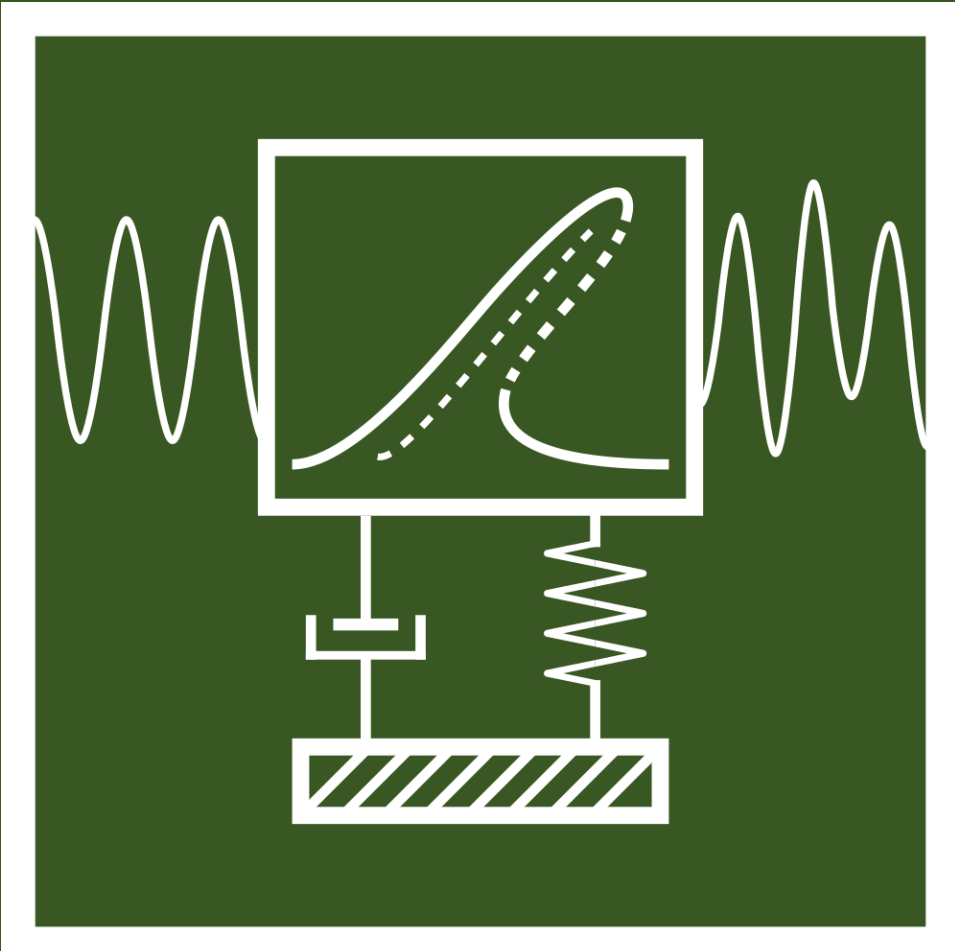


Machine Learning-Based Design Optimization of a Microfluidic Micromixer for Enhanced Mixing Performance

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A Abstract

- A machine-learning-based framework integrated with COMSOL Multiphysics was developed to optimize micromixer geometry for enhanced mixing performance under pressure-drop constraints.
- Gaussian Process modeling and Bayesian Optimization (BO) were employed to explore the design space and identify optimized micromixer geometries.
- The optimized design, combined with acoustic actuation, achieved improved mixing performance compared with the passive configuration, demonstrating the potential of the proposed hybrid approach.

01 Methods

- A machine-learning-based framework integrated with COMSOL Multiphysics was developed to optimize micromixer geometry for enhanced mixing performance under pressure-drop constraints.
- Gaussian Process modeling and Bayesian Optimization (BO) were employed to explore the design space and identify optimized micromixer geometries.
- The optimized design, combined with acoustic actuation, achieved improved mixing performance compared with the passive configuration, demonstrating the potential of the proposed hybrid approach.

02 Results

- The hybrid micromixer achieved a mixing index (MI) of approximately 0.99 at $Re = 0.1$ and 1 , indicating near-complete mixing at low Reynolds numbers.
- At $Re = 10$, the hybrid configuration achieved $MI \approx 0.98$, compared with approximately 0.95 for the passive configuration, demonstrating improved mixing after acoustic actuation.
- At $Re = 20$, the hybrid design achieved $MI \approx 0.96$, whereas the passive configuration decreased to approximately 0.78 , showing a substantial improvement at higher flow rates.

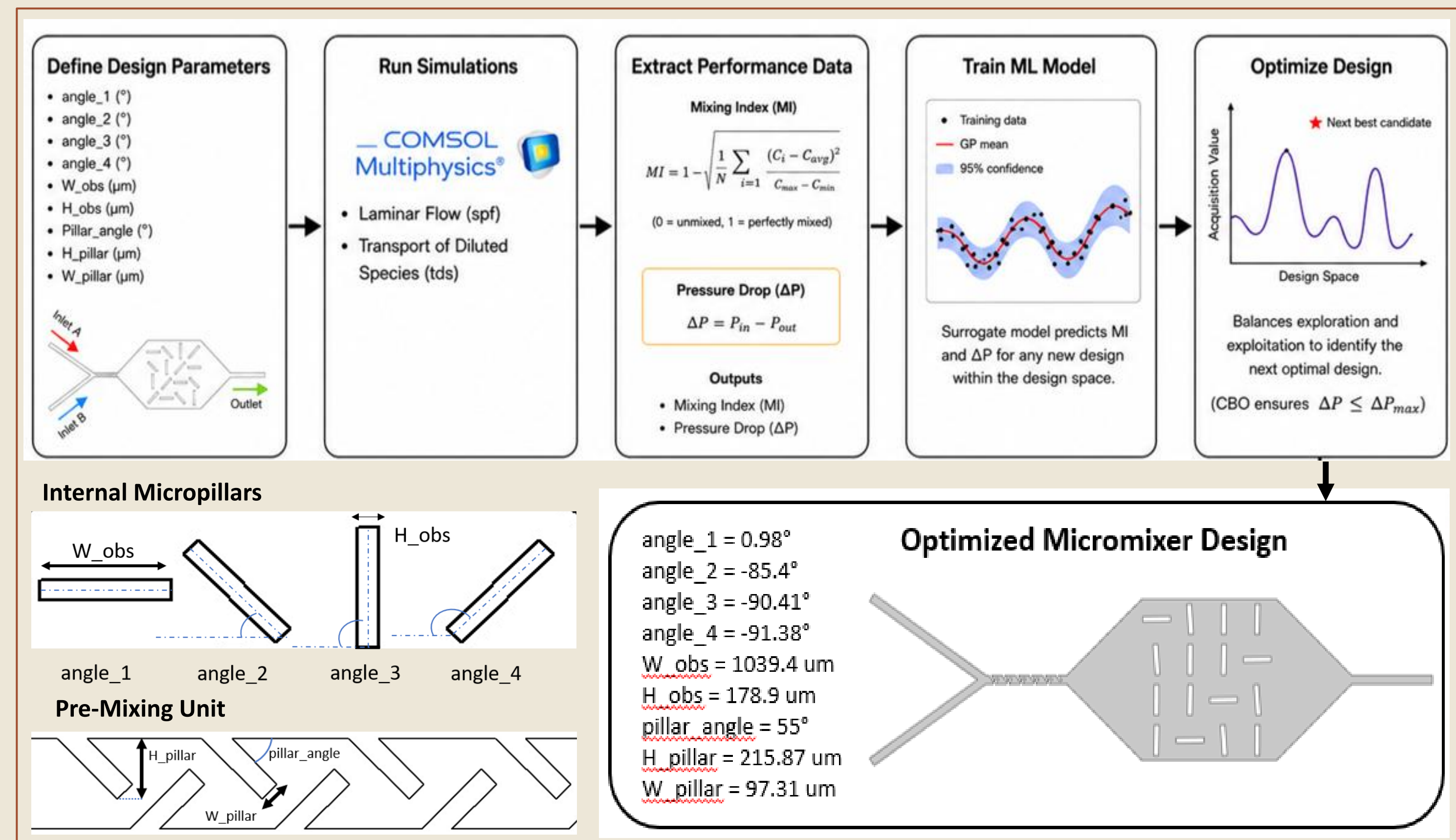


Fig 1. Machine Learning Framework

Acknowledgements

The authors gratefully acknowledge Kaunas University of Technology (KTU) for providing the research facilities and computational resources that supported this work.



03 Discussion

- Passive mixing decreased at higher Re , while acoustic actuation maintained high mixing performance.
- Bayesian optimization efficiently improved the geometry under the pressure-drop constraint.
- The hybrid design provided more robust mixing across the investigated flow conditions.

04 Conclusions

- Machine Learning based design optimization approach can be useful for high-performance micromixer.
- Bayesian Optimization (BO) can be useful for design optimization of micromixer for enhanced fluid mixing.
- Hybrid model integrated with acoustic field delivers higher mixing index compared to passive approach.

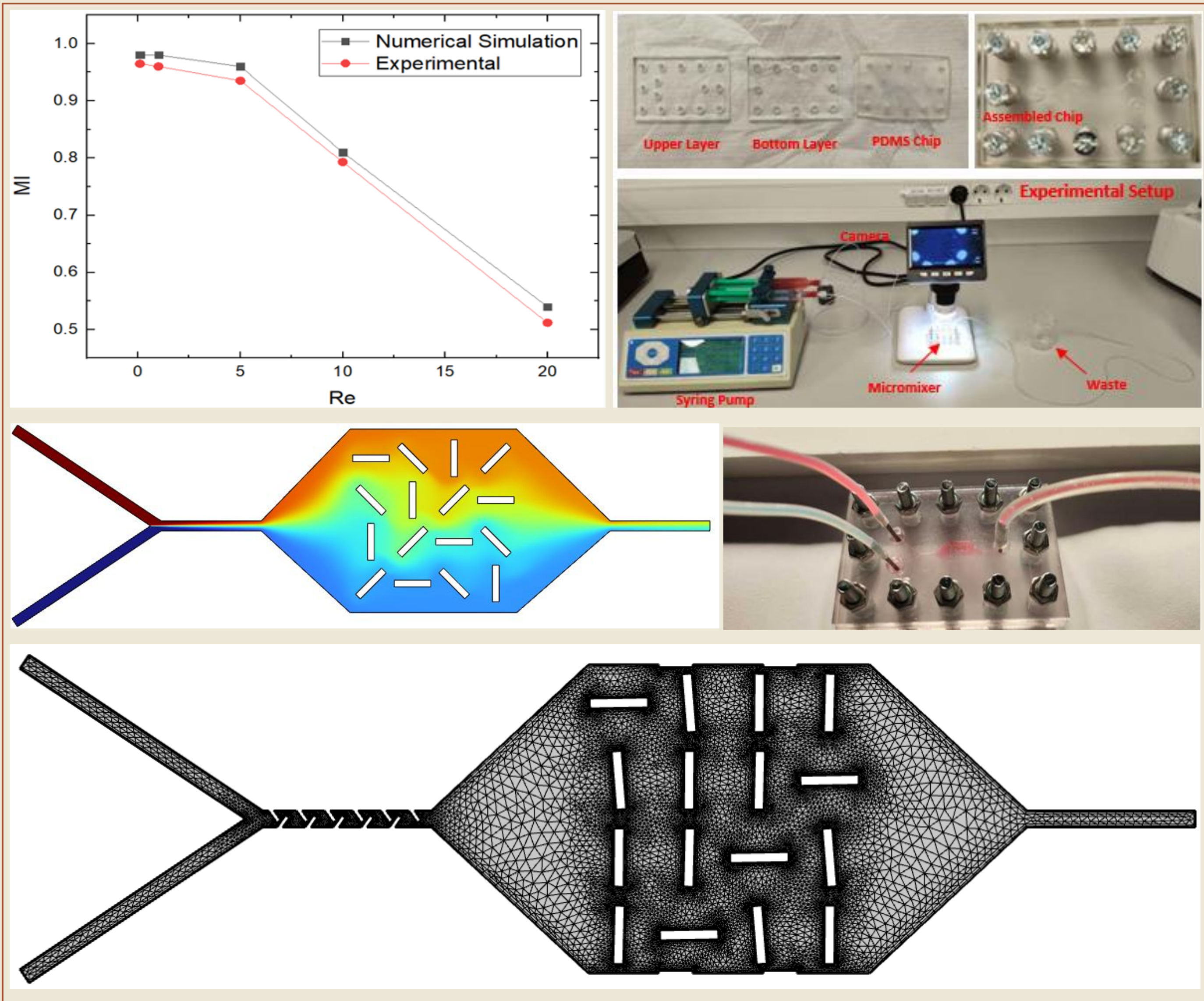


Fig 2. Experimental setup and validation

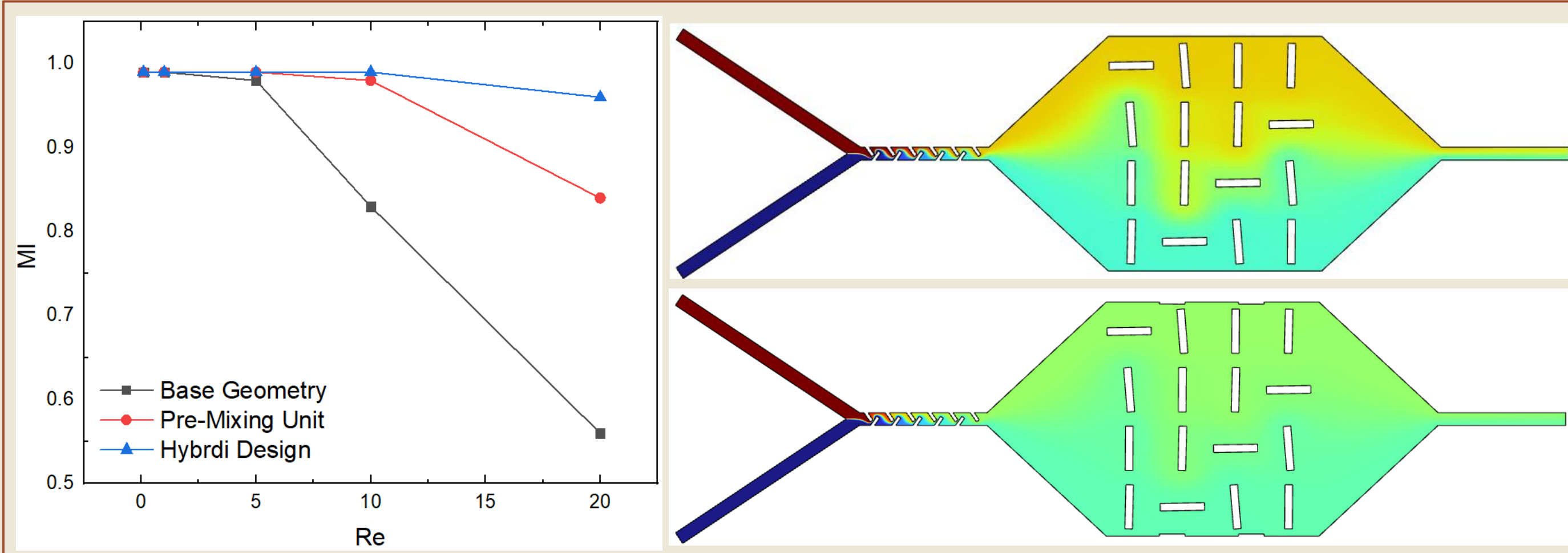


Fig 3. Graphical representations and mixing contours

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