

Full Length Research Paper

Estimation of air aerosol number concentration by indirect method

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The estimation of the air aerosol number concentration variation was carried out in this work making use of data obtained from the Bauchi Road Campus of the University of Jos, Plateau State, Nigeria in 1990. The aerosol number concentration was determined indirectly, making use of the intensity of light scattered by particles. The scattered light intensity is proportional to the average number concentration of the aerosols, averaged during a 7 day sampling period for 3½ h per day from 1200 to 1530 h if the aerosols are in motion. The dimensionless ratio of the voltages V_1/V_2 is proportional to the average aerosol number concentration. From the line of regressions, it becomes obvious that the measured and estimated aerosol number concentrations increases linearly with time over the period of measurement. The slopes, 0.0232 and 0.0233 of the regression lines for the measured and estimated number concentrations respectively are proportional to the rates at which the aerosols concentrations varied with time in the environment.

Key words: Aerosol, estimated number concentration, concentration, indirect method.

INTRODUCTION

When solar radiation passes through the atmosphere, it is absorbed and scattered, not only by atmospheric gases, but also by aerosols and clouds. Reyes (1997) observed that scattering occurs because the index of refraction of the particles differs from that of the homogeneous medium in which they are imbedded. Aerosols are defined as suspensions of liquid or solid particles in the air, excluding cloud droplets and precipitation. The mean radii of aerosol particles range from about 10^{-4} to 10 microns (μm). William and Barbara (2001) observed that wind speed, mixing between air layers, precipitation, and atmospheric chemistry all determine whether pollutants will remain in the locality where they are produced or go elsewhere. Utah (1995) noted that there is a gradation in size of aerosols entrained in the North East trade winds blowing across West Africa during the harmattan months as the aerosols are transported further away from the Saharan source. Liao (1998) reported that desert dust is the second contributor (after marine) to the global aerosol load. Radiative effects of desert dust strongly depend on aerosol altitude, a poorly known parameter. Charlson (1995) observed that aerosol particles physically affect the heat balance of the Earth, both directly by reflecting

and absorbing solar radiation and by absorbing and emitting some terrestrial infrared radiation and indirectly by influencing the properties and processes of clouds and, possibly, by changing the heterogeneous chemistry of reactive green house gases. Crutzen (1998) observed that the chemistry of the atmosphere has major impacts on several important environmental factors: climate, the hydrological cycle, acid precipitation, stratospheric and tropospheric ozone, and local regional air quality. Aerosol brings about great cooling effect on Earth surface temperatures.

Chiemeka (2006) noted that aerosols are important because they are able to alter climate in two ways. First, they scatter and absorb radiation in the atmosphere and, second, they change the microphysical structure and possibly the life time and extent of clouds within the atmosphere.

Aerosols are essential in atmospheric electricity, cloud formation, precipitation processes, atmospheric chemistry, air pollution, visibility, radiation transfer, and hence climate. Chiemeka (2007) observed that aerosols are characterized by low relative humidity and degradation of visibility, attenuation of radio signals, and depletion of solar radiation.

Indirect method (Electro-optical) analysis which is used in this work allows measurements to be made with an absolute minimum of disturbance, that is, 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. The estimation of aerosol number concentration averaged during a 7 day sampling period for 3¹/₂ h per day is of interest and was determined indirectly making use of the intensity of light scattered by the particles. The data of the year 1990 was used because that was the actual period the work was carried out.

Theoretical background

The assumptions made in this work include the following; the effects of multiple scattering were neglected. Total scattering and hence no absorption was considered (that is, 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. The scattered light has the same frequency (that is, the same wavelength) as the incident light. Independent scattering or independent particles are considered (that is, the scattering by well defined separate particles).

Let I_0 be the intensity of the incident light, I_{sc} the intensity of the scattered light at a point located at a large distance R from the particle to the photo detector and k the wave number defined by $k = 2\frac{\pi}{\lambda}$, where λ is the wavelength in the surrounding medium. Since I_{sc} must be proportional to I_0 and R^{-2} we may write

$$I_{sc} = I_0 \frac{F(\theta, \varphi)}{K^2 R^2} \quad (1)$$

For spherical particles, there is no phase dependence ($\varphi = 0$) hence we may write equation (1) as

$$I_{sc} = I_0 \frac{F(\theta)}{K^2 R^2} \quad (2)$$

Here $F(\theta)$ is a dimensionless function $\left(\frac{F}{K^2}$ is an area) of the direction but not of R . It also depends on the orientation of the particle with respect to the incident

wave and on the state of polarization of the incident wave (Van de Hulst, 1957).

Assuming that the centre of the scattering medium is the only point of reference for the scattering to occur for all of the particles passing through the scattering medium. Then we may write

$$R = \lambda + u \quad (3)$$

Where λ is the radius of the cylindrical tube, and u is the distance from outside of the cylindrical scattering medium to the detector surface. Therefore, writing equation (2) in terms of equation (3), we have that

$$I = I_0 \frac{F(\theta)}{K^2 (\lambda + u)^2} \quad (4)$$

but

$$R^2 = (\lambda + u)^2 = \lambda^2 + 2\lambda u + u^2 \quad (5)$$

But $\lambda \ll u$ hence λ^2 is neglected, Therefore, we write equation (5) as

$$R^2 = 2\lambda u + u^2 = u(2\lambda + u) \quad (6)$$

putting equation (6) into equation (4) we have

$$I = I_0 \frac{F(\theta)}{K^2 u(2\lambda + u)} \quad (7)$$

This equation maybe applied to a volume element $d\tau$ of an extended medium that contains δ_i identical particles per unit volume, each characterized by the same function, $F(\theta)$. The number of particles in the element then is, $\delta_i d\tau$, and the scattered intensity at a distance R is given by

$$I_{sc} = \frac{\delta_i d\tau F(\theta) I_0}{K^2 u(2\lambda + u)} \quad (8)$$

We may therefore write equation (8) in terms of the total number of particles in the irradiated volume as

$$I_{sc} = \frac{N F(\theta) I_0}{K^2 u(2\lambda + u)} \quad (9)$$

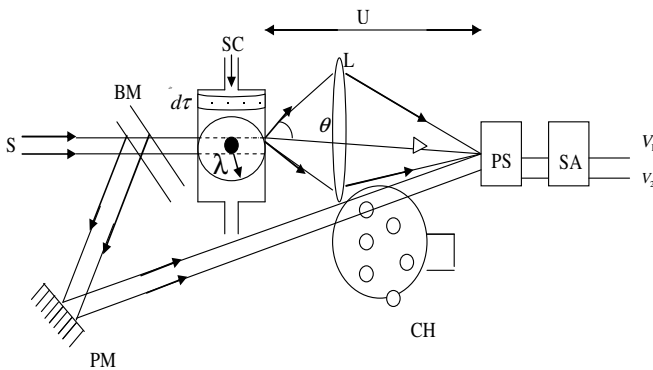
but

$$K = \frac{2\pi}{\lambda}, \quad x = \frac{2\pi a}{\lambda}$$

Where x is the size parameter.

Table 1. Measured and estimated number concentration obtained by indirect method.

TIME	1200-1530 H	
PERIOD	14 TH AUGUST TO 20 TH AUGUST 1990	
TIME (Min)	Y, Measured Concentration (x 10)	Y _e , Estimated number concentration
0	4.960 ± 0.030	5.220 ± 0.068
10	5.310 ± 0.030	5.450 ± 0.019
20	5.730 ± 0.030	5.690 ± 0.002
30	6.140 ± 0.031	5.920 ± 0.048
40	6.200 ± 0.032	6.150 ± 0.003
50	6.360 ± 0.031	6.380 ± 0.000
60	7.070 ± 0.034	6.620 ± 0.203
70	7.290 ± 0.032	6.820 ± 0.221
80	6.930 ± 0.224	7.080 ± 0.023
90	7.290 ± 0.030	7.310 ± 0.000
100	7.590 ± 0.031	7.550 ± 0.002
110	7.300 ± 0.030	7.780 ± 0.230
120	8.050 ± 0.260	8.010 ± 0.002
130	8.390 ± 0.520	8.240 ± 0.023
140	8.150 ± 0.032	8.480 ± 0.109
150	8.260 ± 0.029	8.710 ± 0.203
160	8.670 ± 0.038	8.940 ± 0.073
170	9.120 ± 0.031	9.170 ± 0.003
180	9.390 ± 0.032	9.410 ± 0.000
190	10.690 ± 0.033	9.640 ± 1.103
200	9.580 ± 0.029	9.870 ± 0.084

**Figure 1.** Experimental Set-Up.

S, Sodium source (I_0)
BM, Beam Splitter
SC, Scattering Medium
PS, Photo detector
SA, Circuit Analyzer
CH, Chopper
PM, Plane Mirror

Therefore,

$$I_{sc} = \frac{N a^2 F(\theta) I_0}{x^2 u (2\lambda + u)} \quad (10)$$

Where a is the radius of the particle.

MATERIALS AND METHODS

A sodium Lamp source I_0 is employed because it has a mean wavelength of 589.0 nm (frequency 5.093×10^{14} Hz). 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 1000 Hz. The received optically modulated signal is converted into a voltage variation by the transducer (photo detector) and analyzed by the circuit analyser. The signal analyzer consists of a photo detector, three inverting operational amplifiers ($\mu A741$) with adequate feedback arrangement, two low current diodes as well as LCR series circuit. The out put voltages V_1 and V_2 are recorded by making use of an oscilloscope. A sucking pressure or mass concentration of 1.2 kg/cm² was maintained. The converging lens concentrates the scattered light on the Photo detector. The experimental set-up is as shown in figure 1.

RESULTS AND DISCUSSION

The values of the estimated and measured aerosol number concentration variation obtained by indirect method is as shown in Table 1. Figures 2 and 3 shows the plot of the dimensionless quantities Y and $Y_e = V_1/V_2$ which is proportional to the aerosol number concentration against time and the regression lines. The slopes of the regression lines is proportional to the rates at which the with time. The fitted trend line against time and the plot of the

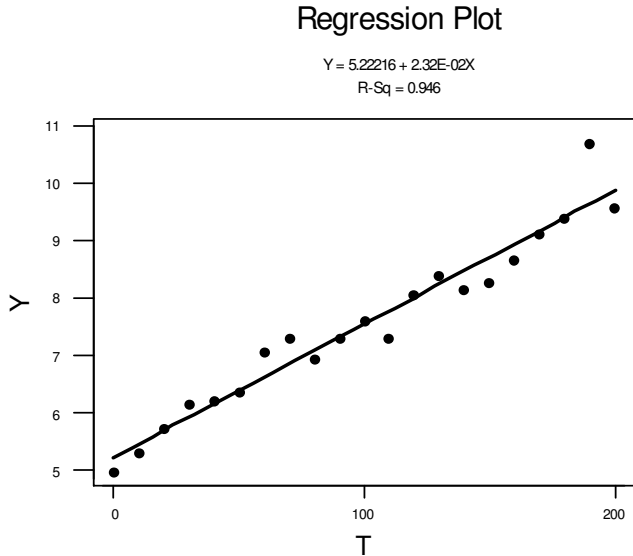


Figure 2. Measured number concentration against time.

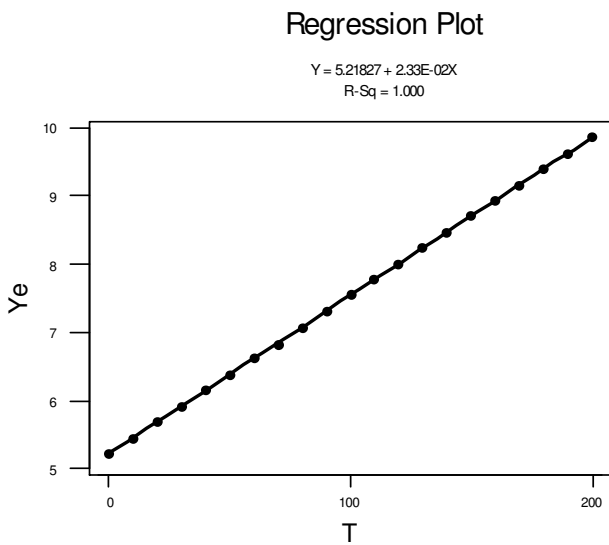


Figure 3. Estimated number concentration against time.

the measured number concentration against time is as shown in Figure 4.

The slope of the regression line for the measured aerosol number concentration variation is 0.0232 (Figure 2). For the measured number concentration, the variation in time, t explains the variation in the aerosol number concentration up to 94.6% since the coefficient of determination R-sq or $R^2 = 0.946$. (Figure 2) and the pooled standard deviation between time and concentration is 0.3551. For the measured number concentration variation, the F-calculated (329.89) is greater than the F-tabulated (4.38) at 95% level of significance and hence

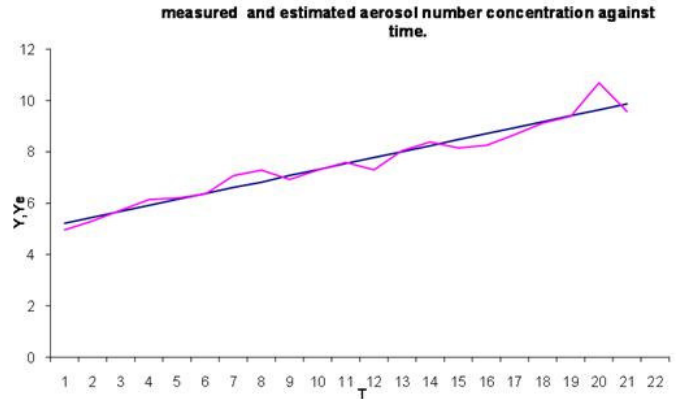


Figure 4. Measured and estimated number concentration against time.

one concludes that the slope of the measured aerosol number concentration is significantly different from zero and hence there exist a relationship between time and concentration.

The slope of the regression line for the estimated number concentration is 0.0233 (Figure 3). The coefficient of determination R-sq (R^2) = 1.000 implies that the variation in time t explains perfectly the variation in the estimated aerosol number concentration up to 100% and the pooled standard deviation is 0.006955. The F-calculated (861527.39) is greater than the F-tabulated (4.38) at 95% level of significance and hence we conclude that the slope of the regression line for estimated aerosol number concentration variation is significantly different from zero. The correlation coefficient between Y_e and Y is 0.972 which implies that there is a high positive relationship between the measured values of the number concentration (Y) and the estimated values (Y_e). Chiemeka et al (2007) opined that the aerosols at the station is partly of local origin, the main source being the harmattan haze that is blown from the Sahara Desert and transported by the North- East trade winds. The great deserts, and semi-arid parts of the world contribute vast quantities of aerosols to the atmosphere thereby leading to an increase in the aerosol number density in air with time.

Conclusion

The estimation of the air aerosol number concentration variation was carried out in this work making use of data obtained from the Bauchi Road Campus of the University of Jos, Plateau State, Nigeria in 1990. The aerosol number concentration was determined indirectly, making use of the intensity of light scattered by particles. The scattered light intensity is proportional to the average number concentration of the aerosols, averaged during a 7 day sampling period for 3½ h per day from 1200 to 1530 h if the aerosols are in motion. The dimensionless ratio of the

voltages V_1/V_2 is proportional to the average aerosol number concentration. From the line of regressions, it becomes obvious that the measured and estimated aerosol number concentrations increases linearly with time over the period of measurement. The slopes, 0.0232 and 0.0233 of the regression lines for the measured and estimated number concentrations respectively are proportional to the rates at which the aerosols concentrations varied with time in the environment.

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