On-line Measurement of Hazardous Fine Particles for the Future APC Technology

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Abstract: At FLSmidth Airtech we have long experience, and good knowledge, on how to design APC equipment such as ESP's, FF's and Hybrid filters. We know how to choose the optimum equipment and how to apply the optimum control strategy. To meet the demand for better performance, lower emissions at lower costs, R&D is considered an important activity at FLSmidth Airtech. Among other tests and investigations we use an Electrical Low Pressure Impactor, ELPI, in R&D to measure time resolved number particle size distributions between 0.007 and 10 µm. The instrument has been used on both ESP's and FF's to establish the performance, and it is also used on R&D projects. The instrument has proven to be robust and useful in real plant situations at severe conditions, and provide very useful information. There are several issues to understand when using the instrument, as described in this paper.

Keywords: ELPI, impactor, size distribution, time resolved

1 INTRODUCTION

In a thesis [1] regarding cardiovascular disease, the main course of death in developed countries, different courses are investigated. One phenomena investigated is different components of ambient air pollutions. For PM10 it was found an odds ratio of 1.39 for fatal myocardial infarction for a difference (30 year average) of 5 µg/m^3. To find the best scientific paper that evaluates all the effects on human health from different particle compositions and different sizes is difficult, but judging from what is happening in the US and the EU, the focus is now on the PM 2.5 values. Small particles remain suspended longer and travel farther than large particles, and toxic elements may be enriched in the small particle fraction of the dust. A recent document updating the World Health Organization (WHO) Air Quality Guidelines [2] provides strong scientific support for policy and a general framework to promulgate air pollution standards in both the developed and underdeveloped world. The long-term air quality guideline for PM2.5 has been set to 10 µg/m^3. An APC technology that is effective on small particles should have a bright future. In this paper we do not speculate in the future of particle busting and the preferred APC technology of the future. For the moment the focus is on PM2.5, but as the knowledge of the effect of particles on human health advances, the focus might change to number densities and/or chemical compositions of the small particles. We are confident that the combined efforts of dedicated scientist and engineers, using all available tools, will develop the equipment that will fulfill the future needs. Mathematical modeling is certainly a tool that will be used to get increased knowledge of different phenomena, but as said by Eugene S Ferguson. "Good engineering is as much a matter of intuition and nonverbal thinking as of equations and computations" [3] For analysis of the performance of different APC's we use many measurement techniques. This is the case both for measure-ments on site and in laboratories. This paper is about an addition to our measurement capabilities. The Dekati Electrical Low Preasure Impactor, ELPI, is already a well known instrument within aerosol physics. [4, 5] Our experience with the instrument is continuously increasing. This paper is not a complete review of the instrument but give some information about it and of our use of it so far.

2 THE ELPI

Fig. 1 illustrates the principle of the instrument. The instrument measures, real time air born, particle size distributions in 12 channels from 0.030 µm to 10 µm. The particles are charged in a positive corona charger and then size classified in a low pressure impactor. An electrometer measures the currents produced by the charged particles on the different impactor stages. With a theory for the charger and the impactor the measured currents are converted to an aerodynamic size distribution. With a filter staged the number density of the sizes between 0.007 µm and 0.030 µm can also be measured. The particles are collected on plane substrates, as Aluminum or polycarbonate foils, placed on the impactor stages. Polycarbonate foils are recommended for chemical analysis of collected dust. It is recommended to grease the Aluminum foils to avoid particle bounce, an issue common to al low pressure impactors. We have not evaluated the bounce problem, but is has been clear, that without greasing we sometimes experienced negative currents on some impactor stages. The negative currents disappeared when the Al foils were greased. There is also an option of sintered porous and oiled metal impcator stages. With the charger turned off the impactor can be used as a gravimetric impactor by weighing the foils before and after particles are collected. Collected particles can also be used to get a size dependent chemical analysis. With the charger turned off the electrical charge on the particles can be measured. The performance of the ELPI is, among many other effects, dependent on the amount of dust

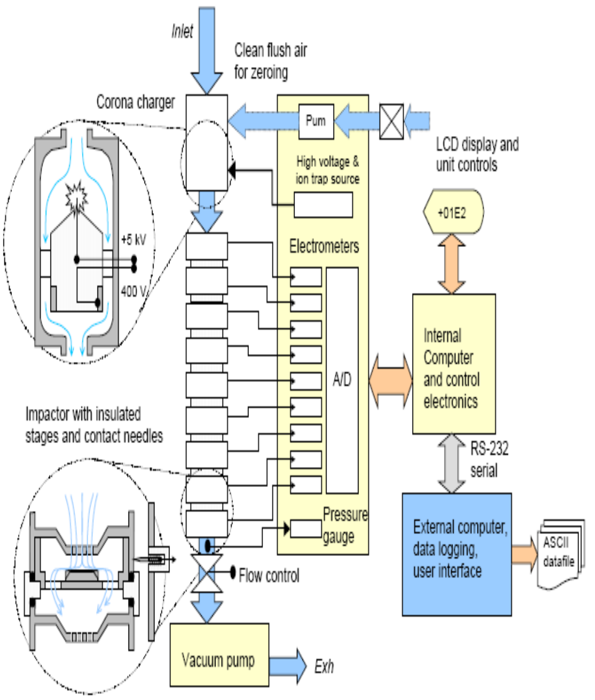


Fig. 1 The principle of the ELPI. The figure is from the Dekati ELPI manual

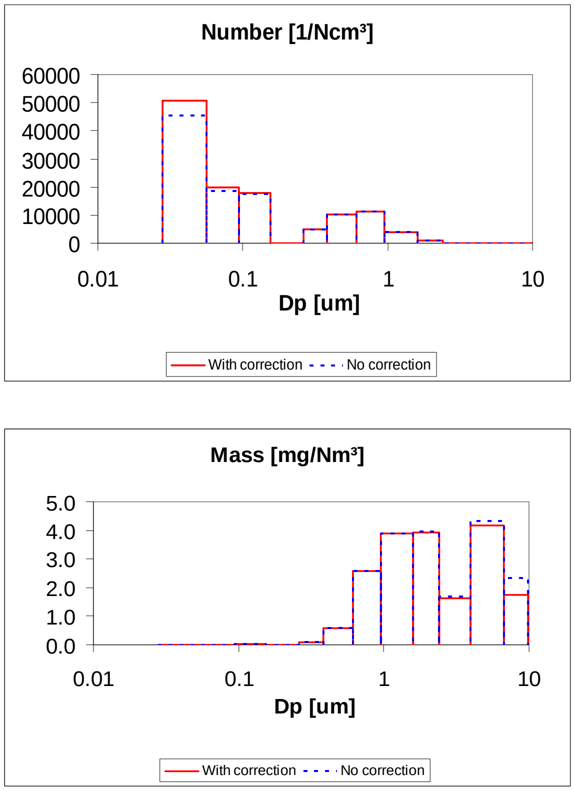


Fig. 2 The influence of correction for small particle diffusion

collected on a stage. A rule of thumb says 1 mg on a single impactor stage. This can lead to a situation where one has to use a diluter in front of the ELPI. The water content in the sampled gas can also create a need for a diluter to avoid condensation in the impactor, which in the standard setup operates at the temperature of the surrounding atmosphere. The diluter can at low particle loads be avoided by using a heated impactor option. The instrument has 4 current measurement ranges. The noise and the response time is dependent on which range is used. There is no simple way to give the sensitivity, accuracy and precision of the instrument. One has to evaluate the specific measurement situation and choose the proper instrument, and if the choice is the ELPI to evaluate the performance at the specific situation.

3 ELPI DATA EVALUATION

There is more than one way to evaluate and present result from ELPI measurements. One can choose an aerodynamic or a Stokes particle model, and for both one can choose a particle density. The Stokes particle model with chosen particle density is always used for the charger. The size positions of the impactor channels are affected by the particle density if the Stokes model is used. Increasing the particle density will shift the distribution towards smaller particle diameters. There is also a possibility to use a small particle diffusion correction. Finally one can choose to normalize the numbers in the size channels with the logarithmic width of the channels. The influence of the different data evaluations is illustrated in Figs. 2, 3 & 4.

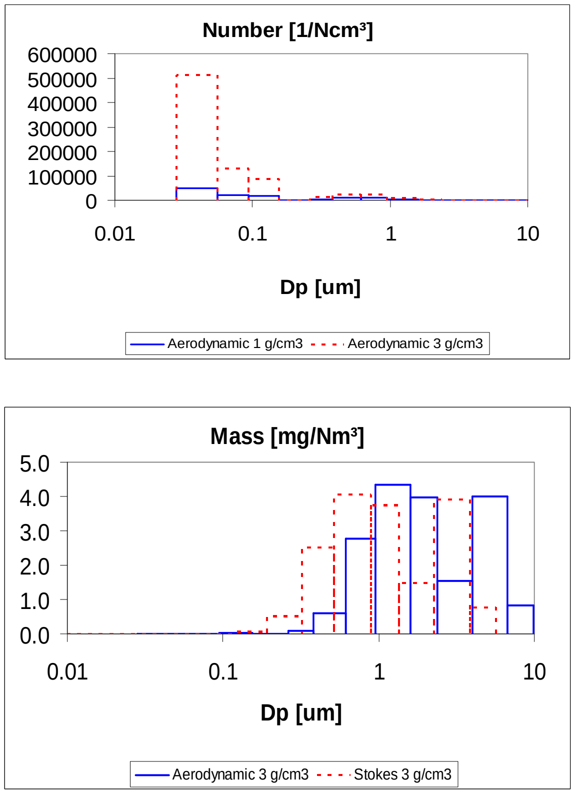
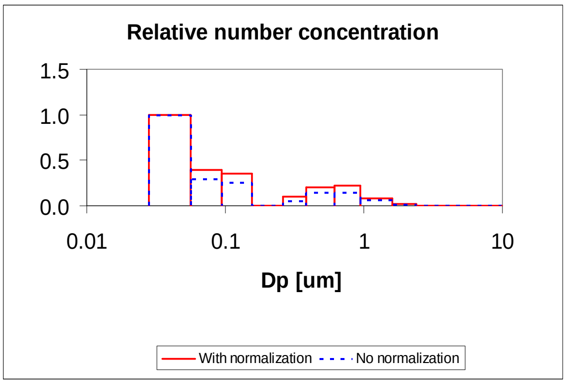


Fig. 3 The influence of particle model and particle density



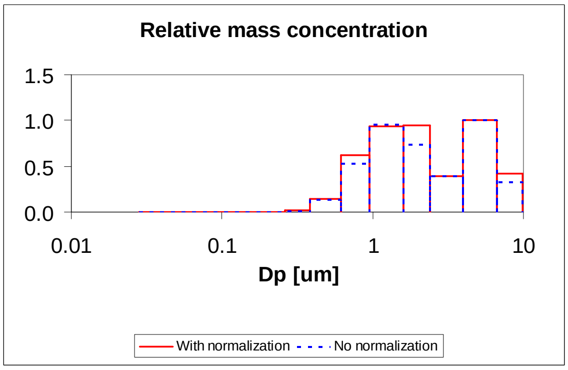


Fig. 4 The influence of normalization by the logarithmic width of the channels

4 ELPI VS BERNER IMPACTOR

The Berner low pressure gravimetric impactor, had the impactor placed inside the stack with a isokinetic nozzle on a swan neck in front of the impactor. The ELPI impactor was placed outside the stack, with the isokinetic nozzle on an ELPI protective cyclone, mounted on a heated probe inserted in the stack. A heated Teflon hose led the gas to a 1:8 ejector diluter where it was diluted by clean heated air. The diluted gas was cooled to ELPI temperature in the pipe and the hose leading it to the ELPI. The two instruments were compared at two sites after three different filters.

In application *A* the emission was very low. The currents that were measured by the ELPI and diluter were close to back ground level. It was also not possible to do the samplings simultaneously with the ELPI and the Berner. In application *B*, when the samplings were done simultaneously the instruments were at different positions. The ELPI measured upstream and close to a fan. The Berner measured downstream the fan in the stack. In application *C* the samplings were done simultaneously at the same level in a large diameter stack. ELPI PM values differed from the Berner values. In applications *A* and *B* the Berner gave larger PM values than the ELPI, but in application *C* the ELPI gave lager values than the Berner. Besides a difference in PM values the mass distributions measured by the instruments were not identical. We haven't yet fully investigated the differences, but one can imagine several reasons for different results with the two instruments. One important and expected difference can be found in particles collected in the sampling line before the gas enters the ELPI. This could explain lower PM values with the ELPI. It is more difficult to explain higher PM values with the ELPI. A not discovered error in isokinetic sampling or dilution factor for the ELPI could be one explanation. A substantial not discovered condensation in the line between the diluter and the ELPI could also be an explanation. The gas in the stack in the third application was a mixture from two filters and a filter followed by a SO_2 scrubber. Fig. 5 shows the relative size distributions for application *C*.

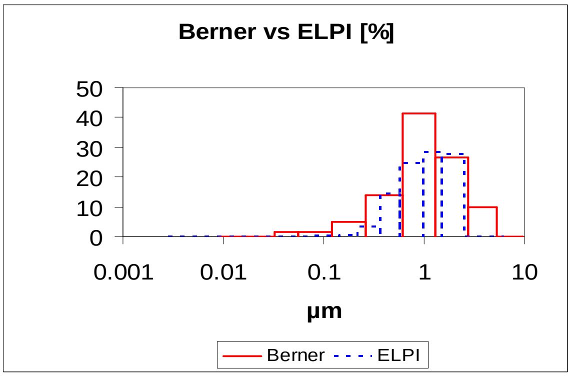


Fig. 5 ELPI and Berner compared

5 SITE ELPI MEASUREMENTS

The ELPI has been used on different sites for different reasons, and although the comparison with a Berner shows that the ELPI may not be the first choice for PM measurements, it has also been used to collect PM values. Some of the measurements needed a diluter and some didn't. The measured PM values are shown for some cases in Table 1. Figs. 6, 7 $ 8 shows the average size distributions for three of the cases in Table 1. The case with extra high ELPI values compared to Berner values, at an unusual application, is not included.

Table 1 A summary of PM measurements on FLSmidh Airtech references

Case	PM 1 [mg/Nm^3]	PM 2,5 [mg/Nm^3]	PM 10 [mg/Nm^3]
1	0.4	1.2	2.0
2	0.03	0.4	1.6
3	1.2	4.7	7.5
4	0.6	0.7	2.8
5	0.5	1.7	3.1
6	0.4	1.2	1.8
7	0.16	0.2	0.6

The values for Case 3 are the latest, and due to gained experience on the other cases, the most reliable results. For this case we do not have a comparison with the Berner, but we have measurements according to the EPA17 procedure which give a total emission just below 10 mg/Nm^3. All values are from ELPI data corrected for small particle diffusion using a Stokes particle model with density 2.5 g/cm^3 and no normalization by the logarithmic widths of the channels. For three of the cases we have done size dependent chemical analysis of dust collected on bare Al foils.

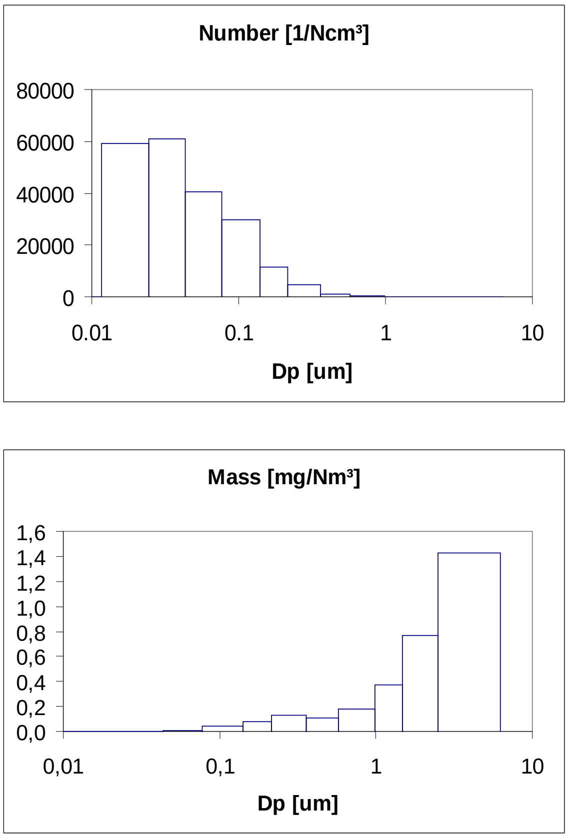


Fig. 6 Average size distributions for Case 5

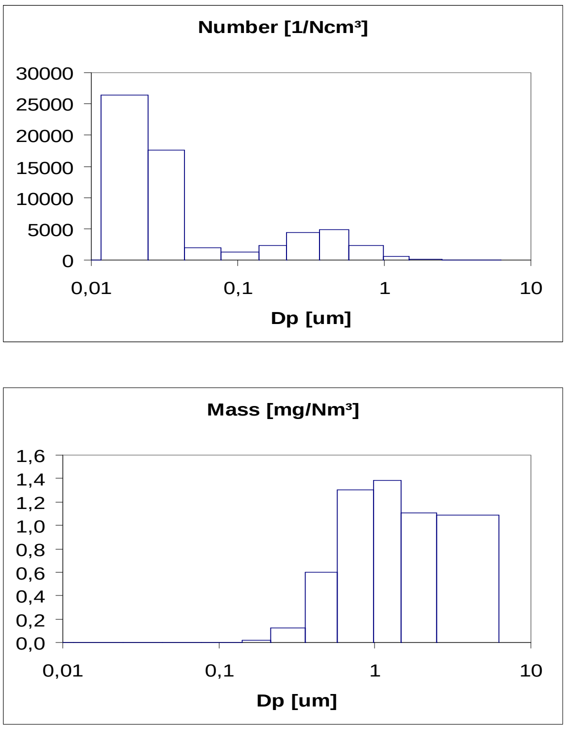


Fig. 7 Average size distribution for Case 3

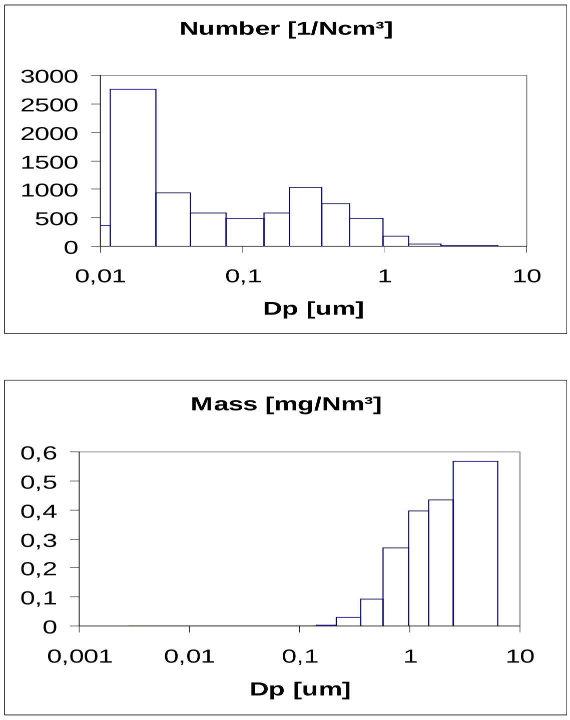
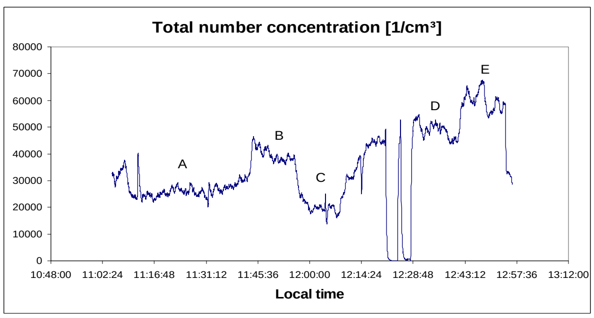


Fig. 8 Average size distributions for Case 6

The analysis was done by ESEM-EDX. This method is considered semi quantitative and the quality of the analysis is very much dependent on how much dust is collected on the foils. We could clearly see interference from a foil Al signal. We could despite this get an upper estimate on heavy metal emissions and clearly see a difference in chemical compositions between two similar applications. On the third we found an unexpected chemical composition of the particles with size less than 0.4 μm.

6 SIZE DISTRIBUTIONS VS TIME

The key feature with the ELPI is that it measures online number size distributions. The number distribution can be recalculated as mass distributions and total number and mass concentrations as function of time. In this section, based a results from *case 3*, everything is presented as a result of ELPI data corrected for small particle diffusion using an aerodynamic particle model with a particle density of 3 g/cm^3 and with normalization by the logarithmic widths of the channels. Fig. 9 shows the total concentrations. Figs. 10 and 11 show absolute and relative size distribution for the positions B and C in Fig. 9 .



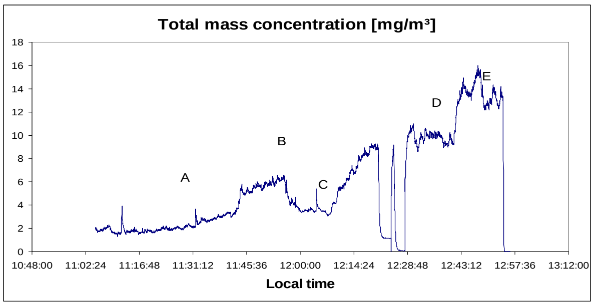


Fig. 9 Total concentrations for Case 3

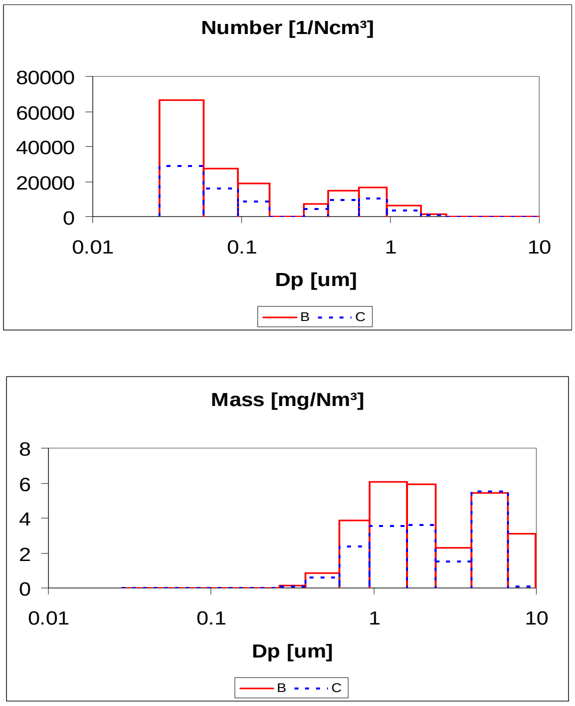


Fig. 10 Absolute size distributions at B and C

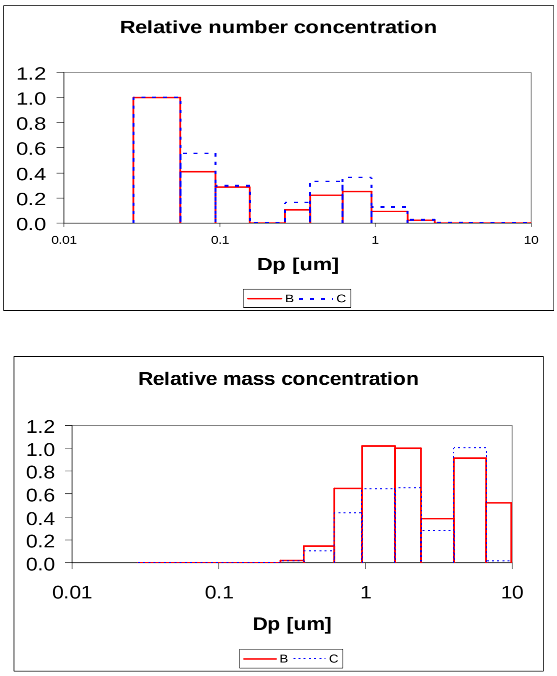


Fig. 11 Relative size distributions at B and C

7 SUMMARY

Our experience with the ELPI is that it is a robust instrument that can be used at sites even during conditions that is far from a laboratory environment. To use the instrument for PM measurements with demands on good accuracy we need more evaluations and comparisons with other instruments. We know from literature and private communications with other ELPI users that there are issues we have to check also for other applications than PM measurements. During a recent laboratory experiment, with no condensation problem, we found a difference in size distributions between measurement with the ELPI alone and with an ejector diluter in front of the ELPI. The total mass was the same, but it seems there is particle breakup in the ejector diluter. It is probable that the dust used in this experiment very easy cause particle breakup, and that the results presented in this paper from other situation has low probability for particle breakup. We are about to investigate this as well as other issue of instrument performance. Transport and setup at site is as compared to a Berner instrument, but when the ELPI is in operation, the results are available without a time consuming weighting procedure. Proper process mapping and synchronization with fast ELPI measurements give the possibility of important findings about particle size distributions that would be difficult to find with a gravimetric impactor. If there are fast and or unexpected changes, and the particle size distribution changes with these fast process variations, the ELPI can capture the change. We have resolved the different size distributions at the beginning of a cleaning process and the end of a cleaning process. We have seen different size distribution for the same cleaning process at different cleaning cycles. We have seen the short time influence of start and stop of a single machine at an industrial plant. Our aim is to acquire increased knowledge of the details governing the performance of all types of particulate APC equipment. Better understanding of the details will form the basis for our development of the future APC systems.

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