

# MEASUREMENT OF AEROSOL CONCENTRATION VARIATION BY OPTO-ELECTRONIC METHOD

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## ABSTRACT

The measurement of air aerosol concentration within the Bauchi Road Campus of the University of Jos was carried out. The variation of the aerosol concentration over the period 14<sup>th</sup> to 20<sup>th</sup> August 1990 was determined electro-optically, making use of the intensity of light scattered by particles. The intensity of the scattered light obtained is proportional to the average concentration of the aerosols, averaged during 3 1/2 hours in a day starting from 1200 hours to 1530 hours. The ratio of the voltages  $M_1/M_2$  is a factor which is proportional to the average value of the aerosols concentration. From the regression line, it is found that average value of the aerosols concentration increases linearly with time over the period of measurement. The slope, 0.023 of the regression line is proportional to the rate at which the concentration of the particles in the environment varied with time.

**KEY WORDS:** Aerosol Concentration; concentration variation; Opto-Electronic.

## INTRODUCTION

### 1.1 Atmospheric Aerosols

An aerosol is defined as a system of solid or liquid particles suspended in a gaseous medium having a negligible falling velocity (United Nations, 2005). Further more, it is defined as particulate matter, solid, or liquid, larger than a molecule but small enough to remain suspended in the atmosphere. Natural sources include salt particles from sea spray, dust and clay particles as a result of weathering of rocks, both of which are carried upward by the wind. Aerosols can originate as a result of human activities and are often considered pollutants. Aerosols are important in the Atmosphere as nuclei for the condensation of water droplets and ice crystals, as participants in various chemical cycles, and as absorbers and scatters of solar radiation, thereby influencing the radiation budget of the Earth's climate system (Office of Policy, 2004). The aerosols are characterised by low relative humidity and degradation of visibility (Utah et al, 1994). Furthermore, attenuation of radio signals by aerosols was reported by (Owolabi, 1987) while depletion of solar radiation was reported by (Oluwafemi, 1981).

Recent studies have suggested that the number, size and composition of particulate matter may all have an important role in health effects attributed to particulate matter (Dockery et al, 1994).

The damage of aerosols to vegetation has been recognised for at least a century (Prindla, 1979).

A variety of analytical techniques for the measurement of aerosol parameters like size and concentration have been developed over the past years ranging from acoustical, mechanical to electro-optical techniques (methods). Filtration, inertial (device used to separate particles according to size), electrostatic, tape sampler (used to determine the transmittance and reflectance of impacted dust), thermal, and smoke-shade methods are various sampling method as well as the start of analytical schemes. Electrostatic and thermal methods are used for special sampling for small quantities of dust. If it is desired to ascertain particle size or other physical characteristics, the inertial sampler, electrostatic or thermal collector, and photometric methods should be used (Arthur et al, 1973).

Electro-optical analysis which is used in this work allows measurements to be made with an absolute

minimum of disturbance, i.e. in situ analysis. Particle counting and sizing of atmospheric aerosols by electro-optical methods are complex and absolute interpretation of measurements is difficult, the scattered light varies in a complicated manner with the system of optics as well as with the size and physical characteristics of particles.

Integrated nephelometers are used to measure aerosol physical properties such as aerosol light scatter, aerosol composition in two size ranges, total aerosol number concentration, and total aerosol light absorption coefficient. As for aerosol chemical measurements, high volume bulk aerosol samples are usually collected and analysed for various soluble species using Atomic Absorption Spectroscopy (AAS) or flame photometer (Prospero et al, 1997). The variation of aerosol concentration averaged during a 7 day sampling period for 3 1/2 hours per day is of interest and was determined indirectly electro-optically making use of the intensity of light scattered by the particles.

### 1.2 THEORETICAL BACKGROUND

The assumptions made in this work include the following; the scattered light has the same frequency (i.e. the same wavelength) as the incident light. Independent scattering or independent particles are considered (i.e. the scattering by well defined separate particles).

The effects of multiple scattering were neglected. Total scattering and hence no absorption was considered (i.e. the intensity of the incident light was high).

Particles are considered as being spherical because surface wave on a spherical particle can exist only if the size of the sphere is larger than the wavelength of the incident radiation.

A plane electromagnetic wave incident on the scattering medium is represented by

$$\vec{E}(\vec{r}, t) = A_0 \exp - i(\vec{k}\vec{r} - wt) \quad \dots\dots(1)$$

Where  $K$  is the wave vector and  $w$  is the incident frequency in radians/second, while  $r$  is the position vector and  $A_0$  is the amplitude for a particle located at position  $P$  representing any point in the medium, the wave degenerates into spherical wave after scattering, we then have

$$\vec{E}_s = \frac{C}{R} \vec{E}(\vec{P}, t) \exp i\vec{k}\vec{r} F(\theta) \quad \dots\dots\dots(2)$$

Where C is the scattering function. This function can be written as  $C(A, B_{sca}, x, \partial, \eta)$  where A represents absorption coefficient,  $B_{sca}$  is the scattering coefficients, x is the size

$$\bar{E}_{sc} = \frac{C}{R} (B_{sca}, X, \partial, \eta) F(\theta) A_{sc} \exp - i \bar{k} \bar{p} \exp i(\bar{k}\bar{r} + Wt)$$

Where R is the distance from the particle to the photo-detector. The out going wave has amplitude, which is inversely proportional to the distance R.

A reference beam is required in the experimental set up. This beam is obtained by the splitting of the main beam using a beam splitter. The reflected reference beam is then interrupted (pulsated) by a chopper at a frequency  $f_0$  (1000Hz). The reference beam from the chopper is given as,

$$\text{Where } \Omega = 2\pi f_0 \\ e(\bar{r}, t) = a_0(\Omega) \exp - i(\bar{k}\bar{r} - wt) \quad \dots\dots\dots (3)$$

The scattered and the reference beam combine at the phototransistor. The combination of the two beams yields  $E_{sc} + e$ . Therefore, the intensity  $I_D$  of the scattered and the reference beam at the detector is given as

$$I_D = (E_{sc} + e)^2 = (E_{sc} + e)(E_{sc}^* + e^*) \quad \dots\dots\dots (4)$$

Where \* indicate complex conjugate  
By expansion, we have

$$I_D = \frac{(CF(\theta)A_{sc})^2}{R} + a_0(\Omega) \frac{A_{sc}CF(\theta)}{R} - 2a_0(\Omega) \frac{A_{sc}CF(\Omega)\sin^2\alpha}{R} + a_0^2(\Omega) \dots\dots\dots (5)$$

Where  $\alpha = K(P - r) + wt$

The first term in equation (5) is the background direct current: It is proportional to the intensity of the scattered light  $I_{sc}$ . The second, third and fourth terms are components of the alternating current or voltage. Therefore the measured voltage is proportional to the intensity  $I_D$ . Hence the current I is such that

$$I \sim A_{sc}^2 + a_0^2(\Omega) + a_0(\Omega)A_{sc} \quad (6)$$

The amplitude of the alternating current or voltage depends on the frequency of the chopper  $\Omega$ , Akpabio (1987). It is readily seen from equation (4) that the amplitude of the scattered beam  $A_{sc}$  is being modulated by the amplitude of the reference beam  $a_0(\Omega)$  passing through the chopper. The second term contains information about the concentration and scattering Coefficient of the particles. In other words, the rectified recorded value of the second term gives the scattering Function of the scatters. The rectified form of the second term is recorded on meter M1 as a voltage. The third term represents the high frequency component that is present in the expression. This is filtered off to the earth.

The fourth term is proportional to the voltage or intensity of the reference beam. The rectified form of the fourth term is recorded on voltmeter M2. It must be mentioned that the amplitude of the scattered wave  $A_{sc}$  is a function of the scattering angle  $\theta$ .

Since the detector surface is made so small compared to the distance R,  $\theta$  must be very small, hence as  $\theta$  approaches zero,  $F(\theta)$  can be assumed to be unity. So  $F(\theta) = 1$

The equation for determining the parameters of the scatters can thus be written as

The ratio  $M1/M2$  is a factor which is proportional to the average concentration of the particles averaged over a given time.

$$\frac{M1}{M2} = \frac{C}{R} (B_{sca}, X, \partial, \eta) \dots \quad (7)$$

## MATERIALS AND METHODS

A sodium Lamp source is employed because it has a mean wavelength of 589.0 nm (frequency  $5.093 \times 10^{14}$ Hz). The diameter of the collimated beam is reduced by the Iris diaphragm before incident on the beam splitter. The beam splitter allows 50% transmission of the incident beam, which is later, scattered by the particles in the scattering medium. The other 50% of the incident beam constitutes the reference beam, which is directed to interfere with the scattered beam at the photo detector through a chopper device operating at 1000Hz. The received optically modulated signal is converted into a voltage variation by the transducer (photo detector) and analysed by the circuit analyser. The out put voltages M1 and M2 are recorded by making use of an oscilloscope. A sucking pressure or mass concentration of  $1.2\text{kg/cm}^2$  was maintained.

## 1.4 RESULTS AND DISCUSSION

Table 1 shows the values of the concentration variation determined by Opto-Electronic method averaged during the period 14<sup>th</sup> to 20<sup>th</sup> August, 1990 for 3 1/2 hours starting from 1200 hours to 1530 hours.

Figure 1 shows the plot of the dimensionless quantity  $y = \langle M1/M2 \rangle$  which is proportional to the particle concentration against time.

The line of regression  $y = 0.023t + 5.222$  was obtained using table 1 as shown in figure 1. The coefficient of determination  $R\text{-sq}$  or  $(R^2) = 0.946$  implies that the variation in time t explains the variation in aerosol concentration up to 94.6% (Figure 1).

Table1: Concentration variation determined by Opto-Electronic method

Time 1200 - 1530 hours	
Period 14 <sup>th</sup> to 20 <sup>th</sup> August, 1990	
Time t (minutes)	Average concentration $y = \langle M1/M2 \rangle$
0	4.960 ± 0.030
10	5.310 ± 0.030
20	5.730 ± 0.030
30	6.140 ± 0.031
40	6.200 ± 0.032
50	6.360 ± 0.031
60	7.070 ± 0.034
70	7.290 ± 0.032
80	6.930 ± 0.224
90	7.290 ± 0.030
100	7.590 ± 0.031
110	7.300 ± 0.030
120	8.050 ± 0.260
130	8.390 ± 0.520
140	8.150 ± 0.032
150	8.260 ± 0.029
160	8.670 ± 0.038
170	9.120 ± 0.031
180	9.390 ± 0.032
190	10.690 ± 0.033
200	9.580 ± 0.029

The slope, 0.023 of the regression line is proportional to the rate at which the concentration of the particles in the environment varied with time. We infer therefore that the concentration of the particles in the air during the period of measurement increased with time.

The variation of the aerosol concentration over a given period was determined indirectly electro-optically,

making use of the intensity of light scattered by particles. The intensity of the scattered light is proportional to the average concentration of the aerosols, averaged during 3 1/2 hour in a day starting from 1200 hours to 1530 hours. The ratio of the voltages M1/M2 is a factor, which is proportional to the average value of the aerosols concentration.

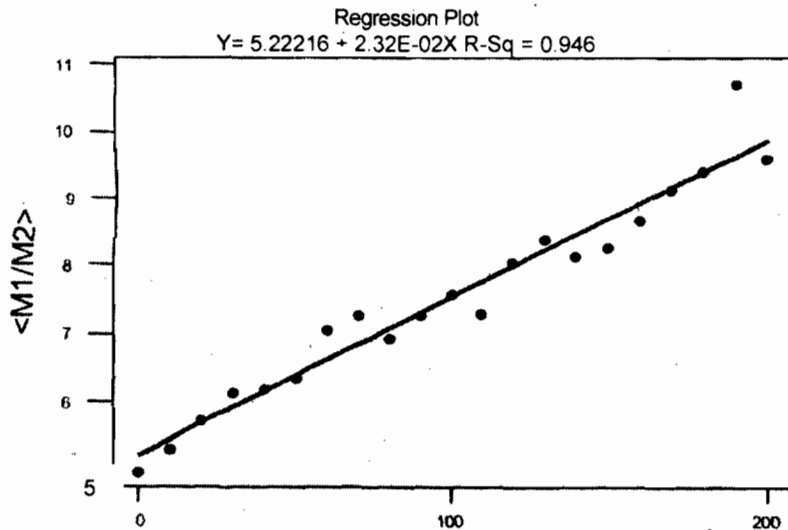


Figure 1: Variation in concentration against time.

As the concentration of the particles passing through the scattering region increases, there will be more of the light losses due to backscattering. Hence less amount of the scattered light will be detected thereby leading to a decrease in the value of the ratio  $M1/M2$ .

While as the concentration of the particles passing through the scattering region decreases, then there will be less of the light losses because most of the scattering is in the forward direction. Hence more of the scattered light will be detected which then implies an increase in the value of the ratio  $M1/M2$ .

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