CHARACTERIZATION OF LIQUID SMOKE BY SIZE DISTRIBUTION AND KAPPA VALUES

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ATMOSPHERIC SCIENCE SENIOR PROJECT

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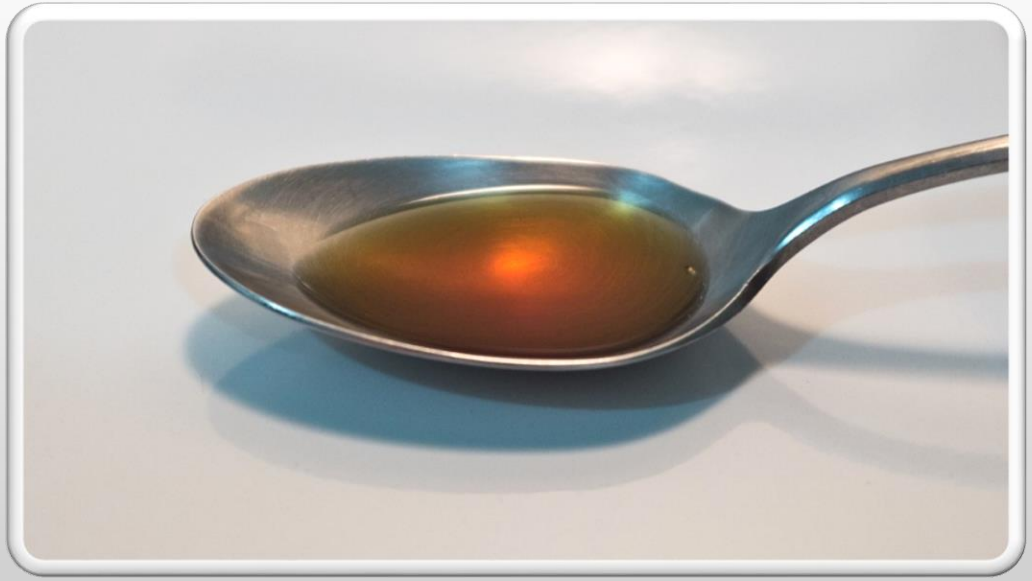
MOTIVATION

- No standard for biomass burning
- Previous experiments had to burn actual biomass in lab to get results
- Fresh biomass has complex hygroscopic behaviors.
- Liquid smoke potential proxy

BACKGROUND

- Liquid smoke production
- Uses
  - Flavor enhancer
  - Preservative
- Brand used in this experiment: Wright's Mesquite
- Data collection at Michigan Technological University (May – June, 2018)



OBJECTIVES FOR RESEARCH

1

Determine the Size Distribution of Liquid Smoke

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Determine the Size Distribution of Liquid Smoke

2

Calculate the Kappa values for Liquid Smoke

WHAT ARE KAPPA VALUES?

- A hygroscopicity parameter that relates dry diameter of a particle and the cloud condensation nuclei (CCN) activity

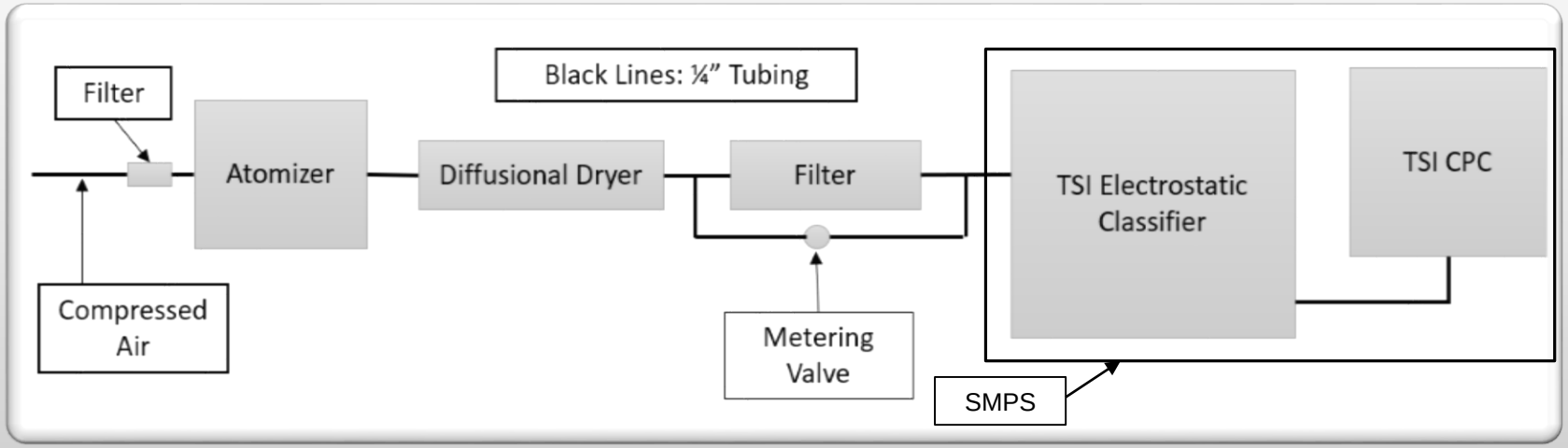
Compound	Kappa
Sodium Chloride (NaCl)	1.28
Sulfuric Acid (H_2SO_4)	0.90
3:7 Organic: Inorganic material	0.62
Ammonium Sulfate ($(NH_4)_2SO_4$)	0.61
Soot	0.00

METHODOLOGY

- Set up lab instruments
- Solution of 0.03% liquid smoke and ultra purified water
- Size distribution found first to determine sample diameters for kappa values
- Sample diameters run at varying supersaturation set points on CCNC
- Kappa values calculated and compared

SET UP SIZE DISTRIBUTION

- Atomizer
- Diffusional Dryer
- Filter and Metering Valve
- Spectral Mobility Particle Sizer (SMPS)
  - Electrostatic Classifier
  - Condensation Particle Counter (CPC)



ATOMIZER AND DIFFUSIONAL DRYER

Atomizer

- TSI Aerosol Generator 3076
- Aerosolizes solution of liquid smoke and ultra pure water using compressed air

Diffusional Dryer

- Uses Alfa Aesar molecular sieve 13X beads to dry aerosols.
- Creates low relative humidity in dryer so water evaporates off of particle

https://tsi.com/aerosol-generator-3076/

TSI SCANNING MOBILITY PARTICLE SIZER (SMPS)

- Consists of TSI Electrostatic Classifier Model 3080
  - Separates particles by size using their electric mobility

https://docs.google.com/document/d/1rT6szXtwZgdUTVcDB13OgYgDgsf7aOVqElKqQKmoXkU/edit

TSI SCANNING MOBILITY PARTICLE SIZER (SMPS)

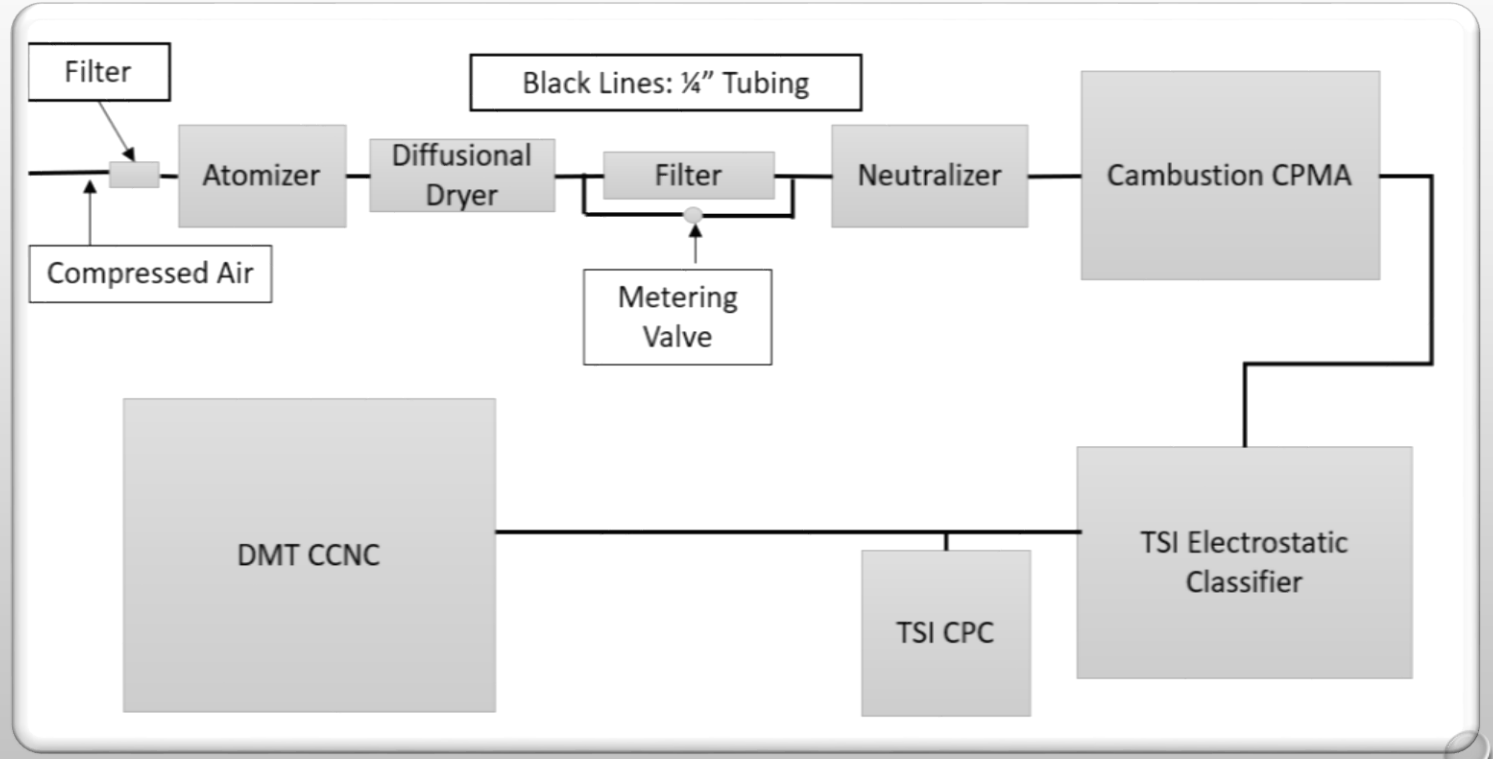
- Consists of TSI Electrostatic Classifier Model 3080
  - Separates particles by size using their electric mobility
- TSI Condensation Particle Counter (CPC) Model 3772
  - Counts particles larger than 10 nm diameter in sample stream

https://docs.google.com/document/d/1rT6szXtwZgdUTVcDB13OgYgDgsf7aOVqElKqQKmoXkU/edit

SET UP KAPPA VALUES

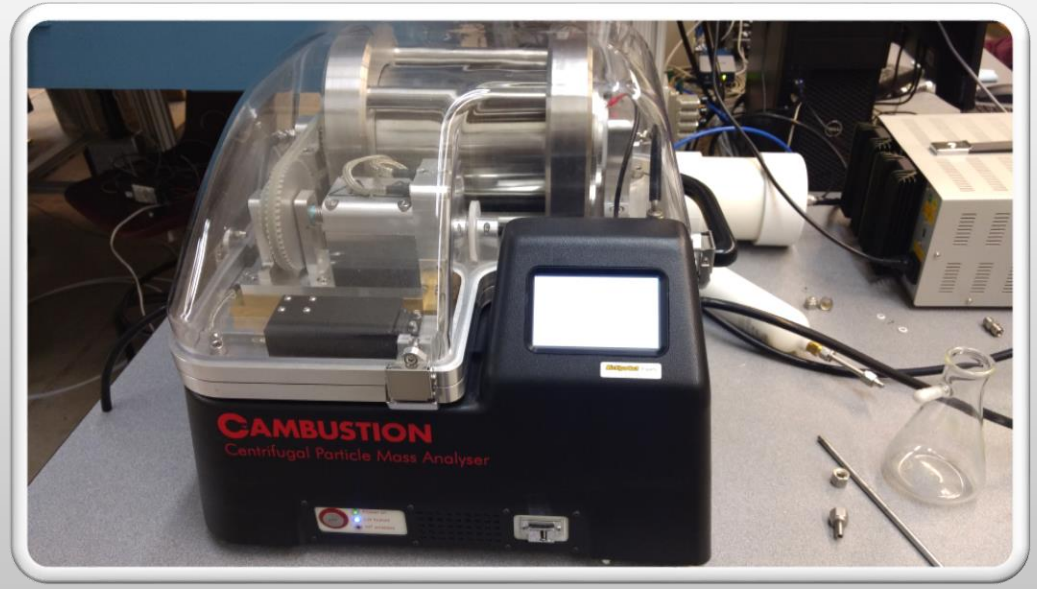
ADDED:

- Centrifugal Particle Mass Analyzer (CPMA)
- Cloud Condensation Nuclei Counter (CCNC)



CAMBUSTION CENTRIFUGAL PARTICLE MASS ANALYZER (CPMA)

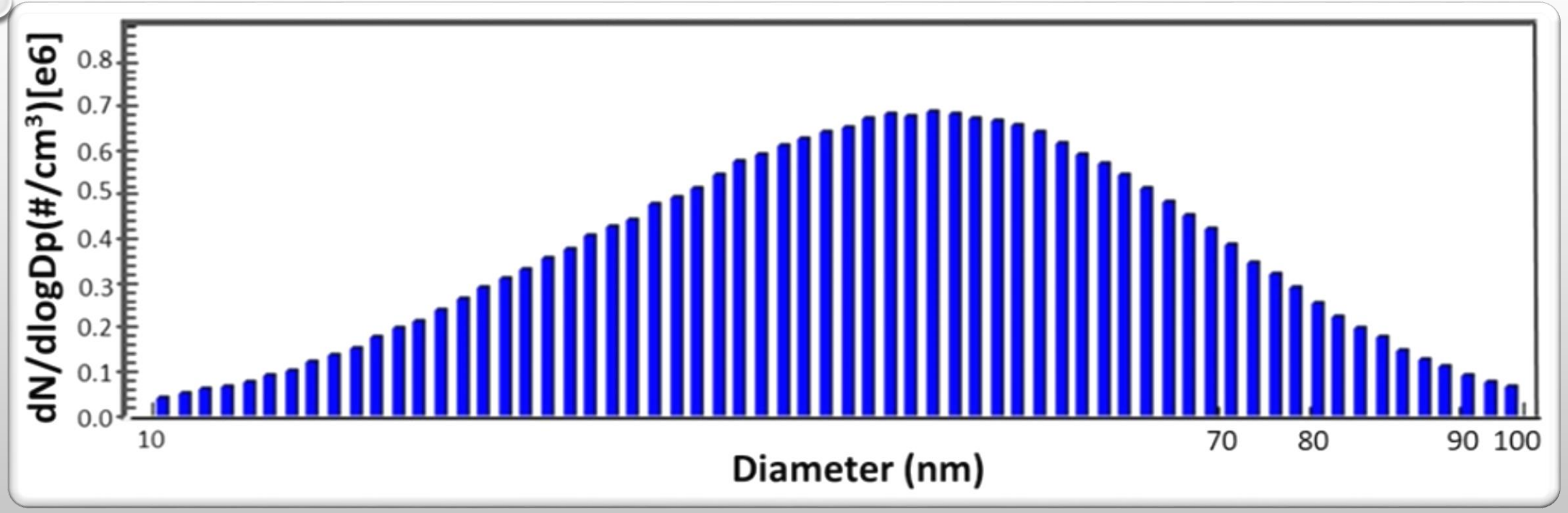
- Classifies particles by their mass to charge ratio
- Utilizes opposite electrical and centrifugal fields to classify aerosols



DMT CLOUD CONDENSATION NUCLEI COUNTER (CCNC)

- Measure cloud condensation nuclei (CCN) concentration
- Creates a supersaturated environment using a temperature gradient in a vertical column

SIZE DISTRIBUTION



- Peak at 40 nm so set points determined to be: 40.0, 55.2, 71.0, 85.0, 98.2 nm

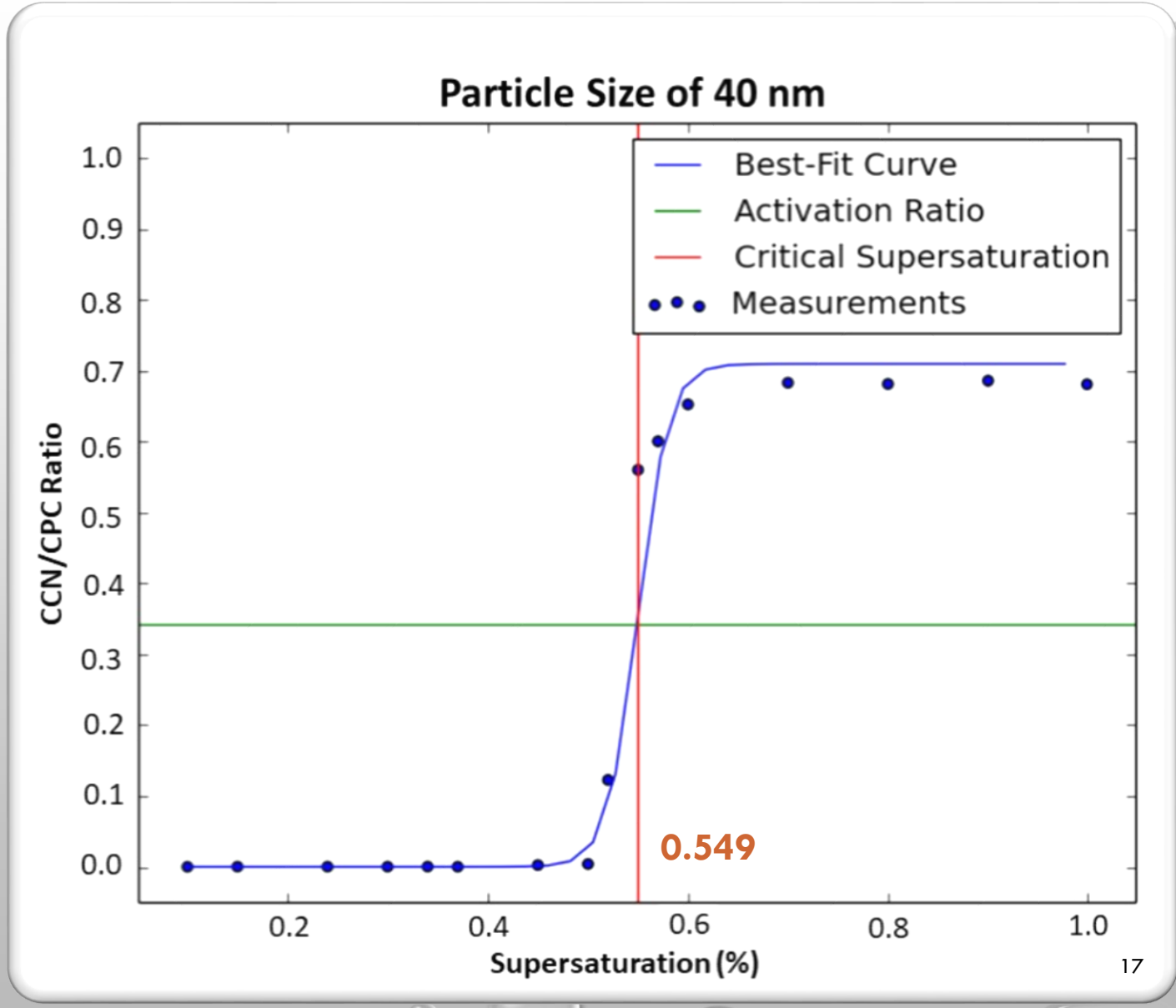
SUPERSATURATION SET POINTS FOR DIAMETERS

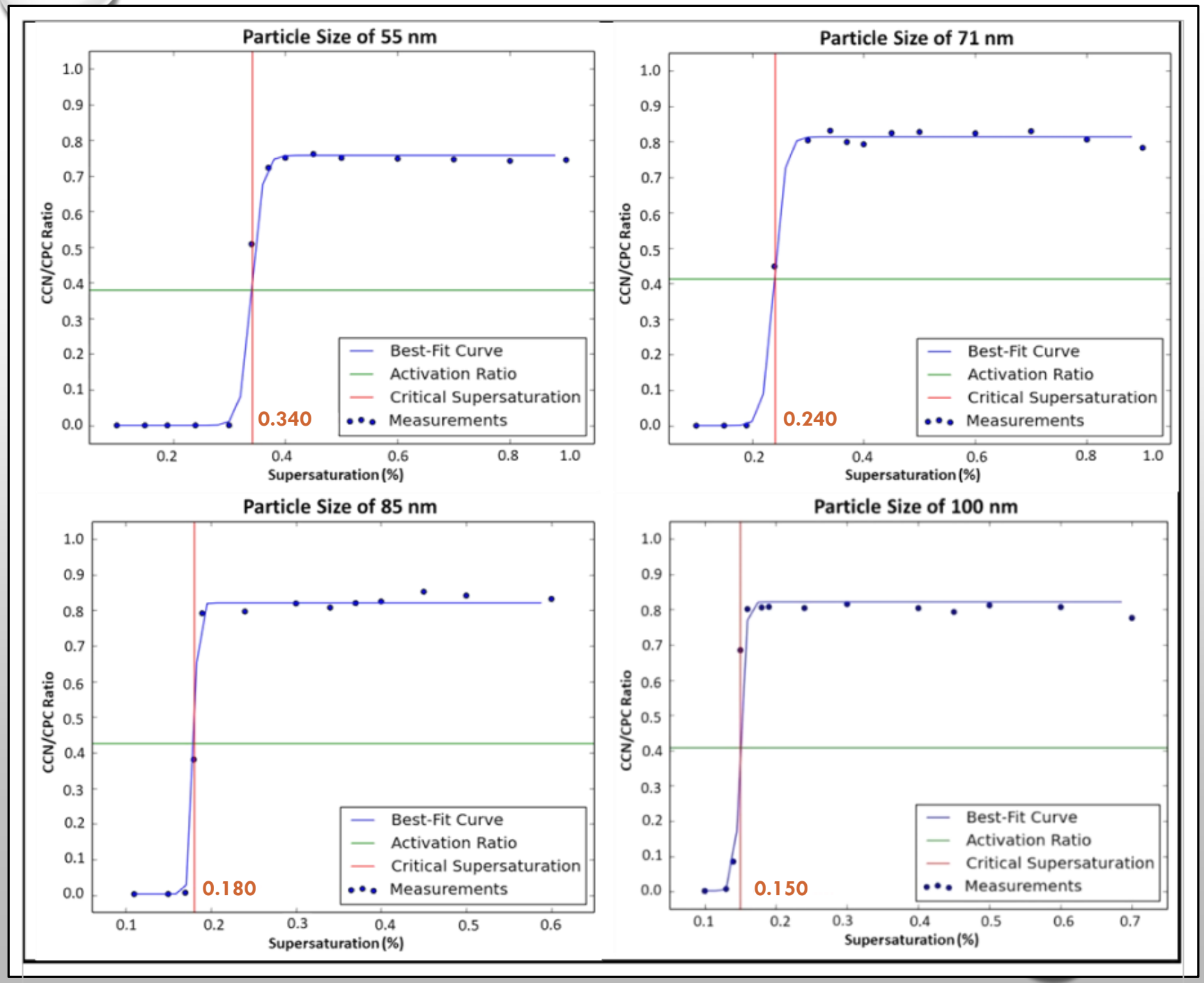
- Varying set points in order to catch activation point (where ratio of aerosols becoming CCN to those going in is 50%)

Diameter	Supersaturation% Set Points
40.0 nm	0.10, 0.15, 0.24, 0.30, 0.34, 0.37, 0.45, 0.50, 0.52, 0.55, 0.57, 0.60, 0.70, 0.80, 0.90, 1.0
55.2 nm	0.10, 0.15, 0.19, 0.24, 0.30, 0.34, 0.37, 0.40, 0.45, 0.50, 0.60, 0.70, 0.80, 0.90
71.0 nm	0.10, 0.15, 0.19, 0.24, 0.30, 0.34, 0.37, 0.40, 0.45, 0.50, 0.60, 0.70, 0.80, 0.90
85.0 nm	0.11, 0.15, 0.17, 0.18, 0.19, 0.24, 0.30, 0.34, 0.37, 0.40, 0.45, 0.50, 0.60
98.2 nm	0.10, 0.13, 0.14, 0.15, 0.16, 0.18, 0.19, 0.24, 0.30, 0.40, 0.45, 0.50, 0.60, 0.70

KAPPA VALUE ANALYSIS

- Data processed using Airborne Data Processing and Analysis (ADPAA)
- Sigmoid fit to data using ADPAA to get critical supersaturation (half point) for kappa calculations




Particle Size of 55 nm
CCN/CPC Ratio
Supersaturation (%)
Best-Fit Curve
Activation Ratio
Critical Supersaturation
Measurements
0.340
Particle Size of 71 nm
CCN/CPC Ratio
Supersaturation (%)
Best-Fit Curve
Activation Ratio
Critical Supersaturation
Measurements
0.240
Particle Size of 85 nm
CCN/CPC Ratio
Supersaturation (%)
Best-Fit Curve
Activation Ratio
Critical Supersaturation
Measurements
0.180
Particle Size of 100 nm
CCN/CPC Ratio
Supersaturation (%)
Best-Fit Curve
Activation Ratio
Critical Supersaturation
Measurements
0.150

KAPPA VALUE ANALYSIS

- Kappa value calculated using the dry diameter of the particle and critical supersaturation

$$\kappa = (4A^3) \div (27Ds^3(\ln(Sc))^2)$$

$$A = (0.66 \times 10^{-6} Km) \div T$$

$\kappa = Kappa$ $\quad Ds = Dry\ Diameter$ (m) $\quad T = Temperature\ (K)$

$Sc = Saturation\ Ratio\ of\ Critical\ Supersaturation$

KAPPA VALUE RESULTS

- Found the average kappa value for liquid smoke is 0.81 +/- 0.042

Diameter	Kappa
40.0 nm	0.88
55.2 nm	0.84
71.0 nm	0.78
85.0 nm	0.81
98.2 nm	0.76

KAPPA VALUE RESULTS

Compound	Soot	Ammonium Sulfate ((NH4)2SO4)	3:7 Organic: Inorganic Material	Liquid Smoke	Sulfuric Acid (H2SO4)	Sodium Chloride (NaCl)
Kappa	0.00	0.61	0.62	**0.81**	0.90	1.28

- Compared to other compounds it is more hygroscopic than ammonium sulfate but less than sulfuric acid.

POSSIBLE ERRORS

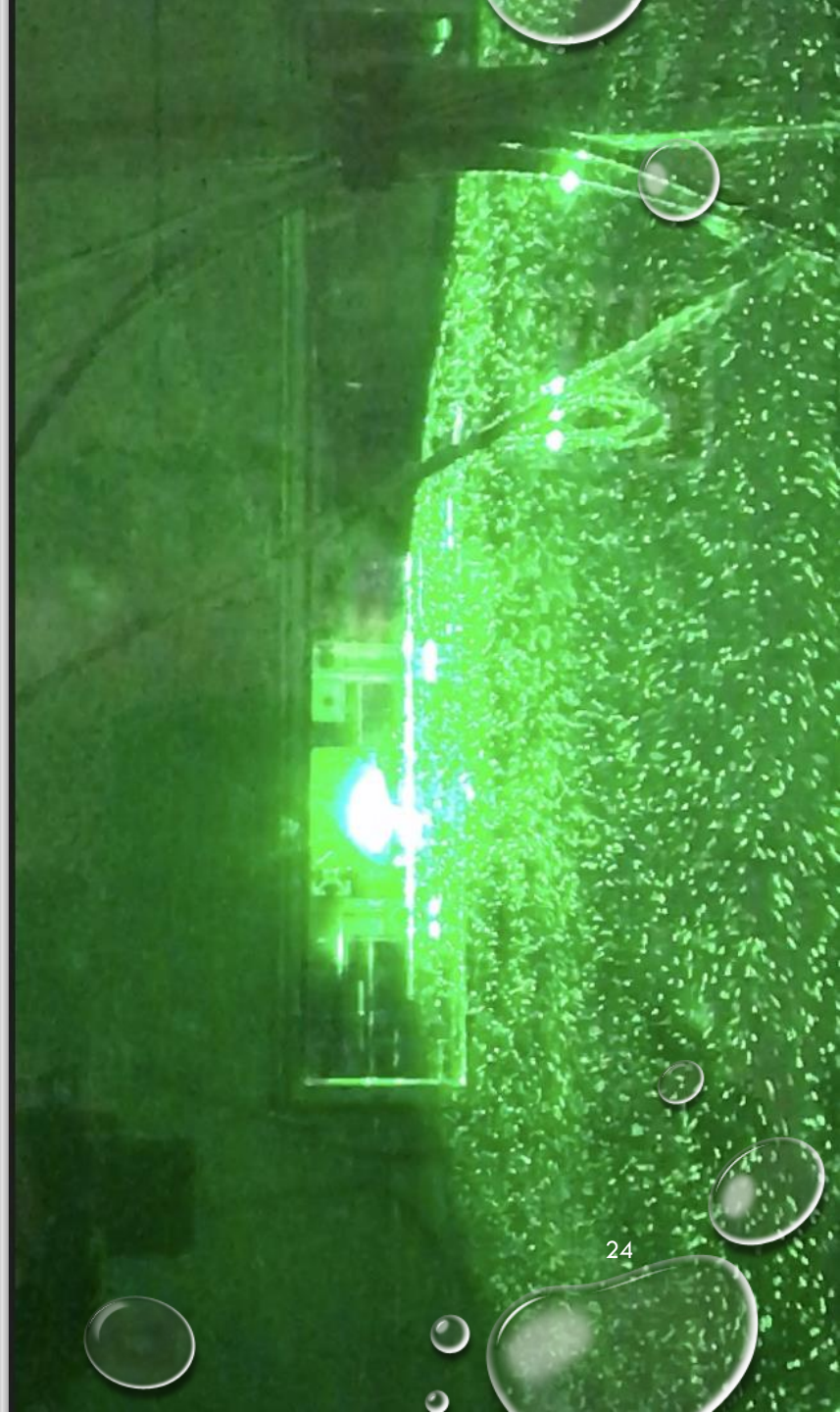
- High kappa values from inefficient drying

CONCLUSION

- Size distribution and kappa values successfully found
- Kappa values range from 0.76 to 0.87
- Average kappa value is 0.81 +/- 0.042
- Slightly higher than expected kappa values
- Further testing needs to be done

FUTURE RESEARCH

- Determine chemical composition of Wright's Mesquite liquid smoke
- Test in the PI Cloud Chamber to look at how it interacts with the "atmosphere"



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SELECTED REFERENCES

- Rose, D., S. S. Gunthe, E. Mikhailov, G. P. Frank, U. Dusek, M. O. Andreae, and U. Poschl, 2008: Calibration and measurement uncertainties of a continuous-flow cloud condensation nuclei counter (DMT-CCNC): CCN activation of ammonium sulfate and sodium chloride aerosol particles in theory and experiment. *Atmos. Chem. Phys.*, 27.

QUESTIONS?