UNC CHARLOTTE

Surface Aeration System Modeling Using COMSOL

George Selembo, PhD, PE

Priscilla Selembo, PhD

James Stanton

Gregory Paulsen, PE

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Presentation Outline

- Motivation for Research
- Background
- Experimental Data
- New COMSOL Surface Aerator Mathematical Model
- Simulation Results and Analysis
- Conclusions

Motivation for Research

- It has been found that tank geometry and baffle configuration have a significant impact on surface aerator performance
- Full-scale experimentation is costly (when it can be done at all)
- Tank geometry cannot easily be altered once a tank is built
- No reliable methods exist for converting results from one tank size to another

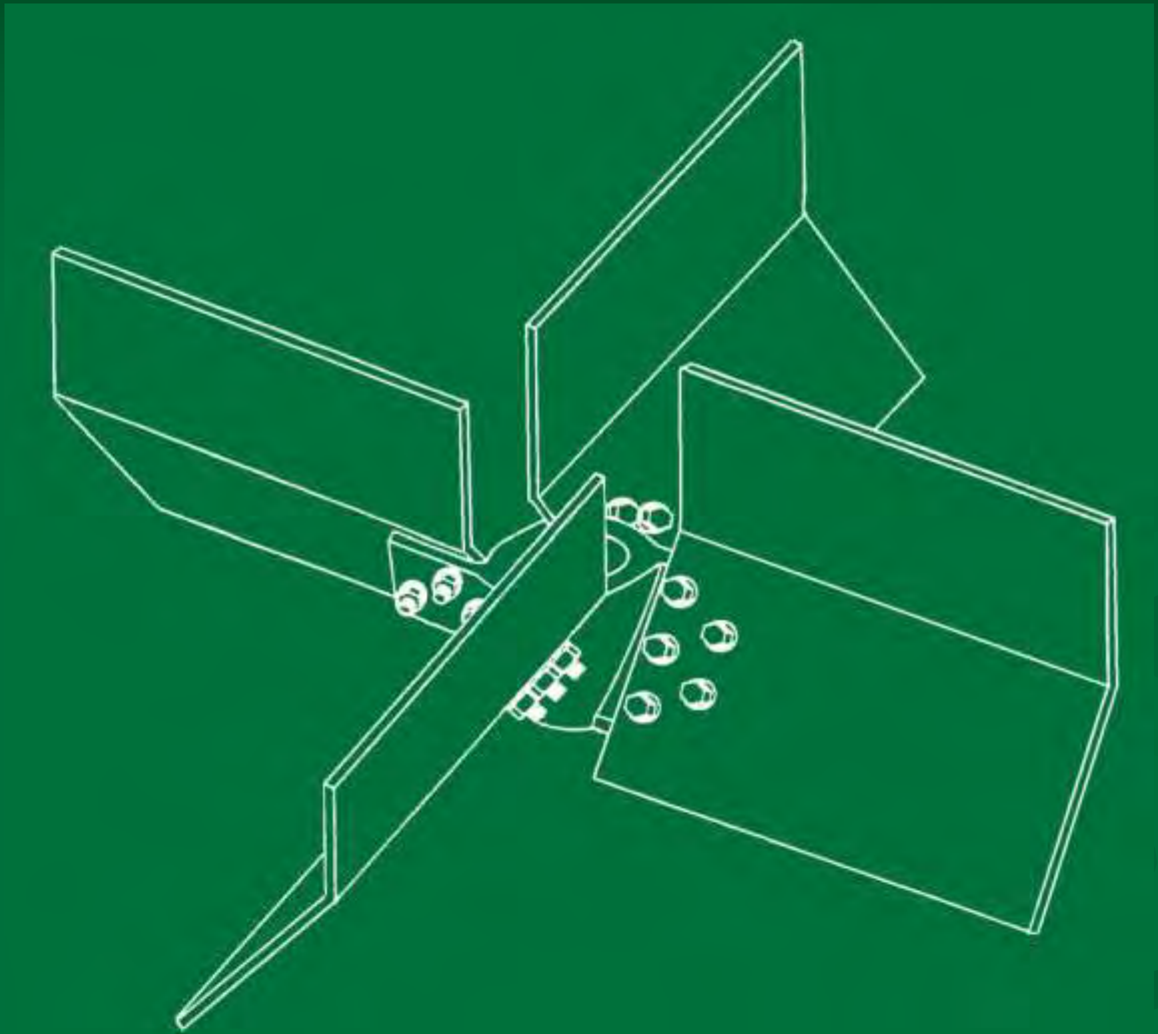
Background

- What is a Surface Aerator?
  - A partially submerged impeller rotating at the liquid surface
  - Liquid is sprayed into the air and reimpinges on the liquid surface
  - This creates a highly turbulent liquid surface for gas-liquid mass transfer
  - Predominately used in secondary wastewater treatment plants

Background

- Function of surface aerators
  - Transfer of oxygen from the gas phase into the liquid phase
  - Bulk tank mixing
  - Solids suspension

Schematic of an Up-Pumping Surface Aerator



Operating Surface Aerator

Operating Surface Aerator

Experimental Data Collection

- Tank Size
  - 43' x 43' x 11' (150,000 gallons)
- Collected oxygen uptake data for several aerator sizes, speeds, and liquid emergences
- Collected velocity data for several runs

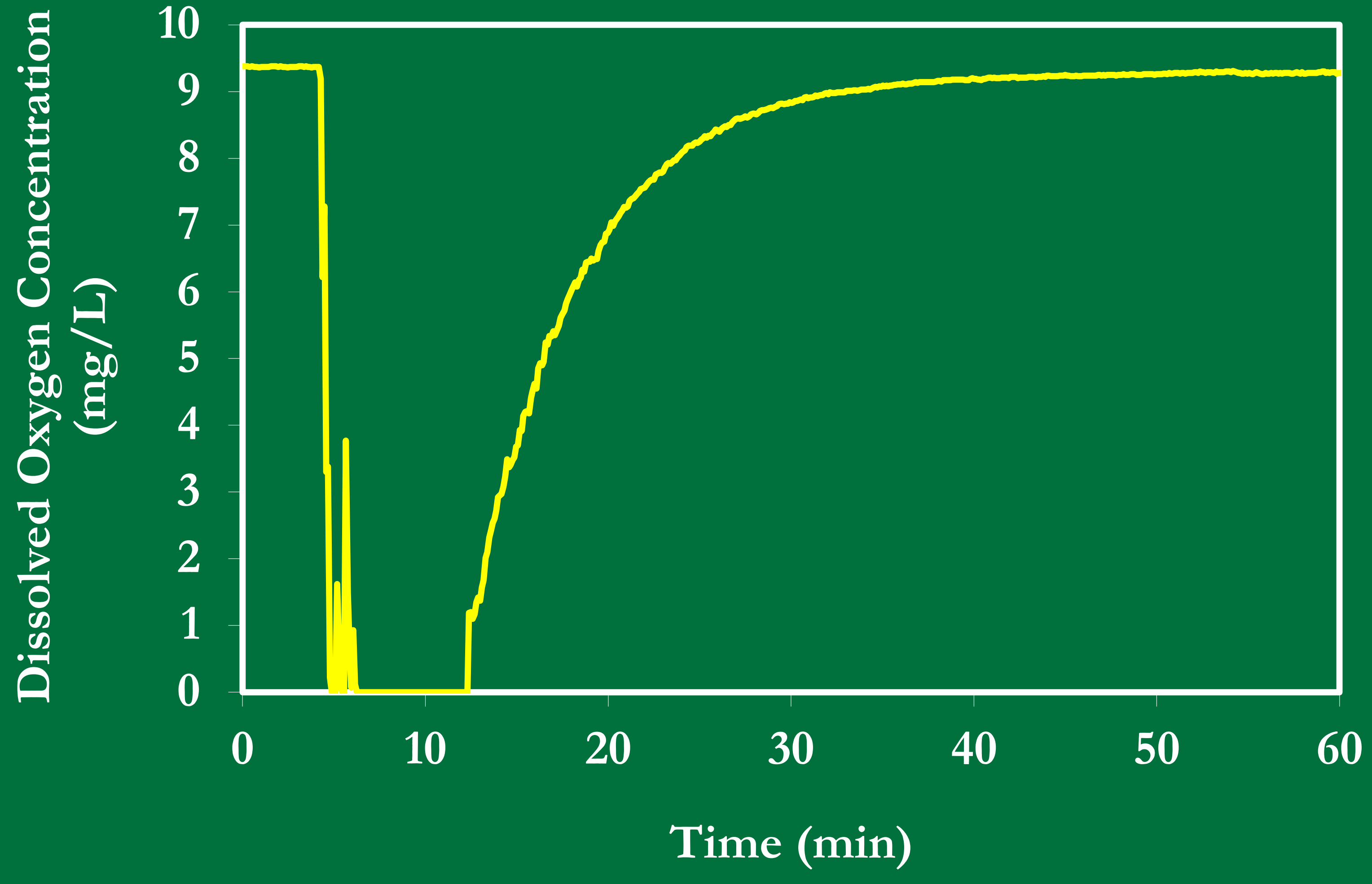
Experimental Data

- Unsteady-State Oxygen Reaeration Test
  - Add sodium sulfite to remove dissolved oxygen in liquid phase

$$Na_2SO_3 + \tfrac{1}{2}\,O_2 \xrightarrow{Co^{++}} Na_2SO_4$$

  - After excess sulfite is consumed, measure dissolved oxygen concentration versus time at several points in the tank

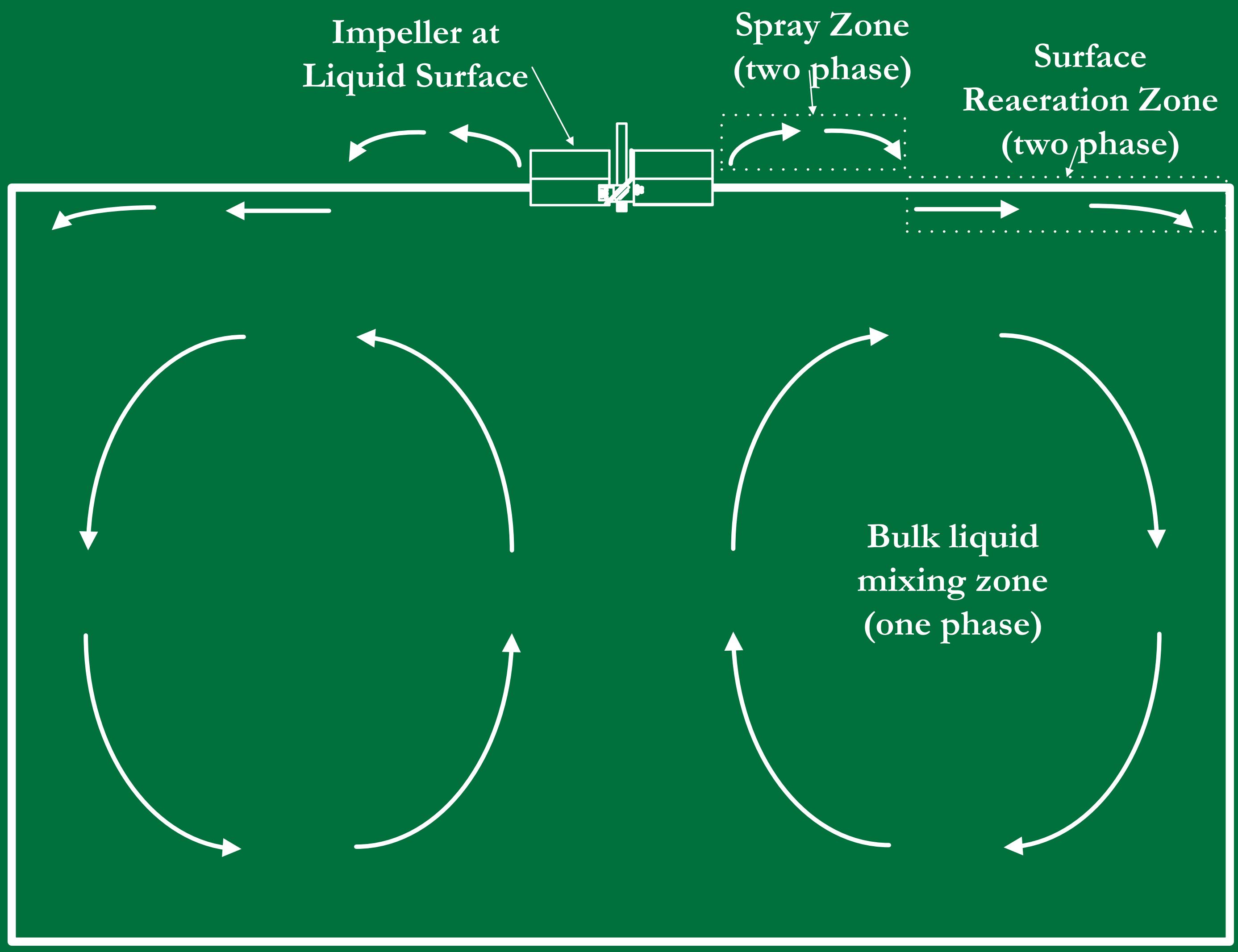
Typical Unsteady State Reaeration Curve



COMSOL Model Construction

- Complex problem
  - Scale – large volume tanks
  - Multiphase flow
  - Free surface
  - Solids suspension
- Need to simplify to create a tractable model
  - Single phase flow
  - Two mass transfer zones
  - Slip boundary condition instead of free surface

Two-Zone Transfer Model



Spray Zone

- Spray Zone Characterization
  - Pumping rate of aerator can be determined through a kinematic analysis of the spray
  - Assume complete conversion of delivered power into kinetic energy

$$Q = \frac{2P}{\rho v^2}$$

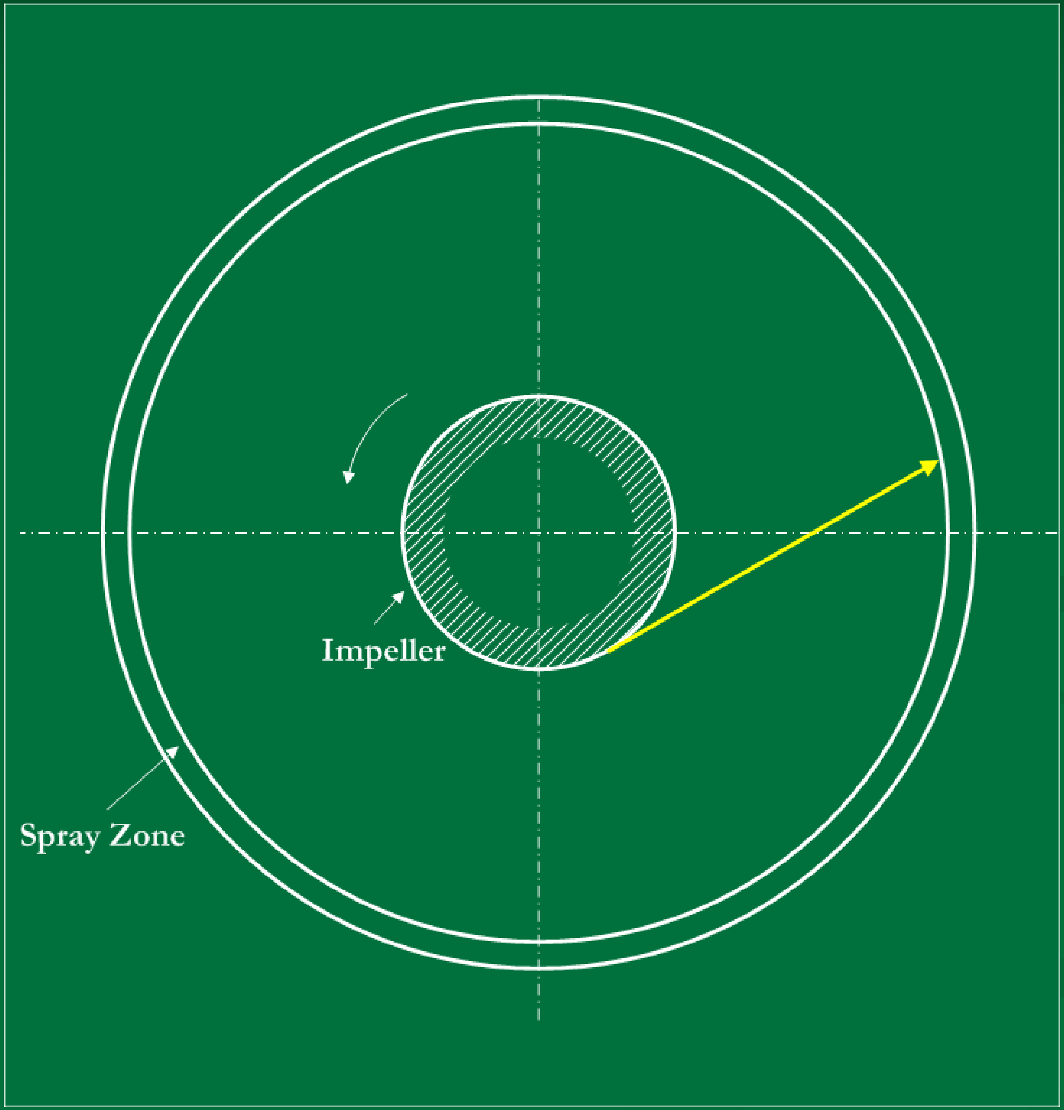
  - The oxygen transfer rate that occurs in the liquid spray zone is given by

$$OTR_{SP} = Q E_{md} \left(C_d^* - C_L \right)$$

Liquid Spray Impingement Surface

- Placed at approximate impact point of spray
- Inlet velocity is determined by overall flowrate and surface area of inlet
- Mass flux through this small surface is based on the actual transfer that occurs while the liquid travels through the air prior to impact

Liquid Spray Impingement Surface



- Flow leaves the impeller blade tangentially
- This creates some fluid spin, and can be modeled within COMSOL
- x,y components of inlet velocity will be a function

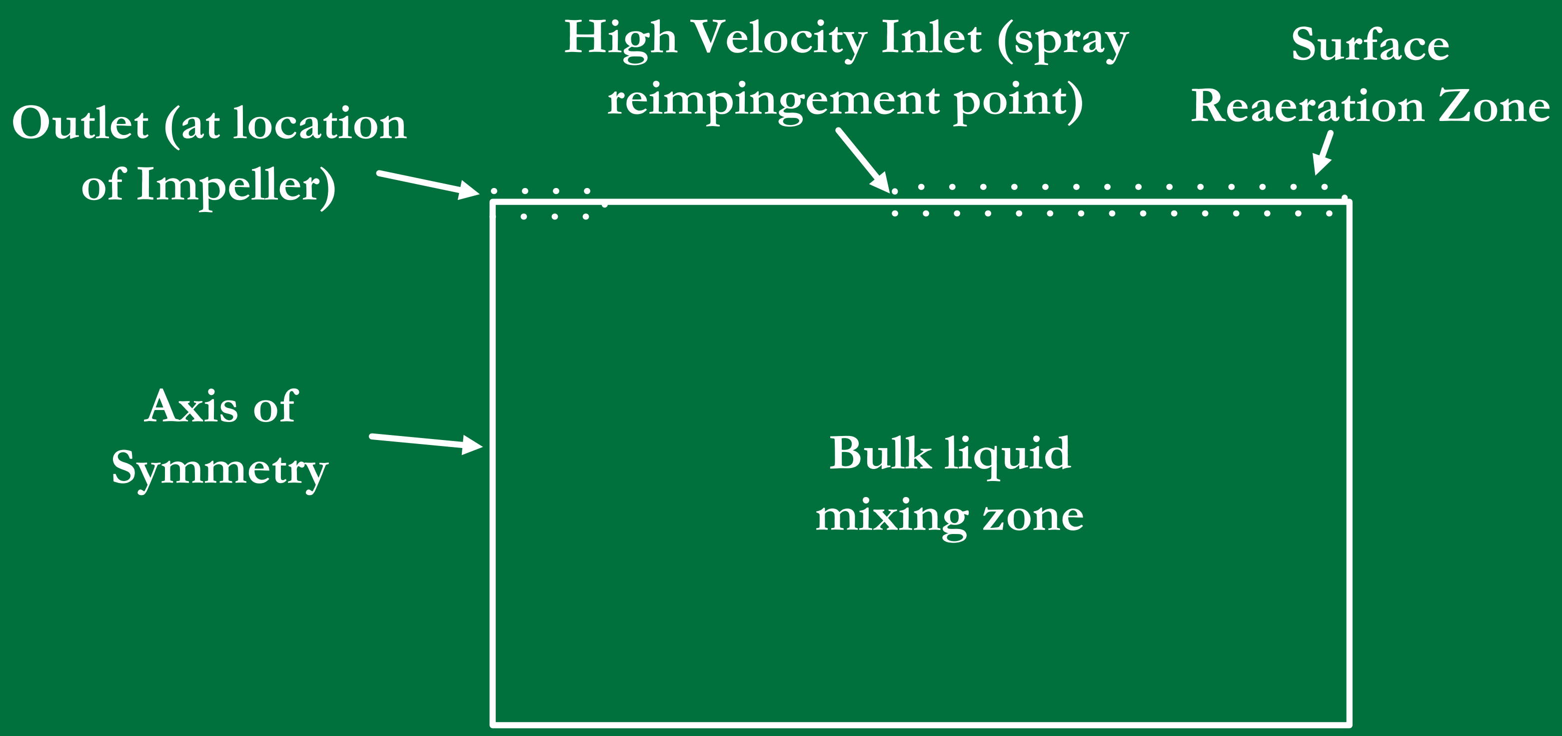
Spray Zone Parameters for Simulations

Q (gpm)	Surface Area of Spray Zone (ft^2)	$SOTR_{SP}$ (E_{md} = 0.4) (lbs O_2/h)
25,000	26.73	45.5

- Velocity in xy plane at inlet is 3.61 ft/s
- Velocity in z direction at inlet is -2.08 ft/s

Surface Reaeration Zone

- Surface Reaeration Zone Modeling



Surface Reaeration Zone

- Located just past liquid spray zone
- Extends out to tank walls
- Zone is 3" deep
- Mass transfer coefficient is based on local liquid velocity within each mesh element
- Defined as a separate domain, with a reaction source term to achieve oxygen transfer

Surface Reaeration Zone

- **Oxygen transfer source**
  - Assume that the mass transfer coefficient in the surface reaeration zone is proportional to the kinetic energy

$$k_{LS} a_S \propto v_{SRZ}^{\,2}$$

  - The oxygen source term in the surface reaeration zone can then be written as

$$OTR_{SRZ} = C\,U^2 \frac{\left(C_L^* - C_L\right)}{C_L^*}$$

  - C is a fitted constant that will be determined by comparison with experimental data

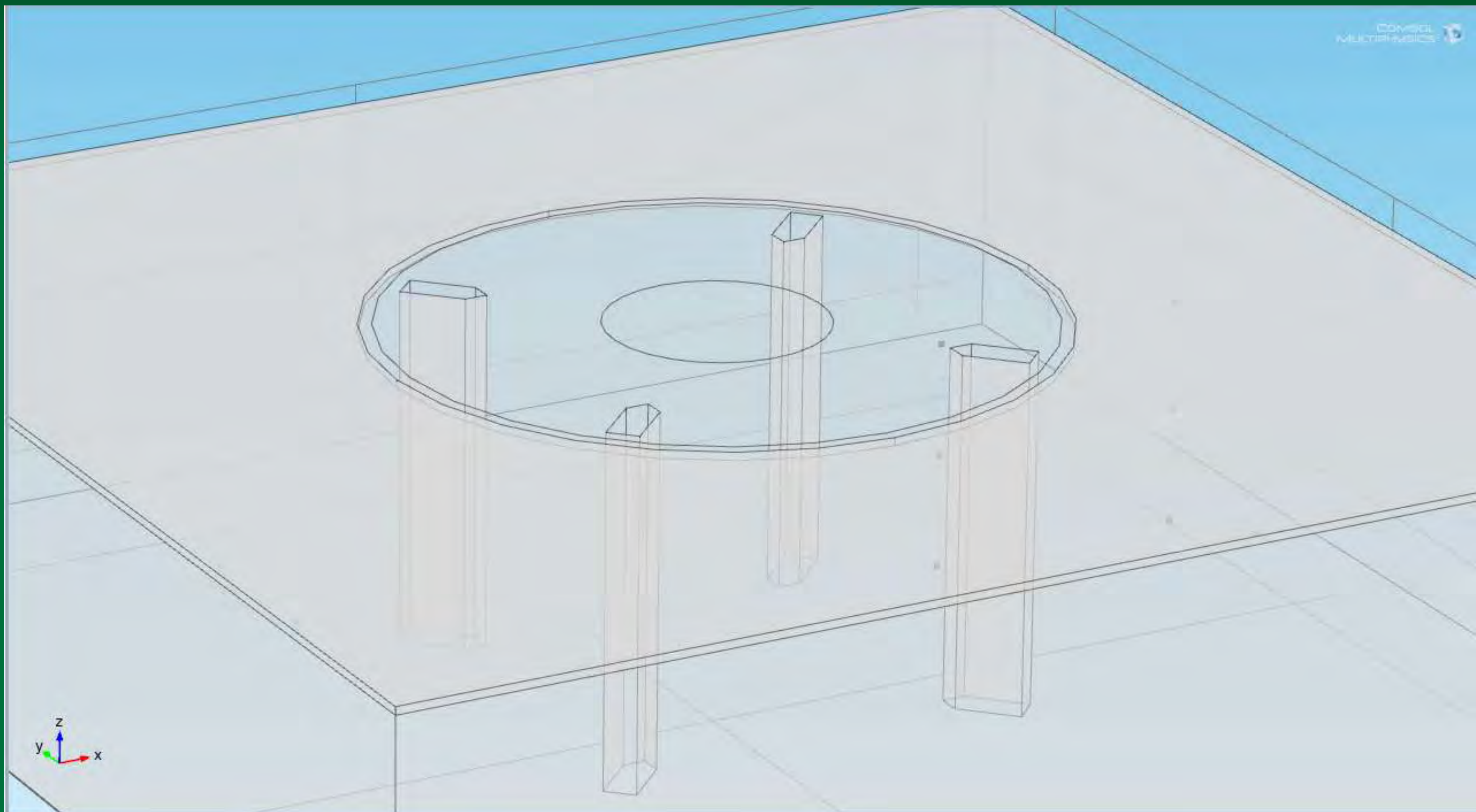
Experimental Run Used for Model Tuning

Aerator Diameter (inches)	Emergence (inches)	RPM	Shaft Horsepower (HP)	ASCE $k_L a_{20}$ (1/h)
80.9	0.59	52.4	33.7	10.87

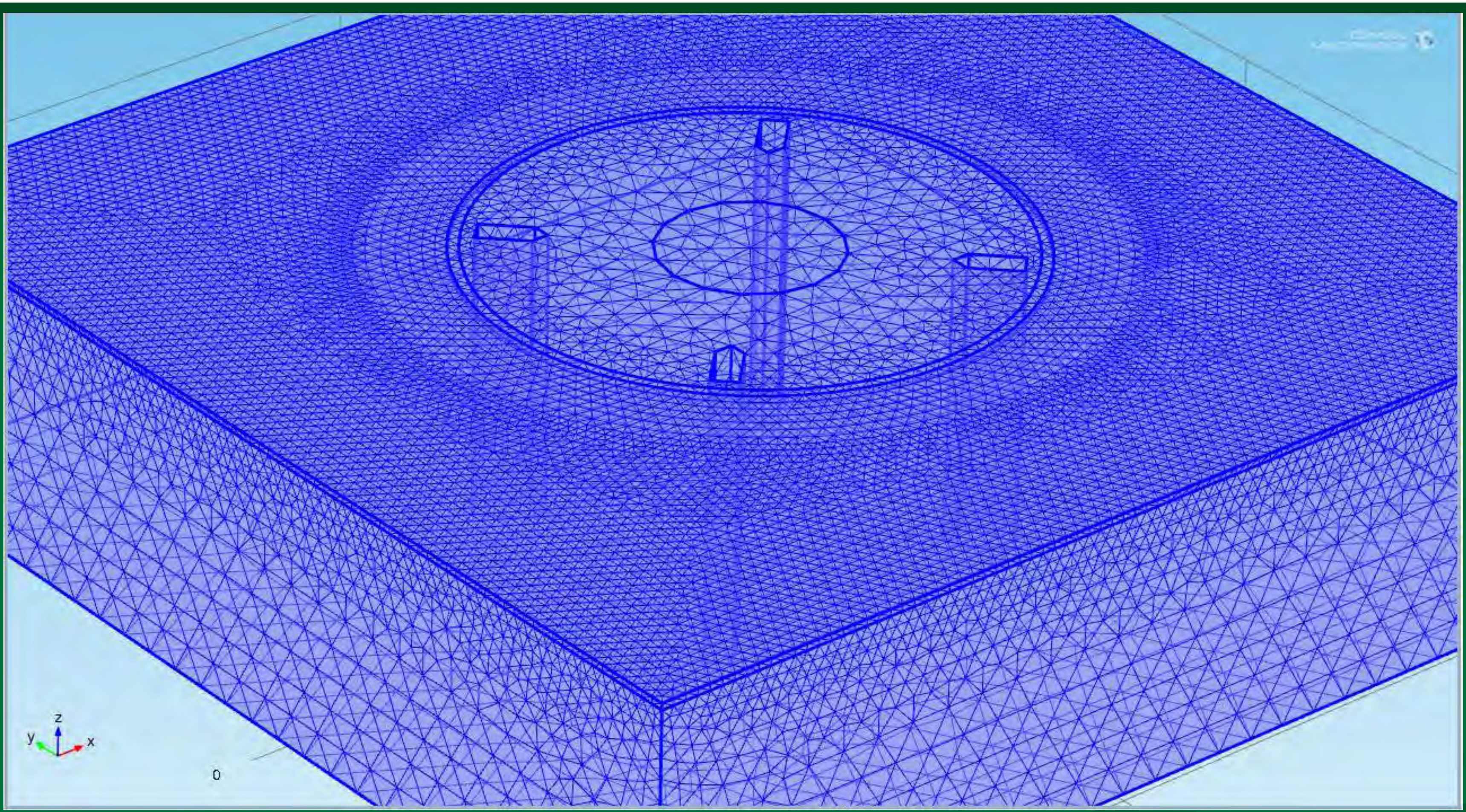
COMSOL Model Construction

- The surface aeration tank fluid consists of two domains
  - Bulk liquid
  - Surface Reaeration Zone
- Turbulent *k*-ε model is used for fluid flow
- Multiple surface types
  - Outlet (where impeller contacts surface)
  - Spray Zone inlet
  - Liquid surface (slip boundary condition)
  - Tank walls and baffles

3D View of COMSOL Model



COMSOL Mesh Construction



Total of 430,000 elements in mesh, mostly focused along the top portion of the tank

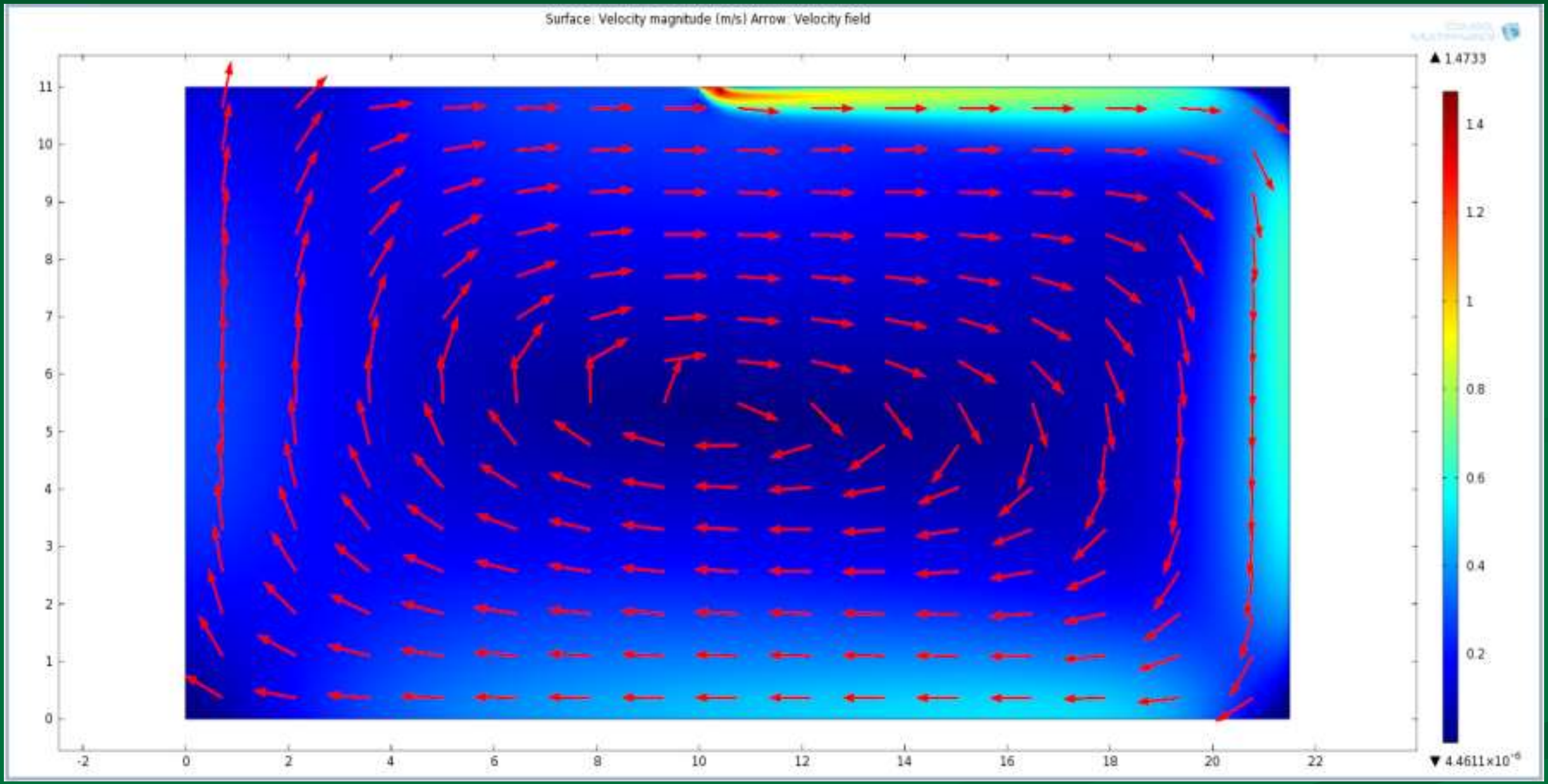
Solution Procedure

- Geometry for surface aeration tank was created in COMSOL as described previously
- A steady-state solution to the velocity flow field was obtained (no mass transfer)
- The O_2 source terms in the liquid spray zone and surface reaeration zone were incorporated into the model
- O_2 source was initially set to zero
- The unsteady state mass transfer simulation was started
- O_2 concentration was recorded versus time (at experimental probe locations) to simulate an unsteady state reaeration test

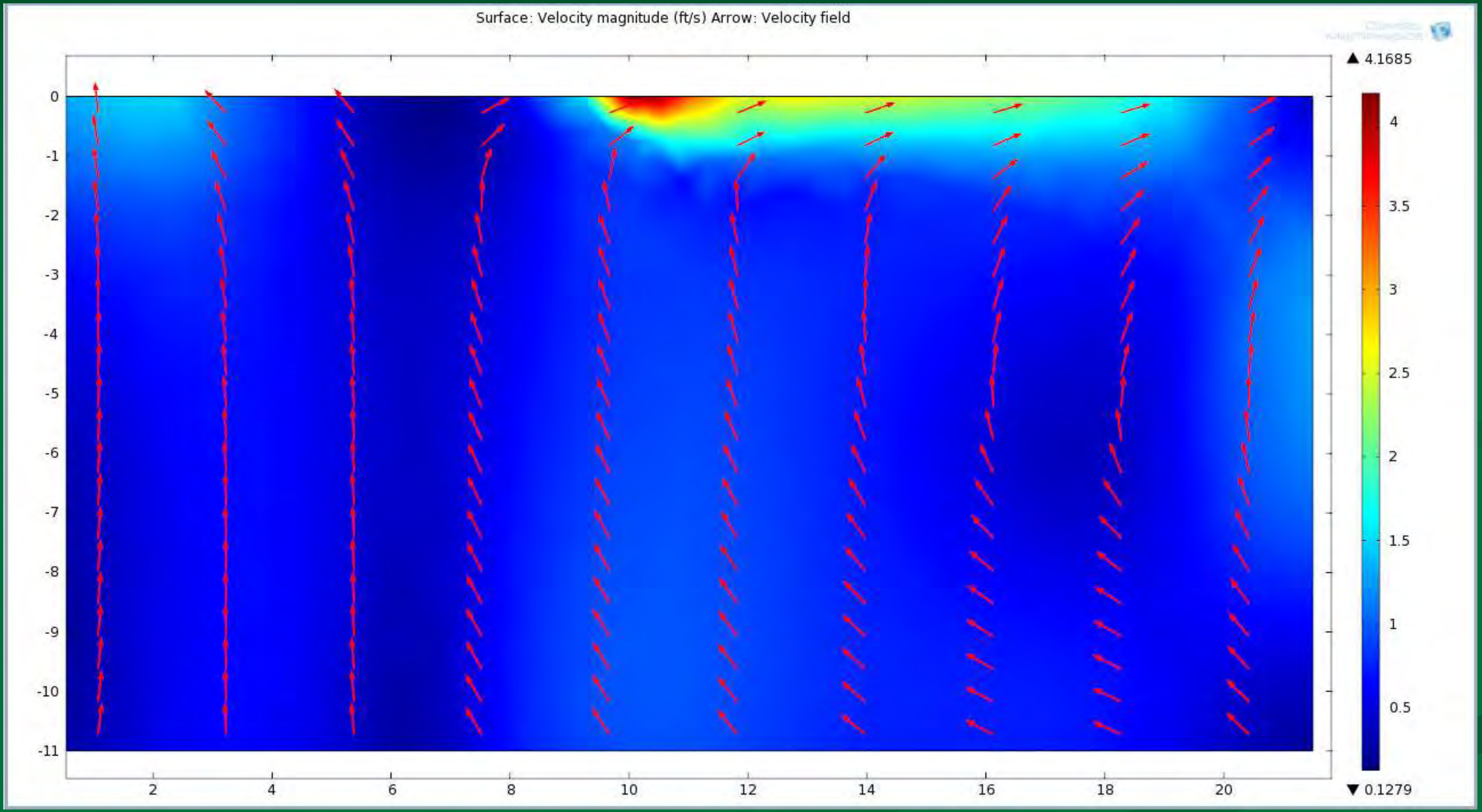
Simulation Results and Analysis

- Velocity profiles
- Unsteady state oxygen uptake results

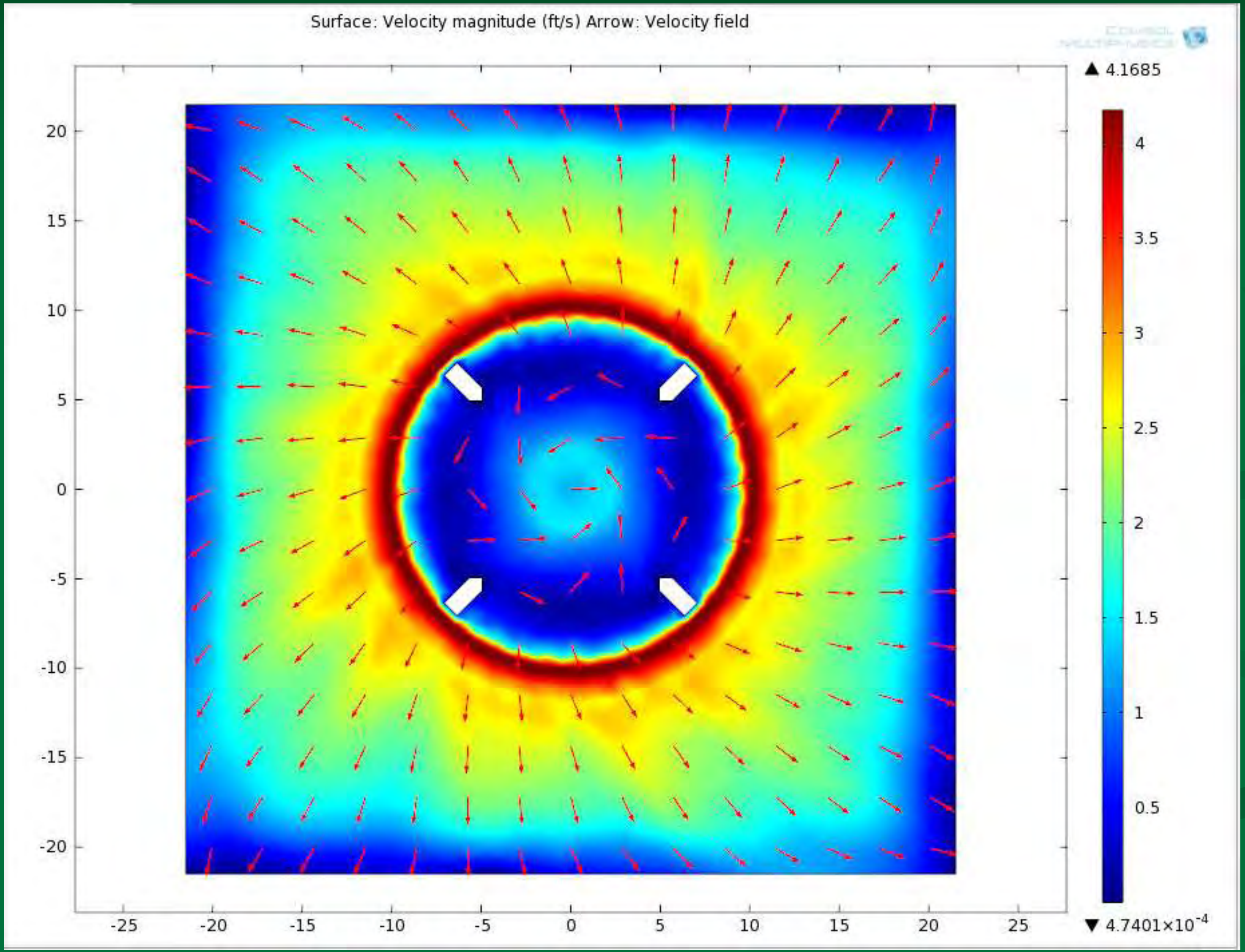
2D Velocity Profile



3D Velocity Profile – Side



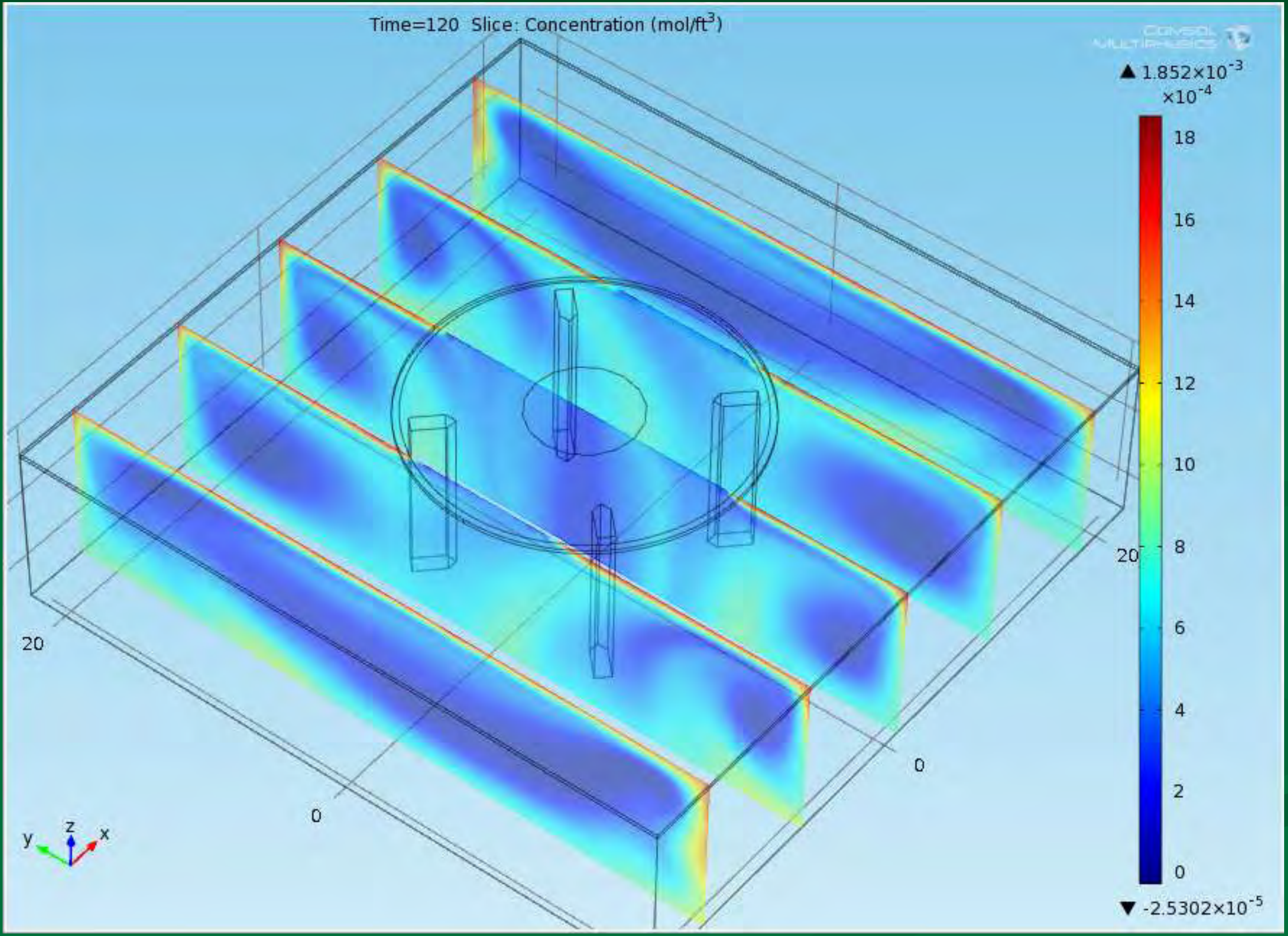
3D Velocity Profile –Top



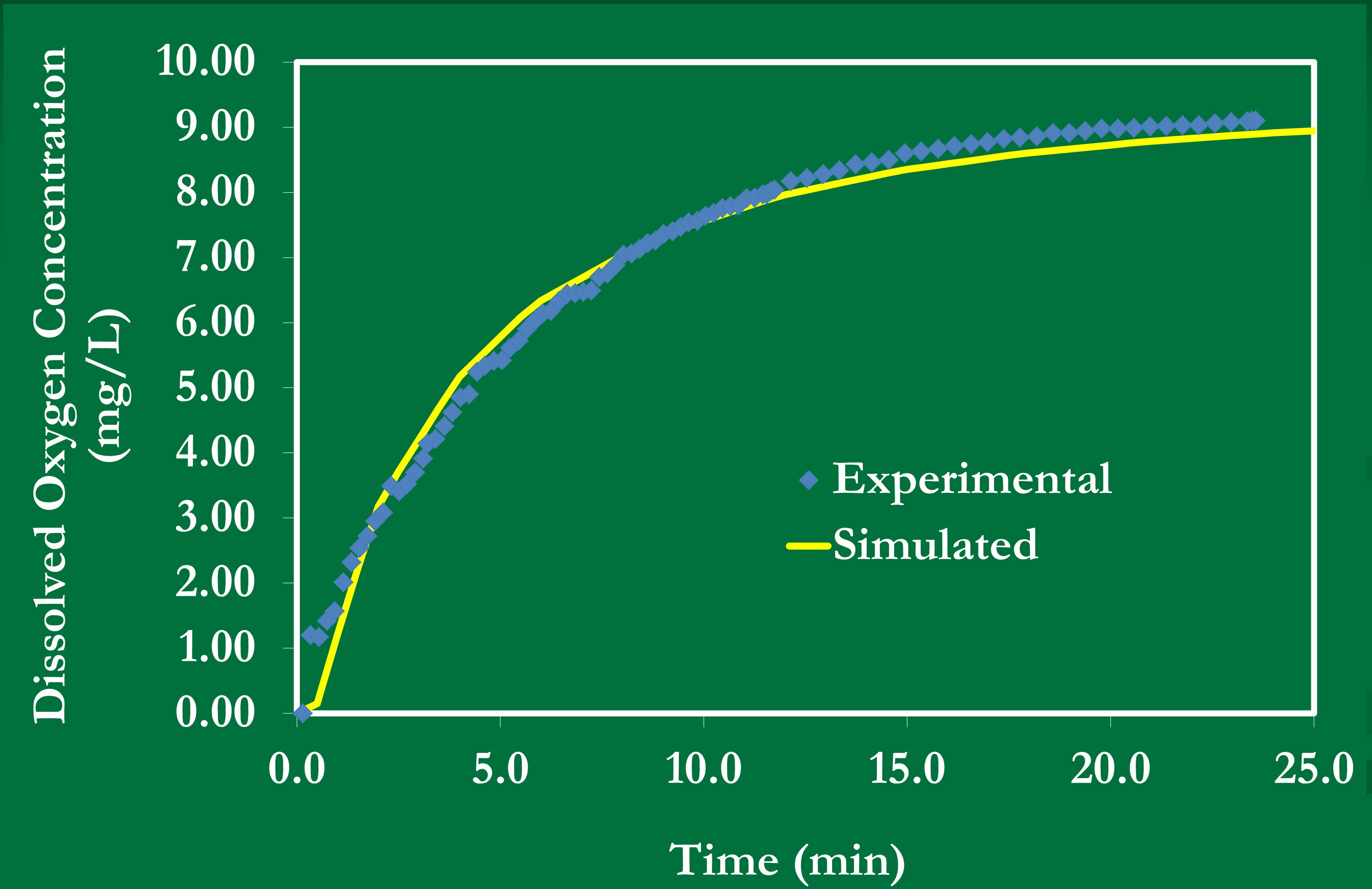
Velocity Data Comparison

Data Type	Velocity Magnitude (ft/s)
Experimental	0.92
Simulated	0.70

Unsteady State O_2 Uptake



Unsteady State O_2 Uptake



Conclusions

- This new COMSOL model will be a useful tool for predicting surface aerator mixing and oxygen transfer performance for any aeration tank size or geometry

- Further development and refinement of this new COMSOL model will substantially reduce the traditional need for extensive and expensive full-scale surface aerator testing

Future Work

- Implementation of Rotating Machinery Model
- Multiphase flow
  - Bubbly flow in the reaeration zone
  - Free surface modeling in the vicinity of the impeller
- Solids suspension