Simulation and performance of pulsed pipe flow mixing in non-Newtonian liquid dispersion media

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Lappeenranta University of Technology

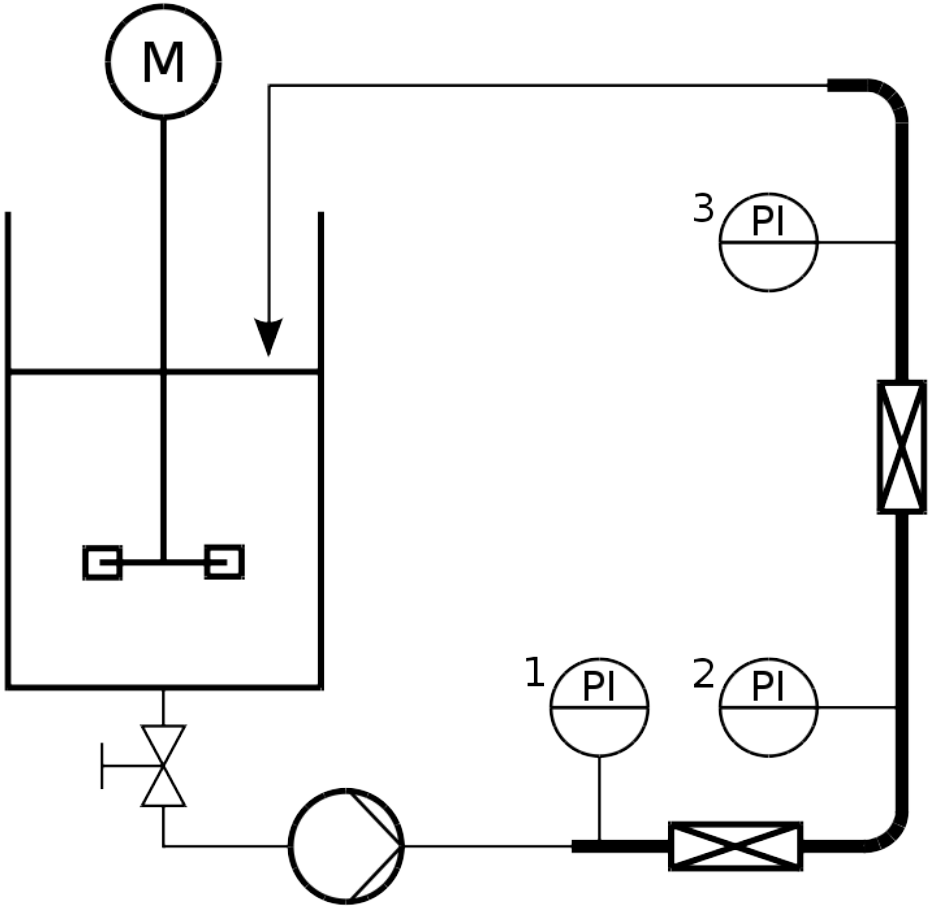
LUT Chemtech

Tuomas Koiranen, Jussi Tamminen and Antti Häkkinen

COMSOL CONFERENCE 2014 CAMBRIDGE

Aim of this work: Understanding the mixing of liquid dispersions in pulsed flow static mixers.

Experimental Set-up



A 50 L mixing tank is equipped with circulation loop: two identical, custom-made static mixers.

Flow in the circulation loop was pulsed (diaphragm pump).

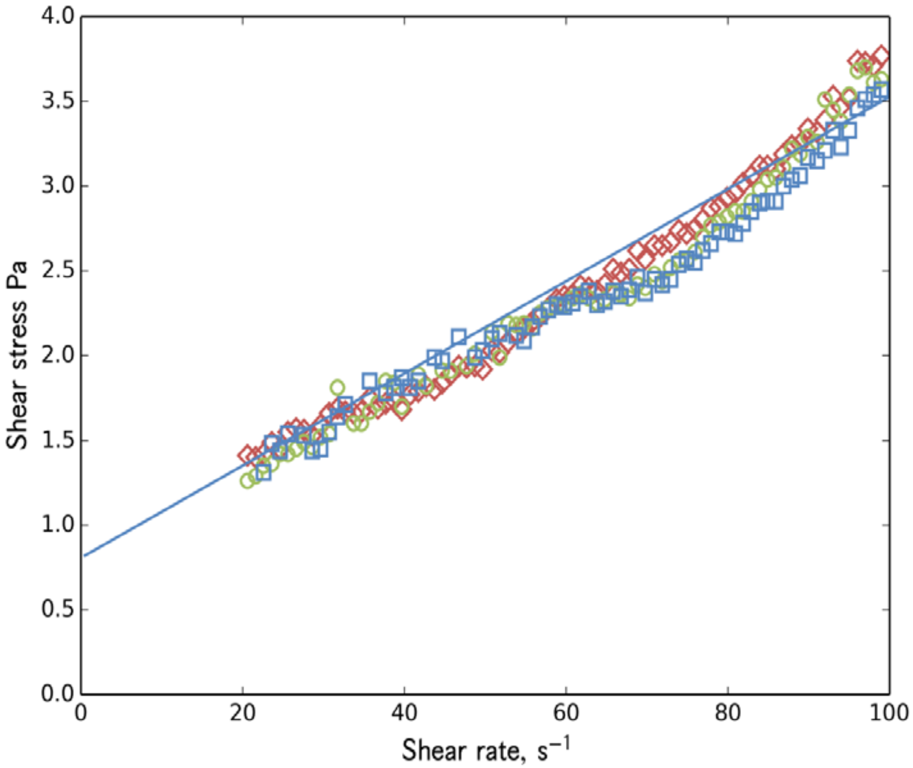
Reference experiments were made using non-pulsing flow (rotor pump)

Mixing power of static mixers were determined based on using pressure drop measurements

$$P = \Delta p Q$$

Liquid Dispersion Fluid properties

Anton-Paar MCR302 :3 parallel measurements

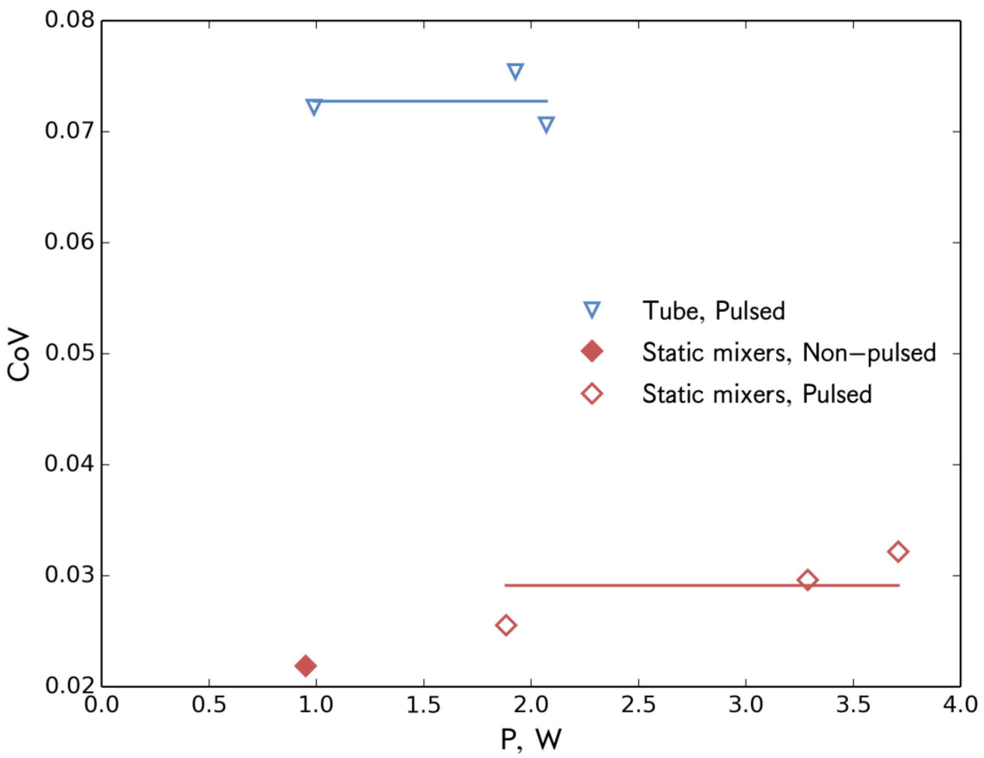


Bingham-plastic rheology is modelled for the experimental data:

Apparent viscosity calculated from experimental data is constant 30 mPas at shear rates greater than 20 1/s.

Dispersion density was 1170 kg/m^3 determined based on the measurement of light and heavy phases and their weight fractions.

Mixing in pulsed and non-pulsed flow



Mixing samples analyzed based on heavy phase mass fractions of liquid dispersion. Sampling between 10 - 60 minutes.

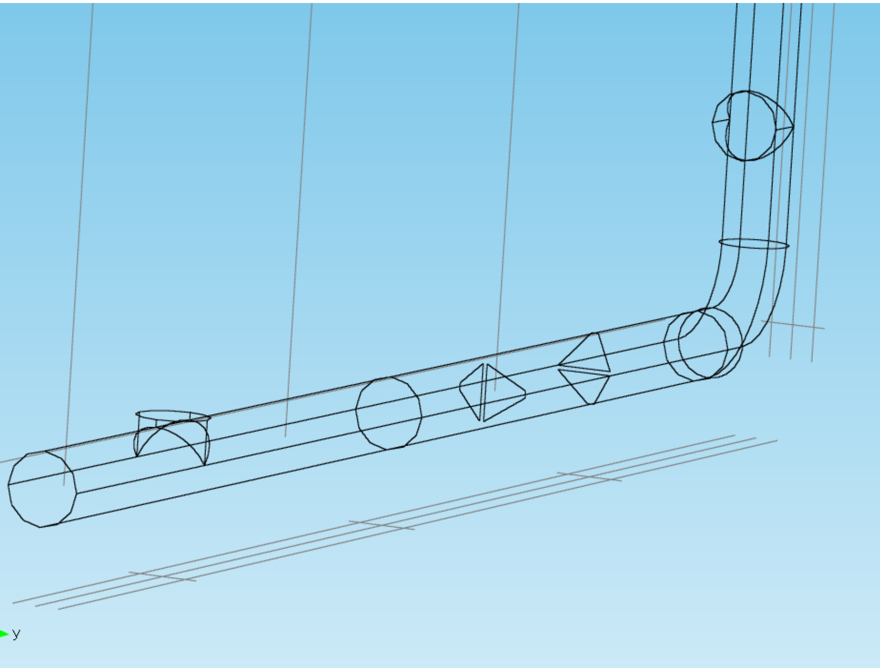
Mixing performance was calculated based on temporal Coefficient of Variation (CoV):

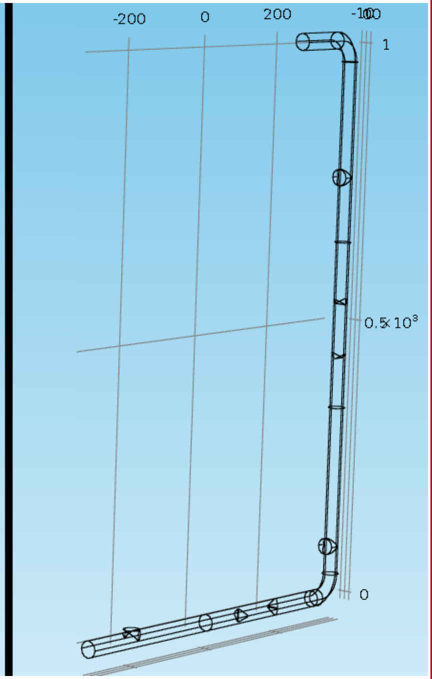
Standard deviation of samples / Average mass fraction of samples

Experimental result:

Non-pulsed flow leads to better mixing

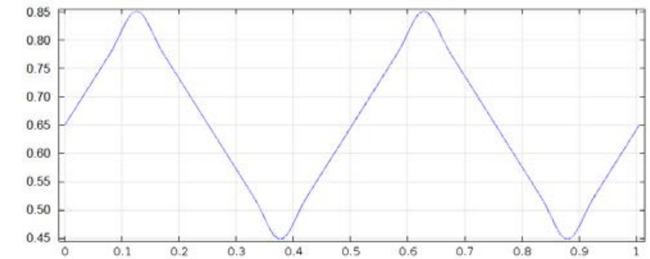
CFD model





Velocity boundary cond.:
Non-pulsed flow: 0.4 m/s
Pulsed flow: 0.65 ± 0.2 m/s

Flow velocity profile had a waveform:

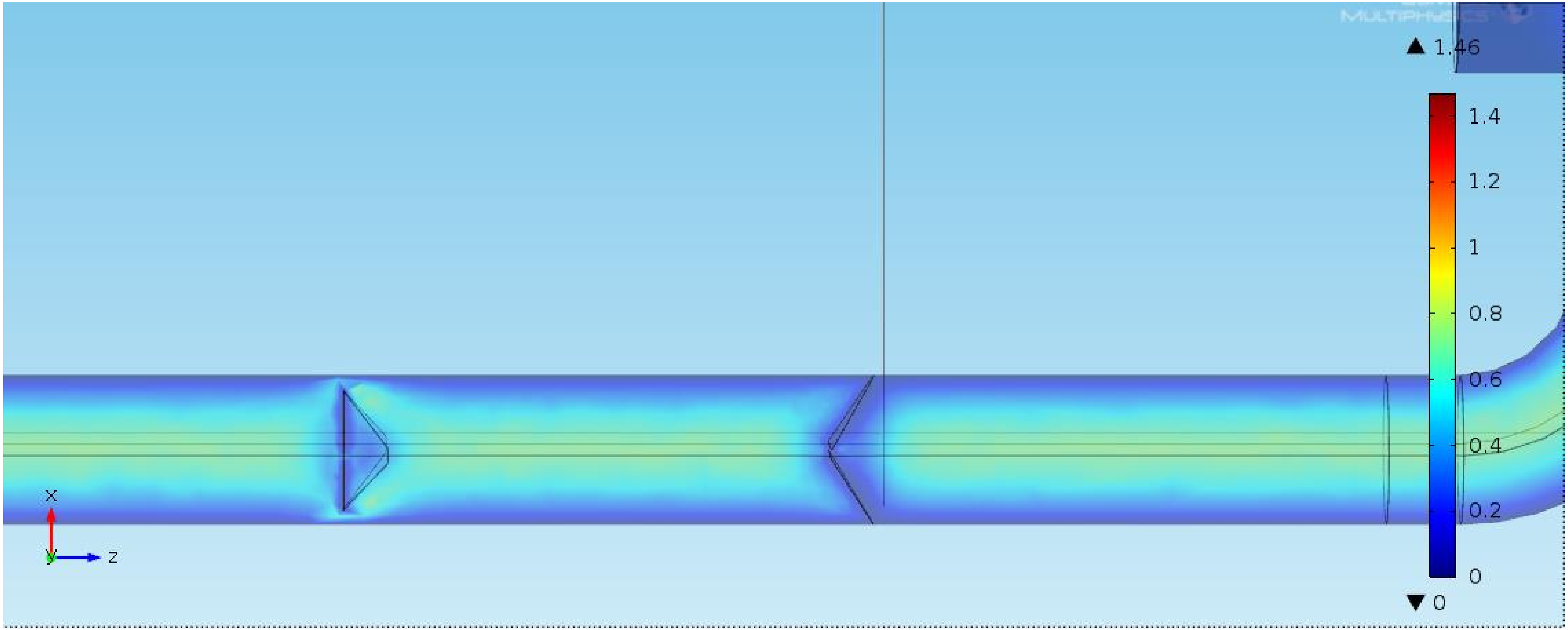


Circulation output flow was filmed on video.
Amplitude: from video frames and volumetric flow measurement
Stroke frequency: from audio track

Modelled flow rates: 17 L/min (Non-pulsed) and 28 L/min (Pulsed)
Average shear rate (8v/d) was between 110 – 227 s^{-1} →
Constant viscosity: 30 mPas
Re: 468 (Non-pulsed flow) and 527 – 995 and Womersley number ($\sqrt{\omega'}=R(2\pi f)^{½}$) was 10.5 (Pulsed flow) → Laminar flow model
Dispersion was treated as a single phase flow in simulations

Non-pulsed flow: steady-state simulation
Pulsed flow: time-dependent solution.
Unstructured grid had 206008 elements

Non-pulsed flow



Velocity magnitude profile of the static mixer. Projection of velocity is at the centreline of the pipe.

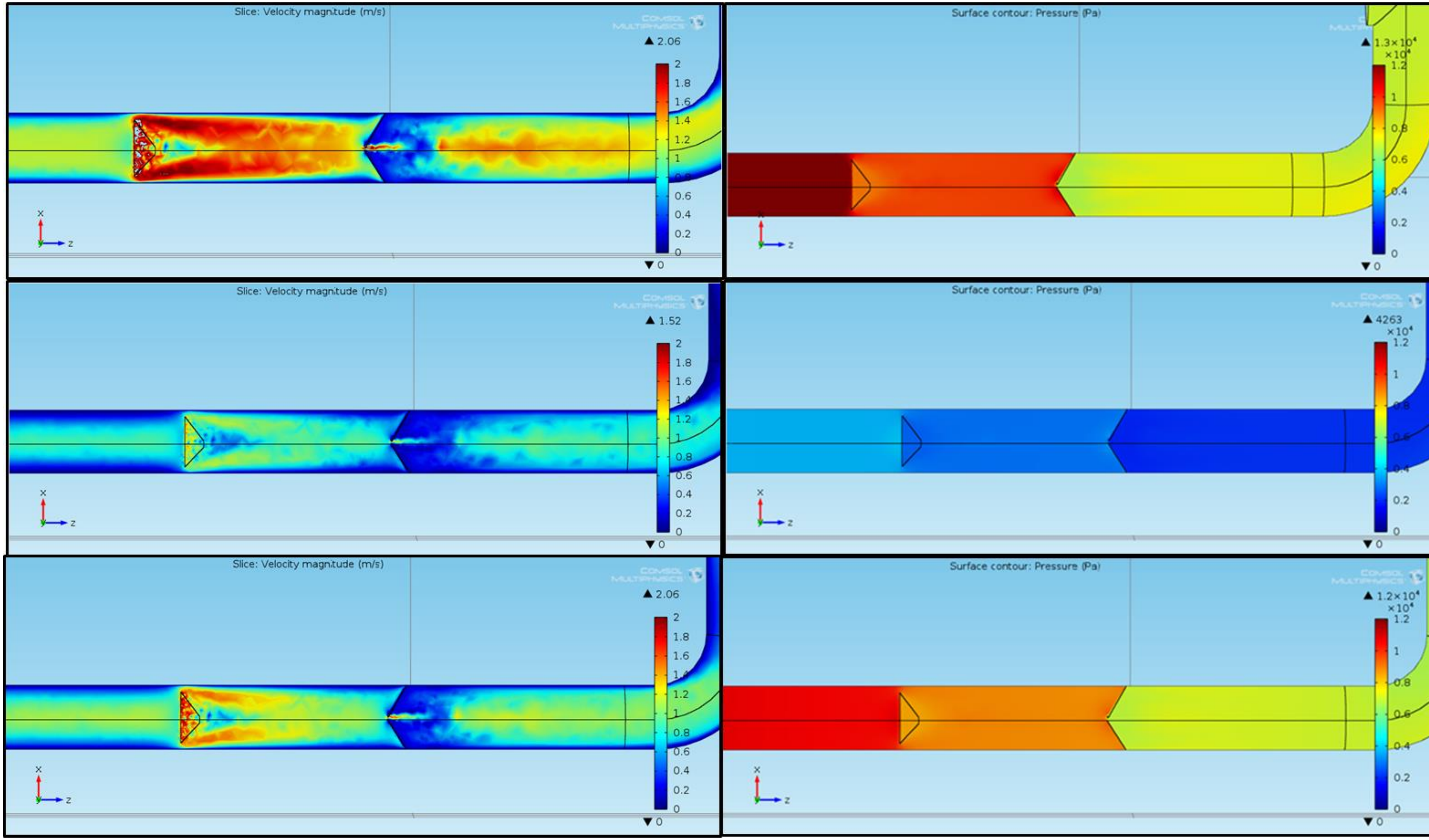
Measured		Calculated	
Non-pulsed flow		Non-pulsed flow	
v, m/s	P, W	v, m/s	P, W
0.4	1.0±0.1	0.4	1.1

Pulsed flow

t = 0.125 s

t = 0.375 s

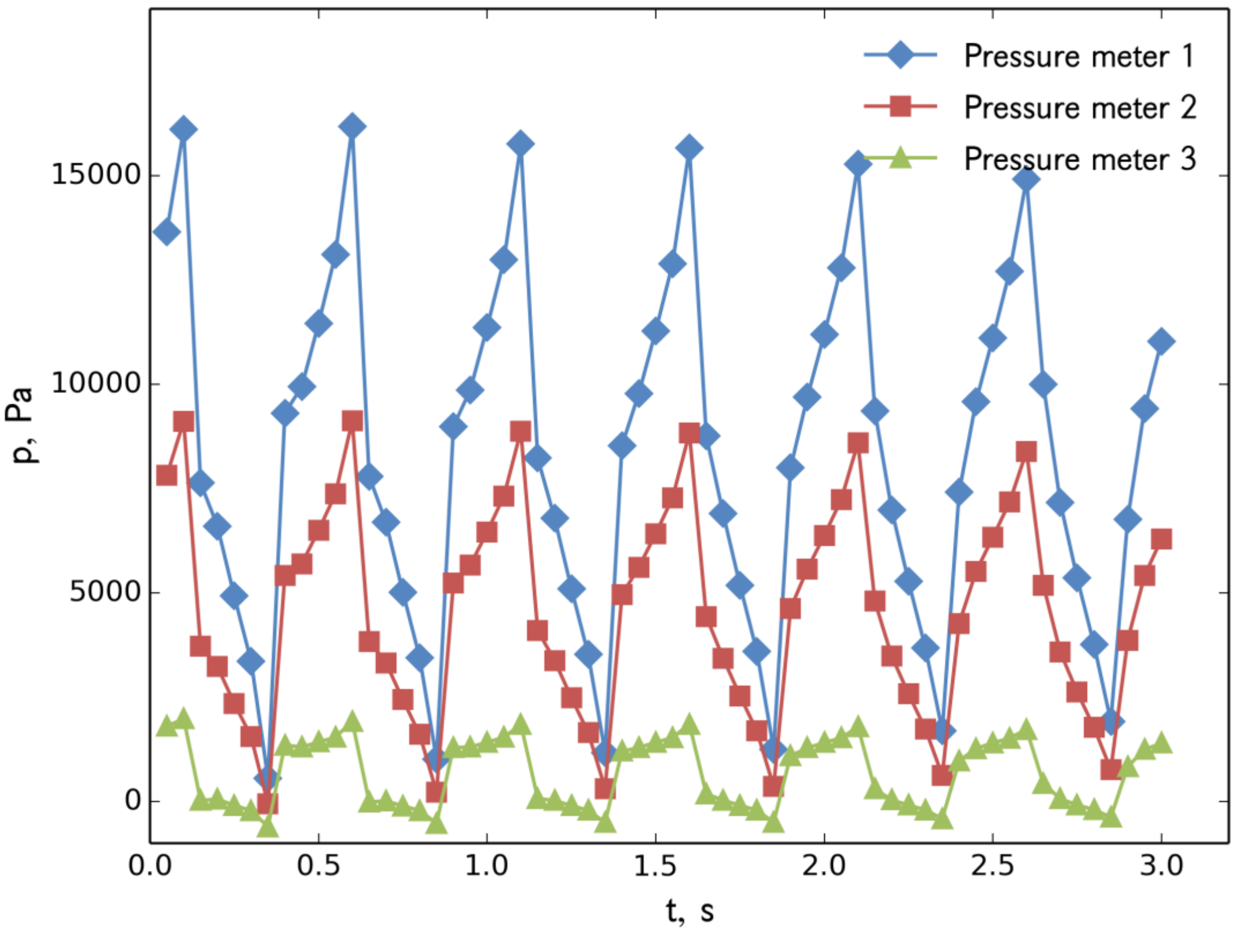
t = 0.5 s



Flow velocity (m/s) (left figure) and pressure (Pa) profiles (right figure) in the first static mixer.

Noisy measurement (average)			Calculated (average)		
v, m/s	Δp(total), Pa	P, W	v, m/s	Δp(total), Pa	P, W
0.65±0.2	6900±1500	3.2±0.7	0.65±0.2	7600	3.5

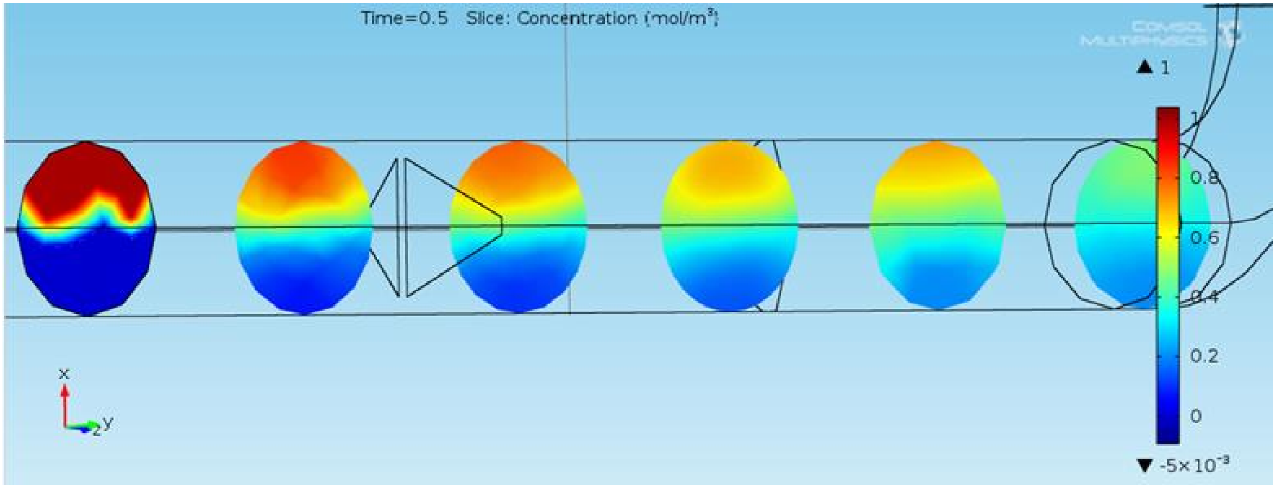
Pulsed flow: Calculated pressures



High pressure variations were observed in measurements.
CFD simulations assured high pressure variations at individual pressure meters.

Mixing simulation

- Step function and the diluted chemical species transport equation as a time dependent simulation.
- Previously calculated flow fields were used for the convective transport and diffusive transport was minimized ($D=10^{-9}$ m^2/s).
- Spatial CoV was determined from simulation data.



Measured temporal CoV				Calculated spatial CoV			
v, m/s	Mixing Power, W	Flow type	CoV	v, m/s	Mixing Power, W	Flow type	CoV
0.4	1.0	non-pulsed	0.022	0.4	1.1	non-pulsed	0.23
0.65±0.2	3.2	pulsed	0.03	0.65±0.2	3.5	pulsed	0.25

SUMMARY

- Immiscible liquids were mixed in custom made static mixers installed in a circulation loop.
- CFD simulations assured high pressure variations at individual pressure meters in pulsed flow.
- When pulsed flow was used, even the increase in the mixing power did not result in better mixing based on experimental and CFD simulated results.