A cloud condensation nucleus spectrometer having a streamwise segmented condensation nucleus growth column. The condensation nucleus growth column includes alternating hot and cold temperature-maintaining segments arranged next to one another. The temperature difference between adjacent hot and cold temperature-maintaining segments increases from the input opening to an output opening of the condensation nucleus growth column to produce a supersaturation distribution that increases from the input opening to the output opening.

10 Claims, 4 Drawing Sheets
Total of 7 Hot/Cold Segment Pairs

FIG. 2

FIG. 2A
FIG. 3

Laser Diode Module 4.0 mW, 670 nm

Wood's Horn Beam Dump

Sample Volume

Pinhole

Mirror 350

Aspheres

Photodetector

Fiber
Scattered Light Intensity (W)

$10^{-9}$
$10^{-10}$

Particle Diameter ($\mu m$)

$7$ $8$ $9$ $10$

FIG. 4

Diethyl Sebacate, Theory
Water, Theory
Open Symbols for Calibration Data
CLOUD CONDENSATION NUCLEUS SPECTROMETER

CLOUD CONDENSATION NUCLEUS SPECTROMETER

This application claims the benefit of the U.S. Provisional Application No. 60/062,013, filed on Oct. 10, 1997, which is incorporated herein by reference.

ORIGIN OF THE INVENTION

The U.S. Government has certain rights in this invention pursuant to Grant No. N00014-96-1-0119 awarded by the Navy.

FIELD OF THE INVENTION

The present invention relates to aerosol measurements, and more particularly, to instruments and techniques for characterizing cloud condensation nuclei.

BACKGROUND

Atmospheric particles influence the climate system, radiative transfer, visibility, and air quality. Hence, aerosol measurements of concentration, sizes, and chemistry of atmospheric particles are important in many applications, including monitoring air pollution and predicting climate change.

One aspect of aerosol measurements is characterization of cloud condensation nuclei (“CCN”). Under proper humidity conditions, certain aerosol particles are able to nucleate to form cloud droplets. Properties of cloud condensation nuclei provide important information on cloud formation and cloud properties. For example, cloud condensation nuclei can influence the droplet number and size distribution in a cloud, which ultimately affect a variety of processes including cloud lifetime and precipitation rate.

The ability of a particle to nucleate is at least in part determined by the saturation level of the environment, the size of the particle, and the chemical composition of the particle. For example, water vapor is more likely to condense on salt particles such as NaCl than on organic particles. When the relative humidity exceeds the saturation level where the vapor phase and the liquid phase are in equilibrium, a supersaturation state establishes and vapor begins to condense on surfaces and some particles to form droplets or condensation nuclei. At a certain critical supersaturation, when the diameter of a condensation nucleus of a given chemical composition exceeds a critical diameter, the nucleus is said to be “activated”, that is, vapor will condense spontaneously on that nucleus and cause the nucleus to grow to a very large size which is limited only by the kinetics of condensational growth and the amount of vapor available for the condensational growth.

The critical diameter at a given supersaturation usually depends on the chemical composition of the particles. Hence, particles of different chemical compositions can become activated at different sizes.

One way to characterize condensation nuclei is to measure the critical supersaturation at which a particle activates. Instruments for such measurements are generally referred to as cloud condensation nucleus counters. Cloud condensation nucleus spectrometers are such counters capable of producing and measuring supersaturations in a desired range. See, for example, Hudson, “An Instantaneous CCN Spectrometer,” Journal of Aerosol Science, Vol. 6, p. 1055, December, 1989, and Hoppe et al., “A Segmented Thermal Diffusion Chamber for Continuous Measurements of CCN,” Journal of Aerosol Science, Vol. 10, p. 369, 1979, which are incorporated herein by reference.

The atmospheric environment is usually dynamic. The activation and subsequent growth of cloud condensation nuclei originated from a subset of atmospheric aerosols are essential to formation of cloud droplets. Therefore, it is desirable to perform in situ measurements in order to accurately measure aerosol samples in real time and monitor the changing climate at a target location. A compact airborne cloud condensation nucleus spectrometer can be used to meet such demand. However, many conventional condensation nucleus spectrometers are ill-suited for small aircraft platforms due to limitations in various factors such as weight, size, time resolution, range of measurable supersaturation.

SUMMARY

The present invention provides a novel CCN spectrometer which has been designed specifically for use on a remotely piloted aircraft for long periods of unattended operation, and which can measure CCN spectra over a wide range of supersaturation at high frequency (one spectrum per minute or faster). The instrument is also designed to be light and consume minimum power in order to conserve the limited resources available on small aircraft.

One embodiment of the CCN spectrometer implements a segmented cloud condensation nucleus growth column. A gas flow channel is formed within the column to receive and transfer a gas flow from an input opening to an output opening and having an inner wall which is wetted by a liquid. The segmented column has a plurality of alternating hot and cold temperature-maintaining segments arranged next to one another relative to the gas flow channel to control and maintain a temperature distribution along the gas flow channel. Each hot temperature-maintaining segment is maintained at a temperature higher than a cold temperature-maintaining segment. The temperatures produce a varying supersaturation environment within the gas flow channel.

In particular, a temperature difference between adjacent hot and cold temperature-maintaining segments increases from the input opening to the output opening to produce a supersaturation distribution that also increases from said input opening to said output opening.

A special optical particle counter is implemented to produce an optical probe beam to illuminate the gas flow in a close proximity to the output opening and to determine presence and dimension of particles in the gas flow.

These and other aspects and advantages of the present invention will become more apparent in light of the accompanying drawings, the detailed description, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing one embodiment of a cloud condensation nucleus spectrometer.

FIG. 2 shows a segmented cloud condensation nucleus column.

FIG. 2A shows a segmented cloud condensation nucleus column.

FIG. 3A shows a layout of an optical particle counter integrated to the column of FIG. 2.

FIG. 4 shows intensity of the scattered light from output aerosol flow as a function of particle size measured by the optical particle counter shown in FIG. 3, where a calculated calibration by using a Diethyl Sebacate flow is also shown.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows one embodiment 100 of a cloud condensation nucleus spectrometer. The spectrometer 100 includes an input flow module 110, a CCN growth column 120, a temperature controller 140 for the CCN growth column 120, and a particle counter 130, an electronic processor 160, and an output flow module 150. The CCN growth column 120 is configured to produce an increasing supersaturation profile from an input end 120A to an output end 120B along the aerosol flow. The aerosol particles having critical supersaturation within the supersaturation range produced by the CCN growth column 120 are activated and exit the CCN growth column 120 with increased sizes.

The particle counter 130 is located at the output end 120B of the condensation column 120 and measures the number of the activated particles in the aerosol flow. Examples of such particle counter includes an optical particle counter which infers particle size from intensity of light scattered from individual particles, and an aerodynamic time-of-flight counter which measures particle size by the particle velocity acquired through rapid acceleration of the gas flow. The electronic processor 160 receives and processes the output signal from the particle counter 130 to produce the respective number of activated particles as a function of the critical supersaturation.

The spectrometer 100 also includes a water supply module 170 having a reservoir 172 to provide water to the CCN growth column 120. Preferably, the CCN growth column 120 may be positioned vertically so that water can be recirculated through the CCN growth column 120 from the top to the bottom by using a single water pump 174. This also minimizes buoyancy induced secondary flows and loss of particles to the wall by gravitational settlement. The flow rate of the water may be maintained at a constant low flow rate (e.g., less than 0.5 ml/min).

The condensation column 120 is preferably divided into a plurality of column segments at different temperatures. FIG. 2 shows the preferred structure of the condensation column 120. Each column segment may be a metal block with a central through hole as shown in FIG. 2A. For example, aluminum block of about 28 mm (H)×25 mm (W)×25 mm (L) with a central hole of about 20 mm in diameter can be used. A thin-walled thermal conductive tube 230 (e.g., formed of stainless steel) may be placed in the center of the condensation column 120 through all column segments to conduct the aerosol flow. Alternatively, the aerosol flow may be conducted by directly using a flow channel formed by the through holes of the column segments. However implemented, the side wall of the flow channel is wetted running the water through the side wall with the water supply module 170. One preferred way of wetting is to line the side wall with filter paper (e.g., Whatman 1 Chra).

The column segments are alternatively maintained at different high and low temperatures which are respectively referred to as “hot” column segments 220 and “cold” column segments 210. Each hot column segment 220 has an electrical heating element (e.g., one or more power resistors) connected to the temperature controller 140 and is maintained at a desired elevated temperature for that segment. A thermal control loop may be implemented to actively control the temperature of each segment. This is well known in the art. Each cold column segment 210 is attached to a cooling element 212, e.g., a thermoelectric cooler, and is maintained at a desired low temperature. A heat sink may be attached to the cooling element 212 to increase the cooling efficiency. At least one thermal sensor (e.g., a thermistor) is disposed in each column segment and connected to the temperature controller 140 to measure the temperature. Adjacent hot and cold column segments 220 and 210 are thermally insulated from each other by a thermal insulation layer 204.

One feature of the condensation column 120 is that the temperature difference between two successive hot and cold column segments increases. One implementation maintains the cold column segments 210 at different temperatures that decreases from the input end 120A to the output end 120B while keeping all hot column segments 220 at a common elevated temperature. Alternatively, the cold column segments 210 may be maintained at a common low temperature and the temperatures of the hot column segments 220 are higher than that low temperature and increase from the input end 120A to the output end 120B. In another variation, neither the cold column segments 210 nor the hot column segments 220 are maintained at a common temperature. However implemented, the temperature profile along the condensation column 120 not only changes in an alternating manner between high and low temperatures from one segment to another but the temperature difference also increases in the hot column segments 220 from the input end 120A to the output end 120B. In the embodiment shown in FIG. 2, the condensation column 120 has a total of seven pairs of cold and hot column segments. The temperature difference between the two segments in each pair can be set at 2° at the beginning and increases 1° per pair. The temperature difference in the last pair at the end 120B is 8°.

This special temperature profile can produce a monotonically increasing supersaturation profile along the center line of the condensation column 120 and can maintain a desired high spatial rate throughout the condensation column 120 without a significant decay near the output end 120B.

The flow rate of the aerosol flow in the condensation column 120 also has a significant impact on the supersaturation profile along the center line of the condensation column 120. When the flow rate is not controlled within a proper range, the supersaturation profile may not be monotonic but may have the same supersaturation at two different positions. The output flow module 150 is used to adjust the flow rate for a given temperature profile in the condensation column 120 to achieve a desired monotonically increasing supersaturation profile.

The input flow module 110 includes an aerosol flow path 112 and a sheath flow 114. The sheath flow 114 is produced by filtering out aerosol particles with a mass flow controller. The relative amount of aerosol versus sheath flow can be controlled by using a mass flow controller 114 (e.g., Sierra Instruments 840). The aerosol flow to the condensation column 120 is the difference between the total input flow 101 and sheath flow 114 and is monitored by measuring the pressure drop across a laminar flow tube in the aerosol flow path 112. The total flow 101 may be controlled by using a critical orifice 152 in the output flow module 150 (e.g., with a nominally flow rate of 0.75 lpm). The output flow module 150 also includes a vacuum pump 154 to induce the aerosol flow.

It should be noted that in this configuration, the instrument is not maintained at a constant pressure. Since the diffusivity of water vapor in air is pressure dependent, this must be accounted for in interpreting the data. Also, since the mass flow controller does not maintain constant volumetric flow rate, rather, the sheath volumetric flow rate increases with decreasing pressure, the relative amounts of aerosol and sheath flow vary with pressure, which also must
be accounted for. These flow rates are fed into the electronic processor 160 for data processing.

The optical particle counter 300 of FIG. 3 can be integrated to the condensation column 120 so that the laser probe beam interacts with the output aerosol flow at a location close to the output end 120B. Since water droplets are volatile and water condensed on an aerosol particle can vaporize after leaving the condensation column 120, it is critical to measure the particles at a location as close to the output end 120B as possible. Many conventional particle counters including optical counters often introduce the output aerosol flow into a flow path before measurements and can significantly degrade the accuracy of the measurements. Implementation of the optical particle counter 300 can essentially eliminate the additional flow path outside the output end 120B and improves the accuracy of measurements.

The above design can be used to significantly reduce the weight (e.g., less than 35 pounds) and size of a CCN spectrometer and thereby reduce the power consumption (e.g., about 100 W) and requirements of the power supply (e.g., a 28-V source). The on-board electronic processor further allows for automatic operation without human intervention.

Although the present invention has been described in detail with reference to the preferred embodiments, various modifications and enhancements may be made without departing from the appended claims.

What is claimed is:

1. A cloud condensation nucleus system, comprising:
   a gas flow channel configured to receive and transfer a gas flow from an input opening to an output opening and having an inner wall which is wetted by a liquid, wherein said liquid vaporizes to form vapor within said gas flow channel;
   a plurality of alternating hot and cold temperature-maintaining segments arranged next to one another relative to said gas flow channel to control and maintain a spatial temperature distribution of said gas flow channel from said input opening to said output opening and to produce a spatially-varying supersaturation environment in said gas flow channel, each hot temperature-maintaining segment having a temperature higher than an adjacent cold temperature-maintaining segment, wherein a temperature difference between adjacent hot and cold temperature-maintaining segments increases with position from said input opening to said output opening to produce a spatial supersaturation distribution that increases with position from said input opening to said output opening; and
   a particle counter disposed near said output opening of said gas flow channel and operable to determine presence and dimension of individual particles in the gas flow.

2. The system as in claim 1, further comprising a flow control module connected to the gas flow channel to control the flow rate in said gas flow channel.

3. The system as in claim 1, wherein said gas flow channel includes a thermal conducting tube.

4. The system as in claim 1, wherein said hot temperature-maintaining segments are maintained at a constant elevated temperature and said cold temperature-maintaining segments are maintained at different temperatures which monotonically decrease from said input opening to said output opening and are lower than said elevated temperature.

5. The system as in claim 1, wherein said cold temperature-maintaining segments are maintained at a constant low temperature and said hot temperature-maintaining...
segments are maintained at different temperatures which contiguously increase from said input opening to said output opening and are higher than said low temperature.

6. The system as in claim 1, wherein said optical particle counter includes a collection optical module having an optic axis which forms an angle of about 45° with said optical probe beam to receive scattered light from illuminated particles in said gas flow.

7. The system as in claim 6, wherein said collection optical module is configured to having a receiving optical aperture which forms a solid angle of about 45° with respect to an intersection between said optical probe beam and said gas flow.

8. The system as in claim 1, wherein said particle counter is an optical particle counter operable to produce an optical probe beam to illuminate the gas flow in a close proximity to said output opening and to determine presence and dimension of particles in the gas flow.

9. The system as in claim 1, wherein said particle counter is a aerodynamic time-of-flight particle counter which is operable to measure a particle size by the particle velocity acquired through rapid acceleration of the gas flow.

10. The system as in claim 1, wherein said cold temperature-maintaining segments are maintained at different low temperatures and said hot temperature-maintaining segments are maintained at different high temperatures.