EXPERIMENTAL STATION
SUFFIELD ALBERTA

SUFFIELD REPORT NO. 172

THE EFFECT OF SHOCK WAVES FROM AN EXPLOSION ON THE CHARACTERISTICS OF AN AEROSOL

By G.O. Langstroth, F.W. Dalby, and T. Gillespie

SUMMARY

Studied have been made of the changes produced in an established aerosol by an explosion set off at the centre of the system. Two series of experiments were performed. In the first a hydrogen-oxygen mixture was exploded at the centre of a 0.6 m cube chamber containing ammonium chloride smoke; in the second, a 4 lb type F bomb was exploded at the centre of a 6.1 m cube chamber containing red dye smoke. Measurements of the particulate number, the particle size distribution, and the mass concentration of the investigated smokes were made in the periods preceding and following the explosion. At the time of the explosion the smokes had a particulate number of from 1 x 10^5 to 4 x 10^5 cc^{-1}, a mass concentration of from 200 to 700 mg/m^3, and a median particle diameter of about 2 microns. No evidence that the explosion caused increased aggregation of particles was found. On the contrary there was evidence of some tendency to shatter the larger aggregates existing in the cloud.

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The problem arose originally in connection with the low efficiency of munitions in producing a cloud of air-borne solid material. Loss of material results from rapid sedimentation of large aggregates in the cloud, and it is important to ascertain whether these aggregates occur because they are thrown out as such in the explosion, or because of rapid coagulation of smaller particles during the formation of the initial puff.

The initial puff of a type F bomb is formed in about 0.05 sec and has a volume of about 160 m^3. It can be shown by a short calculation that an effective coagulation constant about 10^6 times greater than that for vigorously fanned smoke in a chamber would be required to account for doubling of the average particle size during formation of the initial puff from such a bomb charged with 120 gms of 3 μ particles. While the factor 10^6 appears large, conditions within the expanding system are chaotic; it is being traversed by shock waves, and mechanisms not yet appreciated may be in operation. It was therefore decided to study the changes produced in an established aerosol by an explosion set off at the centre of the system. The experiments were not designed to simulate conditions at the burst of a munition; the aerosol system was not expanding and the particle number concentration was possibly smaller than that existing in the early stages of initial puff formation.

Two series of experiments were performed. In the first, a dense ammonium chloride smoke was set up in a small chamber and a hydrogen-oxygen mixture was exploded at the centre. The particle number, particle size, and mass concentration were measured before and after the explosion, and compared. A similar comparison was made for the second series of experiments in which a dense red dye smoke was set up in a large chamber and an uncharged 4 lb type F bomb was exploded at the centre.

Apparatus and Procedure

Experiments with ammonium chloride smoke were performed in a 0.6 m cube chamber enamelled on the inside and carefully cleaned before each test to avoid dust. A 500 cc Florence flask containing a 2:1 hydrogen-oxygen mixture at about 1.2 at. pressure was suspended at the centre of the chamber. This explosive was chosen because of the freedom of its products from serious amounts of matter in particulate form. It was fired by an electric spark when desired.

Ammonium chloride smoke was produced in an external generator. Hot air passing over heated ammonium chloride carried the decomposition products into the chamber where they were diluted and cooled by a small fan and recombined to form smoke. About 0.2 gms of ammonium chloride were dispersed in 10 min yielding a smoke about as dense as could be obtained with this type of apparatus. The fan in the chamber was run for 3 min after the generator was shut off.

Thermal and electrical precipitator samples of the smoke were taken periodically for an interval of from 35 to 105 min, and the hydrogen-oxygen mixture was then exploded. The violence of the explosion was sufficient to drive glass splinters through the 1/4 inch plywood walls of the chamber. After the explosion, thermal and electrical precipitator samples were taken for a further period. The volume of air withdrawn in sampling was negligibly small compared to that of the chamber.

Particle number measurements were made on the thermal precipitator samples in the usual way (1) by counting under dark field illumination the number of particles in 10 traverses of the deposit on each slide and application of factors descriptive of the ratio of scanned to total deposit area and the volume of air drawn through the precipitator. Particle size distribution was determined for thermal precipitator samples with a Patterson-Cawood graticule and substage illumination at a magnification of 1140 x. Mass concentration was measured from the electrical conductivity of the solutions made up from electrical precipitator (1) samples.

Experiments with red smoke were performed in a 6.1 m cube chamber whose concrete walls had been freshly coated with mastic. A 4 lb type F bomb loaded with 105 gms of Pentolite but without other charging was suspended at the centre of the chamber and fired electrically when desired. The smoke was produced by igniting about 500 gms of pellets composed of lactose, potassium chlorate, Red A-100 dye (1-methylamine anthraquinone), and K-D-Cite* in proportions of 18:19:38:8 by weight. The air in the chamber was fanned from ignition of the pellets until 5 min after production of smoke was complete. The sampling program for an experiment was similar to that used with ammonium chloride smoke. The thermal and electrical precipitators were mounted on 5 or 6 ft rods which were inserted through small ports in the chamber walls to take samples.

The red smoke was used since explosion of a bomb in the absence of the aerosol gave rise to numerous airborne particles of dust and smoke (table I) which could lead to erroneous results if included in measurements of the aerosol under investigation. Subsidiary experiments in which red smoke samples were deposited on slides contaminated with other particles showed that the red particles could be distinguished from the others with fair accuracy (table II). Only red particles were counted and sized on slides obtained in the main experiments; otherwise the assessment techniques were similar to those used with ammonium chloride smoke.

Mass concentration measurements of the red smoke samples were made by dissolving the electrical precipitator deposits in known volumes of benzene and determining the transmission values in the 5000 A region with a Coleman Model 11 Universal spectrophotometer. Concentrations cor-

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* A commercial diatomaceous earth

responding to measured transmissions were read from a curve prepared by examination of known solutions made up from a weighed amount of electrically precipitated smoke. No interference from particulate matter arising from the explosion was encountered in this procedure; the transmission of benzene solutions of electrical precipitator deposits obtained in the experiment of table I did not differ detectably from that of benzene alone.

2. Results

The data obtained with ammonium chloride smoke in the small chamber are given in figures 1 to 3, and those for red dye smoke in the large chamber in figures 4 to 6. The serial number of the experiment is given on each graph. In figures 1, 2, 4, and 5, the time of the explosion is indicated by a vertical broken line. The ordinate in the size distribution plots of figures 3 and 6 represents the percentage of particles having an apparent diameter less than the corresponding abscissa value. The distributions are based on examination of rather small numbers of particles, i.e. 200 to 400 particles each for the ammonium chloride distributions and 600 to 700 particles each for the red dye smoke distributions. The data are considered adequate for present purposes.

Characteristics of the solid air-borne material produced in the large chamber by the explosion of a 4 lb type F bomb, are given in table I. Table II contains the results of tests of the ability of observers to distinguish between red dye smoke particles and other types as obtained on microscope slides by successive sedimentation from clouds. In these tests the number of particles of the 'initial' type in a selected area was counted, particles of the second type were added, and a second count of the initial type of particles was compared with the first.

3. Discussion

The data show that the explosion did not cause a detectable loss of mass from the aerosol by driving particles against the chamber walls (figures 2 and 5). In one experiment (E-6, ammonium chloride smoke) the mass concentration was increased by about 8% by the explosion; this may have been due to a stirring up of particles deposited in the period before the explosion on the walls and floor of the chamber -- a situation that might also account for the increased particle number observed after the explosion (fig 1). In all other experiments the mass concentrations immediately before and immediately after the explosion were identical. This is a fortunate circumstance, since it renders the interpretation of data easier and more certain.

Plots of the logarithm of the mass concentration against time were linear in accord with the observations of Langstroth and Gillespie (1). The explosion caused a slight change in the slope of the curves as may be seen from figures 2 and 5. The increased slope of ammonium chloride smoke curves is probably due to sorption of water vapor released by the hydrogen-oxygen explosion since such effects are well known from unpublished studies of the behavior of smokes at different relative humidities. This view is supported by the fact that far greater changes in slope were obtained by introducing a little water to the flask containing the hydrogen and oxygen. The decreased slope of the red dye smoke curves after explosion of a type F bomb is probably attributable to shattering of the larger aggregates in the aerosol with a consequent reduction in sedimentation losses. As will appear later, this view receives support from the particle number and particle size data. The effect on the ammonium chloride mass concentration curves could easily be masked by greater effects arising from sorption of water vapor.

It may be seen from figures 3 and 6 that the apparent particle size distribution curves for samples taken shortly before the explosion favor larger particles than do those for samples taken shortly after. The difference was small, the median apparent diameter being decreased from 10 to 17% by the explosion in different experiments. This is consistent with the view that some shattering of the larger aggregates occurs.

The particulate number was not appreciably changed by the explosion in three ammonium chloride experiments (fig 1); it was increased somewhat in a fourth which has been referred to above. It was also increased in the experiments with red dye smoke (fig 4). The results on mass concentration and particle size distribution would lead one to expect some increase. It should be emphasized however, that in general, particle number and size determinations are not sufficiently accurate to permit detection of small differences.

It seems clear that explosions of the magnitude studied do not lead to any appreciable aggregation in an established cloud. On the contrary there is some evidence of a tendency to shatter the larger aggregates but this effect is not very great. Particulate number at the time of the explosion ranged from 1×10^5 to 4×10^5 cc^{-1} in these experiments, and mass concentration from 200 to 700 mg/m^3.

In conclusion, some speculation may be permissible. As pointed out in the introduction, aggregation sufficient to account for appreciable loss from the initial puff of a bomb would require an effective coagulation constant of more than 10^6 times that found for vigorously fanned smoke in a chamber. If during the formation of the puff, a 120 gm charging of 3 μ unity density particles were completely dispersed in a spherical volume of 25 cm radius, the particle number would be about 10^8

cc^{-1}. This is about 250 times the highest particulate number in our experiments. In spite of this disparity, it seems unlikely that shock waves or eddies set up by the explosion could have the enormous effect of increasing the effective coagulation constant by more than 10^6 in initial puff formation, and yet produce a slight effect in the opposite direction in our experiments.

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References

(1) Langstroth, G. O. and Gillespie, T., Can. J. Research, B, 25, 455, 1947.

Table I

The number and size of airborne particles in the large chamber at different times after explosion of a type F bomb in the absence of an aerosol.

Time after Explosion (min)	Particulate No. ($cc^{-1} \times 10^{-5}$)	Approximate Size Distribution *	
7.5	4.0	Dia. (μ)	% Frequency
14.5	2.4	< 0.4	29.
		< 0.7	62.
		< 1.0	86.
		< 1.4	95.
		> 1.4	5.

* Estimated from examination of 120 particles in a sample taken 32 min after the explosion.

Table II

Tests of ability to distinguish between red and ammonium chloride smoke particles on sedimentation slides; the latter resembled closely in appearance the particles assessed in the experiment of table I.

Slide	Kind of Particles		Particles Counted in a Selected Area		
	Initial	Added	Initial Particles		Added Particles
			Before Add.	After Add.	
1*	Red	Ammonium chloride	297	232	341
2*	"	"	366	353	495
3*	"	"	554	410	64
4*	"	"	480	424	43
5	Ammonium chloride	Red	230	241	60
6	"	"	208	182	800

* Counts before and after the addition of ammonium chloride particles were made by different observers.

Legends to Figures

Fig 1: Particle number data; ammonium chloride smoke; hydrogen-oxygen explosion.

Fig 2: Mass concentration data; ammonium chloride smoke; hydrogen-oxygen explosion.

Fig 3: Size distribution of ammonium chloride particles shortly before (solid lines) and after (broken lines) the hydrogen-oxygen explosion. The samples were taken at 90 and 110 min and the explosion occurred at 105 min in experiment E-6; the corresponding times for experiment E-7 were 92, 102, and 100 min.

Fig 4: Particle number data; red dye smoke; 4 lb bomb explosion. Measurements made on two series of samples obtained from different parts of the chamber are represented by separate symbols.

Fig 5: Mass concentration data; red dye smoke; 4 lb bomb explosion.

Fig 6: Size distribution of red smoke particles shortly before (solid lines) and after (broken lines) the 4 lb bomb explosion. The samples were taken at 40 and 49 min and the explosion occurred at 47 min in experiment R-7; the corresponding times for experiment R-10 are 33, 47, and 46 min.

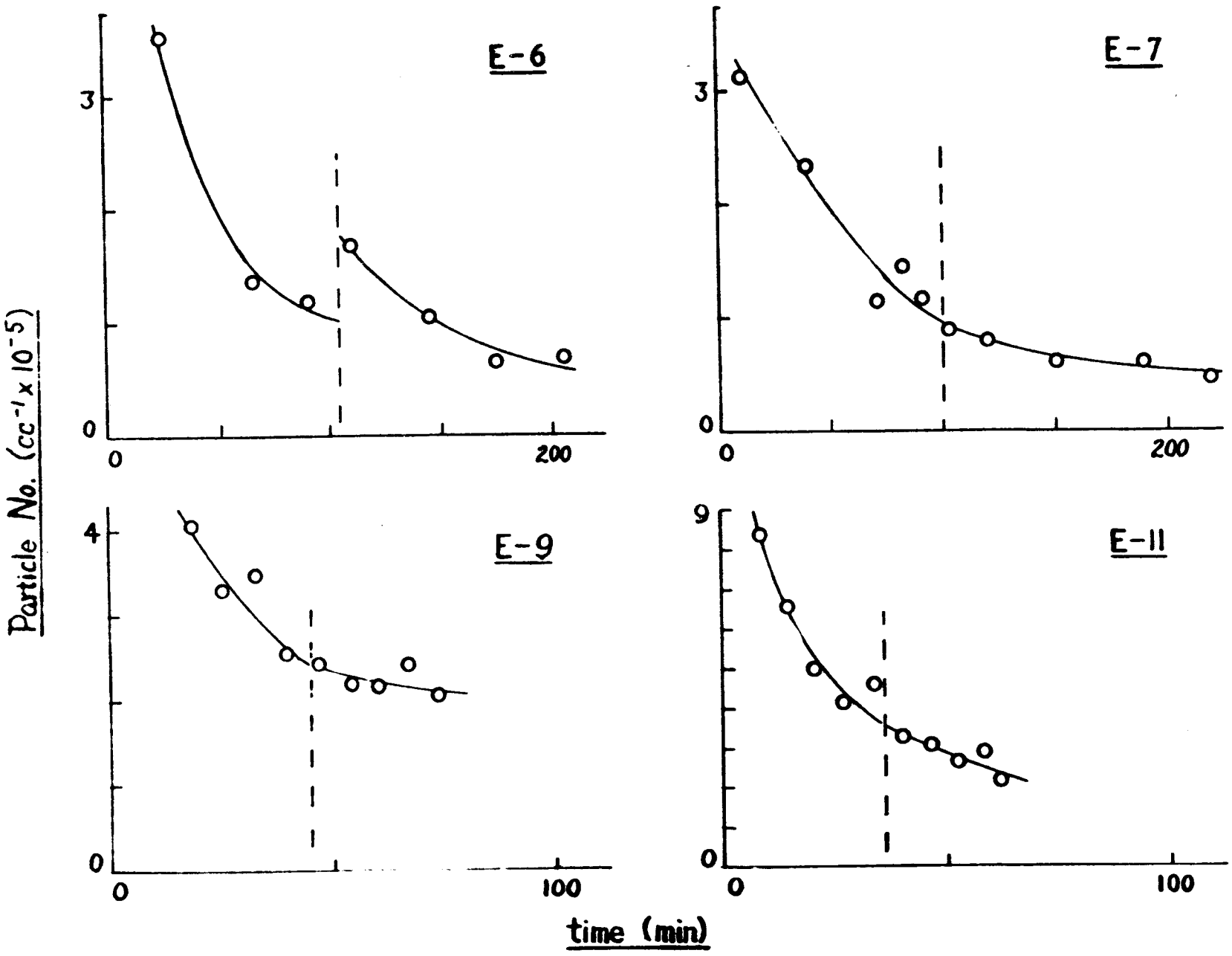

Fig. 1

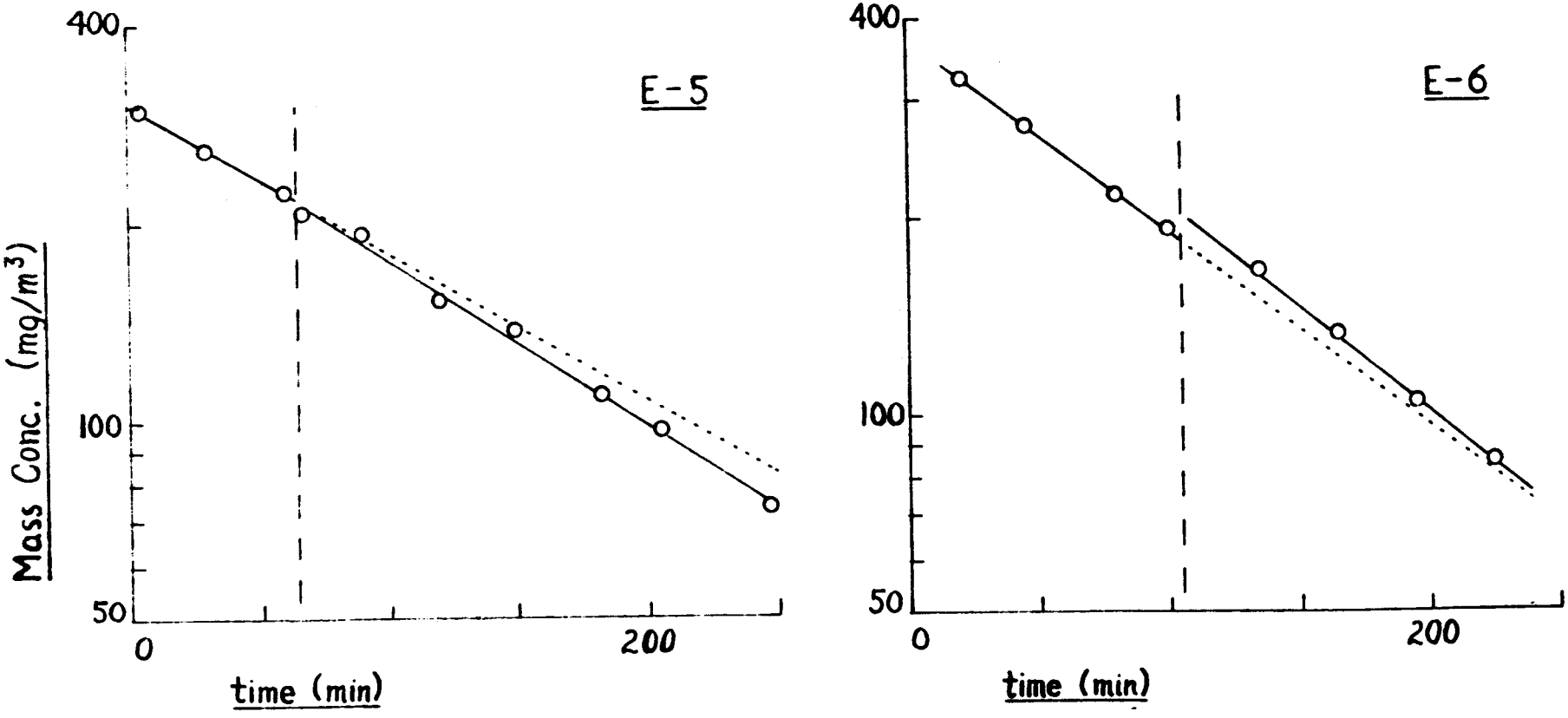
400
100
50
0
200
Mass Conc. (mg/m³)
time (min)
E-5
400
100
50
0
200
time (min)
E-6

Fig. 2

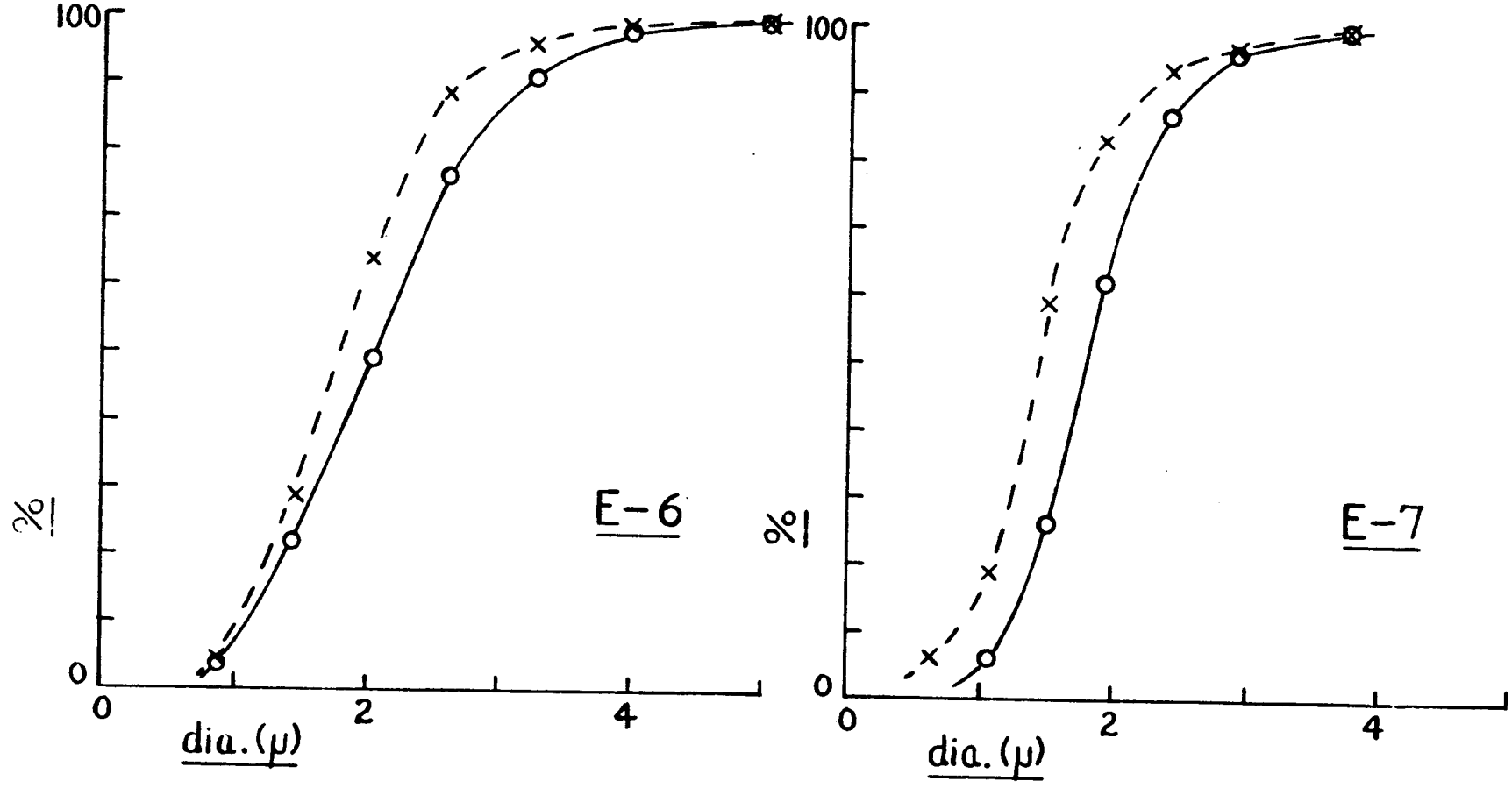

Fig. 3

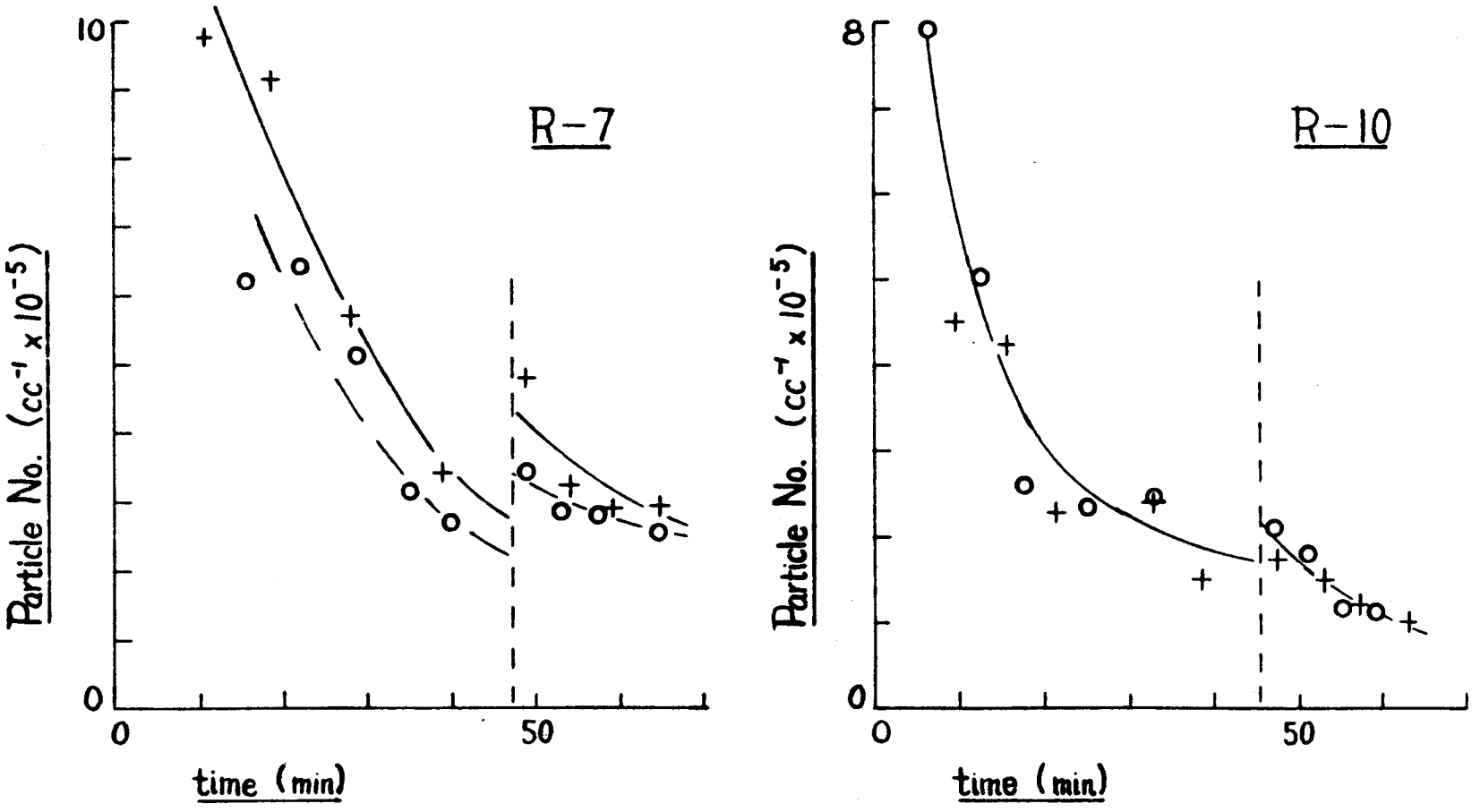

Fig. 4

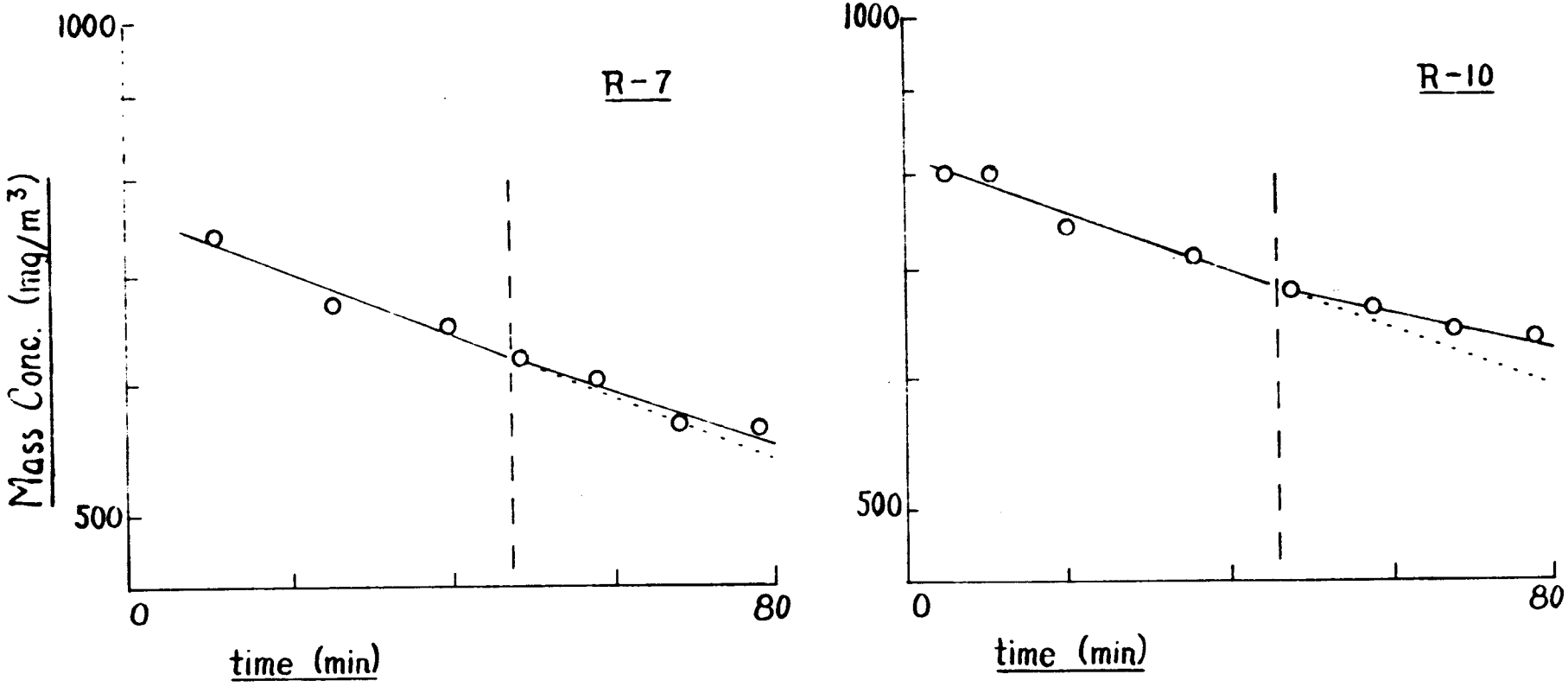
1000
500
0
80
Mass Conc. (mg/m³)
time (min)
R-7
1000
500
0
80
time (min)
R-10

Fig. 5

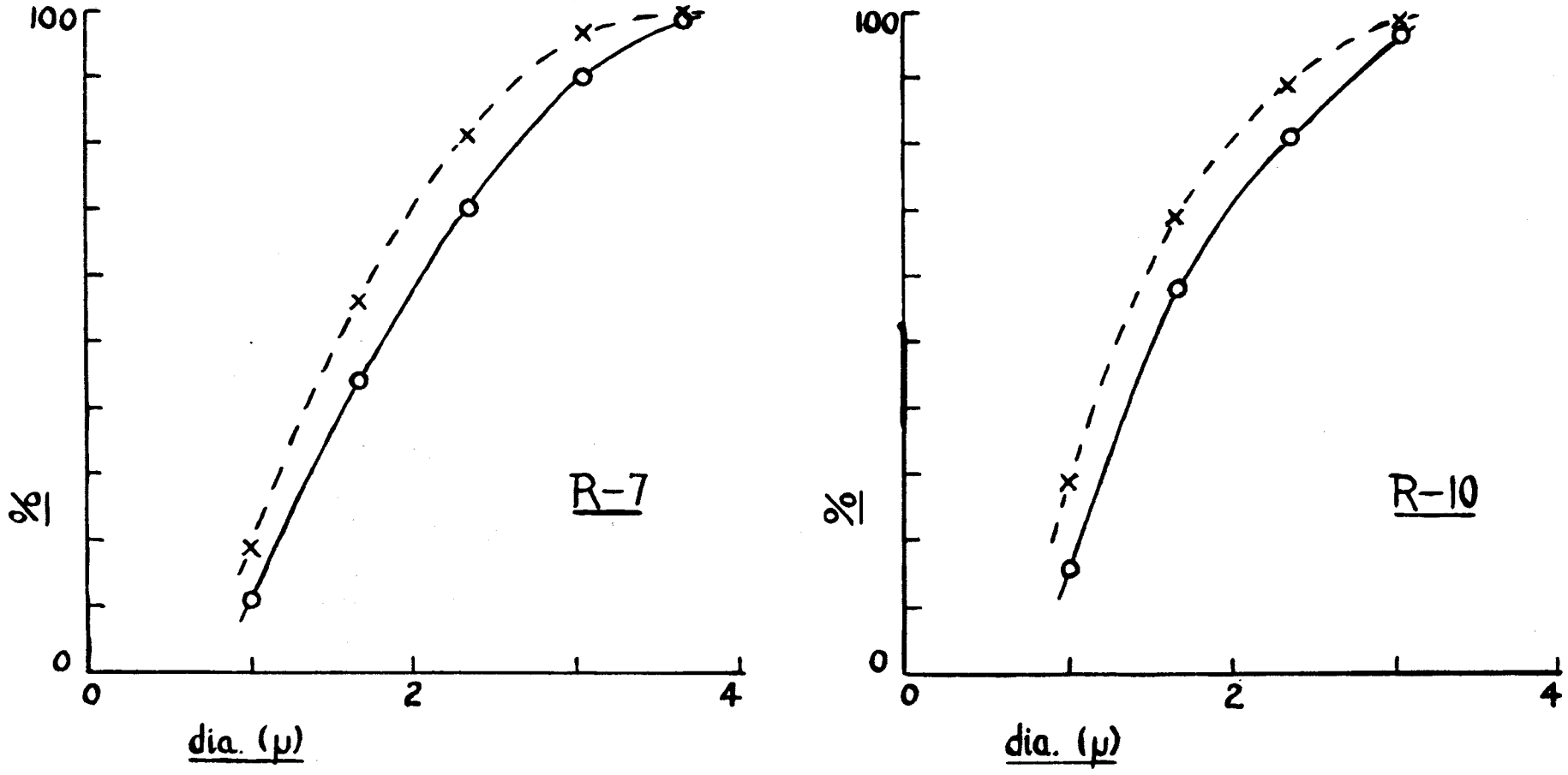

Fig. 6