Comparison of Different Passive Oil-Water Mixing Schemes in a Flow Loop

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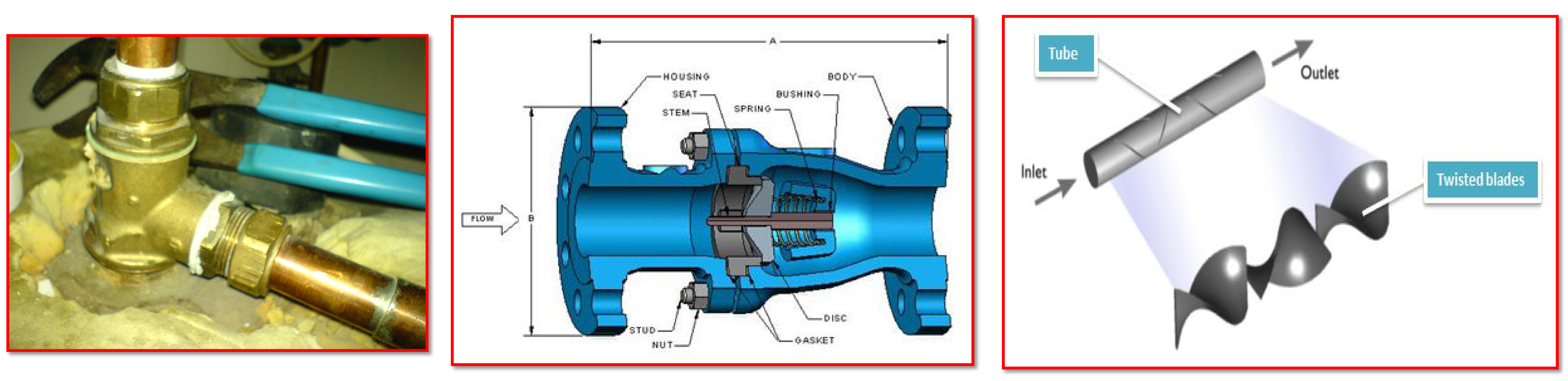
Introduction: Oil and water are immiscible fluids that tend to separate easily when introduced into a flow stream from two different sources. To properly study the behavior of oil-water mixtures in a flow loop, it is necessary to include a mixing device. Static mixing elements (Fig. 1) that work mainly by introducing obstructions and altering the flow pattern are easy to install and operate, but their effectiveness depends on geometrical configuration and flow velocity.



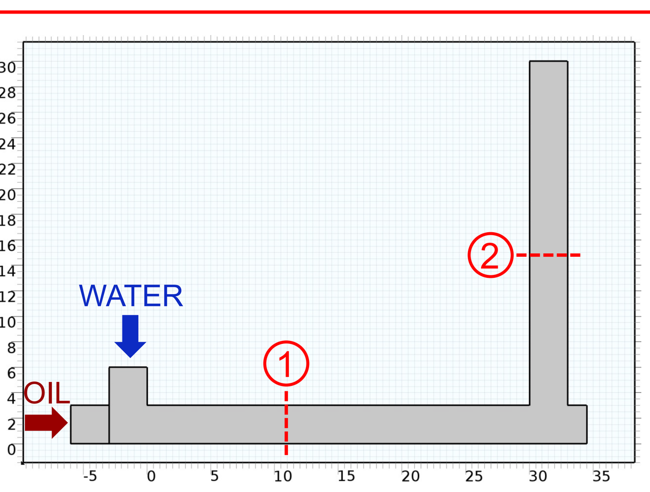
(a) Blind-T **(b)** Spring-loaded check valve **(c)** Static mixer

Figure 1. Passive mixing devices

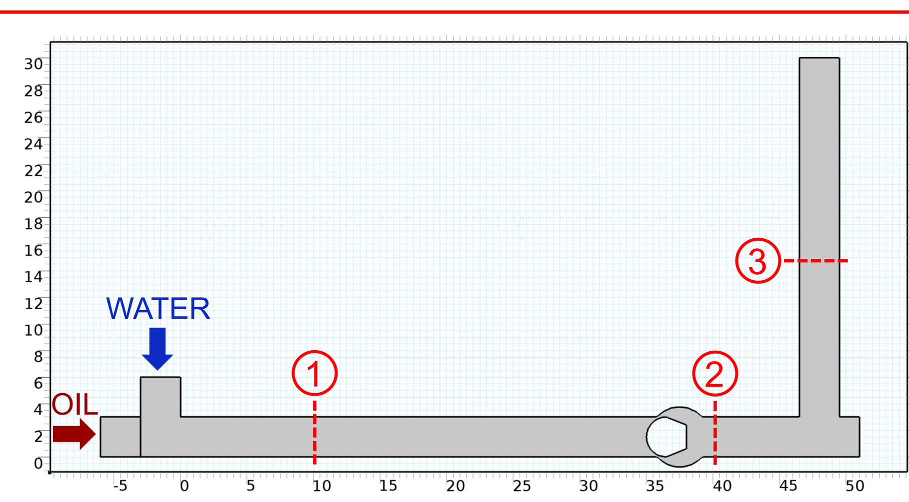
Computational Method: Transient fluid flow and interaction between two liquid components was modeled using the 2-D Multiphase Flow physics within the COMSOL Multiphysics CFD module (Fig. 2). Since the Reynolds numbers are expected to be low, the Two-Phase Laminar Flow Level Set (tpf) interface was chosen to solve for the time-dependent development of the flow profile along the loop and capture the mixing dynamics.

$$\rho\frac{\partial \mathbf{u}}{\partial t} - \nabla\cdot\eta\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} + \nabla p = 0$$

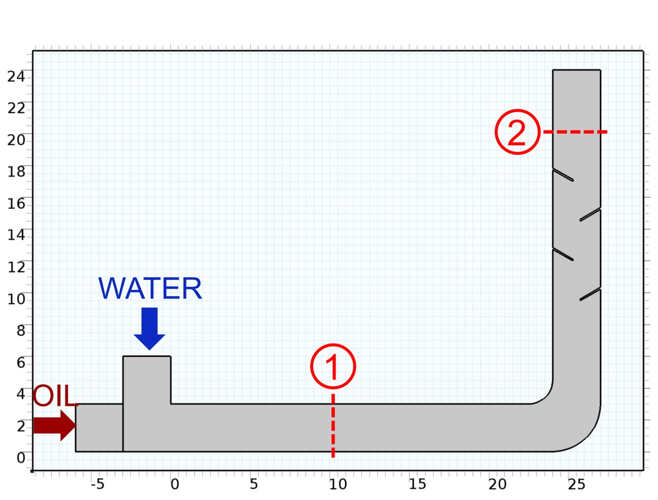
$$\nabla\cdot\mathbf{u} = 0$$



(a) Blind-T



(b) Check valve

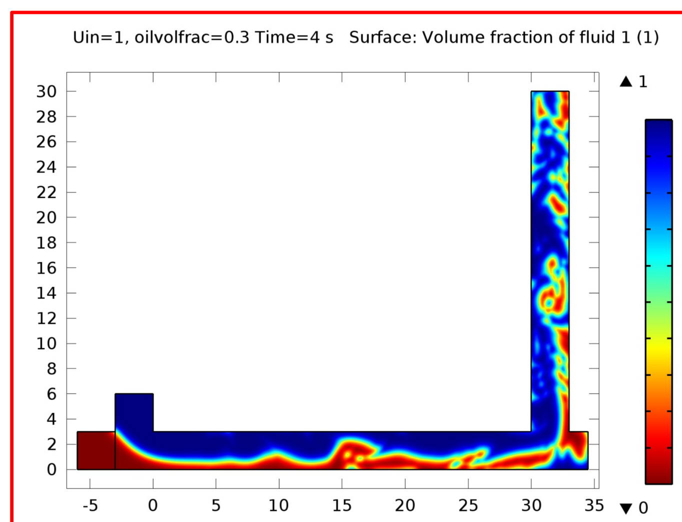


(c) Static mixer

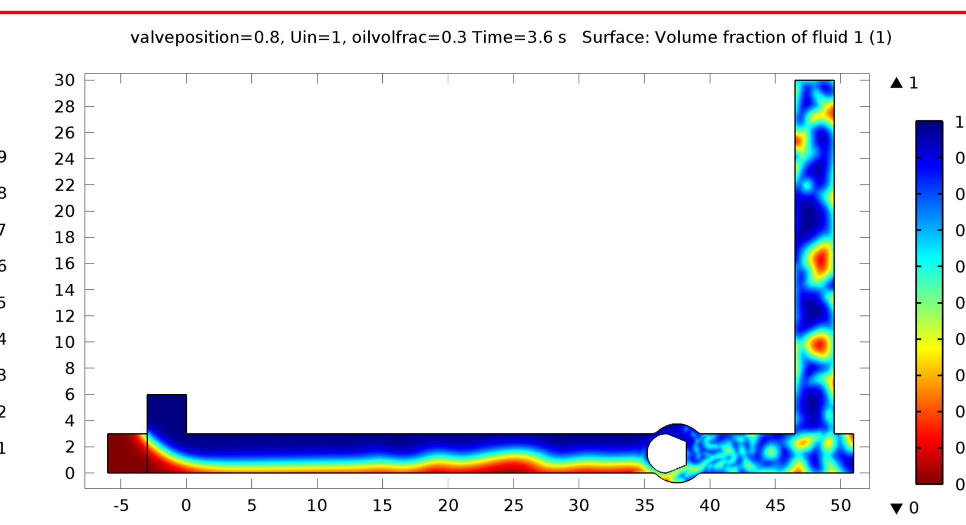
Figure 2. 2-D geometries constructed in COMSOL to represent flow conditions and mixing geometries. Figures also show locations where cross-sectional variations in fluid volume fraction were computed.

COMSOL solves the Navier-Stokes equations (Eqn. 1) for the conservation of momentum and continuity equation for the conservation of mass while satisfying inlet velocity conditions; computed results show volume fraction (ϕ) distribution as a function of time (Fig. 3).

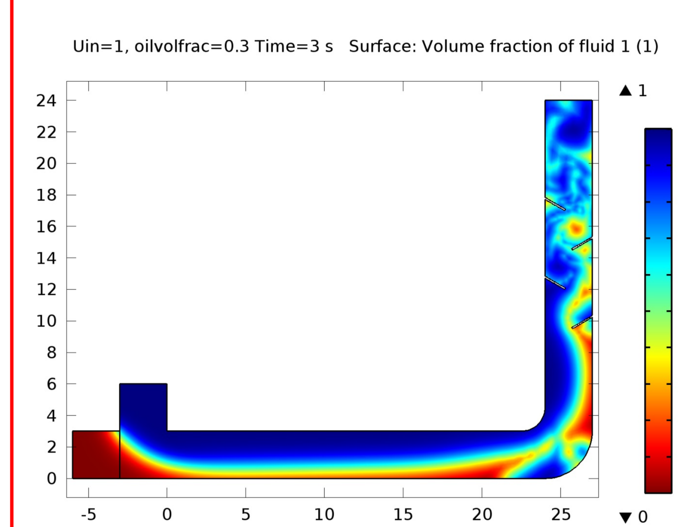
Results: Simulations of the oil-water flow show that the mixture distribution varies with different schemes.



(a) Blind-T



(b) Check valve

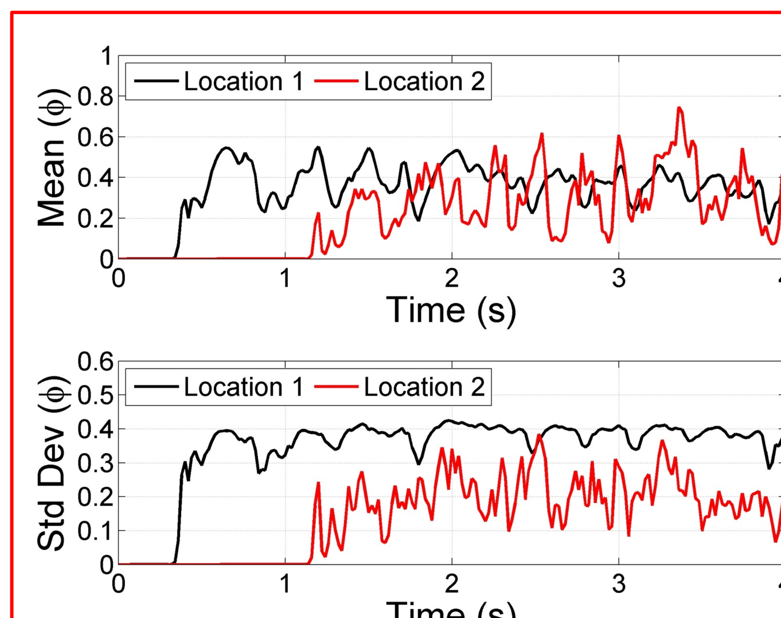


(c) Static mixer

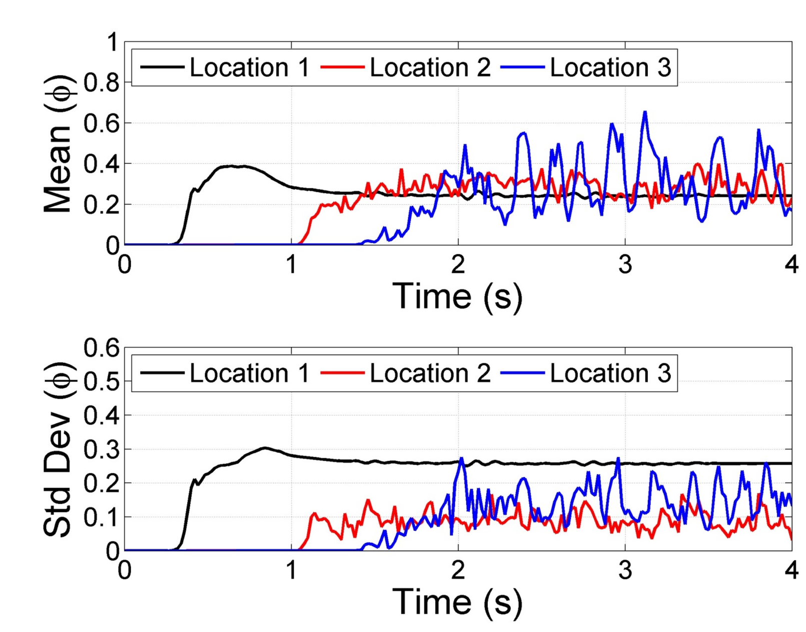
Figure 3. Example volume fraction (ϕ) distributions within the flow loop for $u_{inlet}(oil)$ = 0.3 m/s and $u_{inlet}(water)$ = 0.7 m/s. In all simulations, the fluid mixture is more homogeneous downstream of the mixing device. Note that

$$\phi_{setpoint} = \frac{u_{inlet}(oil)}{u_{inlet}(oil) + u_{inlet}(water)}$$

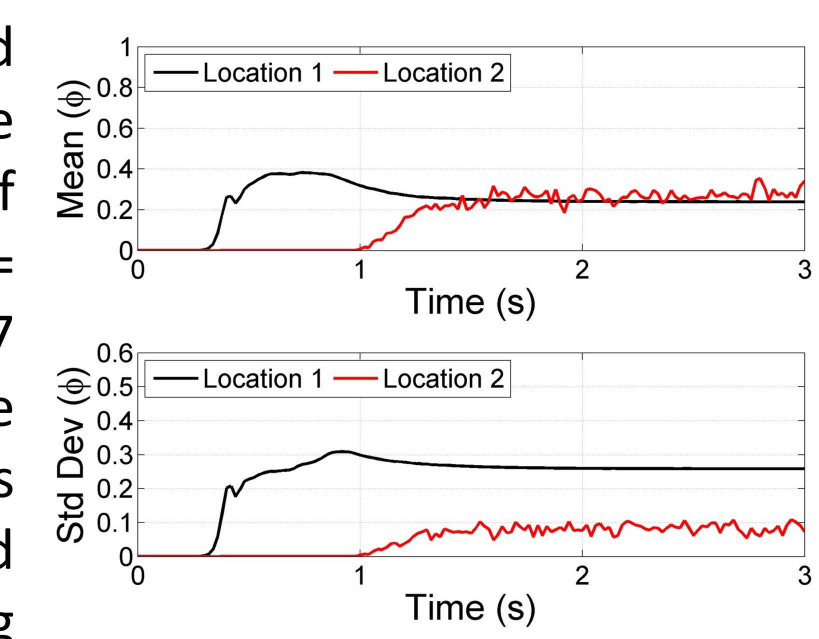
Homogeneity of the mixtures are compared quantitatively by computing the variation in ϕ across the cross-section at locations upstream and downstream of the mixing devices.



(a) Blind-T



(b) Check valve



(c) Static mixer

Figure 4. Mean and standard deviation of ϕ upstream and downstream of the passive mixing device as a function of time. Inlet conditions: $u_{inlet}(oil)$ = 0.3 m/s and $u_{inlet}(water)$ = 0.7 m/s. Mean values of ϕ have similar values (0.3) due to mass continuity, while standard deviation depends on mixing quality and varies with location.

Based on simulation results, the check valve and static mixer have lower variation and perform better than the blind-T.

Conclusions:

(i) Injecting two immiscible fluids into a single pipe does not result in a homogeneous mixture and there are large variations in local properties, and

(ii) introduction of passive mixing schemes improves homogeneity of the mixture but their effectiveness depends on physical configuration.

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