A Photographic Study of Aerosol Particles in a Thermal Gradient

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ABSTRACT: *A photographic method of studying the motion of aerosol particles in a thermal gradient is presented with samples of the data obtained. The method is based upon dark field illumination and forward light scattering. The results of the particle studies based upon this method were quite satisfactory in that particle sizes and thermal gradients grossly in excess of previously used values were successfully studied.*

INTRODUCTION

In connection with the timely subject of air pollution, it was evident that this science is one of such recent origin that the methods for measuring the pollution and for evaluating its effects are poorly developed or only roughly understood. For this reason an investigation was undertaken to further understand the basic underlying principles governing one of the many air pollution sampling procedures. This particular procedure is one whereby airborne particulate matter is sampled through the action of a thermal gradient. This type of sampler is effective for both solid and liquid particulates; however it has no effect upon gaseous contaminants. The objective of this study was to trace the motion of these aerosol patricles in a thermal gradient, evaluating the parameters which govern their motion.

In general, aerosol particles range in size from 0.01 to 50 microns in diameter; therefore it can be seen that for the most part these particles are not visible to the naked eye. Previous studies along this line were restricted to visual observation of single particles in a static chamber in which a thermal gradient was developed. The size range of the particles and the magnitude of thermal gradient was limited by the ability of the observer to accurately time and control the movement of the particles. As particles in the size range of above three microns in diameter were used, the precipitation velocity was increased to the extent that the observer was not able to reliably discern these motions. Similar problems were encountered with thermal gradients of above 100°C. per centimeter.

The research described herein sought to alleviate this problem by recording the particle motion on a photographic film, thereafter evaluating the velocity of precipitation in the thermal gradient. It was also felt that if this procedure could be successfully developed, the motion of particles in an apparatus quite similar to an actual sampler could be used. In this way the particle motion could be studied under conditions quite similar to those encountered in the field.

EXPERIMENTAL EQUIPMENT

The first experiment that was attempted in this program was tried, optimistically perhaps, on a specially constructed camera using cut film. The camera itself worked quite satisfactorily; however the image observed was of such weak intensity that it did not begin to sensitize the large cut film sufficiently. Abandoning this line of investigation it was quickly determined that the largest negative size that could be practically used was a standard 35 mm. Adoption of this size was quite convenient in that a single-lens reflex camera was available, such that the experimenter could observe the precipitating particles immediately prior to recording their motion on the photographic film. Figure 1 illustrates the first of these successful photographs showing cottonseed oil particles suspended in a free space. This particular picture was taken with a Contaflex single-lens reflex at an exposure of $\frac{1}{2}$ second. It can be observed

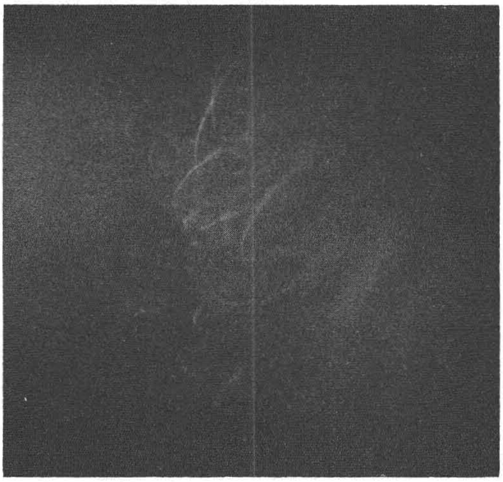

FIG. 1. Aerosols in free space.

how the depth of focus is quite limited and also the degree to which the particle motion can be traced. It might be pointed out that during the course of the investigation those particles which were slightly out of focus were still quite distinct as far as their precipitation paths were concerned. The final arrangement using a similar camera is shown in Figure 2, which schematically illustrates the whole optical arrangement. The light source is an alternating current carbon arc lamp. The illumination produced by the lamp was condensed in a three-lens system consisting of plano convex lenses of approximately eight inch focal-length. After condensing, the illumination was passed through two knife edges to give a thin plane of light rather than a circular beam as produced by the lamp and condensing system. This was necessary in order to set up the dark field illumination within the precipitation chamber. Without this thin beam of light, those particles beyond the field of focus of the observation system would produce excessive background light, therefore obscuring those particles that were in focus. An objective lens of 25 mm. focal-length was used beyond the knife edge. This particular lens allowed the thin beam to be focused at the center of the precipitation chamber. Interspersed between the objective lens and knife edges was a propeller type of interrupter. This interruption was necessary in order to get some manner of time reference on the recorded precipitation path of the particles.

The original intent was to have an interruption of the illumination to the extent that the precipitation path would be, not a solid trace on the film, but rather an interrupted trace. This did not quite work out; however the time indication was successful as will be described in a succeeding paragraph.

The interrupter was fabricated from a synchronous motor properly geared to give the desired number of interruptions per second. The telescope and camera were affixed in such a way that they observed the particles by forward light scattering, using an angle of 37 degrees to the path of the light beam. The telescope consisted of two achromatic lenses of 17 and 25 mm. focal lengths. The camera was mounted in such a way that it received the image from the telescope and focused this upon the photographic film. The particular film used for this investigation was Agfa "Isopan Record." It was developed in a tank for 25 minutes using Kodak D-76 developer.

RESULTS

The results of the photographic procedure were quite satisfactory in view of the problems presented. Due to the angle of observation (37°) and the means of illumination, the photographs gave the impression that the plates forming the thermal gradient were non-parallel. Of course this was not the case and the apparent convergence was due to the distortion inherent in such an observation system.

Figures 3 and 4 show two particularly interesting particle traces of castor oil particles. These particles were 5.5 microns in diameter and precipitating in a thermal gradient of 337°C. per centimeter. These two figures are of particular interest because they illustrate a photophoretic force exerted upon the particles. As previously mentioned a light interrupter was included in the illumination system with the intent of interrupting the illumination to the extent that a time reference could be impressed upon the photographic record of the particle precipitation path. Rather than a definite break in the recorded path it can be seen in Figure 4 that the particle merely assumed a rhythmic type of oscillation caused by the alternate applica-

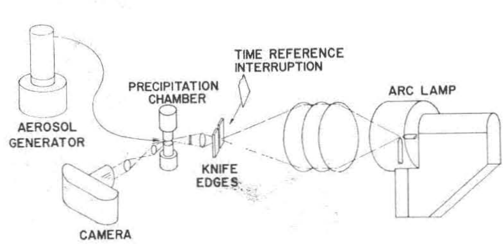

FIG. 2. Optical arrangement for aerosol photography.

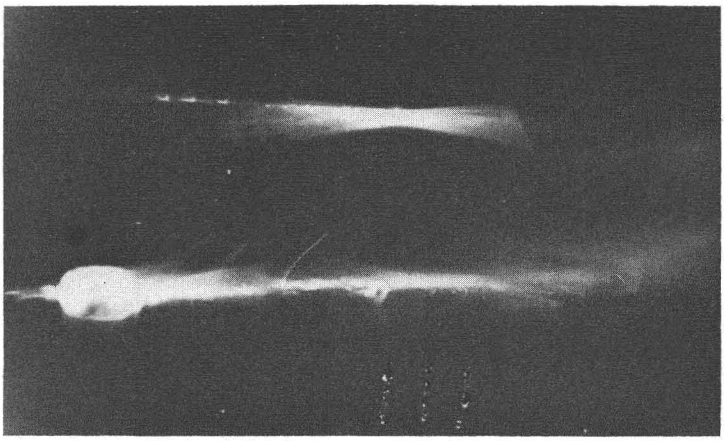

FIG. 3. Precipitating castor oil particle without interruption of illumination.

tion and removal of the photophoretic force due to the high intensity light beam. Figure 3 is a photograph taken immediately prior to Figure 4, the difference being that the light interrupting feature was not operative. If Figure 3 is closely examined a slight rhythmic trace can be identified due to the 60 cycle variation in the current to the carbon arc lamp. It is presumed that a definite break in the particle path could be accomplished if the illumination interruption were of sufficient duration.

The particle velocities were determined by geometrically measuring the particle distance of travel between chosen points on the photographic trace. For example, in Figure 4 the travel was determined between six peaks on the trace, which in time represented an interval of 0.416 seconds.

Figure 5 is a typical example of the type of data obtained using potassium chloride crystals. This crystalline dust was obtained by grinding the larger crystalline material in a mortar and pestle, thereafter working it through a 400 mesh sieve. The potassium chloride crystals had a mean size of 15 microns, and the thermal gradient in this particular case was 836°C. per centimeter. As might be expected, it was found that the crystalline particles did not lend themselves to this type of study as well as the spherical castor oil particles. This not doubt is due to the poorer light scattering properties of the crystalline material.

Additional tests were run on magnesium sulphate particles which were generated by spraying a mixture of magnesium sulphate in water, thereafter evaporating the water, leav-

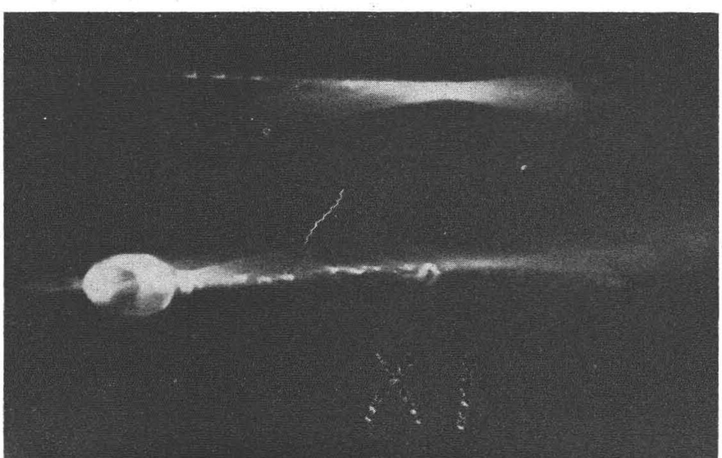

FIG. 4. Precipitating castor oil particle with interruption of illumination.

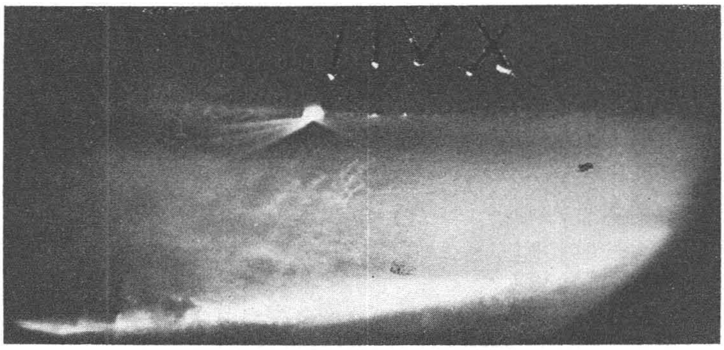

FIG. 5. Precipitating potassium chloride particles.

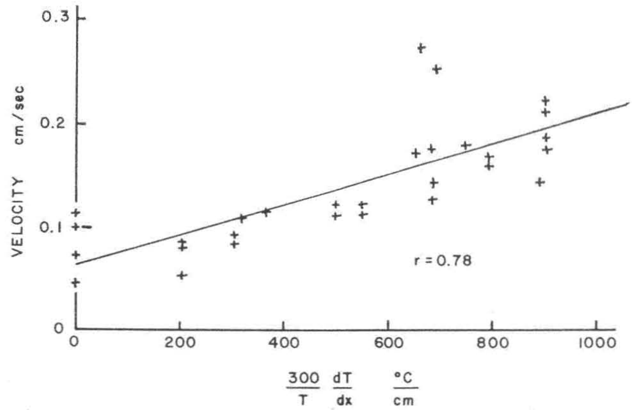

FIG. 6. Precipitation velocity of 5.2 micron castor oil particles.

ing as it turned out, a spherical particle of the magnesium sulphate. Due to a trace of water remaining in these particles they were not transparent and had a definite tendency to be translucent. This translucency cut down on the transmitted light appreciably, and it was necessary to depend almost entirely upon reflected light from the surface of the spherical particles.

The data obtained from the whole series of photographs, some 560 exposures, resulted in most interesting information regarding the behavior of the various particles in a thermal gradient (3). Figure 6 is an example of the velocity data obtained. It shows a typical proportionality between precipitation velocity and thermal gradient. The line shown is one of best fit in the least squares sense, and *r* is the correlation coefficient between the line and set of points. Since this method of study has been proven to be practical it is anticipated that further work will be conducted along these lines.

One encouraging development in this general area is the current production of a photomultiplier capable of raising the intensity of a weak image by a factor of some 1,000. In cases such as the magnesium sulphate particles discussed above, such an image intensifier would be a great advantage in that almost any image could be intensified and therefore photographically recorded. Needless today this ability would greatly enhance the facilities available to an investigation dealing with aerosol particles of the size in question.

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