

Wet Stack Fine Particulate Method/CEMS Development

Measurement Technology Workshop
January 29, 2013



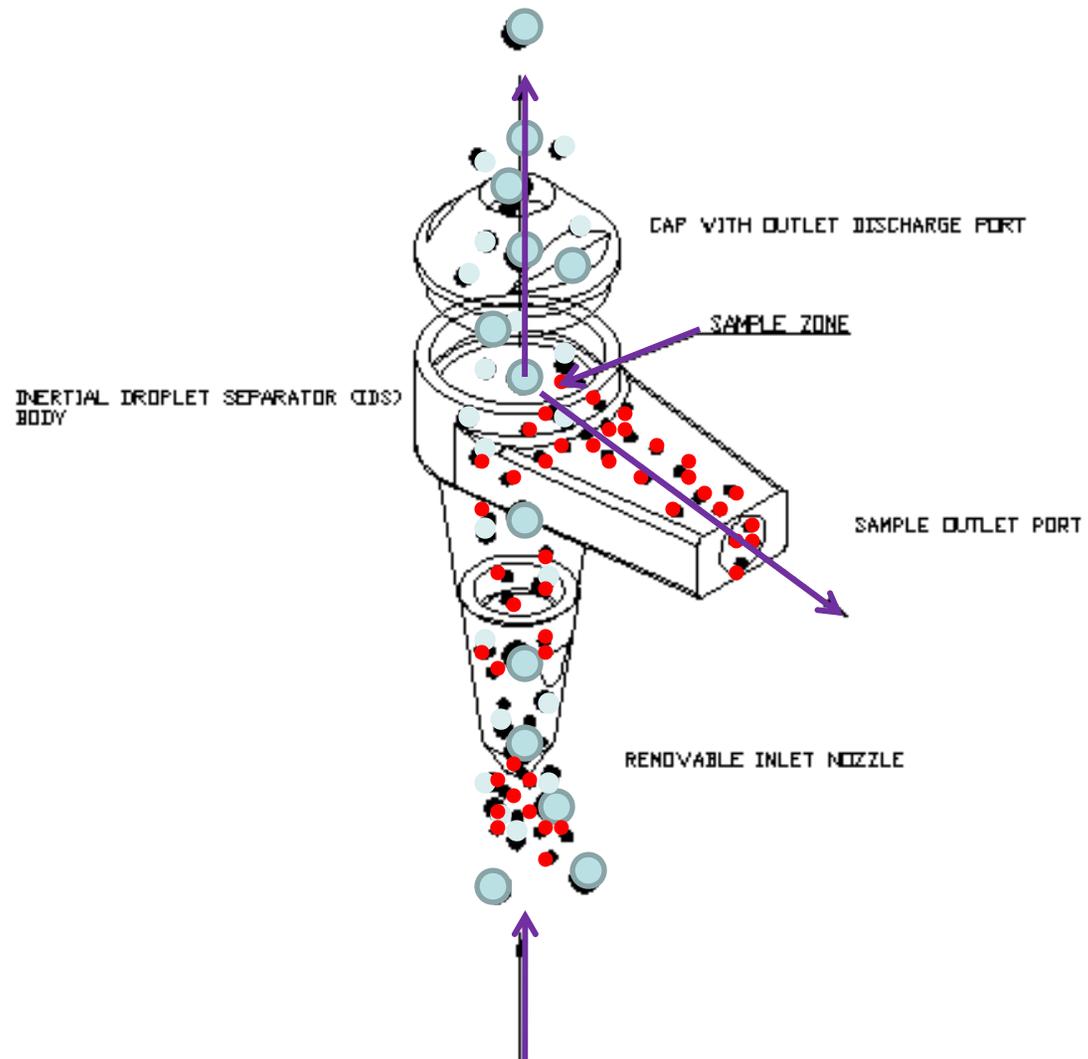
Presentation Topics

- Review of project objectives
- Why monodisperse (MD) test the IDS?
- Test apparatus set up and protocol
- Initial MD test results
- Computational Fluid Dynamics (CFD) modeling of IDS & design modifications
- MD test results for modified IDS (version 5)
- Plans for next steps

Project Objective

Overall goal is development of a method and CEMS for measurement of PM 2.5 under wet, super saturated stack conditions.

IDS DROPLET SEPARATION



IDS/ADS



ADS



Why Monodisperse Test The IDS?

- Polydisperse aerosol tests conducted using the Baldwin Environmental wet-stack simulator:
 - Provided indication of IDS separation performance
 - Lacked desired precision regarding cut point & collection efficiency at key particle size(s)

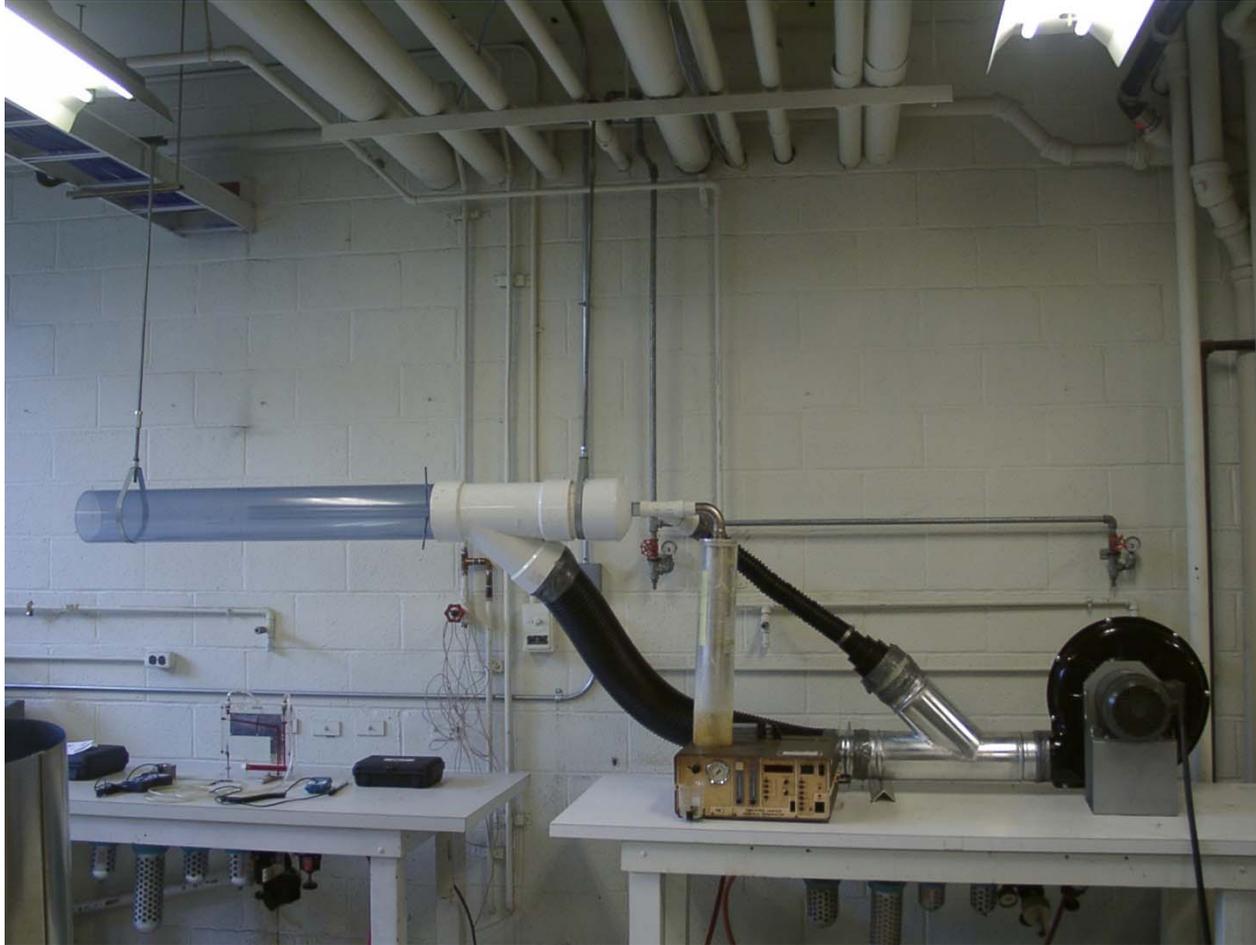
Monodisperse Test Description at University of Minnesota

- Determine IDS sample collection efficiency of various sized liquid aerosols up to 15 μm ;
- Plot collection efficiency curves;
- Determine the D_{50} particle size;
- Verify sample collection efficiency vs. sample loss

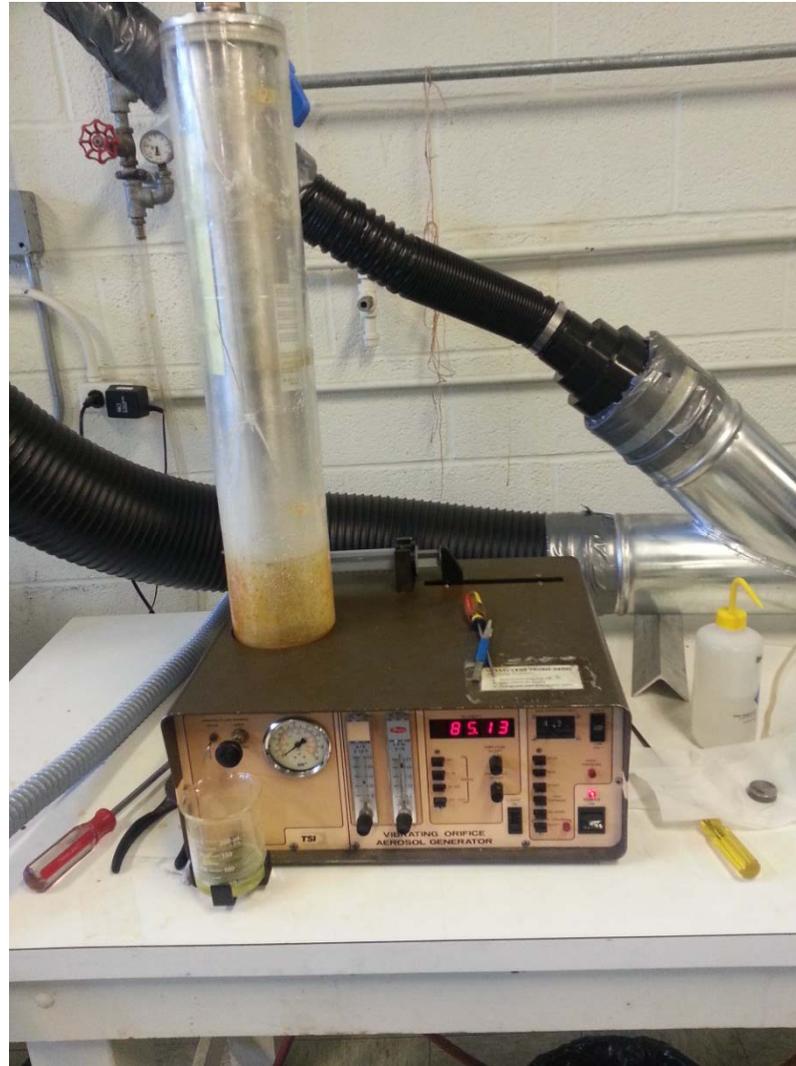
Monodisperse Droplet Test Protocol (cont.)

- Test medium: Fluorescent dye oleic acid
- Use VOAG (Vibrating Orifice Aerosol Generator) to generate known mono-dispersed droplets, verified by an Aerodynamic Particle Sizer (APS) .
- Conduct IDS test runs within a 6” duct, at 20m/s velocity, ambient temperature, pressure, and relative humidity.
- Confirm a flat velocity profile at the sample point, perform a velocity profile before and after each test.
- Conduct three (3) test runs at each droplet size.
- Record fluorometer readings of sample fractions.

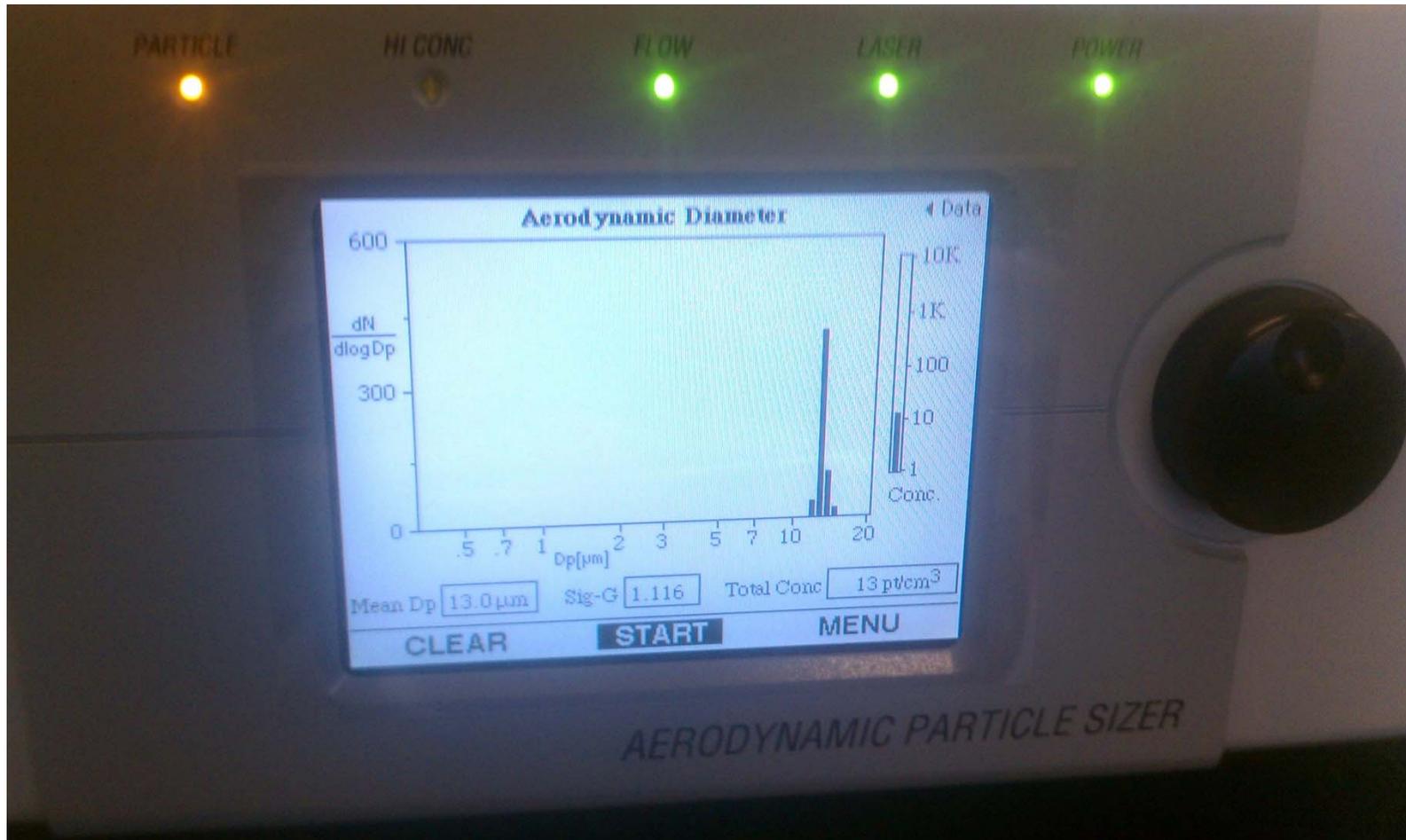
Monodisperse Test Apparatus (University of Minnesota)



Vibrating Orifice Aerosol Generator (VOAG)



TSI 3321 Aerodynamic Particle Sizer



Test Apparatus - Exit End View



Original IDS Test Position



Original IDS Test Position with Filters



QAAP Performance Criterion for IDS Flow Rate of 5 lpm

Particle Sampling Efficiency	
Particle Size (μm aerodynamic diameter)	Sampling Efficiency (percent)
Greater than 100	Zero \pm 10%
Equal to 20	Greater than 50%
Less than or equal to 10	100 \pm 10%

Original IDS Monodisperse Collection Efficiency Test Results

Aerosol size (um)	Collection Efficiency (percent)	Comments Collection Efficiency Compared to Isokinetic Filter or Active Filter
14.93	24.8/29.8	Isokinetic Filter/Active Filter
8.19	39.0	Isokinetic Filter
4.82	58.2	Isokinetic Filter

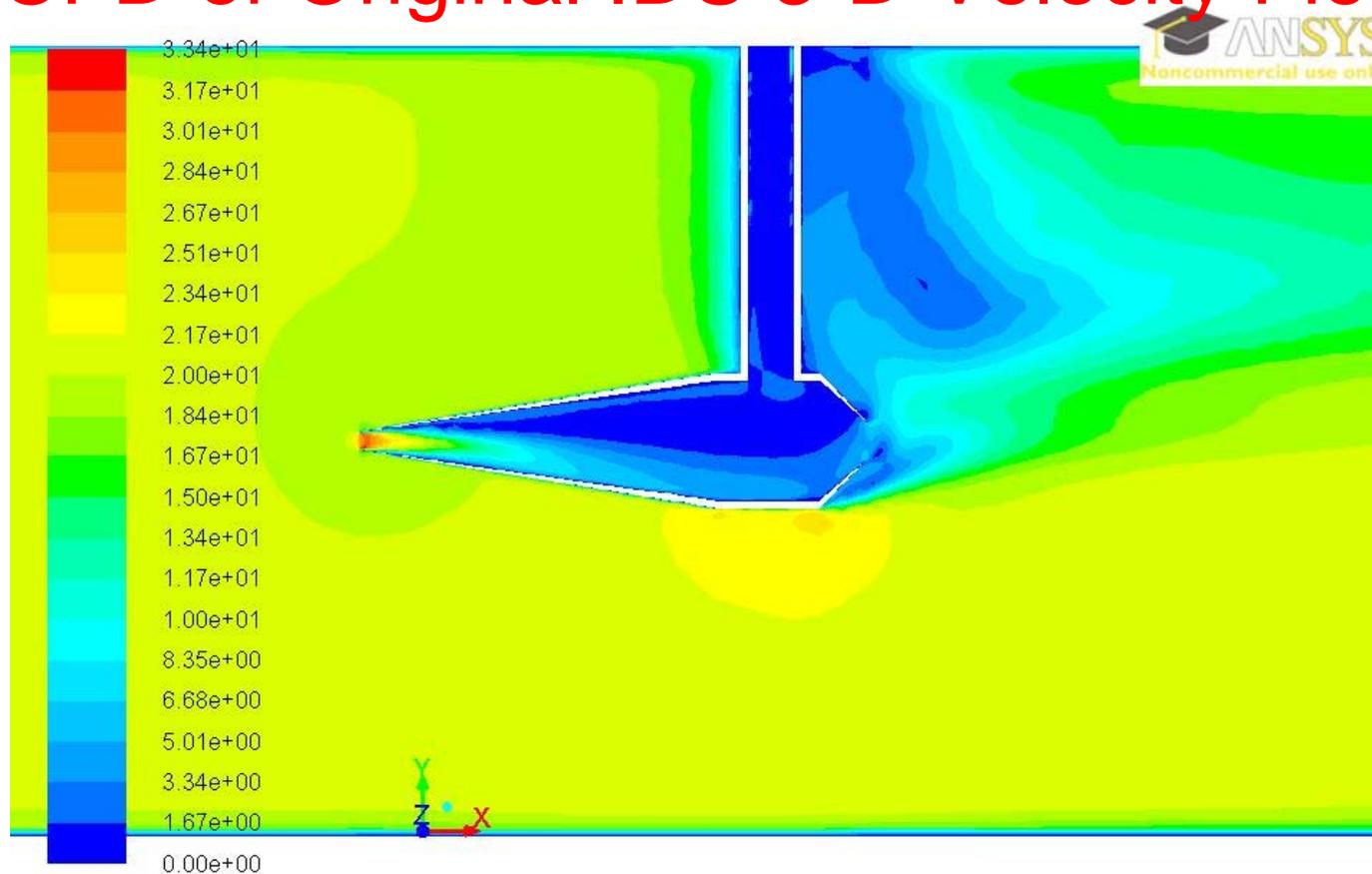
Empirical Test Conclusion Directed Us Back to the Drawing Board

- Lower cone losses unacceptable.
- Something wrong with cone angle?
- Is velocity at sample zone critical?
- Did not meet target performance:
 - D_{50} at 12 μ m or better
 - Sampling Efficiency at 5 μ m >90%
- Need to computer model the IDS for maximum performance

Using Fluent Software, Computer 3-D Model of the Original IDS:

20 m/s Stack Velocity,
16° Nozzle Cone Angle,
0.192" Inlet Nozzle
Sample Zone 31.8 mm diameter
Cap 0.290" Outlet Nozzle
5 LPM Sample Pull

CFD of Original IDS 3-D Velocity Field

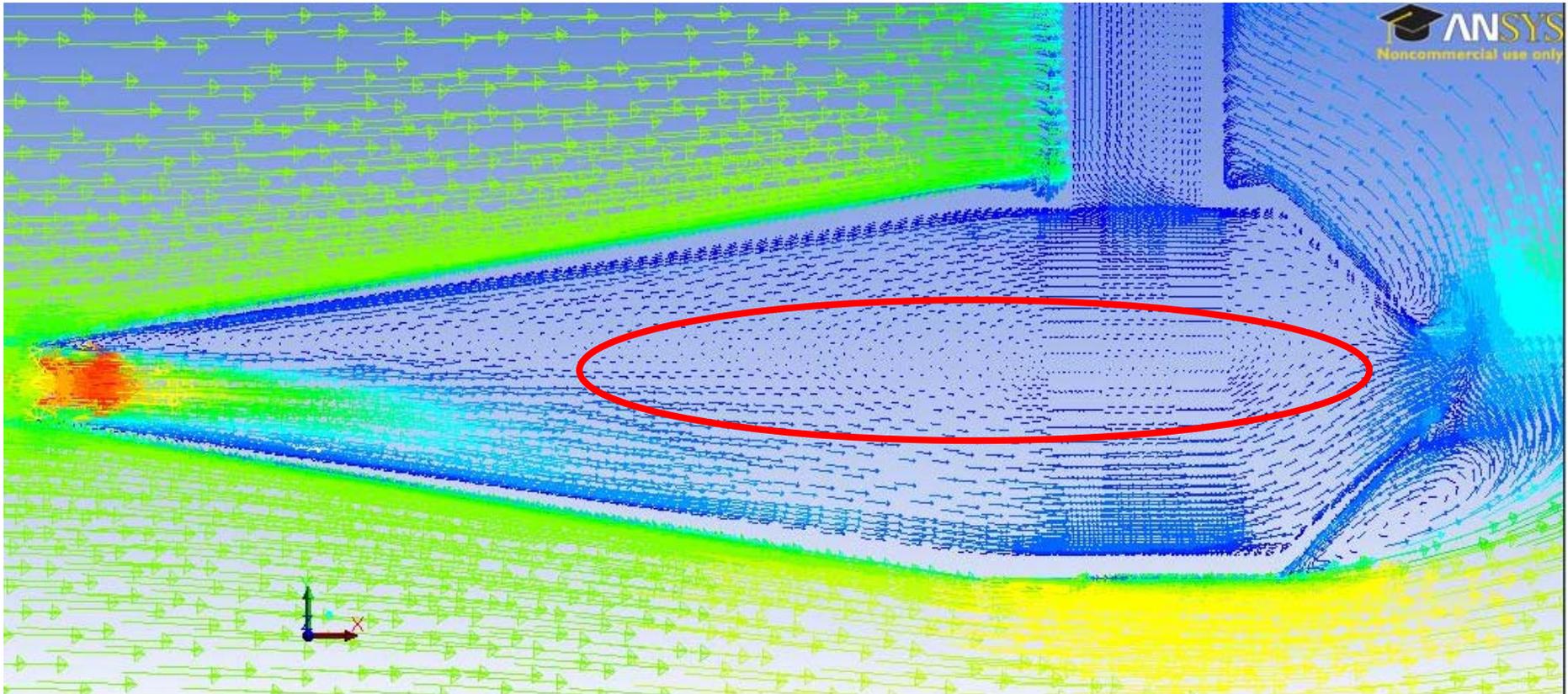


Contours of Velocity Magnitude (m/s)

Jul 17, 2012
ANSYS FLUENT 13.0 (3d, dp, pbns, rke)

This plot shows the velocity contours along the cross section bisecting the IDS. The strangest part of the flow-field shows an acceleration away from the sampling inlet. Mass balance is maintained, and the sampling rate of 5 lpm has been verified. The unintuitive flow potentially appears as a result of anisotropic pressure gradients in the IDS exit flow.

3-D IDS Velocity Vectors



By Velocity Magnitude (m/s)

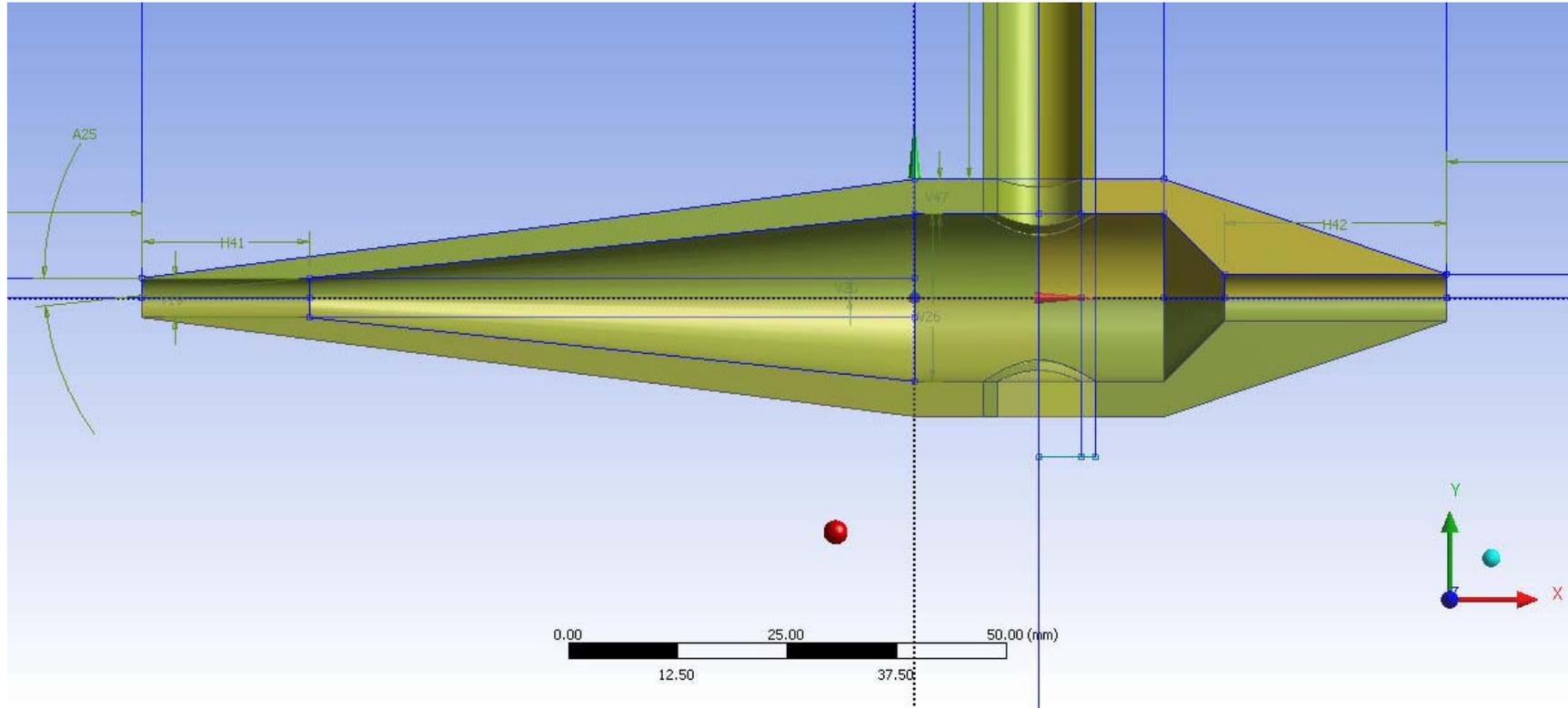
Jul 17, 2012
ANSYS FLUENT 13.0 (3d, dp, pbns, rke)

This plot shows the velocity vector field along the cross section bisecting the original IDS. There is a counter-clockwise flow around the red circle! Further exploration of the results using a transient state model did NOT show this circulation significantly oscillating nor dispersing. This could explain the low collection efficiencies of the original IDS during the wet stack simulations.

Various IDS Configurations



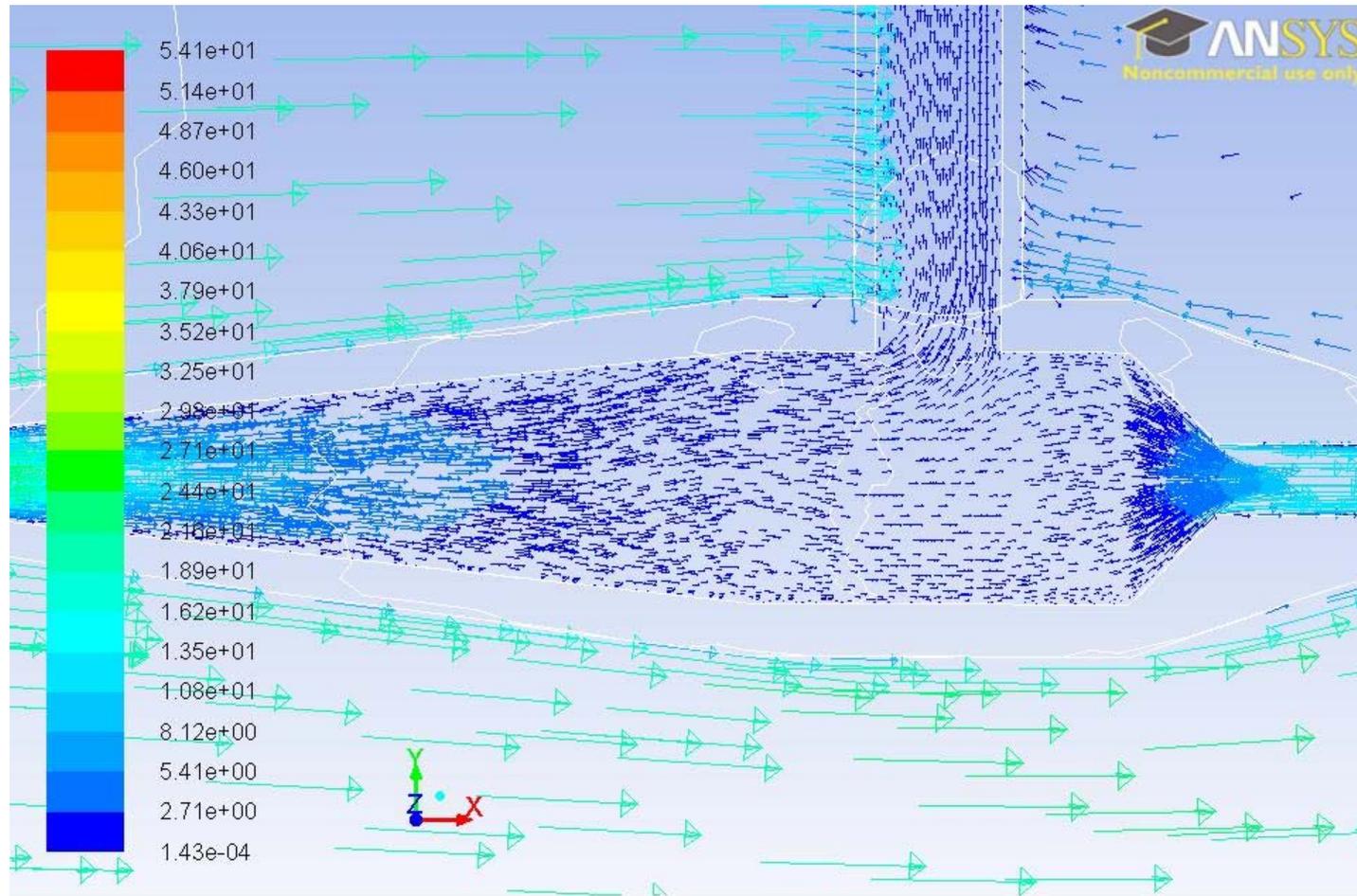
The Modeled V5 IDS



IDS Nozzle Inlet Diameter: 4.52 mm (0.178 in.)
Nozzle Cone Angle: 12°
Nozzle Extension Length: 19.05 mm (3/4 in.)
Sample Zone Diameter: 19.05 mm (3/4 in.)
Sample Zone Length: 28.58 mm (9/8 in.)
IDS Thickness at Sample Zone: 4 mm (0.157 in.)

IDS Cap Outlet Diameter: 5.44 mm (0.214 in.)
Cap Cone Angle: 90°
Cap Extension Length: 25.4 mm (1.0 in.)
Sample Pipe ID: 9.525 mm (3/8 in.)
Sample Pipe OD: 11.125 mm (7/16 in.)
IDS Length ~ 150 mm (5.9 in.)
IDS Width ~ 27.05mm (1.05 in.)

Flow Inside the IDS



Velocity Vectors Colored By Velocity Magnitude (m/s)

Aug 24, 2012
ANSYS FLUENT 13.0 (3d, dp, pbns, rke)

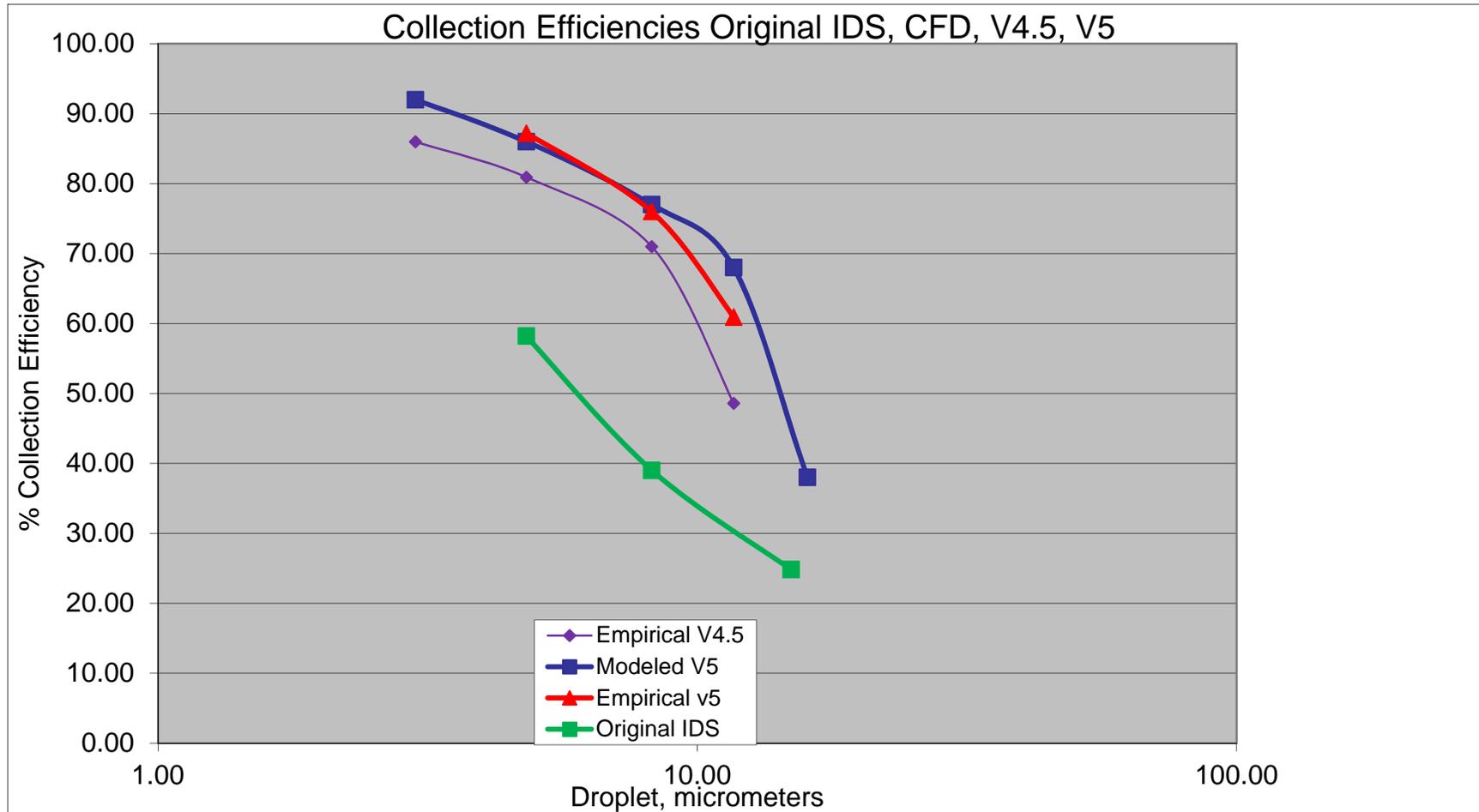
Computer Designed IDS V5



Monodisperse Collection Efficiency Streamlined IDS Test Results

	V5 (19 mm sample zone diam.)		V4.5 (22mm sample zone diam.)	
Aerosol size (um)	Collection efficiency (percent)	Losses: lower cone (percent)	Collection efficiency (percent)	Losses: Lower cone (percent)
14.93				
11.68	60.9	31.9	48.6	37.4
8.23	71.2	28.5	77.5	26.4
4.82	87.5	15.9	80.9	21.1
3.00			86	10.0

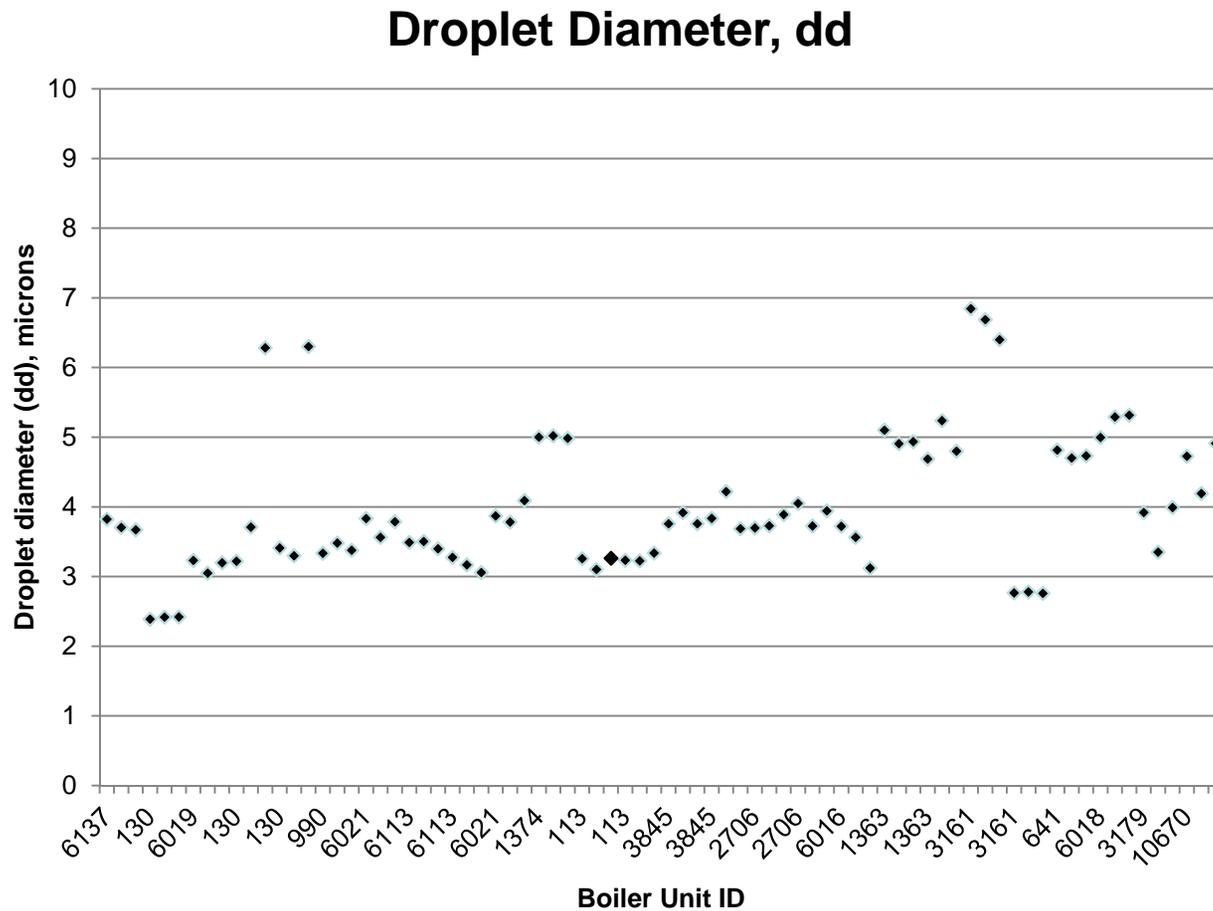
IDS Version Collection Efficiencies



Calculation of Droplet Diameter

- Calculated droplet diameter (dd) resulting in 2.5 um particle (aerodynamic) from scrubber water solids concentration data
- Equation presented in a project development plan (Leith, UNC-Chapel Hill, August 2007)
- Calculated from median solids (TDS +TSS) concentration:
dd = 4.3 um
- dd calculated from individual solids concentrations, TDS +TSS, (excluding 1 facilities data as an outlier) :
mean = 4.0 um
range: 2.4 to 6.8 um
- dd calculated from individual solids concentrations, TDS only (excluding 1 facilities data as an outlier) :
mean = 7.2 um
range: 2.8 to 12.8 um

Calculated Droplet Diameter, dd , from Solids Concentration Resulting in 2.5 μm Particle



Conclusions

- Redesign of IDS significantly improved performance
- Improved design falls short of original criterion: 90%+ efficiency @ 10 um
- Actual performance achieved:
 - 88% efficiency at 5 um
 - 61% efficiency at 10 um
- Scrubber water solids concentration data and calculations indicate performance at 5um aerosol may be sufficient to capture 2.5 um particles

WHAT ARE THE NEXT STEPS?

- More modeling to improve IDS design
- Reconstruct Sampler with new design
- Monodisperse aerosol test of final modified IDS
- Field trial of full sampler at a power plant (China?) with wet scrubber installation to determine proof of concept
- Precision test entire system
- Propose Method