Size Distribution Characterization Of Outdoor Aerosol Particles

Hyam Nazmy, Mona Moustafa, Amer Mohamed, Abdel-Rahman Ahmed, Mostafa Yuness

Abstract: Mass size distributions of atmospheric aerosol particles were measured at four different regions in outdoor of El-Minia governorate (Upper Egypt). The study was conducted during March 2012 to March 2013. Measurements were performed using low pressure Berner cascade Impactor as an aerosol sampler. The Impactor operates at 1.7 m3/h flow rate with aerodynamic "cut-off" size range from 0.06 up to 16 µm. Measurement results show that the log normal size distributions in outdoor were bimodal in nature corresponding to accumulation and coarse modes The variation obtained at the different sampling sites could be attributed to the different aerosol particles emitted sources in each area environment as well as the climatic outdoor changes.

Index Terms: aerosol particles, aerodynamic diameter, size distribution.

1 Introduction

Aerosols are fine particles, solid or liquid, in the size range from about 1 nm up to more than 100 µm suspended in atmospheric air [1]. The aerosols particles are injected into the atmosphere from natural and man-made sources. Natural aerosol particles are formed by the conversion of gases into particulate matter, from re-suspension of powdered materials or by the break-up of agglomerates. Man-made aerosols are formed from combustion products and photochemical reaction between the oxides of nitrogen and the hydrocarbons (smog reaction). Knowledge of the size distribution as a function of size is essential for determining the properties, behavior, atmospheric processes and effects of aerosol particles. A vast number of detailed studies all over the world in very diverse environment have been devoted to measuring the size distributions of aerosol mass [2-5]. The differential size distributions exhibit fundamentally multimodal character with several modes, typically: nucleation, accumulation and coarse modes [6]. Particles of the nucleation mode are originating from condensation of supersaturated vapors. The primary particles are a few nanometers in size (less than 100 nm) but due to the high concentrations they coagulate until the number is too small for further growth. The accumulation mode, consisting of long-lived particles of sizes of a few tenths of a micrometer (100 nm < Dp < 2000 nm). They stay in the atmosphere approximately a week and compete for condensation and coagulation with the particles of the nucleation mode. Due to the larger surface of the accumulation mode particles, the heterogeneous coagulation with them exceeds homogeneous coagulation. The coarse mode, the particles (Dp > 2000 nm) of which are generated by mechanical processes such as sea spray and erosion.

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It must be noted that the sampling of coarse particles can be flawed by the inlet system, which may make sampling of particles above 10 µm is difficult. This mode contains windblown dust, sea salt spray, and plant materials. The modal size and composition is variable, depending on the nature of the surface cover and atmospheric condition, specially the wind speed. Also, the coarse particles are characterized by a high deposition velocity and they have short residence times [7]. Size distribution and chemical composition are fundamental aerosol properties most relevant to environmental impacts [8-11]. Determination of mass-size distribution is thus a fundamental and important means of characterizing atmospheric aerosol [11-13]. The size distribution of atmospheric aerosols strongly depends on the sources as well as on the meteorological processes during their lifetime [14-15], on the type and history of the air mass, as well as on the boundary-layer circulations. While the topography decides the major natural aerosols originating over a region, the anthropogenic contribution is decided by industries/human activities. Aerosols, both natural and anthropogenic, play an important role in atmospheric and astronomical sciences [16]. The removal processes of aerosol particles from the atmosphere, the deposition rate on ground and vegetation and the deposition probability, of attached aerosols with radionuclides, in the human lung during inhalation depend on the aerosol size and their concentrations. The attached aerosols are deposited in different parts of the human respiratory tract due to their different sizes causing the lung cancer [17]. Therefore, the mass size distribution of aerosol particles is the most important parameter must be studied in the environment. Because cascade Impactors are the most suitable devices for determining the size distributions of aerosol particles and their mass concentrations, the following points are the aim of this work is using the cascade Impactor as an aerosol sampler to determine the mass size distributions of aerosol particles and their mass concentrations in the open air.

2 Materials and Methods

Berner Low pressure cascade Impactor (BLPI) (Model, 30/0.06) with eight impaction stages and a back-up filter stage were used as a sampling device. BLPI operates at a flow rate of 1.7 m^3 h^{-1}. Aluminum foils were used as collection media, and a glass fiber filter as the back-up filter [18]. The cut-off diameters for 50% collection efficiency of the impaction stages are 0.082, 0.157, 0.27, 0.65, 1.1, 2.35, 4.25 and 5.96 µm. An accurate method of calibration Impactor has been performed by reineking et al., and EL-Hussein [19, 20] in the isotope

laboratory of Gottingen univ. Germany. the calibration was carried out by using monodisperse test aerosol particles prepared under laboratory conditions. The aerosol generator type Sinclair and La Mer [21] was used for that purpose. The final result for this calibration is the total inters- stage losses of aerosol particles were less than 2% of the total mass [19].

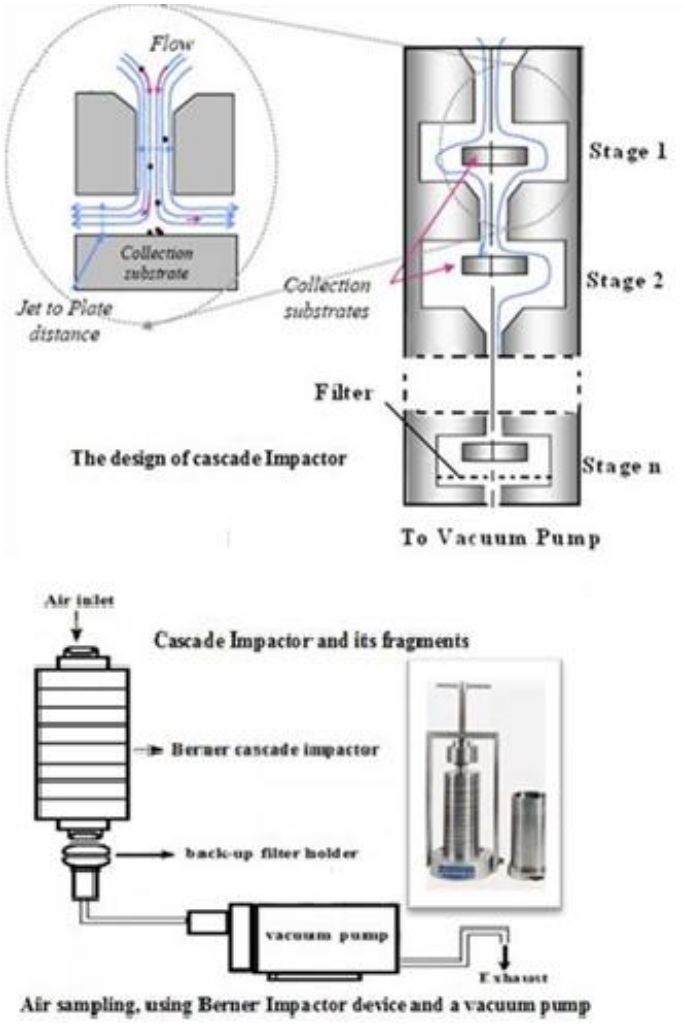

Fig 1. Aerosol sampling set-up using Berner Low pressure cascade impactor (BLPI)

In order to recognize the effect of sampling time on aerosol concentration as well on size distribution, different sampling time was carried out .the suitable time for collecting was found about 6 h. Aluminum foils of the impactor stages were weighted under controlled conditions, temperature and humidity, before and after air sampling with a sensitive balance (Mettler analytical AE240 Dual Range Balance). The difference between the two weights of each aluminum foil is considered to be the deposited aerosol mass. In addition, specific mass concentration after each run was determined as follows:

$$v = \frac{m}{Q.t} ..... \mu g / m^3 \quad (1)$$

where v is the specific mass concentration, m is the total deposited aerosol mass on the impactor stages (μg), Q is the impactor flow rate (m^3/h) and t is the sampling time (hour). The parameters of mass size distribution, Mass Median Aerodynamic Diameter and Geometric Standerd Deviation (MMAD and GSD), were obtained from the lognormal distribution method [22] as

$$\ln(MMAD..) = \frac{\Sigma n_i \ln d_i}{\Sigma n_i} \quad (2)$$

$$\ln(GSD) = \left[\frac{\Sigma n_i (\ln d_i - \ln MMAD)^2}{\Sigma n_i} \right]^{\frac{1}{2}} \quad (3)$$

where n_i, d_i are the fraction and the cut-off diameter in the stage i, respectively. Also, these parameters can be obtained by a graphical cumulative method. The cumulative mass were plotted versus the cut-off diameter of the impactor stages. The MMAD is defined as the diameter at 50% cumulative fractions. The GSD of the size distribution is defined as the diameter at 84% cumulative mass divided by the diameter obtained at 50%.

3 RESULTS AND DISCUSION

Total mass concentration is the mass of all particles in the size range up to 16 μm which is the upper limit of the applied Impactor (Berner Low pressure cascade Impactor (BLPI) (Model, 30/0.06) with eight impaction stages and a back-up filter stage. BLPI operates at a flow rate of 1.7 m^3 h^{-1}. Aluminum foils were used as collection media, and a glass fiber filter as the back-up filter. The cut-off diameters for 50% collection efficiency of the impaction stages are 0.082, 0.157, 0.27, 0.65, 1.1, 2.35, 4.25 and 5.96 μm).The average total mass concentrations within March 2012 to March 2013 are summarized in table (1). The fluctuation in the total mass concentrations may be related to different sources and variation of metrological conditions. In comparison with other experimental results we found that our present value (292 ± 22 μg/m^3) are higher than the values obtained by Parmar in Agra where total aerosol (131.6 μ g/m^3) measured with four stage cascade particle sampler (CPS-105) [24], (190 μ g/m^3) Kulshretha et al [24]. on the other hand the obtained values are too higher than the values obtained in Taipei station (PM10 9.83-104.26 μ g/m^3) with a mean value 39.98 μg/m^3 measured with portable dust monitor [25], EL-Hussein in Germany where (23-48 μ g/m^3) were measured with Berner Impactor [20], in Budapest (24-88 μ g/m^3) were measured with cascade Impactor [26] and in French (35.6-55.7 μ g/m^3) measured with four stage cascade Impactor [27].

TABLE1
AVERAGE VALUES OF TOTAL MASS CONCENTRATION IN FOUR SITES.

SITES	Mass concentration μg/m3
1	315±17.4
2	305±17.0
3	284±15.2
4	265±14.8
Average	292±22

Average mass size distributions of collected aerosol particles are shown in Figure 2. The collection fractions in each stage are plotted versus the geometric midpoints of the size ranges determined by the cut-off values of the collection stages. There is little variation in the shape of the mass size distributions from one site to another. The ordinate of the plot is the ratio of the atmospheric aerosols mass (m) in a given size range to the total atmospheric aerosols mass (m_T) on all stages (mass fraction) instead of the usually applied $m/m_T/\log(d_2/d_1)$ expression (relative mass in an unit size range), where d_1 and d_2 are the lower and upper EADs, respectively, of the given size range. The parameters of mass size distributions at the four sampling sites are listed in table.2. Mass Median aerodynamic diameters (MMADs) and geometric standard deviations were calculated by fitting a lognormal function to the individual size distributions. (The results agreed well with those obtained from the cumulative probability plots on logarithmically probability graph).

TABLE2
AVERAGE VALUES OF MASS MEDIAN AERODYNAMIC DIAMETERS (MMAD) AND GEOMETRIC STANDARD DEVIATIONS (GSD).

	ACCUMULATION		COARSE	
SITES	$MMAD_A$ (nm)	GSD_A	$MMAD_C$ (nm)	GSD_C
1	393	2.4	3676	2.5
2	436	2.4	3502	1.5
3	444	2.2	3711	1.5
4	357	2.5	3709	1.4
MEAN	**407**	**2.37**	**3650**	**1.7**

The obtained mass size distribution was found as bi-modal log normal distribution which was corresponding to accumulation and coarse mode. The bi-modality nature of mass size distribution was confirmed by Whitby et al., in American cities [29], Sega and Fugas in Yugoslavua [30], Kim and Rhoin Korea [31]. Sanhueza et al., in Venezuela [32] and EL-Hussein., in Germany [21].

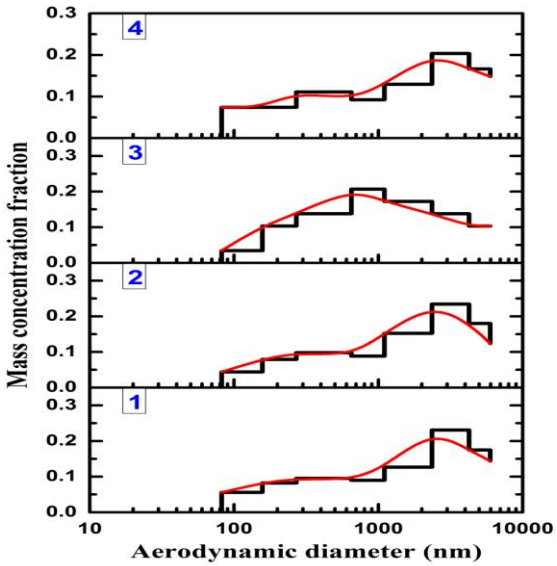

Fig. 2. Average mass size distribution of aerosol particles in the selected four points in El-Minia city.

Because the measurements were performed at different times, considerable fluctuations in the mass size distributions were observed. The most derived mass size distributions could be approximated as bimodal log–normal distributions represented by the accumulation mode (100 nm ≤ aerosol particle size ≥2000 nm) in addition to according to temperature and humidity changes, fractions in the coarse mode (aerosol size range ≤ 2000 nm) were measured. Figure. 2 show that more than about 70% of the mass fraction of the aerosol particles is associated with the aerosol particles of the accumulation mode. This may be traced to the removal processes of large particles, which are controlled by dry deposition. The deposition velocity of particles in the accumulation mode is about 10-2 $cm.s^{-1}$ [7]. Particles with such a deposition velocity are very slowly removed and therefore their residence times are relatively long. On the other hand, the deposition velocity of particles in the coarse mode extends to 20 cm.s-1which is very high in comparison with that of accumulation mode particles. Therefore, the residence time of the particles in the coarse mode is very short and thus it is less likely that these particles will coagulate to produce a broad size distribution of the coarse mode [7]. The coarse particles are characterized by a high deposition velocity and they have short residence times. The residence time of aerosols depends on their size, chemistry and height in the atmosphere. Particle residence times range from minutes to hundreds of days. Aerosols between 0.1 - 1.0 µm (the accumulation mode) remain in the atmosphere longer than the other two size categories. Aerosols smaller than this (the nucleation mode) are subject to Brownian motion; higher rates of particle collision and coagulation increases the size of individual particles and removes them from the nucleation mode. The coarser particles (>1 µm radius) have higher sedimentation rates than the other two size ranges.

4 CONCLUSION

Measurements of aerosol particles in four sits, in outdoor air of el Minia governorate, were performed using low pressure Berner cascade Impactor. Measurement results show that the log normal size distributions in outdoor were bimodal in addition to because the measurements were performed at different times, considerable fluctuations in the mass size distributions were observed. Finally the most collected fraction of aerosols in the range of inhalable particles.

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