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A SIMPLE PHOTOGRAPHING METHOD FOR PARTICLE MEASUREMENTS OF SPRAYS

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ABSTRACT

This paper describes a simple and an inexpensive photographing method for determining size distributions, velocities and directions of flight of drops of liquid sprays. A simple optical arrangement has been developed in-which a magnification order ranging from 1.0 to 8.0 with a small depth of field of the photographed object was reached. With magnification order of eightfolds, photographs were taken of a small known volume of spray, and the images of the drops were counted and measured to give the size distribution. Velocities of the moving drops of the spray were also determined by taking two exposures on the same film and measuring the displacement of the drops in the interval time between exposures. The same photographing records were used to measure angles of drop flight directions. With magnification order of onefold on the negative film, the method was also used to observe the appearance of the spray.

Since the method gives an increase in magnification at the imaging stage with small depth of field, it is applicable to take measurements of drops of dense liquid sprays.

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INTRODUCTION

The process of spraying involves the disintegration of liquid into drops, and the projection and dispersion of these drops in a preffered direction. Spray systems are involved in many physical and chemical processes. The study of sprays and their properties requires measurements of the number, sizes, velocities and flight direction of the drops at various locations within the spray. When investigating a system within which there occurs an interaction between spray drops and their aerodynamic environments, it is essential that the characteristics of the system are not disturbed by probes and other measuring devices.

A survey of drop size measurement techniques reported by Jones [1] , Azzopardi [2] and Hirlman [3] indicated that the most suitable method would be a photographic method. Techinques within this method employ beams of light as experimental probes and as such do not interfere physically with the spray. In some cases, however, in order to obtain increased magnification resolution or image quality it is sometimes necessary to insert part of the photographing optical system into the spray.

The photographic method for measuring drop size involves taking a photograph with illumination of sufficiently short duration to keep image blur to an acceptable level and then counting and sizing the images on the processed film. Although the method was first proposed by York and Stubbs [4] 30 years ago, very little use has been made of it until recently. Much of the development work has been carried out by McCreath et al [5] and Mullinger et al [6], not only on its use for determining spatial drop size distributions but also on its use for determining drop velocities. An optical system for drop measurements of normal density liquid sprays has been previously presented by El-Emam et al [7] . The system contains two lenses of f=75mm and f=20mm that gives an enlargement of eightfolds with a relatively large depth of field.

Perhaps a more serious problem associated with the photographic technique for drop measurements of sprays arises at the analysis stage. The reliability of quantimet analysis is also very dependent on the quality of the photographic record. A further problem that accompanies the attempt to extend the technique to high density sprays is that of drop images becoming more closely spaced and, in some cases, even overlapping. This makes quantimet analysis almost impossible. An increase in magnification at the imaging stage could, however, go some way towards alleviating this problem, but only by forfeiting depth of field. Magnification in this manner has the added advantage of reducing the minimum drop size that quantimet analysis can reliably be measured.

For the reason described above, the main purpose of this work is to introduce a new simple photographing method inwhich an increase in magnification order is reached by only minimizing depth of field. The method was applied for drop measurements of a dense solid cone liquid spray. Photographs were taken for the spray mode and evaluating of size distributions, velocities, and angles of flight direction of drops of a spray were obtained.

DESCRIPTION OF THE METHOD

Principle of the Method

In this method, pictures were taken of a small volume in the spray without disturbing the flow patterns with any objects. Two flashes were used to take double exposures of regions in the spray with a small known interval between exposures. The resulting photographs show a pair of images for each drop, one image made at each exposure. The drop images on the film were measured and counted, giving the spatial size distribution of drops in the small volume of the spray. The velocity of each drop can be calculated from measuring the distance between images and knowing the interval between exposures. Then the temporal size distribution can be calculated from the product of the spatial distribution and the average velocity of drops of each size. Also, the flight direction of each drop was known by measuring angle between the straight line connecting the centers of the two images of a drop and the direction of the spray axis.

Optical System

The optical system of the used photographing method is shown in Fig. 1 . A 50mm Nikkor lens, f/1.2, mounted in reverse on an addpter attachment was fitted to a Nikon FE camera with extension bellows. A graticule scale mounted to a traverser was placed in the plane of focus and used to calibrate and determine characteristics of the optical system. Relation between image magnification values and distance C and F with the associated depth of field is shown in Fig. 2 . Two micro-stroboscopes were used to give two flashes of light, one firing after the other. The light beams were brought into the spray from the same direction by using a half-silvered mirror as a beam splitter. The interval between the two flashes was controlled by an electronic delay unit. The circuit diagram of the time-delay

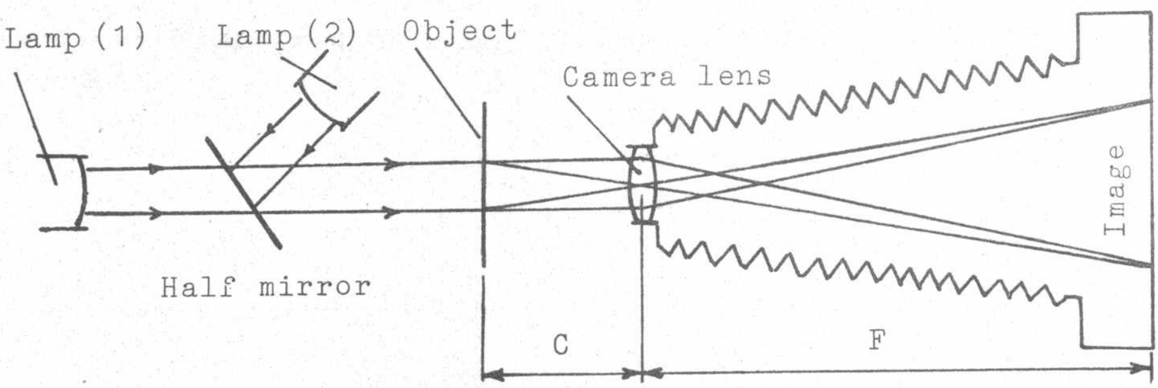


Fig. 2 Optical system

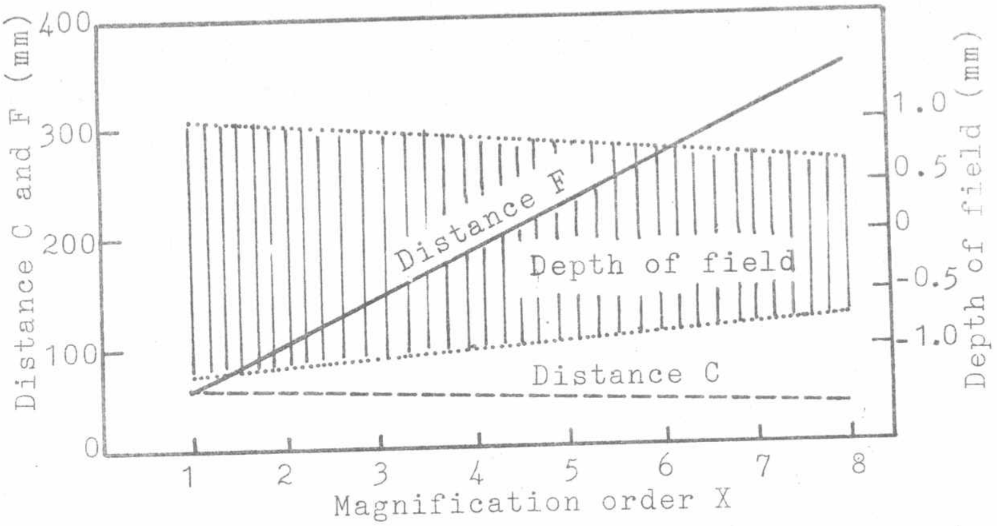


Fig. 2 Characteristics of optical system

unit is shown in Fig. 3 . A capacitor of 0.01μF and a single variable resistor (1 ~ 10kΩ) were used with a silicon monolithic integrated circuit (IC No MC1555) for the timing network. The time interval between the flashes was calculated with the aid of a rotating slotted disc. The interval delay generated can be controlled from 10μs to 100μs. A delay of 20μs or 30μs proved reasonable for the existed work. The opening of the camera shutter was used to trigger each of the first flash and the delay circuit, then the second flash discharged after which the camera shutter closed. Photographs were taken on ASA 400 Kodak films.

Depth of Field for Different Size Drops

The standard images of the different size drops were selected by comparison with a series of photographs of glass balls of 40, 100, 150 and 240μm diameter. The glass balls were placed on a fine wire of 0.02mm after the wire was placed in the focal plane of the optical system by using the traverser. Between photographs, the camera unit was kept fixed and the traverser was

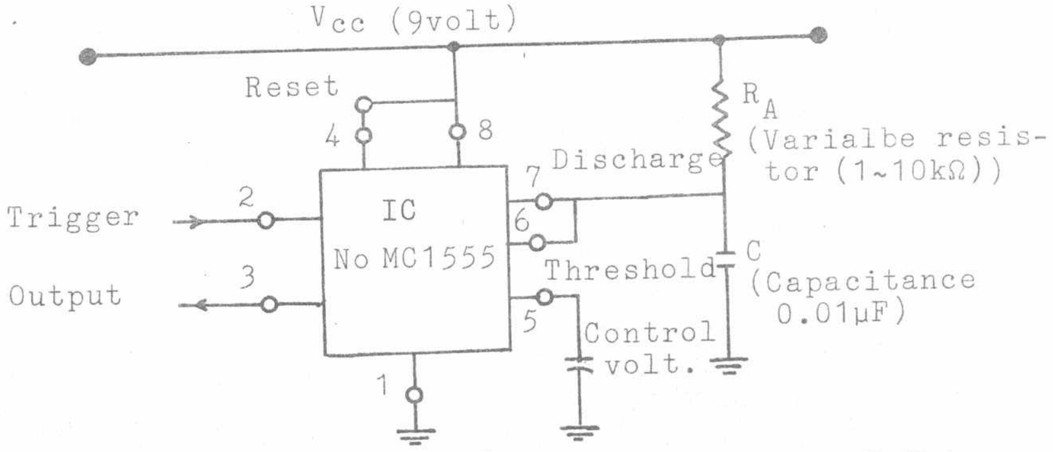
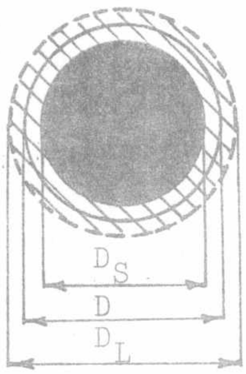


Fig. 3 Time delay circuit (For details see Ref. [8])



D : Drop diameter
D_S: Small size of image
D_L: Large size of image

Fig.4 Model of image of a drop

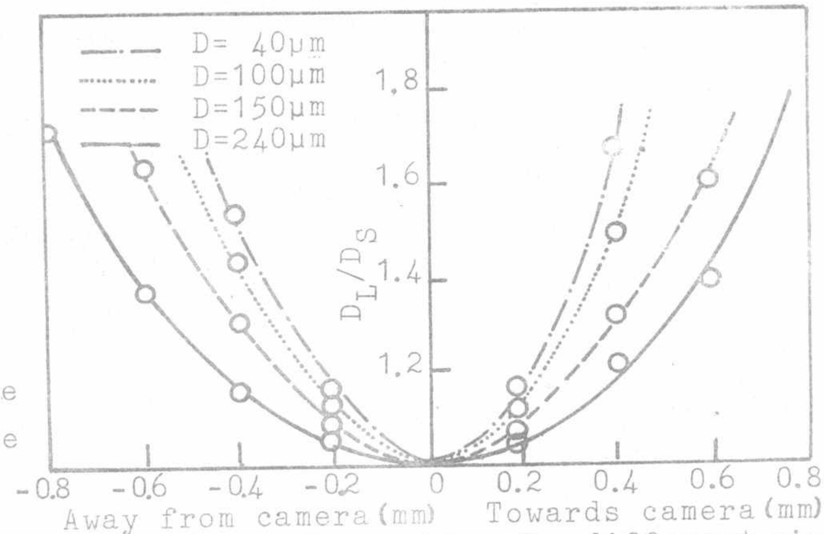


Fig.5 Limits of image blur for different sizes

moved in 0.2mm intervals towards and far from the camera position. Since the movement of the traverser was known, the photographs indicated the degree of image blur corresponding to a certain distance from the focal plane. From these observations, a model of drop image was established, as shown in Fig. 4 , to decide standard images for each size drop. Results of measured limits of blur with distance from the plane of focus for different size drops are shown in Fig. 5 . From this figure a value of D_L/D_S=1.7 was choosed to determine depth of field for each size drop as shown in Fig. 6 . The drop size distribution count obtained from a photograph plate was correlated for any bias resulting from the relationship between drop size and depth of field by means of the following equation;

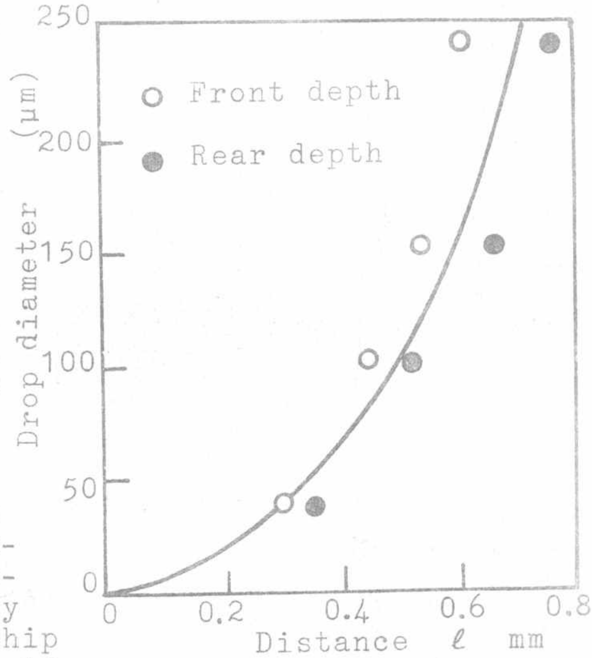


Fig.6 Depth of field for different size drops

$$N_i = N_i' \frac{\ell_{max}}{\ell_i} \quad (1)$$

where N_i is the corrected number of drops of i size range, N_i' is the number of drops counted in the given size range, ℓ_{max} is the maximum distance of bias for the largest drop and ℓ_i is the measured depth of field for the median drop size of the range i.

APPLICATION AND RESULTS

Experimental Apparatus

The photographic method described here has been applied on a water solid cone spray. An apparatus used for the injection of the spray is shown in Fig. 7. The liquid water used for testing was contained in a pressure vessel and injected through the injection atomizer by means of compressed air. The compressed air was supplied by the laboratory main compressor and controlled through pressure control valve to maintain constant liquid injection pressure during a given injection period. The injection atomizer used was a pressure type supplied by Monarch Inc. The nominal specifications of the atomiser are; capacity rating=5.0ℓ/h, spray cone angle=60°, and orific diameter=0.3mm.

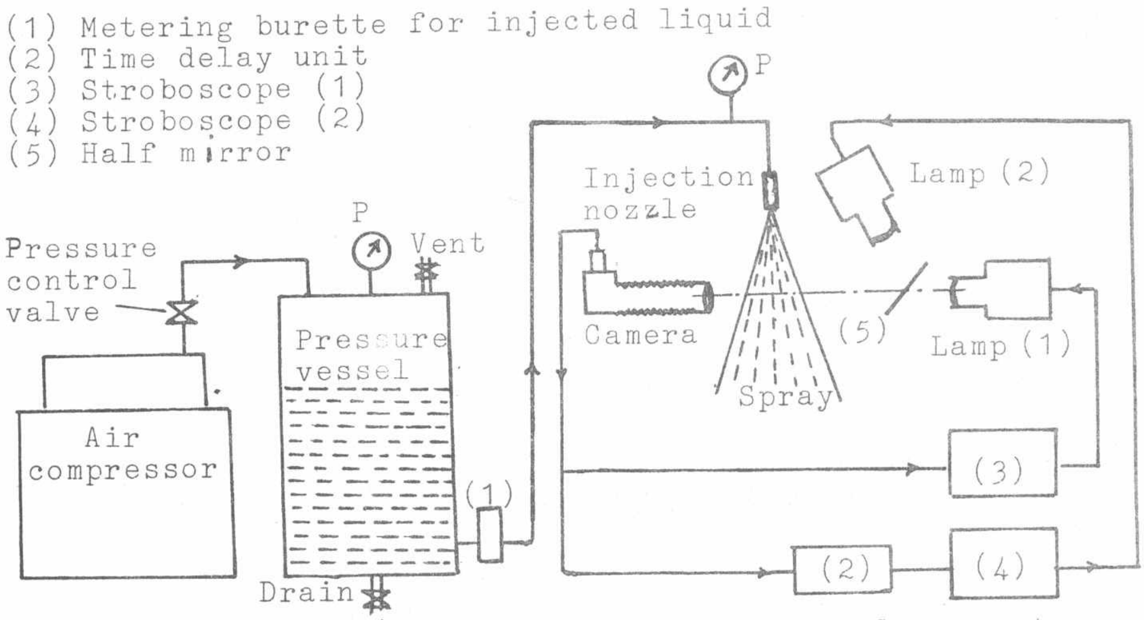


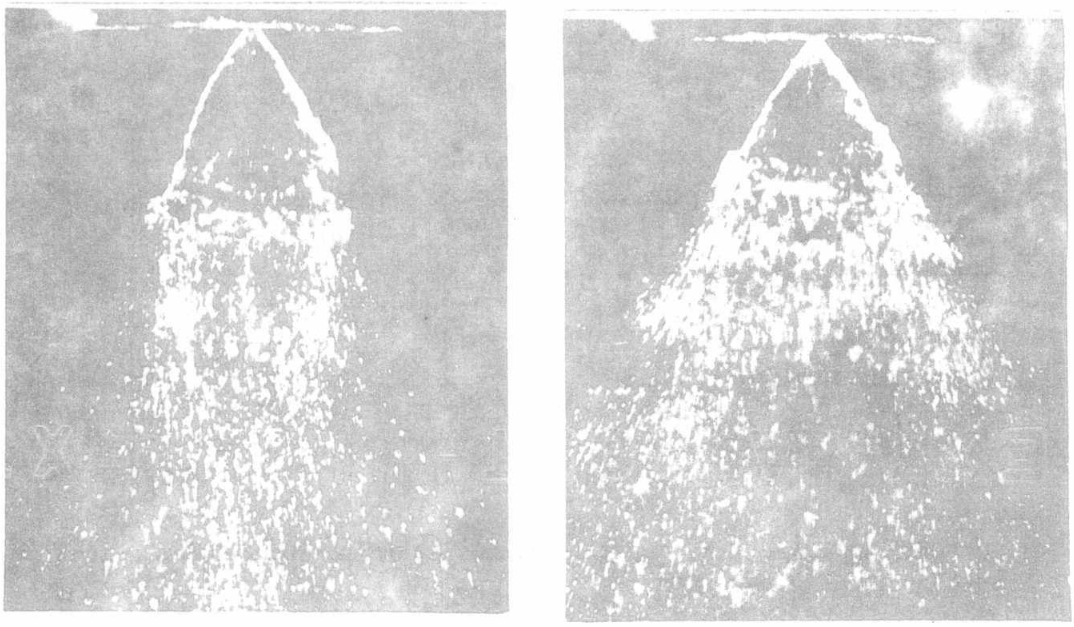
Fig.7 Schematic diagram of experimental apparatus

Spray Photographs

The mode of the injected spray was observed through the optical apparatus and by photographing the appearance of the spray. Examples of spray photographs are shown in Fig. 8. From this figure, it is clear that the photographing method described here can be used to obtain good records for each of spray appearance, breakup length and disintegration mechanism as well as spray cone angle and atomisation mode of liquid sprays.

Drop Measurements

At a plane of an axial distance x=50mm from the atomiser plane, measurements of drop flow of a spray at an injection pressure= 0.8MPa were carried out. An example of double image photographs of drops of the spray is shown in Fig. 9. The results of drop



(a) P=0.5MPa (b) P=0.8MPa

Fig.8 Spray photographs

Fig.9 Twin image photograph of drops of a spray

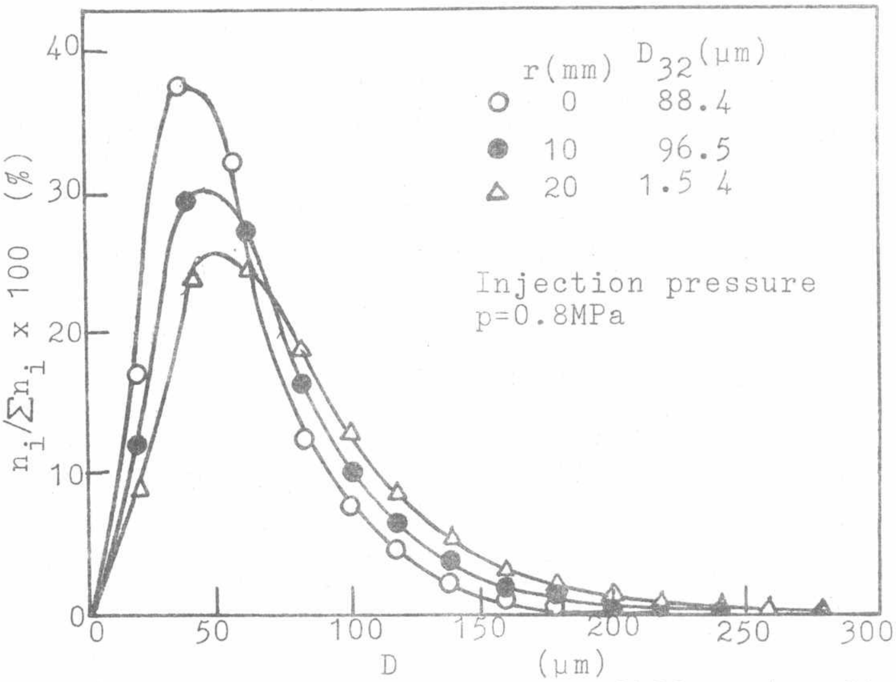


Fig.10 Drop size distributions at different radial positions at x=70mm

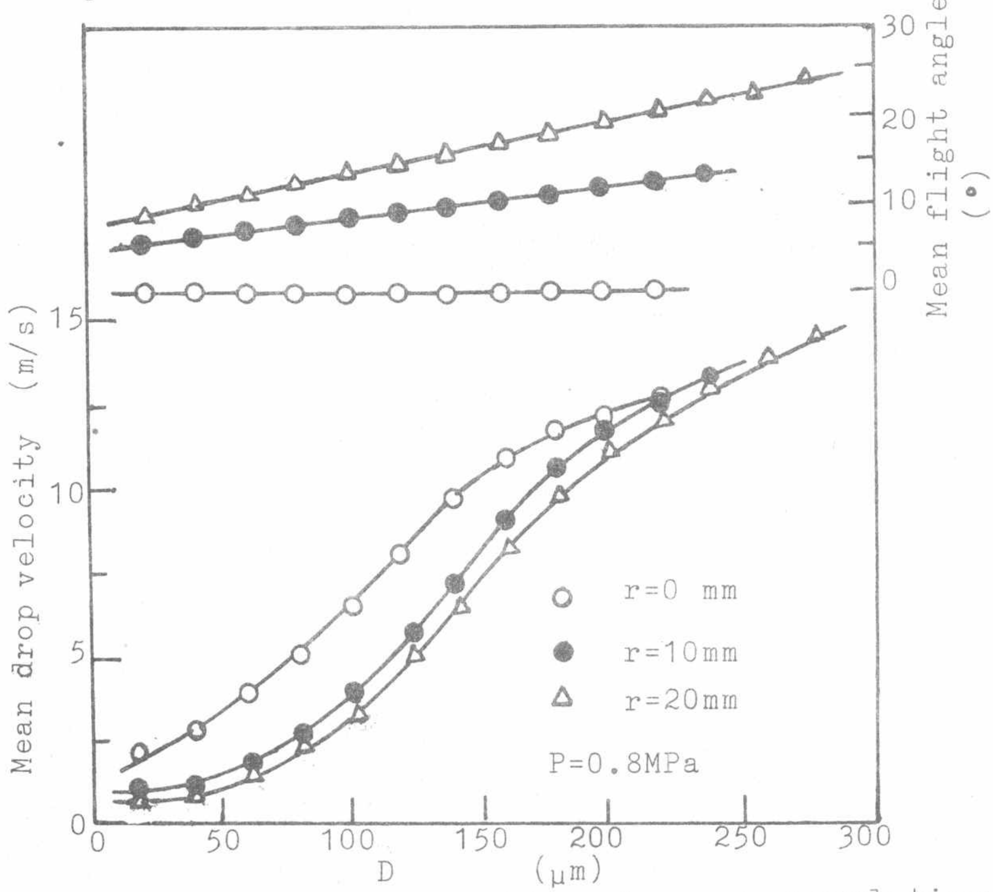


Fig.11 Velocity-size and flight angle-size correlations of drops at different radial positions at x=70mm

counts, sizes, velocities and angles of flight directions from the photographs were tabulated in histogram forms after correction for depth of field. Using an intervals of 20μm of size groups, frequincies of drop size distribution at various radial positions at a distance x=70mm from the nozzle tip are shown in Fig. 10. Also intervals of 1m/s and 3° were used for determining each of drop velocity groups and angle of drop flight direction groups respectively. Results of average velocity-size and flight angle-size correlations for drops at various radial positions at the plane of x=70mm from the nozzle plane are shown in Fig. 11.

CONCLUSIONS

A simple and inexpensive optical photographing method has been developed for drop measurements of liquid sprays. Based on the results of the experimental observations and measurements, the following conclusions are offered;

1. The photographing method described here can be used to obtain good records of spray appearance, breakup length, disintegration mechanism and cone angle of liquid sprays.
2. Since the described method gives enough increase of the required magnification with minimizing depth of field, it can be used for determining each of drop size distributions, drop velocities and drop flight directions of dense liquid sprays.

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