DEKATI
Excellence in Particle Measurements

Dekati Ltd Application Note

ELPI IN COMBUSTION APPLICATIONS

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Introduction

ELPI™ (Electrical Low Pressure Impactor) measures particle size distribution and concentration in real-time. The operation principle is based on particle charging, size classification in an inertial low-pressure impactor, and current measurement with a sensitive multi-channel electrometer.

ELPI™ has been widely used in combustion studies, in fact it was first developed to measure particles from combustion power plants. The instrument was tested in different research programs and very promising results were found (Moisio, M., 1999, Real Time Size Distribution Measurement of Combustion Aerosols). This paper describes the use of ELPI™ in measuring emissions from combustion processes. More detailed information on the use in measuring exhaust from automotive emissions can be found in the ELPI™ application note: *Automotive.*

ELPI™ configuration

ELPIs are provided with two flow rates; 10 lpm and 30 lpm. The ELPI™ configuration that is recommended to be used in combustion measurements is a 10 lpm ELPI™ (ELPI-01) with filter stage (ELA-650). The lower flow rate of 10 lpm makes cleaning intervals longer, and filter stage enables detection of the nucleation mode often present when measuring emissions from combustion processes (7-30 nm). The standard ELPI™ measurement range is 30 nm – 10 µm.

Figure 1. ELPI™ - Electrical Low Pressure Impactor.

Few additional accessories can be recommended to be used with ELPI™ in combustion measurements. The following accessories are not necessary but often useful in this application.

Aluminium foils with grease

The detection of particles in ELPI™ is based on the measurement of electrical current. The particles hit the collection plates and the charge that they carry is detected with the electrometers connected to each impactor stage. It is recommended to use greased aluminium foils on the collection plates. The foils (CF-300) protect the collection plates from fouling, and the plates need not be cleaned after each measurement but changing the foils is sufficient. In addition, greasing of the foils prevents bouncing of the particles, which may distort the detected particle size distribution. If chemical analysis of the particles is wanted, then polycarbonate (IPR-200) foils are recommended.

Dekati provides the grease in two forms. The grease is Apiezon-L vacuum grease, which is pure enough for chemical analysis. The standard grease (AG-10) is dissolved in a solvent after which it is applied on the aluminium foils with e.g. fine brush. Another option is the Apiezon-L grease in spray form (DS-515), which makes the greasing a bit faster. A stencil (DS-125) is needed for covering the edges of the foils during spraying.

Sintered collection plates

Standard ELPI™ collection plates are stainless steel, and aluminium or polycarbonate foils should be used on them. The recommended maximum load of particles per one impactor stage is 1 mg. This value can vary depending on the particle type.

Sintered collection plates (IA-211) are used to make longer measurements without the need to clean the impactor. With sintered collection plates about 10 times more particles can be collected on one impactor stage making the cleaning interval of the collection plates shorter and enabling longer measurement periods. Chemical analysis cannot be performed on the sintered collection plates, nor can gravimetric analysis be done. More information on the sintered collection plates can be found in the Dekati Ltd. technical note: Sintered collection plates.

Sampling

The selection of the correct sampling system is extremely important in all combustion measurements. With a properly designed sampling system, particle losses and sample transformations can be minimised during sample transport, dilution and cooling. Dekati provides state-of-the-art solutions for sampling and the most commonly used options are presented below.

Dekati® DoubleDiluter

Dekati® Double Diluter is a two-stage dilution system with a constant dilution ratio in stabile conditions. The system consists of two Dekati® ejector type diluters (DI-2000), and accessories for heating the first diluter (DI-2001 (110V), DI-2003 (230V)). More detailed information on the Dekati® Double Diluter set-up can be found in the Dekati® technical note Dekati® ejector diluter in exhaust measurements.

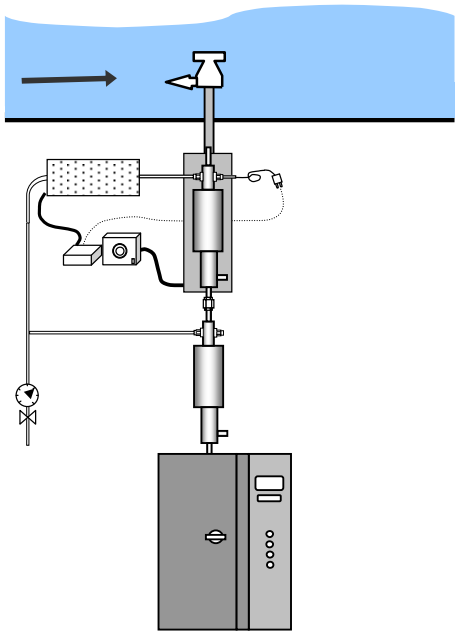

Figure 2. Dekati® Double Diluter set-up in stack sampling.

Figure 2 presents the Dekati® Double Diluter set-up when sampling directly from the stack, and Figure 3 photo of the setup. The sample is taken out of the stack isokinetically into a cyclone that is used as a pre-separator. The Dekati® Cyclone (SAC-65, Figure 4) can be used for this purpose; it has a D50 cut of 10 µm with 10 lpm flow rate. Also isokinetic sampling probes (SAC-100, Figure 4) that can be directly connected into the SAC-65 cyclone are available at Dekati.

If the cyclone cannot be fitted inside the stack it can be placed outside of it. In this case the sample should again be taken out isokinetically, and the cyclone including the sampling line heated up to the temperature of the sample (max. 400 °C).

The sampling line from the stack into the first diluter including the dilution air for the first diluter is heated up to the temperature of the exhaust (max 400 °C). This way thermophoretic losses can be avoided, and the vapour pressures of volatile compounds can be decreased in the first dilution stage to minimise nucleation of the VOCs (Volatile organic compounds).

Figure 3. Dekati Double Diluter setup.

Figure 4. Dekati® Cyclone SAC-65 and
Set of sampling nozzles for isokinetic sampling SAC-100.

The second dilution stage is in room temperature; the sample temperature is decreased to a suitable range for ELPI™, and the particle concentration is further decreased making the cleaning intervals of the ELPI™ impactor longer.

All in all, the Dekati® Double Diluter is an easy-to-operate system for exhaust measurements in stabile conditions with a constant dilution ratio. If the sample pressure varies significantly or if different dilution conditions need to be used, it is recommended to use the Dekati® Fine Particle Sampler.

Dekati® Fine Particle Sampler

Dekati® Fine Particle Sampler (FPS-4000) is a versatile sample-conditioning unit for emission monitoring and combustion studies. In FPS the dilution is also carried out in two phases and it can be made in different temperatures, with variable dilution ratio, and sample residence time. Each of these parameters is easily controlled with the FPSVi software.

The first stage dilution is carried out in a perforated tube diluter and second stage dilution is made in an ejector type diluter. By changing the first stage dilution temperature, and dilution ratio the system can be used e.g. to maximise or minimise nucleation of volatile compounds in the exhaust. More detailed technical specifications can be found in the FPS brochure and user manual.

The combination of ELPI™ and FPS enables fast and efficient studies of sample conditioning effects on combustion particle concentration and size distribution. The FPS can directly be connected into the ELPI™ inlet, dilution parameters can be changed with the FPS software and the changes can be detected with ELPI™ in real-time.

When sampling directly from the stack (Figure 4) the FPS is connected directly into the hot stack. Prior to the perforated tube, a mini-cyclone can be placed inside the stack to remove particles > 2.5 μm. The first stage diluter can be heated with a stack heater (FPS-4110 (110V), FPS-4230 (230V)) and the dilution air with the pressurised air heater (DH-1711 (110V), DH-1723 (230V). The temperatures are controlled with the FPS software. The recommended FPS configuration and set-up for stack measurements are presented in Figure 5.

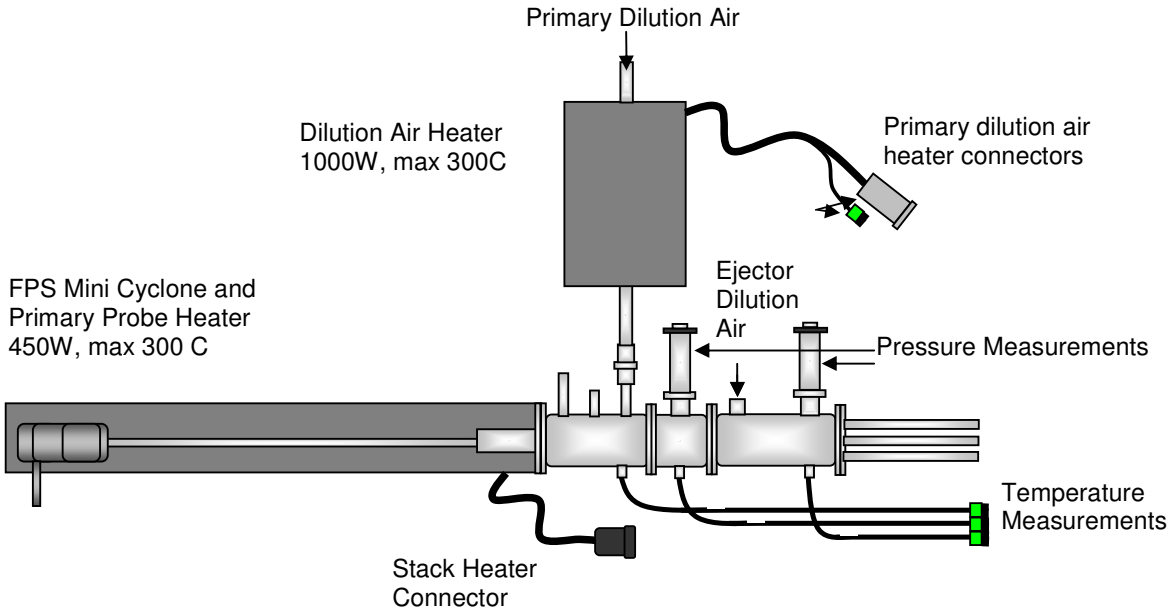

Figure 5a. Dekati® Fine Particle Sampler configuration for stack measurements.

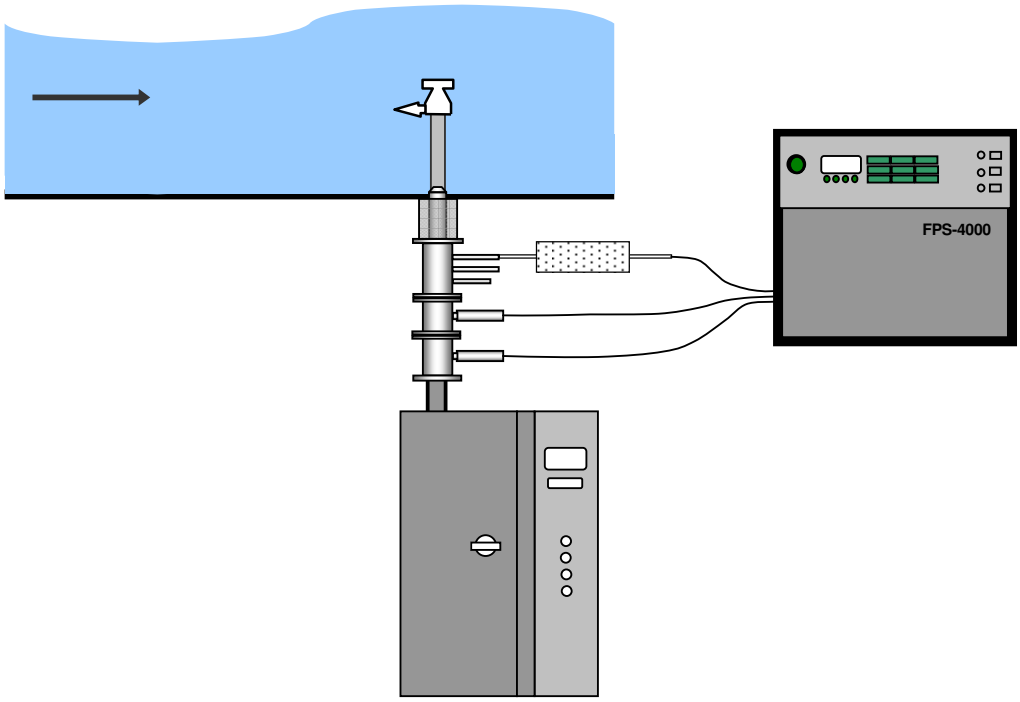

Figure 5b. Set-up for measuring stack emissions with FPS and ELPI™.

Thermodenuder

Dekati® Thermodenuder (ELA-111 (110V), ELA-230 (230V)) removes volatile compounds out of the sample stream. The volatile compounds may form new particles by nucleation, or grow existing particles by condensation. Thermodenuder is used to prevent these effects so that only solid particles are measured.

The effect of sampling conditions on the measured particle size distribution may be significant especially when measuring from conditions where the concentrations of the volatile organic compounds are high. In combustion processes the two major particle modes in the exhaust gas are nucleation mode and soot mode. The nucleation mode is very sensitive to sampling conditions and thus can in some cases overwhelm the accumulation mode when looking at the number concentration data (Figure 6).

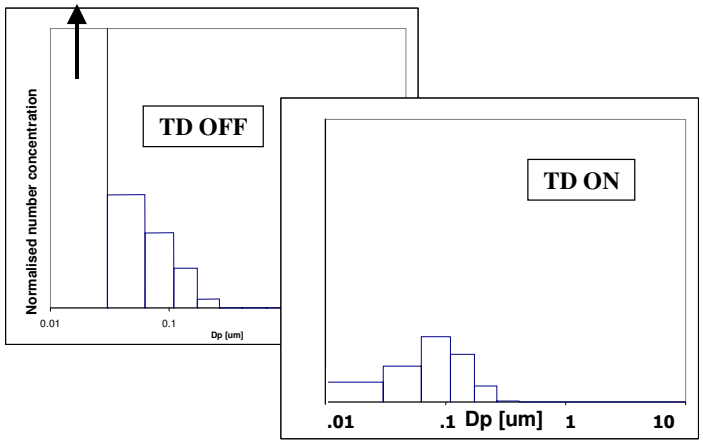

Figure 6. Effect of the Dekati thermodenuder on particle size distribution measured with ELPI™.

In the Dekati® Thermodenuder the sample is first heated up to 250 °C where most of the hydrocarbons in the sample volatilise. After the heating the sample is lead through an adsorber where the sample is cooled and the hydrocarbons adsorbed into active charcoal. The Dekati® Thermodenuder has been designed for flow rate of 10-20 lpm so that it can easily be connected to the ELPI™. More information on the Dekati® Thermodenuder can be found in Dekati Ltd Technical note: Sampling automotive exhaust with Thermodenuder.

Examples of measurements

After the selection of the most suitable sampling system and set-up the use of ELPI™ is quite straightforward. The impactor and charger need to be cleaned every now and then, and also few other checks should be conducted before each measurement.

In combustion measurements ELPI's real-time operation gives the possibility to study the effect of different process parameters on the particle concentration and size distribution. Figure 7a gives an example on the effect of circulated fluidised bed (CFB) replenishment on the fine particle mass and number concentrations during bark combustion. Figure 7b also shows the effect on the size distribution.

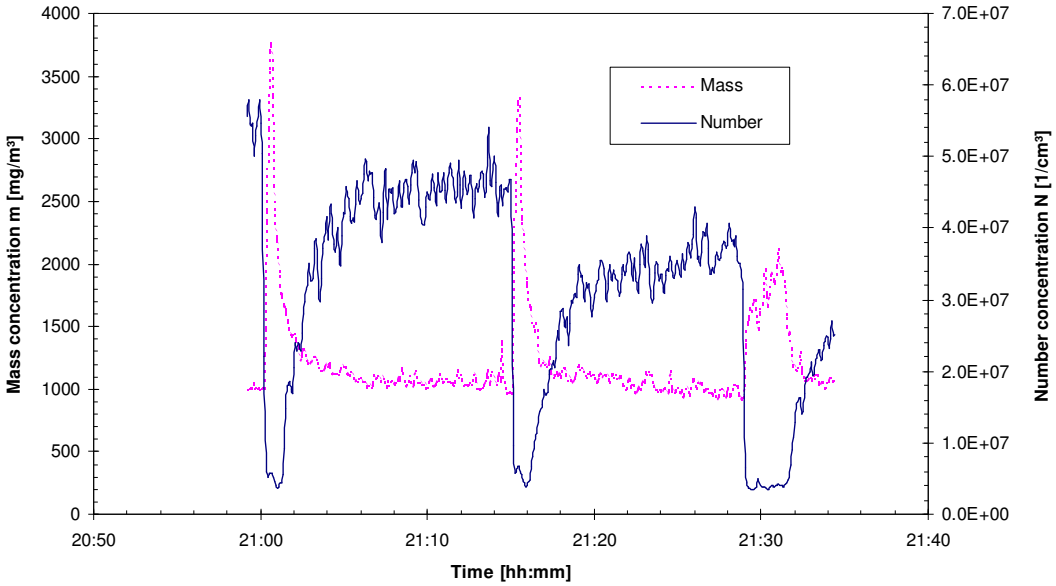

Figure 7a. Effect of bed replenishment on particle number and mass concentrations.

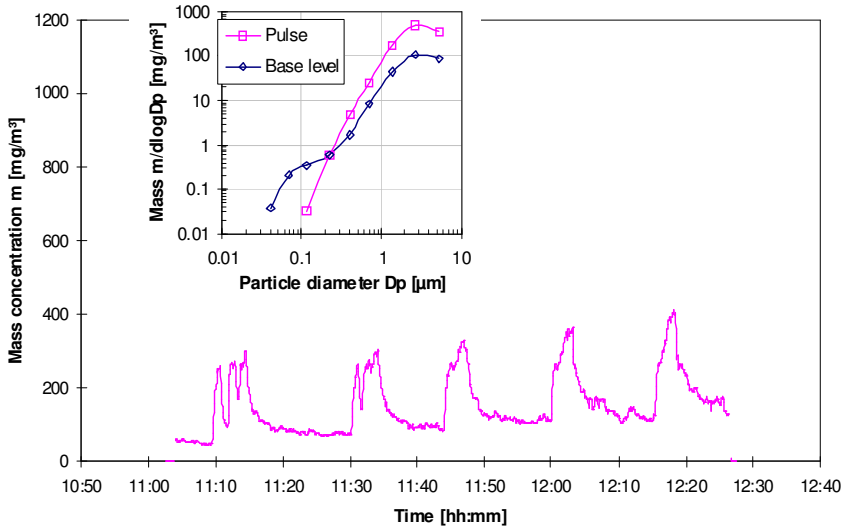

Figure 7b. Effect of bed replenishment on particle concentration and size distribution.

Another data example is presented in Figure 8. It shows the changes in the mass concentration measured with ELPI^{TM} when ESP (Electrostatic Presipitator) is being rapped.

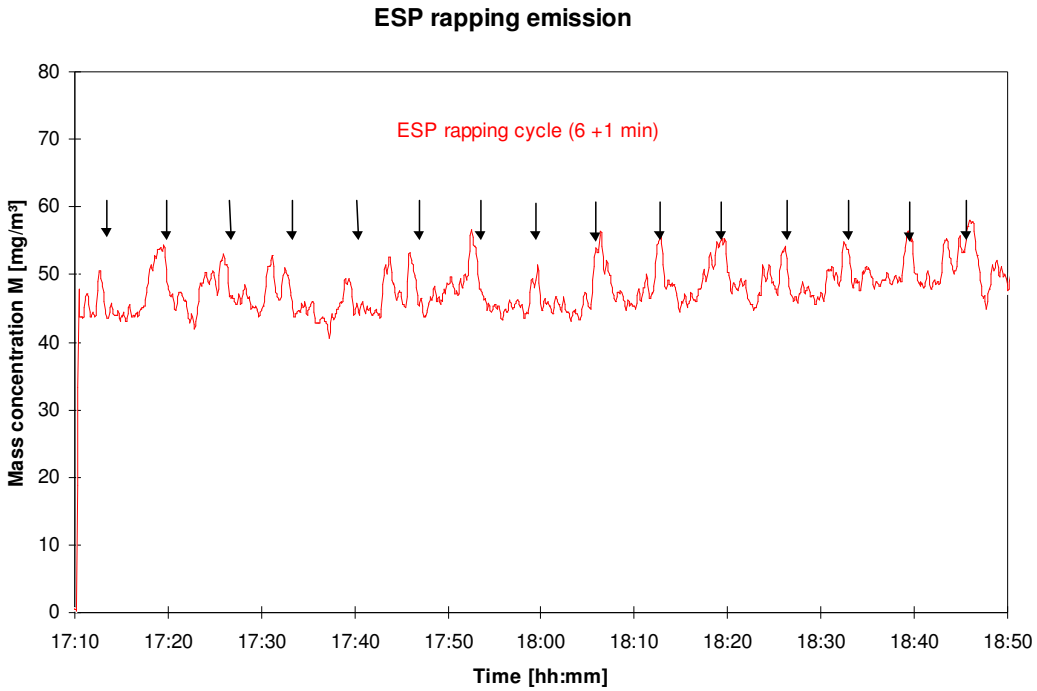

Figure 8. Effect of ESP rapping on particle mass measured with ELPI^{TM}.

ELPI Publications

Examples of the use of ELPI in combustion measurements are found in numerous publications. Below are few examples. More complete list of ELPI related publication is available at www.dekati.com

Kymäläinen, M., Janka, K., Keskinen, J., Moisio, M., Backman, R. and Hupa, M. (1996) Measurement of Time-Dependent Fume Release Rate During Black Liquor Pyrolysis J. Pulp Paper Sci. 22, 17-23.

Latva-Somppi J., Moisio M., Kauppinen E., Valmari T., Ahonen P., Keskinen J. (1998) Aerosol Formation in Fluidized Bed Incineration with Waste Sludge, Journal of Aerosol Science, vol 29, No 4, pp 461-480.

Moisio, M. (1999) Real time size distribution measurement of combustion aerosols. Ph.D. Thesis Tampere University of Technology publications 279, Tampere Finland.

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Dekati Ltd. 2003. Technical note. Substrates and filters for Dekati Impactors.

Dekati Ltd. 2004. Technical Note. Sintered collection plates.

Dekati Ltd. 2002. Technical Note. Dekati ejector diluter in exhaust measurements.

Dekati Ltd. 2004. User Manual. Dekati dilute.

Dekati Ltd. 2005. User Manual. FPS.

Dekati Ltd. 2003. Technical Note. Sampling automotive Exhaust with a Thermodenuder.

Dekati Ltd. 2005. ELPI user manual.

Mikkanen, P., Moisio, M., Keskinen, J., Ristimäki, J., Marjamäki, M. (2001). Sampling Method for Particle Measurements of Vehicle Exhaust, SAE Technical paper series 2001-01-0219

Moisio, M. (1999) Real time size distribution measurement of combustion aerosols. Ph.D. Thesis Tampere University of Technology publications 279, Tampere Finland.

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