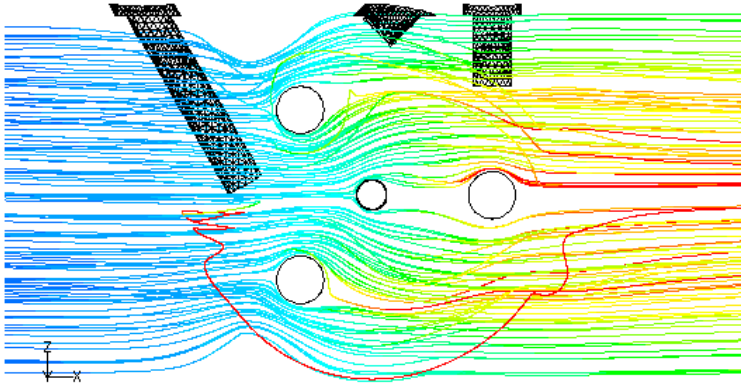
SAND2008-7449C

Important Factors for Computational Modeling of UV Disinfection Systems



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[2]Carollo Engineers

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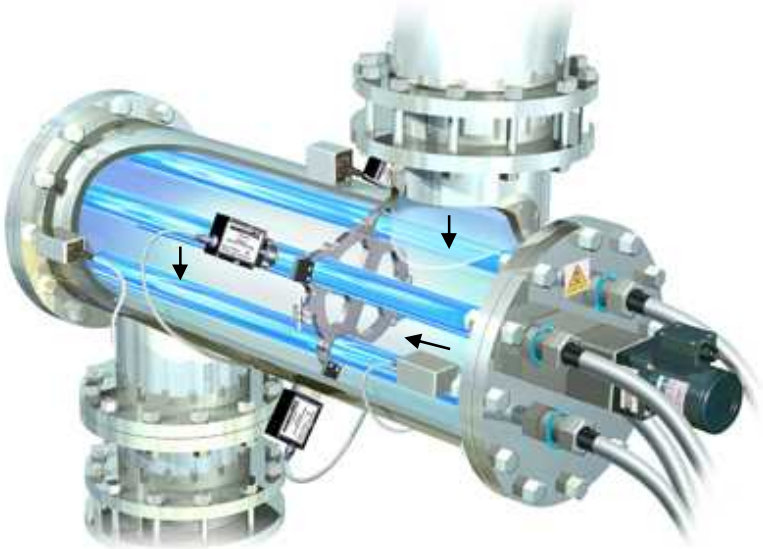
Overview

- Introduction
- Modeling Approach
- Sensitivity Analyses
- Conclusions

How Does UV Disinfection Work?



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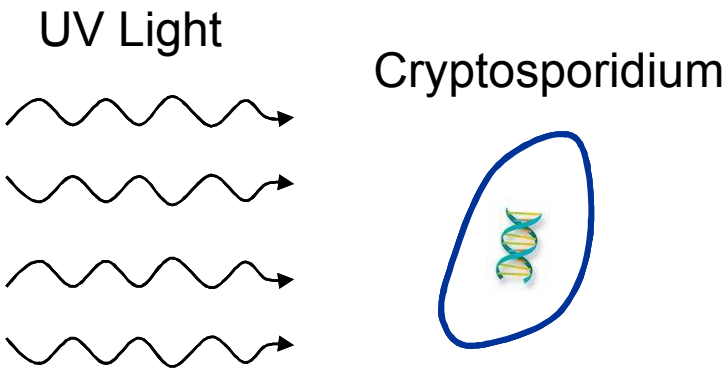
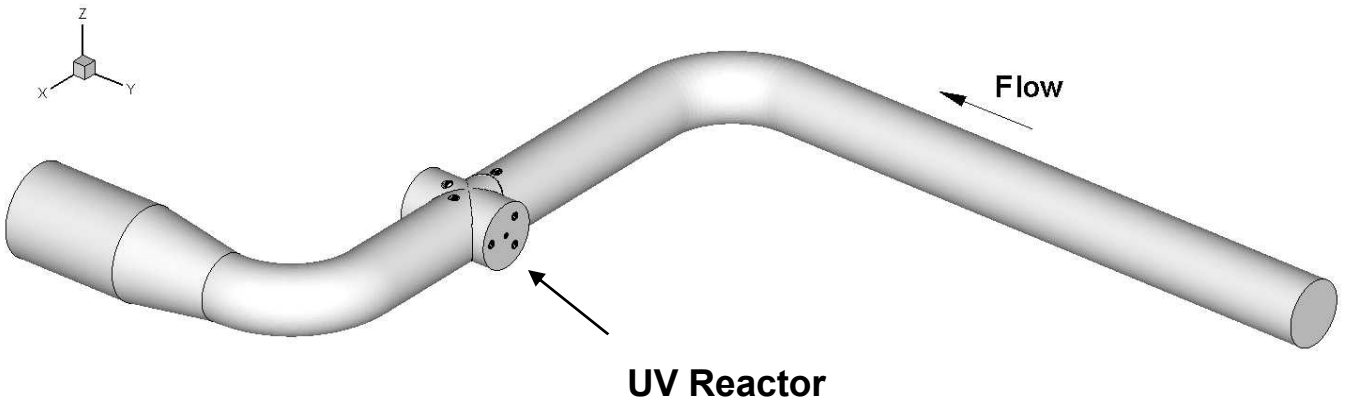
Flowing water is exposed to UV light in a reactor chamber



UV light makes the pathogen non-infectious by damaging its DNA

Problem Statement

- **Validation of UV disinfection systems requires costly biodosimetry tests (usually off-site)**
- **Installed systems may have different piping configurations than the validated system**



Objectives

- **Evaluate computational fluid dynamics (CFD) modeling as a means to assess performance of UV disinfection systems**
  - **Can we replace or minimize biodosimetry with CFD modeling?**
  - **Will the installed system perform at least as well as the validated system?**
  - **What processes and design features most impact performance?**
  - **What factors impact the accuracy of the modeling?**

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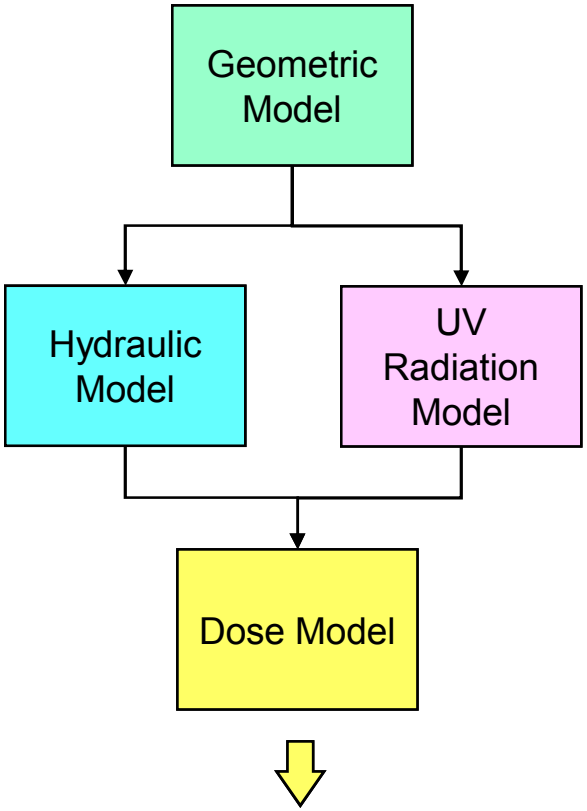
See talk by Wicklein, Wright, and Ho

Time: Wed., 8:30 AM

Title: Computational Fluid Dynamics Modeling of UV Reactor Validation Tests

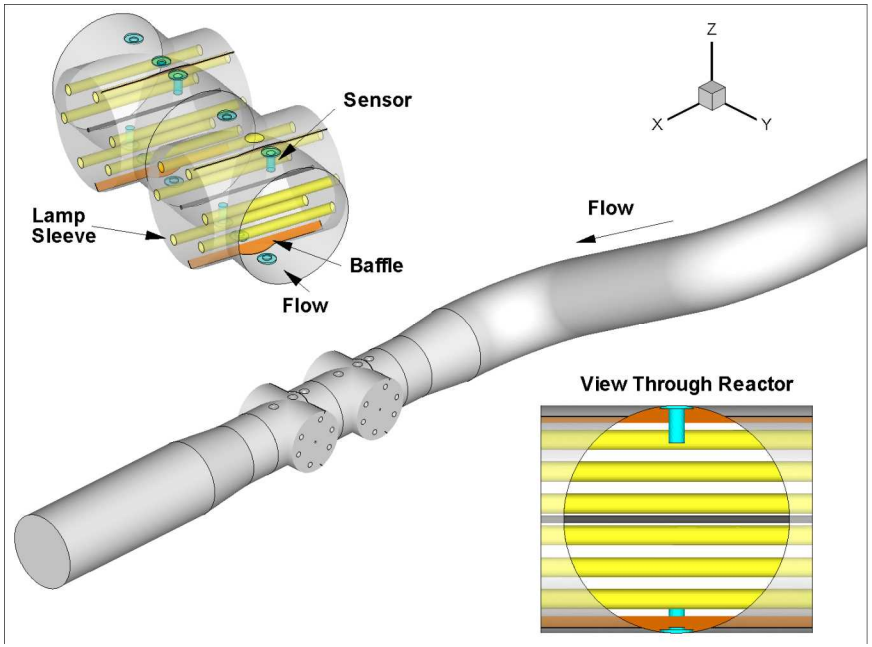
Session: UV Validation and Adenovirus

Modeling Approach



Hydraulic Modeling

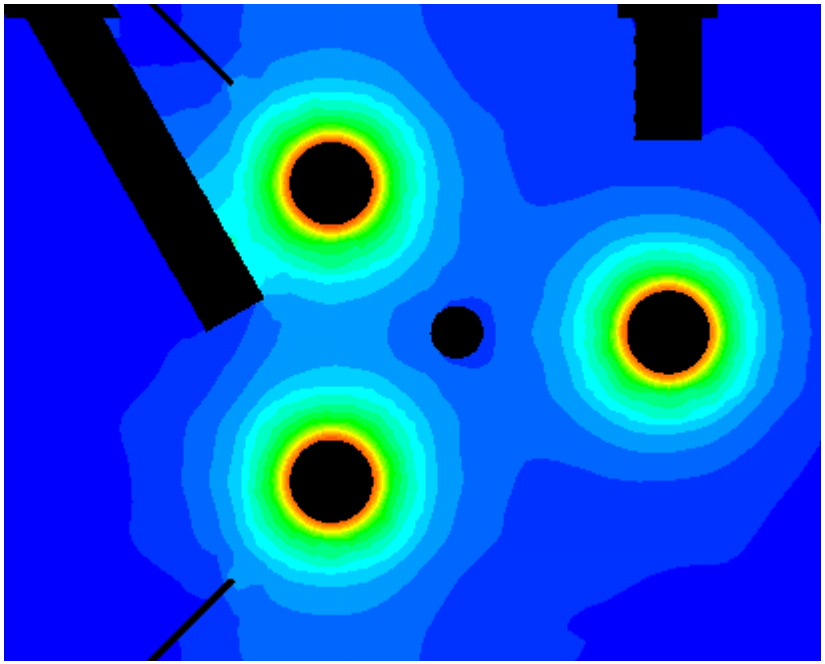
- Develop geometry and grid to represent features of UV reactor and piping
  - Ensure results are grid independent
- Apply appropriate boundary conditions
  - E.g., Inlet velocity, flow rate
- Obtain converged flow field



GAMBIT/FLUENT model of the Ozonia Aquaray® H2O reactor and piping.

Implement UV Radiation Model

- Implement appropriate UV radiation model
  - Lamp orientation and features
  - Sensor orientation and features
  - Spectral dependencies
  - Directional dependencies
  - Refraction through quartz sleeve
  - Wall reflection
- Liu et al. (2004) provides evaluation of alternative models
  - Line source integration, multiple point source summation, discrete ordinates, etc.



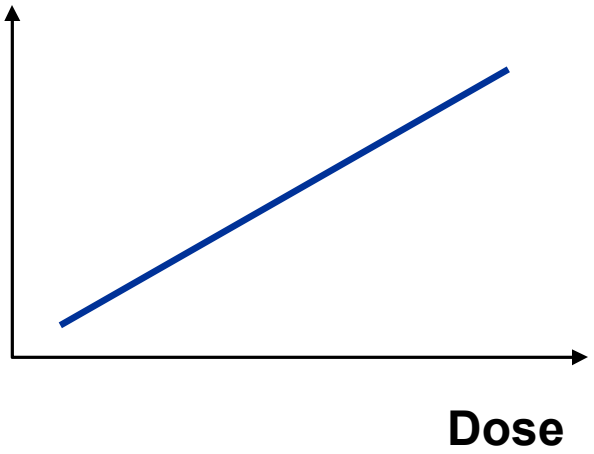
Simulated UV Intensity Field
(Calgon 12" Sentinel® UV Reactor)

Calculate Microbial Inactivation and Equivalent Dose

- **Perform particle tracking in UV radiation field to obtain particle dose distribution**

  Dose (J/m^2) = Incident radiation (W/m^2) x Exposure time (s)

- **Calculate microbial inactivation and equivalent dose (RED) using dose-response curve**



N_o = initial number of microbes
N = number of infectious microbes remaining after UV exposure

Detailed procedure outlined in Munoz et al. (2007)

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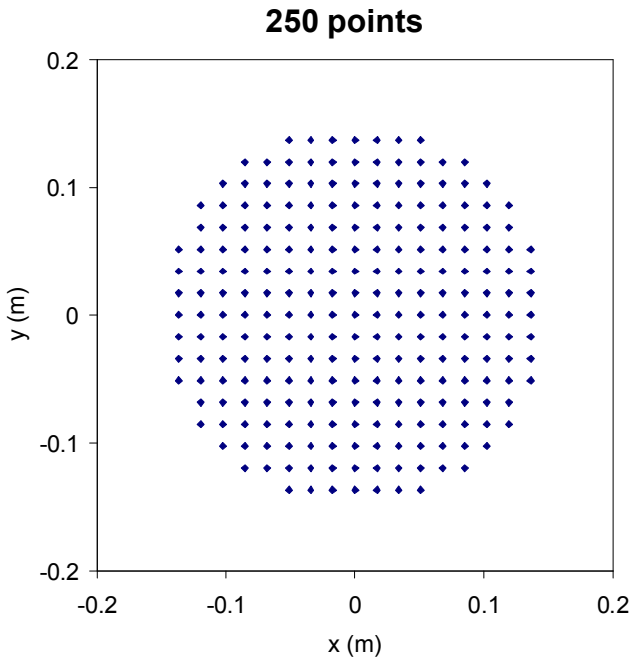
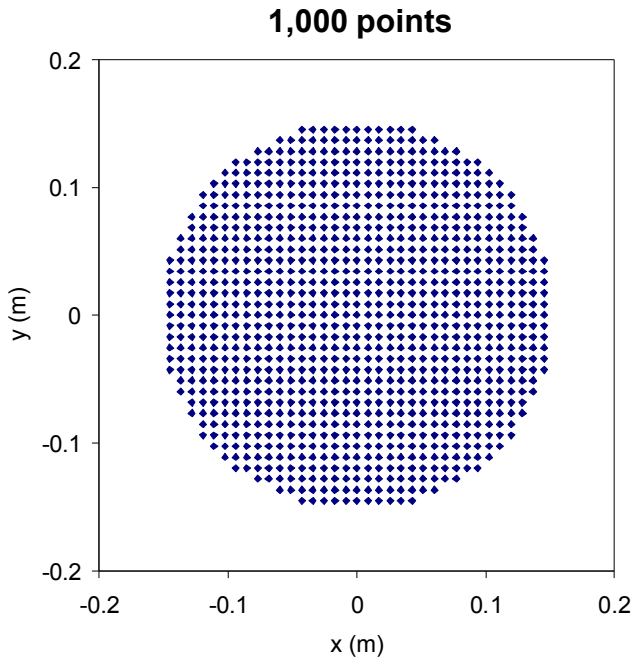
Sensitivity of Simulated RED to Particle Tracking Parameters

- Number of particles injected
- Discrete Random Walk vs. No Random Walk
- Dependence on Flow Rate

Particle Tracking Analysis

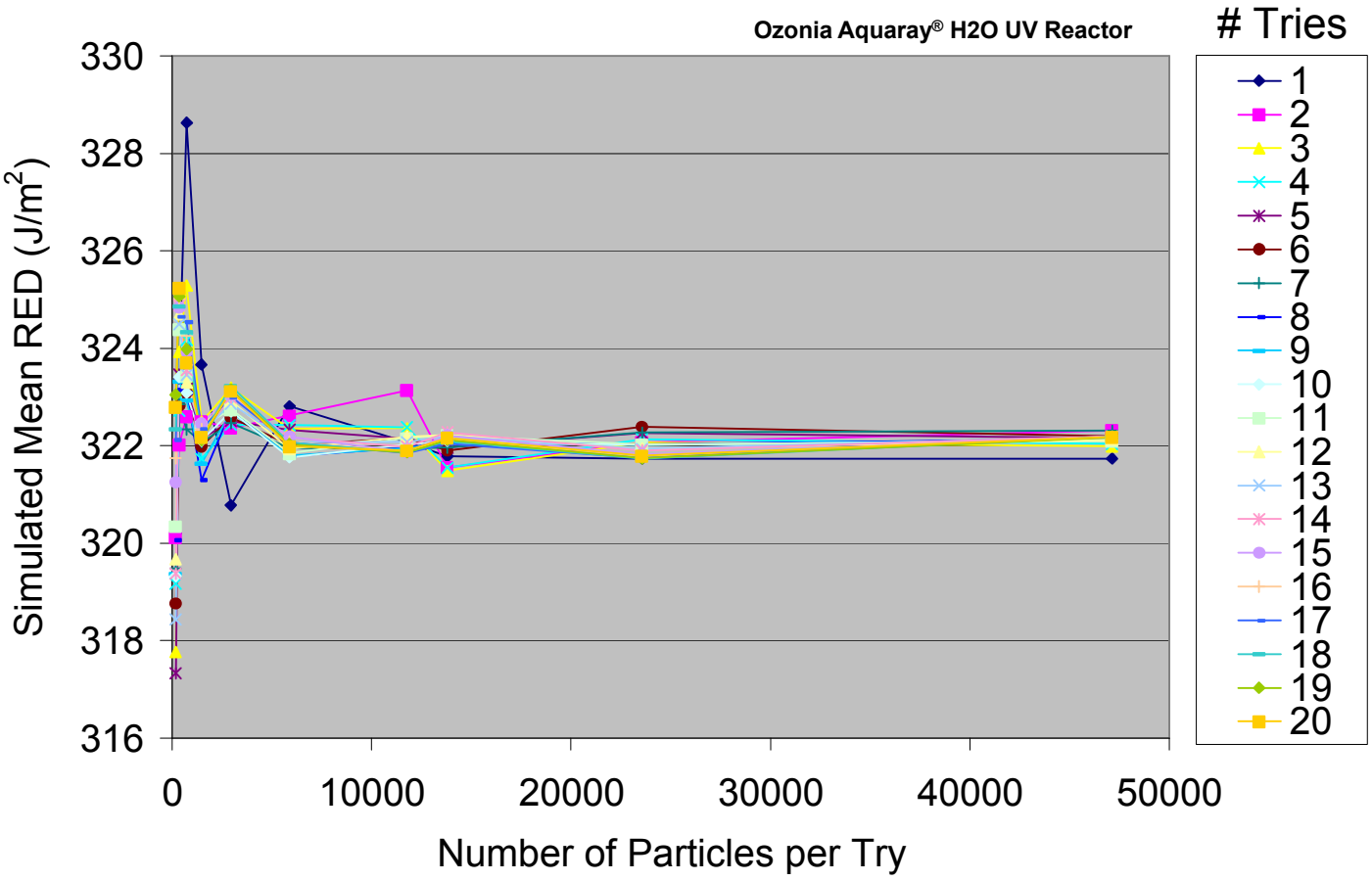
- **Ozonia Aquaray® H2O UV reactor**
- **Number of particles injected: 200 - 50,000**
  - **Number of tries using discrete random walk model: up to 20**





Simulated RED as a function of particles injected

- **Variability in simulated RED less than several percent with more than 5,000 – 10,000 particles for any number of tries**



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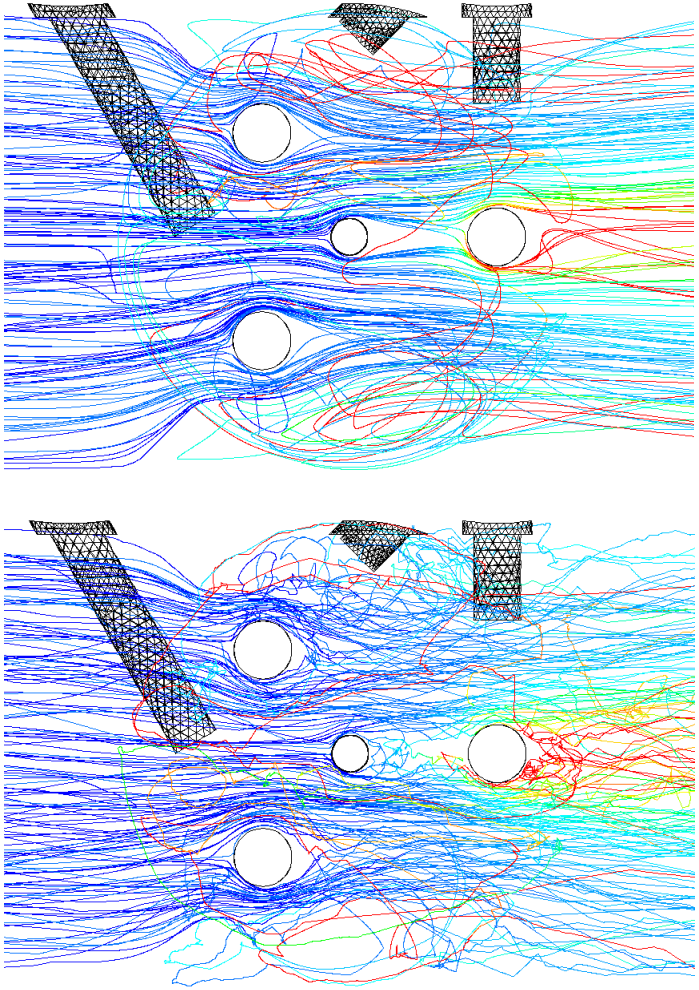
Impact of Discrete Random Walk

- **Without random walk, particle motion calculated using mean velocity at each time step**
- **Discrete random walk model**
  - **Includes fluctuating velocity component at each particle time step**
  - **Adds more noise to particle path**

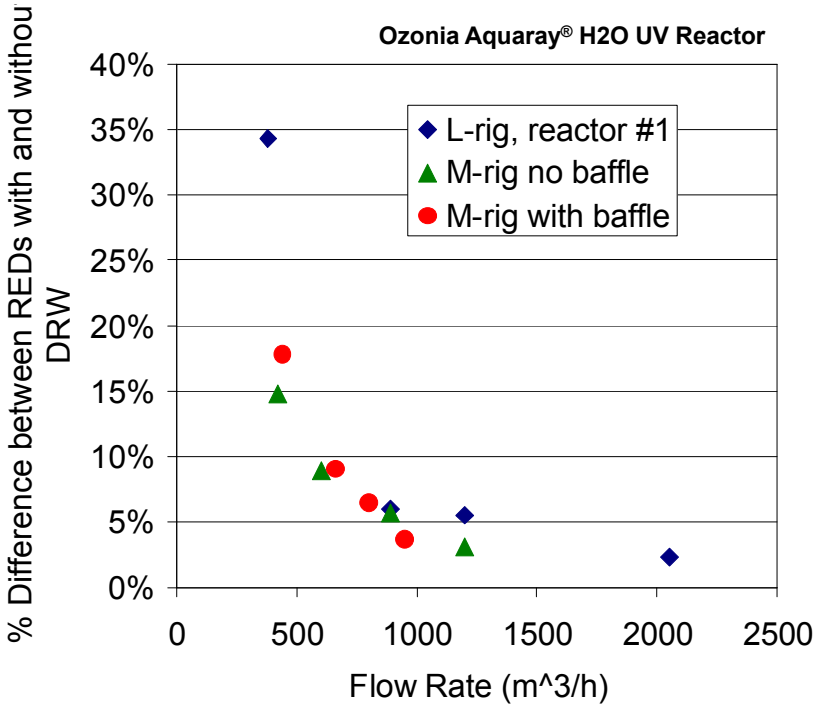


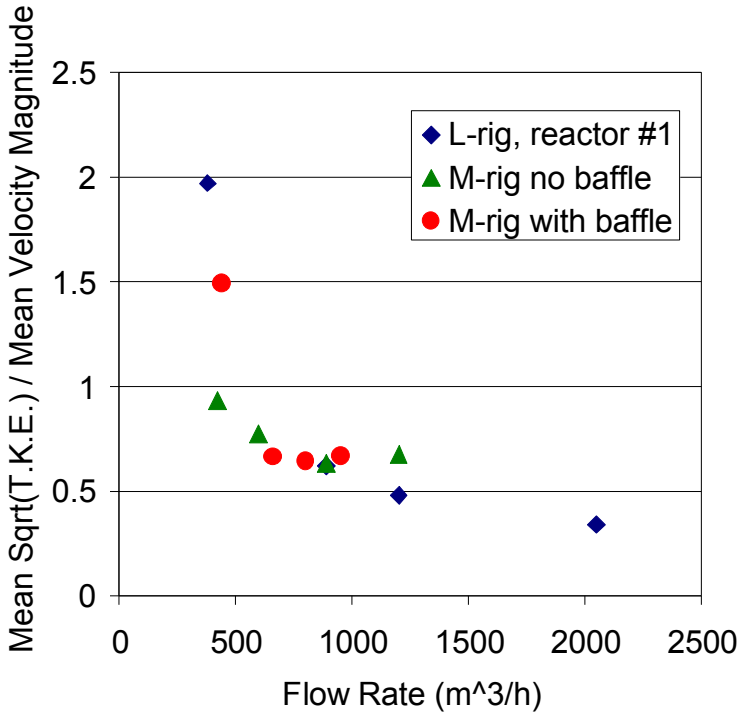
No-DRW

DRW

Calgon 12” Sentinel® UV Reactor

DRW vs. no-DRW Dependence on Flow Rate





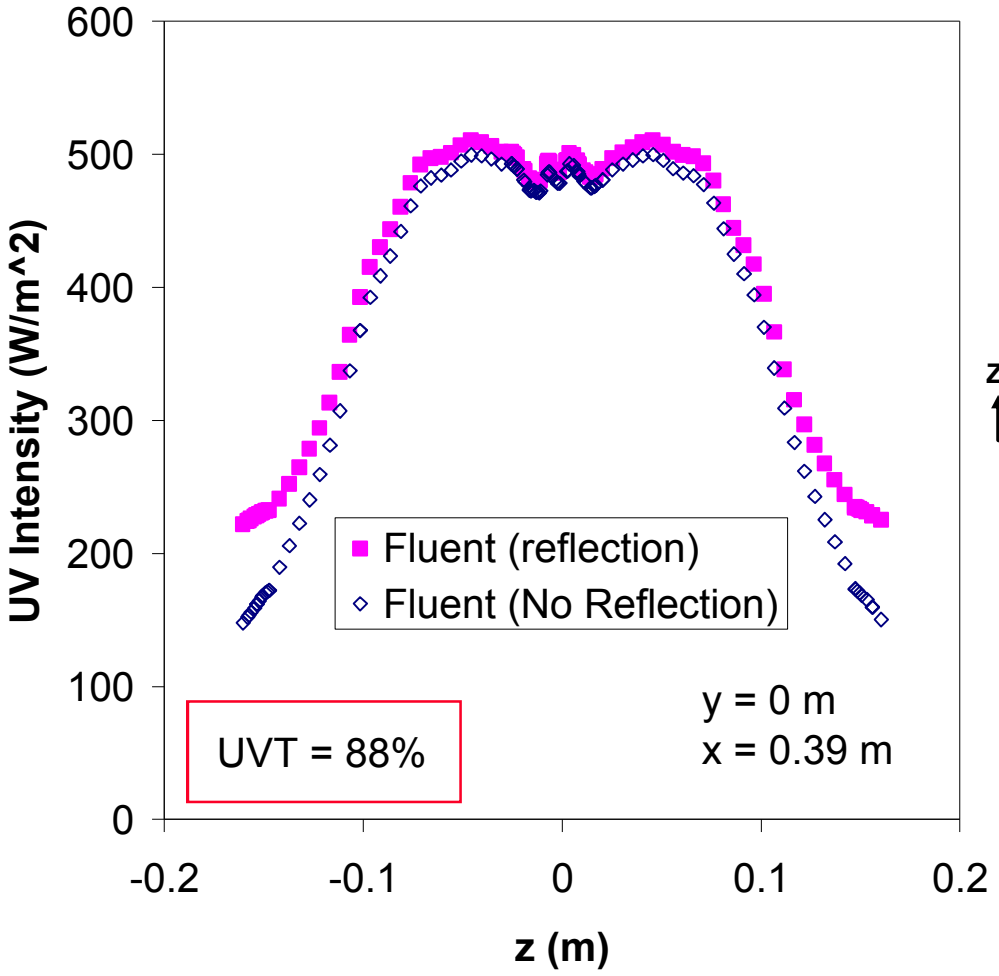
- **Although these runs converged with default criteria, additional iterations reduced the difference in simulated RED, even at low flow rates**
- **Proper initialization of kinetic energy (*k*) and turbulent energy dissipation (ε) parameters can allow improved convergence**

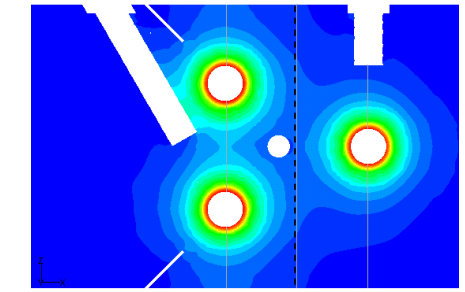
Sensitivity to Reflection

- **Wall reflection is often neglected in UV radiation models**
- **Perform simulations with and without wall reflection to determine impact**

UV Radiation Modeling

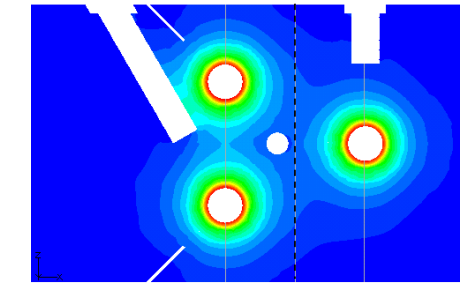
Simulated UV radiation field with and without wall reflection (Calgon 12" Sentinel® UV Reactor)





With Wall Reflection

z
x



No Wall Reflection

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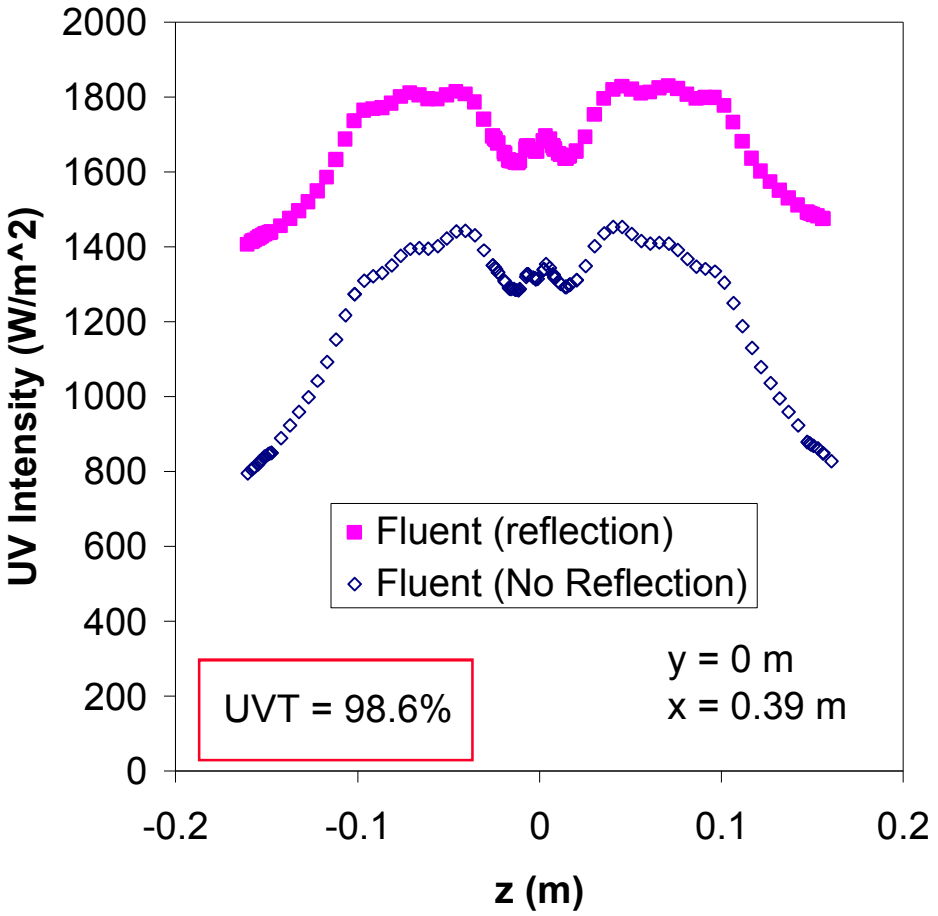
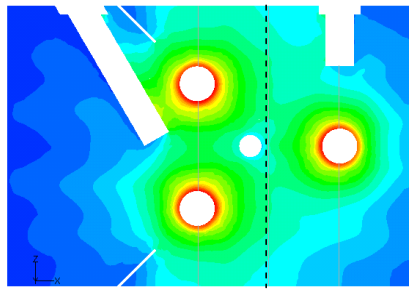
UV Radiation Modeling

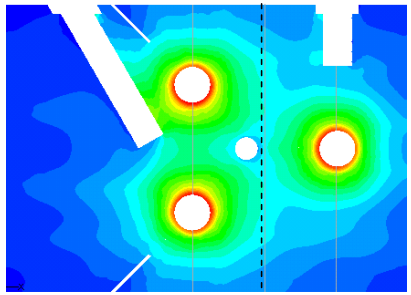
Simulated UV radiation field with and without wall reflection (Calgon 12" Sentinel® UV Reactor)





z With Wall Reflection

Y



No Wall Reflection

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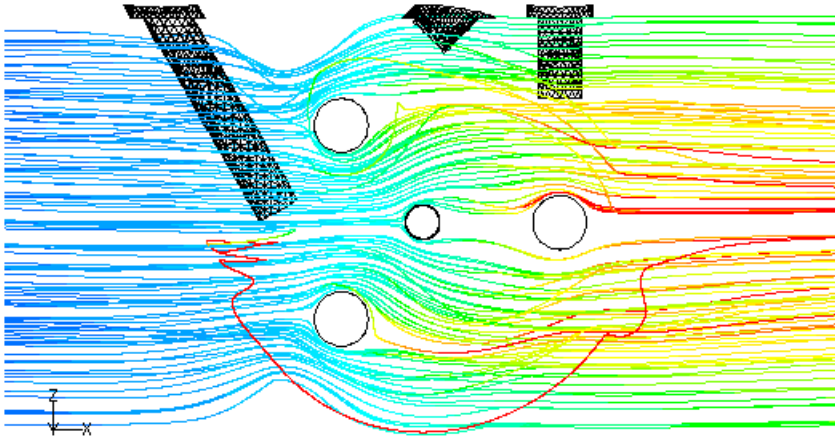
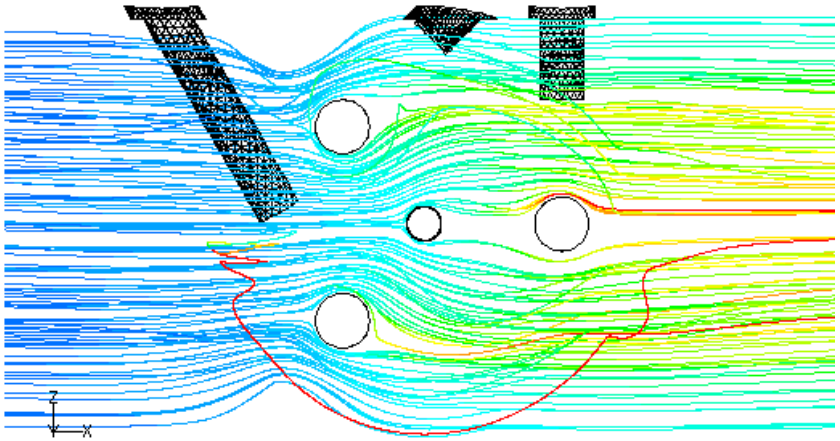
Particle Paths Colored by Cumulative Dose

Calgon 12" Sentinel® UV Reactor

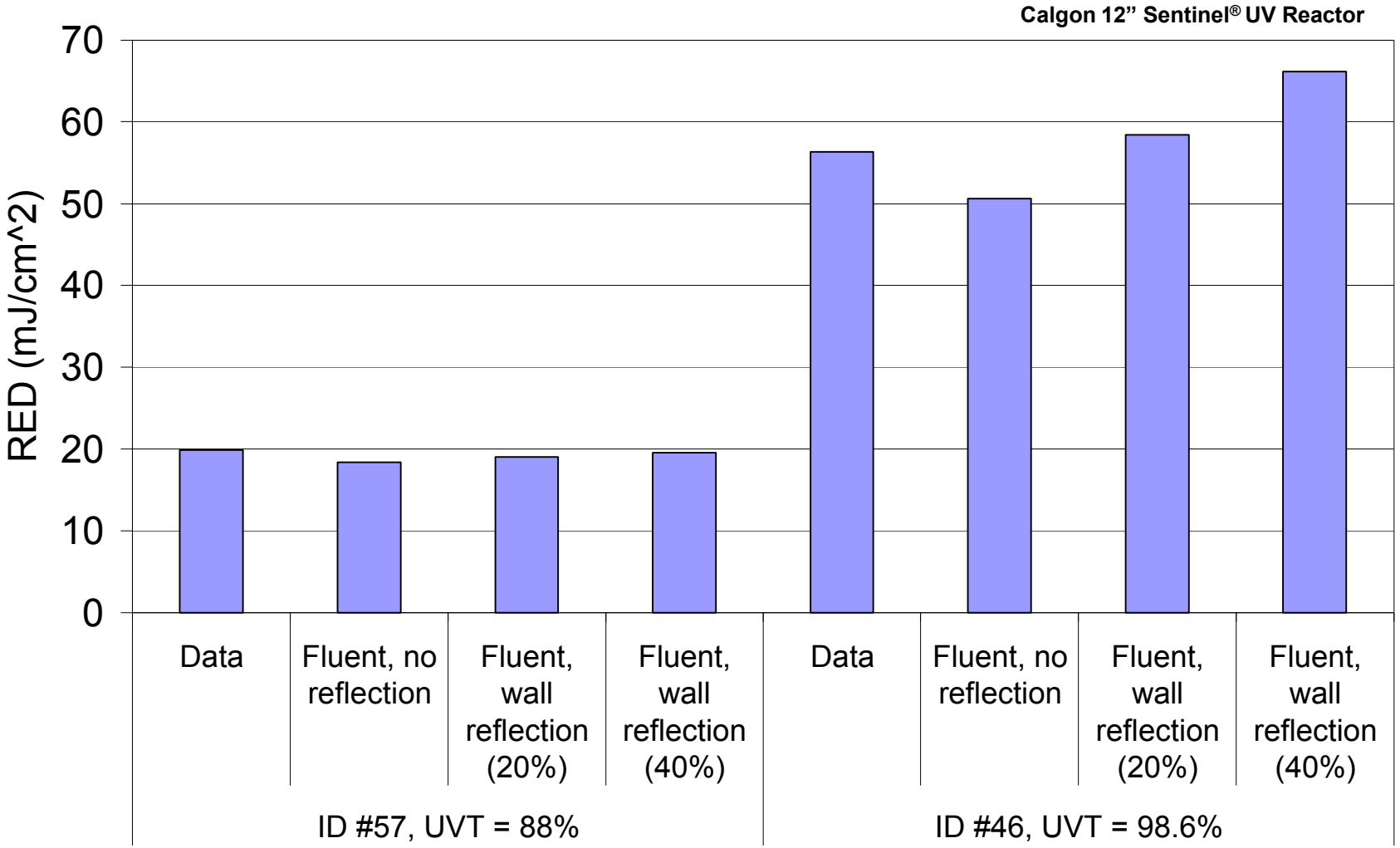


40% wall reflection



no wall reflection

Effect of Wall Reflection on Simulated RED



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Findings

- Particle Tracking Sensitivity
  - > 5,000 – 10,000 particles produced converged RED
  - DRW vs. no-DRW
    - Larger differences at lower flow rates
    - Turbulence intensity increases with lower flow rates
    - Need to ensure convergence; proper initialization of *k* and *e*
- Wall Reflection Sensitivity
  - Inclusion of wall reflection may be important at higher UVTs (>90%)
  - UV Intensity with wall reflection was more than 50% higher near wall than without
  - Simulated RED with wall reflection was ~15-30% higher than without wall reflection

Big Picture Benefits

- CFD-based simulations of UV disinfection can be used to accurately simulated RED
- Performance of installed systems with different piping configurations than the validated system can be assessed using CFD
- Features and designs can be assessed and improved through CFD-based models

Acknowledgments

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- Trojan Technologies Inc.
  - Ted Mao

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