About the irregularities measured with the SMPS without reverse scanning mode

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1. Introduction

The SMPS scanning mobility particulate sizer is used as reliable standard measurement device for the particle number size distributions of nanoparticles approximately in the size range between 10 and 1000 nm. The measurement principle consists of the charging of particles by means of a radioactive source with a defined amount of charge and their subsequent classification in a DMA (differential mobility analyzer). The DMA itself consists of a high voltage source applied to a defined geometry, allowing for classification. Besides the particle flow in the DMA is diluted by the so called “sheath flow”. This sheath flow is separated from the classified particle flow and reinjected after particle filtration. The classified particles are then counted by a CPC (condensation particle counter). By means of the classified and counted particles the particle size distributions can then be determined with the data acquisition software.

2. Measurement of the number size distribution in forward and down scanning mode – Influence of the measurement sequence

To yield reproducible results in measuring the particle size distribution the standard data acquisition software uses an up scanning mode followed by a down scanning mode. Here the question has arisen what happens, when there is only an upscanning mode used? Obviously the up scanning mode alone should be possible to measure the particle size distribution.

The question of concern of this abstract is: What makes the difference between the up scanning mode and the down scanning mode?

Using a LABVIEW application to control the SMPS, measurements of the size distribution with the up scanning mode only were done. Under certain conditions bimodal distributions appeared as results (figure 1). This mode is called in the following ABC→ABC mode. Contrary to this measurement method the standard software has implemented a down scanning mode, which usually is not further used for the corresponding measurement results, and is “obviously” used only for getting reproducible results. This standard mode I will refer to with ABC→CBA mode.

As the results in figure 1 indicate a bimodal particle size distribution with ABC→ABC mode, the same measurement made without in ABC→CBA mode gives an unimodal size distribution without the first peak. Further experiment directed measurements could not be accomplished, but it has to be expected that this “artefact” appears only under certain occasions, with different parameters in using the “recycle reactor” or especially the SMPS (which is identic concerning the operational point of view).

These artefacts also did not appear with a logarithmic scanning mode, where the data points have an equal distance in the logarithmic or particle diameter scale.

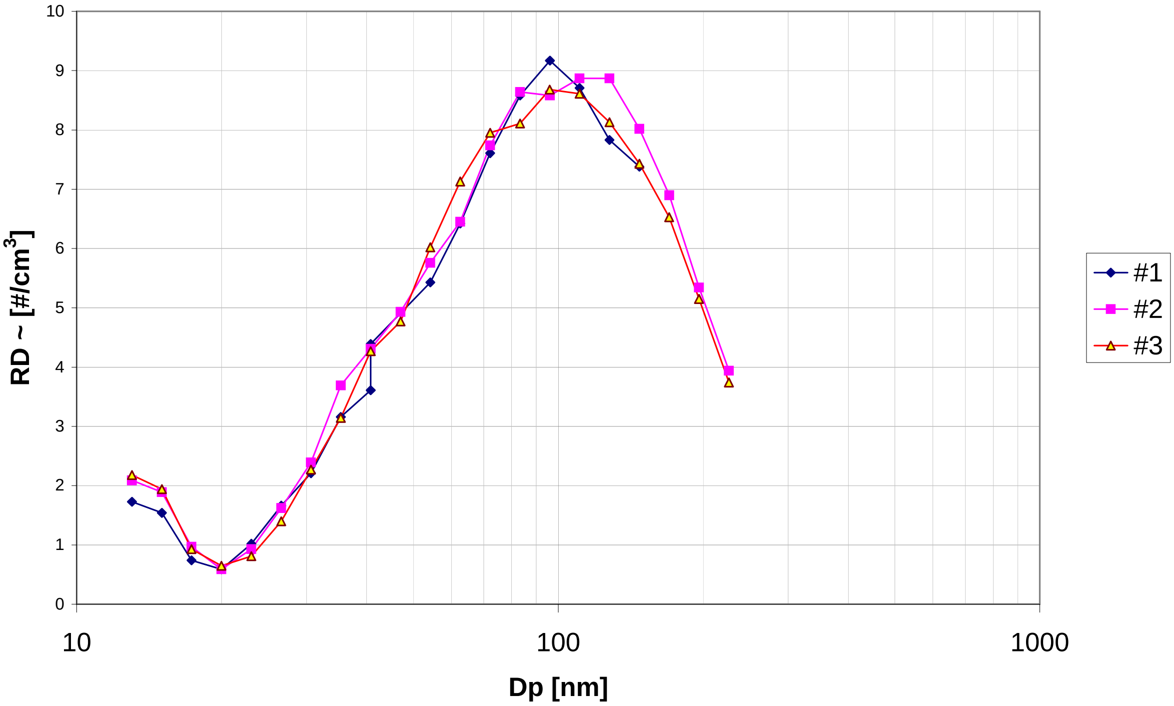

figure 1: Measurement in the sequence ABC→ABC mode. Three measurements with the ABC→ABC mode; The sample flow rate was 0.3 lpm where the residence time τ of the SMPS DMA was ~1.4 min

Typical parameters for the recycle rector would be the recycle flow rate and the sample flow rate or combined R. All the parameters of interest are listed in table 1.

table 1: Parameters for the “particle” recycle reactor and values for the experiments in figure 1

Symbol	*Description*	*Value*
R	recycle flow rate/sample flow rate	10
V_p	Volume flow rate	0.3 l/min
V	Volume of reactor	0.4316 l
C_i	Particles in the volume #/cm³ & size class	~
C_{if}	Particles in the volume #/cm³ & size class in the end	~
C_{i0}	Particles in the volume #/cm³ & size class in the beginning	~
I	Size class 1,2,3...n	~
τ	Residence time	1.439
r_i	Reaction rate of particles formed per volume and seconds #/(cm³*s) & for size class i	~

3. Model of the recycle reactor and the application to the particle number size distribution scanning mode

The irregularities regarded in the last chapter were investigated and put into a model, where the SMPS was regarded as recycle reactor. The sheath flow is then the recycle flow, with tunable recycle rate (**equation 1**, figure 2).

$$\tau = (R+1)\cdot\int_{\frac{C_{i0}+R\cdot C_{if}}{R+1}}^{C_{if}} \frac{1}{-r_i}\,dC_i \rightarrow \tau = (R+1)\cdot\left[\frac{-C_{if}}{r_i} + \frac{\left(C_{i0}+R\cdot C_{if}\right)}{\left[(R+1)\cdot r_i\right]}\right]$$ equation 1

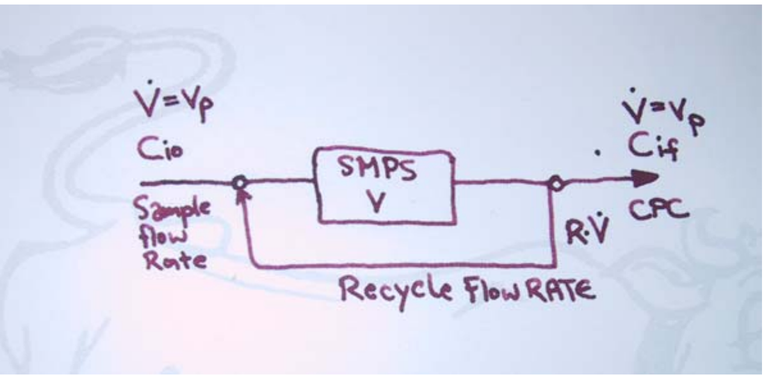

figure 2: SMPS as Recycle reactor

To derive **equation 1**, in equation 6.22 in Levenspiel 1972 p.146 the concentration in mol/cm^3 is supplemented for the particle concentration #/cm^3. We get then a constant reaction rate for the size class I:

$$r_i = \frac{-\left(C_{if}-C_{i0}\right)}{\tau}$$ equation 2

As r_i is constant that means that there is a constant reaction concerning the particle loss or transport into the CPC in the size class i. These equations are hence valid for the constant operation, where a steady state has been established. In the instationary state, that is when the time is smaller then the residence time, there is a different situation in the reactor, as not all particles are filtered away.

Let us consider a particle size distribution ABC according to figure 3. To measure a size distribution we have to pass the sequence I,II,III to the CPC, meaning that the next bigger size class is selected with the DMA and then counted with the CPC. In figure 3 also the size classes that remain in the DMA are depicted. As the recycle flow in the SMPS is filterd resulting in diluting clean sheath air flow, the size of the old step is as long in the system as the residence time has not passed by. The ratio of diluting time to residence time is proportional to the remaining old class in the system.

Here there arises a gap between ABC→ABC mode and ABC→CBA mode, which corresponds according to figure 3 to the sequences I,II,III→I,II,III or I,II,III→III,II,I.

In case of the ABC→ABC mode there is an overlapping of the first classes A,B and with regard to the passed time compared to the residence time there can appear an additional artificial concentration measurement for the first classes.

In case of the ABC→CBA mode the complete residence time has not necessarily to be waited for, as there is a gradual change in particle size selection with the DMA.

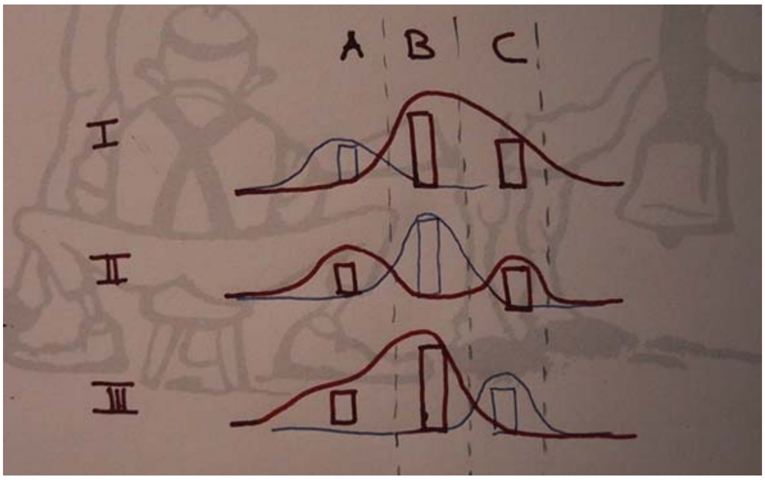

figure 3: Three different sequences I,II,III in measuring the size distribution for three different size classes ABC. The blue size distribution is measured with the CPC the violet is the remaining in the DMA. The initial size distribution is always the same (one row)

Let be now the particle class A 2 particles per cm^3 and class B 9 particles per cm^3 and the measurement has begun after 18 s. The residence time is 84 s and so the ratio of time to residence time t/τ is 21%, indicating that the particle concentration is 9*0.21 or ~2 which is the actual measured value of A. In case of the ABC→CBA mode there appears no additional peak.

4. Conclusion and Outlook

As a result the irregularities of the scanning modes can be explained as a consequence of the measurement type, which can intrinsically be described as recycle reactor. They can be modeled as a function of flowrate, recycle flowrate, the residence time of the particles and the initial particle number distribution in the recycle reactor path. To avoid the irregularities appearing in the ABC→ABC, it is proposed that the measurement time for the transition (→) from one measurement sequence to the next should exceed the residence time τ. An important question stays open: What effects could be caused by completely different scanning methods or what is the influence of measurement time on measurement results in general?

5. Literature

Levenspiel, Octave (1972), *Chemical Reaction Engineering*, 2nd edition, John Wiley & Sons, Inc., New York

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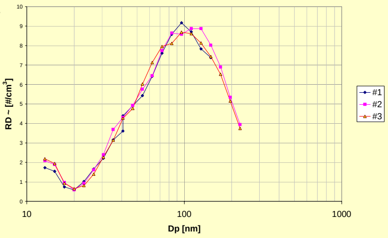

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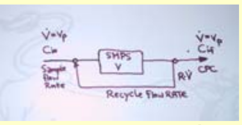

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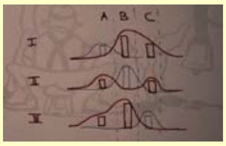

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