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Computational Fluid Dynamics Modeling of UV Reactor Validation Tests

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Sandia National Laboratories

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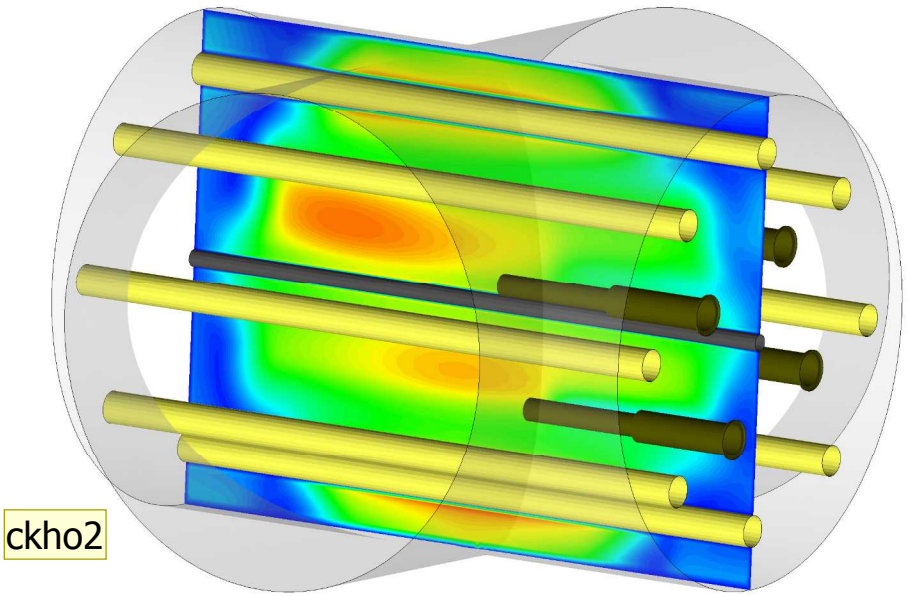
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

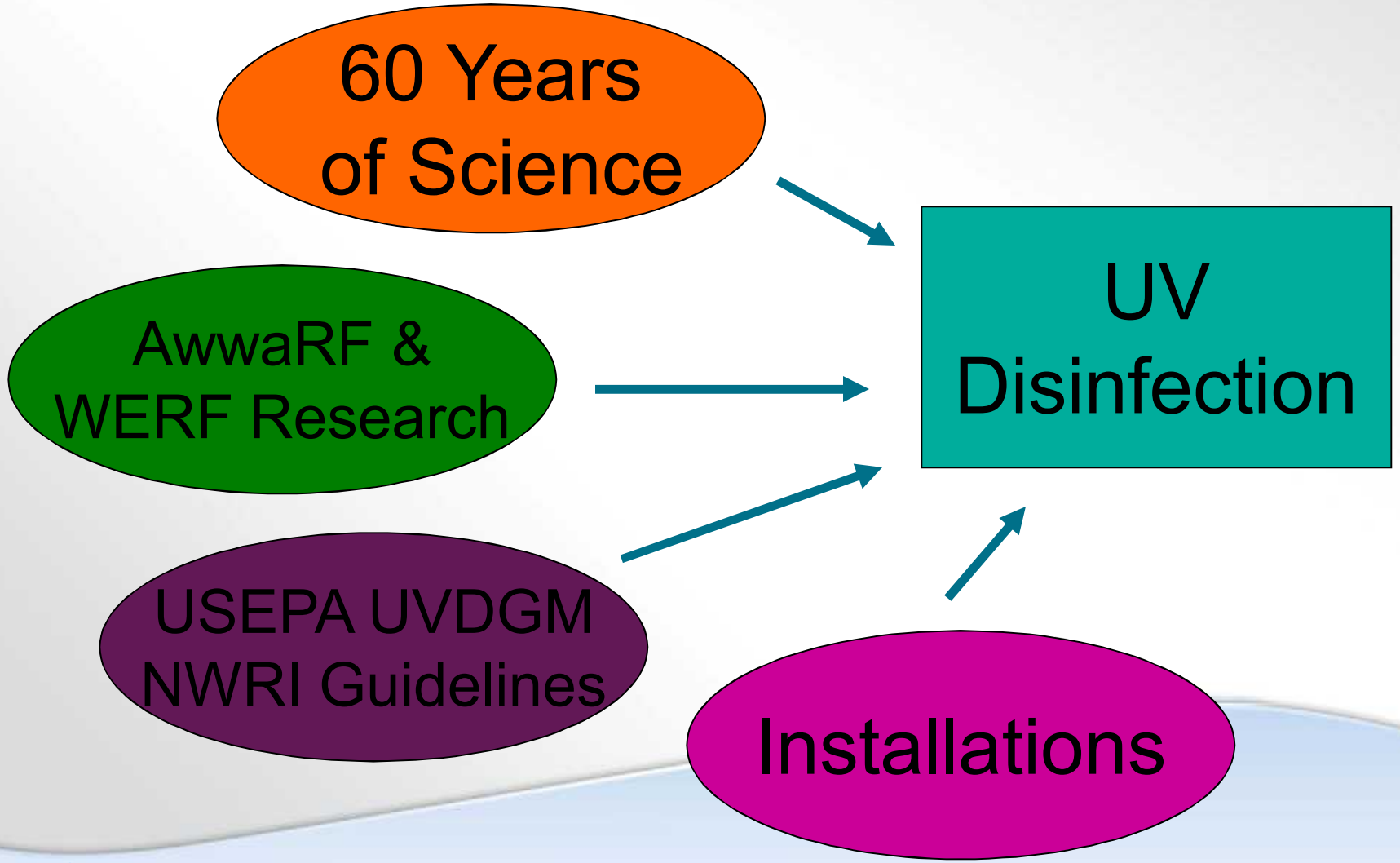
1. Project Motivation
2. First Reactor
   - Model Development and Model Results
3. Second Reactor
   - Model Development and Model Results
4. Conclusions



Slide 2

ckho2 I think this should not be highlighted here. The "Project Motivation" should be highlighted, right?
Clifford K. Ho, 11/11/2008

UV Disinfection is Well Established



UV Reactor Validation

Experimental testing to determine the operating conditions under which a UV reactor delivers the dose required for inactivation credit of *Cryptosporidium*, *Giardia lamblia*, and viruses.

ULTRAVIOLET DISINFECTION GUIDANCE MANUAL FOR THE FINAL LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE, 2006

UV Reactor Validation

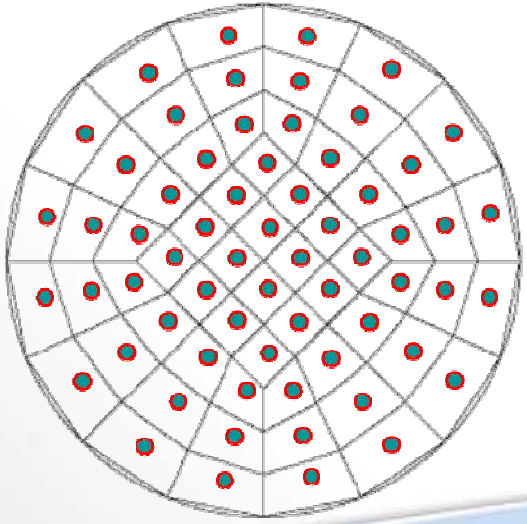
1. Rector installed at test facility and evaluated with challenge organisms
   a. Range of flows
   b. Range of UVT
   c. Combinations of lamps
   d. One or more hydraulic conditions
      - Baffles
      - Pipe bends
2. Results used to develop a dose monitoring equation

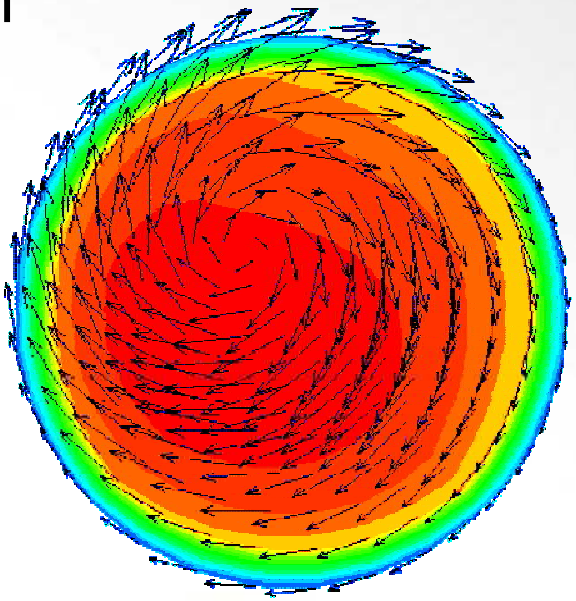
Validation Test Limitations

1. Validation testing is expensive
2. Test configurations can be limited
   a. Approach hydraulics are important
   b. Flow is turbulent
3. Installation site may be constrained

CFD Modeling

1. Computational Fluid Dynamics (CFD) is:
   a. Turbulent fluid motion, energy, reactions, etc
   b. Graphics solution visualization





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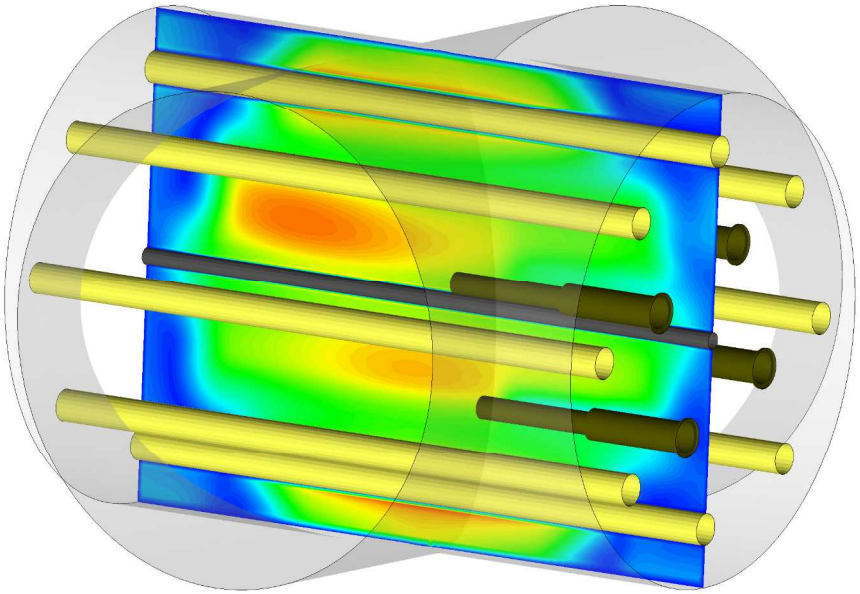
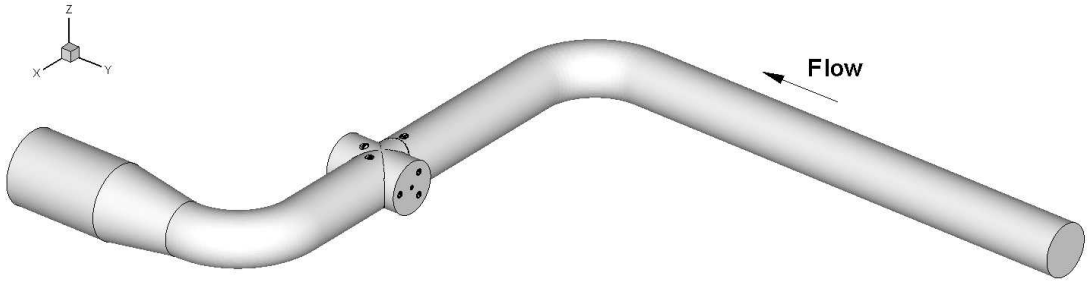
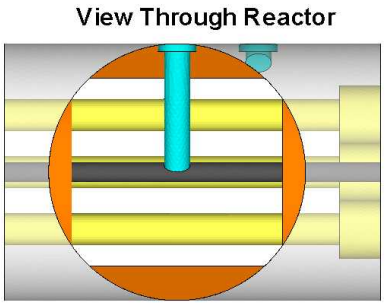
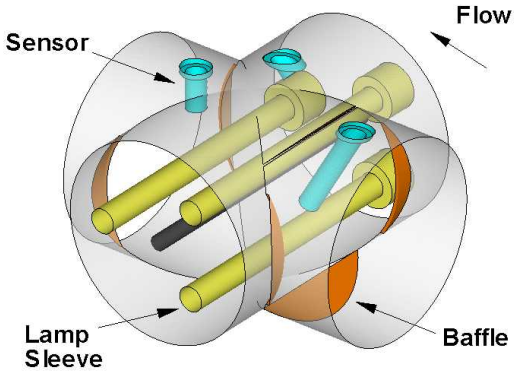


Calgon 12” Sentinel® Reactor Model

1. Three lamps and sensors
2. Internal baffles
3. Validated with 90 degree bend

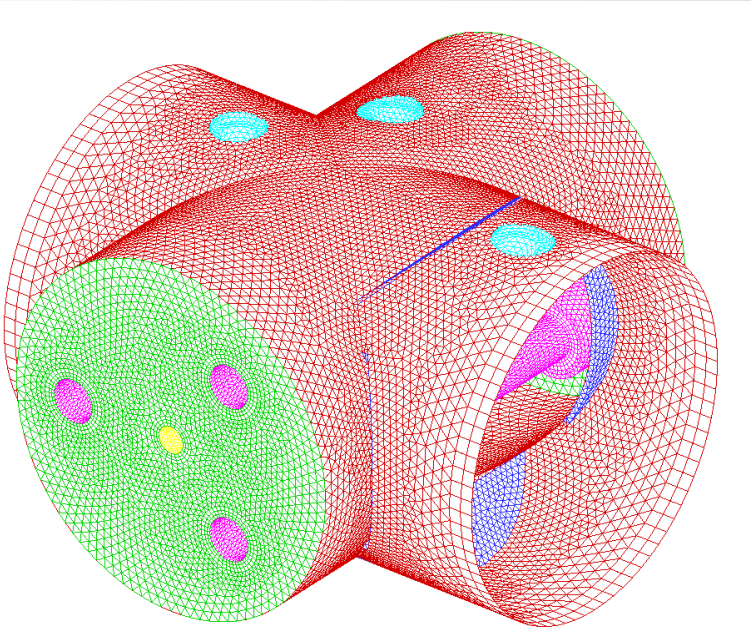




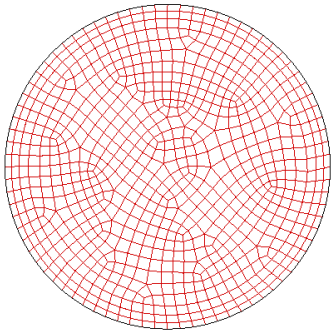


Model Grid

1. Hybrid Grid
2. Grid Sensitivity Evaluated
3. Cells from 0.12-inches to 2-inches



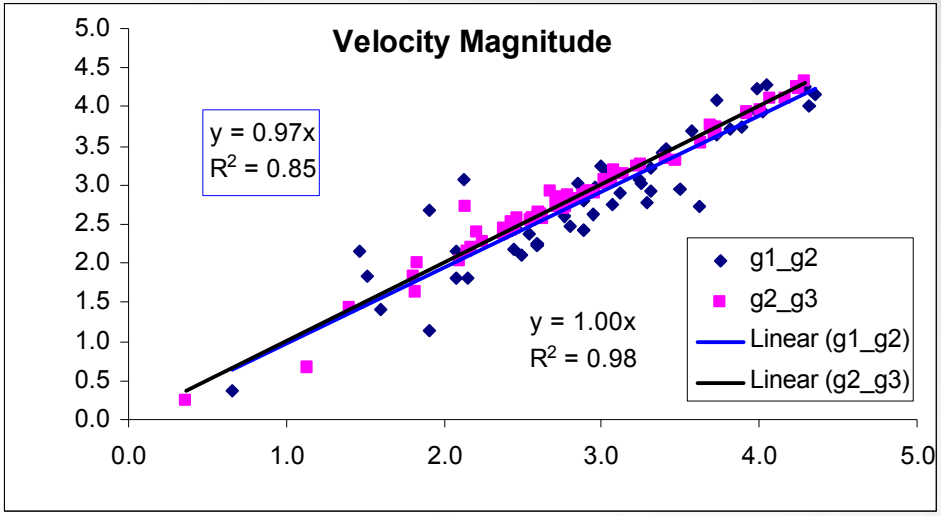
Outside Surface of the Reactor Grid



Piping Grid

Grid Sensitivity Results

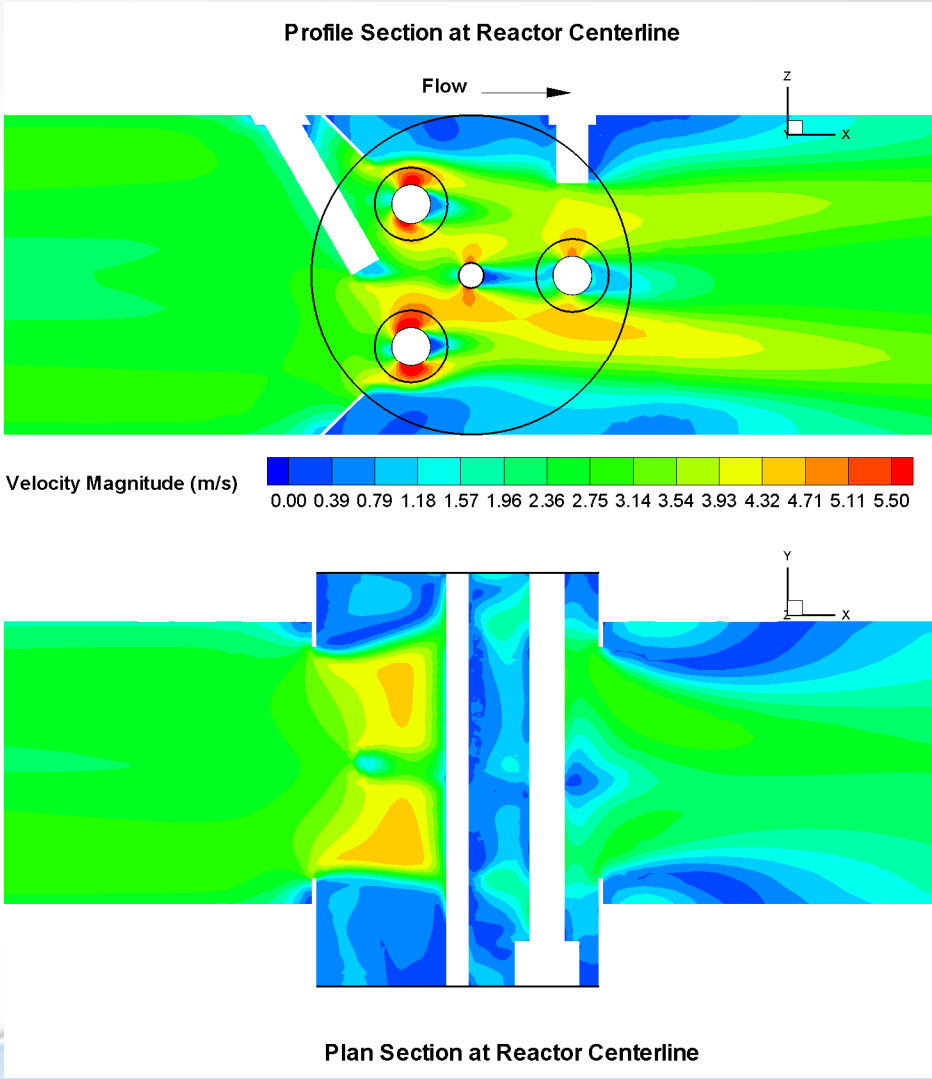
1. 4.9 mgd flow
2. Piping grid constant
3. Little change from medium to fine



Grid	No. of Cells in Reactor	Percent Increase in Number of Cells	Total Cells	Velocity Magnitude Correlation R^2
Initial	465,652	---	715,152	---
Medium	610,716	31	860,216	0.85
Fine	753,564	23	1,003,064	0.98

Hydraulic Results

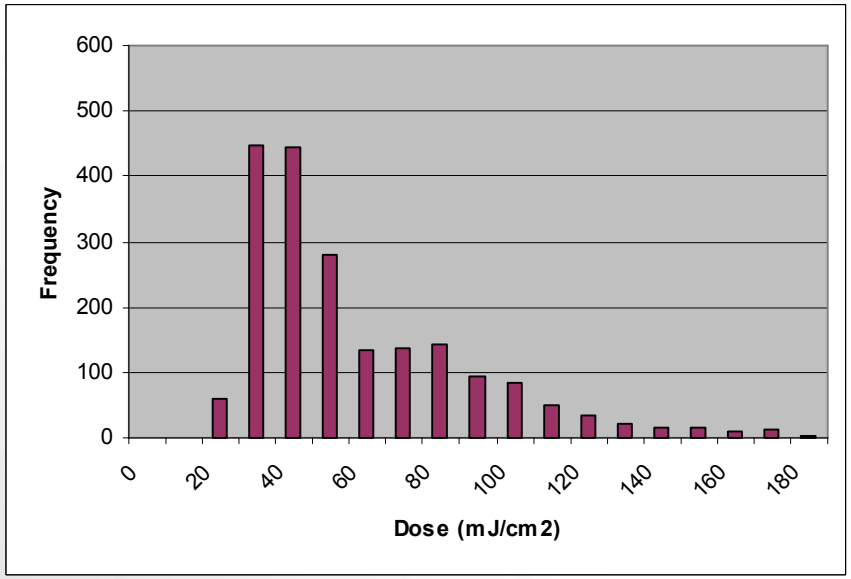
1. Flow directed toward lamp center by baffles
2. High velocity around lamp, wake behind lamps and baffles
3. Limited impact from 90-degree bend

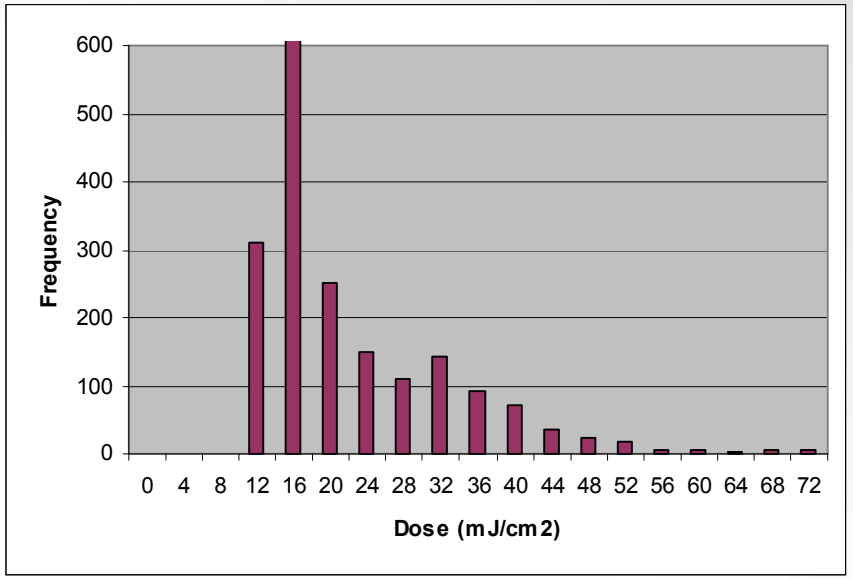


UV Dose Modeled

1. UVXPT – MSSS type Lagrangian model
2. Model incorporates:
   a. Turbulence with RWM
   b. UVT
   c. Operation lamps
   d. Lamp output
   e. Different organisms response

UV Dose Examples Modeled



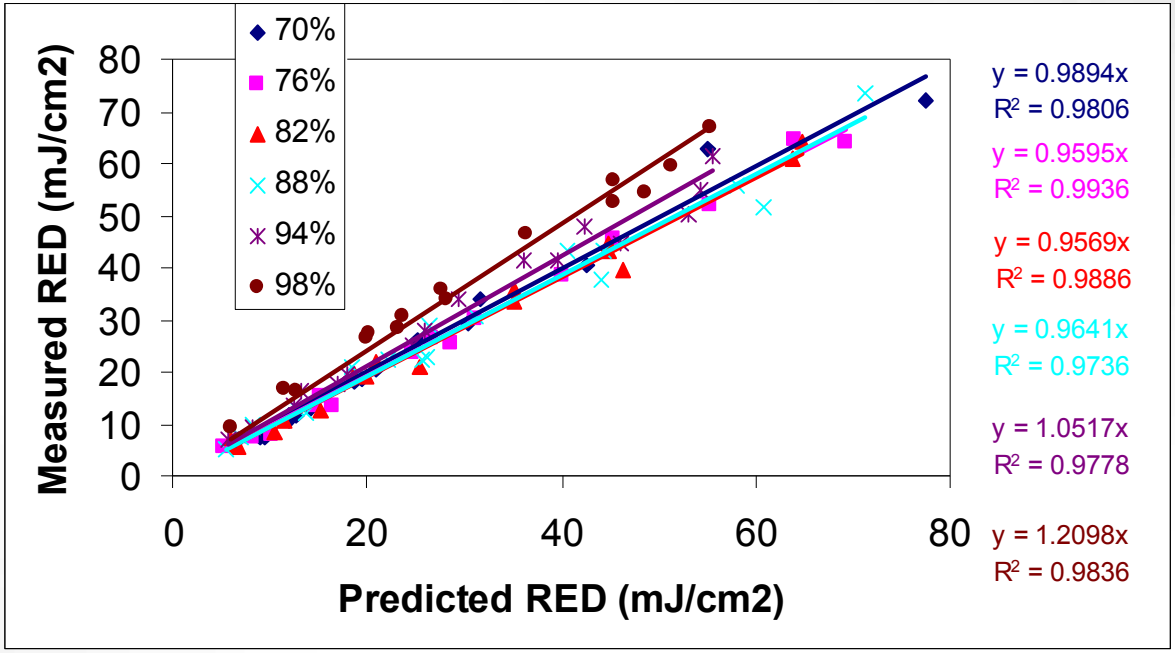


UVT = 69.6%
Flow = 0.3 mgd
Lamp Output = 26%

UVT = 98.3%
Flow = 4.81 mgd
Lamp Output = 84.4%

MS2 Dose Comparison

1. No calibration factors incorporated



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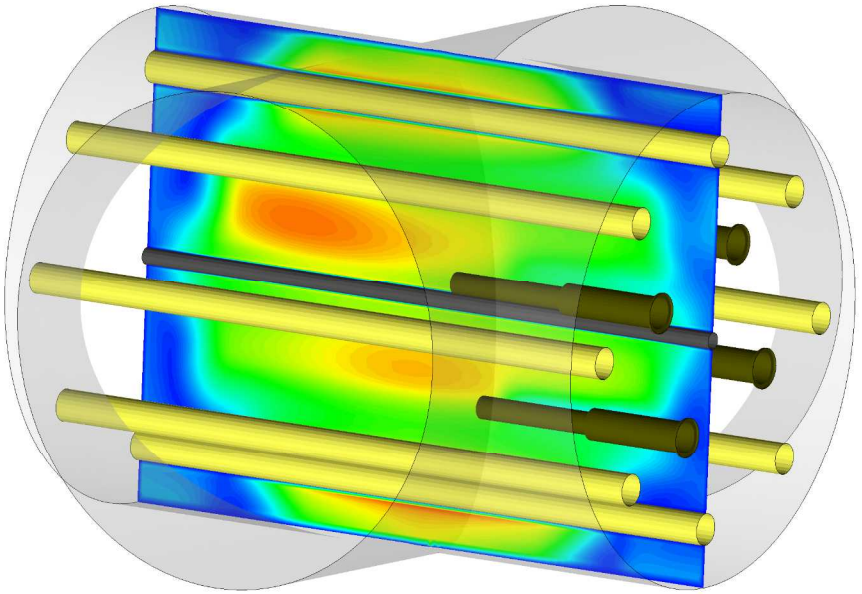
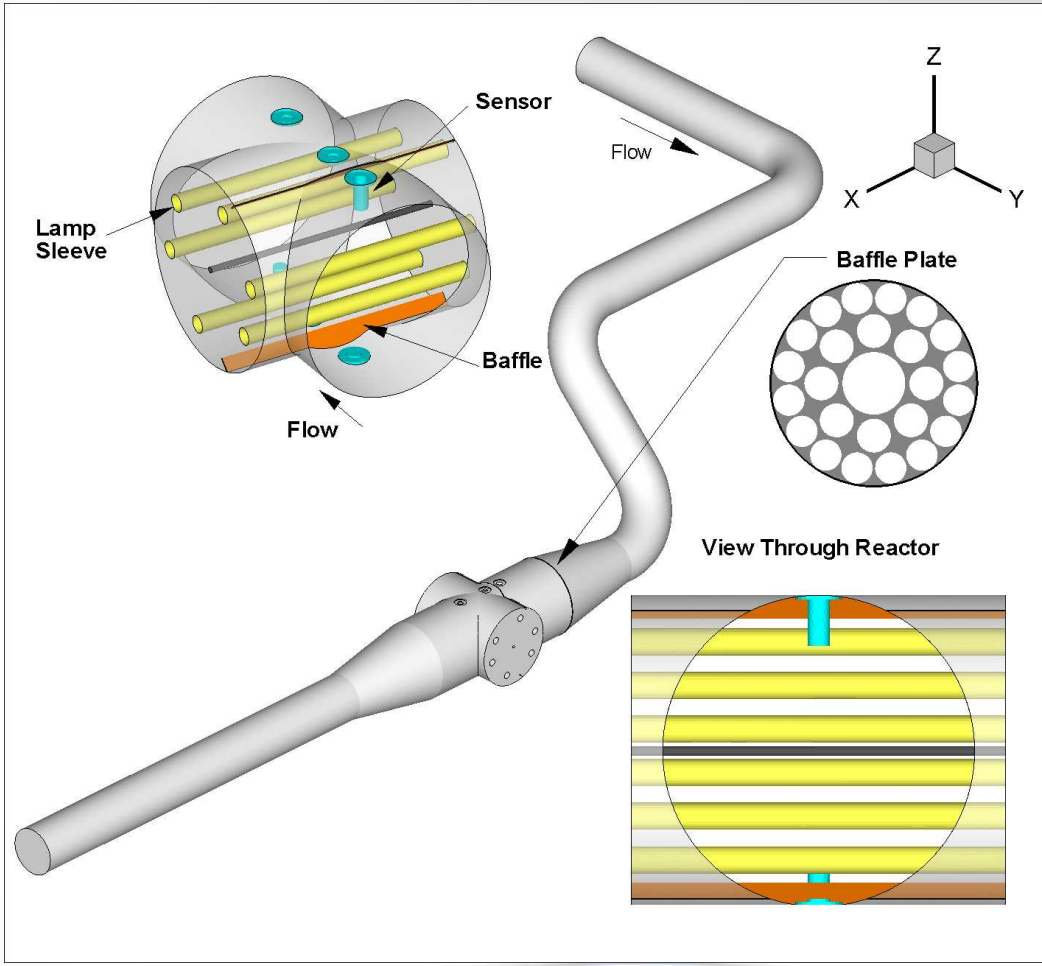


Degremont Technologies Ozonia Aquaray® H_20 20” Reactor Models

1. Three configurations modeled
   a. M-rig: reactor in 12” piping, no baffle
   b. M-rig: reactor in 12” piping, with a baffle
   c. L-rig: 2 reactors in series in 24” piping

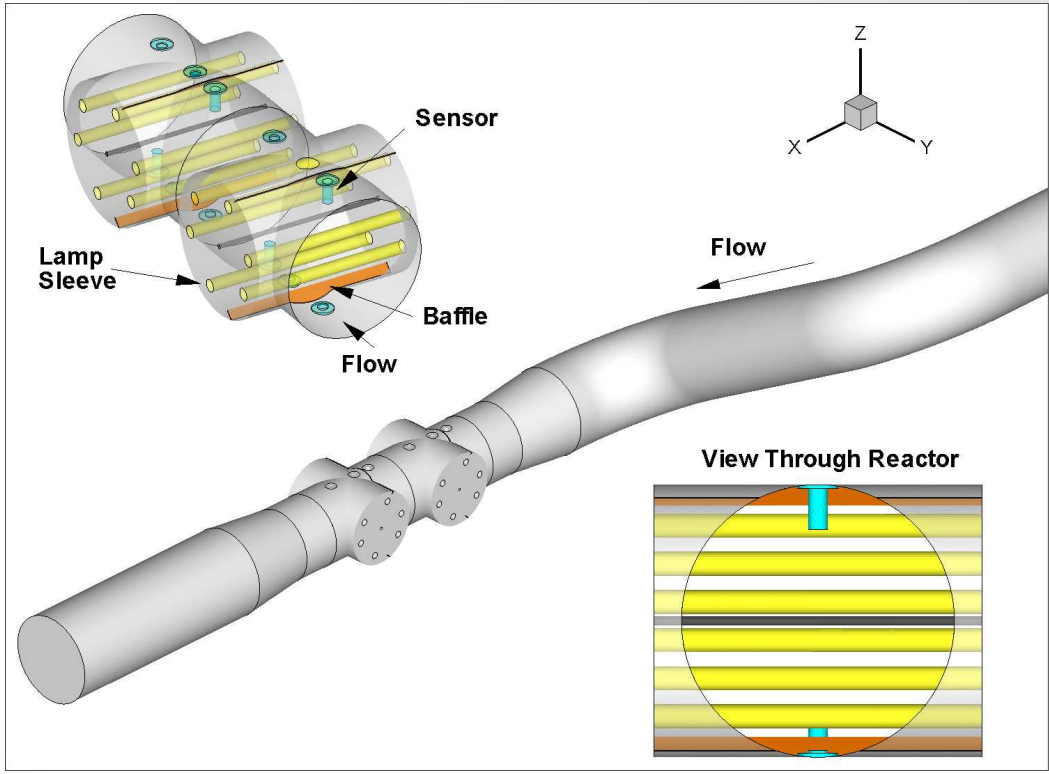
M-Rig model

1. Six lamps and sensors
2. Internal baffles
3. S-bend followed with piping expansion
4. With and without upstream porous baffle plate



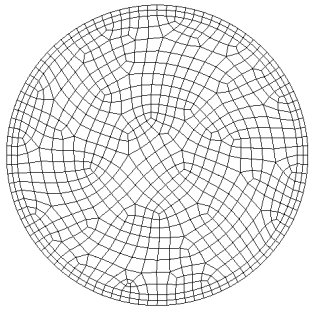
L-Rig Model

1. Same reactor as m-rig, two in series
2. S-bend followed by piping contraction

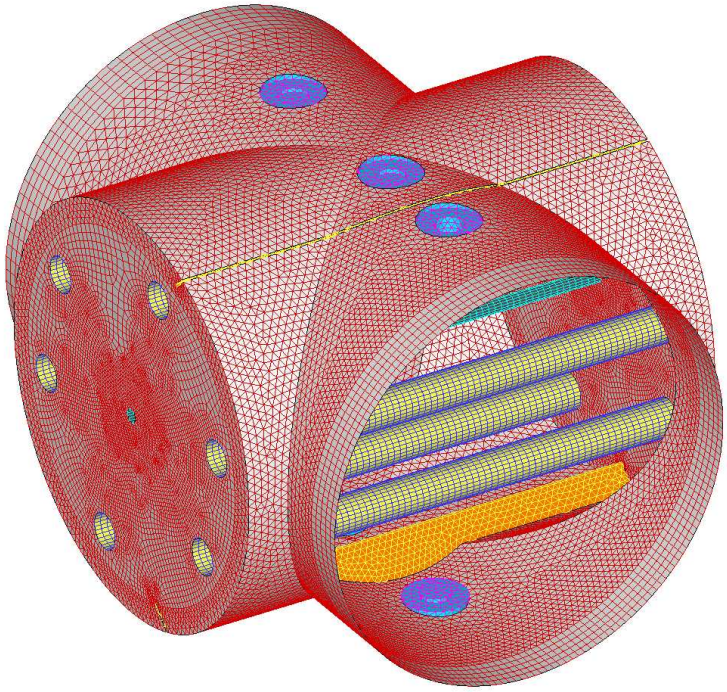


Rector Grid

1. Same grid used for M- and L-rigs
2. Hybrid Grid
3. Grid Sensitivity Evaluated
4. Cells from 0.12-inches to 2-inches



Piping Grid



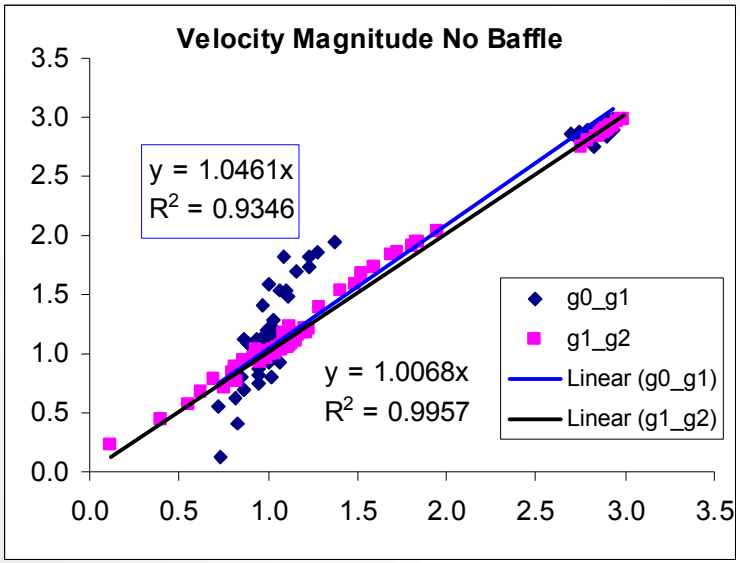
Outer Surface of Reactor Grid

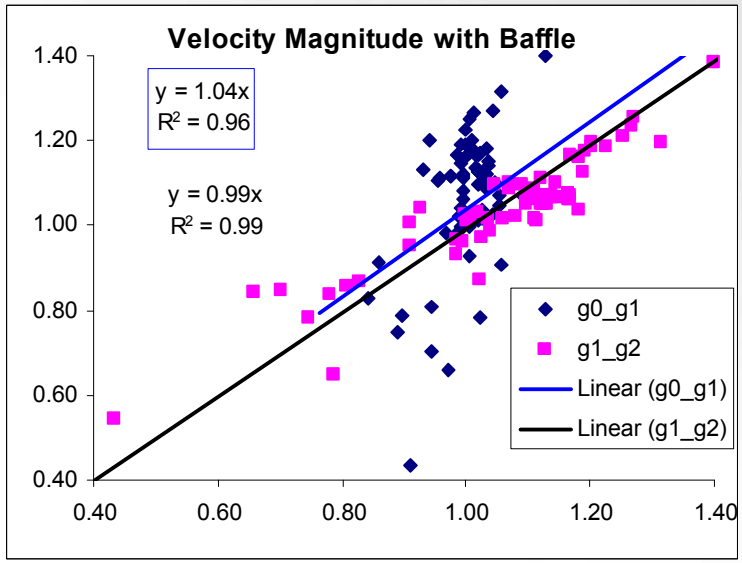
Grid Sensitivity Results

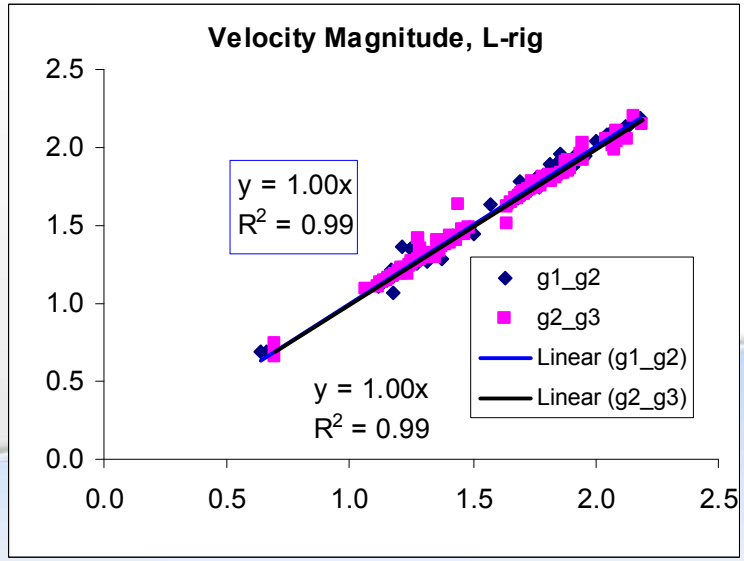
1. M-rig tested at 4.44 mgd
2. L-rig tested at 7.61 mgd

Configuration	Grid	No. of Cells in Reactor	Percent Increase in Number of Cells	No. of Cells in Piping	Total Cells	Velocity Magnitude Correlation R^2
M-rig no baffle	Initial (G0)	494,989	---	669,706	1,164,695	---
	Medium (G1)	681,734	38	682,306	1,364,040	0.93
	Fine (G2)	898,296	32	672,706	1,571,002	0.99
M-rig with baffle	Initial (G0)	494,989	---	668,959	1,163,948	---
	Medium (G1)	681,734	38	681,559	1,363,293	0.96
	Fine (G2)	898,296	32	671,959	1,570,255	0.99
L-rig	Initial (G0)	971,546	---	555,828	1,527,374	---
	Medium (G1)	1,351,067	39	555,828	1,906,895	0.99
	Fine (G2)	1,785,296	32	555,828	2,341,124	0.99

Grid Sensitivity Plots

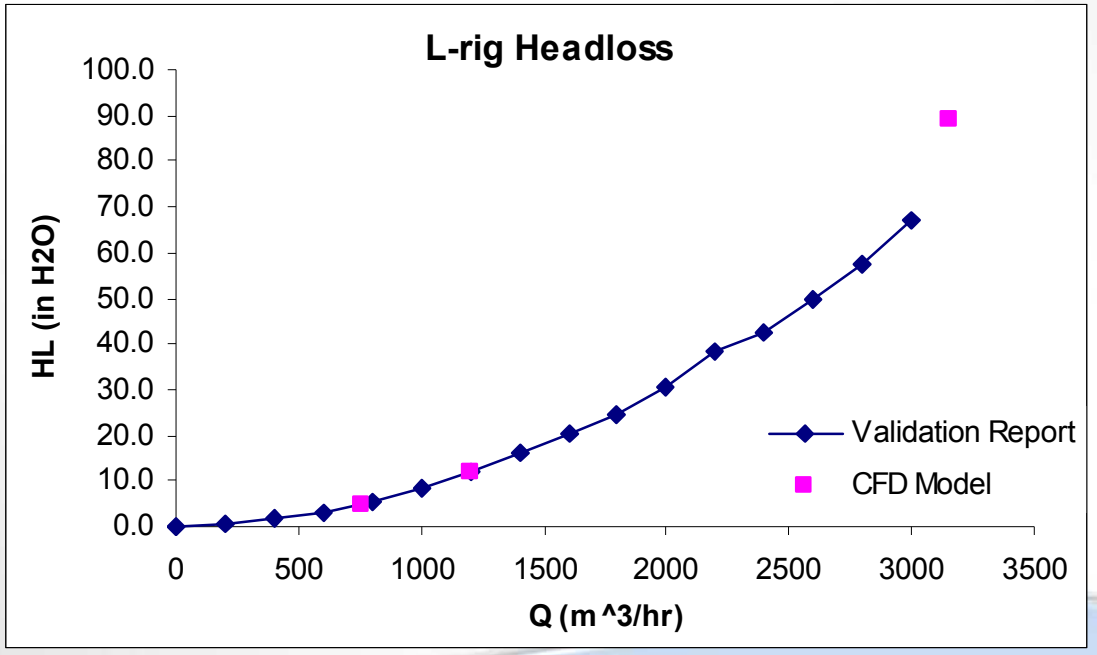






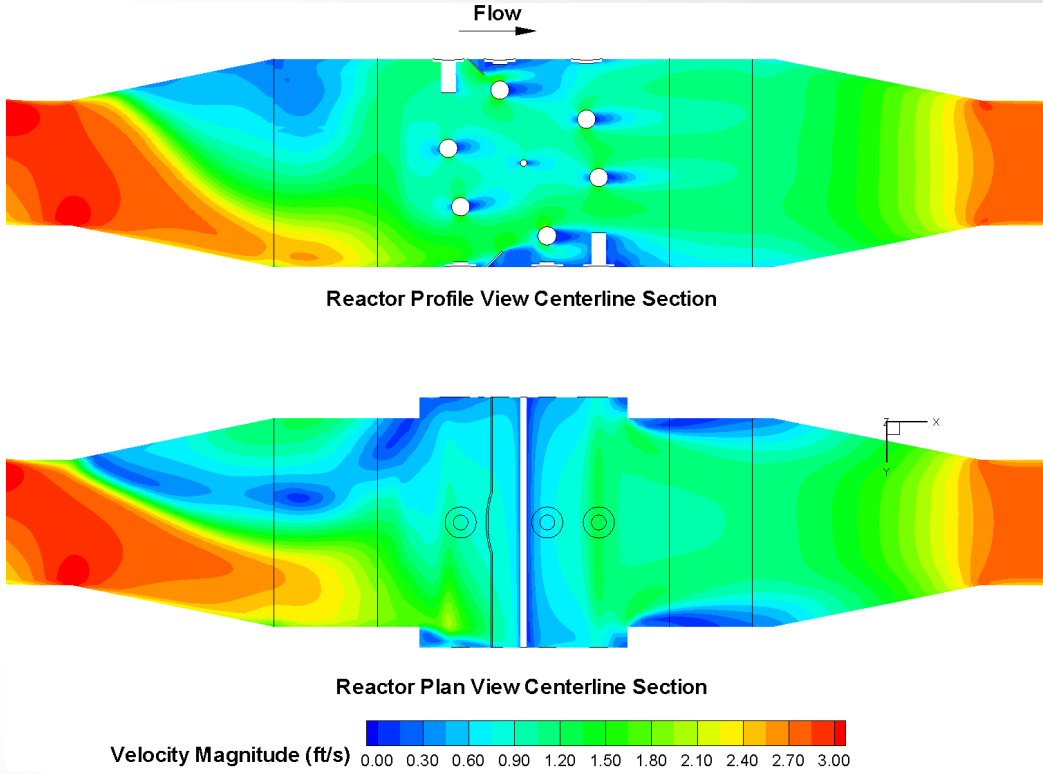
Reactor Headloss

1. Headloss measured in L-rig
2. Model headloss compares well



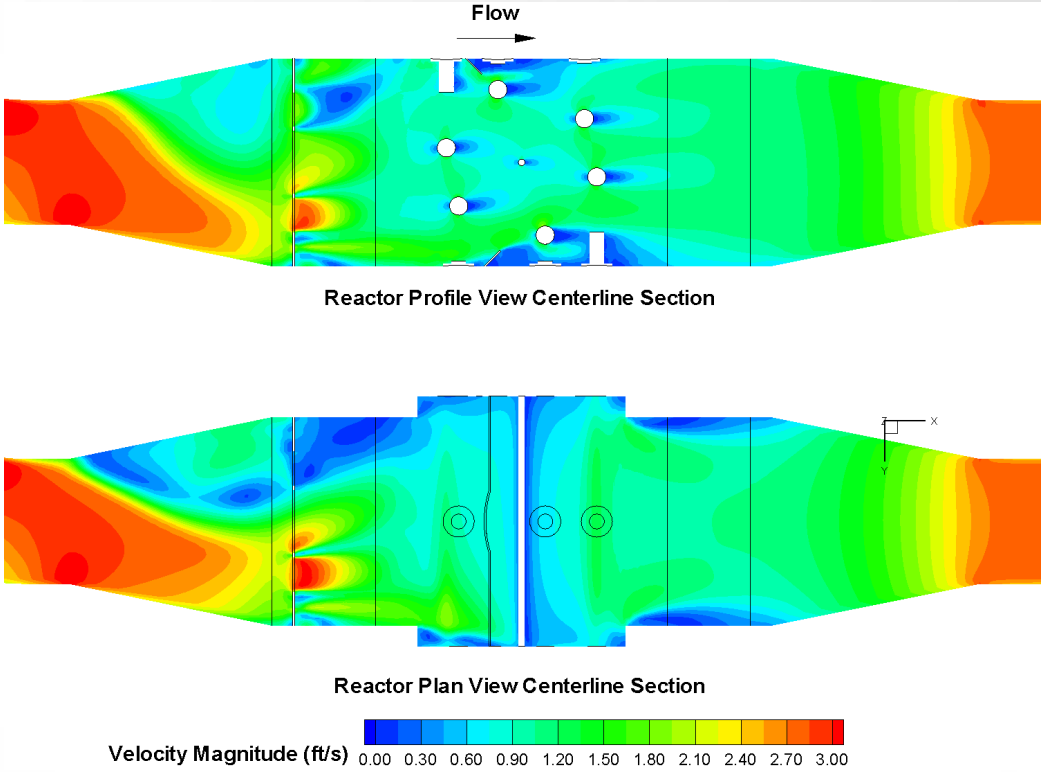
M-rig Without Baffle

1. "Swirling" velocity distribution approaching reactor
2. Low velocity on left side
3. Wake behind lamps



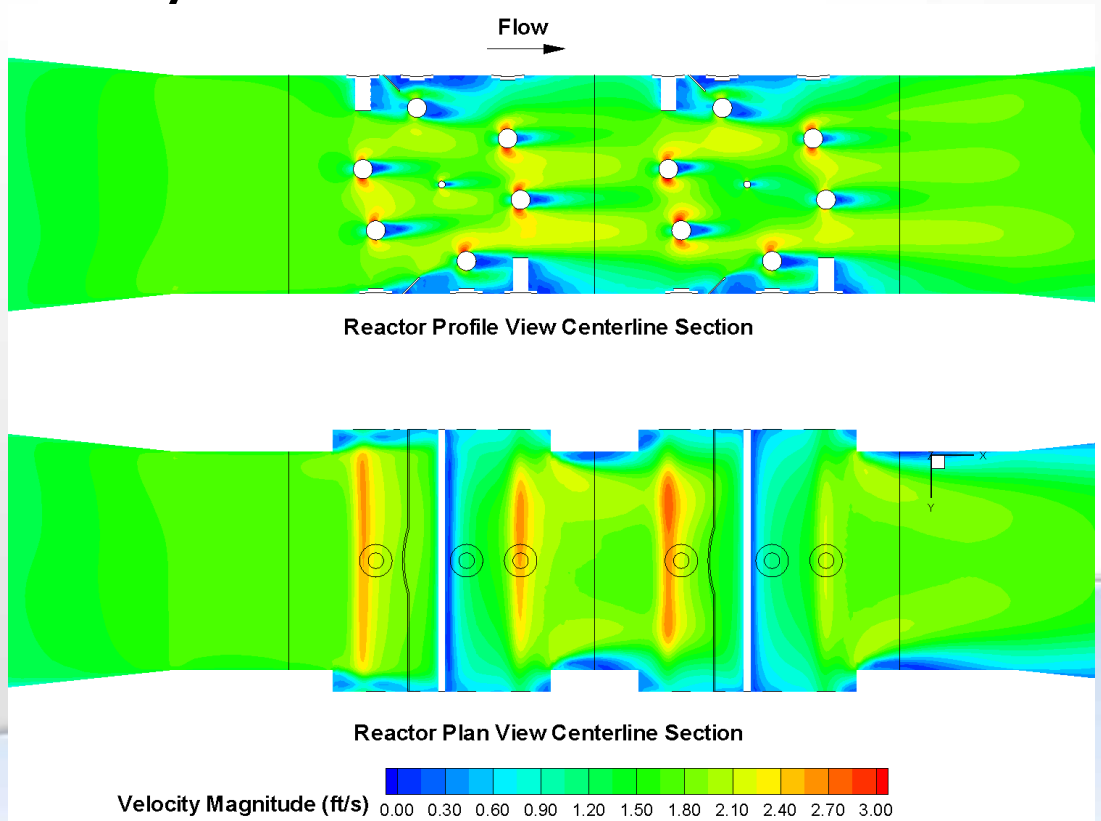
M-Rig with Baffle

1. Baffle improves flow distribution, though still slight imbalanced approaching reactor
2. Velocity higher on left side



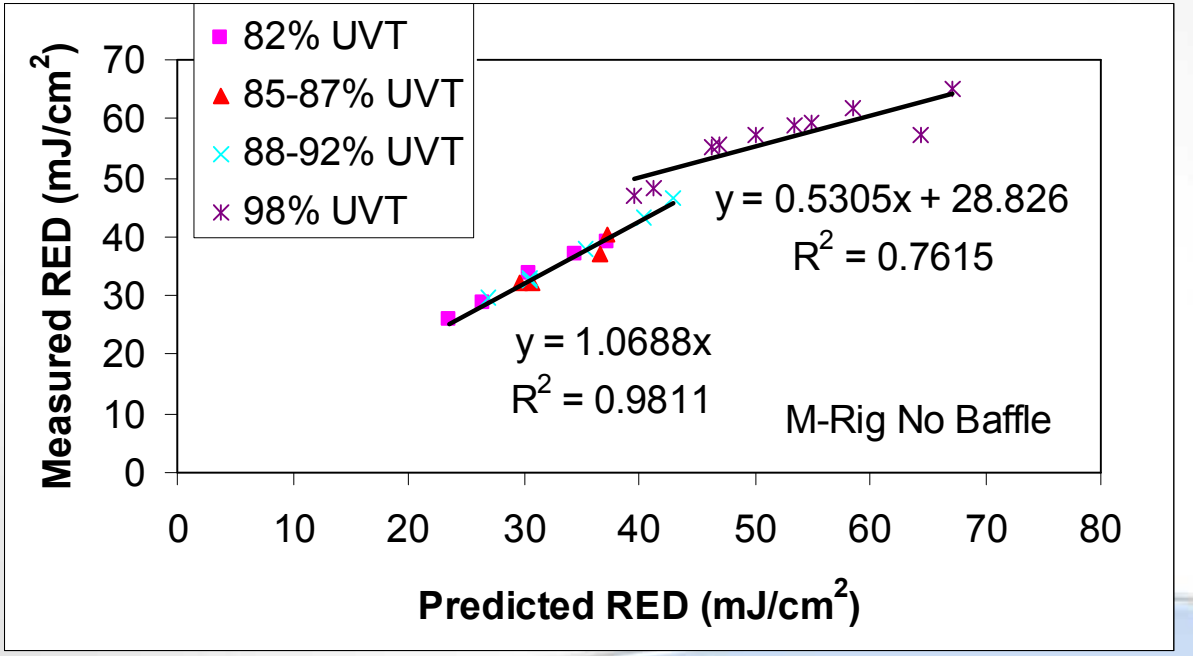
L-rig

1. Pipe contraction improves approach velocity
2. Similar hydraulics in each reactor



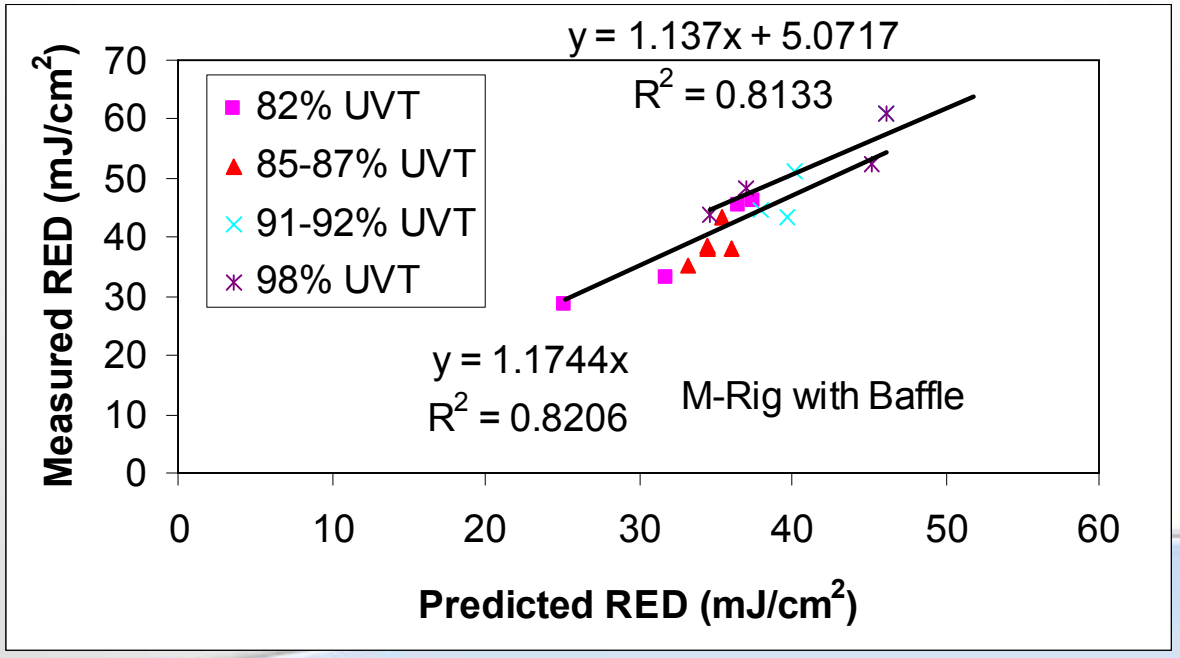
M-rig without Baffle RED Comparison

1. B. subtilis RED
2. Excellent Comparison at lower UVT



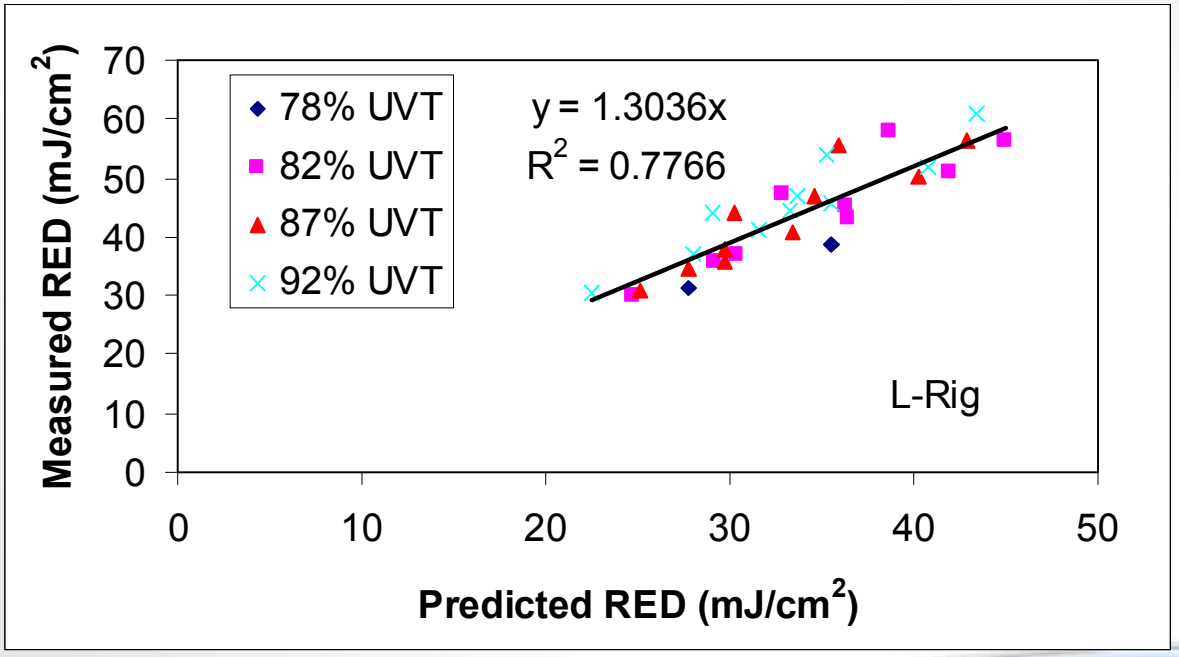
M-rig With Baffle RED Comparison

1. B. subtilis RED
2. Less favorable comparison compared with no baffle model



L-rig RED Comparison

1. Model is under predicting RED
   a. Wall reflection neglected



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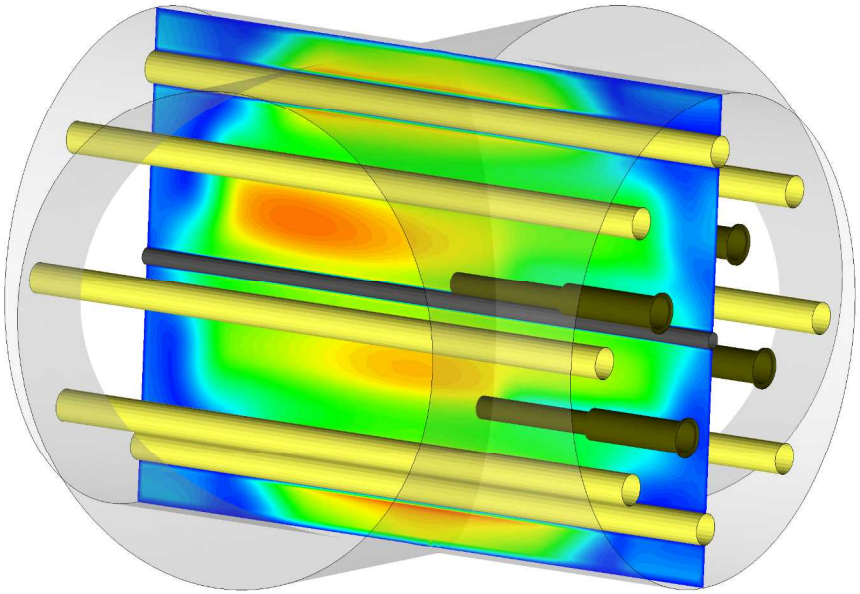

Summary

1. Two reactor were modeled
   a. First modeled in one configuration
   b. Second modeled in three configurations
2. Grid independent solution of complex geometry at reasonable size mesh
3. UV dose simulated

Conclusions

1. The modeling approach generally reproduces results of validations
2. Model accurately calculates headloss
3. Model calculates dose reasonably well
4. Wall reflection may be important at higher UVT
   - explored in a paper By Ho, Khalsa, Wicklein, and Wright, these proceedings

Acknowledgments

1. AwwaRF (Project #4107)
    a. Alice Fulmer, Project Manager
2. Calgon Carbon Corporation
    a. Keith Bircher
3. Infilco Degremont, Inc. (DENARD)
    a. Robert Kelly and Bruno Ferran
4. Trojan Technologies Inc.
    a. Ted Mao

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