Computational Fluid Dynamics Based Models for Assessing UV Reactor Design and Installation [Project #4107]

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OBJECTIVES: The goal of this work was to evaluate whether computational fluid dynamics (CFD) based models could be used to accurately model the hydraulics, ultraviolet (UV) intensity distribution, and reduction equivalent dose (RED) in commercial UV reactors with different reactor and piping configurations. In particular, the primary objective was to demonstrate whether CFD-based models could be used to compare the performance of installed UV disinfection systems relative to validated systems with different piping configurations (potentially caused by retrofits or space limitations at the installed site).

BACKGROUND: The use of UV disinfection for drinking water treatment is expected to increase, and CFD is expected to play an increasing role in the design, implementation, and validation of UV disinfection systems. A CFD model provides detailed simulations of flow fields and hydraulic behavior within the piping and reactor that may impact reactor performance. In addition, UV radiation and dose models can be readily incorporated into or combined with CFD-based hydraulic models for simulation of the RED. Thus, CFD-based models may provide an alternative for expensive biodosimetry validation methods and a potential substitute for revalidation. Although CFD has not yet been accepted as a stand-alone validation method, it may be used to build confidence in the validation process and address “what if” scenarios if different configurations are being evaluated.

APPROACH: Three different commercial reactors were simulated: (1) an IDI (Degremont Technologies) Ozonia Aquaray® H2O 20-inch reactor, (2) a Calgon Sentinel® 12-inch reactor, and (3) a Trojan Swift® 10L30 reactor. The IDI reactor was validated using three different piping and reactor configurations. Each IDI configuration was simulated to determine if the different approach hydraulics and subsequent dose distributions were adequately modeled relative to the trends in the data. The Calgon and Trojan reactors provided an opportunity to model other commercial reactors with different piping, lamp, and sensor configurations. Although these reactors were not validated under different piping configurations, the suite of different operational conditions (i.e., flow rate, UVT, different lamps on or off, lamp power) during the validation tests provided a good basis to assess and compare the capabilities of the CFD-based models.
RESULTS/CONCLUSIONS:
The results of the modeling showed that CFD-based simulations were able to capture the salient trends in measured RED as a function of different flow rates, UV transmittances, and lamp power. In addition, the use of different pipe sizes and the comparison of runs with and without a baffle plate showed notable impacts on the measured RED in the IDI validation tests. The simulated performance of these different IDI configurations matched the observed trends. Simulations of the Calgon and Trojan reactors also resulted in good matches between simulated and measured data for a wide range of operating conditions. A summary of the primary objectives is provided in Chapter 7 of the report.

APPLICATIONS/RECOMMENDATIONS:
Based on the results of this work, the following additional research is recommended:

- Additional work is needed to evaluate the directional profile of emission from UV lamps. The emission profile depends on the optical density of the arc at the relevant wavelength of emitted light (Phillips, 1983). A small element along the lamp acts more like a Lambertian emitter as the optical density of the arc increases. While the output from a linear fluorescent lamp behaves like an ideal Lambertian emitter, the output of mercury lamps without fluorescent coatings (e.g., the 265 nm line of a medium pressure UV lamp) is more complex, behaving between what would be expected with a Lambertian and point source emitter. If the behavior is not known, the angular dependence of the UV lamp’s output represents a potential source of modeling error.

- More work is needed measuring the reflection coefficient of reactor surfaces as a function of the wavelength of light, understanding the impact of the reactor surface finish on specular and diffuse reflection, and modeling the impact of specular and diffuse reflections on UV intensity fields and dose delivery. Experimental work is also needed to confirm the impacts of reflection on UV intensity, log inactivation and RED. Lastly, work is needed on understanding the regulatory impacts of reflection on UV dose monitoring at the water treatment plant application since reflection will be impacted by fouling and surface corrosion, yet UV sensors will not be monitoring the impact of these phenomena on UV dose delivery.

- If additional validation data become available that compare alternative piping and/or inlet/outlet configurations for UV reactors, the methods presented in this report should be applied to further assess CFD-based tools for predicting flow, UV intensity, and UV dose in those systems.

RESEARCH PARTNER:
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PARTICIPANTS:
Calgon Carbon Corporation, Infilco Degremont Inc. (IDI)/DENARD, and Trojan Technologies Inc. provided validation reports of their commercial UV reactors.