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Atmospheric Measurement Techniques Discussions

# *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.

**H. K. Lee et al.**

khahn@hanyang.ac.kr

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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 #1, 12 Dec 2019



General comments

The manuscript presents the experimental work on the development of a nano-particle sizer for measuring a particle size distribution in 1 s time resolution. As a fast measurement system for ambient aerosols has attracted attention, this paper has an originality and deals with important contents. In general, the manuscript shall be considered for the journal publication after some major and minor revisions. Specific comments after reviewing the manuscript are given in the following:

Major comments

1. As shown in fig. 1, the inlet of each port seems to be a small hole not an annular ring. Therefore, only a part of introduced particles would be detected by a CPC because particles would be deposited at the wall. So, the particle loss in the MP-DMA might be significant. If particle loss in MP-DMA is high, NPS could not measure low concentration. Then what is minimum measuring concentration of NPS? If the inlet shape of each port is the annular ring, the flow is expected to be deflected. In a typical DMA, the flow deflection is minimized by centering the flow from the annular ring. How did author solve the flow deflection problem in the MP-DMA?

Ans: Thanks for the clarification. In fact, the shape of the sampling ports is annular. We agree that this is not clearly mentioned in the original manuscript. Therefore, we modified the sentence as follows:

Line 94: "While Chen et al. (2007) employed three sampling ports and applied an exponentially increasing distance between neighboring ports to allow a wide size range of particles, the MP-DMA has 12 annular sampling ports that are placed with a uniform distance of 2 cm between neighboring ports."

2. TSI-SMPS and NPS showed very good agreement for the particle concentration distribution as shown in fig. 7. Can the NPS detect particles smaller than 17 nm by decreasing NPS voltage? Why did not the authors perform the experiment with the

voltage lower than 1000 V?

Ans: Thanks for the good comments. We developed the NPS for measuring particle size distribution up to 300 nm particles; therefore, we can utilize the NPS together with an optical particle counter (OPC) for fast ambient particle measurements. As the reviewer mentioned, the NPS might be used at the voltage range under 1000 V to classify smaller particles down to 10 nm. The developed NPS is a prototype, so we are optimizing the flowrate and configuration of the NPS system to characterize smaller particles down to sub-10 nm particles.

3. As shown in fig. 9, while the SMPS immediately responded when an aerosol valve was closed or opened., the NPS has 15-20 s response time. Authors explained it with concentration stabilization and particle transportation. However, concentration stabilization might not be the reason because the SMPS responded immediately. Furthermore, particle transportation cannot be the reason if the length of transportation pipe of SMPS and NPS were same. It would be only 3 seconds late even considering the flying time in NPS. Why NPS response time was too late?

Ans: Thanks for the good comments. In the data processing, we made a mistake. We did not consider the preparation time (about five seconds) of the SMPS before the scanning process. In the experiments, we clicked the start buttons of SMPS and NPS systems simultaneously. The NPS measures size distribution right after the start; however, the SMPS system takes 4-5 seconds before the scanning process, which was previously not considered in the data processing. Therefore, the NPS measures five seconds prior to the SMPS. Based on this, we corrected Fig. 8 in the revised manuscript. Furthermore, we provide a graph on the peak concentration obtained by the NPS as a function of time for two cases (valve open/close) in Figure S2 in Supplementary Material. We found that the particle concentration started to increase 5 s after the valve was opened, and the particle concentration started to decrease 5 s after the valve was closed. Notably, the colored scale might not be enough to capture the small changes in concentration, but we confirmed that the NPS takes approximately 5 s to



respond to the concentration change. With considering the flight time of approximately 3 s in the classification zone in the NPS as well as the residence time before the flow entering the inlet of the NPS. We found that the observed response time until the signal appears for the TSI-SMPS and NPS seems to be reasonable. Again, thanks for pointing it out, so we could find the mistake in the data processing. We added the plot in Supplementary Material.

Line 276: “In Fig. 8(a-1), the concentration data appeared after the valve was opened (60 s after the first scanning process). However, concentrations for particle sizes below 30–32 nm were not shown during the first scanning process because the corresponding lower voltages applied for classifying this size range were already scanned when only the clean air was being measured. In the second scanning process of the TSI-SMPS, the complete size distribution was obtained. The NPS measurement shows that a few seconds after opening the valve, a rapid increase in particle concentration for the complete size range was observed. Specifically, the particle concentration started to increase or decrease approximately 5 s after the valve was opened or closed, respectively (Fig. S2 in Supplementary Material). Considering the response time of the NPS is approximately 3.3 s, (sum of the M-CPC response time of approximately 0.3 s and particle residence time in the MP-DMA, maximum 3 s), the rest of the delay time might be caused by the time required for concentration stabilization and particle transportation. The delay was also observed in the TSI-SMPS. Approximately 2 s after opening the aerosol path (i.e., 1–2 size bins), the concentration started to increase. During the test for rapid decrease in particle concentration (Fig. 8(b)), the performances of the TSI-SMPS and NPS are quite distinct as well. After blocking the particle path 180 s after the measurement, data from the second scanning of the TSI-SMPS show the size distribution for the smaller particles, in a similar manner to the results in Fig. 8(a), because they were already scanned. However, the size distribution measured by the NPS completely disappeared after some delay time. Therefore, the NPS can be successfully used for unsteady particle size distributions to observe changes in concentration.”

Specific comments

1. It seems that the difference between concentrations obtained by the M-CPC and electrometer was insignificant in fig. 3b. However, in fig. 5, the difference between the data from the M-CPC and TSI-CPC is large. Authors should explain why the two cases are different so that the reader will not be confused.

Ans: Thanks for the comments. We obtained the activation efficiency (Figure 3) of the M-CPCs with the zero voltage in the MP-DMA (due to the assembled configuration) in order to examine the performance of the M-CPCs (experimental setup: Figure 2a). Therefore, all the particles introduced to the NPS can be measured by the M-CPCs. The results are shown in Figure 3. We modified some sentences for the better understanding of the part.

Line 192: "To obtain the activation efficiency, monodisperse particles were measured by the electrometer and NPS operated at 0 V as shown in Fig. 2(a). For the NPS measurement, all aerosols were introduced through the sheath flow inlet only (with a flowrate of 3.96 L min-1), so the particle concentrations could be measured by all M-CPCs. The same flowrate of 3.96 L min-1 was introduced to the electrometer, and the measurements were carried out simultaneously."

On the contrary, to obtain the penetration efficiency (Figure 5), we operated the NPS at 1000 V and 2000 V (experimental setup: Figure 2b). We used the penetration efficiency as a correction factor to have the same performance as the TSI-CPC. Each port has a different sizing resolution due to the different aerosol-to-sheath flowrate ratios. Therefore, the penetration ratio of the MP-DMA is increasing with the increasing port number (far from the aerosol inlet). The detail of the description for the penetration ratio can be found as follows:

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."

2. It should be good to indicate '50 nm monodisperse' in fig. 3b.

Ans: Thanks for the suggestion. We modified Figure 3 as the reviewer recommended.

3. It might be better to change fig. 6 to a table.

Ans: Thanks for the recommendation. We removed Figure 6 and changed it to Table 1.

4. It will be better to denote the "valve open" and "valve close" fig. 9 (1) and (2) as well.

Ans: As the reviewer mentioned, we indicated it in Figure 8 (The figure numbering has been changed). All modified figures are presented in the revised manuscript.

5. The minor ticks in the x-axis in fig. 9 (1) and (2) are hard to recognize.

Ans: We increased the length of the major and minor ticks in Figure 8(1) and 8(2). Please refer to the answer to the previous question (The figure numbering has been changed).

6. Line 85: The NPS seems to be movable. Then, what is the weight of the NPS? Is it hard to move by human hands or not?

Ans: Thanks for the question. The entire system of the NPS is approximately 15 kg. The system can be moved from place to place for sure.

7. Line 168: Author mentioned that the maximum flying time of particles inside the

NPS is approximately 3 s. Were the NPS data corrected based on the flying time?

Ans: Thanks for pointing it out. We already considered the delay from the particle residence time. As the reviewer mentioned the larger particles (latter port) take more time to be classified, so when the size distribution is obtained, the delay factor was considered. This is indicated in the revised manuscript.

Line 144: "The delay due to the residence time inside the MP-DMA was considered when obtaining the size distributions."

8. Line 182: Zp is not presented in Eq. (1), but the description of Zp is shown in the manuscript. Please check the equation.

Ans: Sorry for the confusion. We edited the manuscript as follows:

Line 186: "where Dp is the particle diameter, fc is the charge fraction, P is the penetration ratio, and $\eta$CPC,act and $\eta$CPC,det are the activation and detection efficiency of the M-CPC, respectively."

9. It might be difficult for the readers to understand and compare contour graphs of the NPS and SMPS in fig. 10. It might be better to include in the plot of the obtained mode diameters and concentrations as a function of time.

Ans: We added an additional plot for peak particle concentrations as a function of sampling time, as shown in Figure 9(c).

Line 300: "Figure 9(c) shows the particle concentration at a peak particle size for each measurement of the TSI-SMPS and NPS."

10. Line 283: The authors should state the positions of the sampling inlets of the NPS and SMPS. The sampling positions for the two instruments should be close to each other for the reliable data comparison. This should be also mentioned in the manuscript.

Ans: Thanks for the clarification. As the reviewer mentioned the sampling points for



the SMPS and NPS measurements are close to each other, approximately 10 to 15 cm. Sampling locations are approximately 1 m away from the cooking spot, and the distance from the ground to the sampling port is around 0.8 m. This sampling location, quite close to the cooking spot (1 m), frequently caused sudden changes in concentration. Based on this information we added the comments on this in the revised manuscript.

Line 296: "The sampling location for the TSI-SMPS and NPS measurements is 1 m away from the cooking spot, which caused sudden changes in concentration."

11. Line 307: In general, particle concentration of diesel emission or roadside atmospheric particles is high, and the authors mentioned in the conclusion that the NPS can be used in these applications. Furthermore, the authors mentioned that the advantage of the NPS is in measuring low concentration of particles in the introduction when compared to the FMPS. The authors need to clearly state the purpose (or applications) of the NPS.

Ans: Thanks for the good comments. The advantage of the electrical mobility analyzer system (with a condensation particle counter, CPC) such as SMPS and, in this study, NPS is the wide detection range of concentration (low to high concentrations). Therefore, we take an example of vehicle emission studies in terms of fast-changing concentration condition. As the reviewer mentioned, the statement can be confusing. Therefore, we focused more on the fast-changing concentration conditions and changed the sentence as follows:

Line 320: "From the findings in this study, we believe that the NPS can be a promising instrument providing comprehensive information on fast-changing concentration environments."

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