{\partial x} \end{matrix}\right\} \left\{\begin{matrix} \alpha \rho_G v_G \\ (1-\alpha)\rho_L v_L \\ P \end{matrix}\right\} = \left\{\begin{matrix} -\left(\frac{\dot{m}_G}{A^2}\right)\frac{\partial A}{\partial x} \\ -\left(\frac{\dot{m}_L}{A^2}\right)\frac{\partial A}{\partial x} \\ -\frac{4}{D_i}\tau_w - v_G^*\left(\frac{\dot{m}_G}{A^2}\right)\frac{\partial A}{\partial x} - v_L^*\left(\frac{\dot{m}_L}{A^2}\right)\frac{\partial A}{\partial x} \end{matrix}\right\}$$

- Low numerical diffusion
- Generic implementation

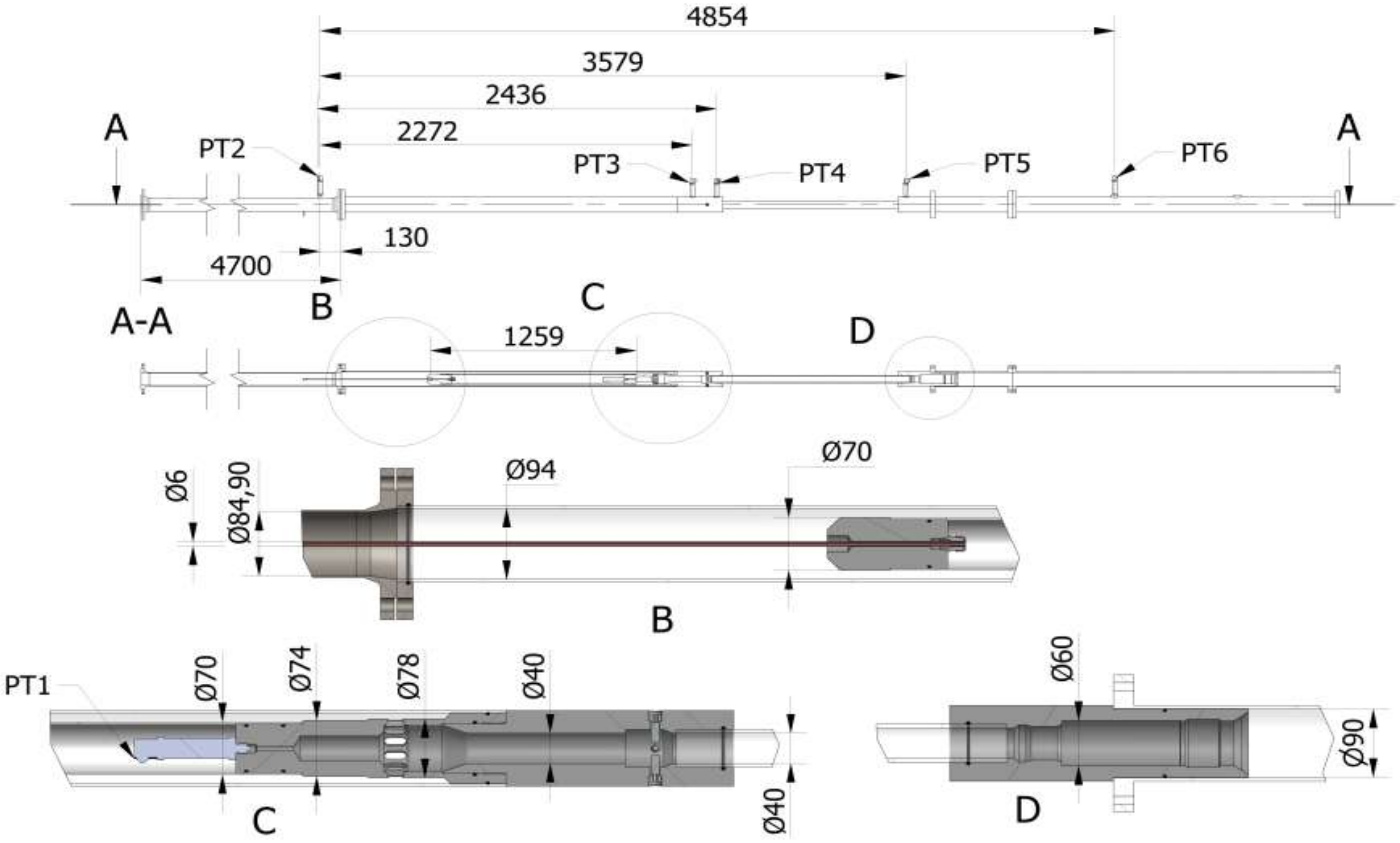
Spectral element formulation

- $u_h^e(x) = \sum_{n=0}^{i} u_n^e \Phi_i(\xi)$
- Higher order method
- Nodal elements:
  - Lagrange polynomial through the zeroes of the Gauss-Lobatto-Legendre polynomials
- Numerically stable without artificial diffusion
- Suitable for the approximation of the Navier-Stokes equation

Multiphase test loop

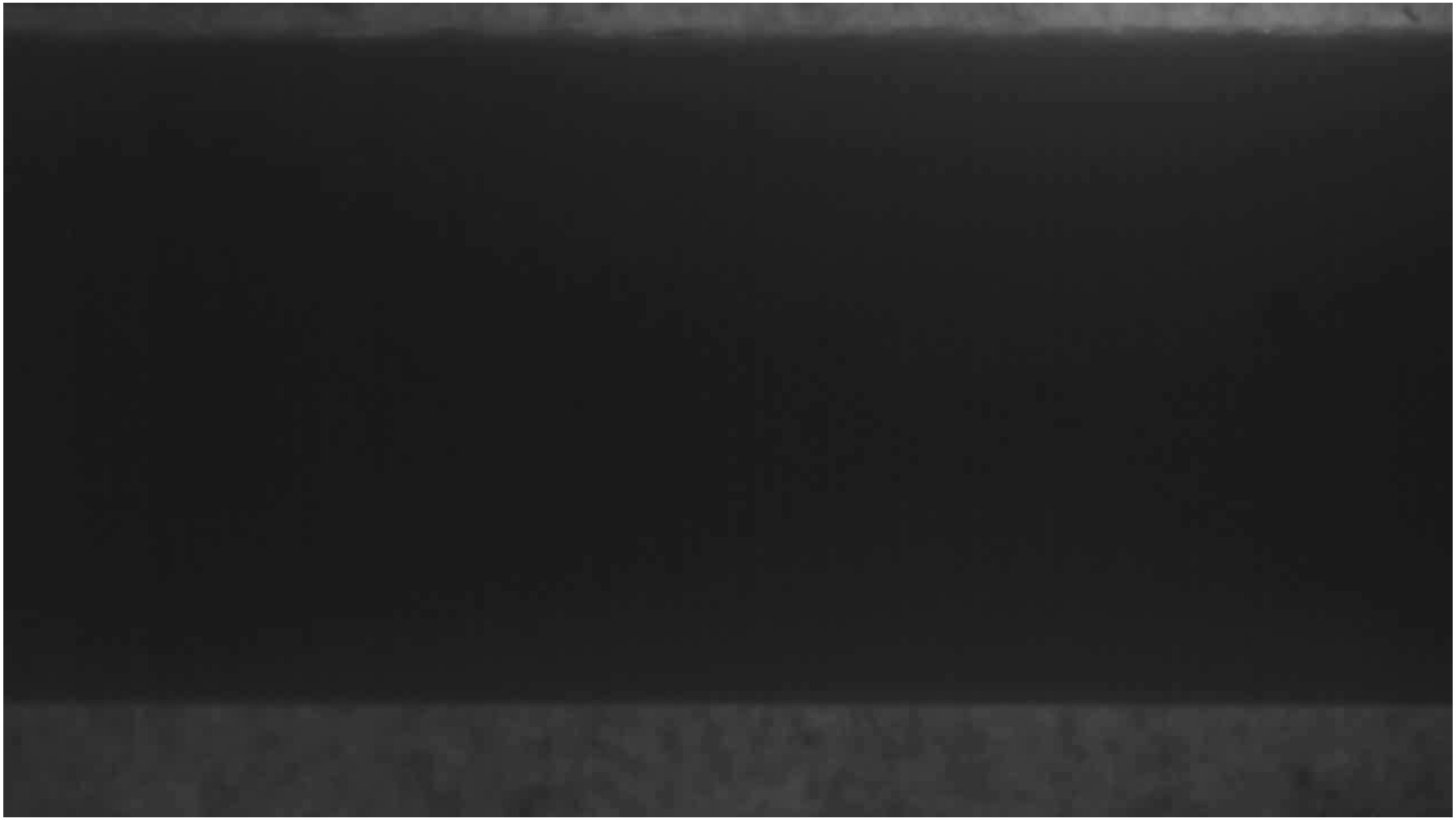


Laboratory valve mock-up

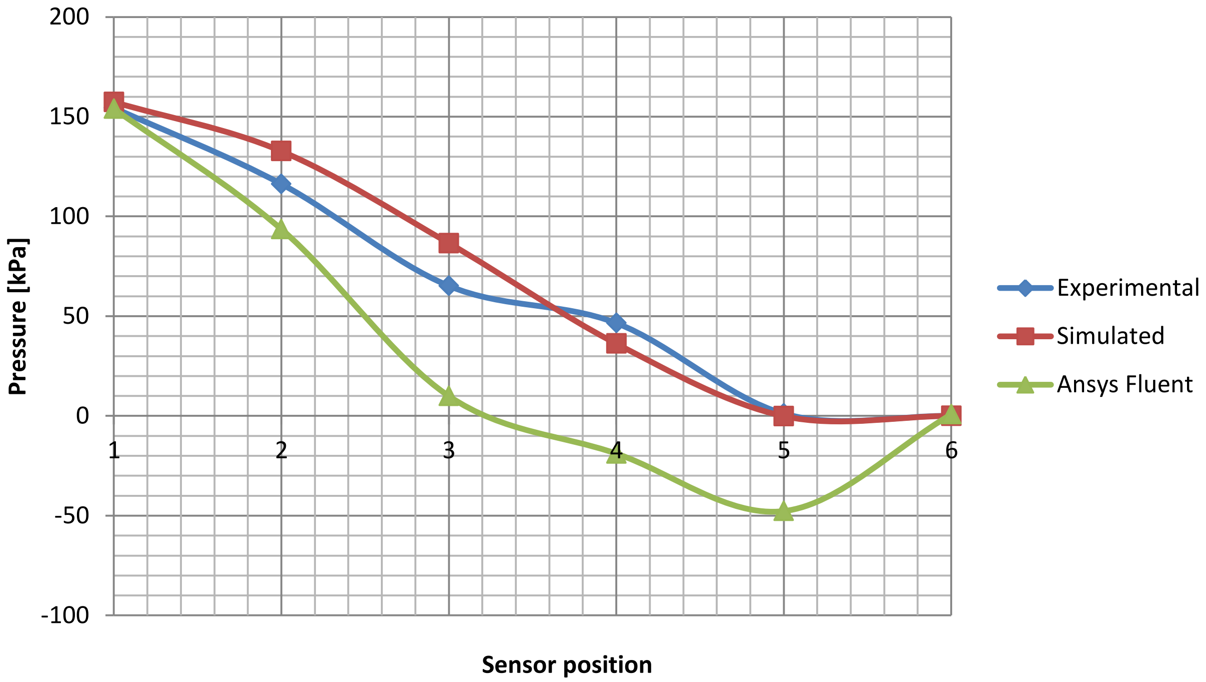


Two-phase flow experiments

Flow pattern detection

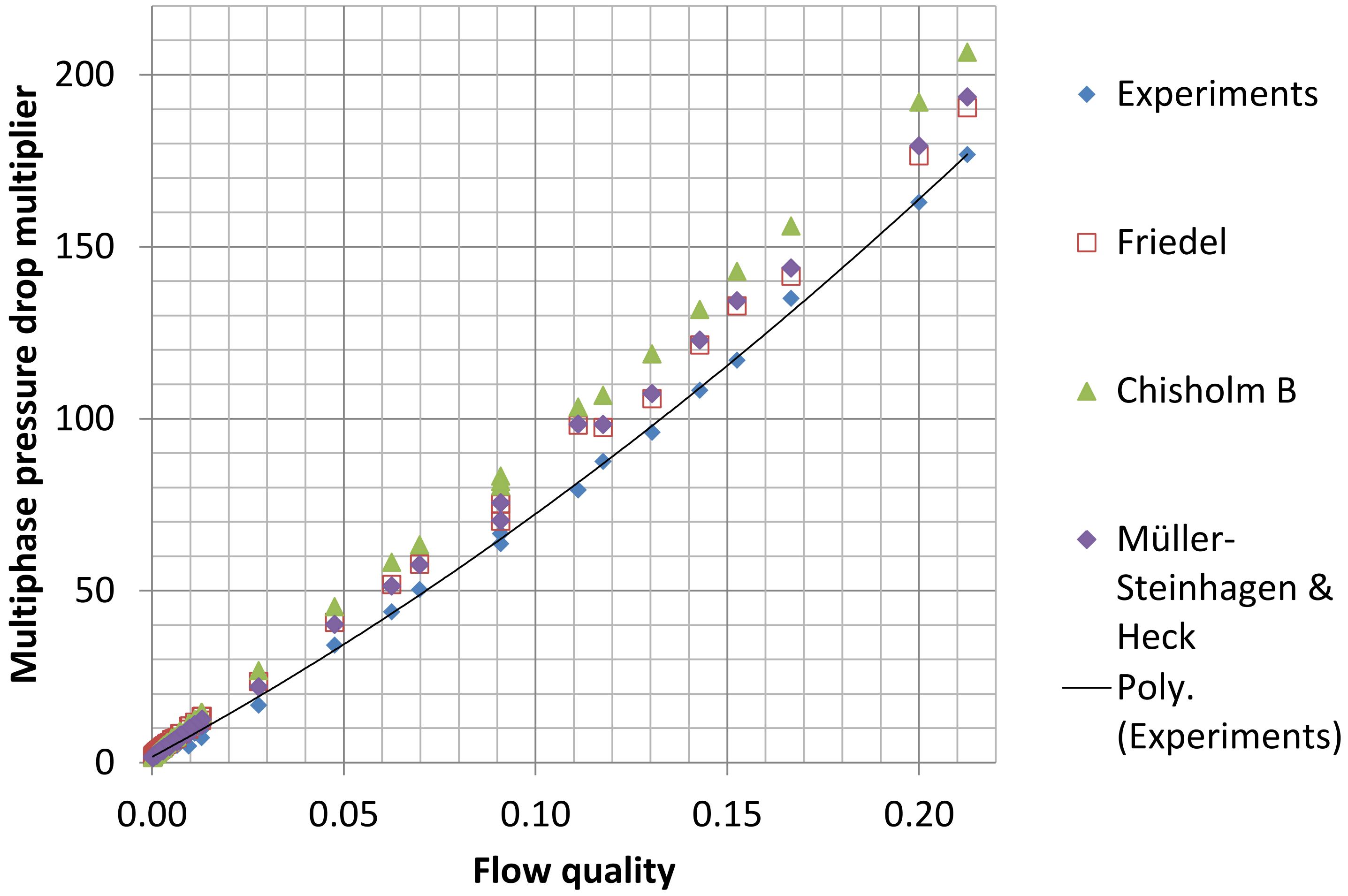


Multiphase flow pressure profile

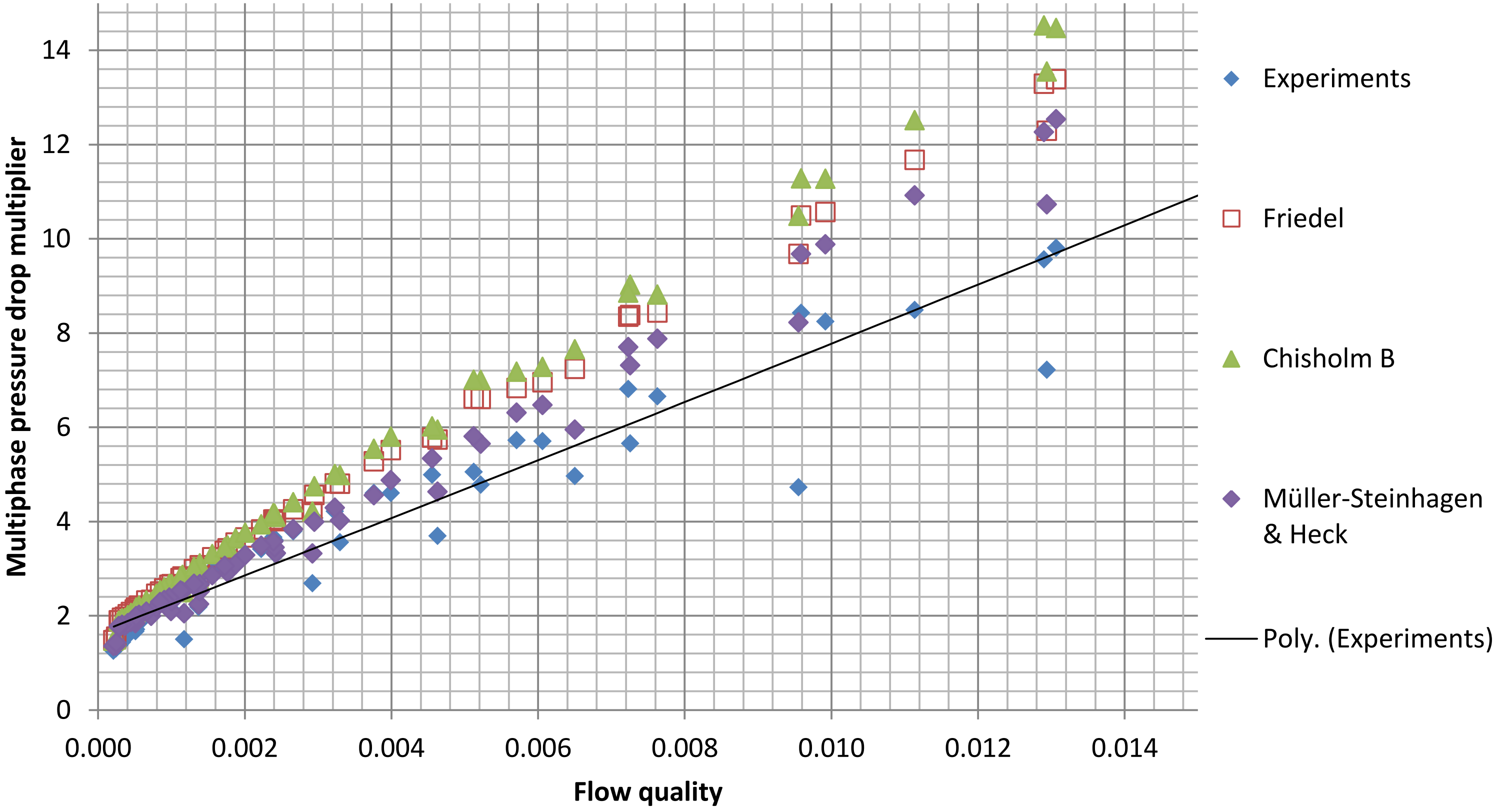


Water flow: 8.74 kg/s
Air flow: 0.020 kg/s

Air-water flow

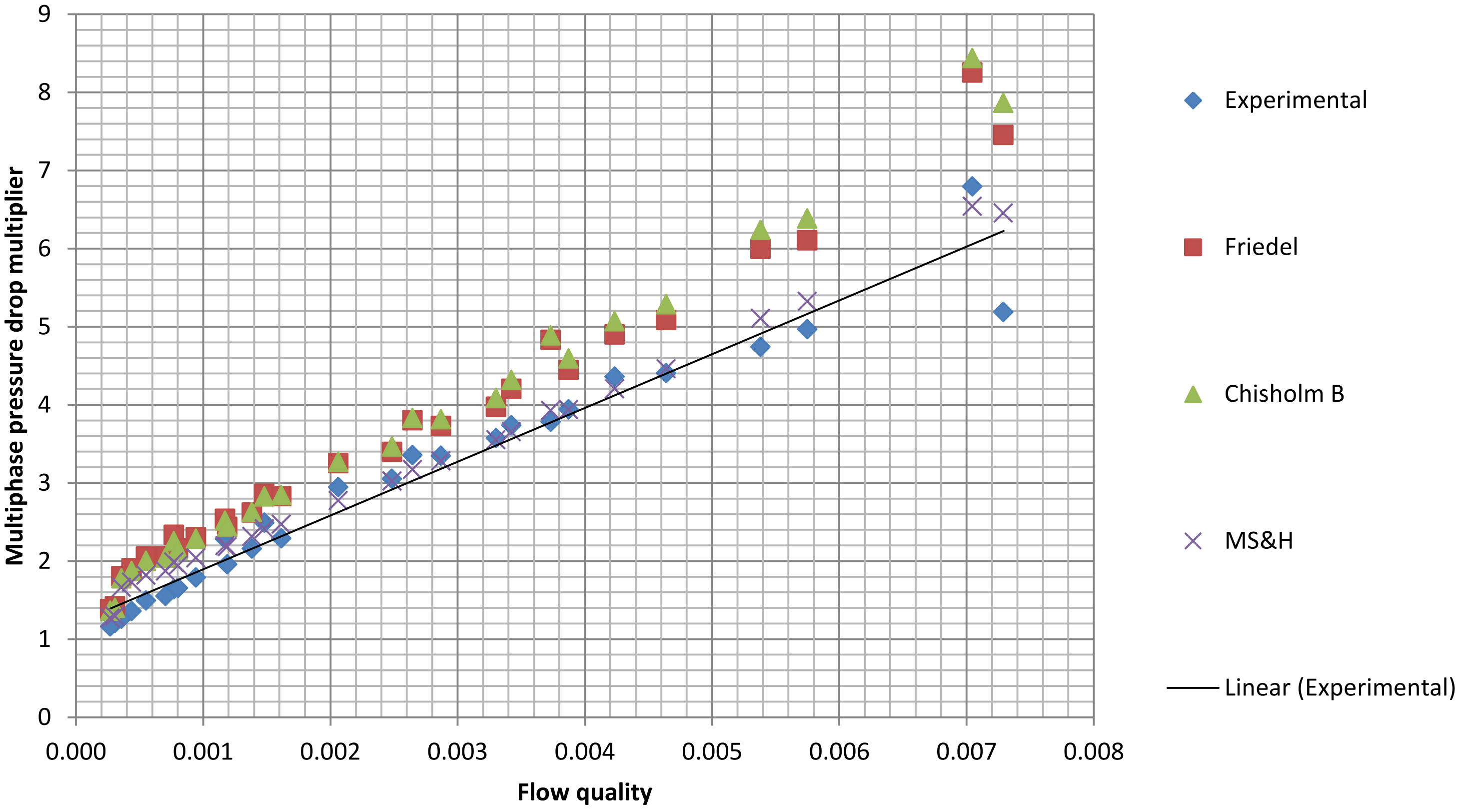


Air-water flow



Correlation	Friedel	Chisholm B	Müller Steinhagen and Heck
Average deviation E_1	22.5%	27.1%	10.5%
Standard deviation E_3	17.3%	19.4%	13.9%

Air-Exxol D80



Correlation	Friedel	Chisholm B	Müller Steinhagen and Heck
Average deviation E_1	29.3%	29.6%	12.1%
Standard deviation E_3	35.4%	32.1%	26.3%

Conclusions

- CFD simulation for single phase flow
- 1D Least Squares Spectral Element Model to be developed from CFD simulation
- 1D LS-SEM method with Müller Steinhagen and Heck correlation for two-phase flow
- Average deviation for pressure drop 10-12%