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A comparative study of the common methods for estimating particulate concentrations of the atmosphere

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ABSTRACT. Relative study of the gravimetric, optical and beta-absorption techniques has been made for the study of atmospheric particulate concentrations. C^{14} and Pm^{147} have been used as beta sources and it is found that for normal atmospheric dust loads the C^{14} betas are preferable and for heavily dust laden atmospheres the Pm^{147} betas are useful for obtaining reliable results.

The results show that the atmosphere around Trombay is loaded with dust in excess of permissible limits and that the observed concentration follow a log-normal distribution and indicate both a seasonal as well as a diurnal variation.

1. Introduction

There are three principal methods for the estimation of atmospheric particulates after collecting them on filter papers of various descriptions. These are (*i*) gravimetric, (*ii*) the optical including one based on fluorescence measurement and (*iii*) the beta absorption method. Apart from the necessity of separately weighing each filter paper before and after sampling and the difficulties involved in accurately determining the very small changes in the weight of the order of 100 μg the gravimetric method is not easily adaptable to automation which can readily be achieved in optical measurements (transmittance or reflectance) of particulates collected on filter tapes. However, it has been repeatedly shown that optical measurements do not universally correlate with mass concentration. Therefore, despite the availability of some excellent soiling index instruments there remains a real need for a technique which gives values that (1) directly correlate with mass, (2) are unaffected by the colour of the deposited material on the filter papers, (3) allows data from various cities and in different locations to be pooled for analysis, (4) allows concentration measurements of atmospheric particulate averaged over a desired period of time in the universally accepted units, *viz.*, micrograms per cubic metre of air (μg/m^3).

Keeping the above points in view a preliminary comparative investigation made at this laboratory showed that the beta-absorption method is a better choice as compared to the optical or the gravimetric methods. A brief discussion of the above investigations is presented in the text. The application of the beta absorption technique for measuring the mass concentration of atmospheric particulates was earlier reported by Nader & Allen (1960). Their work demonstrated the feasibility of this technique for use in automated filter samples. Recently many workers have reported the use of beta attenuation mass monitors using variety of experimental configurations (Lilienfeld 1970 and Husar 1974). In this paper we are presenting a very much simplified system which is suitable for routine surveys on a wide scale. Attention has also been drawn to numerous difficulties that may be encountered by those who adopt this technique and suitable remedies have suggested.

Summary of results obtained by adopting the above technique over a period of about 2-3 years is also presented.

2. Experimental

Since it was desired to make a comparative study of the reliability of the beta absorption

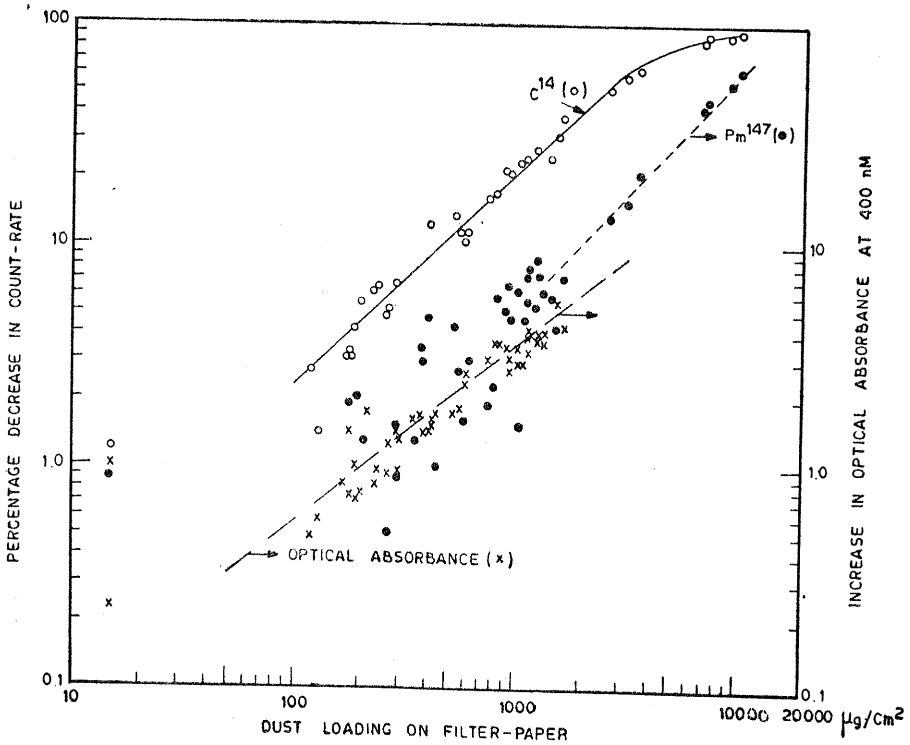

Fig. 1. Percentage loss of count-rates of Pm ^{147} and C^{14} betas and increase of optical density of filter papers loaded with different amounts of atmospheric dust

technique as compared to the optical method the following procedure was adopted.

Air is sucked on a high volume air sampler through a millipore 0.8 μ No. AA filter paper-which was predesiccated and weighed. The suction head (the filter paper with its holder) was always exposed to the open atmosphere and temporarily shielded from rains during monsoon, with the suction line running indoors to the pump. For the same filter paper—in a blank state—(1) the decrease due to absorption of a given beta source is measured and (2) the optical attenuation at 400 nm wave-length is also determined.

After a given period of time, having noted the volume of air sampled the filter paper is redesiccated and reweighed. The difference between the two weighing together with the known area of dust deposition on the filter paper yielded the mass of suspended particulates deposited on the filter paper in microgram per unit area. After weighing, the optical density of the loaded filter paper is again determined in order to estimate the increase in optical absorbance due to the mass deposited on the filter paper. Finally the degree of beta-absorption due to the dust loaded filter paper is also determined and the percentage decrease in the count rate is estimated. For making the beta-absorption measurements we made use of two different sources (1) C^{14} ($T_{\frac{1}{2}}$: 5700 yr, $E=$ 155 KeV) and (2) Pm^{147} ($T_{\frac{1}{2}}$: 2.6 yr, $E=$ 229KeV) for both of which the percentage descrease in count rate is estimated. The results of these experiments are presented in Fig. 1.

From Fig. 1 it can easily be seen that irrespective of whatever error one might have made in weighing—since that remains a common factor—the departure from linearity for dust loads below about 2000 μg/cm² is least pronounced for C^{14} source, indicating thereby that for dust loads less than about 1000μg/cm² the use of softer betas of C^{14} is preferable to the optical density method as well. It can also be concluded that the harder betas of Pm^{147} are very unreliable when one is dealing with dust loads less than about 2000 μg/cm². However, in places where heavy dust loads are likely to be encountered, such as in factories or stack effuents, the stronger betas of Pm^{147} are preferable even as compared to the C^{14} betas.

In view of the above preliminary investigations our subsequent work is based on the C^{14} beta absorption technique for the estimation of the particulate density in the Trombay atmosphere.

3. Instrumentation

In order that the geometry and placement of the relative positions of the source, the filter paper and the detector (GM counter No. MX 123) are mounted

TABLE 1

Eight hourly average concentrations ($\mu g/m^3$) of suspended particulates in the atmosphere at the Modular laboratory site, BARC, Bombay during 1977

Month/hours of sampling	Monthly mean concentrations						Monthly mean of the daily averages	Std. dev.	Observed max. concentrations during the month		
	0800 to 1600 hr	Std. dev.	1600 to 0000 hr	Std. dev.	0000 to 0800 hr	Std. dev.			0800 to 1600 hr	1600 to 0000 hr	0000 to 0800 hr
February	153	73	—	—	94	41	130	70	288	—	157
March	122	55	—	—	82	41	105	53	252	—	190
April	166	71	122	29	106	53	113	55	231	169	216
May	84	61	148	68	103	69	112	68	213	263	257
June	72	83	128	95	59	50	87	83	323	321	162
July	77	83	137	133	131	92	117	105	206	377	271
Six-monthly means	107	75	132	91	91	60	107	75	323	377	271

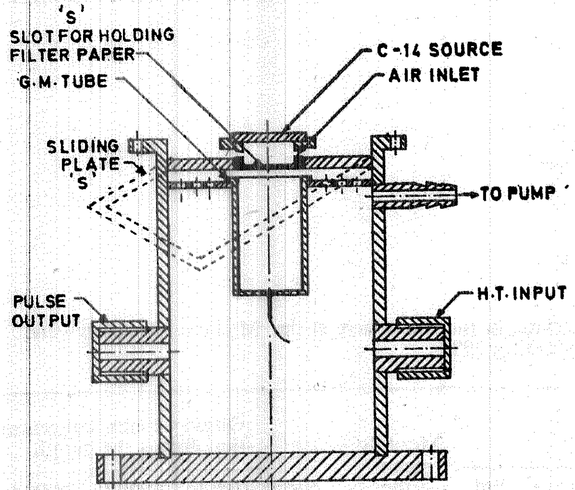

Fig. 2. Atmospheric particulate sampling and counting system

as indicated in Fig. 2. As can be seen from Fig. 2 the source and detector remain fixed for all the time and only the filter paper either blank or loaded is interposed when required by means of a sliding slot "S" as shon in the Fig. 2. The usual precision electronic circuitary with an automatic timer manufactured by ECIL India is used in these studies.

Since a high degree of accuracy is required we used high levels of radioactivity so as to yield count rates of the order of 1000 cps in order to keep statistical errors at a minimum. Since the resolving time of our syseem is found to be 300μ sec, there is a loss of count rate particularly when high count rates are used by us. As such, in each case we estimate the real counts by using the observed counts and resolving time with the help of the well known relation :

$$N_{(\text{real})} = \frac{N_{(\text{observed})}}{1 - N_{(\text{observed})} \times \text{resolving time}}$$

The resolving time of the system is experimentally estimated by counting two beta sources of strength differing by a factor of about two, without and with the same absorber in both the cases. If n_1 and n_2 are the count rates of the two sources without any absorber and $n_1{}^1$ and $n_2{}^1$ respectively are the counts with the same absorber then the resolving time is given by

$$\frac{n_1{}^1\, n_2 - n_1\, n_2{}^1}{n_1\, n_1{}^1(n_2 - n_2{}^1) - n_2\, n_2{}^1(n_1 - n_1{}^1)}$$

In order to successfully use this technique it is essential that the filtering medium or the filter paper that is used to collect dust should be of a uniform texture and be sufficiently thin so that there is not a high degree of soft beta absorption by the blank filter paper itself. If that be so, *i.e.*, if the filter paper is very thick then the method will become insensitive, particularly for soft betas. In view of the above we find that the millipore No. AA (0.8 μ) is most suitable.

Another factor one has to be careful about is the variable humidity of the air between the source and the detector, since a variation in humidity will cause a variation in the density of air which will differently effect the absorption of the very soft betas of C^{14}. In order to overcome

TABLE 2

Eight hourly average concentrations ($\mu g/m^3$) of suspended particulates in the atmosphere at the Modular laboratory site, BARC, Bombay during 1978

Month/hour of sampling	Monthly mean concentrations						Monthly mean of the daily averages	Std. dev.	Observed max. concentration during the month		
	0800 to 1600 hr	Std. dev.	1600 to 0000 hr	Std. dev	0000 to 0800 hr	Std. dev.			0800 to 1600 hr	1600 to 0000 hr	0000 to 0800 hr
February	112	104	220	91	132	100	154	107	315	343	306
March	120	129	320	150	98	97	173	157	310	585	253
June	90	62	107	57	66	59	90	60	260	207	195
July	10	27	71	58	31	38	37	49	76	149	113
August	26	33	65	49	37	46	43	45	83	129	136
October	30	34	120	71	21	31	59	67	76	233	70
Six-monthly means	68	81	139	108	62	73	91	95	315	585	306

TABLE 3

Eight hourly average concentration ($\mu g/m^3$) of suspended particulates in the atmosphere at the Modular laboratory site, BARC, Bombay during 1979

Month/hours of sampling	Monthly mean concentrations						Monthly mean of the daily averages	Std. dev.	Observed max. concentration during the month		
	0800 to 1600 hr	Std. dev.	1600 to 0000 hr	Std. dev.	0000 to 0800 hr	Std. dev.			0800 to 1600 hr	1600 to 0000 hr	0000 to 0800 hr
January	—	—	187	142	101	120	142	139	—	610	382
February	—	—	106	91	43	58	74	81	—	261	149
March	—	—	76	70	54	99	65	84	—	175	277
April	—	—	89	102	72	55	80	81	—	269	159
June	—	—	73	73	60	62	66	67	—	235	177
July	39	71	69	61	47	57	54	61	201	224	187
Six-monthly means	39	71	102	103	64	78	82	93	201	610	382

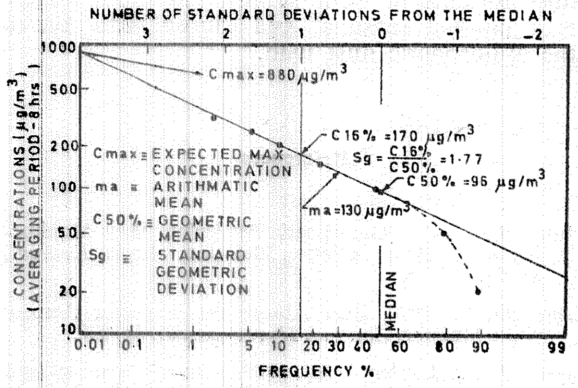

Fig. 3. Cumulative frequency distribution of the atmospheric particulate concentrations (averaging period : 8 hr) for the period February to July 1977

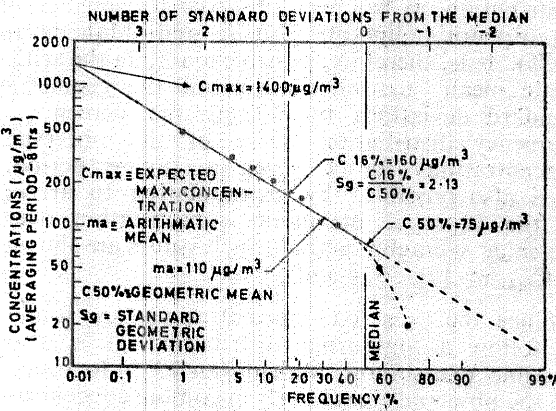

Fig. 4. Cumulative frequency distribution of the atmospheric particulate concentrations (averaging period : 8 hr) for the period February to October 1978

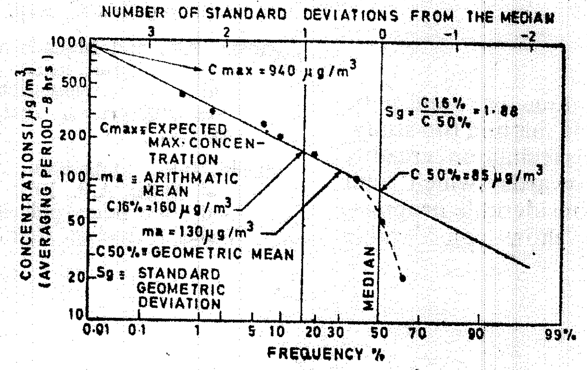

Fig. 5. Cumulative frequency distribution of the atmospheric particulate concentrations (averaging period : 8 hr) for the period January to July 1979

this difficulty we continuously pumped in desiccated air through the space between the detector and the source (as indicated in Fig. 2), so as to maintain an uniform density of air in the space between the source and the detector. Since our system is working in an air conditioned room there was no necessity of providing against the density variations due to change in room temperatures. Where large changes of room temperature do take place, some arrangement might be necessary to keep the source-detector assembly at a uniform temperature.

It may also be mentioned that apart from providing a better statistics, the use of a source of high activity yielding 1000 to 1500 counts per second also eliminates or reduces to a very negligible degree the chances of interference by the natural activity that might get collected on the filter paper along with the inactive particulates.

4. Results

The results obtained by the above technique are presented in Tables 1, 2 and 3 as eight hourly monthly mean concentrations which reveal both seasonal and diurnal variations. It may be observed that the concentrations are higher during the dry pre-monsoon months as compared to the rainy seasons. From Tables 1, 2 and 3 it is also seen that the concentrations are higher during the evening hours—when the wind speeds in Bombay are relatively higher — than during the rest of the day (Zutshi 1970). Here it may be observed that higher concentrations are not always associated with higher wind speeds. However, when the wind directions are favourable (from source to sampling site) relatively high wind speeds lead to higher concentrations (Zutshi *et al.* 1978). In the same tables we have also presented the monthly means of the 24-hourly averages as well as observed maximum concentrations during the eigth hourly periods.

The percentage frequency distribution of the observed eight hourly concentrations during the period February to July 1977, February to July 1978 and January to July 1979 are plotted in Figs. 3, 4 and 5 respectively. It may be observed from these figures that the dust load concentrations – particularly on the higher side — follow a log-normal distribution, as has been observed for some other atmospheric pollutants (Zutshi and Mahadevan 1975). It is, therefore, possible to obtain the arithmetic mean, geometric mean and the geometric standard deviations by plotting the percentage frequency distribution curve of the observed concentrations for a given averaging period. It is also possible, by extrapolation to arrive at the expected maximum concentration over the same averaging period. Such values are shown as C_{max} in Figs. 3, 4 and 5.

Since the dust load concentrations are found to follow a log-normal distribution, it is also possible (Zutshi and Mahadevan 1975) to transfer the observed eight hourly maximum concentrations to the expected maximum concentrations over any specific averaging period.

5. Conclusions

The beta absorption technique is found to be a very convenient and reliable method for studying atmospheric dust load. This technique is readily adaptable to automation towards which end this laboratory has made considerable progress. The results presented here show considerable dust nuisance in the area surveyed and that there is a marked seasonal and diurnal variation of the atmospheric dust load.

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