Environment Protection Engineering

Vol. 32 2006 No. 3

MAREK BOGACKI*, ROBERT OLENIACZ*,
MARIAN MAZUR*, STANISŁAW KAMIŃSKI**

REAL-TIME MEASUREMENT OF THE SIZE OF AIR PARTICULATES

The gravimetric method of measuring PM10 particulate concentration in the air is the reference method used in Poland and in the European Union. To gain information on mass fractions of lower-diameter particulates (e.g., PM5, PM2.5 or PM1) one usually has to apply various pre-sorters (most often of the impact type). This paper presents a new device for measuring air particulate sizes in real time. The device makes it possible to classify (sort) air particulates according to size into 256 granularity classes from about 0.4 μm up to 300 μm. The tests of a device prototype were conducted in Warsaw on the turn of 2005/2006.

1. INTRODUCTION

The concentration of PM10 particulates in the air is – according to the decree which deals with the acceptable concentrations/alarm levels of some substances in air and tolerance margins for the concentrations and was issued by the Minister of Environmental Protection on June 6, 2002 (Dz. U. of June 27, 2002, No. 87, pos. 796) – one of the criteria used to assess the air quality [1]. The reference method of measuring the concentration of PM10 particulates in the air consists in blowing a known volume of dusted air through a filter and manually weighing the mass accumulated on the filter (the gravimetric method described in the PN-EN12341:2005 standard). The elements of the measuring setup that operates according to that principle include: an inlet head equipped with a PM10 pre-sorter (e.g. of the LVS-PM10, HVS-PM10, or WRAC-PM10 type), a holder/cartridge for disposable filters, an air volume/stream gauge, and an adjustable suction device (pump).

Several various automated methods of sampling and measuring PM10 concentration have been developed. The most popular ones can be itemized as follows: the gravimetric method, based on the principle of sedimentation balance (mainly known from the TEOM

* Department of Management and Environmental Protection, University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków, Poland.

** Kamika Instruments S.C., ul. Strawczyńska 16, 01-473 Warszawa, Poland.

analyzers); the radiometric method, based on absorption of β radiation; and a number of optical methods: laser diffraction methods based on the Fraunhofer and/or MIE theory, reflected light-based methods, and transmitted light-based methods. Gravimetric and radiometric methods by themselves (i.e. without additional equipment) do not allow a direct determination of various dust fractions. Specialized pre-sorters must be applied at the inlet of the suction head to determine the concentration of the PM10, PM5, PM 2.5, PM1 or any other dust fraction in the air. These pre-sorters are usually equipped with a cascade impactor and/or a deposition plate covered with a sticky substance, and sometimes with a specially constructed micro-dust extractor. In optical methods, we do not deal with the problem of separating dust fractions prior to the measurement: individual fractions are simultaneously analyzed by an opto-electronic device operating according to the well-known laws of physics (diffraction, reflection, etc.). Therefore, optical methods seem to be a very interesting alternative to the gravimetric and the radiometric ones.

This paper presents a new opto-electronic method capable of measuring in real time both air particulate sizes in the entire granularity range as well as the concentration of individual dust fractions. The method has been developed by the Warsaw-based Kamika Instruments company and is applied in their automatic IPS P particulate matter size analyzer/dust concentration meter.

2. DESCRIPTION OF THE METHOD USED IN THE IPS P ANALYZERS

IPS P analyzers measure the smallest particulates by means of laser diffraction in infrared. For larger particulates the analysis technique smoothly shifts towards the measurement of the intensity of beams of light reflected from moving dust particles. This approach made it possible to avoid weaknesses of the laser diffraction technique within the size range, in which individual large particles very weakly modify diffractograms. As a result, the analyzer does not exhibit optical limitations when measuring individual small or large particles. A laser-generated infrared light beam measures particle size in the entire measurement range and makes it possible to accurately count the particles. Each particle produces an electrical pulse of the amplitude proportional to the size of the particle. Since the analyzer uses a 12-bit ADC converter, the raw measurement data is acquired in 4096 channels and is then calibrated (sorted out) into 256 size classes available to the user.

The analyzer samples dusty air iso-kinetically by means of a specially designed aerodynamic device supported by an electronically-controlled compressor, whose characteristic is matched to low-volume air streams that can occur with winds of minimal speed. An actual wind speed measured by means of a Pitot tube acts as a control for the sampling device.

Air volume is sampled every 0.2 seconds with an accuracy of 0.4% and recalculated to the normal conditions (101.3 kPa, 273 K) using information on air temperature measured inside the device. Fluctuations of the sampled air volume do not influence the analyzer accuracy.

The analyzer measures air particulate sizes within the 0.4–300 μm range [2]. Its software may calculate differential and integral distributions of such characteristic particulate parameters as their surfaces or volumes. If the specific density data is supplied with dust matter, it also may re-calculate the distributions into particulate mass distributions. However, it must be stressed that particulate-size distributions determined by the analyzer calibration are dependent on particle shapes. Surfaces and volumes may be unambiguously, mathematically calculated only for ideal spheres. IPS P analyzer may be calibrated not only against spherical standards (e.g., those made by Duke Scientific Corporation, Palo Alto, California, USA), but also against standards of shapes other than spheres. If non-spherical calibration data is to be useful, an actual particle distribution must be supplied to the calibration program, provided that such data has been found by means of some previously performed sieve analysis.

IPS P analyzers also record basic meteorological parameters: air humidity, wind direction, and wind speed. This makes it possible to assess the degree to which meteorological factors may influence the air particulate granularity distributions and dust concentrations in individual size sub-ranges. All the parameters measured are stored in the mass storage system of the analyzer-controlling computer.

3. SAMPLE MEASUREMENT RESULTS

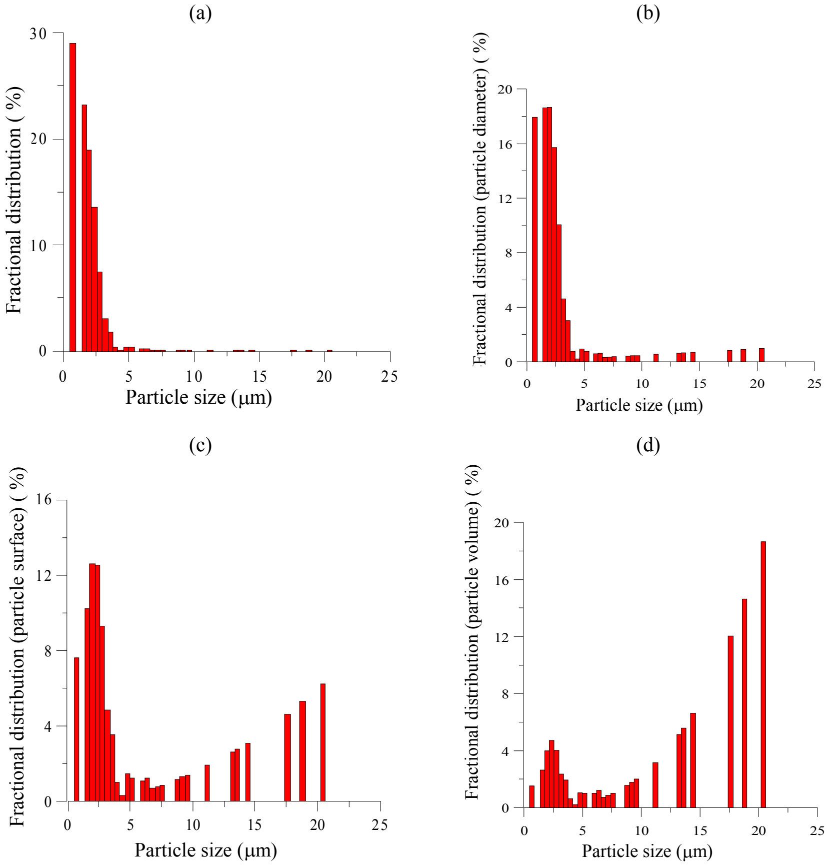
The sample results presented below were obtained from a single measurement of the granular-particulate composition of the air taken at a point located at a Warsaw-Bemowo housing estate of single-family homes on March 19, 2006. The measurement started at 7:15 pm and lasted 900 seconds. Meteorological conditions: air temperature, minus 2 °C, relative humidity, 64.5%; western wind speed 3.3 m/s. The results are summarized in the table, while in the figure the fractional distributions of air particulates are given.

Table

Basic parameters of the analysis

Parameter	Unit	Value
Number of air particulates in 1 m^3, size equal to or below 10 μm	[–]	105961
Number of air particulates in 1 m^3, size above 10 μm	[–]	776
Assumed specific density of particulate matter	[g/cm^3]	2.54
Assumed shape factor of particulates	[–]	1.00
Total particulate mass in 1 m^3	[$\mu g/m^3$]	7.0
Median	[μm]	1.8
Modal	[μm]	1.4
Arithmetic mean of particulate size	[μm]	2.2
Particulate size surface mean	[μm]	2.7
Particulate size volume mean	[μm]	3.7

Sauter size (volume mean weighed by surfaces)	[μm]	6.9



Fractional distributions of the air particulates analyzed:
(a) raw number of the air particulates detected, (b) number of air particulates related to particle diameters, (c) number of air particulates related to particle surfaces, (d) number of air particulates related to particle volumes

4. CONCLUSIONS

The capabilities of the measuring method described threw new light on the question of assessing the quality of air that is polluted by various aerosol pollutants. The method makes it possible to count individual air particulates. Such data is much more valuable from the toxicological point of view since it presents much broader capabilities of assessing pollution-related risks to human health than assessments made so far on the basis of gravimetric or radiometric measurements.

BIBLIOGRAPHY

~~1.~~[1] Decree dealing with the matter of acceptable concentrations/alarm levels of some substances in air and tolerance margins for the concentrations, issued by the Minister of Environmental Protection on June 6, 2002 (Dz. U. of June 27, 2002, No. 87, pos. 796).

Formatted: Bullets and Numbering

~~2.~~[2] IPS P Analyzer User Manual (Kamika Instruments, Warszawa, 2004).

POMIARY WIELKOŚCI CZĄSTEK W POWIETRZU W CZASIE RZECZYWISTYM

W Polsce i Unii Europejskiej referencyjną metodą pomiaru stężenia PM10 w powietrzu jest metoda grawimetryczna. Informację o udziale wagowym w powietrzu cząstek o średnicach mniejszych od 10 μm (np. PM5, PM2,5 czy PM1) uzyskuje się zwykle, stosując różnego rodzaju rozdzielacze wstępne (najczęściej impakcyjne). W artykule przedstawiono nową metodę pomiarową umożliwiającą ocenę wielkości cząstek w powietrzu w czasie rzeczywistym. Metoda ta pozwala ocenić wielkości cząstek w 256 klasach ziarnowych począwszy od 0,4 μm aż do 300 μm. Badania o charakterze wdrożeniowym były prowadzone w powietrzu miejskim (Warszawa) na przełomie lat 2005/2006.