Journal of Aerosol Science 69 (2014) 150–159

Contents lists available at ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

Calibration of the new electrical low pressure impactor (ELPI+)

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ARTICLE INFO

Article history:
Received 12 September 2013
Received in revised form
2 December 2013
Accepted 9 December 2013
Available online 18 December 2013

Keywords:
Electrical Low Pressure Impactor
ELPI+
Impactor
Charger

ABSTRACT

A renewed Electrical Low Pressure Impactor (ELPI+) was introduced by Dekati Ltd. in late 2010. This study presents the collection efficiencies of the ELPI+ cascade impactor stages and the back-up filter as well as the charging efficiency of the corona charger in the size range of 0.01–10 μm. According to the measurements the impactor cut diameters are within ±10% to the predecessor except the upmost stage for which the difference was found to be −18%. The secondary collection of nanoparticles was found to be similar to the predecessor for stages with the largest cut diameters but higher for the stages with the smallest cut diameters. The charging efficiency is higher for the new charger compared to the old one by 54% at 20 nm particle size. This study also presents the first use of the Single Charged Aerosol Reference (SCAR) for impactor and charger calibrations.

1. Introduction

Cascade impactors are widely applied for aerosol particle measurements. Numerous impactors have been designed, manufactured, and applied for aerosol studies (Marple, 2004). The Electrical Low Pressure Impactor (ELPI) enabled real-time detection of particles by combining electrical detection of charged particles with a 12-stage low pressure cascade impactor (Keskinen et al., 1992; Marjamäki et al., 2000). The ELPI has been manufactured and distributed by Dekati Ltd. since 1995. It has become a widely used instrument for air quality (Gouriou et al., 2004), combustion aerosol (Yi et al., 2008; Coudray et al., 2009) and engine exhaust measurements (Shi et al., 1999; Maricq et al., 2000; Zervas et al., 2005). It has also been applied to pharmaceutical inhaler development (Glower & Chan, 2004), as well as to atmospheric aerosol research (Held et al., 2008; Virtanen et al., 2010).

Along with time, the measuring particle size range of the ELPI has been extended towards smaller nanoparticles. Marjamäki et al. (2002) introduced a filter stage in order to detect particles smaller than 30 nm, which was the cut diameter of the lowest impactor stage at that time. In addition, an extra stage with a design cut diameter of 17 nm was developed by Yli-Ojanperä et al. (2010a). The extra stage was demonstrated to improve the nanoparticle resolution of the ELPI, but it has not been commercially available. Owing to the fixed dimensions of the impactor assembly, two uppermost stages had to be removed in order to make use of both the filter stage and the extra stage at the same time.

In 2010 Dekati Ltd. introduced a new instrument version called ELPI+, in which the impactor assembly was realized so that all the designed stages, including the 17 nm extra stage, can be used simultaneously. This increased the total number of stages to 15, including 14 impactor stages (contains one precut stage, not measured electrically) plus a filter stage. This allows real-time measurements of particle size distributions in wide particle size range from 6 nm to 10 μm according to manufacturer with 14 particle size fractions. The appearance is changed moderately from the previous model, including modification of the impactor stages. The new instrument can also be used as stand-alone, thus PC connection is not required

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http://dx.doi.org/10.1016/j.jaerosci.2013.12.006

but can be used. The electrometers have been redesigned and a sampling rate of 10 Hz can now be achieved. The unipolar corona charger is completely new. The most significant modification to the previous model is the smaller inner volumes of the charger and the impactor. The smaller volumes are motivated by decreased instrument size and mass, improved time response, and by smaller space charge losses at high concentrations.

The calibrations are the subject of this study. Both the charger efficiency and the impactor collection efficiency functions were measured over the operating particle size range of the instrument. The collection efficiency of the new filter stage was measured using nanoparticles. In addition to the cutpoints, all the other impactor stage parameters that are required in order to apply inversion algorithms (e.g. Lemmetty et al., 2005) and to estimate the effective density of the particles (Ahlvik et al., 1998; Maricq et al., 2000; Ristimäki et al., 2002) were evaluated. All of the calibration results and associated uncertainty values, as well as the calibration setups are presented in this paper. All measurements were conducted using monodisperse di-octyl sebacate (DOS) particles generated either with an Evaporation Condensation Generator (ECG), a Vibrating Orifice Aerosol Generator (VOAG) or with the recently introduced Single Charged Aerosol Reference (SCAR, Yli-Ojanperä et al., 2010b).

2. ELPI+ instrument

The particle measurement method of the ELPI+ has been introduced by Keskinen et al. (1992) and is based on unipolar charging of particles, size classification of these particles in cascade impactor and electrical measurement of collected particles. The operating principle and main components of the ELPI+ are presented in Fig. 1.

The aerosol is introduced into a unipolar diffusion charger which is based on needle type corona discharge. The discharge is achieved by positive high voltage of approximately 3.5 kV. In order to achieve stable charging conditions, the discharge current is kept at a constant value of 1 μA. Both discharge current and voltage are monitored by the electronics for diagnostic purposes. In the following stage the remaining ions from the corona discharge are removed from the flow by an ion trap. In the ion trap aerosol flows between two concentric cones with a potential difference of 20 V, resulting in an electric field which removes the ions from the flow.

The size classification occurs in the cascade impactor. The first stage is used as a pre-separator to remove large particles. The following 13 impactor stages are separated from each other by electrical insulators and connected to a multichannel electrometer. The unipolarly charged particles depositing on the stages are detected by measuring electric current from each stage. The last impactor stage is based on design by Yli-Ojanperä et al. (2010a). The final stage is the filter collecting the particles which are too small to be deposited by impaction in the previous stages. The filter stage is connected to the electrometer as the impactor stages. The downstream pressure is measured and can be set to the manufacturer specified value of 40 mbar by adjusting a control valve, situated between the filter stage and the connection to external vacuum. In addition to downstream pressure also the absolute pressure in the charger is measured by the electronics.

The ELPI+ is equipped with a pump which provides filtered particle free air into the charger region when the flush mode is activated. This enables zero check and adjustment of the electrometer zero levels. The electrometers are bipolar allowing particle charge studies when the diffusion charger is switched off. The operation of the instrument is controlled by an internal computer and as already mentioned, the instrument can be used as a stand-alone unit.

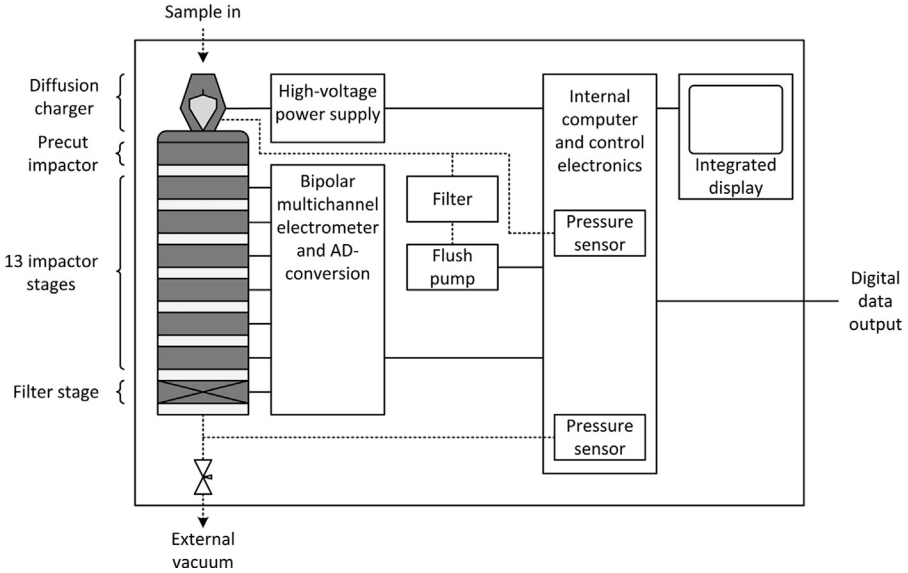

Fig. 1. The schematics of the ELPI+.