Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2019-438-AC2, 2020

Atmospheric Measurement Techniques Discussions

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Interactive comment

Interactive comment on "Development of a new Nano-particle sizer equipped with a 12 channel multi-port differential mobility analyzer and multi-condensation particle counters" *by* H. K. Lee et al.

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Received and published: 19 February 2020

Atmospheric Measurement Techniques (Discussions)

Ref.: Manuscript No. amt-2019-438-RC1

Title: Development of a new Nano-particle sizer equipped with a 12 channel multi-port differential mobility analyzer and multi-condensation particle counters

Anonymous Referee #2, 11 Feb 2020

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Discussion paper

General comments

This manuscript presents a design of a novel differential mobility analyzer with multiple outlets enabling fast parallel measurement of particle size. The manuscript is written mostly in a clear and concise manner presenting the main details of the design of the instrument and tests done to verify its operation. However, some parts of the manuscript explaining the experiments need clarification (see questions below). This manuscript is fit for publications once the questions and comments below have been addressed.

1. (Page) 4, L. (Line) 87: Suggest changing wording to help the reader to understand the difference between "aerosol flow rate" and "sampling flow rate". Perhaps "sampling flow rate for each CPC".

Ans: Thanks for the good suggestion. We modified the sentence as follows:

Line 87: “The flow systems and paths for the NPS are depicted in Fig. 1, including the aerosol flowrate (Qa, 0.18 L min-1), sheath flowrate (Qsh, 3.78 L min-1), sampling flowrate for each CPC (Qs, 0.18 L min-1), and exhaust flowrate (Qe, 1.8 L min-1).”

2. P. 4, L. 95: As each CPC samples through a single port, how uniform are the sample flows across the circumference of each annulus? One would expect needing multiple ports per annulus to ensure uniformity of flows. Was any CFD modelling done to study the internal flows? Please discuss it.

Ans: Thanks for the good comments. The “uniform” in the line 95 (in the original manuscript) means that the annular ports are placed with the uniform distance of 2 cm. We agree that this wording might be confusing to readers. Therefore, we deleted the part. As the reviewer mentioned, we recently performed and published the numerical work on the MP-DMA performance, using the computational fluid dynamics (CFD) tool. The numerical simulation focused on flow field and particle transport inside the MP-DMA. The numerically obtained transmission efficiency and resolution agreed well with experimental data.The particle transport (with particle residence time) obtained after flow field simulation is presented in the point-to-point response. Furthermore, we expect that the flow through each annulus might be quite uniform owing to the small sampling slit (approximately 0.5 mm), which might result in pressure drop and thus uniform flow through the annular slit. It is not easy to observe and evaluate the uniformity of the flow inside the instrument experimentally, but from the consistent results between the experiments and numerical simulations (transmission efficiency and resolution of the MP-DMA), we can assume that flow inside the NPS should be similar to the flow obtained in the simulation, which does not show any uniformity issue. Based on the reviewer's comment, we put some information in the revised manuscript as follows:

Line 96: "The MP-DMA uses an inner electrode with the increasing diameter along the longitudinal direction."

3. P. 4, M-CPC: are there any publications about the M-CPC which could be referenced in this manuscript? If not, then more information about the design and working parameters of the M-CPC should be provided here.

Ans: Thanks for pointing it out. In our lab, we developed aerosol instruments including condensation particle counter, optical particle counter, differential mobility analyzer, etc. We have been employing our homemade CPC for investigating atmospheric aerosols. It has the same parts including a saturator, condenser, and optical part. We list the references below that employed our CPC.

(1) Querol, X., Gangoiti, G., Mantilla, E., Alastuey, A., Minguillón, M. C., Amato, F., Reche, C., Viana, M., Moreno, T., Karanasiou, A., Rivas, I., Pérez, N., Ripoll, A., Brines, M., Ealo, M., Pandolfi, M., Lee, H. K., Eun, H. R., Park, Y. H., Escudero, M., Beddows, D., Harrison, R. M., Bertrand, A., Marchand, N., Lyasota, A., Codina, B., Olid, M., Udina, M., Jiménez-Esteve, B., Jiménez-Esteve, B. B., Alonso, L., Millán, M. and Ahn, K. H.: Phenomenology of high-ozone episodes in NE Spain, Atmos. Chem. Phys., 17(4), 2817–2838, doi:10.5194/acp-17-2817-2017, 2017.

(2) Zhu, Y., Wu, Z., Park, Y., Fan, X., Bai, D., Zong, P., Qin, B., Cai, X. and Ahn, K. H.: Measurements of atmospheric aerosol vertical distribution above North China Plain using hexacopter, Sci. Total Environ., 665, 1095–1102, doi:10.1016/j.scitotenv.2019.02.100, 2019.

(3) Minguillón, M. C., Brines, M., Pérez, N., Reche, C., Pandolfi, M., Fonseca, A. S., Amato, F., Alastuey, A., Lyasota, A., Codina, B., Lee, H. K., Eun, H. R., Ahn, K. H. and Querol, X.: New particle formation at ground level and in the vertical column over the Barcelona area, Atmos. Res., 164–165, 118–130, doi:10.1016/j.atmosres.2015.05.003, 2015.

(4) Hwang, I. and Ahn, K. H.: Performance evaluation of conventional type conductive cooling continuous flow compact water-based CPC (Hy-WCPC), J. Aerosol Sci., 113(July), 12–19, doi:10.1016/j.jaerosci.2017.07.007, 2017.

Line 106: “The operating principle of the M-CPC is same as other typical CPCs. Particles are introduced to the saturator (temperature: 35 °C), and the condensational growth of the particles occurs in the condenser at a temperature of 10 °C. The condensed particles are detected in the optical part.”

4. P. 8, L. 210 and below, also start of P. 9: This paragraph needs elaboration with more explanation provided on how the experiment and data analysis was done. For example, what is meant by "central particle diameter"? How were penetration ratios obtained? Was the TSI SMPS size classification point changed or kept constant? What were the parameters of the aerosol size distribution coming from the SMPS? Was the SMPS data corrected in any way (multiple charging, diffusion losses etc.)? Please add more details.

Ans: Thanks for the comments. The answers are presented below.

4-1) what is meant by "central particle diameter"? How were penetration ratios obtained?

Ans: The central particle size represents the mode diameter of the classified particles at each port as shown in Table 1 below. The penetration ratio is defined as the ratio between the concentrations of monodisperse particles, generated by the DMA in Fig. 2(b), obtained by each M-CPC and TSI-CPC. For example, we generated 17.4 nm monodisperse particles by using a DMA in Fig. 2(b) and measured the concentrations using the NPS operated at 1000 V and TSI-CPC (as shown in Table 1). For better clarification, we modified some sentences in the revised manuscript.

Line 217: “The penetration ratio is defined as the ratio of the total concentration at the central particle diameter (ref. Table 1) measured by the NPS to the reference concentration obtained by the TSI-CPC as presented in Fig. 2(b). For example, monodisperse particles with a mode diameter shown in Table 1 were generated by using a DMA and introduced to the NPS and TSI-CPC to achieve the penetration ratio.”

Line 221: “The penetration ratio of the MP-DMA ranges from 0.099 to 0.765, and these data were used for calibrating the NPS system to convert the raw data obtained by the NPS to the reference concentration data. The theoretical resolution of the MP-DMA decreases from 21 (Port 1) to 10 (Port 12) due to the increasing aerosol-to-sheath flowrate. However, the resolution of the first DMA (TSI standard DMA) is 10 owing to the ratio between aerosol and sheath flowrate of 1:10. Therefore, the CPC at Port 1 might count the particles in the narrower size distribution classified by the first DMA, resulting in a low penetration ratio. Thus, the penetration ratios for all ports were used as correction factors in Eq. (1) to achieve the same concentration as the reference data measured by the TSI-CPC.”

4-2) Was the TSI SMPS size classification point changed or kept constant? What were the parameters of the aerosol size distribution coming from the SMPS? Was the SMPS data corrected in any way (multiple charging, diffusion losses etc.)?

Ans: We employed the TSI-CPC, not TSI-SMPS size classification, for the penetration ratio. As shown in Fig. 2(b) we did not use the scanning-voltage DMA and CPC combination, but we only measured the concentration using the CPC. The DMA in Fig. 2(b) was operated in a fixed voltage mode to generate the monodisperse particles, not scanning voltage mode. The SMPS (scanning voltage mode) was only used for observing the particle size distribution (Fig. 2(c) and from Fig. 7). The SMPS data obtained in this study were corrected based on the multiple charging, charge fraction, and diffusion loss. We used the TSI software to operate the TSI-SMPS system, and this software supports the all the corrections.

Line 261: “For all TSI-SMPS measurements performed in this study, the corrections for the multiple charging and diffusion loss were applied.”

5. Figure 2: Is the SMPS in 2(c) the same as "standard DMA" on 2(a) and 2(b)? If so, state it clearly.

Ans: Thanks for the suggestion. Yes, the DMA included in the SMPS system is the same as the DMA used in Fig. 2(a) and 2(b). We clearly denoted it in the revised manuscript. Thanks a lot for the clarification.

Line 248: “The TSI-SMPS system consists of the TSI standard DMA and TSI-CPC which were used in Fig. 2(a) or 2(b).”

6. Figure 3: Is the bias at higher concentrations taken into account in data inversion?

Ans: That is a good question. Thanks. Yes, we included the correction for the bias at higher concentrations based on the results obtained in this study. However, this high concentration range has never been reached in the real applications such as measuring atmospheric particles. The concentration range shown in Fig 3 represents the performance of the M-CPC. From the experiments, we found the detection limit of the M-CPC by introducing the high concentration of aerosols. However, in the real situation, the M-CPC always measures the concentration of particles classified by the MP-DMA. Therefore, the concentration is usually very low because only small fraction of introduced particles (single positively or negatively charged particles) is detected.

As the reviewer pointed it out, we put the correction factor in the NPS system in case of the higher concentration introducing to the M-CPC.

Line 204: “It should be noted that a correction factor was considered in the concentration range higher than 20,000 # cm-3. Furthermore, each CPC in the NPS always measures the concentration of particles classified by the MP-DMA; therefore, in real applications such as atmospheric particle measurements, this high concentration after classified by the MP-DMA can be rarely achieved.”

7. P. 9, L. 248 and Figure 8: There's a 5500 cm^{-3} bias between the total number concentration measurements from the two instruments, with NPS measuring lower than SMPS. Where does this difference originate from? Is this corrected in data analysis/inversion? Does this mean that the NPS can't measure total particle number concentrations less than 5500 cm^{-3}? That's a fairly high number for many atmospheric applications. Please discuss.

Ans: As the reviewer mentioned, we observed a 5500 # cm-3 bias for the NPS measurement compared to the TSI-SMPS total concentration. We believe that the difference originates from the loss inside the NPS. Due to the low sampling flowrate of 0.18 L min-1 for each CPC, there might be additional diffusion loss. We are now optimizing the flowrate and trying to minimize the loss inside the system by increasing the flowrate control system. Therefore, in the future we believe that the bias will be reduced. Thanks a lot for the good comments again. Based on the reviewer's comment, we added a sentence in the revised manuscript.

Line 257: “As shown in Fig. 7(b), we observed the approximately 5500 # cm-3 bias in the total concentration for the NPS measurement compared to the TSI-SMPS. We believe that this originates from the particle loss inside the NPS due to the low sampling flowrate for each CPC in the NPS system.”

8. Figures 7, 8, 9: Were any corrections applied to the SMPS data (multiple charging, diffusion losses etc.)? State this clearly to help the reader make accurate assessments

of the results.

Ans: We used the TSI-SMPS system by using the package and the software that the TSI company provides. Therefore, in the system there are options for the multiple charging and diffusion loss corrections. We turned on the corrections when we obtained the data in this study. We stated this in the revised manuscript. Thanks for the good suggestion.

Line 261: “For all TSI-SMPS measurements performed in this study, the corrections for the multiple charging and diffusion loss were applied.”

9. Figure 9: What is meant by first and second scanning data in the figure caption? If these are SMPS scans taken during the measurement, then indicate when they were taken on the NPS color plot. Also, please label the individual plots clearly to indicate from which instrument they are from.

Ans: Thanks for the comments. In the experiments, we compared the NPS and TSI-SMPS measurements. Two cycles of the TSI-SMPS measurement were performed consecutively with 120 s scanning time for each cycle, and the NPS obtained concentration data every 1 s. Therefore, “first” and “second” in the figure caption represent the first cycle of 120 s and the second cycle of 120 s for the TSI-SMPS measurements, respectively. The left figure in Fig. 8(a) (we changed the numbering from Fig. 9 to Fig. 8 in the revision process) represents the TSI-SMPS data from the first cycle, and the right figure in Fig. 8(b) shows the data from the second cycle. As the reviewer mentioned, we modified the figure, so it can be more clear to readers.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2019-438, 2019.