Compact Cloud Condensation Nucleus Counter for Unmanned Aerial Systems (UAS) and Long-Term Monitoring Applications

Phase I

Final Report for the Period Feb 2017-February 2019

March 2019

Fredrick J. Brechtel
Principal Investigator

Brechtel Manufacturing Incorporated
1789 Addison Way
Hayward, CA 94544

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Fredrick J. Brechtel
(510) 732-9723; fredj@brechtel.com

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Table of Contents

1. Abstract

Brechtel Manufacturing Incorporated (BMI) is developing a compact, modular suite of new aerosol measurement technologies optimized for use on Unmanned Aerial Vehicles (UAVs) and other applications where space, weight, power and cost are significant barriers to deployment. The project is focused on a cloud condensation nucleus counter that exposes sampled particles to a simulated cloud environment and counts how many of the particles grow to micron-sized droplets. The new development helps address the need for reduced uncertainties in climate model sensitivities to ambient aerosol properties by promoting the capability to perform aerosol measurements more often, in more locations, and at reduced cost. Applications of the new technology include long-term measurements of the aerosol effects on cloud radiation, microphysical and precipitation processes, weather prediction and modelling studies, and weather modification studies.

2. Technical Description of the Technology

The CCN device being developed consists of 4 major sub-systems: 1) a small chamber within which the water supersaturation is generated and the particles are grown into droplets, 2) a system to create particle-free, water saturated air, 3) an optical particle counter to count the grown droplets, and 4) micro-controller hardware and software to control the instrument and acquire data. The proposed specifications for the system are listed in Tables 1 and 2.

In the miniaturized CCN device, particles are sampled at atmospheric pressure from outside the UAS, other research aircraft or even from a ground-based sampling inlet. The sampled particles are drawn into the device where they combine with a flow of filtered, saturated air to produce a known supersaturation. The combined flows pass into an optical particle counter where only droplets larger than 1 micrometer diameter are detected. By varying the temperature operating conditions of the supersaturation chamber, different supersaturations are generated. The microcontroller electronics and software will be integrated into the instrument so that the CCN device can be easily operated independently, or as part of an integrated measurement suite.

Table 1: Specifications of UAS CCN device.

Supersaturation Range	Number Concentration	Sample & Saturator Flows	Time Resolution	Precision	Accuracy
0.2-1 %	0-10,000 cm^{-3}	0.06 lpm sample; 1.2 lpm saturator	1 sec	1-5%	10%

Table 2: Physical specifications of the CCN device.

Parameter	Value	Unit
Size	<15x14x13	cm
Weight	<4	kg
Power	<60	watts

The Phase I technical objectives are to:

1. Complete the supersaturation chamber design and fabricate and test a prototype,
2. Complete and test the prototype saturation, supersaturation and OPC systems, and
3. Test the prototype with known aerosols having known CCN activity.

3. Phase I Progress

A detailed description of the progress made to meet each of the objectives during the current reporting period is provided below.

1. *Miniaturize, prototype & test the supersaturation chamber*

C. Patmont completed the assembly of the first version saturation chamber and tested the unit. A. Corless designed, built and tested the prototype OPC and calibrated it with monodisperse ammonium sulfate and polystyrene latex sphere (PSL) particles. The OPC is capable of detecting 100% of all particles with diameters between 0.19 and 3 microns.

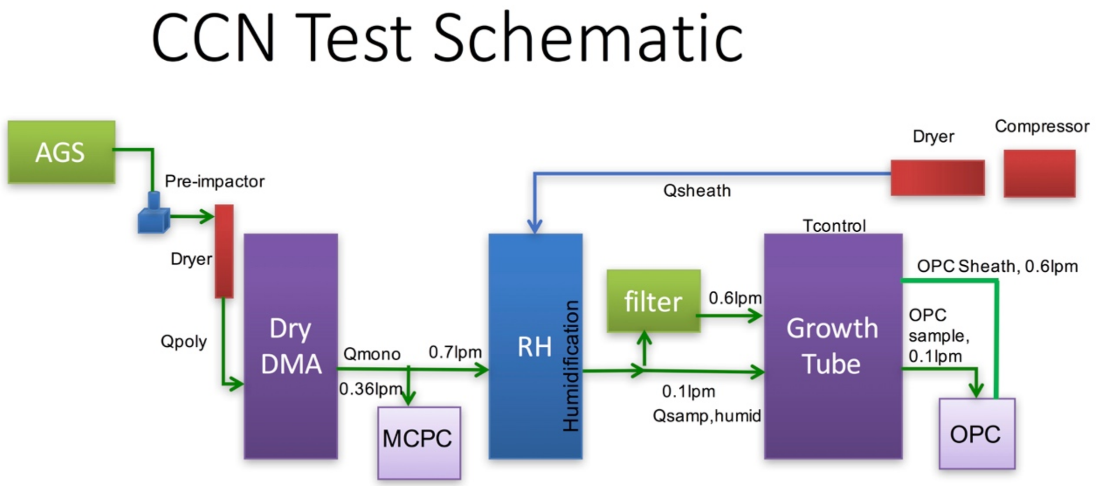


Figure 1 Schematic of test setup.

The test setup (see Fig. 1) included: Aerosol Generation System (AGS), dry Monodisperse Size Particle source (Dry DMA), Mixing Condensation Particle Counter (MCPC), humidification and growth tube (saturation chamber, under green insulation in Fig. 1), and an Optical Particle Counter (OPC) to detect grown droplets. The test setup was used with no humidification to determine that the OPC has a 50% detection size of 170 nm. A photo of the actual test setup is shown in figure 2. The AGS generates known chemical composition aerosol for which CCN activity can be calculated. The Dry DMA selects one particle size and the MCPC measures the total number concentration of the size-selected aerosol. For a given composition, only particles above a certain size will activate to droplets at a given water supersaturation in the growth tube. When the droplet concentration measured by the OPC equals the total number concentration measured by the MCPC then the sampled dry particles are said to be CCN active.

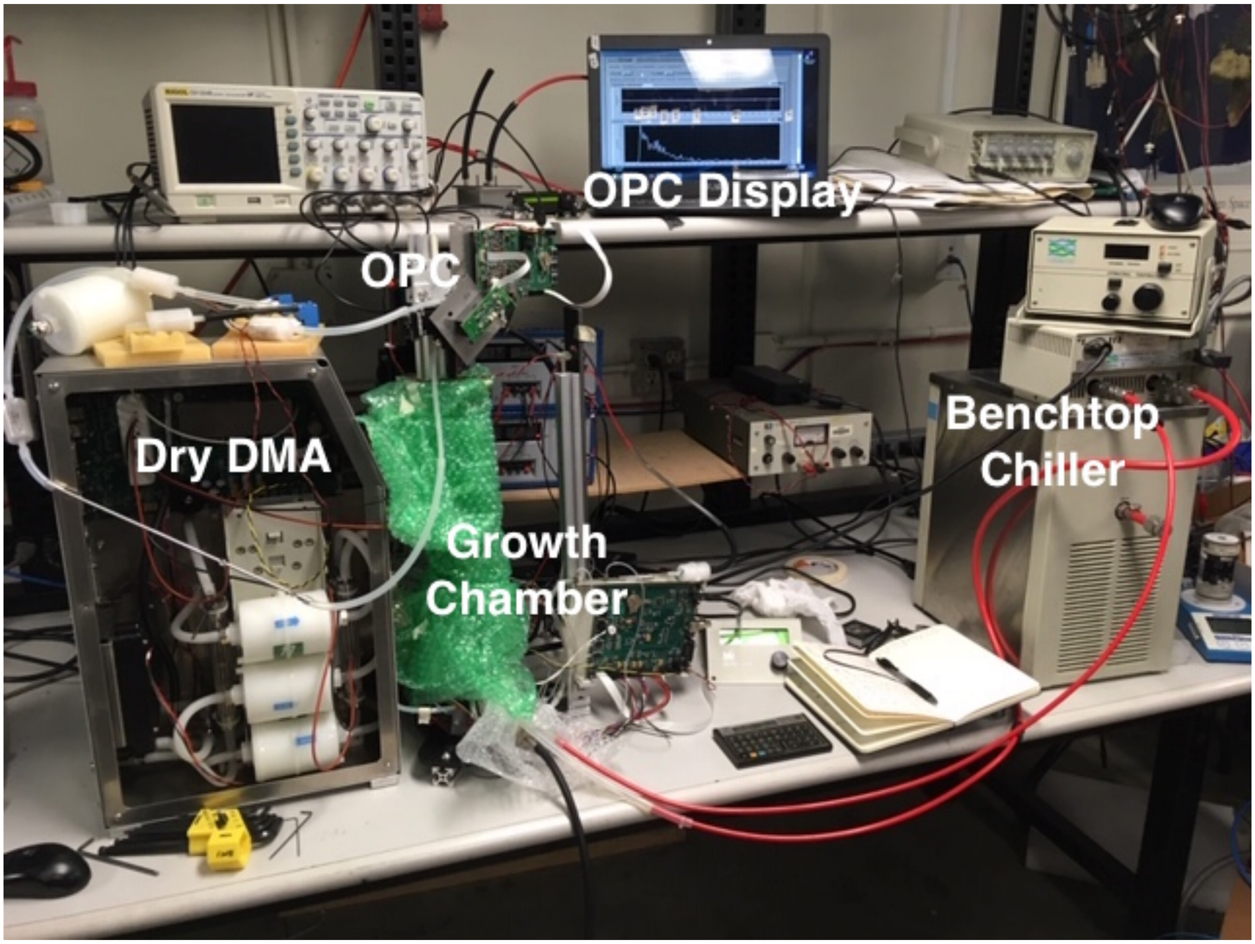


Figure 2 Photo of test setup.

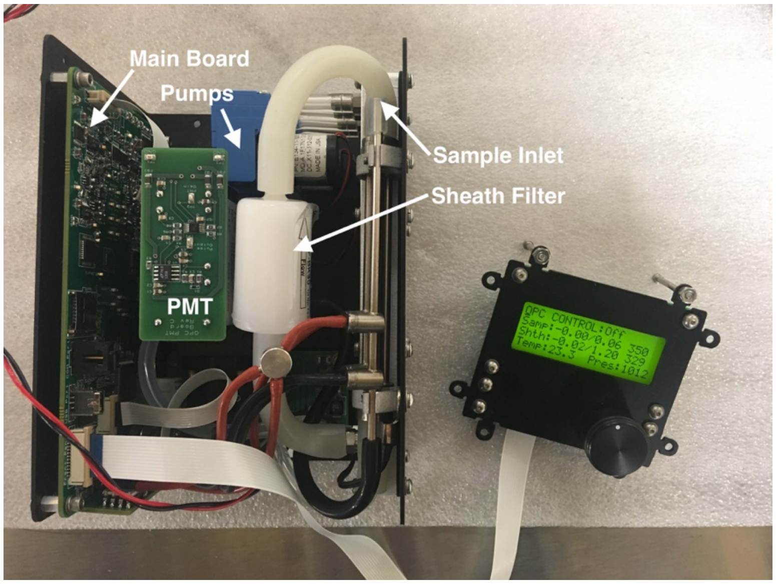
There is no direct measurement available of water vapor concentration under supersaturated conditions. Therefore, we chose to indirectly validate the supersaturation in the chamber with two techniques. First, dew point hygrometers were used to measure known mixtures of air flows with known water vapor concentrations mixed with the supersaturated air from the mCCN chamber. Unfortunately, this method consistently measured low values for the supersaturated air leaving the mCCN, likely due to condensation or some other unknown loss of water vapor.

The second method involved measurements of the CCN activity of known size ammonium sulfate particles for which the activation supersaturation was known. The second method so far has also proved difficult to utilize as the expected activation and growth of particles inside the growth tube is not occurring. Particles are consistently growing much less than expected, consistent with the low water vapor concentrations derived from the first method using the dew point hygrometers. Work on the supersaturation chamber is on-going.

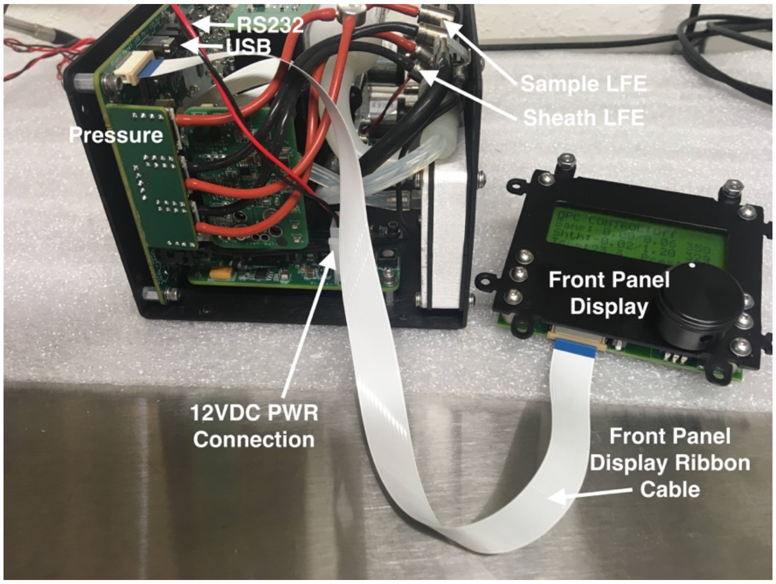
2. ***Design, Prototype & Test Saturator and OPC***

The test setup shown in figures 1 and 2 was used to examine the particle sizing performance of the OPC and the particle activation of dry monodisperse ammonium sulfate particles as a function of particle size and operating conditions in the saturator.

Photos of the prototype OPC are shown below. The main control board, pumps, sample inlet and sheath flow filter are labelled in the first figure. The front panel display to the right is removable to allow the unit to fit into small payload bays.



The second OPC photo below shows the RS232 serial and USB interface connectors for external control and data transmission, as well as more detailed views of the laminar flow elements used to measure the volumetric flow rates inside the unit.



The first set of experiments involved sampling dry monodisperse particles directly from the DMA into a mixer where the flow was split between a Mixing CPC that detected all particles and the OPC under test. By taking the ratio of the measured concentrations from the OPC and MCPC the size-dependent sampling efficiency of the OPC could be determined. The results from one test are shown in figure 3 and indicate a 50% detection efficiency in the 200 nm range. Between 210 and 1000 nm the OPC detects 100% of sampled particles.

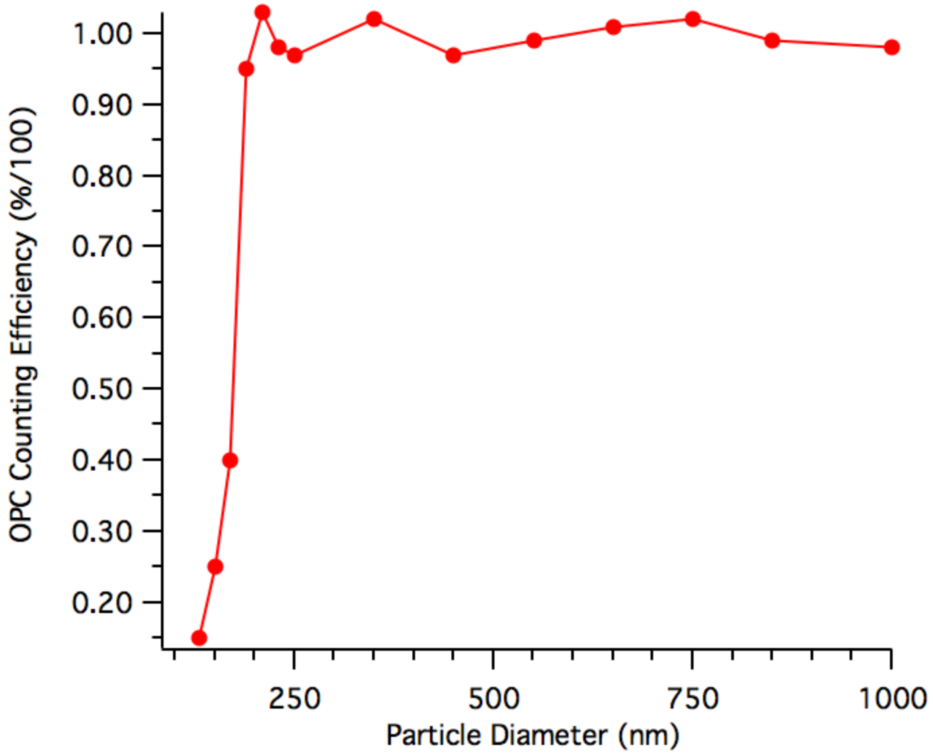


Figure 3 Measured OPC sampling efficiency.

During activation and droplet growth tests initial results indicated very few large droplets were formed on the dry nuclei, even after the supersaturation chamber residence time was increased to several seconds. Only one second is expected to be required for the desired growth. Additional tests are required to determine if the sample-to-sheath flow ratio is too high and if the residence time for growth is still too short.

3. *Prototype Testing*

Continued testing to improve the supersaturation performance of the saturator is on-going. The tests outlined above will be performed using dry monodisperse ammonium sulfate particles with known CCN activation properties.

4. *Design and prototype the system control hardware and software*

The BRECHTEL UAV Reader software controls and communicates with all of the UAV modules including the mini CCN to integrate them into one manageable suite with a unified graphical user interface (GUI) for the user. A. Corless completed work on the mOPC-specific software module for the UAV Reader (version 5.4). The GUI allows the output from multiple instruments to be viewed simultaneously and automatically adjusts to the configuration of instruments connected to the GUI computer. The GUI is written to allow multiple modules of each type to be connected simultaneously and to be independently addressed and controlled. The software was successfully tested with the uav-MCPC, mOPC, filter sampler, and STAP modules, all connected simultaneously. Additional modules will be integrated over the coming months. Since the mCCN uses the mOPC as its detector, the mCCN will easily integrate with the GUI when ready.

In addition to the reader software efforts, the calibration software subroutines for the mini-OPC that is used for the mCCN was completed during the current period. New mOPC firmware was developed to function with the GUI. Significant progress was made on the integrated GUI to control and communicate with multiple modules at one time.

4. Development Challenges & Solutions

The departure of a junior mechanical engineer (C. Patmont) slowed progress on the project, in particular on the supersaturation chamber. On-board data storage must still be implemented on the OPC so the Windows PC is not required to deploy the unit. The saturation chamber design requires significant changes to improve the water supersaturation performance.

5. *Cumulative Expenses & Labor*

Cumulative Expenses	
	To 2/28/2019
Senior Key Personnel (FJB)	48,108.00
Engineers - Professionals	57,613.71
Interns, Technical Staff, Admins	2,401.09
Fringe Benefits	27,400.20
Equipment	2,139.65
Material, Supplies & Meals	6,216.82
Commercialization Budget	5,000.00
Indirect Costs	66,993.48
Fee (7%)	15,111.10
Project Total to Date	**230,984.05**

Cumulative Labor Hours

Category	**Employee**	**Hours Worked**
Senior Key	FJB	827.10
Engineer/Professional	FPB	22.00
Engineer/Professional	ABC	724.50
Engineer/Professional	CSP	666.75
Engineer/Professional	XLY	7.00
Technician	HTJ	2.00
Technician	LJG	12.00
Technician	CT	6.00
Technician	TMJ	12.25
Technician	RS	12.00
Administrative	GTP	27.50
Labor Hours Total to Date		**2,319.10**