Optimizing Performance of a Vortex Diode as a Cavitation Reactor

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Highlights

- Characterized inception and extent of cavitation in a vortex diode
- Experimentally investigated degradation of four benzene derivatives/ pollutants in water
- Developed reaction engineering models to simulate degradation performance
- Work paves way to develop multi scale model for cavitation reactors

1. Introduction

Recently Ranade et al. [1] have disclosed a novel hydrodynamic cavitation (HC) device based on vortex diode (VD). Unlike conventional devices, it relies on tangential flow for generating cavitation. The unique design allows superior performance as a cavitation reactor for variety of waste water treatment applications [2]. The available experimental data indicates that there exist an optimum pressure drop across VD for maximizing degradation of pollutants. Despite the superior cavitation performance demonstrated by VD, most of the published studies on VD are rather empirical. No systematic modelling efforts have been reported to interpret the cavitation performance of VD. No quantitative understanding or guidelines are available for optimizing performance of VD as cavitation reactor. We aim to address this gap in the present work. Our prior experience with cavitation reactors indicate that it is important to quantify cavitation inception and evaluate the performance of cavitation reactor in the context of relative position of operating point with respect to inception and choking conditions. There have been contradictory claims about the optimal operating point with respect its distance from inception and choking conditions. In this work, therefore, we have made systematic efforts to quantify inception and choking cavitation conditions. Systematic experiments were then carried out on degradation of four aromatic pollutants with different functional groups (toluene, aniline, nitrobenzene and chlorobenzene). Cavity dynamics models coupled with reaction engineering models were developed to simulate per-pass degradation of pollutants processed through VD as a cavitation reactor. Computational models were evaluated by comparing simulated results with the experimental data. Efforts were made to quantify optimum operating points and develop generalized guidelines. The developed approach, models and results will provide useful design guidelines for pollutant degradation using VD as a cavitation reactor and will also will provide a useful basis for comprehensive multi-scale modelling of HC reactors.

2. Methods

Experimental set-up used in the present work is shown in Fig. 1. The noise produced from collapsing cavities was monitored at multiple points at different operating pressures with the help of a hydrophone. The acoustic signals were analyzed to identify cavitation inception. Four pollutants in water with known initial concentration were used for degradation experiments. A cavity dynamics [3] was formulated & solved using the ode15s solver. Formation of hydroxyl radical as a function of operating conditions was simulated. Per-pass degradation model was developed. Experimental data and simulated results from the computational models were used to identify optimal operating conditions and desired design guidelines.

Figure 1: Experimental setup.

3. Results and discussion

A new method to identify inception of cavitation based on experimental pressure drop data and analysis based on Rankine vortex (Figure 2). Detailed method will be discussed in a full paper. The inception point was verified by analysis of acoustic data acquired by hydrophones from the outlet of VD. After establishing cavitation inception, pollutant degradation experiments were carried out at different extent of cavitation (from inception to choking cavitation). A sample of results which clearly shows the existence of optimal extent of cavitation (pressure drop across VD) is shown in Figure 3.

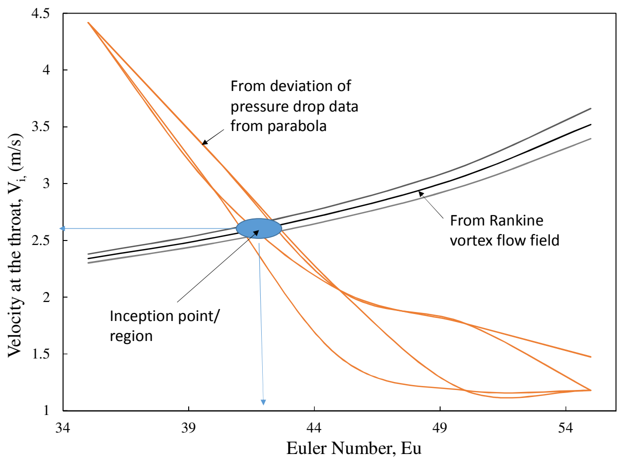

Figure 2: Identification of cavitation inception.

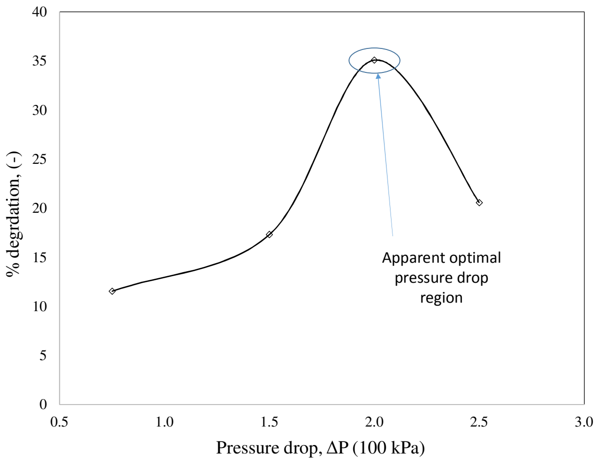

Figure 3: Existence of optimal pressure drop.

A set of computational models was developed to understand and interpret the observed optimal pressure drop. Cavity dynamics model was formulated for simulating oscillations and eventual collapse of generated cavities. The model and computer program was verified initially by comparing simulated results with the published results on single cavity dynamics [3]. The CFD simulations of flow in VD were then used [4] for simulating pressure history experienced by generated cavities. The cavity dynamics model was then used to estimate generation of hydroxyl radicals at different operating conditions using the trajectories generated by CFD models and the Gibbs Energy minimization for simulating equilibrium composition at the collapse pressure and temperature. A simplified reaction engineering model using a per-pass degradation factor was used to describe the experimental degradation data. The results obtained through cavity dynamics model were used to correlate the per-pass degradation factor. The models were also used to understand influence of nature of functional groups on degradation performance. The experimental data, the computational model and the simulated results were used to develop guidelines for optimizing performance of VD as a cavitation reactor. The work will provide a basis for further development of multi-scale models of cavitation reactors.

4. Conclusions

VD has shown to be an effective cavitation reactor for degrading pollutants in water. There exists an optimum region/ extent of cavitation with respect to degradation performance. It is essential to quantify relative position of this optimal region with respect to inception and choking cavitation. The approach, methods, models and results presented in this work provide useful guidelines for optimizing performance of VD as a cavitation reactor.

References

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Keywords
Hydrodynamic Cavitation; Vortex Diode; Effluent Treatment; Reaction Engineering Modelling.