[Reprinted from BULLETIN OF THE AMERICAN METEOROLOGICAL SOCIETY, Vol. 42, No. 9, September, 1961, pp. 664–665]
Printed in U. S. A.

Mean Atmospheric Residence Times for Particulate Air Pollutants [1]

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(Manuscript received 9 January 1961)

In considering the balance between addition and removal of any atmospheric constituent, it is helpful to have in mind at least a rough estimate of the mean atmospheric residence time for that particular constituent. For instance, the mean residence time of atmospheric water vapor is easily shown to be about 10 days; that for radioactive particles injected into the troposphere by nuclear explosions is now known to be about twice to three times that length of time; that for carbon dioxide is some half-dozen years; etc. The purpose of this note is to point out that available data can be used to obtain a similar weighted-mean estimate of the average residence time T for pollutant particles released into the atmosphere over urban-industrial areas. T proves to be of the order of only *half a day*.

Data on the so-called "dustfall rate" D have been gathered and published for industrial areas for many years. More recently, high-volume samplers, using filters capable of trapping all particles down to diameters of a few tenths of a micron, have been operated routinely in many American cities to obtain data on the mass concentration C of such airborne particulates.

By the nature of D-measurements, the observed values represent the integral effects of fallout of particulates of a wide variety of sizes descending from all altitudes up to some rough upper height-limit of appreciable contamination. Data on the *vertical* distribution of C are scanty, but we will probably not be seriously in error to assume that C varies roughly as does the distribution of Aitken nuclei and other submicron particulates. Penndorf (1954) has presented a summary of vertical distribution data for such particles, from which one may conclude that the distribution is exponential with an e^{-1} height of about 1 km. This is in fair accord with the nuclei distribution data of Sagalyn and Faucher (1956), and will be used here. Although both references indicate uniformity of particulate concentration above an altitude of the order of two or three kilometers, ignoring this feature will not alter any conclusions drawn here, for we are concerned with the columnar totals and these are insensitive to values above a few kilometers. Integration, for an exponential distribution varying with altitude z as $\exp(-z/h)$, with $h = 10^5$ cm gives, as the columnar total mass of all particulates, $10^5 C_0$, where C_0 is the surface concentration in units of gm cm^{-3}.

If we assume a horizontally uniform distribution of D, C_0, and h over a wide enough area that edge effects vanish, then the weighted-mean residence time T for all particulates satisfies the simple relation

$$T = k\, C_0/D \qquad (1)$$

where k is a unit depending on the units employed. Conventionally D is reported in units of tons/mi^2 per month and C_0 in micrograms per cubic meter. Hence if we wish to express T in hours, the absolute magnitude of k must be very nearly 2.

Some representative D values are summarized by Faith (1959, p. 98). A very extensive tabulation of C_0 values has recently been published by the U. S. Public Health Service (1958). These sources suggest, as values typical of large cities, $D = 30$ tons/mi^2 per month, and $C_0 = 150 \times 10^{-6}$ gm/m^3, whence (1) yields $T \approx 10$ hours. This result may seem fairly large, or very short, depending upon one's point of view. In either event, the very important point to keep in mind in placing an interpretation on T as estimated from (1) is the fact that T is a *weighted-mean residence time,* just as is, say, the 10-day figure for atmospheric water vapor. Just as any given molecule might be evaporated from the sea and reprecipitated in a maritime storm within a time period of only a few per cent of the weighted *mean* of 10 days, so also some industrial and urban pollutants can be emitted and deposited on the ground or

[1] Work supported by the Office of Naval Research.

on some white shirt in only a very small fraction of the above time T. On the other hand, those particulates that are, by chance, turbulently dispersed to altitudes of the order of a kilometer are destined to be removed chiefly by scavenging effects of precipitation processes, whence their individual residence times must approach those recently ascribed to radioactive particulates, *i.e.*, something like a month. To repeat, T is, by definition, an average over *all* of these times simply because D is made up of contributions from fallout particles having a wide variety of histories.

Although it is a reasonable suspicion that T is overestimated by use of the assumption that C falls off with height no more rapidly than do concentrations of submicron-size particles, it does not seem likely that (1) fails to yield the proper order of magnitude of T. However, the validity of T, as so estimated, is increased by restricting its application only to large urban-industrial complexes that best fit the tacit assumption that dustfall and pollution are quasi-uniform over distances of the order of the wind-drift displacement of particulates in time T. An area such as greater New York City may fulfill this requirement tolerably well. In highly industrialized sections of that city, published data suggest $D = 220$ tons/mi^2 per month, but we will probably match the assumptions of (1) better if we used instead the value found to be typical of the surrounding urban-commercial sections, $D = 80$ tons/mi^2 per month. The cited air-sampling reference gives $C_0 = 200 \times 10^{-6}$ gm/m^3 as an annual average over several years for four sites in New York City. Hence from (1) we find $T \approx 5$ hours. Using similar published data for the Detroit area yields $T \approx 2$ hours. An intercomparison is of rather dubious value since one cannot be certain that available measurements of D and C_0 are equally representative in the two cities. But it appears that one may safely conclude that T, in large and heavily industrialized metropolitan areas, may drop to as low as a quarter of a day, or even less.

The important implication of such T estimates is this: Compared with almost all other known atmospheric residence times, T is surprisingly short. Inasmuch as casual observation of the behavior of smoke plumes in cities gives convincing evidence that a fairly significant portion of total industrial effluent rises high enough to escape deposition within the confines of the surrounding metropolitan area, the quite small values found for T clearly imply that this escaping component of long lifetime is complemented by another equally significant portion that must have extremely short residence time in order that the weighted average shall be held to only a fraction of a day. This latter short-lifetime component is inevitably the coarser fraction of the particulate effluent (fly-ash, etc.). The chief value of T values as estimated from (1) is that they condense into a single figure, in a simple manner, important information concerning the average time-scale of a complex set of processes governing the atmosphere's gains and losses of particulate pollutants.

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