Available online at www.sciencedirect.com

ScienceDirect

Precision Engineering 32 (2008) 88–99

PRECISION ENGINEERING

www.elsevier.com/locate/precision

Image processing nanoparticle size measurement for determination of density values to correct the ELPI measures

Nicolas Coudray [a], Alain Dieterlen [a,*], Loïc Vidal [b], Estelle Roth [c], Gwénaëlle Trouvé [c], Sophie Bistac [b]

[a] *Laboratoire MIPS Group Lab.El, I.U.T. de Mulhouse, 61, rue Albert Camus, 68093 Mulhouse Cedex, France*
[b] *Institut de Chimie des Surfaces et Interfaces, 15, rue Jean Starcky, BP 2488, 68057 Mulhouse Cedex, France*
[c] *Laboratoire de Gestion des Risques et Environnement, 25 rue de Chemnitz, 68200 Mulhouse, France*

Received 21 February 2006; received in revised form 12 March 2007; accepted 17 April 2007
Available online 5 July 2007

Abstract

The ELPI is an electrical low-pressure impactor that classifies aerosol particles according to their aerodynamic diameter, and generates the amount of particles impacted on each of the 12 stages. This number depends on the measured current induced by the pre-charged particles and on the density which is given by the user and may not be a priori known. In addition, the density used by the software is considered to be similar for all stages. In this paper, a method to evaluate the density of the particles on each stage is proposed in order to consequently increase the accuracy of the results given by the software. The data needed are the aerodynamic diameter, the equivalent diameter and information on the form. The aerodynamic diameter is a range defined by the cut-off aerodynamic diameter of the stages of the ELPI. To measure the equivalent diameter and evaluate the form, an adapted procedure that used microscopy and image processing tools was set up with the study of two different polydispersed aerosols, silica and fly ash particles from wood combustion. This method was validated with Silica particles ($\rho = 2.5\,\mathrm{g\,cm^{-3}}$ with the pycnometer): the density was found to be $2.2\,\mathrm{g\,cm^{-3}}$ and $2.4\,\mathrm{g\,cm^{-3}}$ for stages 2 (d_{ae} around 76 nm) and 3 (d_{ae} around 127 nm), respectively. The results match reality for fly ashes from wood combustion as well: $\rho = 1.0\,\mathrm{g\,cm^{-3}}$ for the stage 2 and 1.9 for stage 5.

Keywords: Image processing; ELPI; Cascade Impactors; Nanoparticles; Microscopy; Density measurement

1. Introduction

Fine particles are likely to pose a risk to environment and health since they can travel deeply into the respiratory apparatus. In this context, cascade impactors are of great interest since they can collect particles and measure the size distribution. They can be used in many fields, e.g. particles emitted from diesel engines, ambient aerosols or other aerosols from combustion sources [1–3].

In this study, the Electrical Low Pressure Impactor (ELPI) manufactured by Dekati Ltd., Tampere, Finland, collects particles from 29 nm to 10 μm, and classifies them into 12 size fractions. The ELPI can be divided into three parts: the particles are first electrically charged, then impacted on different stages according to their inertia, and finally, the number of particles is measured. The number of particles depends on the induced current measured at each stage, and it also depends on the density ρ, which has to be given by the user. For the calculation of the size distribution, the same ρ is used for each stage. However, in practice the density may vary from stage to stage. Particularly combustion processes produce aerosols with particles of different nature, each type having a specific density. Indeed, the mineral parts of these aerosols present densities from 2.0 to 3.5. They can reach 12 when the fuel contains a great heavy metal part. On the contrary, the flying ash density ranges from 0.6 to 1.2 and the soot one around 0.8. The choice of the density has a great influence since it may cause a fluctuation of more than 100% in the evaluation of the number of particles. The shape of the distribution is not modified but the number is affected. As a consequence for an accurate number determination, the density has to be set very precisely.

The density ρ cannot be easily measured with classical experimental tools (like pycnometer) since there is not enough matter

* Corresponding author. Tel.: +33 3 89 33 76 61; fax: +33 3 89 33 76 05.
E-mail address: alain.dieterlen@uha.fr (A. Dieterlen).

0141-6359/$ – see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.precisioneng.2007.04.009

collected on each stage. This information is not only essential for the evaluation of the number size distribution done by the ELPI, but also in the characterization of the studied aerosol.

This paper presents a method for the evaluation of ρ using imaging tools, as the density is proportional to the Stokes diameter and the aerodynamic diameter d_{ae}. d_{ae} is known from the ELPI since each stage is characterized by a lower cut-off aerodynamic diameter. As for the Stokes diameter, it is supposed to be the projected equivalent diameter d_{eq} for spherical particles (thus, in this paper, only d_{eq} is always used). The d_{eq} can be measured on images acquired with a scanning electron microscope whose resolution allows precise measure of the sizes. The repartition of the particles, the homogeneity and the regions of interest were selected according to observations done with a light microscope.

First, ELPI operations which are essential to understand the benefit of our method are described. ELPI collects particles on substrate whose choice is directly connected to the analysis that needs to be done. In order to study light microscope images, coverglasses substrates were placed on each ELPI plates. Images from light microscope were taken and used to validate the effectiveness of this substrate and for general observations. Furthermore, this analysis made us aware of the losses that can occur in such an impactor. Having a valid support and protocol, and knowing the different losses, it became then possible to apply adapted image processing tools to extract the equivalent diameter. The protocol to extract the diameter and calculate the density of the particles is fully described in this paper.

Validation of this procedure was tested with Silica particles. Then, improvement with loss estimation was studied and the method was extended to fly ashes density measurement.

2. Experimental

2.1. Principle of the electrical low pressure impactor

The ELPI is made of three parts: the particles are firstly electrically charged by the corona charger, then, they are impacted according to their inertia in the impactor and finally, the size distribution is evaluated from the induced current of the pre-charged particles.

2.1.1. Corona charger

The aerosol is sampled at a flow rate of 9.82 l min^{-1} and flies across the corona charger, whose higher part is made of a 5 mm long tungsten electrode which supplies a 5 kV positive voltage. The particles coming perpendicularly to the electrical field are charged with positive ions.

The performance of the charger is characterized by the product between the penetration through the charger P and the average number of charges per particle n. This product Pn is used by the ELPI software and has been experimentally determined by the method described by Marjamäki et al. [4]. In our case, the values are given by Eq. (1):

$$P \times n = \begin{cases} 5.941 \times d_{eq}^{1.637}; & d_{eq} < 0.0239\,\mu\text{m} \\ 1.819 \times d_{eq}^{1.3201}; & 0.0239\,\mu\text{m} \le d_{eq} < 10\,\mu\text{m} \\ 79.732 \times d_{eq}^{0.5909}; & 10\,\mu\text{m} \le d_{eq} \end{cases} \quad (1)$$

d_{eq} being the particle diameter, which is the equivalent diameter of a spherical particle. This equation is then used to convert the current into size distribution.

2.1.2. Impactor

A multi-stage cascade impactor (shown in the Fig. 1) is then used to classify the particles. A single stage is made of two collinear plates, the jet plate and the collection plate. The flow is going by the nozzles of the jet plate and turns sharply. Bigger particles that cannot follow the stream because of their inertia are impacted on the second plate where the substrate has been fixed. Smaller particles that follow the stream are impacted on the next lower stages.

The size and the number of the nozzles vary from plate to plate. It permits the impaction of particles of different inertia and governs the size distribution. The repartition of the particles on the substrate is directly related to the number and lay out of the nozzles.

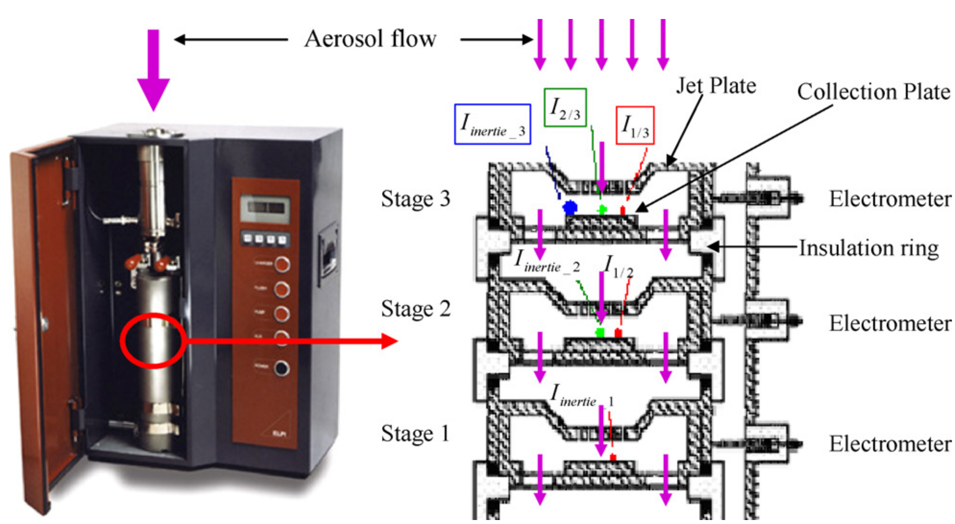

Fig. 1. Photography and Scheme of the three lower stages of the ELPI with induced current of impacted ($I_{inertie\_i}$) and lost particles ($I_{i/k}$).