

# Simulation and Performance of Pulsed Pipe Flow Mixing in Non-Newtonian Liquid Dispersion Media

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## Abstract

A non-Newtonian water based oil dispersion was mixed in a mixing tank and a 0.03 m diameter circulation loop pipe of 1.7 m length (Figure 1). Typically oil dispersions are mixed in pipes using static mixers as is described e.g. by Thakur et al.. The Bingham-plastic type fluid rheology was determined experimentally. Experiments were made with custom-made static mixers and empty tubes at different flow rates. The rotor-pump was used in a non-pulsed flow circulation, and diaphragm pump was used for pulsed flow circulation. COMSOL Multiphysics® was used for the modeling and simulation of non-pulsed flow velocity 0.4 m/s and pulsed velocity  $0.65 \pm 0.2$  m/s using the actual geometry of the experimental circulation loop. The simulations were performed using single-phase laminar flow model in steady-state and in time-dependent modes based on the pump type. The laminar flow model in pulsed flows was also used by Timité et al. especially in the same magnitude Reynolds number region. The pulsed flow was modeled using the sinusoidal form of velocity inlet boundary condition for the feed flow pipe. The pulsed flow was experimentally determined based on acoustic signal and video interpretation from the circulation loop outlet. The simulation was used for the estimation of the fluid mixing efficiencies of pulsed and non-pulsed flows based on the coefficient of variation (CoV). The mixing was modeled using diluted species transport equation as described by e.g. Andersson et al..

The static mixer model with Bingham-plastic flow rheology was verified against the pressure data in the case of non-pulsed flow. The simulations assured high pressure variations of individual pressure meters in case of pulsed flow (Figure 2), and the calculated flow fields at different time intervals are presented in Figure 3. The experimental results were compared between non-pulsing and pulsing flows. The most efficient mixing was accomplished with static mixers and non-pulsed flow. The temporal and spatial concentration step function at time interval 0.5 s throughout the first static mixer at pulsed flow rate  $0.65 \pm 0.2$  m/s is presented in Figure 4. The 5 isosurfaces are situated at 0.067 m from each other which equals one pulsed flow cycle 0.5 s. The simulated mixing performance supports the experimental results.

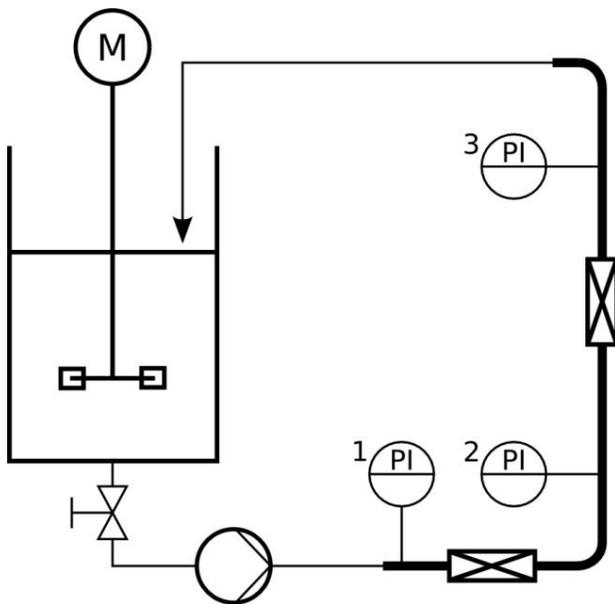
## Reference

Andersson, B. et al., Computational Fluid Dynamics for Engineers, 2012, Cambridge University Press, Cambridge, UK.

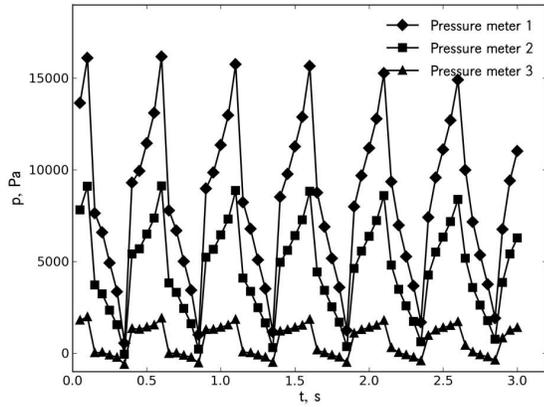
Thakur, R. K. et al., Static mixers in the process industries – A review, Trans IChemE, 81A, 787–823 (2003).

Timité, B. et al., Pulsatile viscous flow in a curved pipe: effects of pulsation on the development of the secondary flow, Int. J. Heat Fluid Flow 31, 879–896 (2010).

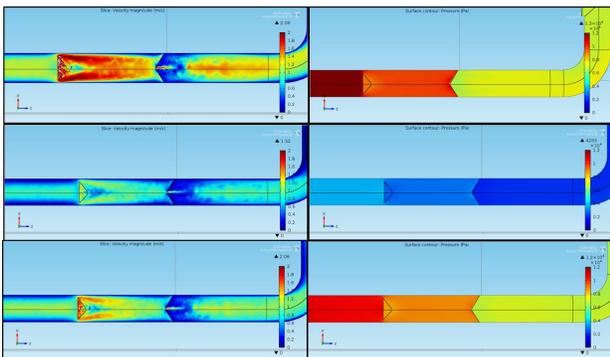
## Figures used in the abstract



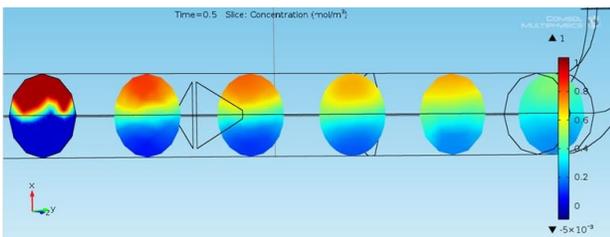
**Figure 1:** The experimental set-up consists of a mixing tank and a circulation loop. The numbering of pressure meters is shown. The thick line indicates the steel tube where the static mixers and pressure meters are installed.



**Figure 2:** Simulated pressure curves for laminar pulsed flow in static mixer loop at flow velocity  $0.65 \pm 0.2$  m/s.



**Figure 3:** Flow velocity (m/s) profile (left figure) and pressure (Pa) profile (right figure) in the first static mixer at times  $t = 0.125$  s (figure above),  $0.375$  s (middle) and  $0.5$  s (figure below).



**Figure 4:** Visualization of the concentration step function throughout the first static mixer introduced at time step  $0.5$  s, the average flow velocity is  $0.65$  m/s. The distance between the isosurfaces is  $67.8$  mm.