Real-Time Size-Distributed Measurement of Aerosol Mass Concentration

Modi Chen, Lin Li, Virgil Marple, Amir Naqwi, Francisco Romay, Daryl Roberts, MSP Corporation, Shoreview, MN
James C. Wilson, University of Denver, CO

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SUMMARY

A prototype of a new instrument is developed for airborne aerosol mass measurements. MSP Corporation has modified and upgraded its Micro-Orifice Uniform-Deposit Impactor (MOUDI) to provide real-time measurements. This device consists of multiple stages. At each stage, aerosols of a certain size class are deposited on an impaction plate (Marple et al. 1991 and Marple & Liu 2006). In this work, we report a Real-Time MOUDI instrument that incorporates a quartz-crystal microbalance (QCM) on each stage to enable real-time mass measurements. In airborne atmospheric measurements, this instrument will provide a time history of aerosol mass distribution that would elucidate differences between the aerosol size distribution near and far from a cloud and the effect of altitude on the aerosol size distribution.

Real-Time MOUDI has been tested extensively with a variety of particle materials and particle sizes. QCM-based measurements are compared with alternative measurements based on a condensation particle counter. These experiments highlight the importance of humidity conditioning of the aerosol sample. QCM-based measurements are in good agreement with the alternative measurements for moderate relative humidity.

INSTRUMENTATION DEVELOPMENT

A cascade impactor consists of multiple stages. Two such stages are shown in Figure 1. Flow of sampled air is maintained through these stages using a vacuum pump. Each stage has a nozzle plate and an impaction plate. Air containing particles is accelerated through the nozzles and approaches the impaction plate, where particles above a certain aerodynamic diameter (cut-point of the stage) are deposited due to inertia. Finer particles are carried over with the air to the next stage. This stage has finer nozzles and accelerates the flow to a higher velocity, so finer particles are deposited, i.e. subsequent stages have lower cut-points. The net result of this process is that aerosols in the sampled air are size-classified and deposited on separate impaction plates with the coarsest particles depositing on the first impaction plate and the finest on the last. MSP's conventional MOUDI consists of 13 stages covering a size range of 10 – 10,000 nm. As shown in Figure 2, QCM sensors are mounted to Stage 6 – 13 of MOUDI that cover an aerosol size range of 10 – 600 nm, which is of most interest in several atmospheric applications (Stages 1 - 5 covering larger particles up to 18 micron are not included in the current prototype).

Figure 3 shows the impaction plate of a Real-Time MOUDI with a QCM crystal flush mounted to it. Crystal has gold electrodes on both the sides, which are connected to frequency analyzer that determines the resonant frequency of the crystal. As aerosols deposit and attach to the upper surface, effective mass of the crystal increases and its natural frequency of vibration drops. Using state-of-the-art electronics, mass deposition as low as 10 ng can be detected.

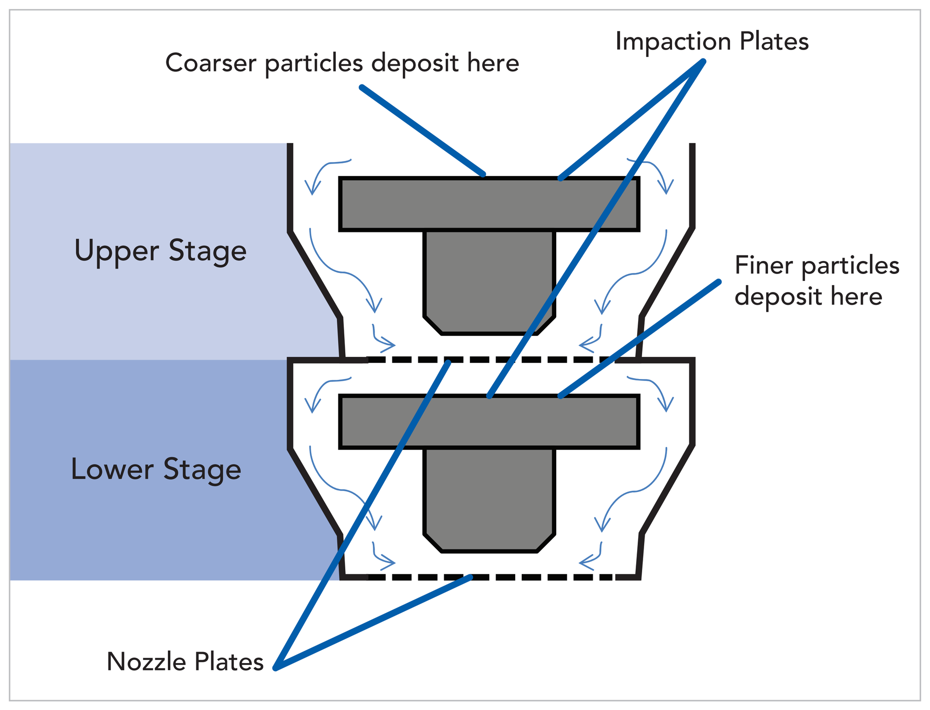

Figure 1—Principle of a cascade impactor

Figure 3—QCM mounted to an impaction plate

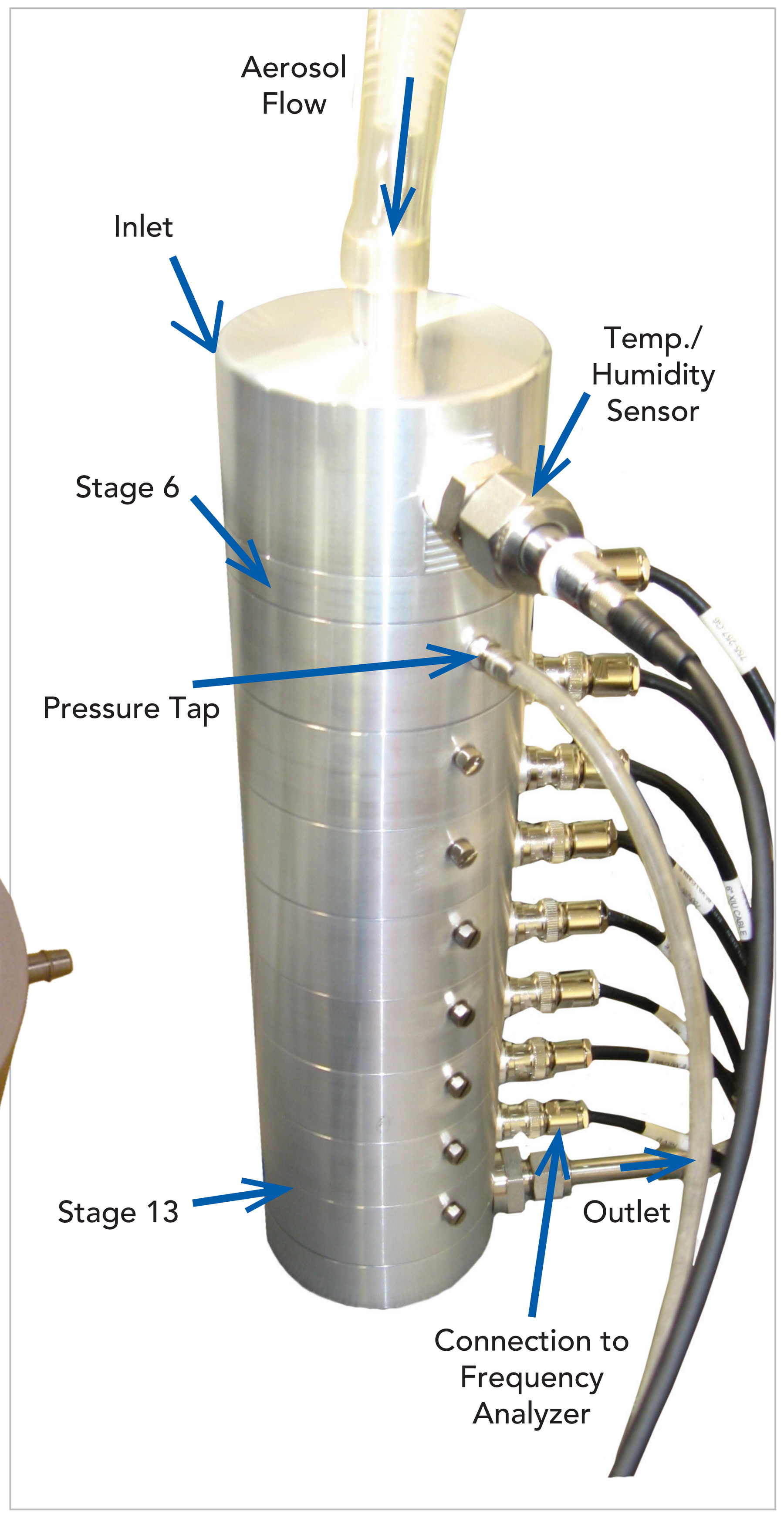

Figure 2—Prototype of Real-Time MOUDI

EXPERIMENTAL DESIGN AND RESULTS

Figure 4 shows the setup for the Real-time MOUDI calibration. Particles of various compositions are generated by atomizing their corresponding solutions or suspensions. A nafion drier (Perma Pure MD-050-12-S-4) is used to remove the water content in the particles before they enter the differential mobility analyzer (DMA), where the particles are classified according to their electrical mobility. An impactor is used after the DMA to remove the multiply charged large particles. Remaining mono-dispersed particles are then mixed with RH conditioned make-up air. Flow is split and sent into water CPC (MSP M1120) and a Real-time MOUDI.

The total mass of particles sampled by the Real-time MOUDI can be estimated by measuring the drop in the resonant frequency of the QCM. Since these particles after the DMA are highly mono-dispersed with known density, their total mass can also be estimated based on particle concentration from the CPC.

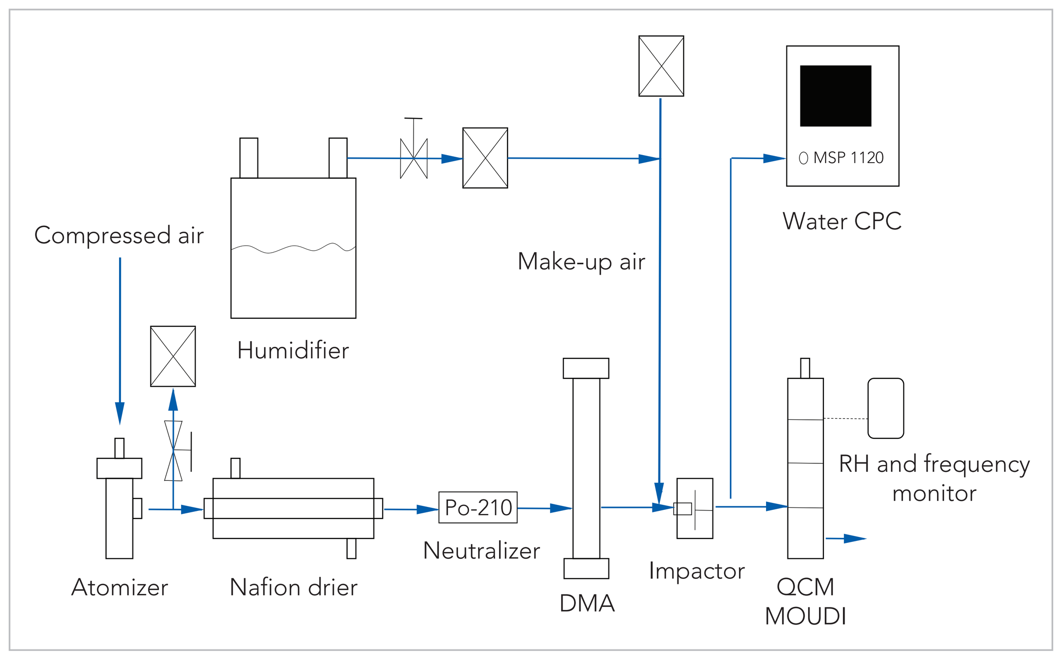

Figure 4—Experimental setup for Real-Time MOUDI testing

Total mass measured by real-time MOUDI is compared with the estimate based on CPC in Figure 5 for sodium chloride and in Figure 6 for PSL particles. About 1 microgram was collected in both cases. Good agreement was observed with a maximum difference of about 10% between the masses based on these two independent methods.

The effect of RH on particle deposition on the Real-time MOUDI was also investigated in this study. Below 50% RH, particle bouncing became significant. Total mass estimated by particle concentration was higher than that estimated by frequency drop, since Real-time MOUDI was no longer able to collect all the mass in the sampled flow due to bouncing (Figure 7). Certain coating on the surface of the QCM has been demonstrated to reduce bouncing. An example is shown in Figure 8. In this case, the surface of the QCM was coated with MSP silicone spray. Particles are collected at the efficiency close to 100% at RH as low as 40%.

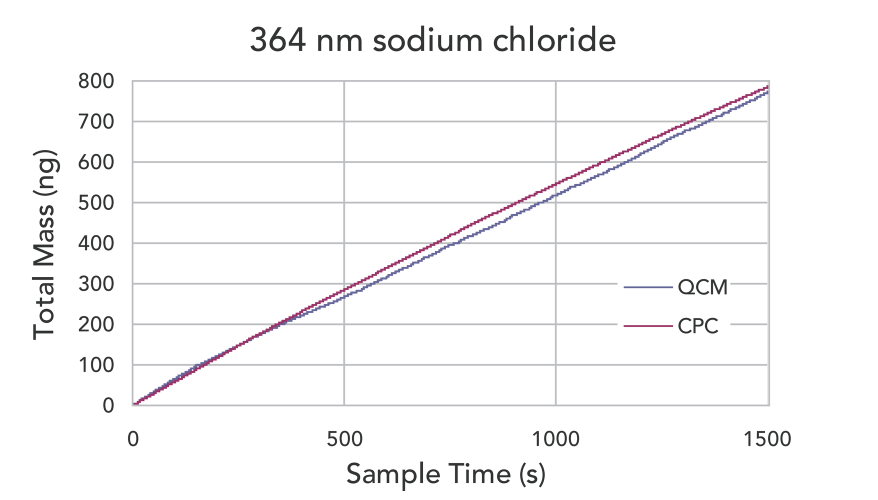

Figure 5—Total mass of sodium chloride aerosol measured with QCM versus an estimate based on CPC data. Experiment was carried out at 50% relative humidity.

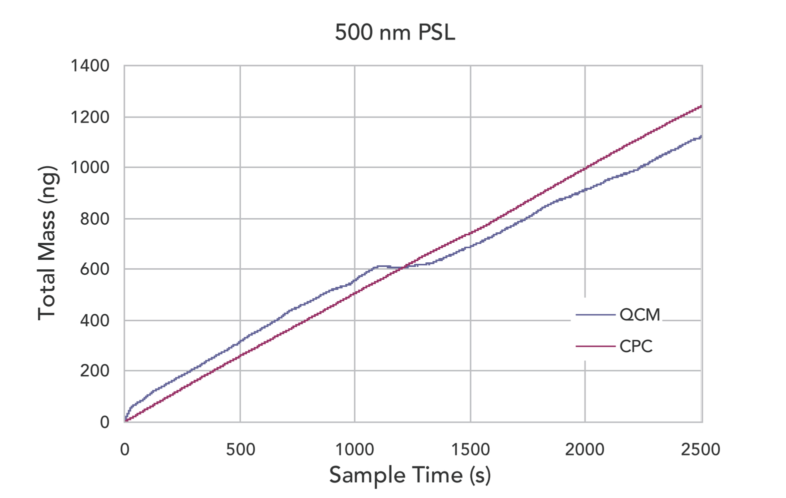

Figure 6—Total mass of PSL aerosol measured with QCM versus an estimate based on CPC data. Experiment was carried out at 50% relative humidity.

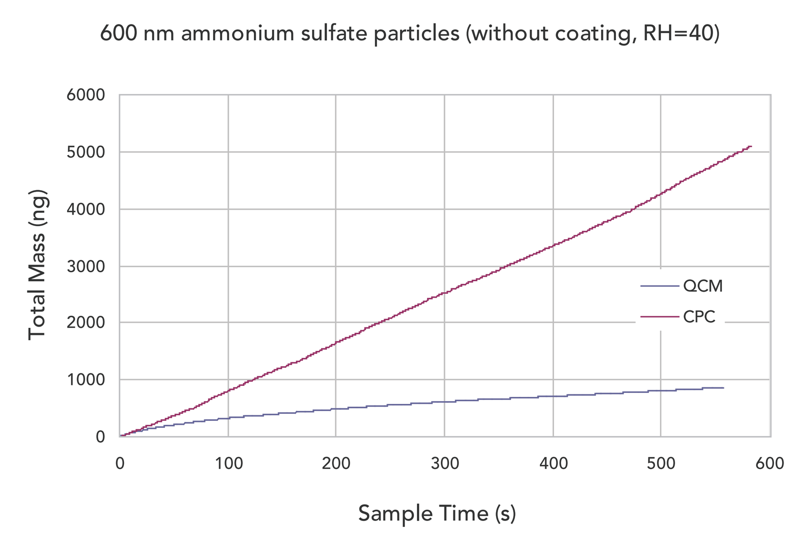

Figure 7—Ammonium sulfate particles sampled at 40% RH without coating.

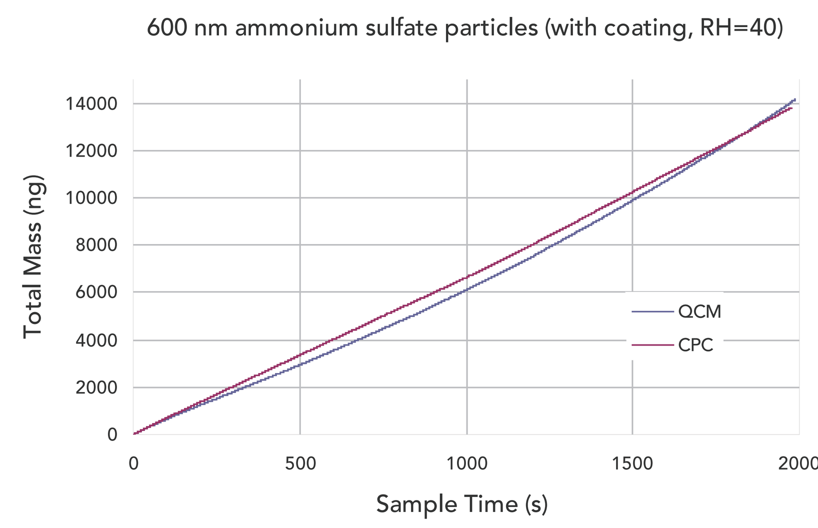

Figure 8—Ammonium sulfate particles sampled at 40% RH with silicone coating. Good agreement was observed.

CONCLUSIONS AND FUTURE WORK

Prototype of a precision real-time cascade impactor is developed for the measurement of real-time size-distributed aerosol mass concentration. Accurate mass measurements can be obtained with humidity conditioning of the aerosol stream. Future work will involve development of a fully-functional flight-worthy instrument that will include a heater to heat the incoming air sample to 25 °C, and a humidifier to obtain suitable conditions for aerosol mass measurements, as well as for the study of hygroscopic properties of the collected sample.

REFERENCES

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