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DOE/SC-ARM-TR-161

3002 Humidified Tandem Differential Mobility Analyzer (HTDMA) Instrument Handbook

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April 2024

ARM

DOE/SC-ARM-TR-161

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How to cite this document:

Uin, J. 2024. 3002 Humidified Tandem Differential Mobility Analyzer (HTDMA) Instrument Handbook. U.S. Department of Energy, Atmospheric Radiation Measurement user facility, Richland, Washington. DOE/SC-ARM-TR-161

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AC	alternating current
ARM	Atmospheric Radiation Measurement
BMI	Brechtel Manufacturing, Inc.
CPC	condensation particle counter
DMA	differential mobility analyzer
HSEMS	Humidified Scanning Electrical Mobility System
HTDMA	humidified tandem differential mobility analyzer
NIST	National Institute of Standards and Technology
PSL	polystyrene latex
RH	relative humidity
SEMS	Scanning Electrical Mobility System
UTC	Coordinated Universal Time

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1.0 Instrument Title

The instrument discussed in this handbook is the Model 3002 humidified tandem differential mobility analyzer.

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Instrument manual available from manufacturer http://www.brechtel.com/products-item/humidified-tandem-differential-mobility-analyzer/

4.0 Instrument Description

The Brechtel Manufacturing, Inc. (BMI) humidified tandem differential mobility analyzer (HTDMA Model 3002) (Brechtel and Kreidenweis 2000a,b, Henning et al. 2005, Lopez-Yglesias et al. 2014) measures how aerosol particles of different initial dry sizes grow or shrink when exposed to changing relative humidity (RH) conditions. The instrument uses two differential mobility analyzers (DMA) and a humidification system to make the measurements. One DMA selects a narrow size range of dry aerosol particles, which are exposed to varying RH conditions in the humidification system. The second (humidified) DMA scans the particle size distribution output from the humidification system. Scanning a wide range of particle sizes enables the second DMA to measure changes in size or growth factor (growth factor = humidified size/dry size), due to water uptake by the particles. A condensation particle counter (CPC) downstream of the second DMA counts particles as a function of selected size to obtain the number size distribution of particles exposed to different RH conditions.

5.0 Measurements Taken

The main HTDMA system measurement outputs are the selected initial size and RH of dried ambient aerosol particles, RH of the humidifier, and size distribution of humidified (grown) particles (particle concentration in counts/cc per predefined size bins). Particle growth factor and the hygroscopicity parameter kappa are derived from these measurements by the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility in a higher-level data product. Additionally, RH, temperature, and various air flowrates throughout the system are measured.

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

Raw HTDMA data are recorded in column format with appropriate headers specifying the data and units of measurement. Growth factor and kappa are not recorded in the data files but can be calculated from the recorded particle size data. The data fields recorded include scan start date/time, scan end date/time, selected initial particle size, sample pressure, sample temperature, sample RH, sample flow rate, edges and midpoints of the size bins of the particle size distribution, and particle concentration in each size bin. The parameters controlling the particle size scans (set by the user) are also recorded, along with numerous flow rates, pressures, and temperatures throughout the system that are mainly used for diagnostic purposes.

Output data are recorded after each size distribution scan, which typically occurs every 10 minutes. A new data file is started every midnight (instrument computer time, typically UTC) and following each system restart. This data object description is subject to change with future instrument software revisions.

6.2 Data Ordering

Data from the HTDMA can be ordered from http://www.arm.gov/instruments/htdma. Data are organized according to measurement location and campaign (both past and ongoing).

6.3 Data Plots

Figures 1 and 2are examples of typical HTDMA data outputs. Figure 1 shows measured particle size distributions (particle counts per size bin) as a function of time. The visibly intermittent nature of the size distributions is due to different ambient aerosol selection sizes, which are repeated periodically. Figure 2 shows total particle number concentration (calculated from the measured size distribution) as a function of time, for each ambient aerosol selection size. The selection size periodically varied between 50 and 250 nm (from blue to green on Figure 2) so that the five consecutive steps give a measure of the ambient aerosol size distribution. The Figure 1 plot was generated using the ARM's Program Data Quality Diagnostic Plot Browser (http://plot.dmf.arm.gov/plotbrowser/).

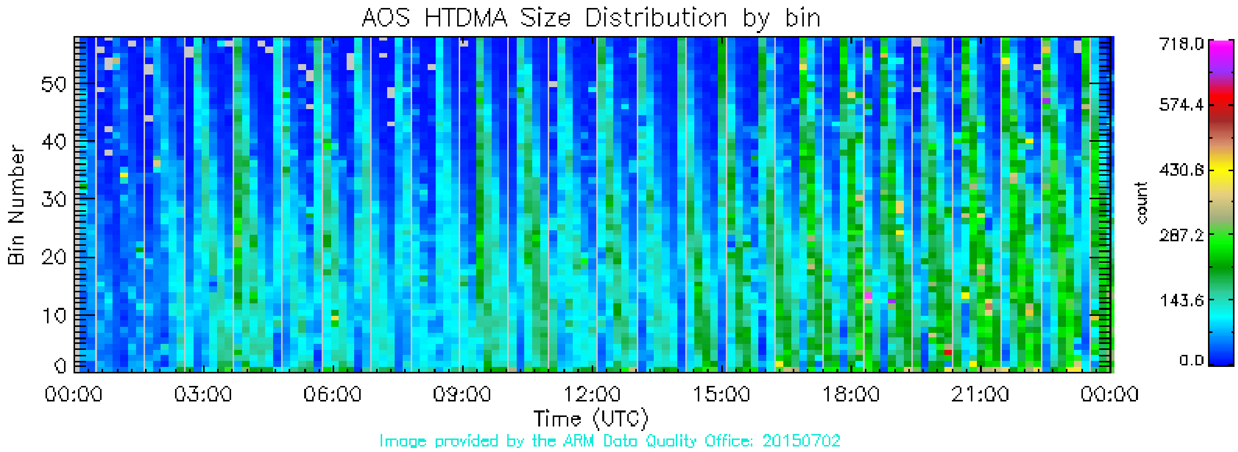

Figure 1. Aerosol size distribution as measured on June 30, 2015 by the HTDMA deployed at the Eastern North-Atlantic site on Graciosa Island, Azores, Portugal.

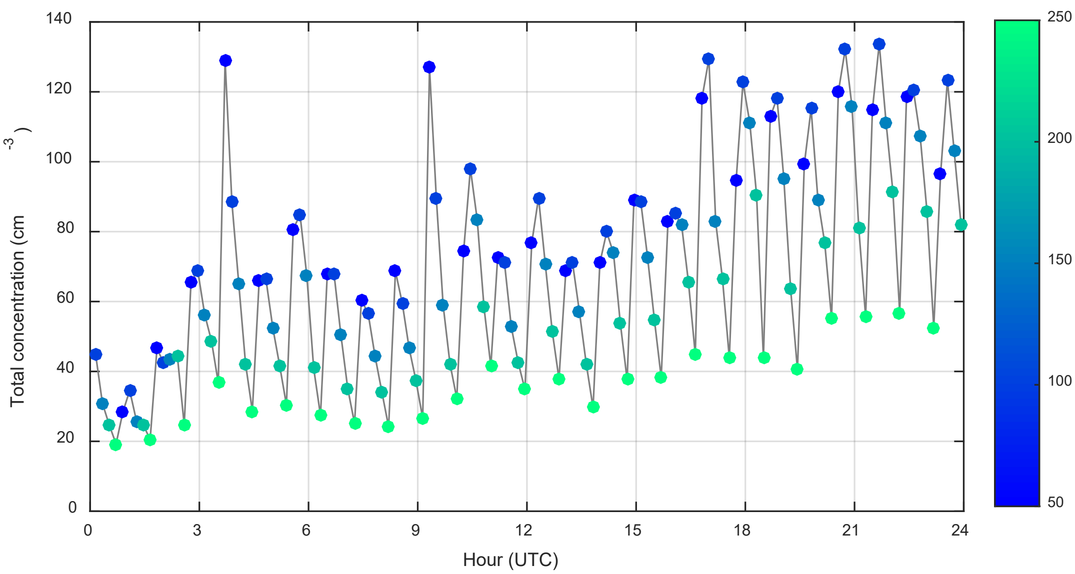

Figure 2. Humidified aerosol total number concentration for each ambient aerosol selection size as measured on June 30, 2015 by the HTDMA deployed at the Eastern North-Atlantic site on Graciosa Island, Azores, Portugal.

6.4 Data Quality

Data quality evaluation involves the automatic generation of the following plots, in collaboration with the ARM Data Quality Office (see also Figure 2):

- Humidified aerosol total particle concentrations (per ambient aerosol selection size) in time should be above 0 (otherwise indicating there is enough butanol for the internal particle counter), follow the same general trend, and not fluctuate erratically (Humidified Scanning Electrical Mobility System [HSEMS] internal CPC is not flooded and air flows/pressures are stable).

- Humidifier RH should be close to 90%. Values below 85% indicate an issue with water level, temperature, or air flows.

6.5 Calibration Data Base

During deployment, the HTDMA system is periodically (every six or twelve months) calibrated by the instrument mentors. This includes verifying/adjusting instrument's internal flow rates, verifying DMA sizing, and recording the growth factor of generated aerosol particles with a known chemical composition (ammonium nitrate or ammonium sulfate), as a function of RH. The growth factor value is compared to the Köhler model's theoretical values to ensure the HTDMA is in a proper operational state. No correction factors are usually derived. Calibration data are collected and maintained by the instrument mentors.

7.0 Technical Specification

7.1 Units

The units used in the HTDMA's technical specification procedures include aerosol particle size: nanometers (nm); aerosol particle concentration: particles per cubic centimeter ($1/cm^{-3}$); growth factor: dimensionless; and RH: dimensionless (%).

7.2 Range

Particle size can range from 20 to 2,500 nm. Particle concentration can be measured from 0 to 100,000 cm^{-3}. RH can be controlled/measured from 2 to 93%.

7.3 Accuracy

Particle sizing accuracy depends mainly on the precision of the DMA sheath flows and voltages. The manufacturer specifies a value of 10 nm to obtain accurate particle sizing, based on measurements of National Institute of Standards and Technology (NIST) traceable monodisperse calibration aerosols (polystyrene latex [PSL]).

The humidification system's accuracy depends mainly on the precision of temperature and flow control. The manufacturer specifies a value of 1% for achieving accurate humidification system readings. This percentage is based on NIST traceable factory calibrations of built-in hygrometers, validation of factory-calibrated temperature sensors with a precision resistance temperature detector, and measurements of flows with a DryCal calibration standard.

Particle concentration measurement accuracy depends mainly on the CPC's inlet flow rate. The manufacturer recommends setting a value of 3% for the flow set point value to obtain correct flow control. This percentage is based on air flow measurements taken using a DryCal calibration standard.

7.4 Repeatability

Particle sizing repeatability depends mainly on DMA sheath flow and voltage control precision. The manufacturer specifies a desired repeatability within 10 nm between each successive particle size measurement, based on measurements of NIST traceable monodisperse calibration aerosols (PSL).

Humidification system repeatability depends mainly on temperature and flow control accuracy. The manufacturer specifies a desired repeatability within 0.8% between each successive RH measurement.

Particle concentration measurement repeatability depends mainly on the CPC's inlet flow rate. The manufacturer specifies a desired repeatability within 1% between successive concentration measurements of generated test aerosols.

7.5 Sensitivity

HTDMA operation is sensitive to temperature fluctuations and low RH of the ambient aerosol sample (e.g., arctic conditions). During deployments, the instrument is operated in an air-conditioned enclosure and care is taken to minimize temperature changes.

Aerosol particle concentration measurements are sensitive to particle concentration (due to particle coincidence when counting at higher concentrations) and to particle size (due to limited particle growth from condensation at lower particle sizes). Both are accounted for in the instrument software, based on comparison experiments done by the manufacturer using an aerosol electrometer and commercially available CPCs.

7.6 Uncertainty

Particle sizing uncertainty is approximately ±1% and ±4% for RH measurements, according to the manufacturer. These values are based on assessments of the instrument's monodisperse calibration aerosol measurements (PSL), internal temperatures, and air flows.

7.7 Input Values

Parameters set by the user include ambient aerosol selection size, humidifier RH, particle size distribution measurement range, and number of size bins. Additionally, various parameters affecting the instrument performance, such as time delays and internal flow rates, can be specified.

7.8 Output Values

The recorded data includes scan start date/time, scan end date/time, selected initial particle size, sample pressure, sample temperature, sample RH, sample flow rate, edges and midpoints of the size bins of the particle size distribution, and particle concentration in each size bin. ARM-provided higher-level data include growth factor and hygroscopicity parameter kappa, calculated from raw instrument data.

The parameters used for controlling particle size scans, set by the user, are also recorded, along with numerous flow rates, pressures, and temperatures throughout the system that are mainly used for diagnostic purposes.

8.0 Instrument System Functional Diagram

The HTDMA system consists of two separate instruments: 1) The Scanning Electrical Mobility System (SEMS), which houses the first DMA for ambient aerosol size selection. 2) The HSEMS, which contains the humidifier, second DMA, and a CPC for measuring the size distribution of humidified aerosol particles. The entire system can be divided into three separate subsystems: a) flow system with humidity and temperature control, b) sensors and electronics and c) built-in computers, as pictured in Figure 3.

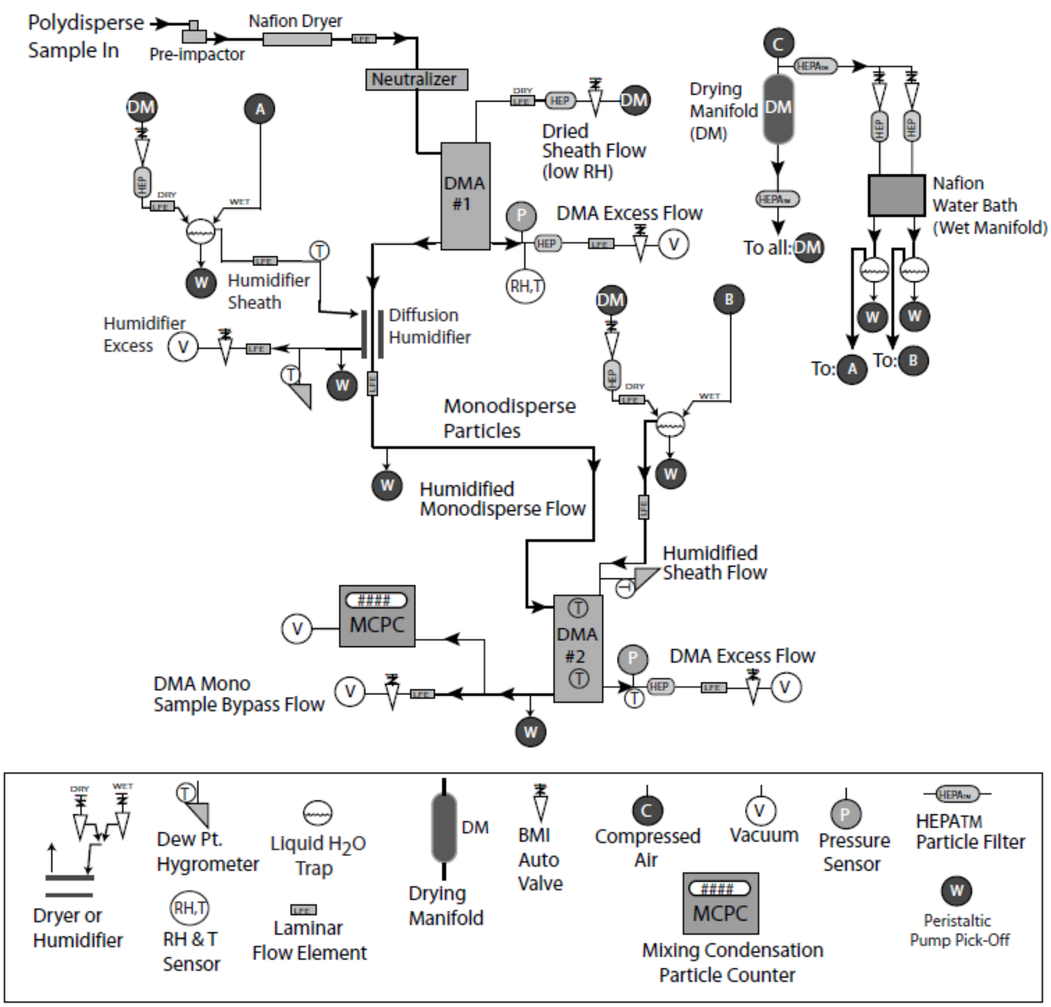

Figure 3. HTDMA flow diagram (Lopez-Yglesias et al. 2014).

9.0 Instrument/Measurement Theory

In the HTDMA, dry monodisperse particles are selected using an upstream DMA (pictured as DMA #1 in Figure 3) and exposed to a controlled RH in a humidification system upstream of the second DMA (Hennig et al. 2005, Brechtel and Kreidenweis 200a,b). The DMA selects particles based on their electrical mobility (which is related to their size) (Knutson and Whitby 1975). The voltage in the second DMA (pictured as DMA #2 in Figure 3) is scanned over time to determine changes in dry particle sizes due to water uptake. A CPC monitors the concentration of particles exiting the second DMA to construct the size distribution of droplets formed on originally dry particles. The growth factor and kappa are calculated from this size distribution and the selection size of the upstream DMA.

10.0 Setup and Operation of Instrument

Follow the steps listed below to set up and operate the instrument.

1. Connect the vacuum source to the vacuum fittings on the HSEMS and SEMS rear panels (20 lpm, 15’’ Hg). Be careful not to confuse the compressed air source and vacuum source; follow the labels marked on the back panels (only for initial setup).
2. Connect the compressed dry-air source to the fittings on the HSEMS and SEMS rear panels (20 lpm max, 15 psig). Connect both the dried and un-dried compressed air ports to the dry-air supply (only for initial setup).
3. Do not start the vacuum or compressed air flows into the instruments until the mixing CPC is on (i.e., HSEMS is running). Butanol may be drawn into the optics, or out the mixing CPC inlet, if the following procedure is not followed.
4. Connect the SEMS monodisperse outlet to the HSEMS sample inlet (only for initial setup).
5. Fill the water bottle with distilled deionized water.
6. Fill butanol supply bottle with reagent-grade n-butyl alcohol (butanol).
7. Before connecting the HSEMS alternating current (AC) power, verify that the voltage selector in the power connector matches the supply voltage. The voltage selector should have been pre-set at the factory. Connect the AC power to the connector on the front panel (only for initial setup).
8. Connect the SEMS AC power. The SEMS automatically adjusts to the input voltage (only for initial setup).
9. Connect the serial crossover cable between the appropriately labelled serial ports on the HSEMS and SEMS. During HTDMA operation, the HSEMS software controls the SEMS and requires serial communication to do so (only for initial setup).
10. Boot the SEMS computer by pressing the power button on the front panel. Boot the HSEMS computer by pressing the power button on the front panel.
11. Turn on both vacuums and compressed air sources.
12. Launch the instrument software in both the SEMS and HSEMS (if they do not start automatically).

13. Press "Flow Control" and "Water Heater" buttons in the HSEMS software main screen. If HSEMS does not connect automatically to SEMS, press "Connect SEMS" button in the HSEMS software main screen.
14. On the "Scanning" tab of the HSEMS software, press "Start" in the "Autoscan" section of the window. A scanning program written by Brookhaven National Laboratory for the measurement site should load automatically.

For further details, consult the manufacturer's manual.

11.0 Software

Instrument control and data acquisition are performed by NI LabView-based software, written by the manufacturer. Additional LabView-based software, written by Brookhaven National Laboratory, reformats and relocates data files saved by the manufacturer's software.

12.0 Calibration

The HTDMA system is calibrated and validated by the manufacturer prior to delivery and during routine instrument maintenance tasks, performed at the manufacturing facilities. During deployment, subsets of the manufacturer's calibration are performed every six or twelve months by the instrument mentors.

Manufacturer's calibration includes:

- Measuring the size distribution of a NIST traceable monodisperse calibration aerosol (PSL) to validate the proper operation of the DMAs.
- Measuring the growth factor of generated aerosol particles with a known chemical composition (ammonium sulfate or ammonium nitrate) as a function of RH and comparing the resulting curve to a theoretical one from the Köhler model to validate the proper operation of the HTDMA.
- Calibrating the high-voltage power supply, absolute pressure sensor, and laminar flow element against precision instruments and recording-derived correction factors in the software configuration files, which is used automatically.

Calibration and validation completed by the instrument mentors, like the manufacturer's calibration activities, includes:

- Recording the growth factor of generated aerosol particles with a known chemical composition (ammonium sulfate or ammonium nitrate), as a function of RH and comparing the resulting curve to a theoretical one from the Köhler model to validate the proper operation of the HTDMA. If the recorded growth factor curve differs from the theoretical curve by more than the accuracy value specified by the manufacturer, it should be investigated on a case-by-case basis and corrected.
- Measuring the internal flow rates using a precision flow meter and applying calibration factors to the raw flow rate sensors.
- Correction factors (if any) are derived according to the issue in question. Please consult the manufacturer's manual for more details.

13.0 Maintenance

The HTDMA requires the following maintenance activities to function properly:

- Fill the water bottle when the water level is below 50%.
- Fill the butanol bottle when the butanol level is below 50%.
- Empty the drain bottle when the butanol bottle is filled or if the liquid level exceeds 50%.
- Clean the SEMS impactor when the impactor status light in the main software window turns red.

14.0 Safety

Please familiarize yourself with the following safety considerations before attempting to operate the HTDMA.

- The internal CPC of HSEMS uses n-butyl alcohol (butanol) as a working fluid, which is flammable and toxic if inhaled.
- The internal CPC of HSEMS is a Class I laser-based instrument. During normal operation, the user is not exposed to laser radiation.
- The SEMS part of the HTDMA system uses a radioactive 210Po source for charging aerosol particles. During normal operation, the source is shielded and therefore the user is not exposed to radiation.
- The SEMS and HSEMS are heavy (each weighing more than 50 kg or 110 lbs). Appropriate precautions should be taken during instrument installation and removal to avoid injury.

15.0 Citable References

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