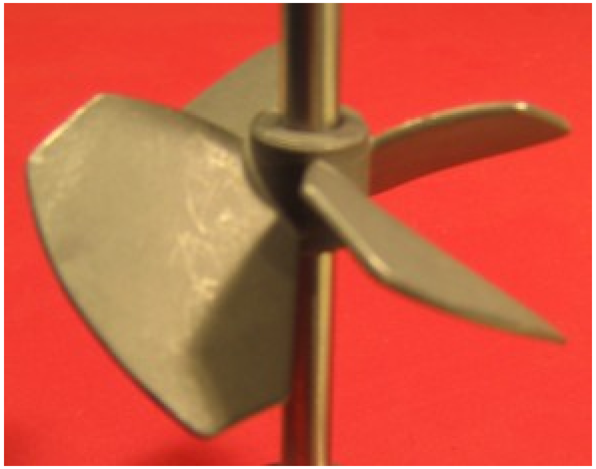
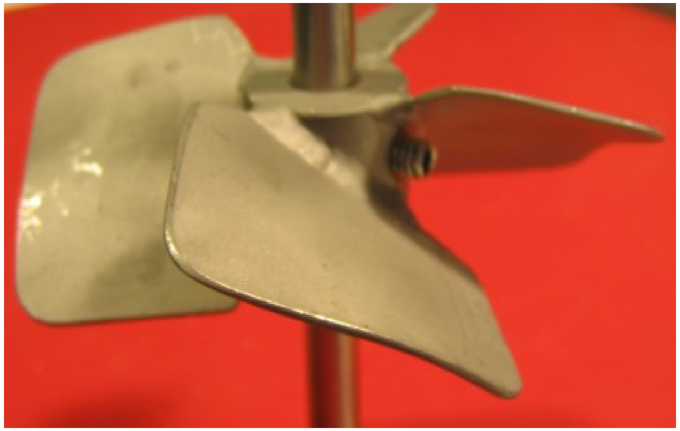
Gas Handling and Power Consumption of High Solidity Hydrofoils:

Philadelphia Mixing Solution's HS



Lightnin's A315



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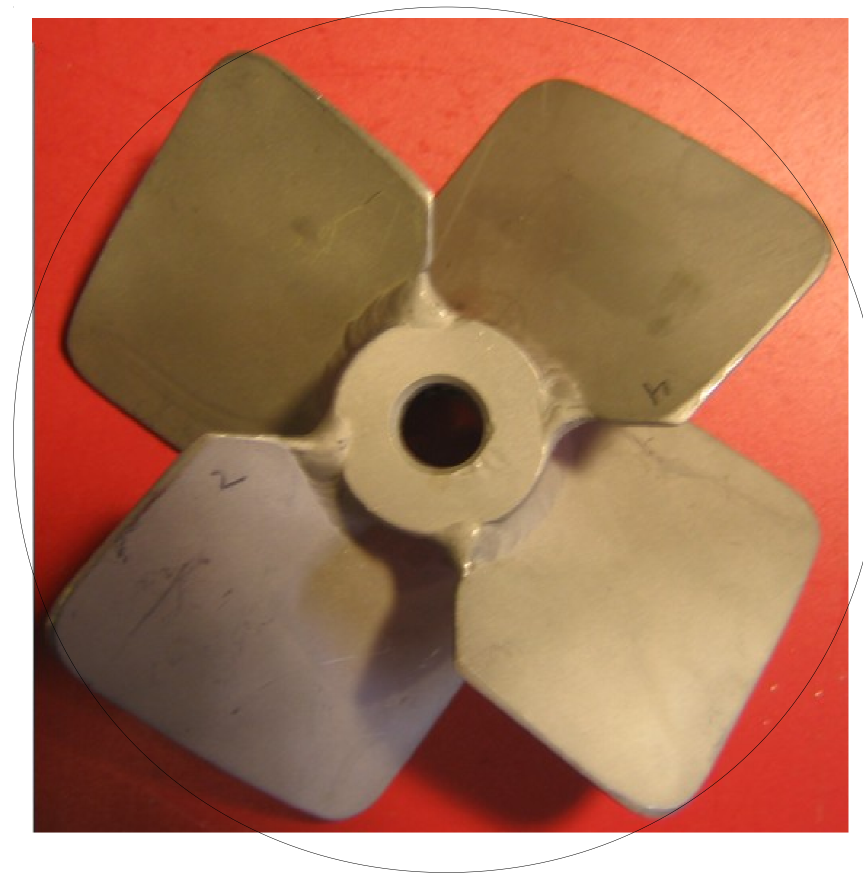
High Solidity Impellers

- HS

- A315

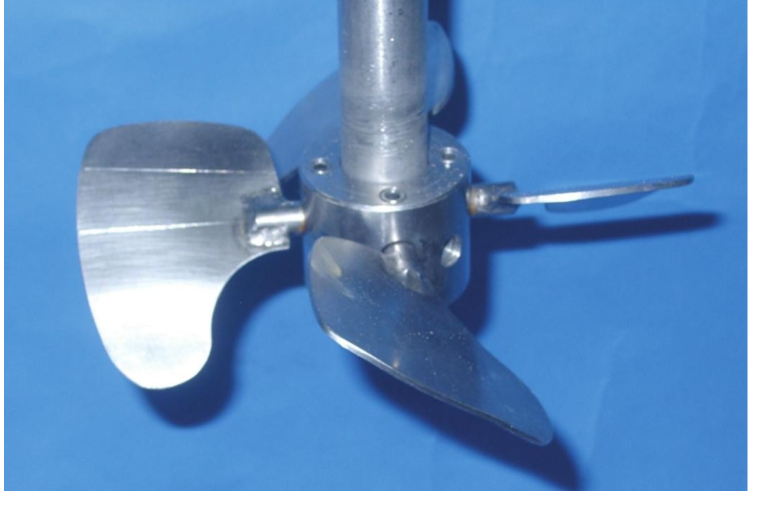


Purpose of this project

- Better understand the flood points of down-pumping, high solidity hydrofoils
- Use CFD to predict these points
- Compare with experiments
- Comparing the two impellers is ***NOT*** the purpose of this project. We chose two competing impellers to demonstrate how these concepts apply broadly to the class of high solidity hydrofoils

Motivation

- There is not a lot of data available on these impellers in the literature
- Would have included Ekato's Isojet B if we could have gotten a model
- Large gas-liquid mixers in the mining industry can have impeller powers greater than 1000 kW
- Curiosity
  - Can we get CFD to do it?
  - And who's best?

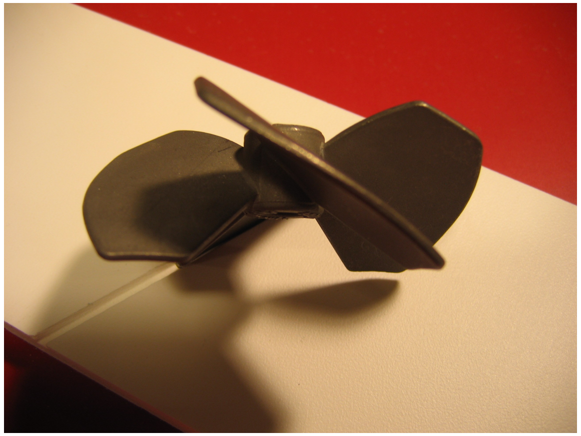


Experimental

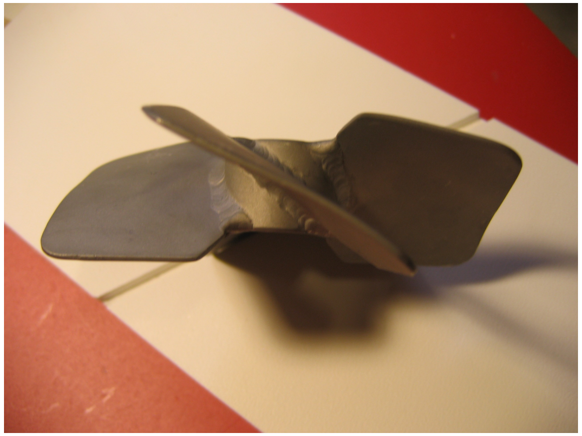
- T = 289.6 mm (11.4”)
- Z = 285.8 mm (11.25”)
- V = 18.8 L (5 Gallons)
- Water / Air 20 C (68 F)
- D_{Sparge} = 76.2 mm (3”)
- d_{Sparge} = 8 mm (0.315”)
- OB_{Sparge} = 25.4 mm (1”)
- 8 holes facing up 1.59 mm (1/16”)
- 4 baffles, no gap
  - 24.6 mm (0.97”) wide
  - 5.7 mm (0.224”) thick

Impellers

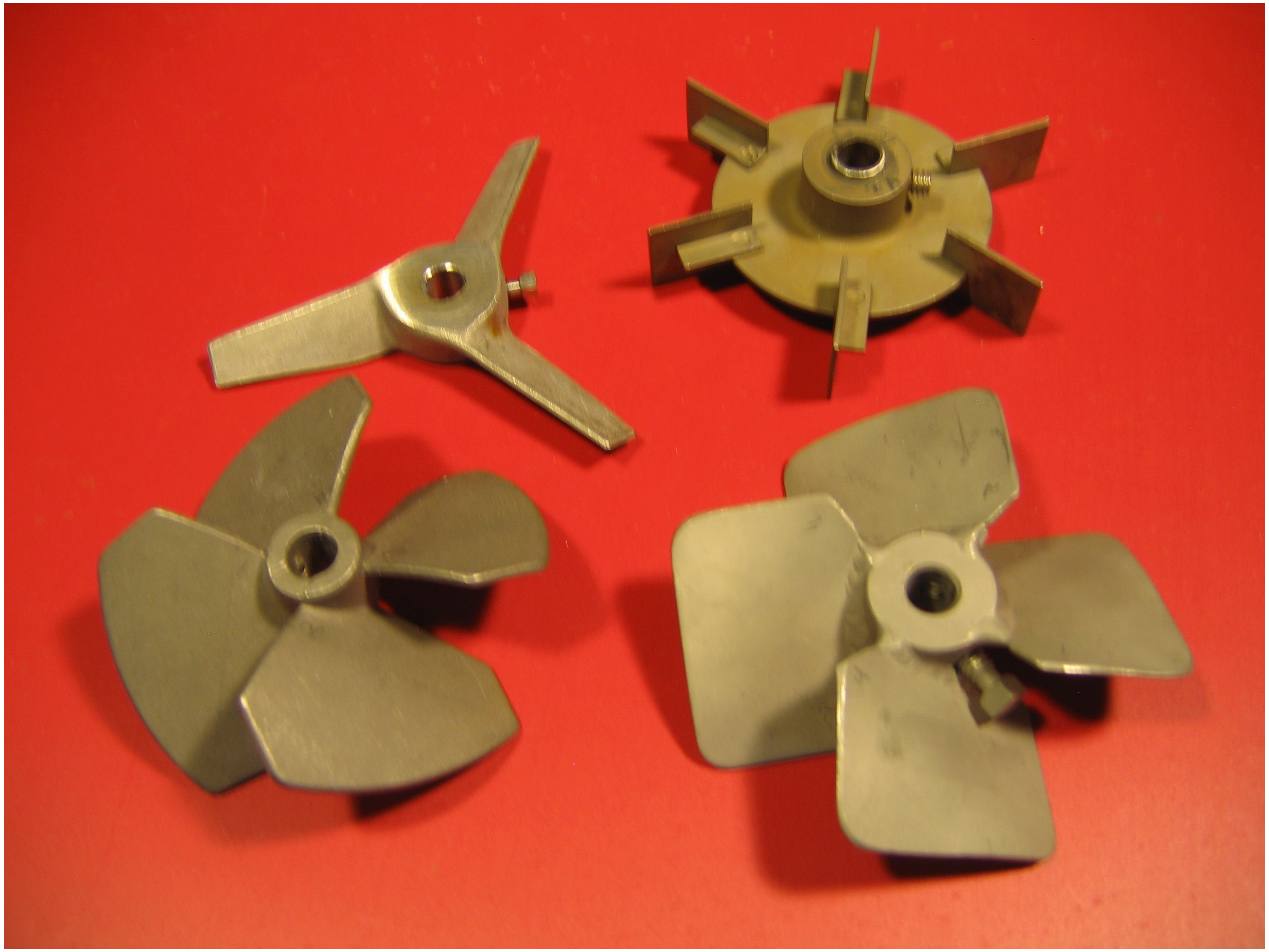
- HS
  - D = 89 mm (3.507”)
  - D/T = 0.31
  - OB = 76 mm (3”)
  - OB/D = 0.86
  - HCA = 43.5-45.0^0
  - TCA = 31.5-32.0^0



- A315
  - D = 102 mm (4.000”)
  - D/T = 0.35
  - OB = 89 mm (3.5”)
  - OB/D = 0.88
  - HCA = 35.5-37^0
  - TCA = 26.5-29^0



Other Impellers



Speed and Power Measurement

- Lightnin LabMaster
- Ranges
  - P = 0.5 – 27 W
  - N = 275 – 1000 RPM
  - Fr = 0.22 – 2.88
  - P/V = 0.26 – 2.1 kW/m^3
  - CS = 1.5 – 6.4

Gas Flow Measurement

- Dwyer Rotameter
  - Ranges
    - Q_{Rot} = 10 – 95 LPM
    - BP = 0.5 – 15 psig
    - Q = 10 – 147 aLPM
    - vsg = 0.0025–0.0281 m/s
    - F = 0.49 - 5.5 ft/min
    - NaeW = 2 – 26%
    - NaeL = 3 – 36%

Computational System Information

- ATX size computer system
- CPUs: (2) dual core AMD Opteron 270 chips

  => 4 CPU SMP system, at 2GHz each (Shared Memory Parallel)

- Memory:
  - 8 GB memory connected via on chip memory cross bar. (Very good memory bandwidth)
- CPU effort
  - ungassed steady state models - 1 hour
  - gassed transient analysis - 1.5 to 2 days - 4 CPUs

CFD Background - Codes

- For Geometric Model – SYNERGY
  - Parasolids based, geom primitives, Boolean ops
- For Pre-processing – AcuConsole
  - Mesh generation, BC's,
  - Problem set-up
- For Solution – AcuSolve
  - Galerkin/Least-Squares (GLS), FE formulation
  - Full Native Transient Variation
  - Full Variable Density Formulation (conservation of mass)
  - Locally / Globally Conservative, Mass, Momentum, Transport

CFD Background - Assumptions

- Mesh Discretization Structure
  - Represent Gradients, flow / concentration gradients
  - Assessment of error of approximation
- Miscible Fluid approach – Scalar transport
  - Gradient Driven Diffusion = 0 => Transport Only
  - Phases implicitly segregated by viscosity difference
- Density / Viscosity function of concentration
  - Needs calibration
  - Could be related to bubble size
- Modeling Approach – Quasi-Transient (time accurate)
  - Fully transient flow / transport, density
  - Rotating Reference Frame rather than Sliding Mesh

Objectives

- Proof of concept and approach
- Evaluate legacy assumptions / rules of thumb
  - Is Nae=f(Fr or P/V or a constant)?
- Assess miscible fluid approximation to gas-liquid mixing
- Direction for future work
- Compare with specific / direct experimental data

Approach – Accuracy Considerations

- Accuracy Considerations
  - Full time-accurate transient Flow / Transport / Geometry
    - Adaptive time step (to get a solution)
    - Sliding Mesh (moving geometry)
    - Max delta t governed by impeller speed e.g.
      - delta t = 2.0/(rpm*2*pi/60) = .0236 s for 2 deg impeller resolution of rotation
  - Quasi Transient (Rotating Reference Frame)
    - Assume impeller speed is sufficiently fast so that position is not important.
    - Allows larger time steps
    - Less computer intensive – works for people on a shoestring budget
  - Solution Strategy Trade-offs – solution time versus resources
  - Fixed delta t, iteration limit per time step, sufficient for this work

Approach – Scalar Transport

- Solve / propagate scalar transport equations along with momentum and continuity equations in time
- Assume miscible fluids
- Set Diffusion Constant / Term of Transport equation to zero
- Motion is by fluid convection only

Approach – Variable Density/Viscosity

- Develop density / viscosity function of scalar transport as a function of concentration gas bubbles.
  - Linear fit implies extremely fine bubble size
  - More aggressive curve fit could be understood to be related to “bubble size”
  - Bubble size calibration required for further development
- Viscosity variation provides natural implicit barrier against undesired transport (mixing of the two phases)

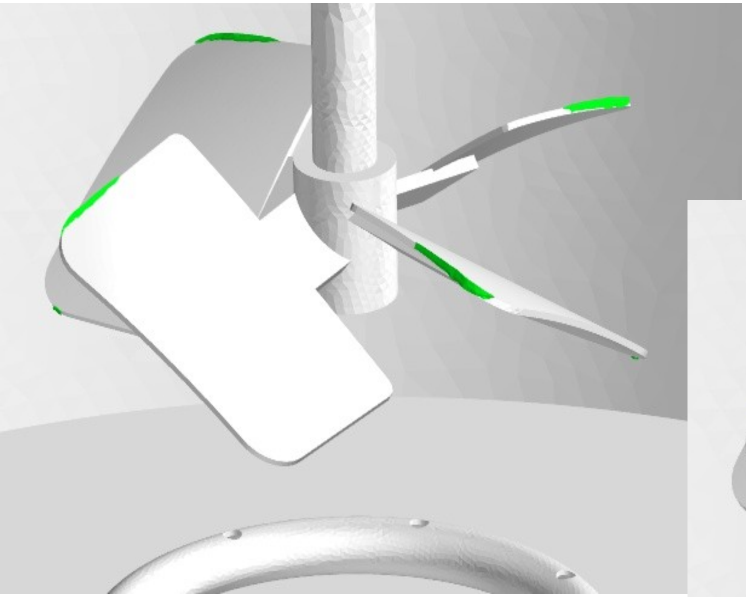
Model Characteristics

- 2.6 Million Tetrahedra (fluid)
- 500,000 Nodes
- Boundary layers on all solid surfaces
- Boundary layer thickness on impeller surface 0.25 mm
- Triangle Facet Characteristic length 1.5 mm
- Aspect ratio 6 (characteristic length to thickness)

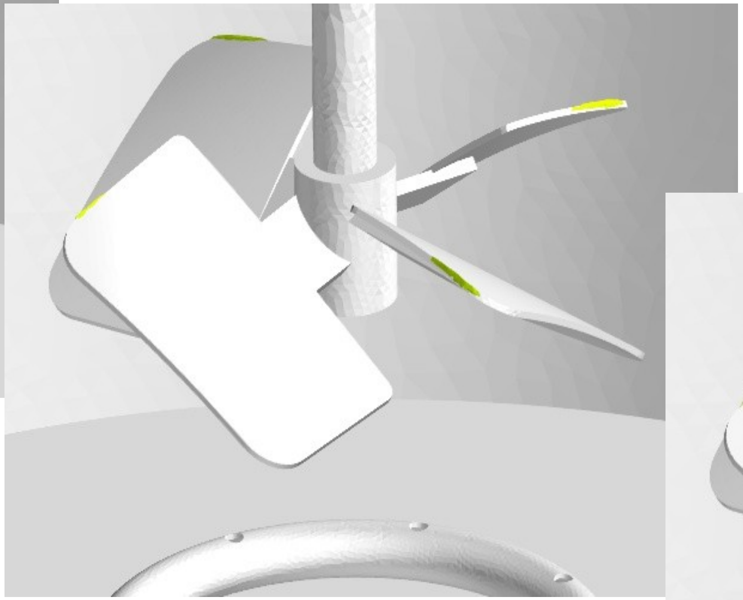
General Error Assessment

- Use built in error estimator
- Relative measure
- IsoSurface of volume within with a specified percentage is contained

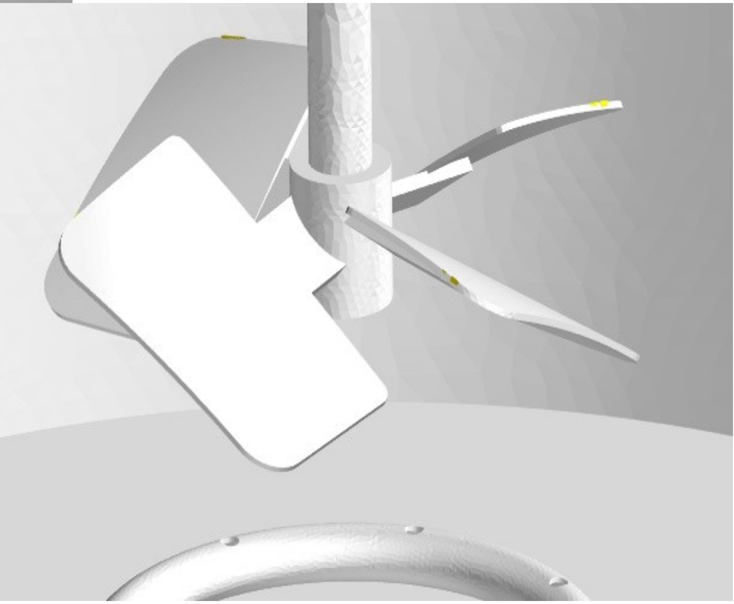
Error Estimator Isosurface



50 % Error Magnitude

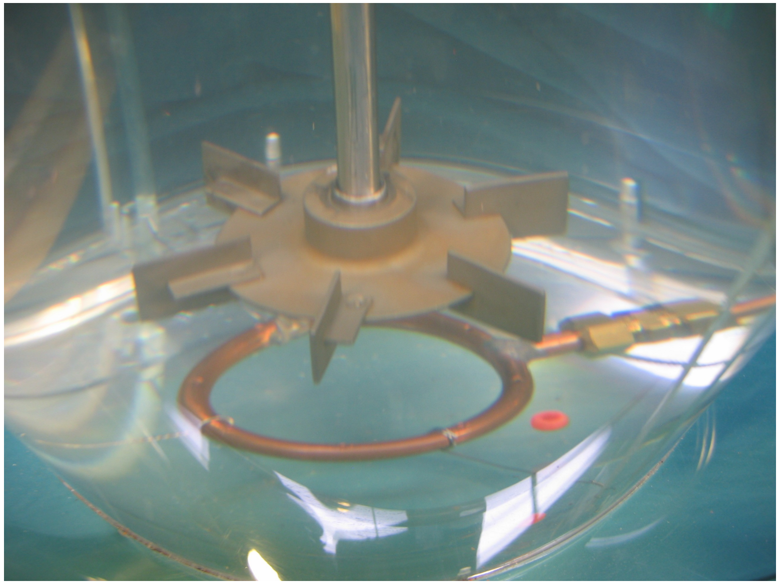


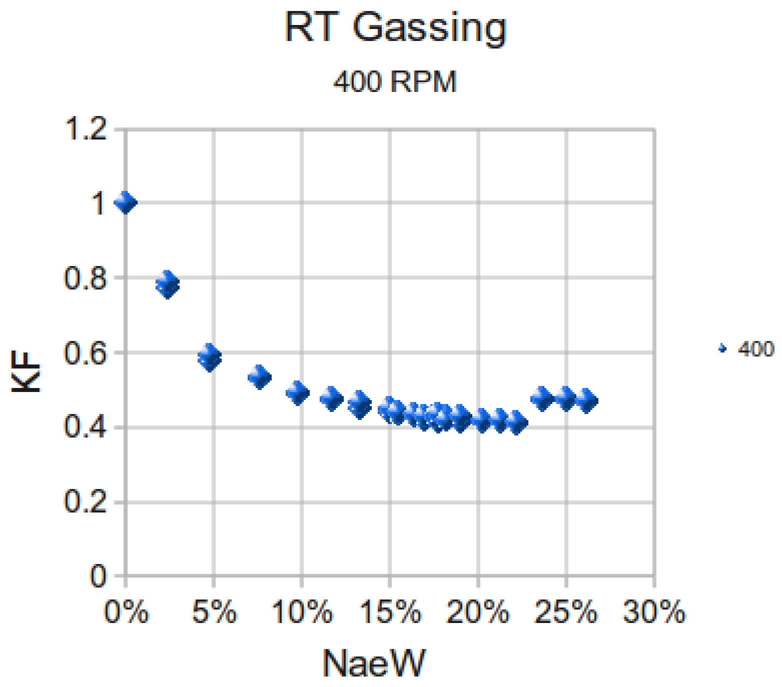
75 % Error Magnitude



95 % Error Magnitude

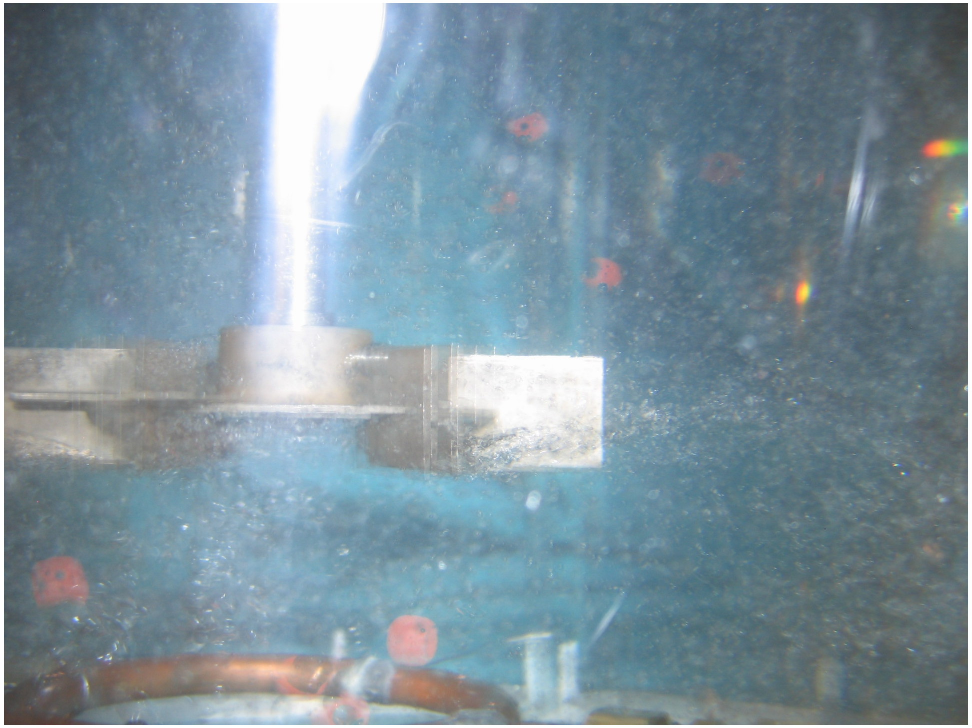
Some Results

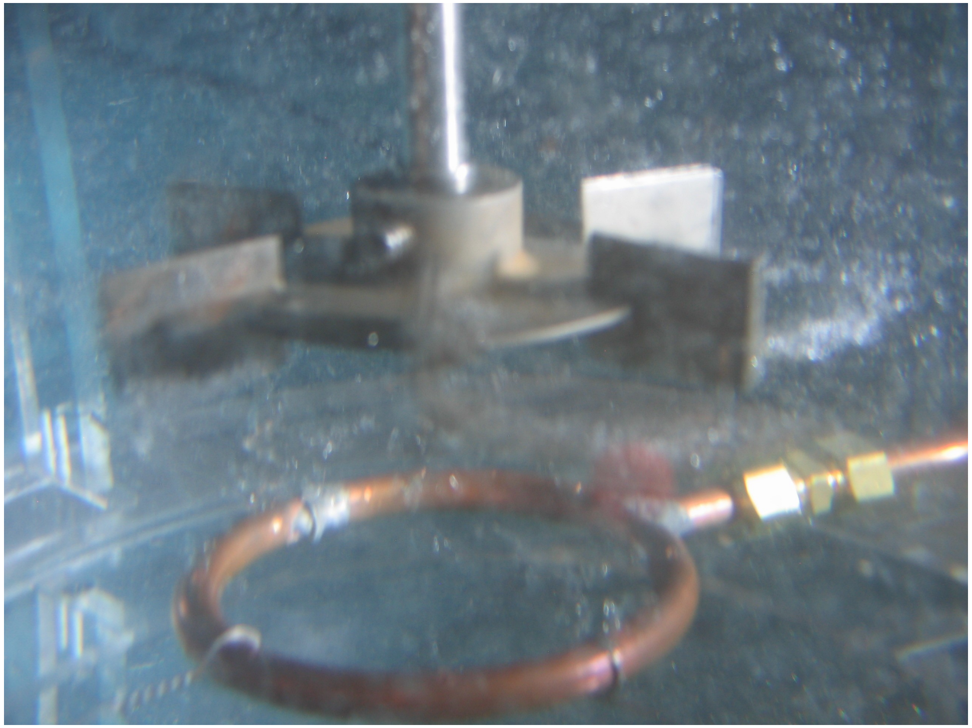




- Rushton Turbine
  - T=0.29, D/T=0.35, Fr=0.46, NaeW=0.236
  - Nienow et. al (1985) would have gotten approx. 0.21

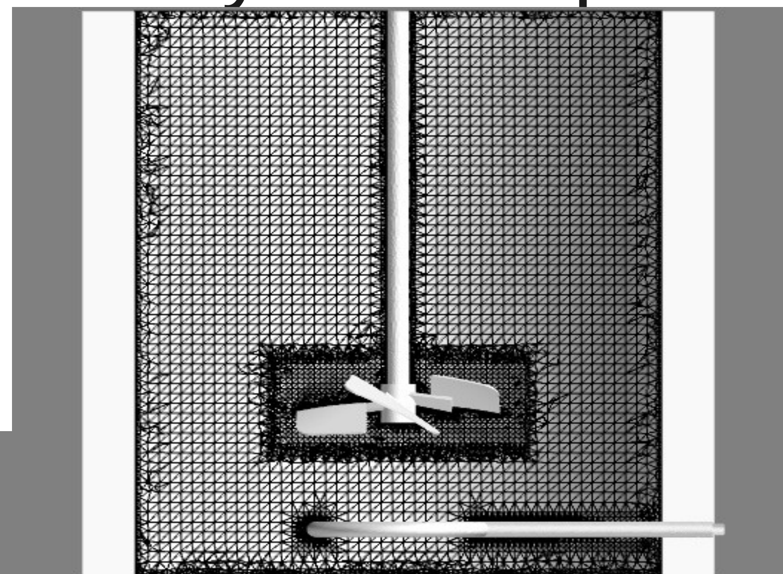
Rushton Trailing Vortices

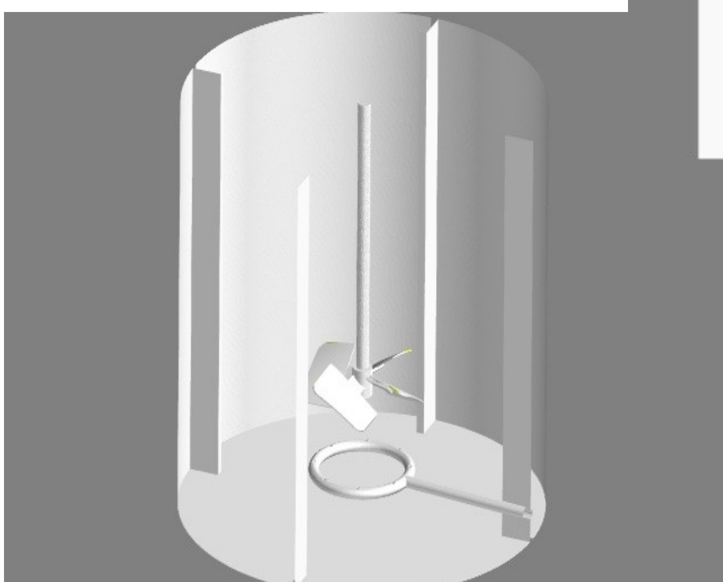


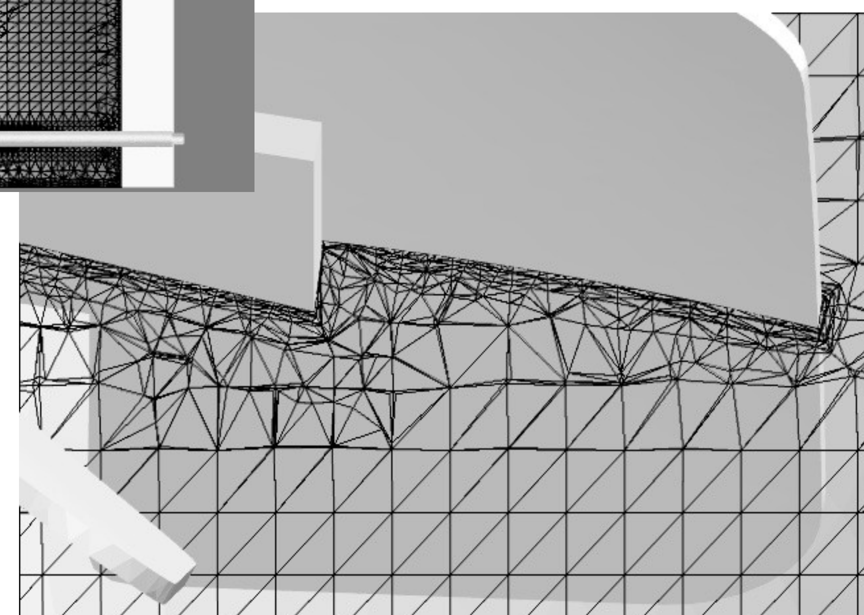


A315 Approximation

- Idealized geometry from experimental impeller

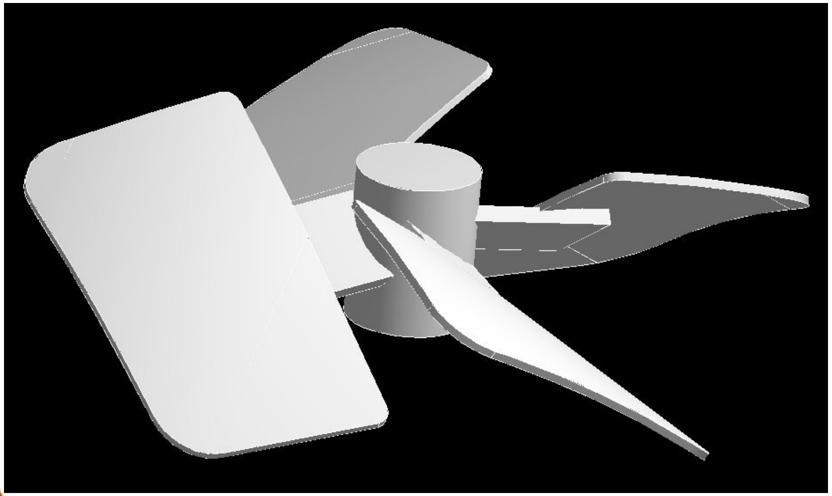


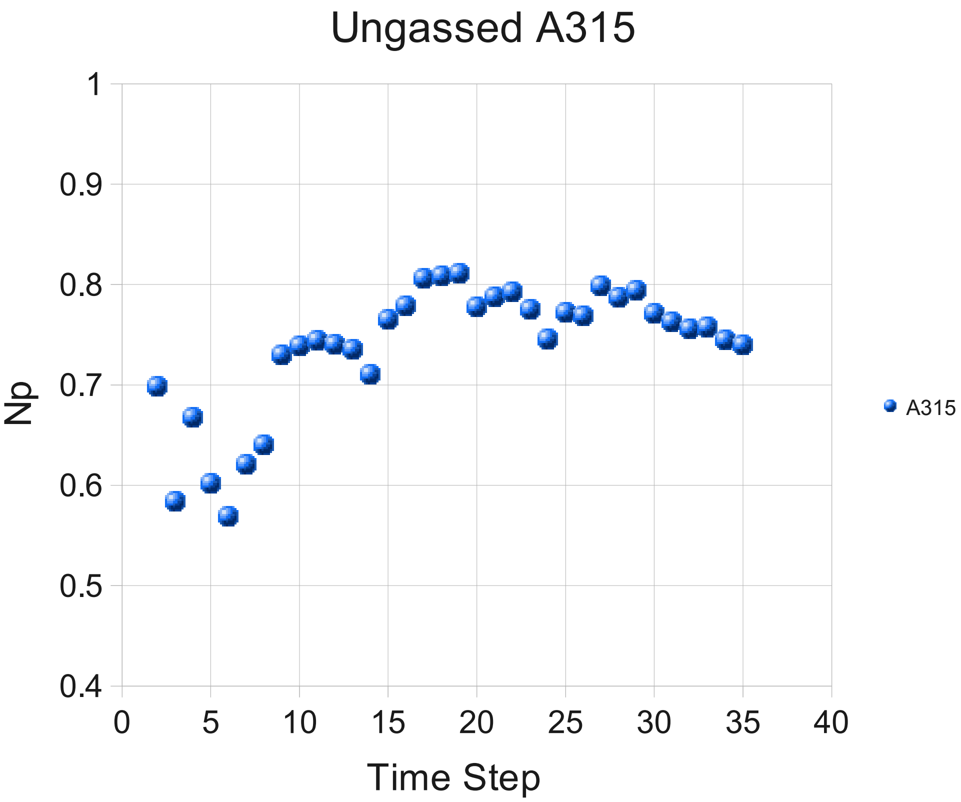




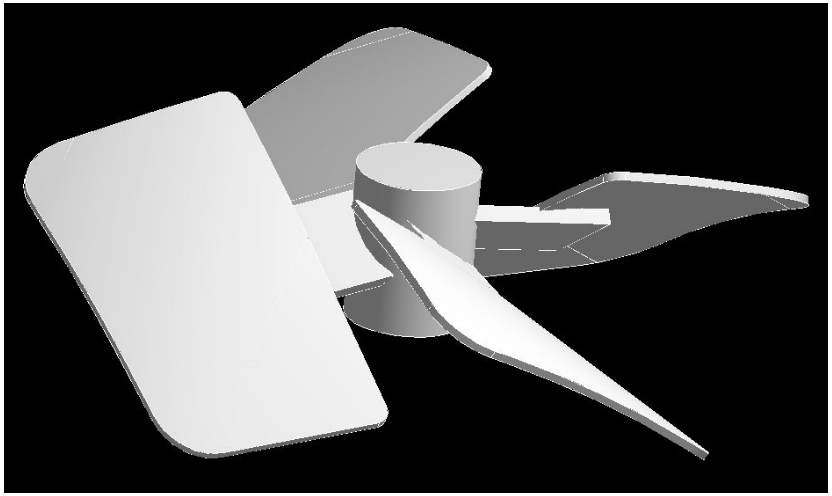
A315 Approximation

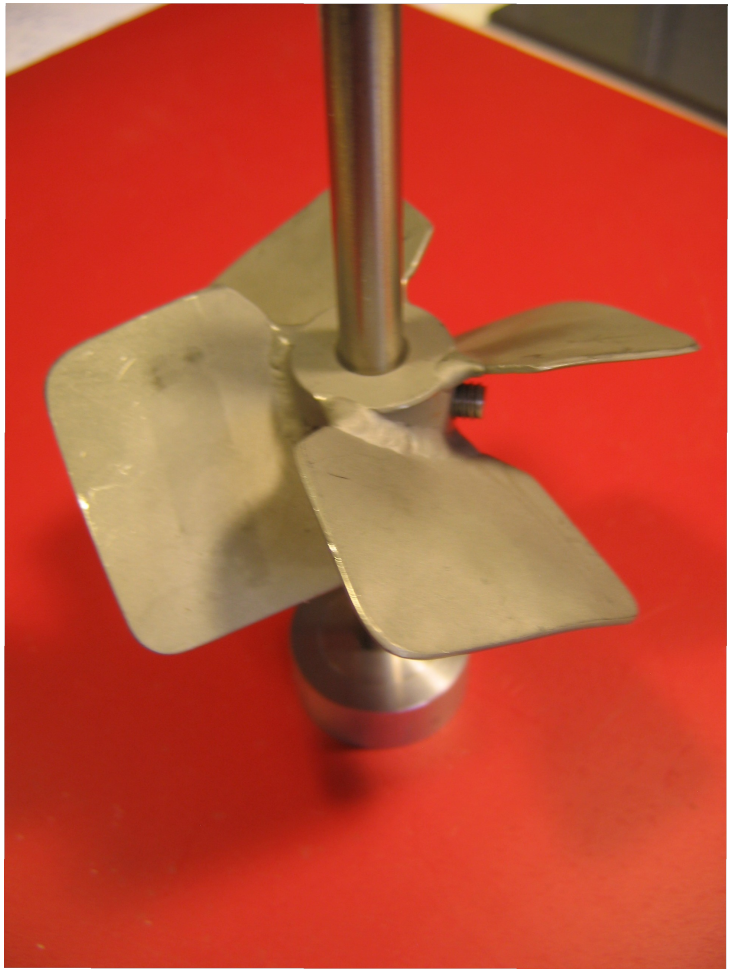
- Ungassed power number
- Np(CFD) = 0.78 – steady state CFD
- Np(Exp) = 0.79
- Nq(Lit)= 0.73
- Flow, inherently unsteady, Np ± 0.05



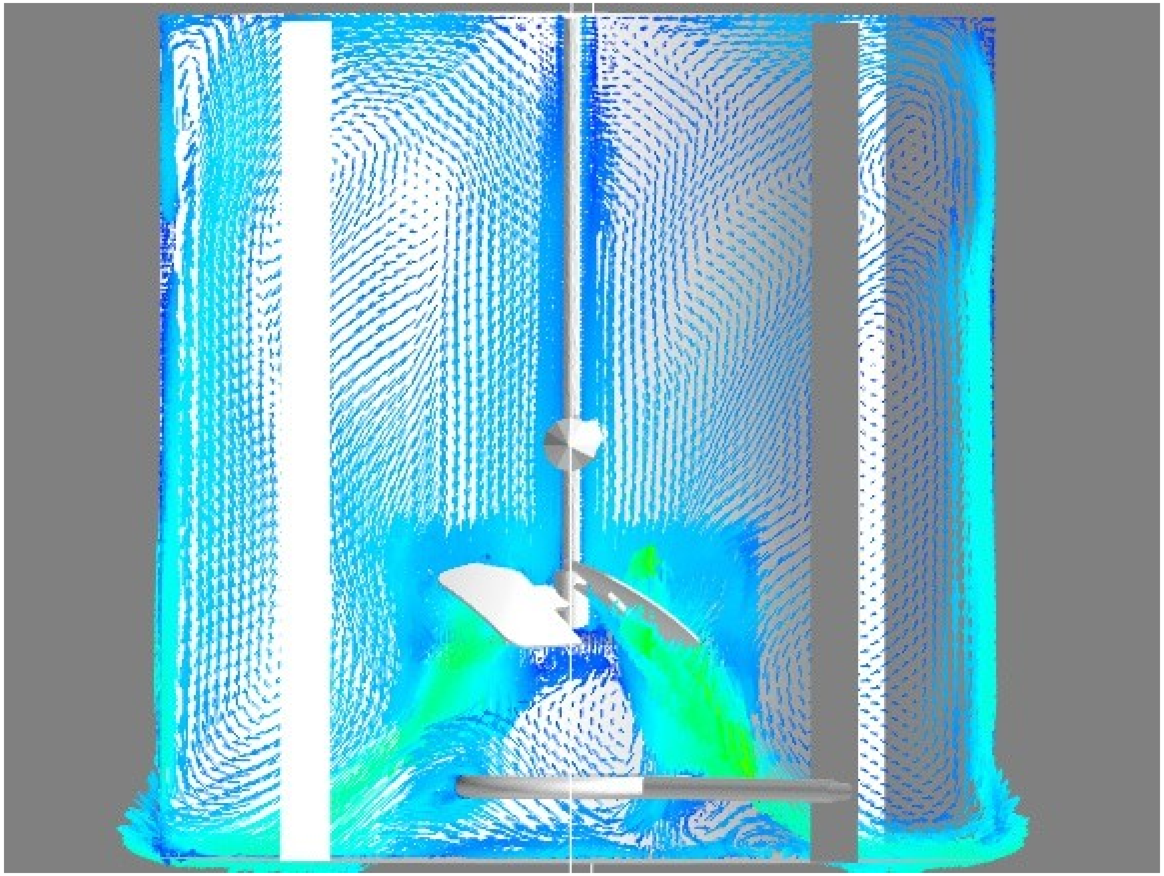


A315 Approximation

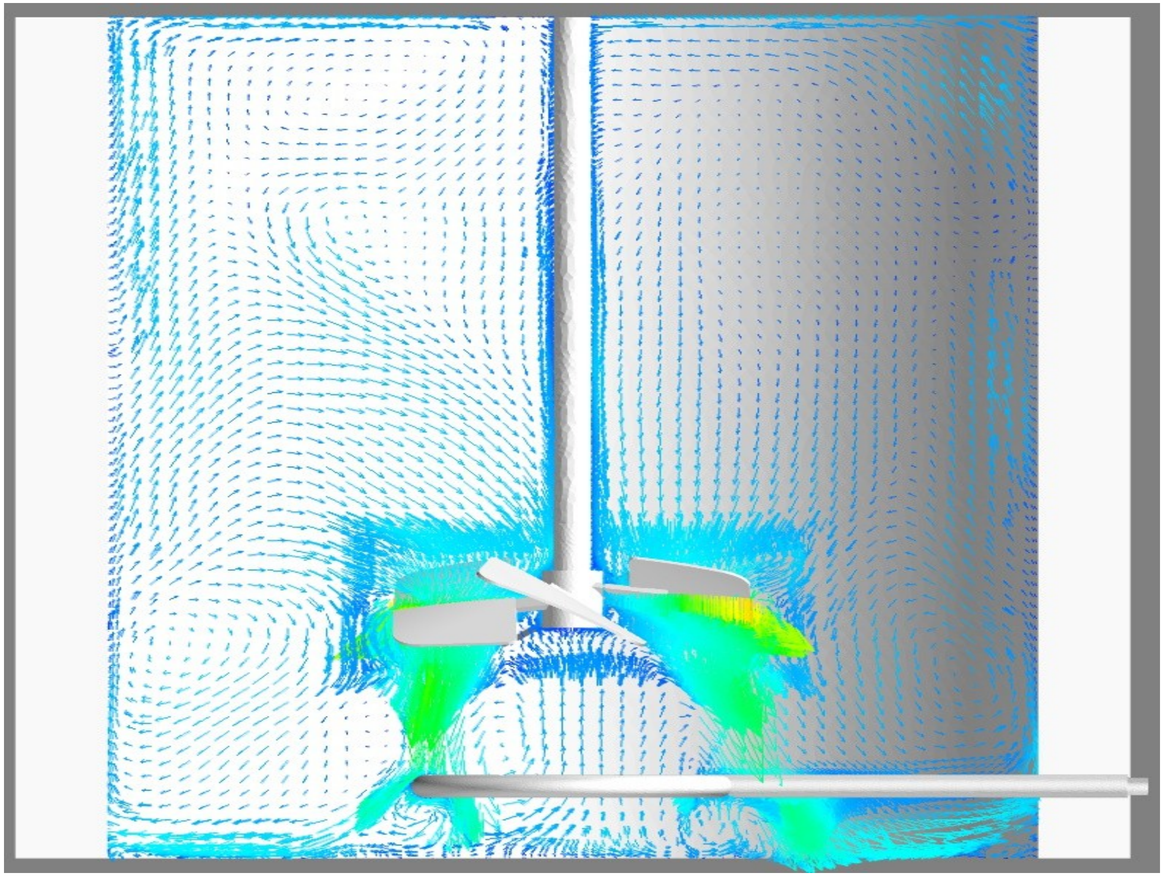




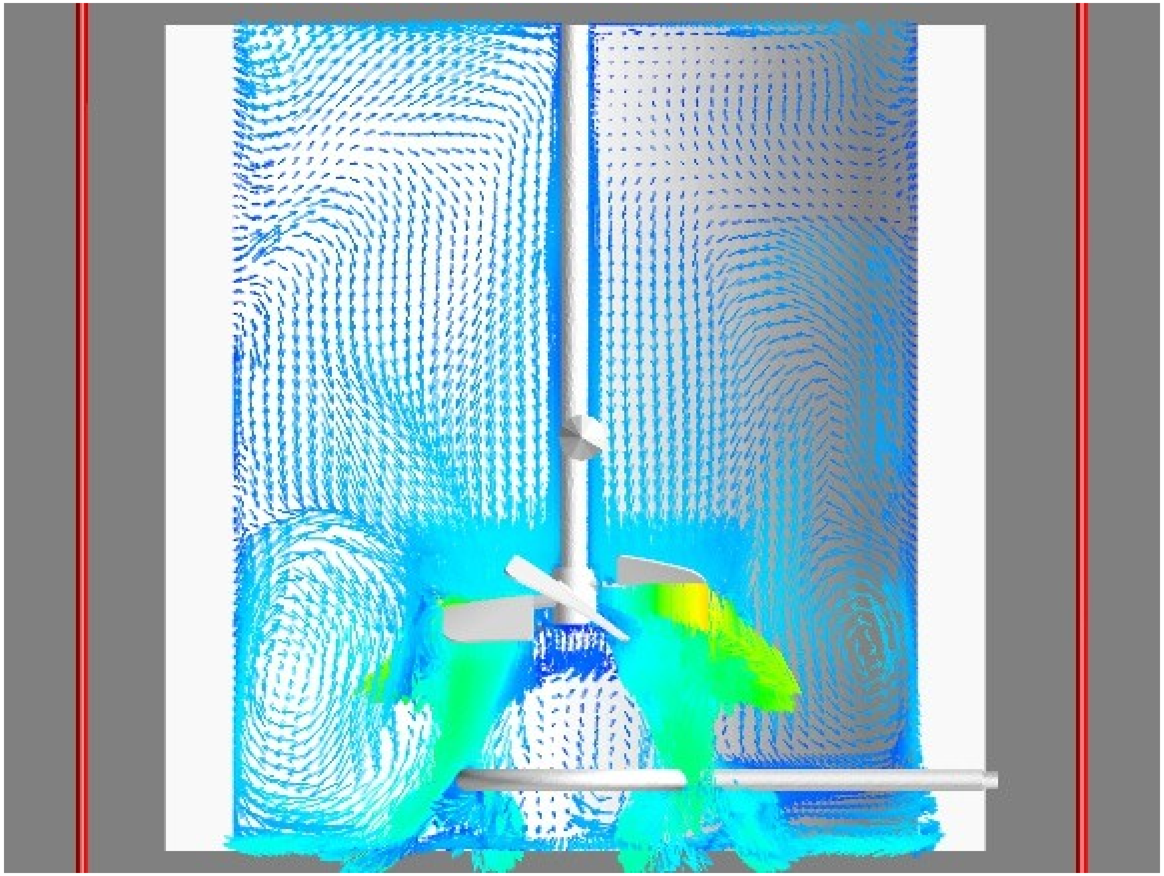
A315 Approximation
Ungassed Flow Solution 810 RPM



A315 Approximation Ungassed Flow Solution 810 RPM

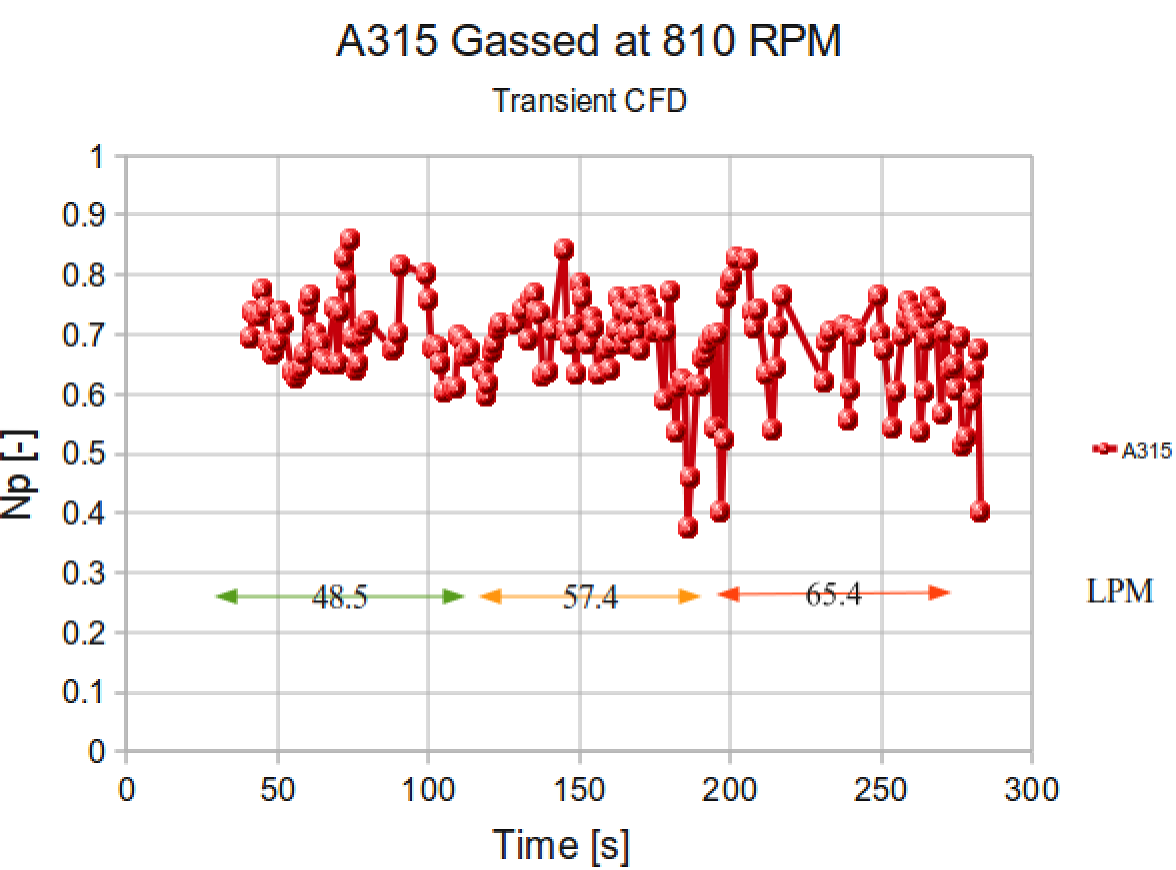


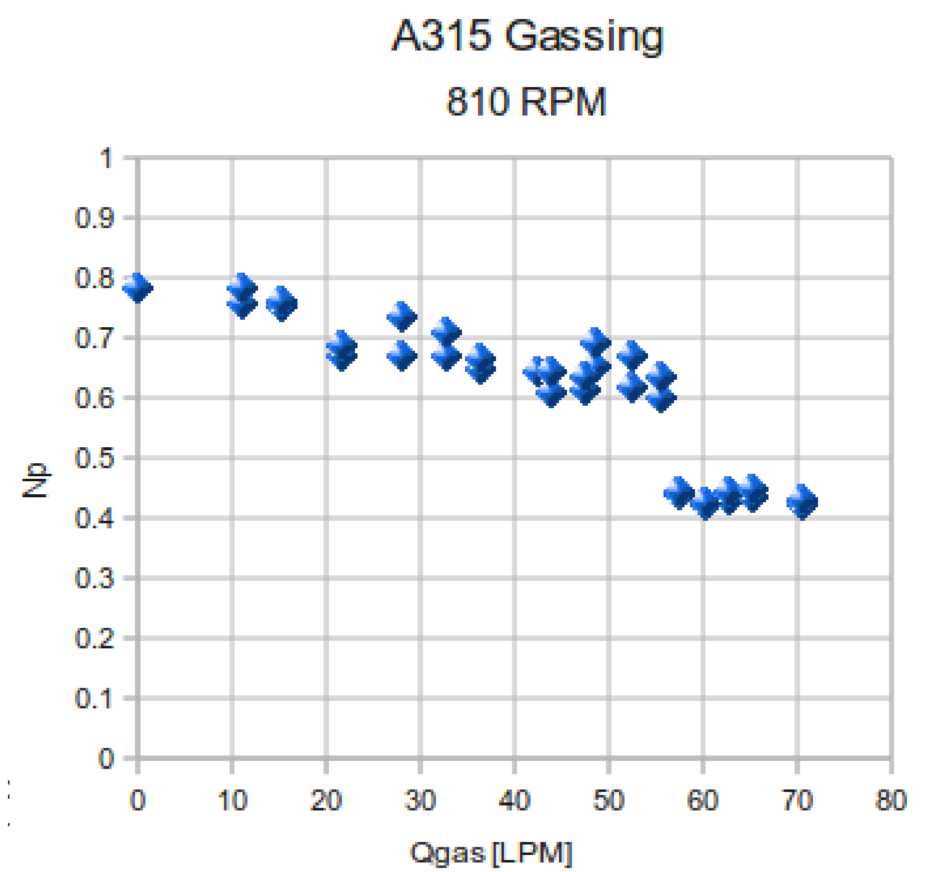
A315 Approximation Ungassed Flow Solution 810 RPM



Gassed power number data - A315

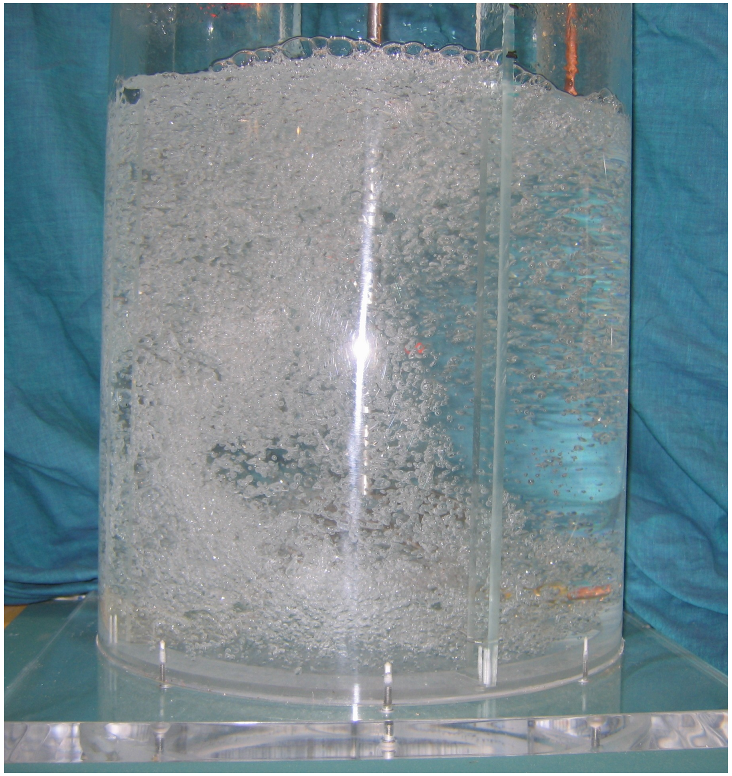
- Qg=48.5 LPM
  - Not flooded
  - NpCFD=0.70±8.3%
  - NpEXP=0.65±7.7%
- Qg=57.4 LPM
  - Flood point
  - NpCFD=0.68±12.5%
  - NpEXP=0.4-0.66±32.5%
- Qg=65.4 LPM
  - Flooded
  - NpCFD=0.67±12.9%
  - NpEXP=0.43-0.44±2.3%

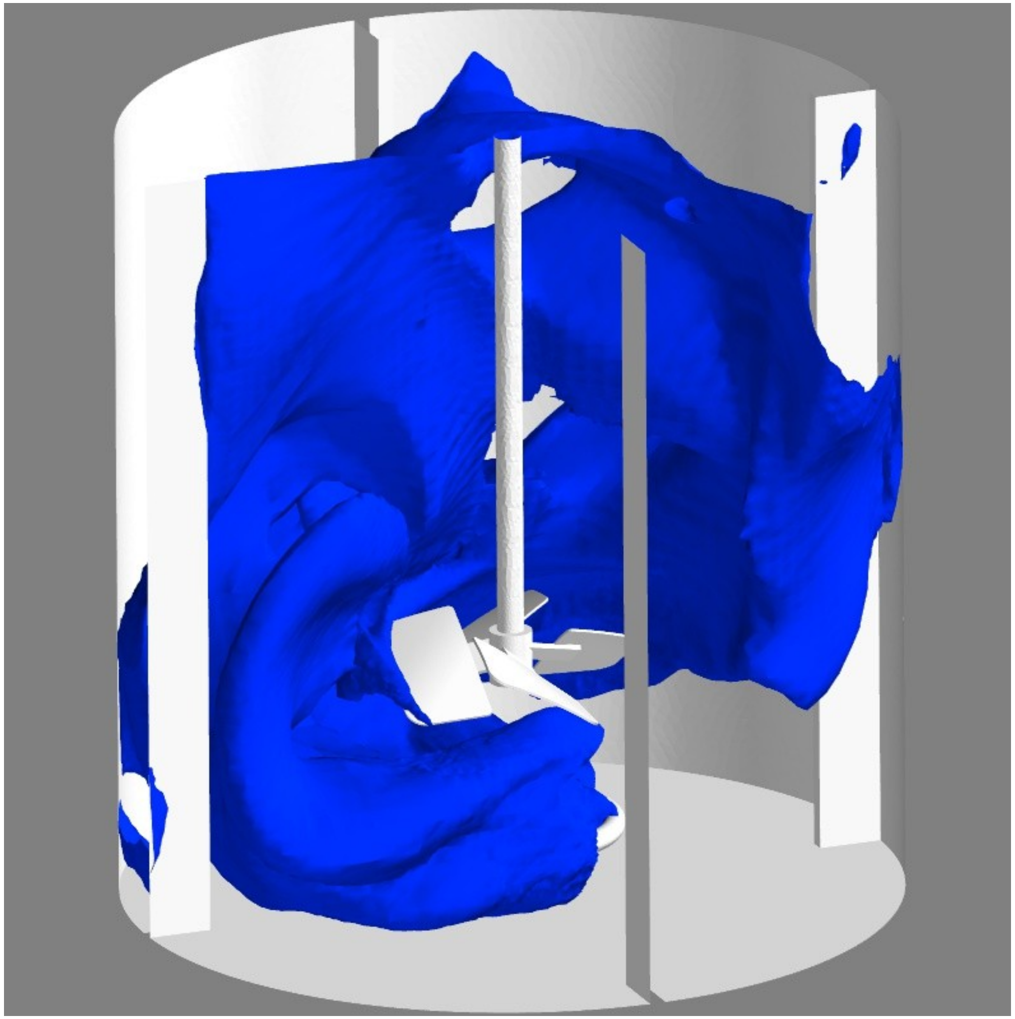




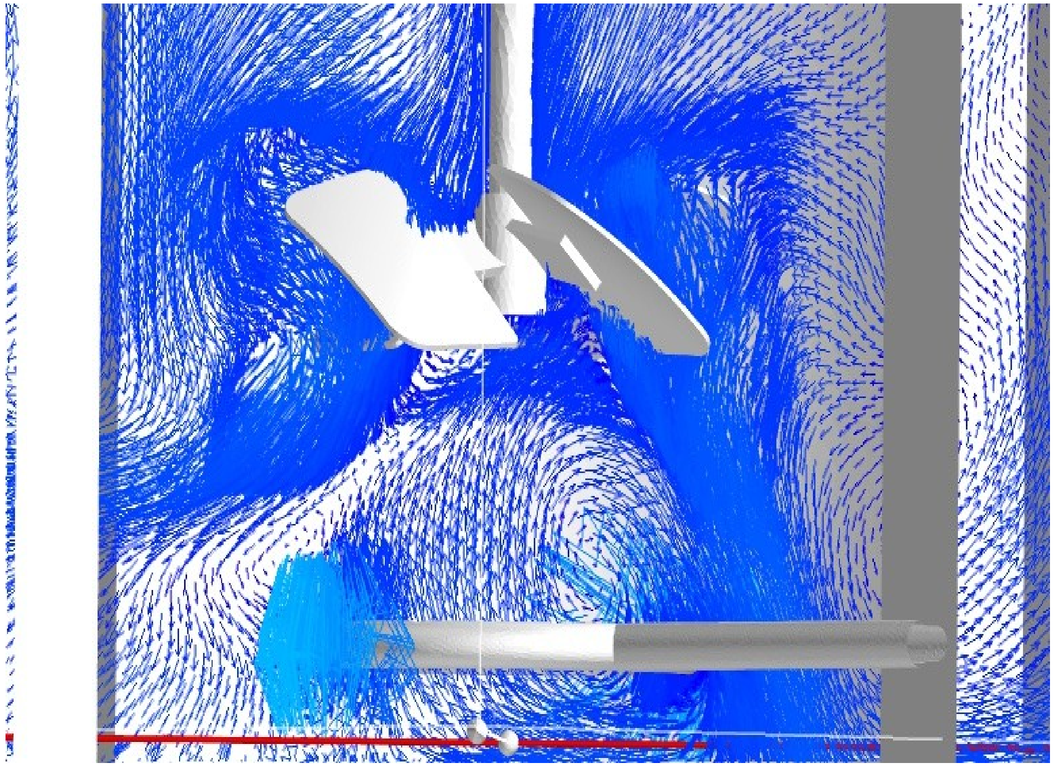
Gassed transport pictures

- Iso-surface of 5% v/v of gas at 810 RPM
- Not flooded



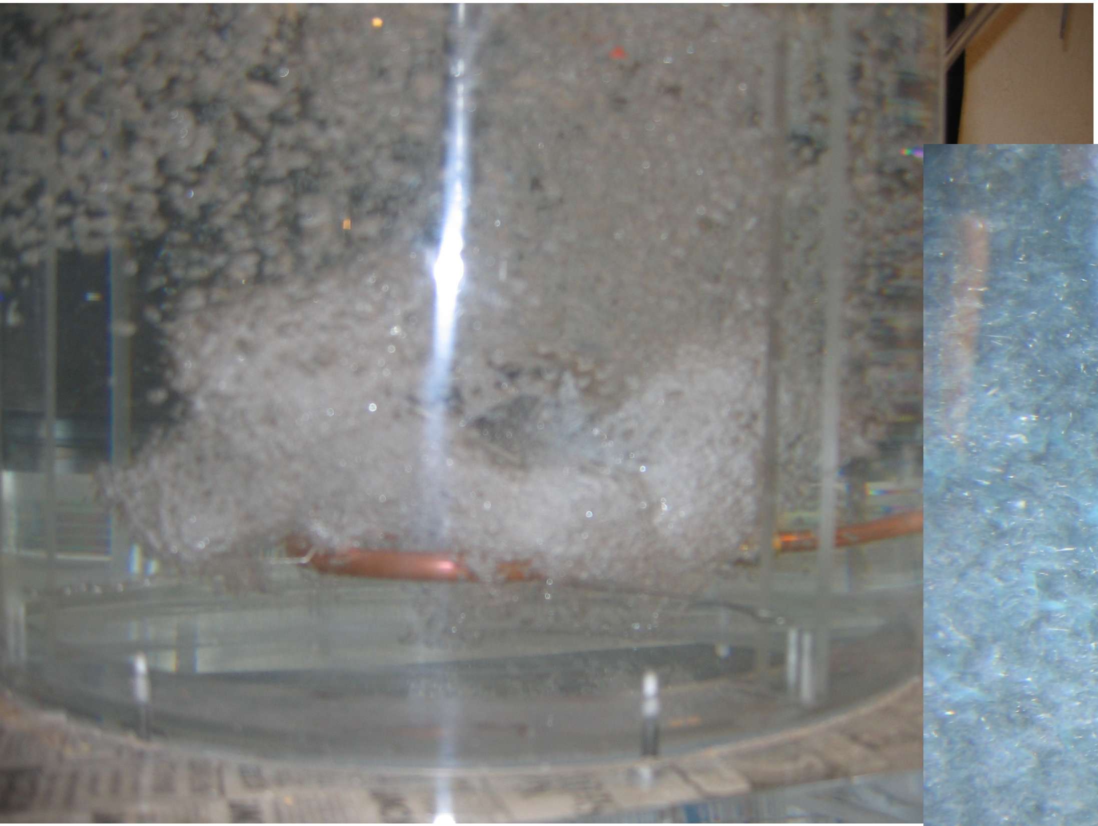


Flooded A315



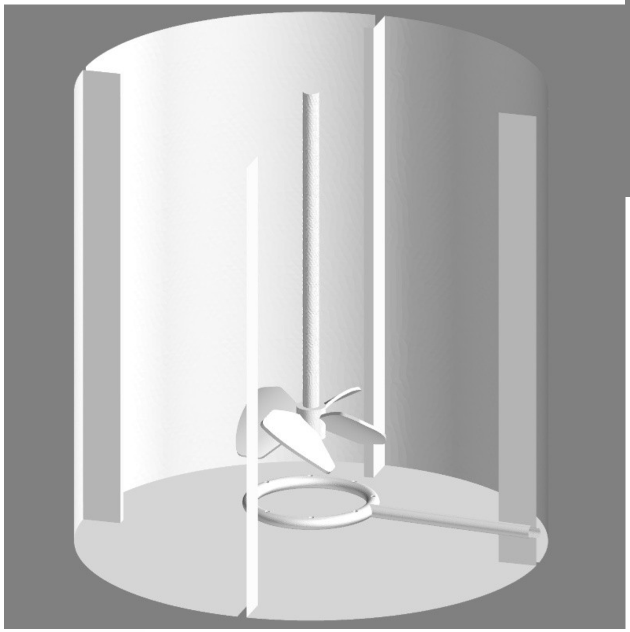
- Vector plot
- Iso-surface of gas concentration = 5% v/v

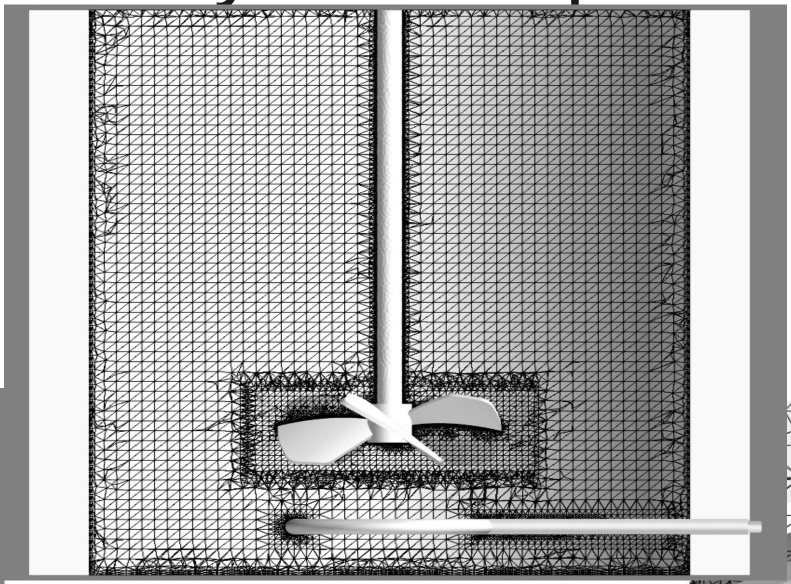
Some A315 experimental stuff

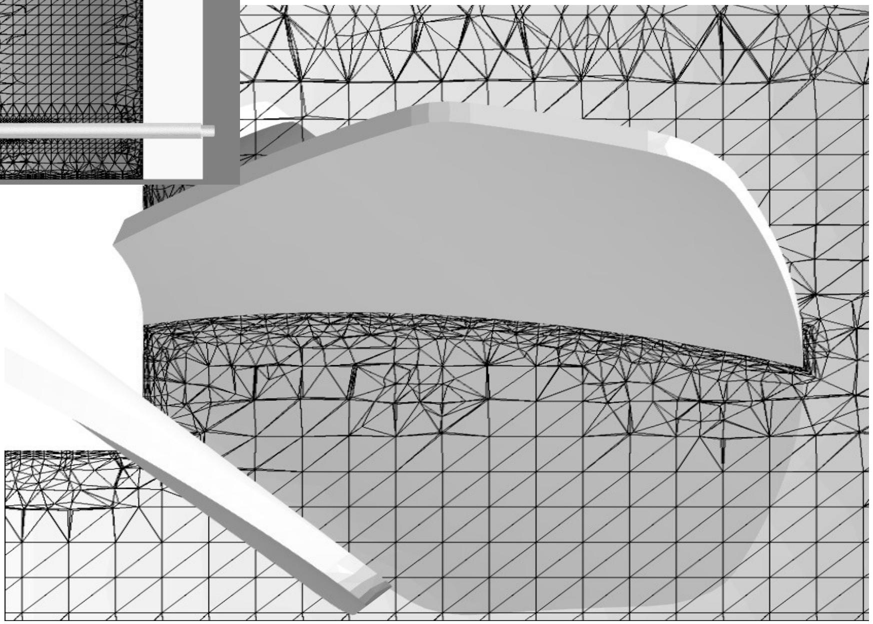


HS Approximation

- Idealized geometry from experimental impeller

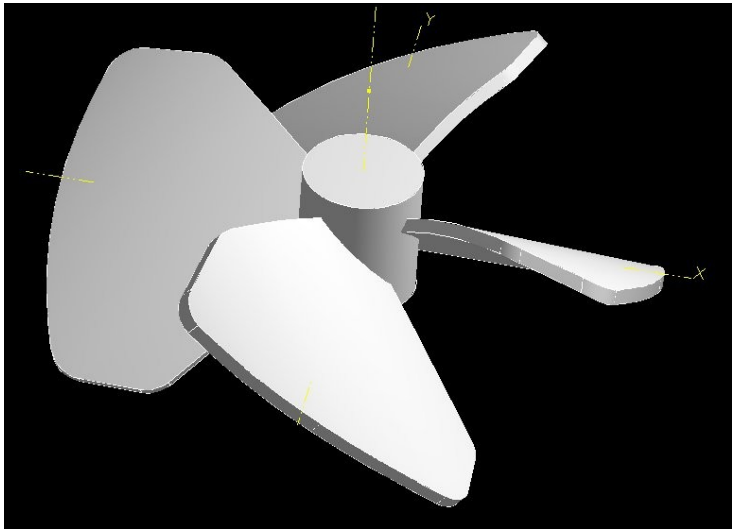


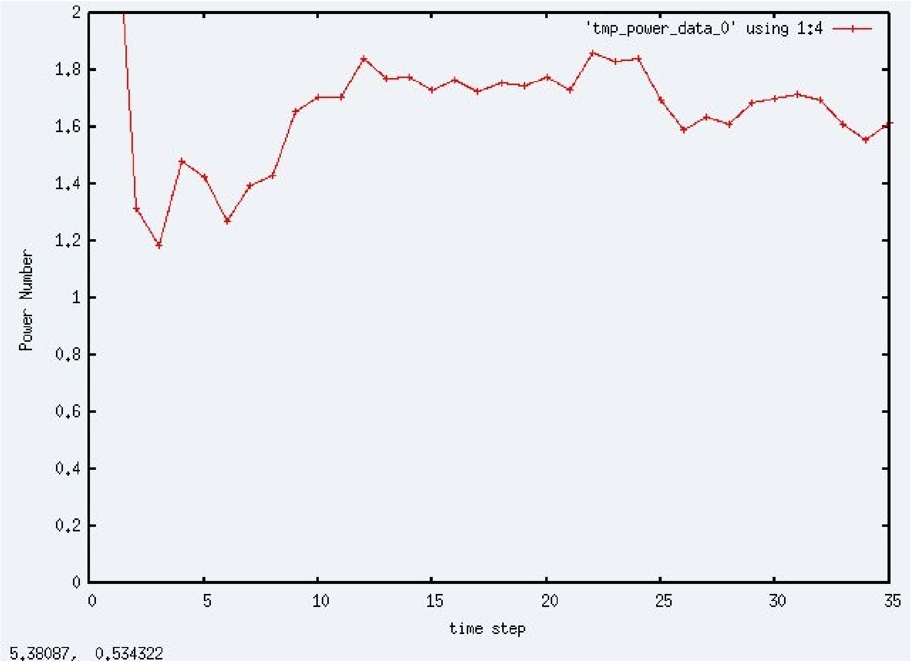




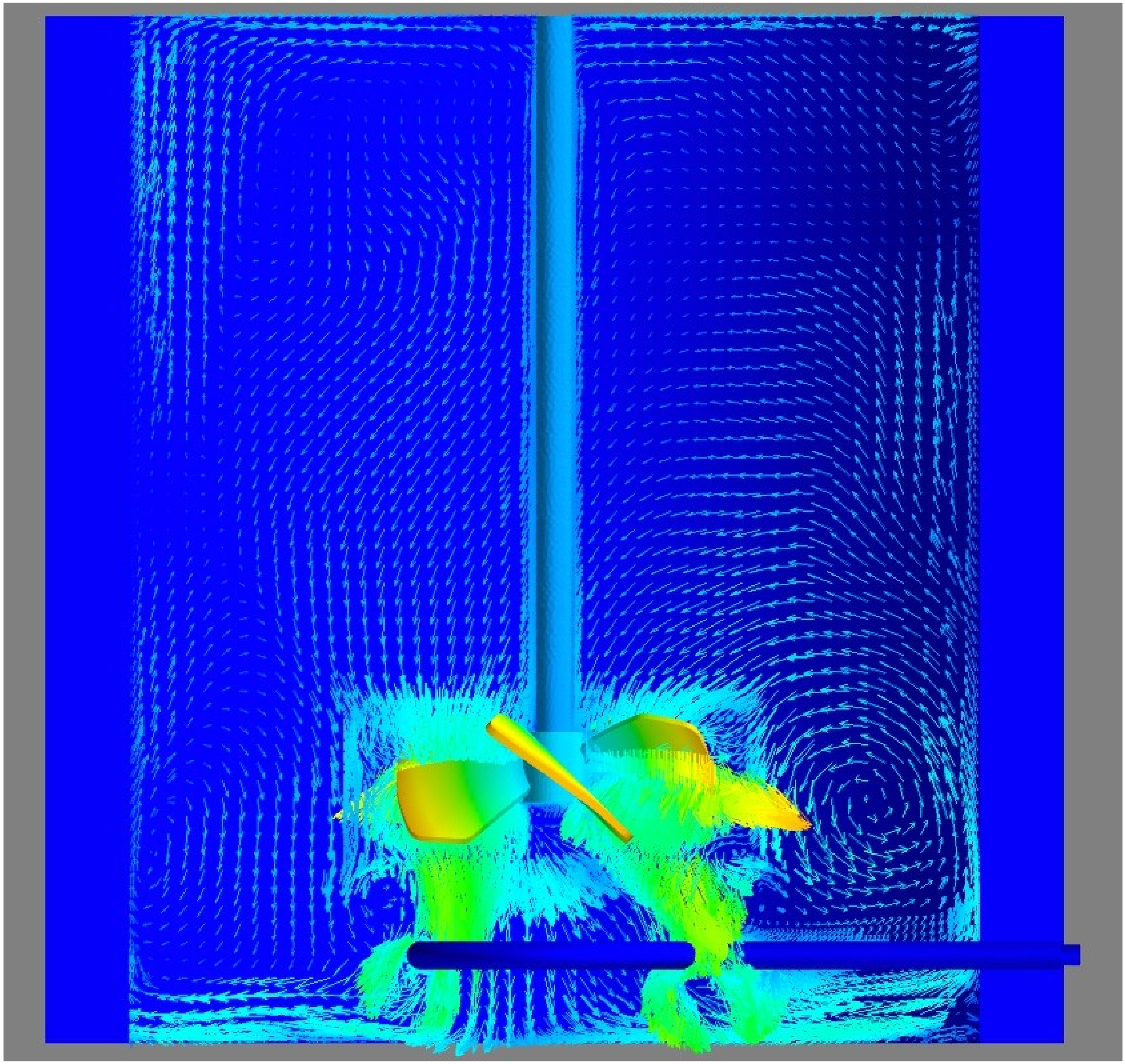
PM HS Approximation

- Idealized geometry from experimental impeller
- Ungassed Power number Np0=1.6, experimental Np0=1.35
- Nq0=0.94 (Np0=1.6) or Nq0=0.87 (Np=1.35)
- Flow, inherently unsteady



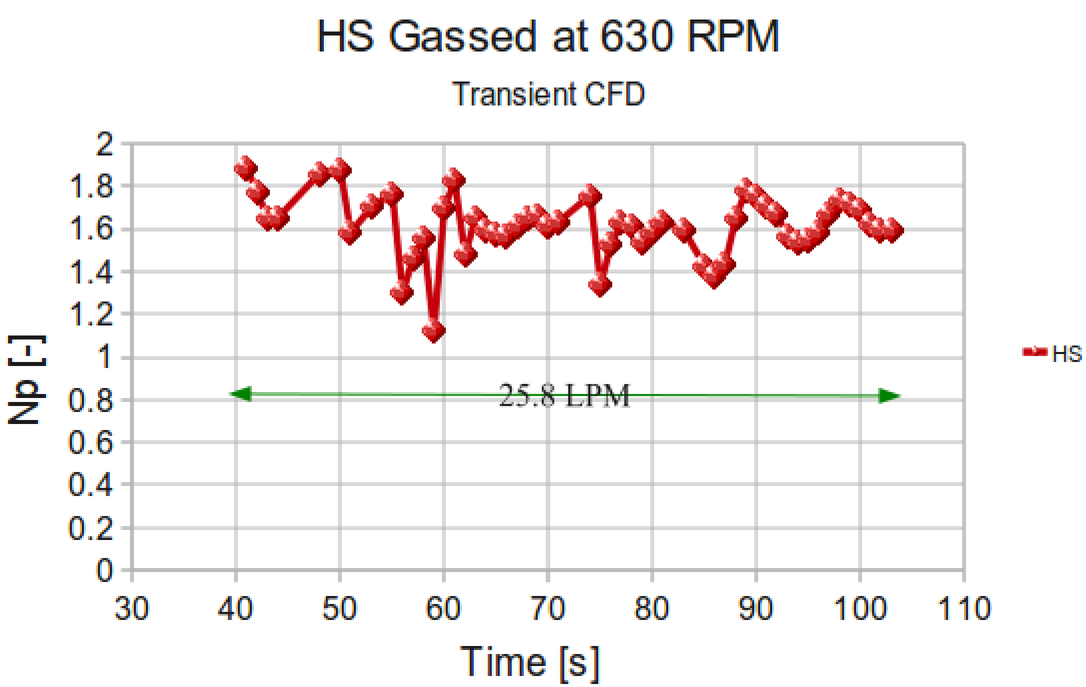


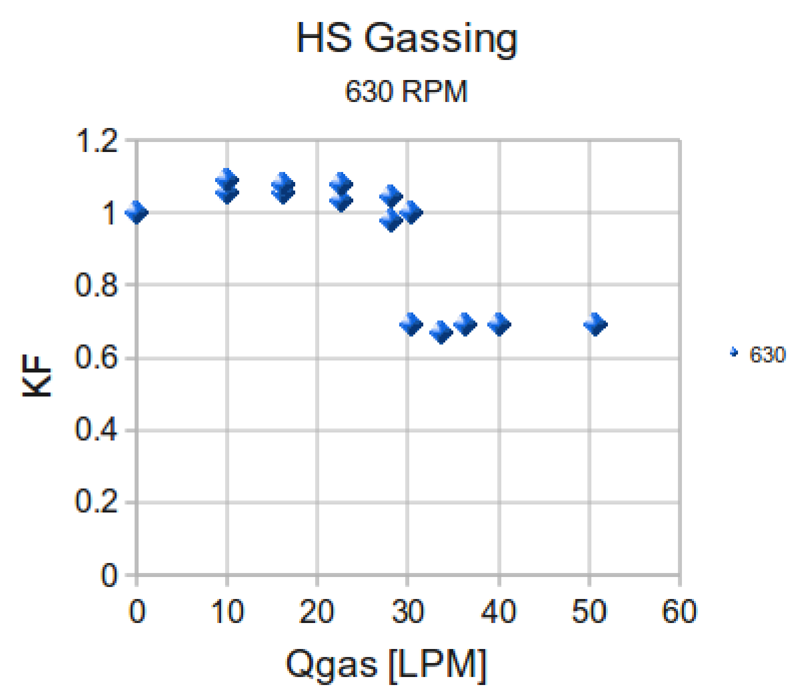
HS Approximation
Ungassed Flow Solution at 630 RPM



Gassed power number data - HS

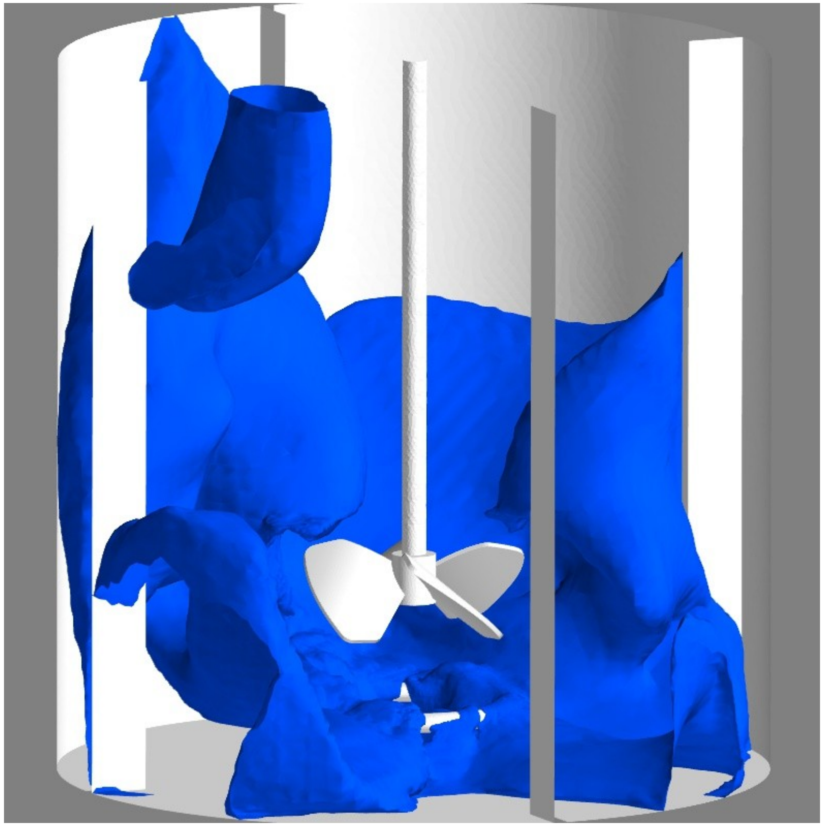
- Qg=25.8 LPM
  - Not flooded
  - NpCFD=1.61±8.8%
  - NpEXP=1.35±3.0%
  - KF=1.00±3.0%
- Qg=30.4 LPM
  - Flood point
  - NpCFD=Not done
  - NpEXP=0.93-1.34±18%
  - KF=0.69-1.0
- Qg=34.9 LPM
  - Flooded
  - NpCFD=Not done
  - NpEXP=0.93-0.93±0%
  - KF=0.69





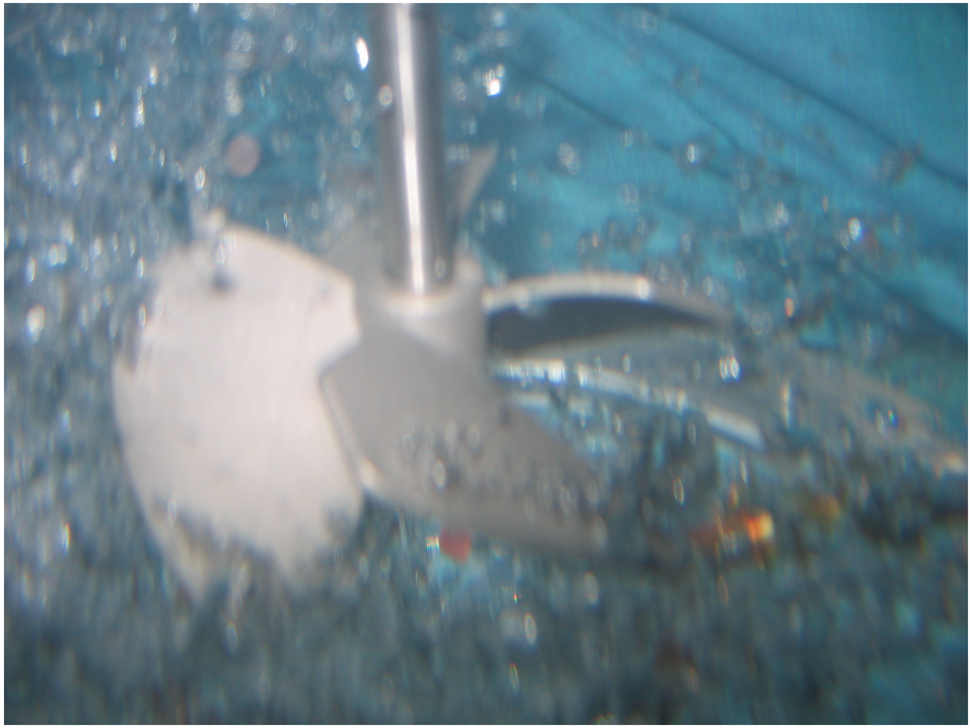
Gassed transport pictures

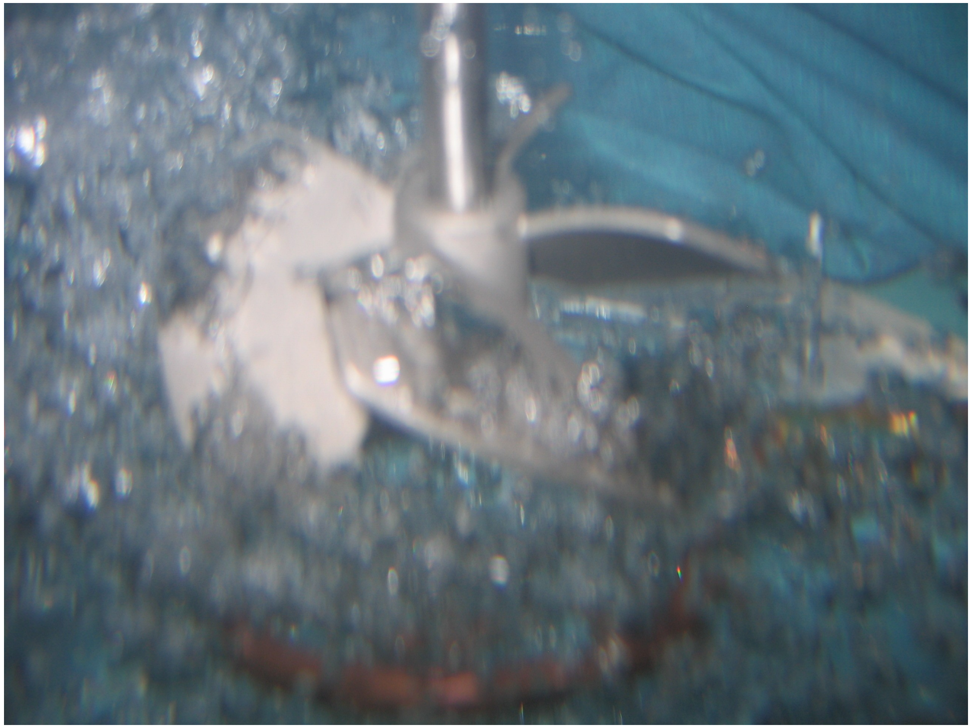
- Iso-surface of 1% v/v of gas at 630 RPM after 56 s
- Not flooded



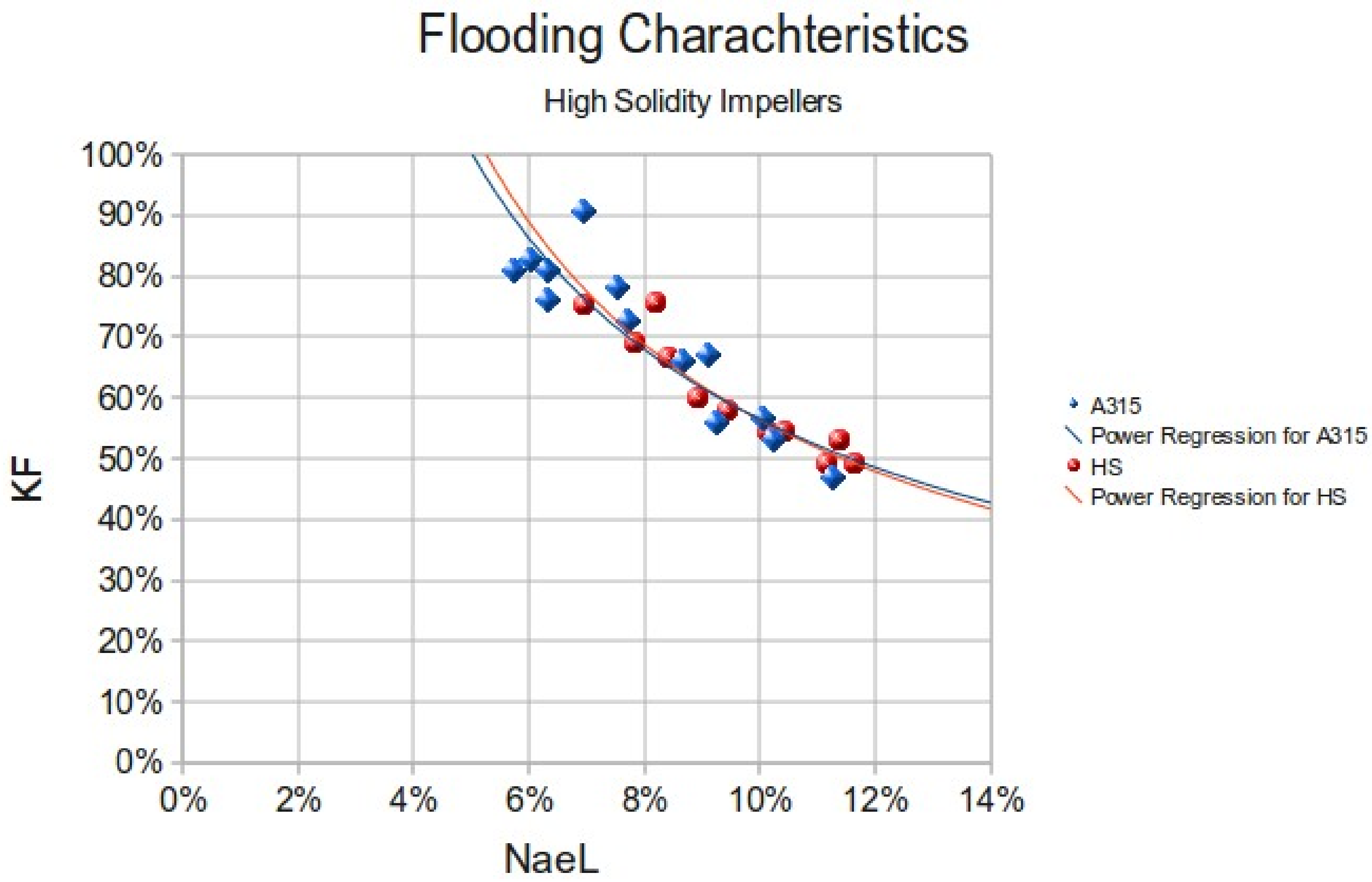
- Iso-surface of 1.25% v/v of gas at 630 RPM after 62 s
- Not flooded

Some HS stuff

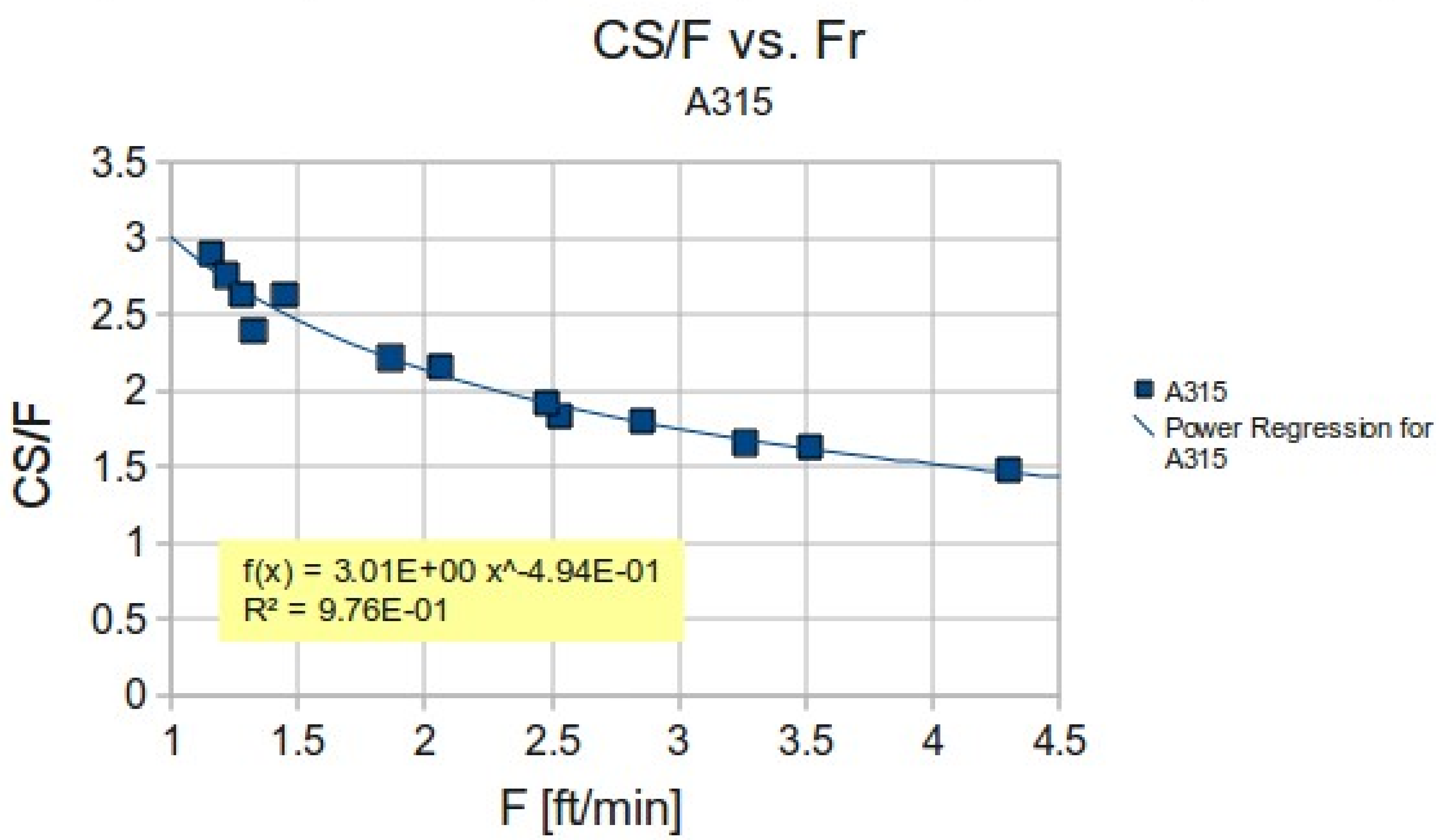




Only HS – A315 comparison



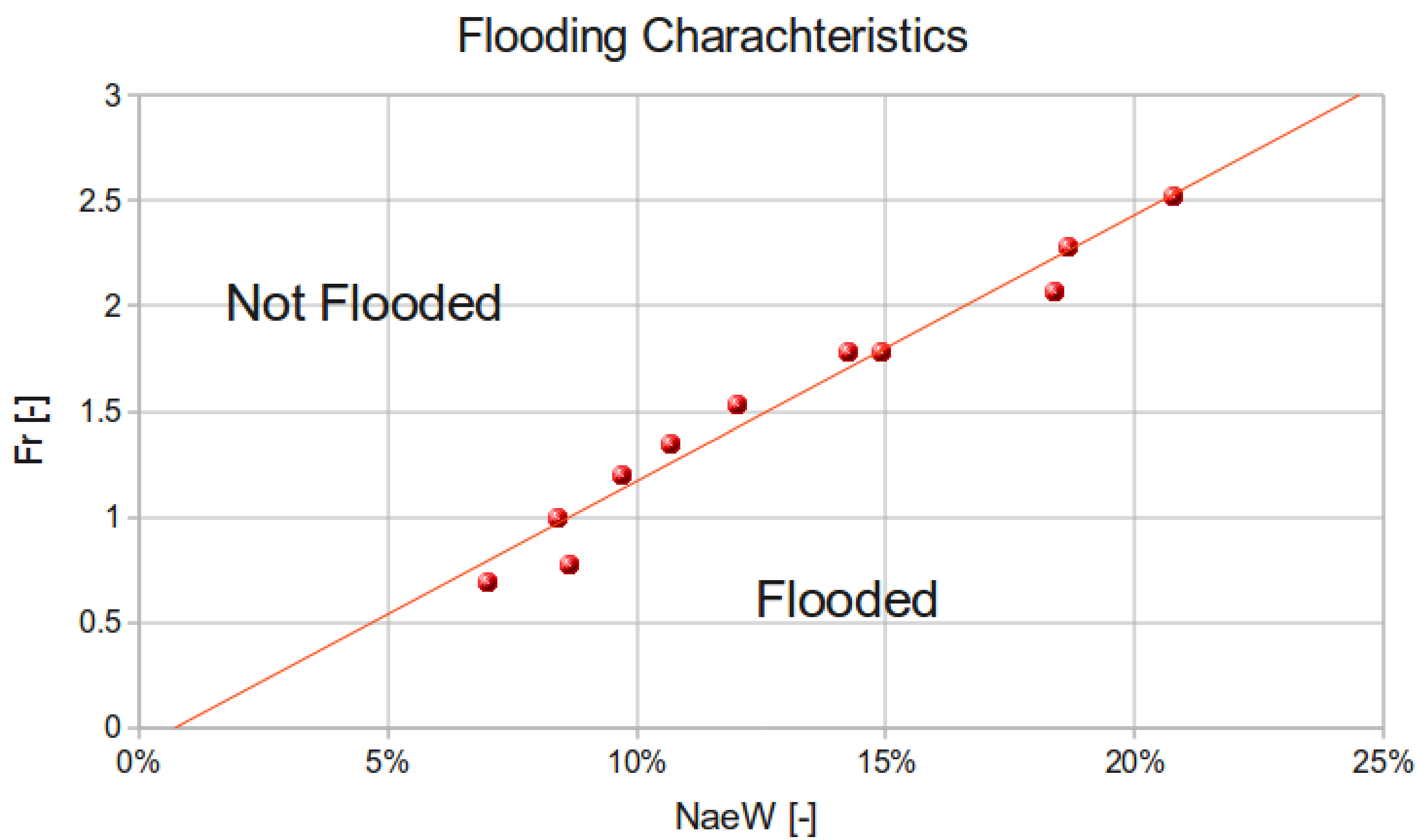
A315



CS/F vs. Fr
A315
3.5
3
2.5
2
1.5
1
0.5
0
CS/F
1
1.5
2
2.5
3
3.5
4
4.5
F [ft/min]
f(x) = 3.01E+00 x^-4.94E-01
R² = 9.76E-01
A315
Power Regression for A315

Scale-up

- Consequences of scaling up on Froude Number



Conclusions

- Experimental
  - Experiment appears to be working on a shoestring budget
  - High Solidity Hydrofoils can also be correlated like the Rushton and Smith Turbines
    - When a radial floods Npg has a step change increase
    - When an axial floods, Npg has a step change decrease
  - First time public report on the PMS HS impeller
  - Both high solidity hydrofoils behave similarly
  - This and more will soon appear on my new website www.postmixing.com
    - Many more impellers will be described on the Impeller Page including Ekato's IsoJet B (Np=1.1-1.15)

Conclusions

Computational Work

- Acusolve has shown potential for dealing with very complex problem in an approximate fashion
- The variable density / variable viscosity approximate model approach has demonstrated some potential
- Viscosity model helps reduce general unwanted diffusion
- Model needs to be calibrated for flow rates / bubble sizes, etc.
- Need to investigate the local highly unsteady behavior with variable time steps, and better convergence metrics which are available in Acusolve.
- Accuracy considerations in the above, may require a full transient with sliding mesh
- All of these capabilities are available in Acusolve.
- Perhaps need a bit more powerful computer

Thank you

- I would like to thank **Richard Kehn** of Lightnin for willingly giving me an A315 to experiment with, even after he knew I would also be looking at his competitor's impeller
- I would like to thank **Bob Dowd** of PMS for giving me a bag full of impellers to play with (including the HS) about 5 years ago, which allowed us to come up with the premise of this project in the first place.