PHYSICO - CHEMICAL STUDIES ON DUSTS

"DUST SUPPRESSION BY WATER SPRAYS"

By

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A thesis submitted to the University of Glasgow in fulfilment of the requirements for the Ph.D. degree in Science.

SEPTEMBER, 1961.

SUMMARY

This study is specially concerned with combating, by using water sprays, the incidence of pneumoconiosis in coal mines. Health hazard in coal mines is discussed and existing methods of dust control are surveyed. Formation of water sprays is explained and classification of spray nozzles is given.

Experiments were performed on moving dust clouds in an experimental wind-tunnel of 18 in. diameter and 63 ft. length under controlled conditions. Simultaneous dust sampling was made by operating two thermal precipitators located before and after the spray nozzle. Dust clouds were produced using Hattersley's laboratory type dust cloud generator.

Coal dust was specially prepared for producing a dust cloud with 95 per cent particles below 5 μ size.

Distribution and deposition of dust particles in the wind tunnel were studied.

A photoelectric device was built for monitoring dust cloud concentration instantaneously. It was proved that short interval variations in the dust cloud concentration were not significant for the planned work on dust suppression.

A system for counting thermal precipitator slides using an Automatic Particle Counting Machine, was developed, and found to give fairly reproducible results. This instrumen
was extensively used for evaluating most of the thermal

precipitator slides taken in the course of dust suppression work.

The dust suppression work is concerned with :-

(a) Dust suppression with small high pressure spray nozzles.

(b) Dust suppression with full size swirl-spray nozzles as used by the National Coal Board.

The high pressure spray variables tested included droplet size, throughput, dust concentration, position of the spray nozzle, type of spray - hollow and solid cone, two stage spraying, and effect of turbulence. These were studied under conditions of dust flow in the wind tunnel.

It was found that applied pressure played a more important part in removing dust particles from air than the amount of water sprayed. There is however a certain minimum flow rate required to achieve good dust suppression.

In general more dust suppression was obtained when the dust cloud concentration was high. Solid cone sprays removed more dust than hollow cone sprays when used at the same pressure.

In two stage spraying, 86.0 per cent dust was removed in the 1/2 - 5 μ size-range, this being the best result achieved. Position of the spray nozzle is of relatively low importance for experiments carried out in the wind tunnel.

The sprayed droplets did not appear to be selective in suppressing any particular size-range of dust particles.

Using full size spray nozzles the characteristics affecting dust removal were studied in the laboratory, e.g. droplet size, spray uniformity, spray penetration etc. It was found that sprays produced from most of these nozzles were conical in shape with hollow cone and that the distribution of droplets in the spray cone was uniform. Spatial dispersion of these nozzles was more uniform if the target distance was greater than 4 feet.

Dust removal up to 70 per cent was achieved by some of these nozzles in the wind tunnel when used at 40 p.s.i. applied pressure. The nozzle efficiency increases with the increase in applied pressure and increase in the relative velocity between the spray droplet and the dust particle.

When these nozzles were used for suppressing dust produced during the transportation of coal, reduction in the dust concentration up to 50.0 per cent was achieved with a Hayden-Nilos spray operating at 50 p.s.i. applied pressure. When the sprays were working, the relative humidity of the mine atmosphere was increased by 6-10 per cent.

ACKNOWLEDGEMENTS

The author records his grateful appreciation to Professor P.D. Ritchie and Dr. W. Gibb for their advice and encouragement during the course of the work and for providi the necessary laboratory facilities.

Thanks are also due to Professor G. Hibberd and Mr. A. Stewart of the Mining Department of the Royal Colleg of Science and Technology, Glasgow, and Dr. E.A.C.Chamberla and Dr. Bloomfield of the National Coal Board for helpful discussion.

The work was part of a pneumoconiosis research programme supported financially by the National Coal Board (Scottish Division).

Thanks are also due to Mr. Hindmarch and Staff (Dumbreck Laboratory, N.C.B.) for providing the necessary facilities to carry out counting of dust samples.

Further thanks are due to Mr. R. Sweetin and Mr. R. Gopalakrishnan for the co-operation given to perform some special experiments and to Mr. A. Clunie and Staff (Chemical Technology Department Workshops) for help in preparing various pieces of apparatus.

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LIST OF SYMBOLS

A = orifice area

C = mean coefficient of discharge

C_D = drag coefficient

D = diameter of the wind tunnel

D_p = diameter of liquid droplet in microns

$\overline{D}_p$ = average droplet diameter, in microns

$\overline{D}_{p50}$ = the volume median diameter, half the total volume of droplets is made of droplets with diameters less than $\overline{D}_{p50}$, in microns

D_{pm} = maximum diameter of liquid droplet in microns

$\overline{d}$ = mean size of particle oversize Z.

d_p = average dust particle diameter in microns

F_n = flow number, gals./hr. $\sqrt{\text{lbs.per sq.in.}}$

G = mass of air flowing per unit time

g = acceleration due to gravity, ft./sec.^{2}

h = height of fall

h_p = height of the particle

K = particle parameter

k, k_1, k_2, k_3 = proportionality constants

L = length scanned in m.m.

M = micrometer setting in m.m.

N = number of particles per unit area

n = number of particles

n_o, n_1 = initial and final dust concentrations in p.p.c.c.

P = amplitude discriminator value

AP = applied pressure (above atmosphere) in lbs./sq.in.

Q = water throughput in gals./hr.

S = penetration of a liquid droplet

t = time in seconds

Re = Reynolds Number

U_c = Reynolds critical velocity

u = fluid velocity relative to water droplet at large distances from water droplet

V_t = terminal velocity

V_o = projection velocity

v = volume fraction of the droplets having diameter less than D_p

$\phi W, \phi W_1, \phi W_2$ = number of intercepts for particular slit width W.

W = weight of dust sample

x = distance travelled or length of droplet trajectory

y_o^2 = Fonda and Herne's dimensionless capture cross-section

Z = sensitivity

z = distance from wall

E = nozzle efficiency

$\bar{E}$ = collection efficiency

α = half the spray cone angle in °

δ = size-distribution parameter

ρ_a = density of air g./c.c.

ρ_1 = density of liquid lbs/cu.ft. or g./c.c.

ρ_s = density of dust material, g./c.c.

σ = standard deviation

η = absolute viscosity poise

a,1 = subscripts stand for air and liquid

ν = kinematic viscosity

INTRODUCTION

1. Health hazard in coal mines

It has been known since about the 15th century that certain industrial occupations are associated with lung disease.[1] In coal mining the disease is known as "Coal Miner's Pneumoconiosis".[2] As yet it cannot be cured and may be progressive,[3][4] in that the lesions continue to develop even after the patient has left the dusty occupation. Simple pneumoconiosis uncomplicated by infection, however, is not progressive.[5] Under these circumstances the only alternative is to give coal-miners dust-free conditions either by modifying dust generating process or by suppressing dust near the source so that it is not long airborne. The designs of present mining machinery, although aimed at a dust free atmosphere, however are not one hundred per cent effective.

The reputed safe working conditions in coal mines vary according to the type of work being carried out and are given below:-

Nature of Dust	Particle size range (microns)	Safe number of particles/cu.cms.
Rock Dust	1/2 - 5	450
Coal Dust	1 - 5	700
Anthracite Dust	1 - 5	650

(1 micron = .001 m.m.)

The above so called maximum permissible dust concentrations are derived from the rate of incidence of pneumoconiosi cases and experiments on animals.[6]

2. <u>Existing methods of dust control</u>

It is well realised that the modern coal mining metho still produce dust. To overcome the dust produced by modern mining machinery, a number of protective measures have been suggested. Some are feasible, others are not.

(a) Protective Dust

(b) Air-flushing during drilling operation

(c) Water-spraying: Spraying water through jets on the cutting jib, transfer and loading points

(d) Steam

(e) Sound waves or Ultrasonics

(f) Calcium Chloride to consolidate the roadway dust

(a) <u>Protective Dusts</u>: The idea of using one dust to counteract the bad effects of silica and coal dusts, serves two purposes. The possibility of an explosion due to high coal-dust concentration may be reduced and it may act as antidote for pneumoconiosis.

Haldane[7] used shale dust to suppress the ill effect of silica dust in coal mines. At present in some mines stone dusting is done to reduce dust explosions. Here the stone dust is made available to be dispersed by an explosion of coal dust and prevent spread of flame.

Aluminium dust is also used as a silicosis antidote. Gardner etc.[8] used aluminium hydroxide. This dust is is administered by dispersing it into the miner's changing room or by allowing the men to inhale the dust through mout pieces from a chamber in which the dust is dispersed.

The discovery that aluminium[9] can itself cause pneumoconiosis reduced its popularity as an antidote.

(b) Air Flushing: This method enables one to remove fine dust before it is airborne. It is a somewhat specialised technique and may only be applied to drilling operatio

In drilling, the fine dust is generated at the cutting edge of the drill bit. This dust is collected after extrac tion from the hole in an air stream induced by an ejector system. In some cases the cuttings are extracted at the mouth of the hole by a dust hood; in others they are extracted from the point of drilling through the drill rod.

Tests have proved that this method is as effective as wet drilling.

(c) Water Sprays: Water in the form of a spray is nowadays very widely used in coal mines as a major dust deterrent. It is essential that the right type of spray equipment be used and that the water should be fed to the spray nozzle at high pressure.[10]

If wetting agents are used, it is claimed that the dust suppression efficiency increases and that less water is required. No consistent results however using wetting agents, are as yet available.

It has been claimed that water sprays not only reduce the dust hazard but increase working efficiency by as much as 10 per cent because of improved visibility.(11) A reduction of dust concentration up to 90 per cent has been claimed for water sprays in some coal mines.(12)

Water sprays are normally used on coal cutting machines and during the transfer of coal from face to mine mouth.

Perhaps the best effect is obtained when water is injected at high pressure through holes drilled in the coal face. This is known as water infusion and is practised in most of the British collieries. The coal seam is saturated with water and little dust is formed when the coal is won or transported.

It is believed that water infusion and the dust removal through hollow drills will dramatically reduce the incidence of pneumoconiosis.

The Pease-Anthony venturi scrubber specially designed to remove dust from gaseous systems claims to have 99.9 per cent dust removal efficiency(13) but the snags with this apparatus are that the pressure losses are high, as are the capital and operating costs.

(d) <u>Steam Suppression:</u> For a considerable period steam was used to suppress dust at dumps and other points especial in the open air. A few years ago steam was tried instead of water in the infusion of coal seams and in the suppression of airborne dust at loading and transfer points. It was concluded that the same degree of dust removal was obtained with less water when used in the form of steam than by water spraying.(14)

Its use is limited, however, because of the safety regulations which demand a suitable flame-proof boiler. A flame proof electrode boiler has recently been designed for underground use and this should revive this particular trend of research.

(e) <u>Ultrasonics or agglomeration of the Dust Particles by Sound Waves</u>: It is now understood that it is practically impossible to remove all submicroscopic particles from air. It is known, however, that small airborne particles can be aggregated by powerful sound waves, particularly if standing waves are set up in a resonant enclosure. Thus such agglomer tion makes it possible to remove the dust by using conventio techniques like cyclone separators, water sprays or gravitational settling etc.

The equipment consists of a sound generator, a floccula chamber, and a collecting unit such as a cyclone. The sound energy can be produced from a Hartman Whistle, or by a transducer actuated by high frequency oscillator, e.g. a magnetostriction transducer. The required frequency depends on the particle size and varies from audible to ultrasonic range. The increase in the particle size depends upon the sound intensity and other factors, and at the largest amplitude investigated the particle mass has been increased 200 times.(15)

Two other very important features of its use are (a) th concentration of the aerosol to be suppressed must be very high, i.e. 1 grain/cu.ft. when particle size is 1 - 10 μ, and (b) the sound output should be 10 - 50 k.watts to get the best results.

Sonic agglomeration has been tried in U.S.A. and found to be extremely successful in the collection of sulphuric acid mist, soda ash particles from stack gases and carbon black etc. However the practical application of this idea is lacking for economic reasons. In Germany the method has been shown to be quite useful even underground.(16)

(f) Calcium Chloride Usage: Hygroscopic salts are used to consolidate the roadway dust in coal mines. These salts are generally dispersed manually in the mine roadways and the particles adhere to the roof and the walls of the road. Afterwards the roadway has the appearance of a white-washed alley.

The effectiveness of calcium chloride as consolidating agent has been estimated(17) and for this, calcium chloride was applied to the sides and the roof of the roadway in the form of paste. It is suggested that in order to bind dust more effectively, a paste layer of at least 5.0 m.m. thicknes must be applied and estimated results show that one kilo of paste will bind one kilo of dust.

3. Water application methods:

Not a single protective measure against pneumoconiosis described above can be used everywhere, every method is useful only for a specific operation. Among the six methods, water infusion and spraying appear to be most economic and useful in the sense that they can be applied to a maximum number of operations, and water is abundant.

By 1956, 27 per cent of the total length of coal face requiring dust suppression was water infused. This infusion was carried out by forcing 5 - 20 gals. of water per hole at the rate of 2.5 g.p.m. at 800 p.s.i. through water-sealed, drilled holes of $1^{3}/4$ - $2^{1}/8$ inch diameter and 5 feet deep, which were located in the upper third part of the seam and were completely free from dirt bands.(18)

Nowadays advantage is taken of the water infusion method when winning coal by blasting. This is a slightly modified technique and commonly known as "pulsed infusion". The normal practice is to infuse the coal seam first in the usual way. The shot hole is then charged, the infusion tube is placed in the mouth of the shot hole, the water turned on and the shot fired while under water pressure. This process not only produces little dust but reduces the required amount of explosive required.

During coal cutting, in the majority of cases, water is sprayed at the rate of 3 - 4 g.p.m. at 100 p.s.i. on to the cutting chain by jets located on the machine. Some machines are equipped with bars with internal jets, which spray water in all directions inside the cut and this ensures thorough mixing of the dust with water. When cutting is done in dirt bands, foam is used in addition to water as it has been proved to be most successful in keeping the dust concentration down.

For drilling operations rotary drills replace old percussive drills wherever practicable, because the former reduce the dust concentration to about one tenth of its original value. Wet drilling is also used in many coal mines. In this technique water is inserted between the drilling machine and the drill rod. The jet in the drill rod delivers water at the rate of 0.6 g.p.m. and suppresses very effectively the dust produced by the drill.

Dust generated at transfer and loading points is suppressed by spraying water through specially designed nozzles at pressures varying from 100 - 500 p.s.i. Calcium chloride, or less frequently sodium chloride, is also used for consolidating the roadway dust. An automatic spraying apparatus has now been developed for use on conveyor belts which overcomes the difficulty of belt slipping due to excess water. The apparatus can give water pressures up to 1,300 p.s.i. and can be fitted to conveyor belt of any size.(19)

4. Water Sprays:

A spray may be defined as a zone of liquid droplets suspended in gas, and spraying is the act of breaking up a liquid into a multitude of these droplets. The general purpose of spraying is to increase the surface area of a given mass of liquid in order to speed up certain physical or chemical processes. The breakup mechanism is complex and sprays accordingly encompass a 10^6 fold range of drop sizes, a 10^{12} fold range of drop areas, and a 10^{18} fold range of drop volumes.[20]

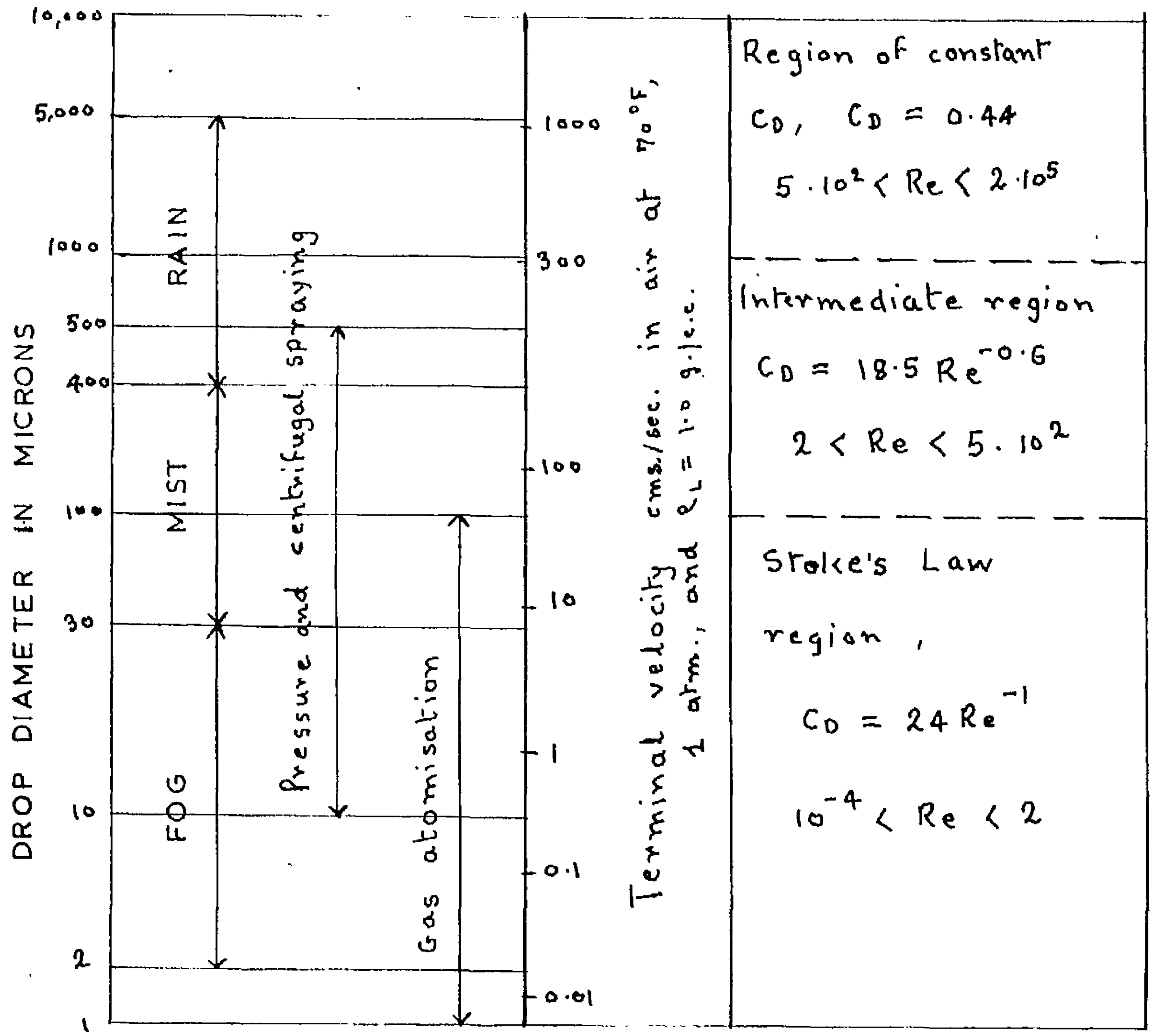
To atomise a liquid mass, it is first forced to assume an unstable free liquid configuration of large surface area. This is accomplished by imparting to it, kinetic energy which causes it to flow through some device such as an orifice to form a liquid sheet, which later break up into innumerable droplets of very small size due to the friction between the gas and the liquid phase. The process of surface formation is resisted by surface tension and viscosity, the process of break-up is solely governed by viscous forces. Some kinetic energy imparted to the liquid mass appears as surface energy in the spray, but the major portion of kinetic energy is retained by the spray drops, causing them to penetrate and mix with the gas into which the spray is directed.

During formation a spray droplet will be rapidly accelerated and decelerated in the surrounding gas stream. Very soon however it will take up a terminal velocity which is equal to its falling velocity under gravity. The factors affecting the terminal velocity of a drop are deformation, internal circulation, and the presence of other drops. Table No.1 shows the free fall of a droplet in infinite gas volume.

The physical properties of sprays depend both on the liquid and on the gas phase into which it is sprayed. The basic variables affecting the sprays and spraying are surfac tension, density, viscosity, the drop diameter, the deviatic of drop size, and the linear dimensions of the spray device. Apart from this, the vapour pressure of the liquid may have remarkable effect in reducing the size and number of drops in the small size range. During spraying, electrostatic charge separation occurs between the spray and the nozzle, and within the spray itself, but very little is known of this latter effect. It is found that mutually repulsive charges concentrate on the surface of the liquid and act as a disruptive force equivalent to a negative surface. For this to happen a maximum equilibrium surface concentration of charge of about 2.65×10^{-9} coulomb per cm^2 in air is required.[21,22] At this condition water droplets with a diameter of about one millimetre will act as though they possess no surface tension.

Turbulence is another factor affecting sprays and spraying which has been subject to much speculation and a very little investigation. Turbulence is probably an importance consideration in the development of spray zone, in gas and drop mixing, and in penetration.

TABLE 1 TERMINAL VELOCITIES OF SPHERES



$$V_t^2 = \frac{4}{3\,C_D}\left[\frac{\rho_L - \rho_a}{\rho_a}\right] g\, D_p$$

$$Re. = \frac{D_p\, \rho_a V_t}{\eta_a}$$

Note: See list of symbols at beginning of thesis.

5. <u>Classification of Spray Nozzles:</u>

Atomisers can conveniently be classified into three groups from a consideration of the type of energy they utilise for atomising a liquid, thus -

(a) Rotary atomisers using centrifugal energy

(b) Pressure atomisers using pressure energy

(c) Twin fluid or blast type of atomisers using gaseous energy.

The demand for simplicity often sways the choice to pressure nozzles. If the liquid has a low viscosity this type operates very satisfactorily.

Nozzles may also be classified according to their feeding systems. In general three feeding systems are used

(i) Simple orifice nozzle: In this nozzle the liquid is injected at high pressure into the gas through a plain orifice (e.g. Morris Spray used in later experimental work).

(ii) Hollow cone nozzle with tangential feed: In this type the liquid is introduced tangentially into a cyclone chamber in which it rotates as a whirlpool and is ejected from the orifice in the shape of rotating hollow cone (e.g. Porter Sprays used in later experimental work).

(iii) High capacity swirl nozzle with fixed screw: In this type, the rotation of the liquid is achieved by fixed screw or slanted channels (e.g. Korting Spray used in later experimental work).

6. Object of Research Project:

In the past many research workers have determined the effect of siliceous dusts on human lung tissue and the wetting characteristics of siliceous dusts. A sketch of the human lung-respiratory channels and the deposition of dust on the viscous mucous layer is shown[23] in Figs. 1 and 2. A proportionately small amount of work has been done however on the formation of aqueous sprays suitable for dust suppression and their ability to suppress dust under carefull controlled conditions. This possibly has been due to the difficulty of producing in a laboratory a reproducible dust cloud and of obtaining the conditions of dustiness and spray formation that would simulate conditions in a mine roadway.

Glen[24] and Hunter[25] measured the effectiveness of swirl-atomisers on static dust clouds and studied the use of wetting agents for dust suppression. It was felt that this type of approach to the problem would have more value if carried out on a dust flow system rather than on a static dust cloud, and as far as possible the measurements should be made using spray nozzles that were of the type and size used in coal mining practice. It was also felt that water spraying at very high water pressures should be looked into as the gain in suppression might outweigh the increased energy requirements. Finally, the ability of the nozzles tested in the laboratory to remove dust in a mine roadway, should be measured.

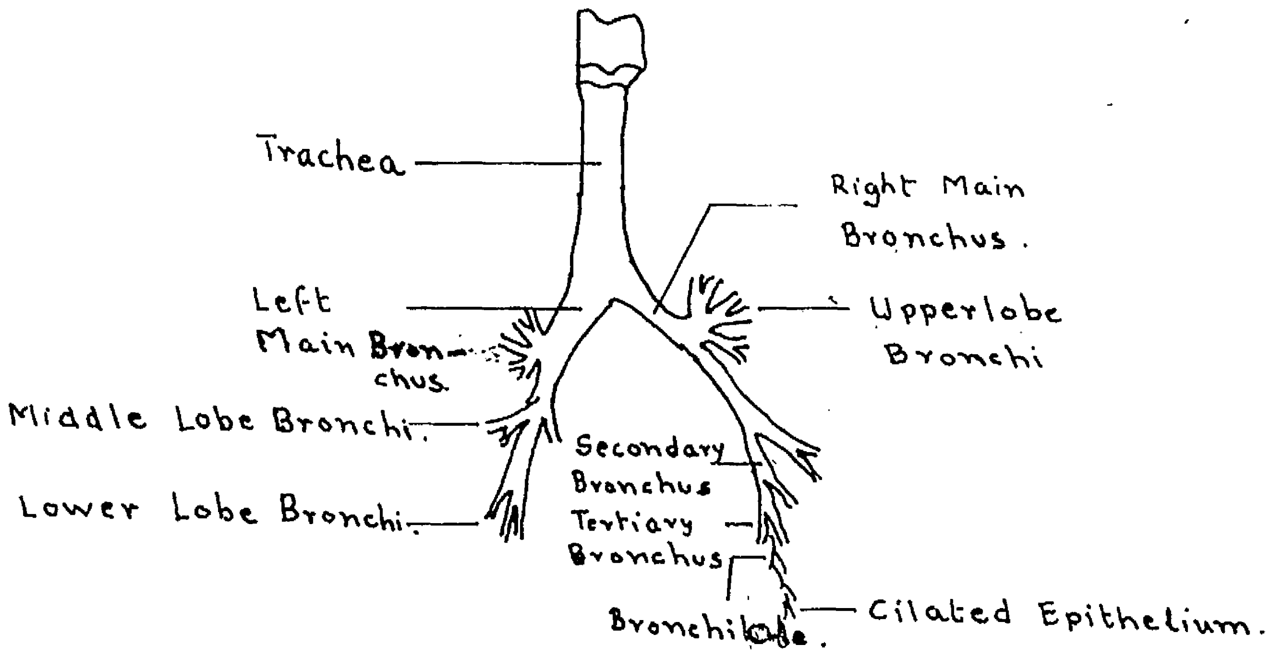


FIG.1 MAIN RESPIRATORY CHANNELS OF HUMAN LUNG

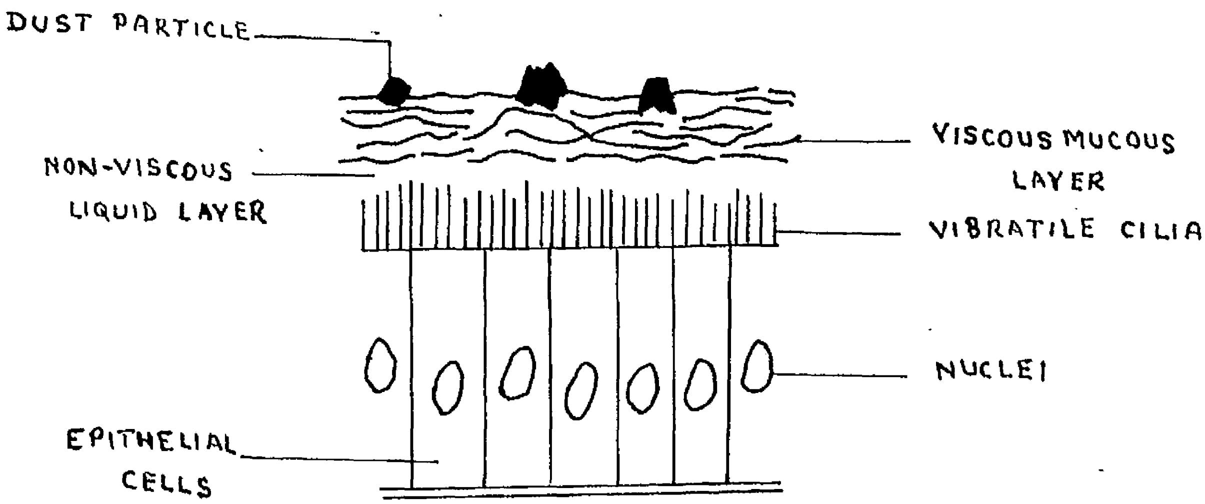


FIG.2 BRONCHIAL EPITHELIUM

The great advantage of laboratory flow system experiments is that it should enable one to determine the quantity of water required to suppress a given amount of dust.

In all previous work reported by the workers from this laboratory, the evaluation of the dust sample has been the main bottle neck to progress. The availability of an automatic particle counter made it possible to develop a standard method for the rapid evaluation of dust samples and enabled more trustworthy results to be obtained.

SECTION I

Design and Construction of Experimental Wind Tunnel and Allied Equipment

1. Wind Tunnel: All previous experiments on dust suppressio were performed on static dust clouds and though much useful information was obtained, it was difficult to relate the laboratory work to actual mining conditions. A wind tunnel was built by Sweetin(26) to simulate the flow of a dust cloud under conditions approaching that in the mine.

This experimental wind-tunnel as it stands now is the outcome of many alterations and modifications made from time to time by the author.

A view of the wind-tunnel is shown in Plate I and a drawing in Fig.3. The tunnel consisted of seven lengths of 16 gauge mild-steel welded ducting, flanged at the ends and fitted with rubber gaskets. The overall length of the tunnel is just over 63 feet, and the outside diameter 18 inches.

A perspex window was provided in the centre section of the tunnel. Holes were cut for two thermal precipitator head the "top" and "bottom" thermal precipitators being placed at 22 feet and 50 feet distance from the blower. A venturi was fitted at the bottom end of the wind tunnel for measuring air velocity.

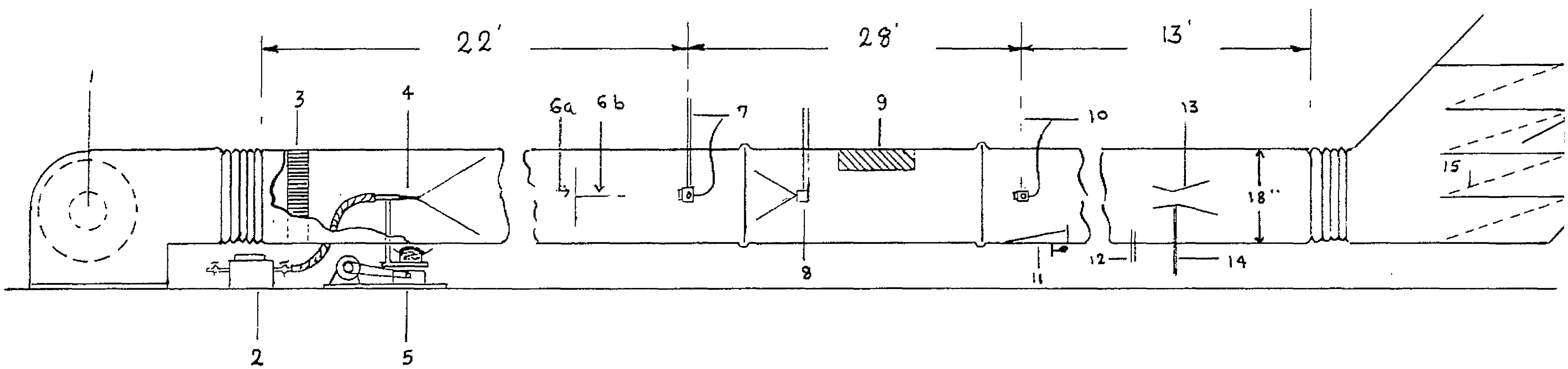
The tunnel was mounted on angle-iron and wood supports with the bottom end 6 inches lower than the fan end, so that the water from the sprays would drain out. A one inch high

PLATE X

View of the experimental wind tunnel
(looking from the top end)

FIG. 3

EXPT. WIND TUNNEL



1] FAN
2] AIR BLOWER
3] HONEY COMB
4] DUST INJECTOR
5] DUST CLOUD PRODUCER
6] BAFFLE PLATE a] mixing b] anti-spin
7] THERMAL PRECIPITATOR (1)
8] SPRAY NOZZLE
9] WINDOW
10] THERMAL PRECIPITATOR (2)
11] WATER TRAP
12] STATIC PRESSURE
13] VENTURI TUBE
14] STATIC MINUS VELOCITY
15] VISCOUS OIL FILTER UNIT
16] EFFLUENT AIR

catchment dam was built across the lower end of the tunnel and a 0.5 inch hole was drilled in the tunnel wall for draining out water. This catchment dam was inadequate for later tests using 200-300 gallons of water per hour and was subsequently replaced by a 3 inch high catchment dam before the end of the fifth ducting and a 2 inch diameter hole was drilled for draining out water.

An 18-inch Keith-Blackman centrifugal fan, capable of providing an air-flow of 2,000 ft/min. against a back pressur of 2 inches w.g., was fitted to the higher end of the ducting by a flexible rubber tubing. The fan was driven at 1,500 r.p by a 2 h.p. fan-cooled squirrel-cage motor (400/440 volt, 3 phase, 50 cycles A.C.). The air flow was made variable by fitting an 18-inch Keith-Blackman Radial-leaf Damper to the fan inlet. This enabled the air-flow to be set at velocities between 100-2,000 ft/min.

A Keith-Blackman W-type viscous oil film filter batter comprising of 4 trays soaked with light lubricating oil which were set at 45° to the horizontal and were enclosed in a stee box connected to the lower end of the wind tunnel by flexible rubber tubing. The dust laden air had thus to pass through an oil film before escaping to the outside atmosphere. This was done to reduce the nuisance due to the operation of the dust tunnel.

A section of paper honeycomb 4 inches thick and with 1/4-inch holes, was situated in the tunnel as shown, together with mixing baffles to straighten out the air flow pattern.

The inside surface of the wind tunnel was painted white and the angle-iron and wood supports along with the flexible rubber tube connection from the blower to the main tunnel, kept the vibrations due to the electric motor to a minimum.

2. <u>Wind Tunnel Instruments:</u>

(a) <u>Dust Feeding Machine:</u> The unit used to produce dust clouds of controlled concentration was fixed at the top end of the wind tunnel about 3 feet down-stream from the blower. The outlet end of the dust injector was set exactly at the centre of the wind tunnel. The dust feeding machine is shown in Plate II. It follows the design of Hattersley <u>et al</u>[27] slightly modified for use with our apparatus. It consisted of a truncated cone hopper for storing dust fixed to a vertical steel column, but able to be raised and lowered. Two interchangeable circular 7-inch perspex plates with three concentric grooves were arranged to rotate under this hopper. The groove sizes are given below for the two plates.

<u>Circular Plate A.</u>

Outer Groove		Middle Groove		Inner Groove	
Width In.	Depth In.	Width In.	Depth In.	Width In.	Depth In.
0.36	1/16	0.48	1/16	0.48	1/16

Circular Plate B.

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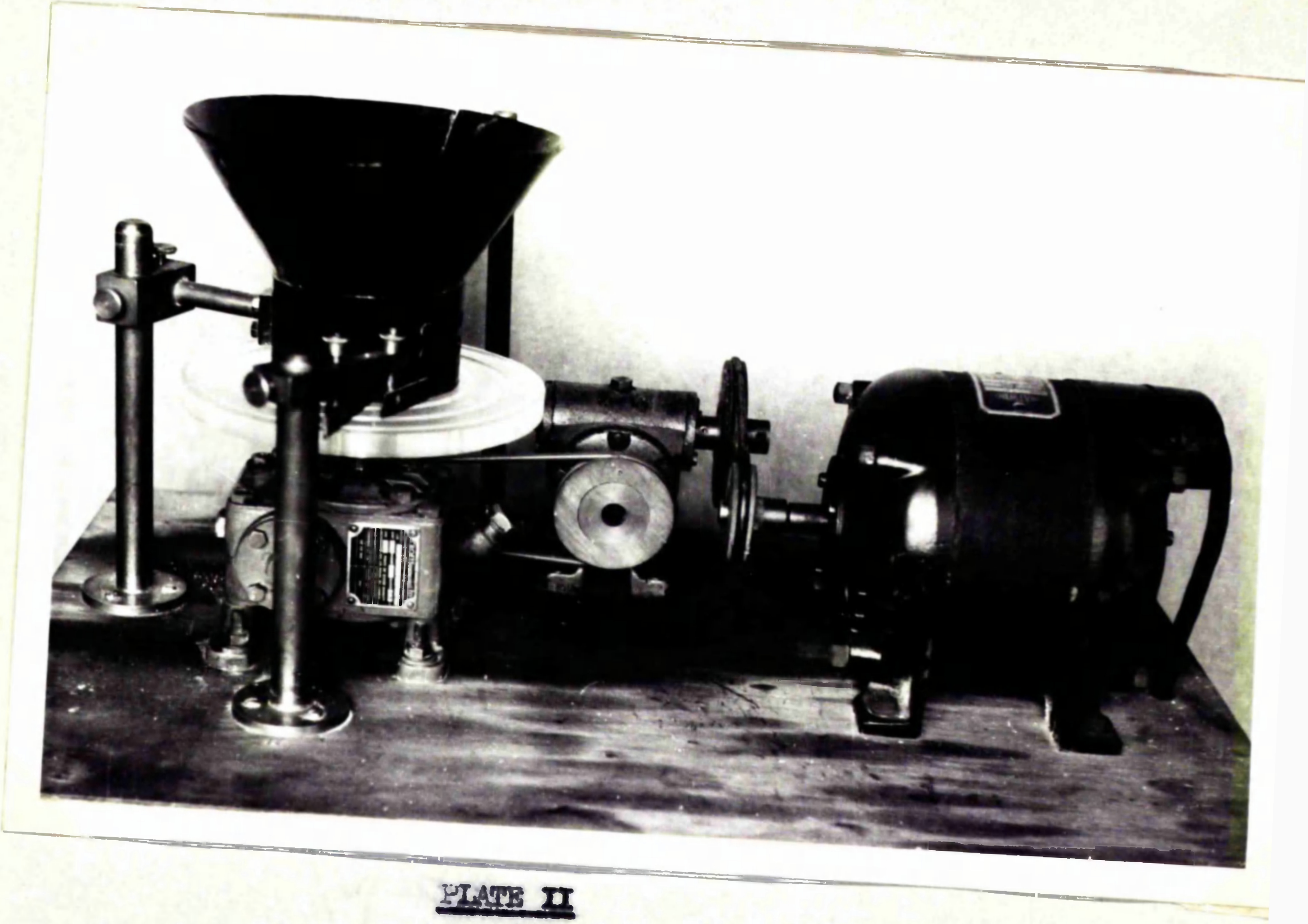


PLATE II

DUST FEEDING MACHINE

Circular Plate B.

Outer Groove		Middle Groove		Inner Groove	
Width In.	Depth In.	Width In.	Depth In.	Width In.	Depth In.
0.20	1/16	0.17	1/20	0.18	1/20

These plates were rotated by a small electric motor operating through a miniature V-rop belt, running on cone pulleys and a step down gear box. With this system it was possible to run the dust feeding machine at the following 8 different speeds -

Pulley Reference:

Pulley Ref:	1-1'	1-2'	2-1'	2-2'	2-3'	3-1'	3-2'	3-3'
Speed r.p.m.	1.185	0.885	0.940	0.705	0.568	0.700	0.520	0.420

Inside the hopper was placed a wooden cone of small diameter with four scraper blades attached to its base. These blades threw the dust out through the small space left between the hopper and the rotating plate. A secondary scraper in the form of thin brass strip of trapezium shape was fixed to a second vertical steel column to pack the dust thrown out by the primary scraper into the concentric grooves This scraper could be adjusted at various angles by pressing on to the rotating plate so that the grooves were nicely and evenly filled with dust. To obtain good results about 1/8 in clearance was left between the hopper and the rotating plate. This adjustment filled the groove in the plate completely with a slight trickle of dust going to waste.

Theoretical dust concentrations based on dimensions of the rotating plate and size-analysis of the coal dust are given in Appendix I.

For dispersing the dust, an all-glass ejector was used. It could be set on middle and outer grooves just behin the secondary scraper. This ejector was operated by an air blower and is shown in Fig.4. The blower provided compressed air at 1.5 in. w.g. and the suction developed at the tip of the ejector was 0.2 in. w.g.

(b) Instruments for Measuring Air Velocity: Two instruments were used for measuring air velocities in the win tunnel (1) Venturi and (2) Hot-Wire Anemometer.

(1) Venturi: A standard 6-inch Venturi tube was fixed inside the wind tunnel, about 55 feet from the blower. The pressure difference between the upstream end of the cone and the throat (see Fig.5.) was recorded on an inclined manometer. The Venturi was calibrated against a low-reading vane anemometer and was used for measuring air velocities greater than 1,000 ft/min.

(2) Hot-Wire Anemometer: This is a sensitive instrument for measuring very low air velocities. Similar instruments are mentioned by Prandtl.[28] A sketch of the anemometer used is shown in Fig.6. It consisted of a copper-constantan thermocouple with one junction directly exposed to the air in the wind tunnel. The other junction had a

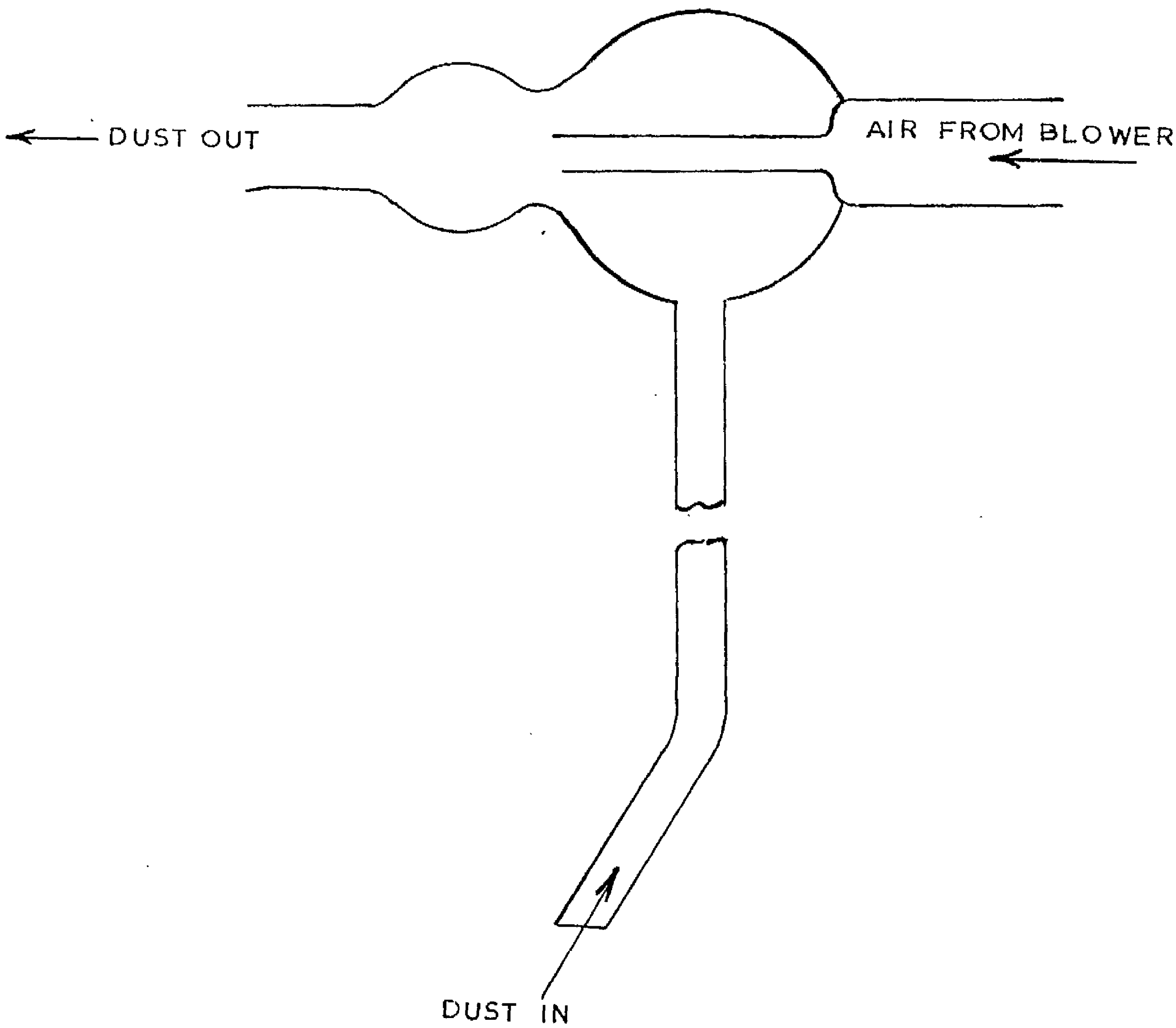


FIG. 4 DUST INJECTOR

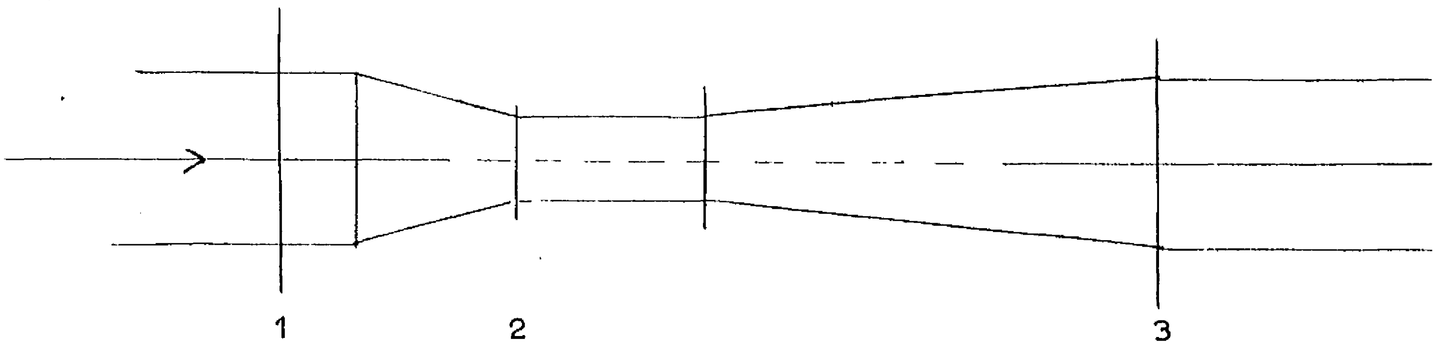


FIG. 5 VENTURI METER

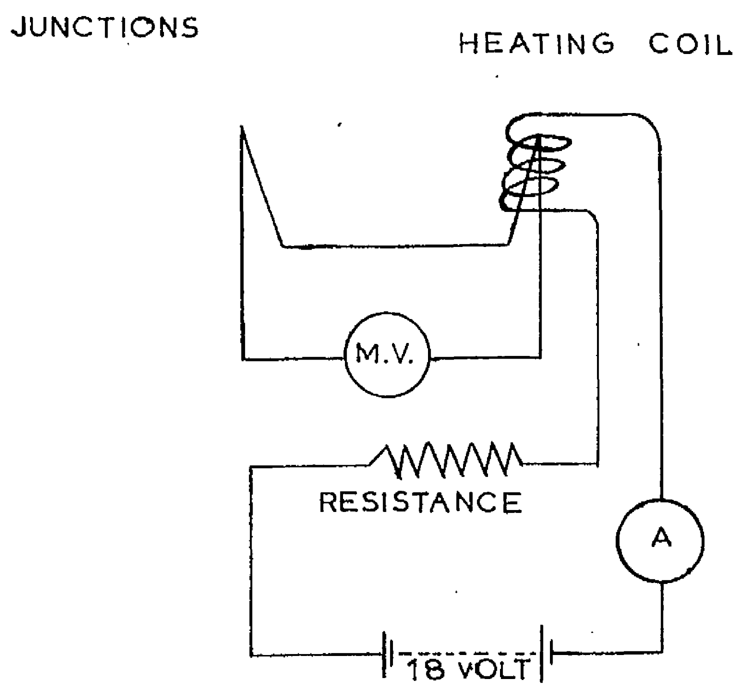


FIG. 6 HOT-WIRE ANEMOMETER

heating coil of 60 ohms resistance wound round it. A steady current (0.26 amp.) was passed through this coil from an 18-volt accumulator. This heated the junction giving rise to the potential difference which was recorded on a milli-voltmeter. When air was passing through the tunnel, the heat received by the junction was dependent on the cooling effect of the air on the coil and thus on the air velocity.

The hot-wire anemometer was calibrated against an accurate vane anemometer. Since the air temperature has also a significant effect on the result, care was taken to make an allowance for any change in it.

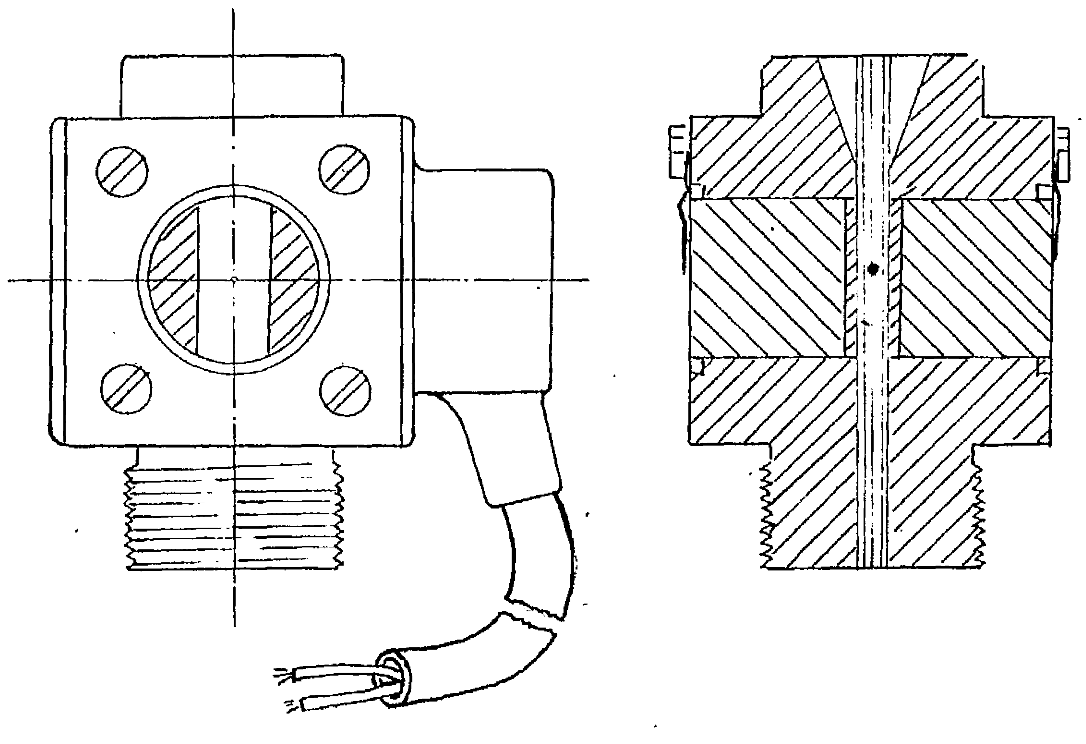
(c) Spraying Unit: This unit was the outcome of much preliminary work and was modified to suit the experimental needs of each set of tests as described in later sections of this work.

(d) Thermal Precipitator:[29] In this instrument dust particles were deposited by thermal means on thin microscope cover glasses. The instrument consisted of two main parts, the head carrying a heated wire and the aspirator which drew the air past the heated wire. The head was made from two brass blocks screwed together to form a 1.5 in. cube. The two brass blocks were separated by thin strips of insulating material known as 'spacers', arranged in such a way that they formed a vertical slot.

An electrical resistance wire passed horizontally across the slot half-way between the top and the bottom block. Two solid brass plugs ($^3/4$-in. diameter) were closely fitted into holes in two opposite faces of the combined block. Views of the head are shown in Fig.7(a) and 7(b). Into the above mentioned holes were inserted the cover glasses which thus rested against the spacers and at the correct distance from the wire. The upper and the lower end of the brass cube were extended and threaded, two slots being carried through these extensions. The lower extension screwed into an aspirator which provided the necessary air movement. The slot in the upper extension was opened out to form a straight-sided smooth surfaced mouth. The electrical resistance wire was 9.65 m.m. long and 0.8 m.m. thick and attached to one end of a spring to keep it taut, as it expanded on heating. This end was connected by means of an insulated wire to a terminal placed under a cover. Under the same cover was another insulated terminal to which the other end of the insulated wire was secured. This insulated wire could be connected to a small battery.

To operate the instrument, clean microscope cover glass were inserted in the spaces provided in the precipitator head and these were subsequently closed by the close-fitting brass plugs. The reistance wire was initially heated for about 30 seconds by passing 1.3 amp. of steady current from a 4.5 volt Edison's alkaline battery. After this the aspirator

FIG. 7 THERMAL PRECIPITATOR



A) SIDE ELEVATION WITH PLUGS REMOVED

B) TRANSVERSE SECTION

was switched on and the air was drawn at the rate of 7.0 c.c./min. from the precipitator head. This is a critical sampling rate and precipitation is claimed to be nearly one hundred per cent for particles of diameter less than 10 micro After sampling the desired volume of air, the aspirator and heating current were switched off. The cover glasses were carefully removed and mounted on a standard 3 in. x 1 in. microscope slide.

The necessary presence of airborne dust in the tunnel air made a regular check and frequent cleaning of all instruments imperative. This regular maintenance included (a) cleaning and resetting of the Keith-Blackman oil film filter, (b) oiling the blower and realigning of it with the main tunnel, (c) recalibration of the hot-wire anemometer to offset the effect of seasonal fluctuations in air temperature, (d) cleaning of precipitator head, aspirator, and subjecting it to a smoke test, and (e) adjustment of dust injection unit to maximum efficiency.

(e) Dust Preparation: About $^1/2$-cwt. of coal (boiler house singles) were first dried overnight at about 110°C, then passed through jaw crusher and roller mill until the product obtained was about $^1/8$-in. size. This was further passed through a high speed laboratory hammer mill to give a ground coal all less than 300 B.S. sieve in size. Since this product was not sufficiently fine for dust suppression studies, further grinding was continued in batches of 40-50 g. in a mechanical agate mortar for 1-hour periods. The product obtained from agate mortar was sieved to ensure that no particle in the dust was greater than 53 microns in diameter.

(f) <u>Dust Size-Analysis:</u> A known weight of coal dust sample, 0.30565 g., (before passing through the sieving machine for the second time) was allowed to settle through a height of 26 cms. of 2 per cent sodium citrate solution in an Andreason Sedimentation Apparatus.[30] Incremental samples were taken from the sampling end of the apparatus at calculated intervals and the results computed assuming that the particles obeyed Stoke's Law.[31]

$$V_t = h/t = g\, d_p^2\, (\rho_s - \rho_1)/18\eta$$

(A list of symbols and their meaning is given at the beginning of this thesis)

The above equation was used to calculate the times of settlement of a particular range of particles, and in special units it reduced to

$$t = (h\ \eta) \times 10^7/5.45\ d_p(\rho_s - \rho_1) \text{ seconds}$$

where h is the height of fall in the Andreason apparatus and measured in cms.,

ρ_s and ρ_1 are measured in g./cc.,

η in dynes/cm^2., and

d_p in microns.

For this determination the mean particle diameters were arranged in a $\sqrt{2}$: 1 ratio, in order that the sampling times become convenient multiples of 't'. The results are shown in Table 2.

Since we were primarily interested in particles below 5 microns in diameter, the sedimentation test was continued to a mean particle diameter of 1.4 microns using careful temperature control of the apparatus. The results are shown in Table 3. Because the weight of the particles less than 5 microns in diameter was small in relation to the total weight of the dust taken for analysis, these results should only serve as a guide and are not taken as very accurate for calculations.

In Table 4 the average particle diameter and the percentage number of particles below 6.59 microns in diameter is given. This was calculated from the data of Tables 2 and 3.

The accuracy of the test was ascertained by estimating the surface area of the coal dust and comparing it with that of standard results calculated by physical methods. The result is in close agreement with that given by Skinner <u>etal.</u>(32)

The calculation of surface area is made as follows :-

Surface area of a spherical particle $= \pi d_p^2$

Volume of a spherical particle $= \pi d_p^3/6$

Total weight of particles in sample $= w = n\rho_s \times \pi d_p^3/6$

(where n is the number of particles in sample)

TABLE 2

Size* - distribution of coal dust

Size-range microns	Mean size microns	Wt. of increment in g.	True wt. of sample in g.	Per cent by weight
76 - 106	89.0	0.06695	0.02670	8.75
53 - 75.99	63.0	0.04025	0.02850	9.35
37.5 - 52.99	44.5	0.05200	0.06705	22.00
26.5 - 37.49	31.50	0.03695	0.04930	16.15
18.8 - 26.49	22.20	0.02460	0.03690	12.09
13.2 - 18.79	15.70	0.01230	0.01710	5.60
9.40 - 13.19	11.10	0.00750	0.01204	3.94
6.6 - 9.39	7.90	0.00296	0.00422	1.38
3.97 - 6.59	5.60	0.00170	-	-
< 3.96	-	-	0.06384 **	21.00

** Weight found by difference.

* "Size" in this context signifies the diameter of a sphere having the same density and Stokes law terminal velocity as the particle.

TABLE 3

Size - distribution of coal dust below 6.59 microns

Size-range microns	Mean size microns	Wt.of increment in g.	True weight of sample in g.	Per cent by weight
4.69 - 6.59	5.60	0.00170	0.00185	0.605
3.30 - 4.68	3.79	0.00155	0.00015	0.0049
2.39 - 3.29	2.86	0.00245	0.00523	1.71
1.69 - 2.38	1.98	0.00067	0.00067	0.022
1.20 - 1.68	1.40	0.00671	-	-
$<$ 1.19	-	-	0.05594 *	18.6

* Weight found by difference.

TABLE 4

Evaluation of average particle size of dust and number per cent of particles below 6.59 microns in diameter.

Mean size microns	No. of Particles 10^6	Total diameter in microns 10^6
89	0.0569	5.0250
63	0.1710	10.7900
44.5	1.1390	50.6000
31.5	2.3600	74.0000
22.2	5.0400	119.0000
15.7	6.6000	104.0000
11.1	12.4500	138.0000
7.9	12.8000	101.5000
3.3	2690.0000	8850.0000
Total	2730.6169	9452.9150

Average particle size (i.e. Stokes diameter) $= \dfrac{9452 \quad 10^6}{2730 \quad 10^6} = 3.46$ microns

Per cent No. of particles below 6.59 microns in diameter $= \dfrac{2690 \quad .10^6}{2730 \quad .10^6} = 98.5\%$

$$\therefore \; n = 6w/\rho_s \pi d_p^3$$

Total surface area $= n \pi d_p^2 = 6w/\rho_s d_p$

$\therefore$ Surface area per gramme of material

$$= 6/\rho_s d_p$$

For example:-

Weight of dust sample = 0.3056 g.

Density of dust material = 1.279 g./cc.

Average particle diameter = 3.46 microns

$\therefore$ Surface area per g. $= 6/(1.279 \times 3.46 \times 10^{-4})$

$= 1.355 \times 10^4$ cm.^{2}/g.

3. Distribution of Air in the Wind Tunnel:

The critical velocity Uc for turbulent flow in the wind tunnel is given by -

$$Uc = Re \times \nu / D$$

where

Re is equal to 2300 (the critical value of Reynolds number for turbulent flow).

$$\therefore \; Uc = \frac{2300 \times 0.14}{18 \times 2.54}$$

$$= 7.05 \text{ cms/sec.}$$

$$= 13.9 \text{ ft/min}$$

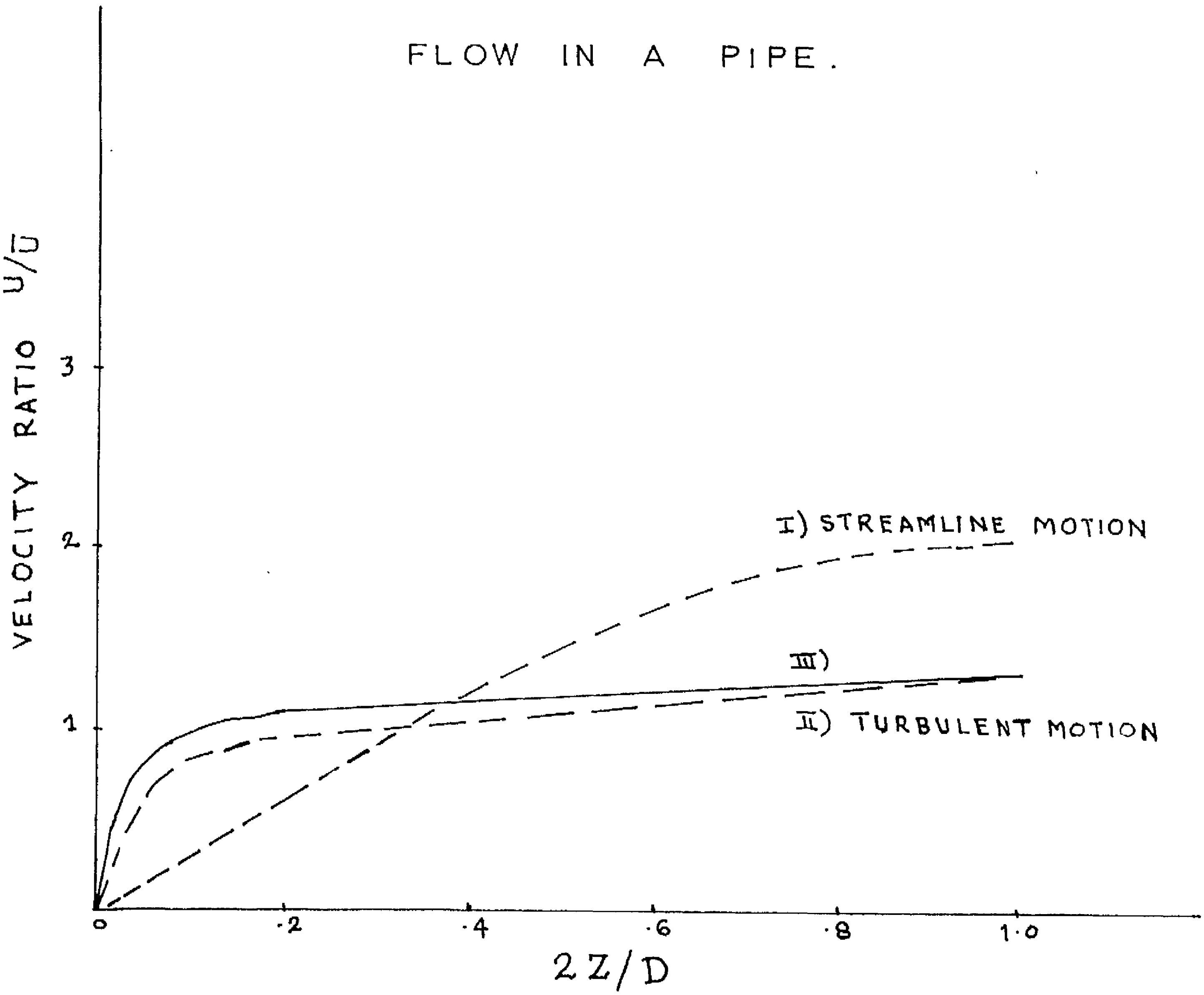
Since the air velocity measured while keeping the radial leaf damper completely closed is about 100 ft/min., the air distribution in the wind tunnel should be characteristic of a turbulent regime.

Typical velocity profiles for flow in pipes are shown in Fig.8[33] and are quite comparable to one measured in this tunnel by Sweetin[34] in a far down stream section.

In turbulent flow, the transfer of mometum takes place as a result of the movement of comparatively large groups of molecules. From the results of some preliminary tests it was felt that the air distribution was not at all uniform near the dust injection machine and thermal precipitator I. Gopalakrishnan[35] measured the air distribution in the tunnel and representing the results as iso-velocity curves showed that air velocity was unduly high in one particular quadrant of the wind tunnel section near the blower and became more uniform as one passed down the tunnel.

Conditions were improved by inserting a honeycomb structure 4 in. thick with openings $^1/_4$-in. wide and a mixing baffle of $D/\sqrt{2}$ diameter (where D = 18 in.) together with an anti-spin baffle of 3 D length, into the wind tunnel at about 12 ft distance from the blower (see Fig.3 of wind-tunnel). This arrangement greatly improved the air distribution around thermal precipitator I.; for instance, when the fan was set to give 1,000 ft/min. air velocity, the actual measurement of air flow with pitot tube and micromanometer showed that the air velocity across the wind

FIG. 8 TYPICAL VELOCITY PROFILES FOR FLOW IN A PIPE.



Here :-

U = air velocity at distance Z from the wall.

Ū = mean air velocity.

D = diameter of the pipe.

Range of application of Laws:-

I) Streamline motion, up to $Re = 2.1 \times 10^3$

II) Turbulent motion, $Re \simeq 2.3 \times 10^3$ to $Re \simeq 1$

III) Turbulent motion, $Re = 10^7$

tunnel varied within 950 ± 50 ft/min.[35] Obstructions like the thermal precipitator head and spray nozzle had of course a significant effect on the air distribution.

4. <u>Deposition of the Dust in the Wind Tunnel:</u>

It was noticed that in spite of the turbulence in the wind tunnel a certain amount of dust settled on the walls and on the baffle plates fixed inside it.

Dawes and Slack[36] have given a theoretical formula relating to airborne dust concentration, and floor deposition, at a given cross section. As it was not possible to use their relationship, a quantitative estimate was made of the way in which dust concentration varied over a cross section of the wind tunnel and down the length of the wind tunnel.[37]

From the dimensions of dust in the machine grooves and the working speed, the amount of coal dust present in the air in the wind tunnel should have been 0.1115 grains/cu.ft. According to a careful estimation made using a salicylic acid filter sampling unit, and sampling isokinetically at an air speed of 200 ft/min., the dust concentration was 0.0575 ± 12.25 per cent grains/cu.ft. just before the mixing baffle. This meant that about 50 per cent of the dust by weight was deposited before this baffle.

After the baffles, the airborne dust concentration was found to be reduced to 0.02743 ± 0.003 grains/cu.ft. and just before thermal precipitator II it was further reduced to 0.02135 grains/cu.ft. (after 28 ft. of travel). Therefore, the fall-out of dust after the baffles amount to about 22 per cent by weight.

To study further the sedimentation of the dust particles along the wind tunnel, dust concentrations in particles per cu.cm. of air were measured at the top and the bottom end of the wind tunnel at three different air velocities by means of the thermal precipitators. The dust machine was adjusted to give maximum dust concentration. The results are shown in Table 5.

TABLE 5.

Comparison of Dust Concentration along the Wind Tunnel

Air Velocity ft/min.	Dust Concentration at the top T.P. p.p.c.c.	Dust Concentration at the bottom T.P. p.p.c.c.	Difference in the dust concentration p.p.c.c.
150	1447	1420	27
400	1030	1020	10
900	640	628	12

It would appear from Table 5 that the number concentration of particles, as determined by thermal precipitator does not alter appreciably between the two sampling positions. The thermal precipitator is known to sample with almost one hundred per cent efficiency up to a particle diameter of about 10 microns and at higher diameters the efficiency drops off rapidly. On the other hand the gravimetric filter sampling unit if operated isokinetically should sample all sizes equally well. From Table 2 it can be seen that 26.32% by weight of the dust was less than 13.2 microns in diameter. It can be calculated from the results of Table 4 that this represents about 99.4% by number of the particle. Comparison of the gravimetric and thermal precipitator results would appear to indicate that no significant amount of particles less than about 10 microns in diameter deposit in the tunnel but a considerable proportion of the larger particles which constitute about 75% of the weight of dust and less than 1% of the number of particles do fall out. Inspection of the gravimetric results suggests that 60% by weight of the large particles fall out between the injector and the baffles, about 33% are deposited in traversing the baffles and the remaining 7% deposited on the tunnel walls before the bottom thermal precipitator. Since in this work we are primarily concerned with particles less than 10 microns in diameter and all later sampling is carried out by thermal precipitator this deposition of a relatively small number of large sized particles should have little effect on the latter results.

By suitable alteration of the speed of the dust machine and the air velocity it was possible to achieve dust concentrations in the tunnel ranging from 400 to 1600 p.p.c.c. at air velocities from 150 to 900 ft./min.

SECTION II

A Photoelectric Device for Monitoring the Dust Cloud Concentration

1. Need for a Monitor: It was felt that a monitoring device was necessary to assess continuously the concentration of the dust travelling along the wind tunnel and to show up unexpected and systematic fluctuations that might be arising. An instrument was therefore designed and built, which incorporated two photo-multipliers and a pen recorder. The instrument utilised the light obscuring power of suspended particles.

2. Application of Light Obscuration: If a beam of light is passed through a suspension of dust particles in air a proportion of the light will be obscured from some suitably placed light-sensitive element by the projected area of the particles suspended in the beam. It may be simply shown[38] that for a given dust material the optical density of the suspension is directly proportional to the length of the light path through the suspension, the concentration of suspended dust in g./c.c. of air, and the projected area of the particles per g. of dust. In a unit of fixed light path through which suspended dust of constant size distribution passes, any detectable change in optical density of the suspension will be directly related to a change in the concentration of particles in the air crossing the beam.

3. <u>Description of Experimental Dust Monitoring Unit:</u>

The instrument finally utilised after much modification is shown in Figs. 9 and 10.

It consisted of two sections -

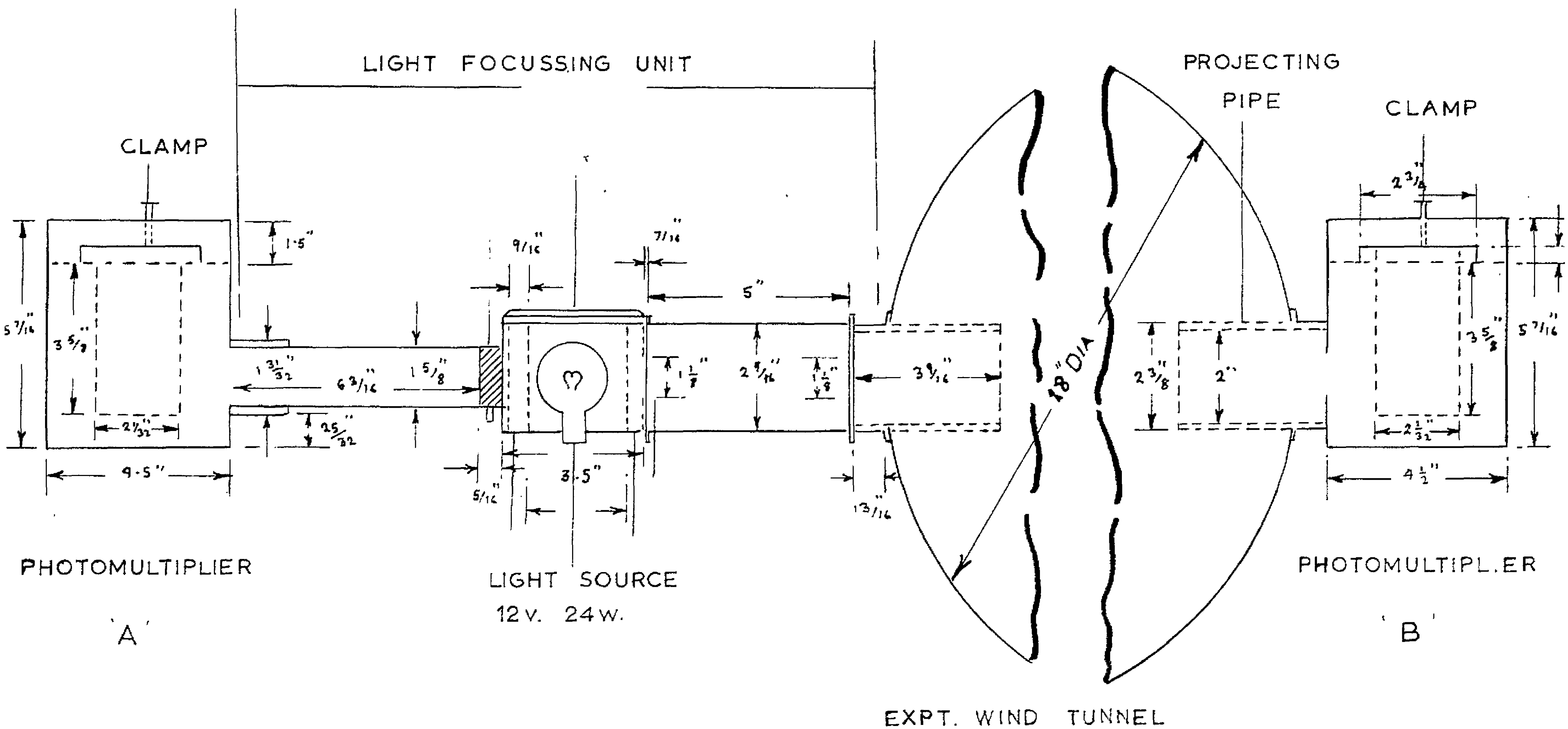
(i) optical and (ii) electronic.

The optical section was divided into two parts (A) and (B), which were fixed to the wind tunnel in such a way that they were in one straight line. The light source was a 12-vol bulb with a stabilized power supply. It was located in the (A) part of the unit. The filament of the bulb was arranged to be at the focus of two bi-covex lenses, in order that the light might emerge as a parallel beam. The light beam from on of the lenses fell on the window of photomultiplier (A). An iris diaphragm arranged between the lens and the photo-multiplier (A) made it possible to reduce the light falling on it. The light from other lens passed across the wind tunnel and fell on photomultiplier (B) in the unit (B), fixed to the opposite wall of the wind tunnel. A short cylindrical extension piece protruded into the wind tunnel from (A) and (B) units and helped to prevent the dust from settling on plastic windows.

The photomultipliers were of standard G.E.C. type with Caesium cathode and Nickel anodes. They could be operated up to 2.0 milli amp. output at 500 volts supply.

The photomultipliers were connected through milli-voltmeters to a detector which recorded the amount of light

FIG. 9 SIDE ELEVATION OF PHOTOMULTIPLIER UNIT



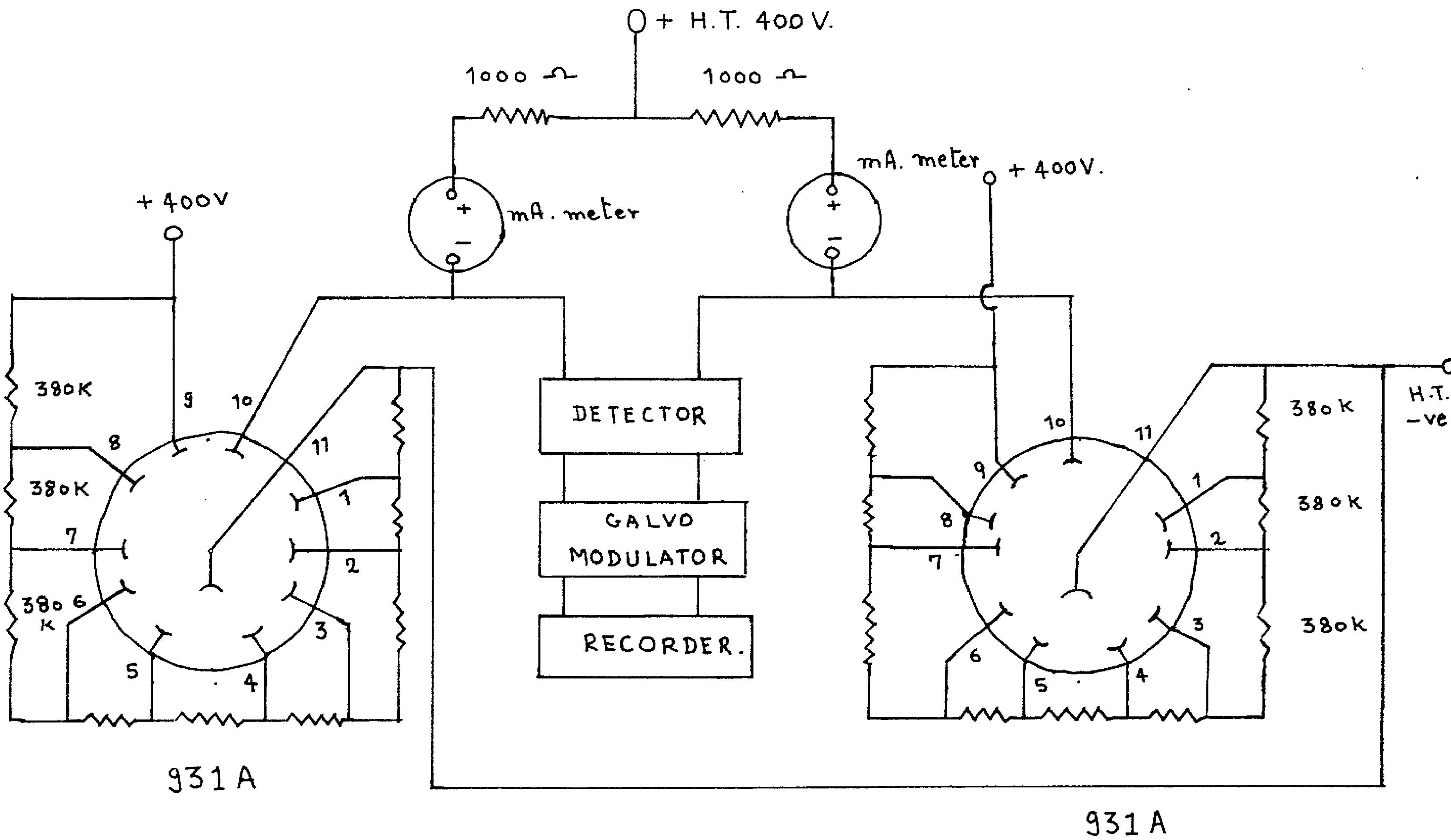


FIG.10 CIRCUIT DIAGRAM OF PHOTOMULTIPLIER UNIT.

obscured. Any changes in the mains supply were therefore automatically compensated when using two photomultipliers in opposition. The detector was coupled through a modulator which amplified the current to the recorder. The pen recorder ran at two speeds, 6 in./hr. and 30 in./hr., and gave a graph which was proportional to the moving dust cloud concentration. The recorder could work at four sensitivities depending on the accuracy required.

4. <u>Testing of Unit</u>: When tests were started, no change was noticed in the reading of the recorder with air flowing down the wind tunnel, indicating that the instrument was not sensitive to the dust present in the laboratory air.

With the dust passing down the wind tunnel, it was found that the recorder reading continued to rise till it reached a maximum over a period of 20-30 minutes. This proved to be due to settling of the dust on the lenses. To avoid this, two windows of thin glass were placed in position at the points where the apparatus was connected to the wind tunnel. However it was found that the dust particles again settled on the glass surfaces making them dirty, and a steady rise in the recorder reading was still obtained. This is shown in Fig. 11.

An alternative transparent material was sought and was found in thin sheets of transparent "Acetate".[38a] This material was completely successful with little dust collecting on its surface. The recorder trace obtained, using this material,

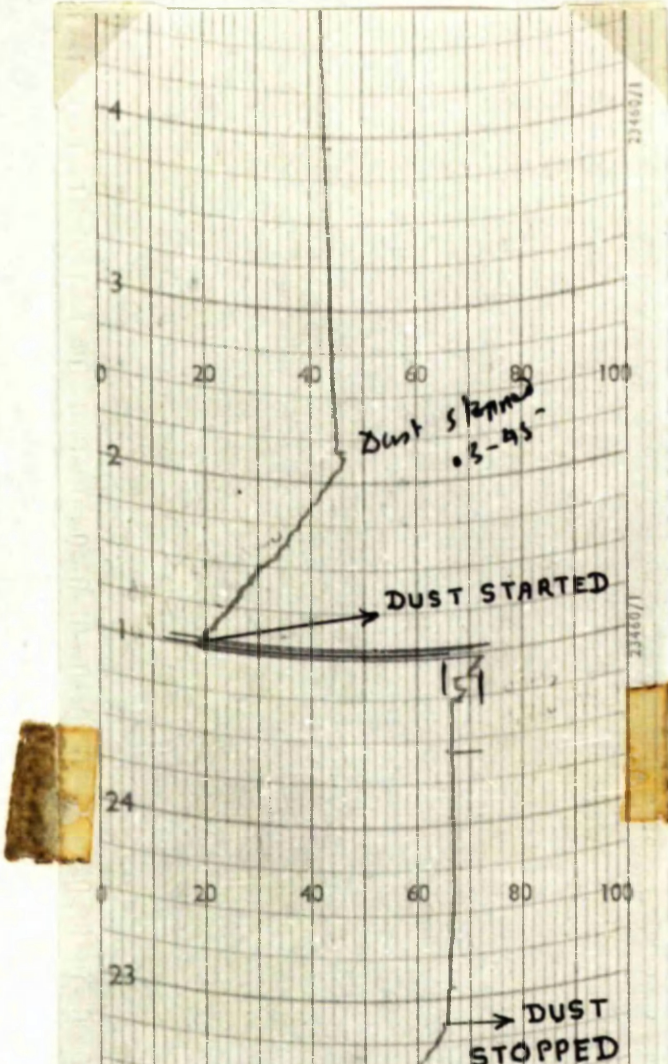

DUST STARTED
DUST STOPPED
DUST STARTED
SENSITIVITY 100
RECORDER SPEED 6"/HR.

FIG. 11

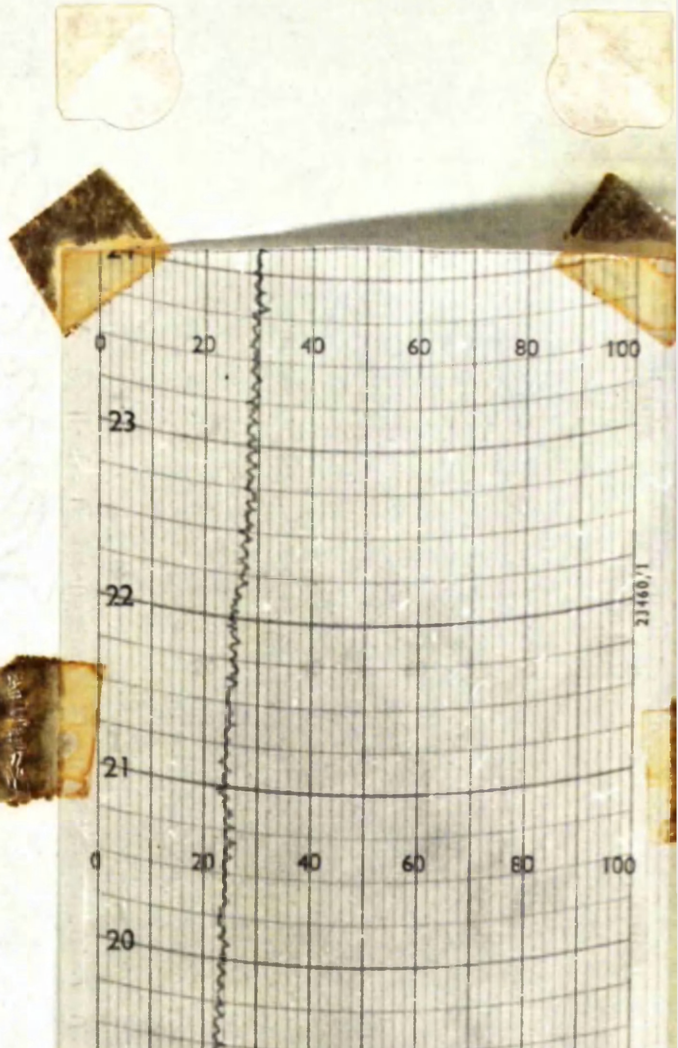

DUST STARTED
SENSITIVITY 100
RECORDER SPEED 6"/HR.

FIG. 12

is shown in Fig. 12, where a residual drift due to electronic instability is still apparent.

So far the recorder was running at 6 in./hr. speed and S/100 (moderate) sensitivity. With these conditions and about 600 p.p.c.c. dust concentration, a 6 per cent change in the recorder reading was obtained. Moreover it can be seen that the trace is zig-zag.

To investigate further the underlying structure of this zig-zag trace, a recorder of the same type but of higher chart speed was installed. Dust was injected into the wind tunnel with the air velocity set at 100 ft/min., the photomultiplier unit set at S/100 sensitivity, and the dust machine adjusted to give low dust concentration (from previous experiment about 600 p.p.c.c.) When the recorder was showing a steady reading and no electronic drift (i.e. about 10 minutes from the start of dust injection) practically continuous dust sampling was carried out. This was possible because of the two thermal precipitators being available. When one was sampling, the other was unloaded and recharged with new cover glasses, thus ready for use. The recorder trace obtained is shown in Fig. 13.

This sampling procedure was continued for about an hour and 6 dust samples were taken by the two thermal precipitators. Finally the dust samples were evaluated using an Automatic Particle Counting Machine. The results are shown in Table 6.

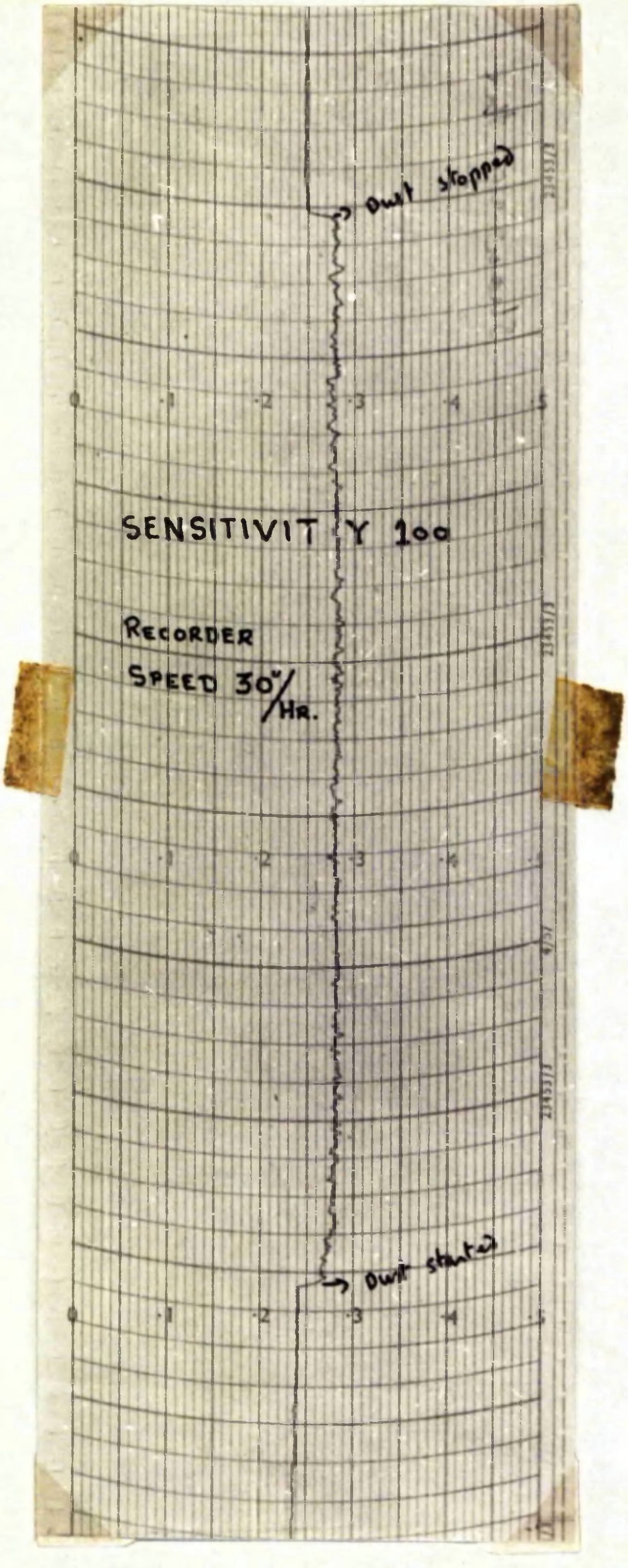

Dwt stopped
SENSITIVITY 100
RECORDER
SPEED 30"/HR.
Dwt started

FIG. 13

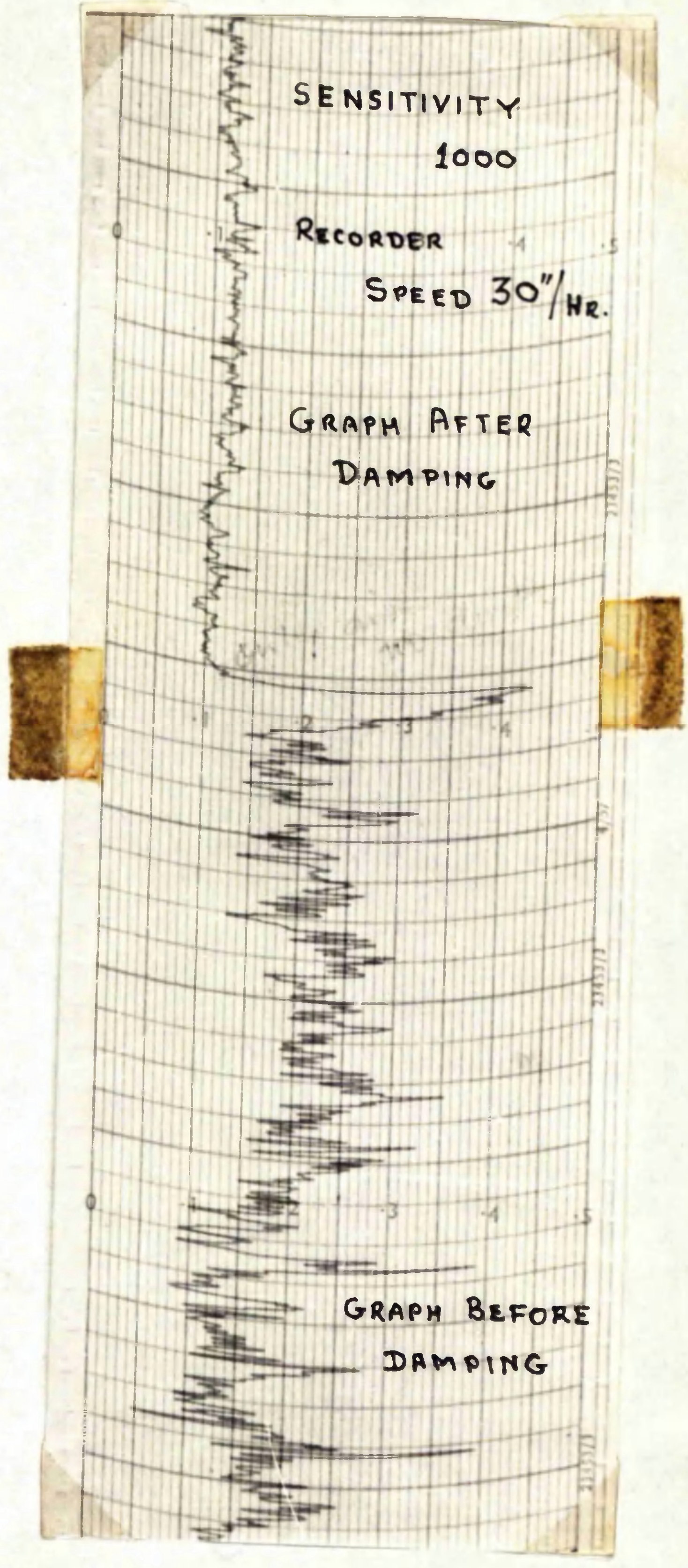

SENSITIVITY
1000
RECORDER
SPEED 30"/HR.
GRAPH AFTER
DAMPING
GRAPH BEFORE
DAMPING

FIG. 14

TABLE 6.

Fluctuations in the Dust Concentration

Slide No.	Dust Concentration p.p.c.c.	Recorder
1	594	Graph is shown in Fig.13.
2	665	
3	511	
4	509	
5	490	
6	533	

The results showed that while there was little significant overall variation in the dust concentration as given by the thermal precipitator, the zig-zag trace appeared to indicate quite large momentary changes in the dust concentration.

The sensitivity of the recorder was increased ten times and the large fluctuations shown in the lower part of Fig.14 were obtained. The zero corresponding to dust-free air was now well off the scale on the left hand side of the chart. Although a useful record of momentary changes in dust concentration had now been obtained an average value of dust concentration could only be obtained by damping the fluctuations by connecting a suitable resistor (575 ohms) across the recorder terminals. The damped recorder trace is shown in the upper part of Fig. 14.

The unit was thus used thereafter merely as a qualitative monitor of dust concentration variations rather than as a quantitative measuring instrument. It was realised that the photomultipliers would require stronger illumination than that available before quantitative measurement of dust concentrations could be attempted.

SECTION III

Automatic Particle Counting Machine

1. A Method of Automatic Particle Counting and Sizing:

There has long been a need for an instrument which could count and size small particles on a microscope slide independent of human agency. With visual counting of particles there is always a chance of human error and very well trained personnel are required. Apart from this visual counting is most tedious and time consuming.

Modern electronics has provided a solution to this problem and the work of Walton, Hawksley etal[39] has culminated in the automatic particle counting machine of Casella Electronic Coy., London.[40]

The Casella machine uses a wide track scanning technique, as it has a number of advantages, viz: (a) no critical timing circuits are required to measure the "intercept length", the only thing required being the recording of the amplitude of the voltage pulse which is produced by a particle passing under a scanning slit.
(b) the particle produces a voltage pulse whose amplitude is proportional to the amount passing under the slit.
(c) the instrument can be set to suit the optical characteristics of the material being sized.

2. Theory of Operation of the Unit: The number of "intercepts" ϕ (W), (intercept here means the number of times the slit has been obscured by the particles),

obtained by scanning a length L of the specimen with a slit of width W and sensitivity Z is given by the equation

$$\phi(W) = N(W - 2Z + \bar{d})L$$

where N = the number of particles per unit area oversize Z

and $\bar{d}$ = the mean size oversize Z

Sensitivity Z may be defined as the slit area obscured by a particle, which should be greater than Z, if the particle is to be recorded. (See Fig. 15)

The number 'N' of particles per unit area is obtained by scanning a specimen twice with two slits of different width W, but a constant Z value.

$$\therefore \quad N = [\phi(W_2) - \phi(W_1)]/(W_2 - W_1)L$$

A straight line graph with slope equal to NL is obtained if $\phi(W)$ is plotted against W for a constant value of Z.

To obtain size distribution the method of counting is extended by using various values of Z. This is shown in Fig. 16.

The amplitude of the voltage pulse is proportional to the amount h_p of the slit W obscured by the particle and is a maximum when the slit is fully obscured. The amplitude discriminator setting is calibrated from 0 - 100, this is called the P value and is related to the sensitivity value Z by PW equal to Z.

Thus the original equation may be rewritten as

$$\phi(W) = N[W(1 - 2P) + \bar{d}]L$$

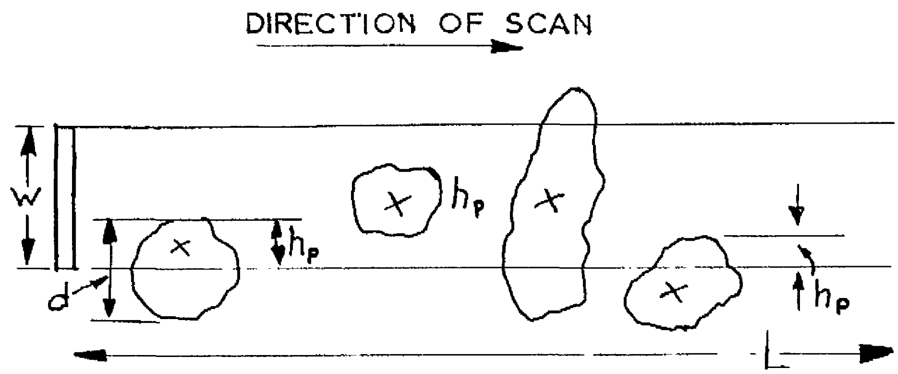


FIG.15 RECORDING OF A PARTICLE BY SLIT W

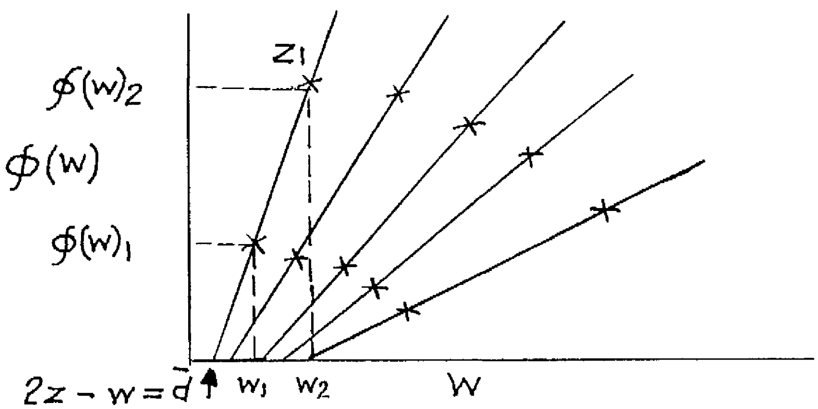


FIG.16 REPRESENTATION OF RESULTS FROM A. P. C. M/C.

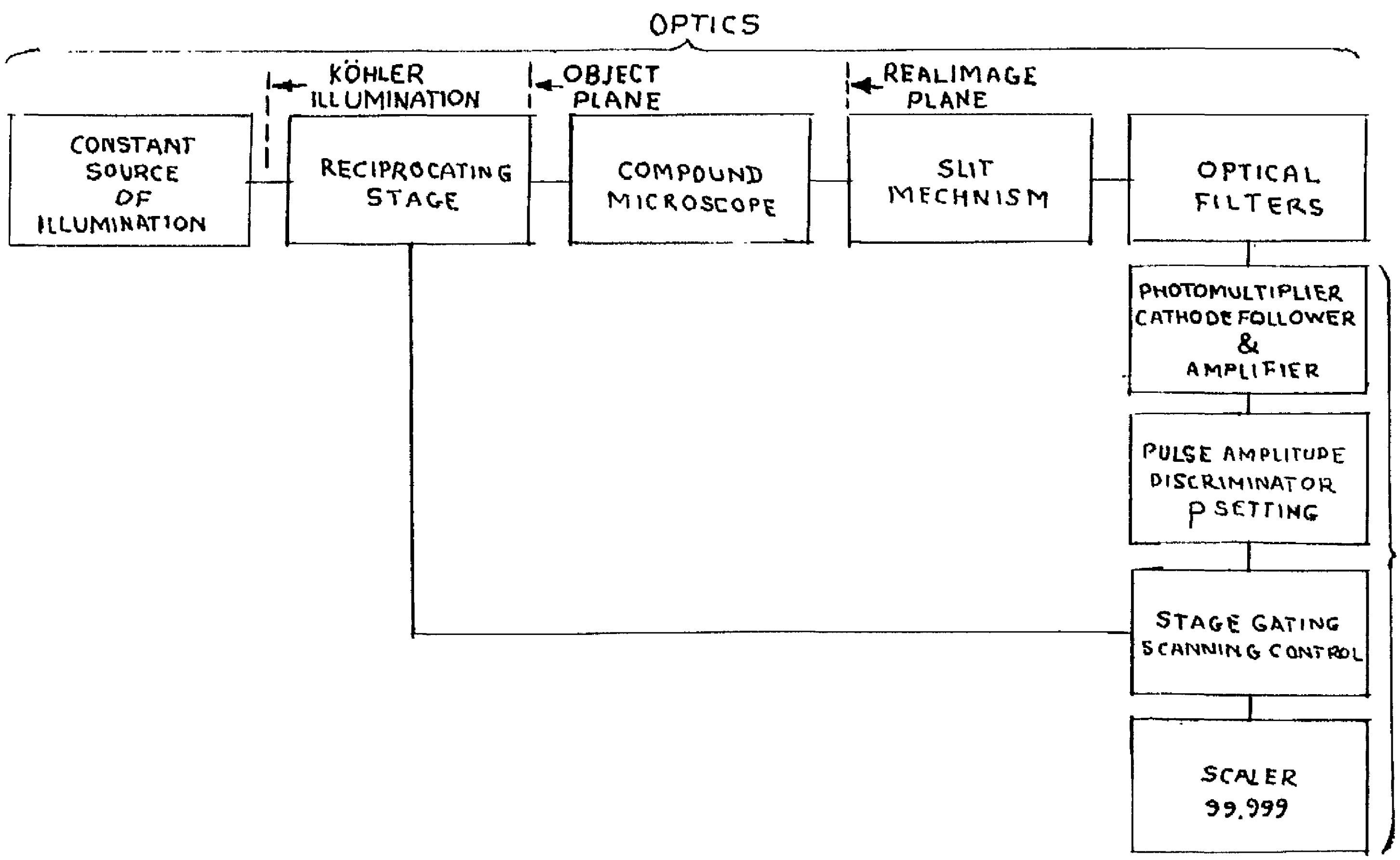


FIG.17 BLOCK DIAGRAM OF AUTOMATIC PARTICLE COUNTER

3. <u>Description and operation of the Casella instrument</u>

The instrument is shown schematically in Figs. 17 and 18, and is housed in a console unit. The console unit may be further subdivided in 5 separate units.

(a) All the amplitude discriminator settings and zero base line settings are located on the left hand side of the instrument, (b) in the centre is the microscope with its scanning stage, (c) the decatron scalers are on the right, (d) below the microscope is the reciprocating stage which is operated by an electric motor with an automatic reversing system, (e) the automatic controls are on a panel siuated below the stage.

A filament type of lamp is used for illumination as it gives high intensity when using Kohler's system and uniform illumination over the field of object.

Initially a programme is worked out according to the size - distribution required. The programme is shown in Table 7.

The machine is switched on and allowed to warm up for a few minutes. Then the light is switched on and meter value is set at 7.8 amps.

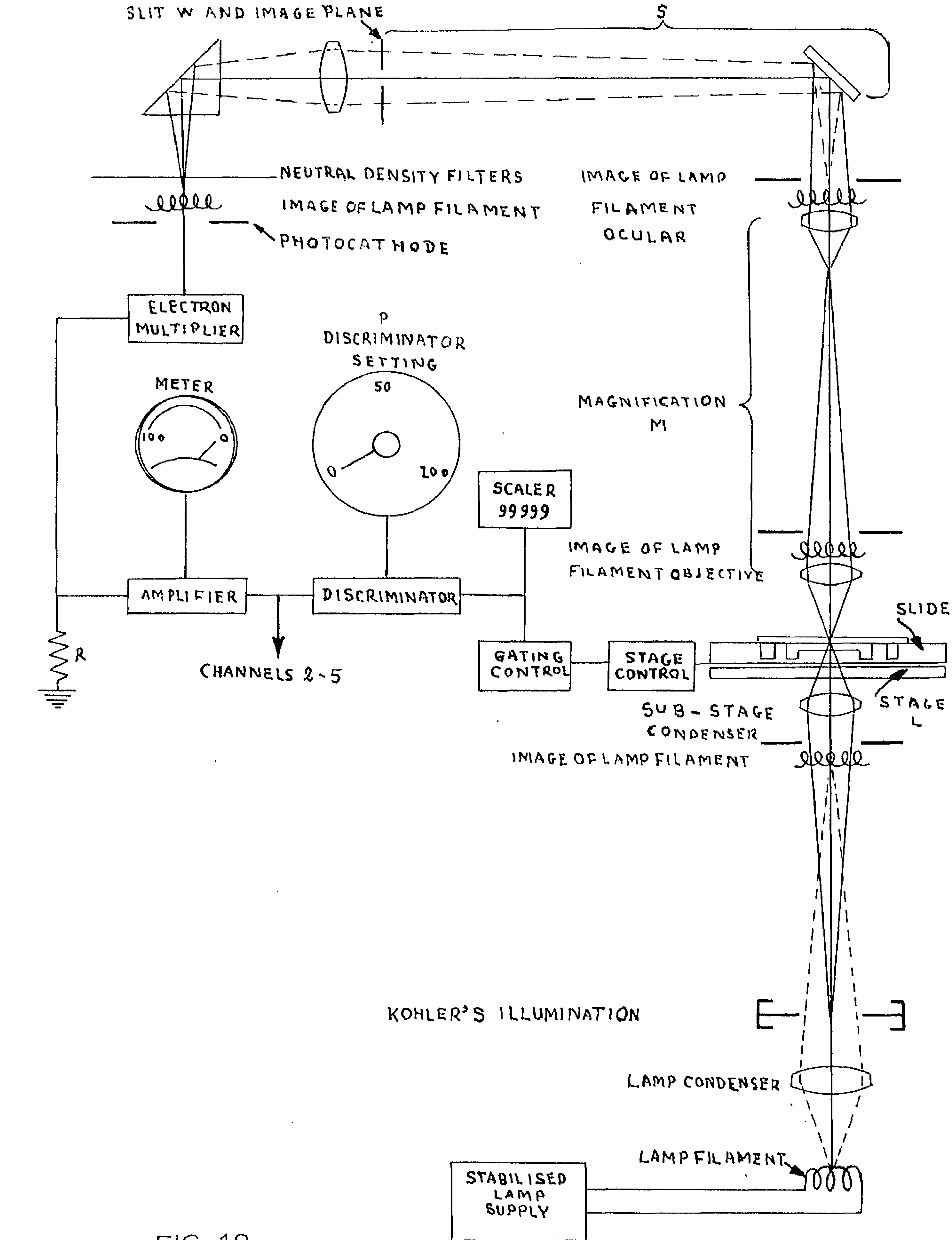


FIG. 18

SCHEMATIC DIAGRAM OF AUTOMATIC PARTICLE COUNTER

TABLE V.

Programme for Automatic Particle Counter

Optics : Baker 8.0 m.m. objective x 25 ocular N.A. (numerical aperture) = 0.5

Magnification = 500 times

Z	P	W	M
0.5 µ	0.707	0.707	9.646
"	0.500	1.000	9.500
"	0.354	1.414	9.293
"	0.250	2.000	9.000
1.0 µ	0.707	1.414	9.293
"	0.500	2.000	9.000
"	0.354	2.828	8.586
"	0.250	4.000	8.000
2.5 µ	0.707	3.536	8.230
"	0.500	5.000	7.500
"	0.354	7.072	6.465
"	0.250	10.000	5.000
5.0 µ	0.707	7.072	6.465
"	0.500	10.000	5.000
"	0.354	14.14	2.930 (f)

Where (1) Z = Particle size in microns, (2) P = amplitude descriminator value, (3) W = slit width = Z/P in microns, and (4) M = micrometer setting for, W = $10 - \frac{W \times \text{magnification}}{1000}$

The slide is now mounted on the reciprocating stage in such a way that the bright spot of light is exactly below the centre of the dust strip. This setting is obtained by operating the two micrometers which are fixed to the stage. The slide is fixed in position by means of two clips. The particles are focessed with a 8.0m.m. objective on the small screen just in front of the gate, and the slit set at the desired value. The pulse meter is adjusted to read 0 with clear filter and 100 with opaque filter. The optical density of a few particles is determined by bringing each of them in turn before the slit to produce a pulse on the meter. The average optical density so calculated is used to enable the discriminator to be set at the desired value. When the stage motor is switched on, the stage travels 80 times forwards and backwards, reverses after 40 scans and takes a track differing by 50 microns from the original. Each scan is of 10.0 m.m. in length. The slit is instantaneously obscured by particles and if the particle produces a pulse greater than the discriminator set value, it is recorded on the decatron scalers. The procedure is now followed on simply by changing slit setting, until the programme is worked out.

A number of objectives and oculars may be used depending on the particle size-ranges of interest and the manufacturers of the instrument provide a range from which one may select the most suitable.

To obtain reproducible results from the counting machine, the electronic "noise" caused by using a very small slit and extreme gain, must be reduced to a minimum. The light falling on the photo - cathode increases as the square of the aperture of the system. This means that one must choose an objective with a proper aperture not only to get the correct size of the particle from its image but also to keep electronic "noise" low by getting through as much light as possible.

The magnification of the optical system is checked by using a stage micrometer.

The dust on a thermal precipitator slide was counted and sized using a variety of arrangements of objectives and oculars, various size-distribution programmes were also tested. It was finally decided that the most suitable arrangement for the purpose of this work was the magnification produced by a 4.0 m.m. objective and a x6 ocular. A selection of P values was also made by counting a slide with numerous P settings and the best 5 P values were taken for programming.

4. Specimen calculation of size distribution:

The programme used gave the size-distribution in the following form:

Number of particles ins.	Size ranges			
	0.5 - 1μ	1 - 2.5μ	2.5 - 5μ	> 5 μ

From the results given by the scalers, graphs of W against $\phi(W)$ were plotted as previously mentioned. This is shwon in Fig. 19. Each Z line on the graph represents the number of dust particles over size Z. (Z represents the lower limit of the particle which will be counted).

$\therefore$ No. of particles/unit area $= [\phi(W_2) - \phi(W_1)]/(W_2 - W_1)$

where L = total length scanned = 800 m.m.

No. of particles/unit area on cover glass A = 658.4

No. of particles/unit area on cover glass B = 889.4

$\therefore$ Total No. of particles = (658.4 + 889.4) 20 = 30,956

Note: the photomultiplier counts particles only within $10 \times 2 = 20$ sq. m.m. area on the slide.

$\therefore$ Dust concentration in p.p.c.c. $= \dfrac{\text{total no. of particles on slide}}{\text{volume of air sampled}}$

$= 1345$ p.p.c.c.

The size-distribution of particles is given in Table 8.

TABLE 8

Size-distribution of Particles

	Cover Glass A				Cover Glass B			
'Z'	> 1/2μ	>1μ	>2.5μ	>5μ	>1/2μ	>1μ	>2.5μ	>5μ
Gradient	658.4	225.5	57.5	22.04	889.4	325.6	86.00	25.44
Size-range	1/2-1μ	1-2.5μ	2.5-5 μ	>5μ	1/2-1μ	1-2.5 μ	2.5-5 μ	>5μ
No. of particles	422.9	168.6	35.4	22.04	563.8	239.6	60.56	25.44
Per cent	64.23	25.52	5.38	3.35	63.39	26.94	6.81	2.86
Mean per cent	63.81	26.23	6.09	3.10	-	-	-	-

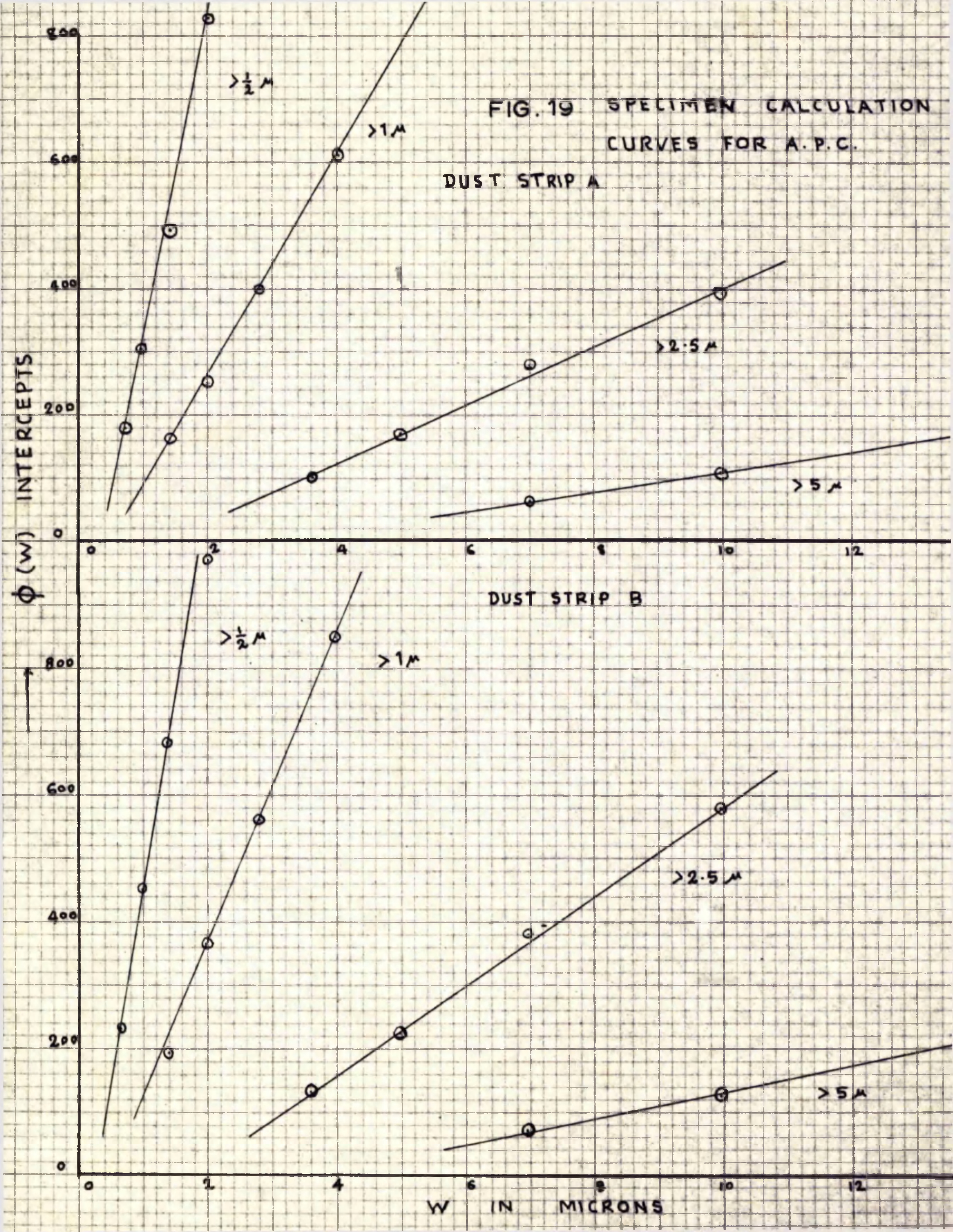


FIG. 19 SPECIMEN CALCULATION CURVES FOR A.P.C.
DUST STRIP A
DUST STRIP B
ϕ (W) INTERCEPTS
W IN MICRONS
$>\frac{1}{2}\mu$
$>1\mu$
$>2{\cdot}5\mu$
$>5\mu$
800
600
400
200
0
2
4
6
8
10
12

5. Verification of the reproducibility of the counting machine:

Six thermal precipitator slides were taken in the wind tunnel under controlled conditions. Each slide corresponded to the different dust cloud concentration. For each slide six replicate sets of observations were made, the setting of the instrument being deliberately disturbed and readjusted before each set of observations.

The results are shown in Tables 9, 10 and 11.

Note:

One difficulty arises when using the machine for Thermal Precipitator slides mounted in the usual way (Coal Board System If the cover glass is not exectly parallel with the microscope slide, a faulty count is obtained when a 20 m.m. oil immersion objective is used, due to the variations in focus over the dust strip. A method of overcoming this has been developed by Stewart of the R.C.S.T. Mining Department, and although not essential when a 4.0 m.m. objective is employed, was used in all our work. A strip of lens cleaning paper is laid between the two glass surfaces using dilute glue solution. This effectively holds them parallel.

From the results it is quite clear that 97 per cent of the coal dust collected by the thermal precipitator is under 5 microns in diameter.

The variations small though they be in the count for the same slide, are possibly due to focussing error, as it is quite difficult to obtain the same focus after disturbing

TABLE 9

Variation of Results on one Slide

Slide Ref.	Air Velocity ft/min.	Dust Concentration p.p.c.c. Measurement No.						
		1	2	3	4	5	6	Average Dust Concentration
1	100	516	596	711	691	725	699	643
2	200	1345	*1980	1463	1460	1480	1403	1522
3	700	650	644	736	834	883	824	762

TABLE 10

Standard Deviation of the Results in Table 9

Slide Ref.	1	2	3
Standard Deviation	81.80	102.30	92.26

*Not considered for calculating standard deviation.

TABLE 11.

Showing variation in size-distribution

asurement Number	Total Number of Particles on the Slide	% Size Distribution on Glass A				% Size Distribution on Glass D			
		½ - 1u	1 - 2.5u	2.5-5u	5u	½ - 1u	1-2.5u	2.5-5u	5u
Vol. 100									
1 ft./min.	25,784	58.25	24.91	19.52	2.32	64.46	23.23	7.82	4.18
2	27,815	60.31	29.50	8.20	2.11	56.82	32.73	6.72	3.73
3	35,544	72.62	17.42	7.55	2.42	63.18	24.8	6.92	5.10
4	34,544	59.85	27.32	10.04	2.79	53.50	38.27	6.49	1.70
5	36,244	63.82	24.74	8.77	2.65	54.01	33.68	9.04	3.26
6	34,932	62.73	25.01	-	-	61.74	29.32	6.09	2.85
Vol. 200									
1 ft./min.	30,956	64.23	25.52	5.38	3.35	63.39	26.94	6.81	2.86
2	45,726	63.20	27.49	7.14	2.16	63.93	24.08	9.17	2.82
3	32,654	50.77	36.54	8.77	3.94	60.92	27.33	7.89	3.86
4	32,592	54.69	35.14	5.84	3.02	53.31	34.69	8.65	3.34
5	33,139	63.93	27.54	6.67	2.36	54.03	36.68	6.57	2.73
6	32,393	62.62	27.70	6.45	3.22	53.34	33.05	8.96	4.78
Vol. 700									
1 ft./min.	27,310	63.60	27.53	5.97	2.94	52.84	36.28	8.01	2.22
2	27,940	52.21	37.08	7.82	2.88	50.02	36.87	9.94	3.17
3	30,908	54.08	34.25	9.21	2.32	57.19	33.33	6.18	2.50
4	35,031	57.99	31.80	7.22	2.99	59.65	29.54	7.60	3.08
5	37,088	65.32	25.10	6.65	2.95	55.33	32.45	9.17	3.07
6	34,610	52.64	36.07	7.88	3.41	58.11	30.96	8.15	2.77

the slide. The average opacity of the coal particles was found to be 60 per cent and this was kept constant for all the slides. Variations in the opacity were automatically compensated for by the instrument.

The standard deviation (σ) for all the slides can be seen to be below 100 p.p.c.c. when replicate determinations were made in spite of the fact that the three slides selected for this test widely differed in dust concentration. It was found that the ϕ(W) value varied by $\pm$ 5 per cent when replicate determinations were made for a particular W and P setting.

The main advantage of an Automatic Particle Counter over visual counting would appear to be as follows:-

(1) The track scanning covers almost all the particles on the dust strip as compared to visual counting where only particles present in two or three traverses are counted. Thus it is more reliable.

(2) Human error is reduced to a constant minimum. The unit is most useful where skilled personnel are not available for counting work.

(3) Counting is done more speedily. Even for a beginner, an hour is sufficient to make a total count and complete size-distribution.

From experience it looks as if the machine will work most efficiently and accurate particle counts w ill be obtained for $2.0 - 6.5 \times 10^4$ particle density.

SECTION IV

Dust Suppression in Wind Tunnel by High Pressure Water Sprays

1. Scope of Work: Glen[24] and Hunter[25] and Jaap[41] have all reported on dust suppression with small spray nozzles under laboratory conditions. The water pressure, however, was never greater than 500 p.s.i. and the spray efficiency was in general found to be quite small. The dust concentrations tested were in the region of 6000 p.p.c.c; rather high for comparison with mining conditions.

Due to improvements in apparatus as already described, it was now possible to generate dust clouds containing only 350 p.p.c.c. of sizes $^1/_2$ - 5 microns. Moreover it was now found to be possible to generate water sprays at pressures up to 5000 p.s.i. This in conjunction with the availability of the automatic particle counting machine made the study of dust suppression at practical dust concentrations with high pressure water sprays quite feasible.

It was decided to consider the effect of the following variables:

(1) Droplet size.

(2) Quantity of water required.

(3) Relative velocity between a dust particle and a water droplet.

(4) Position of the spray nozzle.

(5) Concentration of the dust cloud.

2. <u>Spraying Unit</u>: A three stage reciprocating pump manufactured by G. and J. Weir[42] of Glasgow, was used to obtain high pressure atomisation. An air cushion cylinder was installed in the delivery line of the pump to even out the piston pulses and to give a steady reading on the pressure gauge. The water pressure could be very easily controlled by manipulating the speed of the motor and the by-pass valve.

All the connections were made in heavy gauge $^1/_8$ in. I.D. copper tubing and all joints were welded or brazed. The characteristic curve for the atomising pump for delivery of water through different orifice sizes is shown in fig.20.

3. <u>Nozzle Characteristics</u> A detailed drawing of the nozzle is shown in fig. 21. It can be seen to consist of a nozzle cup and a grooved plug. Six nozzle cups were used in the tests, the same plug being used throughout.

The diameter of the cup, the depth and the width of the groove were measured by means of a travelling microscope.

The throughputs and cone angles for all these six spray-nozzles were determined using the above pump at pressures from 50 - 500 p.s.i. The technique was similar to that described for the large nozzles in Section V. The throughput curves obtained are drawn in fig.22. Since the pressure gauge was only a short distance from the nozzle, pressure losses in the pipeline were negligible.

FIG. 20 CHARACTERISTIC CURVE OF ATOMISING PUMP.

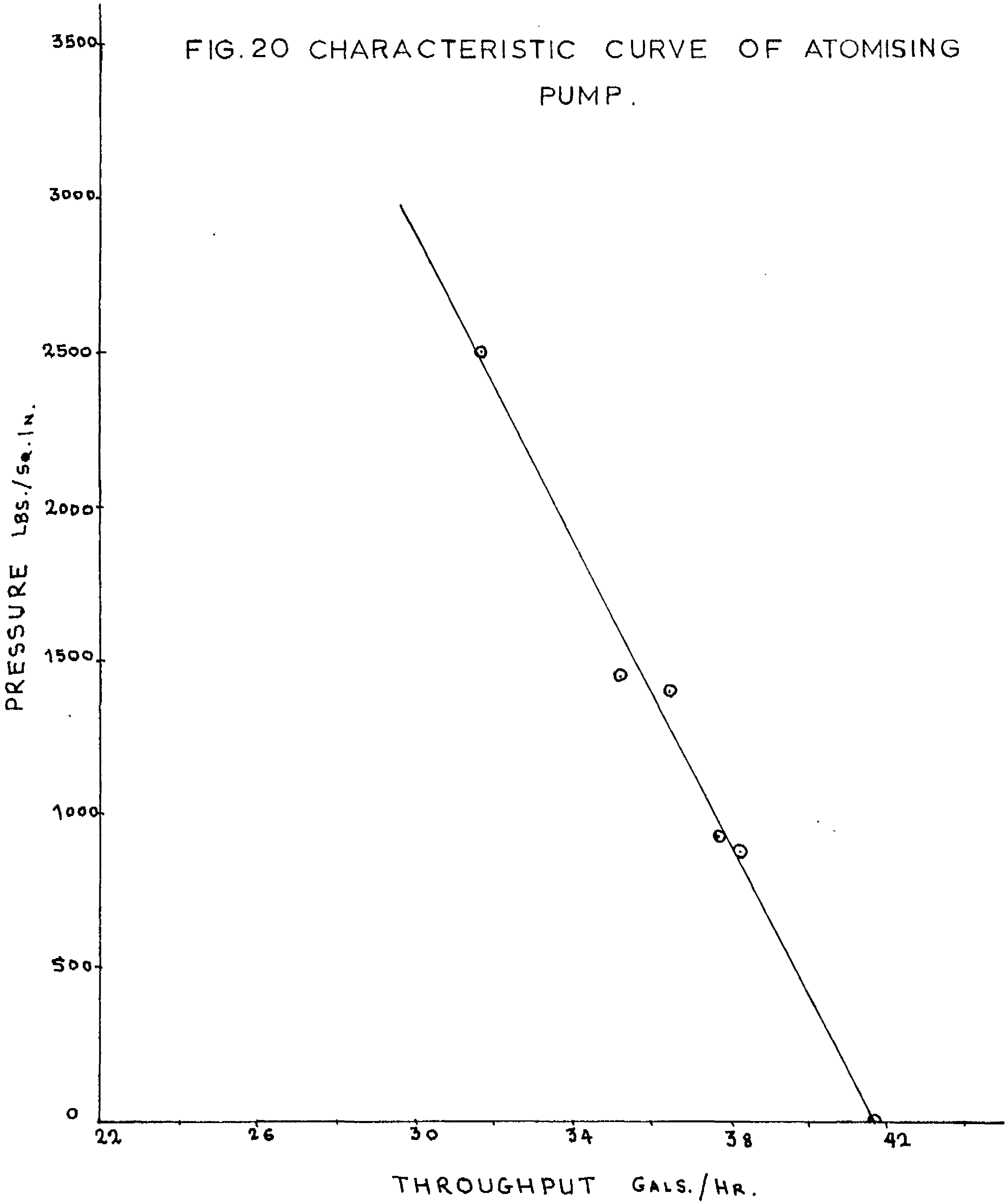
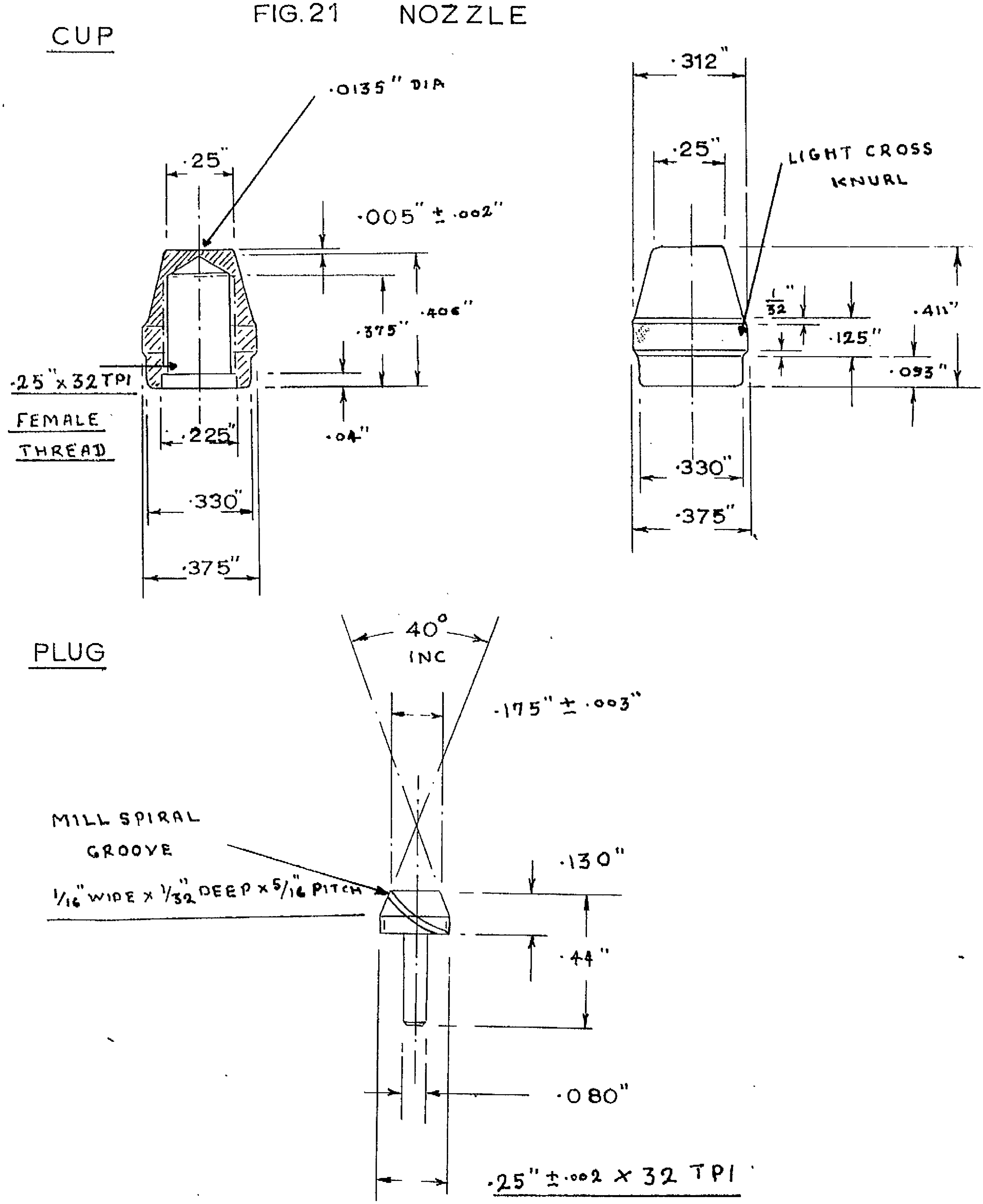


FIG. 21 NOZZLE



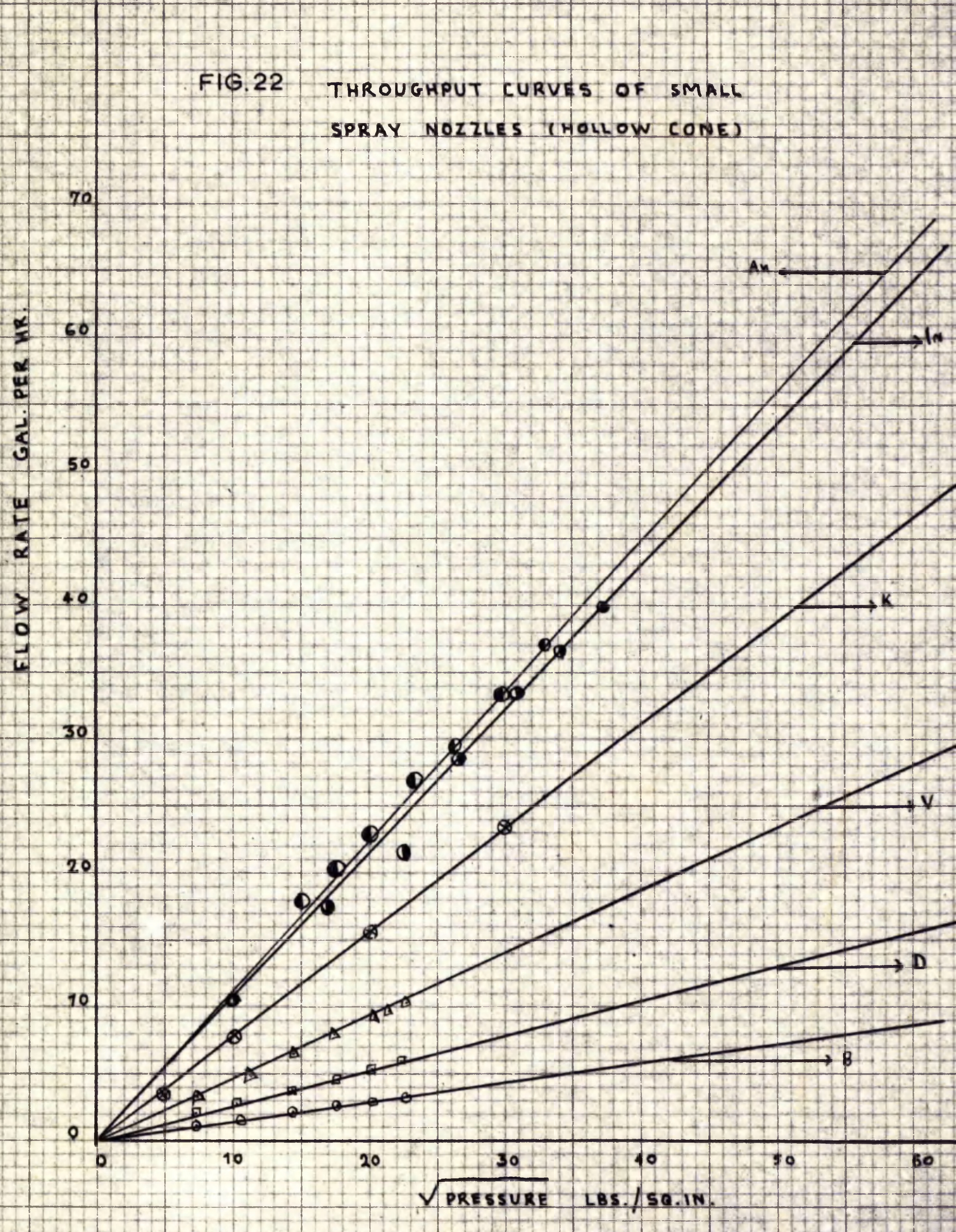


FIG. 22
THROUGHPUT CURVES OF SMALL SPRAY NOZZLES (HOLLOW CONE)
FLOW RATE GAL. PER HR.
√PRESSURE LBS./SQ.IN.
0
10
20
30
40
50
60
70
An
In
K
V
D
B

To produce a solid cone spray, a 0.02 in. diameter hole was drilled through the centre of one of the plugs. The throughput curves of the nozzles using this plug are shown in fig.23.

The characteristics of the nozzles using a solid plug (hollow cone spray) are shown in Table 12.

TABLE 12

Nozzle Characteristics

Nozzle Reference	Orifice Diam. inches	Ratio:- Orifice Length / Orifice Diam.	Flow No. (Fn) Imp.gal. / hr/lbs/sq.in.	Mean Coeff.of Discharge (C)	Cone Angle (2α) degrees
B	0.0139	0.36	0.1584	0.553	50
D	0.0355	0.141	0.2679	0.141	85
V	0.065	0.077	0.4522	0.0715	112
An	0.0984	0.051	1.15	0.0771	112
In	0.1298	0.038	1.028	0.0427	115
K	0.1608	0.031	0.777	0.020	160

The arithmetic mean droplet diameters ($\Sigma nD_p/n$) obtained for four of the nozzles using a solid plug at pressures 50 - 500 p.s.i. are given in Table 13.[25]

FIG. 23 THROUGHPUT CURVES OF SMALL SPRAY NOZZLES (SOLID CONE)

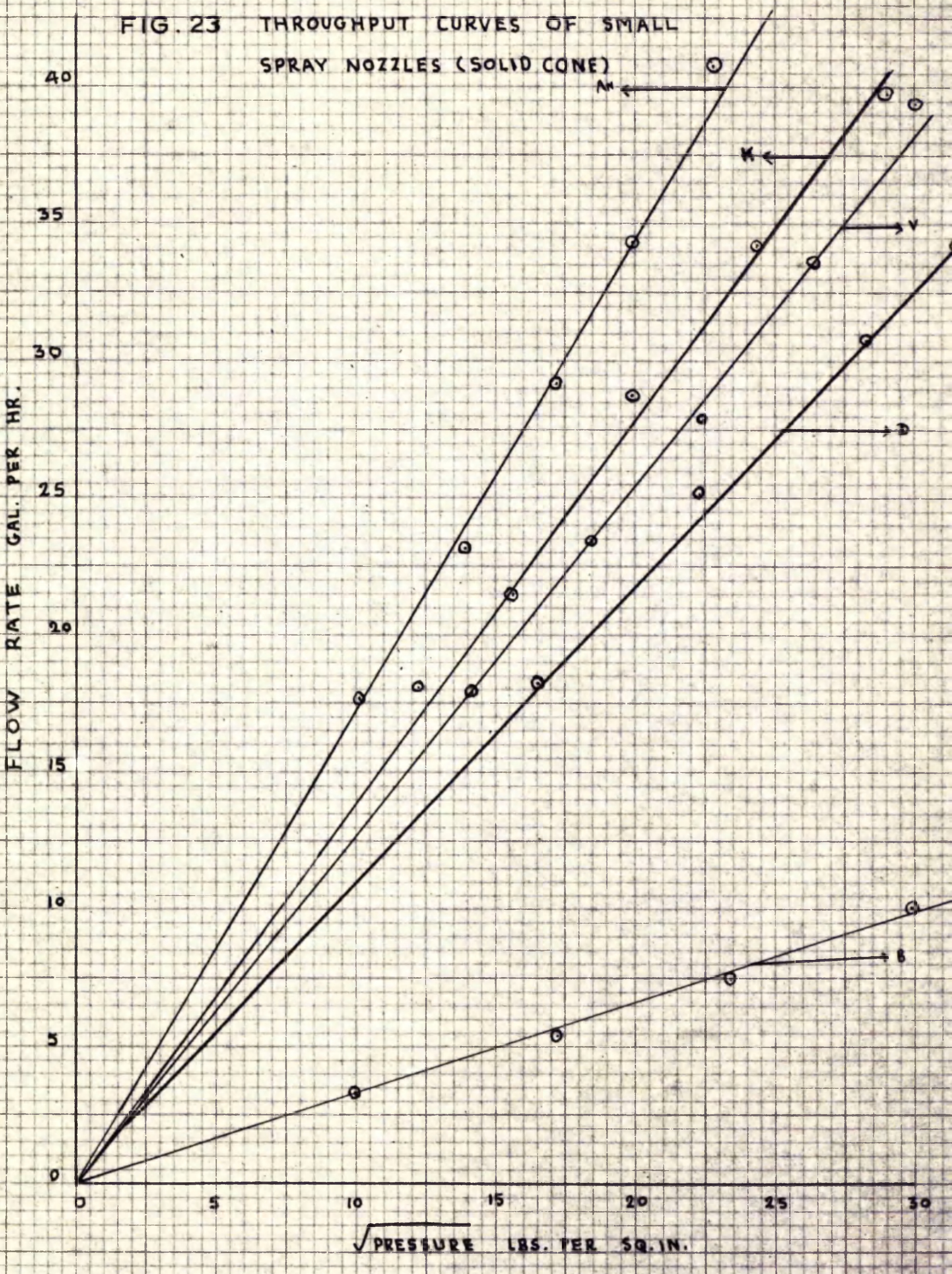


TABLE 13

Average Droplet Diameter in microns
(droplets sampled 18 inches from nozzle)

Nozzle Ref.	Pressure lbs/sq.inch							
	50	60	70	80	150	250	400	500
	Droplet Diameters (microns)							
B	55.1	56.6	46.0	46.2	38.4	34.2	28.1	24.9
D	42.9	53.7	42.7	38.2	39.2	31.9	27.6	24.6
V	78.4	62.5	60.0	51.1	45.8	42.0	37.4	33.0
An	88.0	69.8	59.4	65.6	46.6	45.6	39.6	36.1

4. <u>Experimental Technique</u>: The experiments were performed on moving dust clouds by setting the spray nozzle in the axis of the tunnel and spraying water directly upstream against the flow of airborne dust. The dust concentration samples were taken by means of thermal precipitators placed before and after the spray.

The top and the bottom thermal precipitators were placed 20.5 ft. and 48.0 ft. away from the dust ejector. The spray nozzle was placed between the two thermal precipitators 9 ft from the top thermal precipitator and 30 ft. away from the dust ejector. The perspex window was very useful in setting the spray nozzle in place and for other visual observations.

The fan was switched on and the air velocity inside the wind tunnel was set at the desired value by manipulating the radial-leaf damper and observing the corresponding change in the reading of the calibrated hot-wire anemometer. Before starting the dust flow this hot-wire anemometer was taken out and the hole in the tunnel wall sealed with a rubber bung.

The dust cloud was developed at the top end of the tunnel by starting the dust injecting machine which was adjusted beforehand for speed, dust collecting groove, etc. The water pump was switched on and the water pressure at the spray nozzle was adjusted to the required value by manipulation of the speed of the motor and the by-pass valve. The spray cone was inspected through the perspex window and any necessary final adjustments made to the nozzle position so that the spray was accurately centered on the axis of the tunnel.

At least two minutes were allowed for conditions to reach equilibrium inside the wind tunnel. The two thermal precipitators which had been previously loaded were then switched on and the current adjusted to 1.3 amp. After about a minute the air was simultaneously sampled for its dust content, before and after the spray by the two thermal precipitators. The run was continued until a suitable volume of air had been sampled.

When the run was in progress, the spray pressure, the air velocity, the working efficiency of the dust machine, the air sampling rate, etc., were checked periodically.

Finally everything was switched off, the thermal precipitators were carefully unloaded and recharged with clean cover glasses. The cover glasses with the dust strips were mounted on a standard microscope slide (3 in. x 1 in.) as described in Section III, for counting on the Automatic Particle Counter.

5. <u>Test conditions</u>: Tests were performed under the following conditions and the results are shown in the tables which follow.

(i) The effects of varying the water pressure for four nozzles at high dust concentration and 110 - 130 ft./min. air velocity. This is shown in Tables 14, 15, 16 and 17. In all cases the nozzle cup was fitted with a solid plug and a hollow cone spray was obtained.

TABLE 14

Effect of Spray Pressure on Dust Suppression at Constant Air Velocity

Air Velocity = 110 ft./min.

Flow No. = 0.4522

Cone Angle = 112°

Nozzle V

Water Pressure lbs/sq.in.	Dust Concentration p.p.c.c.		No. of Particles knocked down per cc.of air	Per cent reduction in dust concentration %
	Before Spraying	After Spraying		
55	909	818	91	10.00
155	887	800	87	9.82
250	762	675	87	11.42
350	814	625	189	23.25
450	736	493	243	30.30

The above results were typical of the effect of sprays on airborne dust in the tunnel when the water pressure was less than 500 p.s.i. When the spray nozzles of smaller orifice than the above were used at this pressure no apparent reduction in the dust concentration could be obtained. Table 15 shows the effect of higher water pressures on the suppression of dust in the tunnel.

TABLE 15

Effect of higher spray pressure on dust suppression at constant air velocity

Air Velocity = 130.0 ft./min.

Dust Machine groove = Plate A (middle)

Nozzle Ref.	Dust Concentration Range p.p.c.c.	*Efficiency per cent at water pressure lbs/sq.inch									
		500	1000	1500	1700	1800	1900	2000	2200	2500	2800
D	1700 - 2400 (1)	22.65	32.40	35.60	-	-	37.50	-	-	42.0	55.20
V	2150 - 2580 (2)	37.00	44.00	48.00	-	-	-	49.70	-	65.10	67.30
An	2555 - 3285	73.25	73.20	66.00	-	64.00	-	-	66.00	-	-
In	2175 - 3560	35.10	61.40	66.20	65.10	-	-	57.80	-	-	-

$$* \text{ Efficiency} = \frac{\text{No. of dust particles knocked down (p.p.c.c.)}}{\text{No. of dust particles in the dust cloud (p.p.c.c.)}} \times 100$$

(1) and (2) In these tests the average dust concentrations of 2050 and 2428 p.p.c.c. were used for calculating efficiencies. In the other tests each efficiency was calculated from the particular initial dust concentration in the tunnel at the time of the test.

TABLE 16

Effect of Water Pressure and Water Throughput on Dust-Water ratios

Nozzle Ref.	Flow No. (F_n)	Air Velocity ft./min.	Dust concentration range p.p.c.c.	Dust-water ratios at pressures lbs./sq.in.																	
				500		1000		1500		1700		1800		1900		2000		2200		2500		2800	
				1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
D	0.27	130	1700-2400 (av.2050)	6.45	1.091	6.86	1.171	6.29	1.165	–	–	–	–	5.80	0.983	–	–	–	–	5.70	0.966	6.95	1.
V	0.45	130	2150-2580 (av.2428)	7.62	1.29	6.32	1.170	5.72	0.965	–	–	–	–	–	–	5.14	0.870	–	–	6.04	1.025	5.39	0.
A_n	1.15	130	2500-3000	8.27	1.400	5.37	0.910	2.92	0.495	–	–	3.84	0.650	–	–	–	–	2.82	0.477	–	–	–	–
I_n	1.03	130	1600-3500	2.00	0.339	3.68	0.623	5.06	0.856	3.88	0.656	–	–	–	–	2.62	0.444	–	–	–	–	–	–

1 – No. of dust particles knocked down per c.c. of water 10^6

2 – Weight of coal dust removed per gallon of water sprayed (grains)

[It is assumed in this calculation that the average diameter of the coal dust particle to be 1.54 microns which was obtained after analysing T.P. dust samples taken in the wind-tunnel, using automatic particle counting machine and the density of the coal dust was taken to be 1.279 g./c.c.]

TABLE 17

Effect of Water Sprays on particle size-distribution

Nozzle Ref.	Water Pressure lbs./sq.in.	Dust Concentration Before Spray p.p.c.c.	Dust Concentration After Spray p.p.c.c.	Number per cent of each size remaining after spraying			
				0.5-1 microns	1-2.5 microns	2.5-5 microns	>5 microns
D	2500	2050	1188	57.80	64.25	33.35	65.00
V	2800	2428	796	33.35	33.80	27.60	28.00
An	500	3285	880	26.80	26.35	29.50	24.80
An	2200	2555	857	30.60	39.70	35.40	36.60
In	1000	2175	830	39.10	38.20	36.20	25.70
In	1500	3000	1016	32.10	33.80	27.20	20.20

The size distributions of Table 17 are shown in Figure 24 in histogram form. The height of each column represents the number of dust particles present in that size-range. For convenience the effect of the spray on each size range is shown in the same figure. Each size-range has two heights indicated by the thick horizontal lines. The height shown to the left of the centre line gives dust concentration before spraying, while the height indicated by right hand side of the size-range shows the concentration after spraying.

(ii) The effects of varying air velocity at constant water spray pressure .

The results are shown for two hollow cone spray nozzles in Tables 18(a) and (b).

TABLE 18(a)

Effect of air velocity on airborne dust suppression at high water pressure.

Nozzle: V Water Pressure = 2400 p.s.i.

Air Velocity ft./min.	Dust Conc. before spray p.p.c.c.	Dust Conc. after spray p.p.c.c.	No. of dust particles knocked down per c.c of air	Efficiency per cent
130	2428	850	1578	65.10
250	1960	1165	795	40.60
350	1820	1070	750	41.20
450	1336	828	508	38.10
600	670	421	249	37.20
750	551	300	251	45.50

FIG. 24 PARTICLE SIZE-DISTRIBUTION BEFORE AND AFTER SPRAY

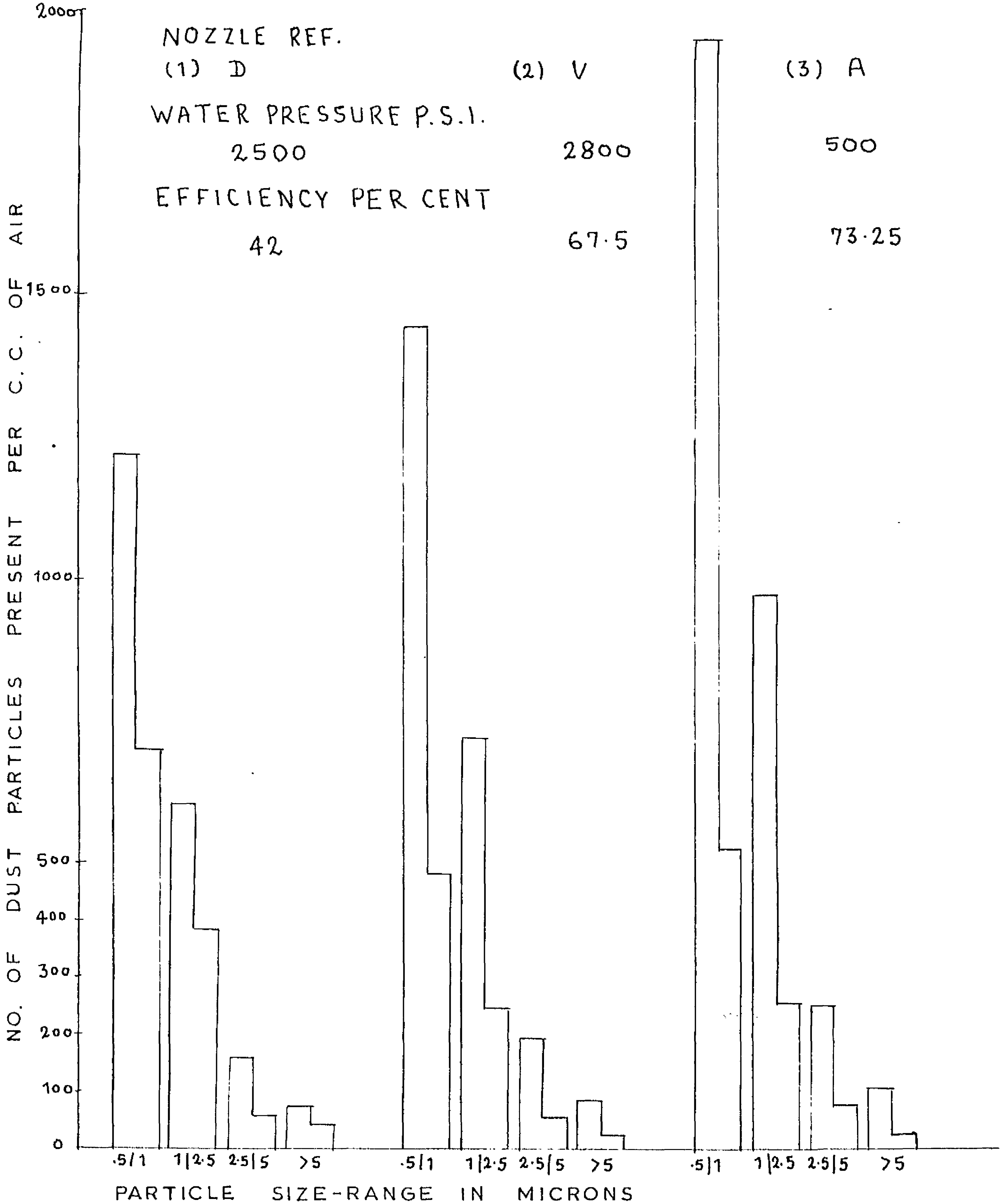


FIG. 24 (CONTD)

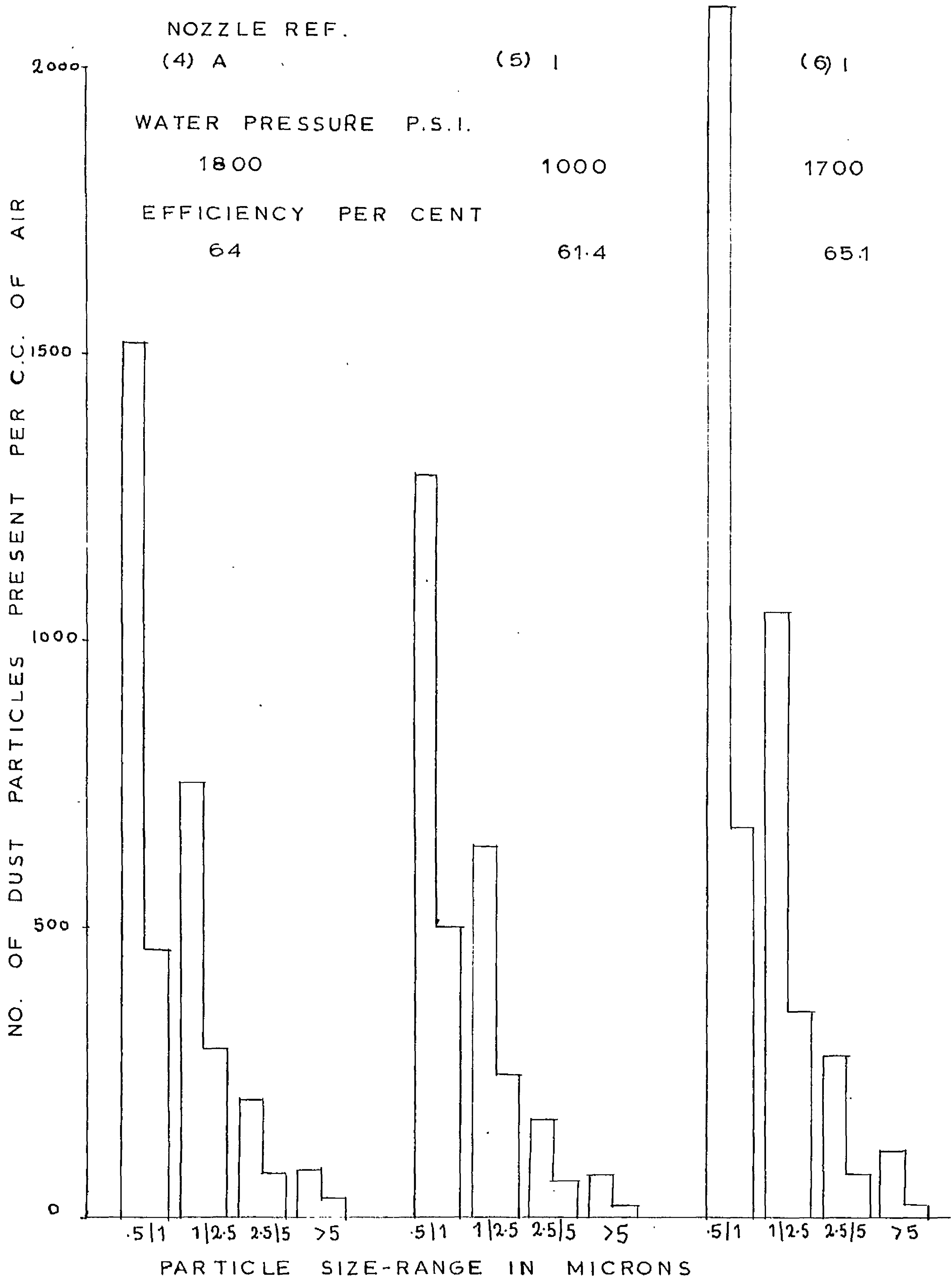

NOZZLE REF.
(4) A
(5) I
(6) I
WATER PRESSURE P.S.I.
1800
1000
1700
EFFICIENCY PER CENT
64
61·4
65·1
2000
1500
1000
500
0
NO. OF DUST PARTICLES PRESENT PER C.C. OF AIR
·5|1
1|2·5
2·5|5
>5
PARTICLE SIZE-RANGE IN MICRONS

TABLE 18(b)

Effect of air velocity on airborne dust suppression at lower water pressure

Nozzle: An Water Pressure: 500 p.s.i.

Air Velocity ft./min.	Dust Conc. before spray p.p.c.c.	Dust Conc. after spray p.p.c.c.	No. of dust particles knocked down per c.c. of air.	Efficiency per cent
150	3285	880	2405	73.25
250	2040	1565	475	23.30
350	1880	1515	365	19.45
450	1020	771	249	24.40
600	1109	724	385	32.40
750	1009	839	170	16.85

(iii) The effect of varying the initial dust cloud concentration at constant water pressure and constant air velocity. The results are shown in Table 19, for hollow cone nozzles.

(iv) The effect of changing the orientation of the nozzle with respect to the axis of the tunnel. The results are shown in Table 20 for hollow cone nozzles.

Inspection of Table 15 indicate that as might be expected for the nozzles of smaller orifice size the dust suppressing efficiency increases with spray pressure. The results, however, for the two larger nozzles do not follow

TABLE 19

Effect of Variation in Dust Concentration on Dust Suppressing Efficiency

Nozzle Ref.	Air Velocity ft./min.	Water Pressure lbs/sq.in	Water flow rate galls/hr.	Concentration I		Concentration II		Concentration III		Concentration	
				Before Spray p.p.c.c	Efficiency per cent	Before Spray p.p.c.c.	Efficiency per cent	Before Spray p.p.c.c.	Efficiency per cent	Before Spray p.p.c.c.	Efficiency per cent
D	130	2800	13.9	308	31.20	757	59.20	2542	65.75	2050	55.20
V	130	2500	23.4	430	31.90	1348	52.10	2240	51.60	2428	67.50
An	130	1000	35.0	514	59.25	984	67.50	2535	63.50	3055	73.20
In	130	1000	33.6	472	57.80	1017	47.70	1878	55.50	2175	61.90

Note: The pressures selected for these tests were those which had been shown to give high dust suppression with that particular nozzle (Table 15).

TABLE 20

Effect of orientation of Nozzle on Dust Suppression

Nozzle Ref.	Air Velocity ft./min.	Water Pressure lbs./sq.in.	Water flow rate galls/hr.	Nozzle facing upstream		Nozzle facing downstream		Nozzle perpendicular to air flow	
				Dust concentration Before Spray p.p.c.c.	Efficiency per cent	Dust concentration Before Spray p.p.c.c.	Efficiency per cent	Dust concentration Before Spray p.p.c.c.	Efficiency per cent
D	130	1000	8.2	2050	32.40	2670	46.00	2420	30.40
V	130	1000	14.2	2428	44.00	1603	57.25	2375	57.10
An	130	1000	35.0	3055	73.20	1736	64.10	2620	61.50
In	130	1000	33.6	2175	61.90	1269	46.50	2780	53.25
				Average values		Average values		Average values	
				2427	52.6	1819	53.5	2549	53.1

this trend. The results for nozzle In pass through a maximum while those for nozzle An decrease slightly to a steady value. Since it was suspected that there might be a maximum efficiency for each nozzle whose value would be dependent on the orifice size, and that the value of this maximum for the smaller nozzles might be reached at pressures in excess of those already tried, a new series of tests were carried out to study this point, i.e.

(v) Effect of elevated spray pressure on the dust suppressing efficiency of the smallest hollow cone nozzle tested. The results are shown in Table 21.

TABLE 21

Effect of very high pressure atomisation on airborne dust

Nozzle: B   Air Velocity: 120 ft/min.

Water Pressure lbs./ sq.in.	Dust Concentration p.p.c.c.		No. of Dust Particles Removed	Efficiency per cent
	Before Spray	After Spray		
50	1330	1360	(-30)	-
450	1330	1088	242	18.20
1000	1589	746	843	53.00
1500	1225	847	378	30.80
2000	1451	600	849	58.60
2500	1091	564	527	48.30
3000	1695	772	923	54.50
3500	965	505	460	47.60
3850	1625	833	792	48.80
4500	735	480	255	34.60
5000	1409	707	702	49.60

(vi) The effect of throughput of spray water at constant pressure. All six nozzles were tested at three pressure levels. The results are compared in Table 22. Hollow cone sprays were used.

(vii) The effect of water spray pressure at constant water throughput. All six nozzles were tested at three throughput levels. The sprays produced were hollow cone and the results are given in Table 23.

In both (vi) and (vii) the air velocity was set at 120 ft./min. and the dust concentration was held between 700 - 1000 p.p.c.c.

TABLE 22

Effect of throughput on Dust Suppression at constant Water Pressure

Nozzle Ref.	Test at 1000 p.s.i.				Test at 600 p.s.i.				Test at 300 p.s.i.			
	Flow Rate gal./hr.	Dust concentration p.p.c.c.		Efficiency	Flow Rate gal./hr.	Dust Concentration p.p.c.c.		Efficiency	Flow Rate Gal./hr.	Dust Concentration p.p.c.c.		Efficiency
	-	Before Spray	After Spray	per cent	-	Before Spray	After Spray	per cent	-	Before Spray	After Spray	per cent
B	4.7	920	546	40.6	3.8	1000	936	6.4	2.80	997	900	9.7
D	8.2	910	547	39.9	6.5	725	505	30.4	4.6	716	495	30.9
V	14.2	856	425	50.3	11.0	592	333	43.75	8.00	595	375	36.8
K	24.50	876	657	25.00	19.0	675	547	19.0	13.50	744	850	-
In	33.6	805	350	56.5	26.0	714	476	33.3	18.30	773	620	19.8
An	35.0	660	218	67.0	27.1	927	564	39.2	19.20	749	706	5.5

TABLE 23

Effect of Water Pressure on Dust Clouds at constant throughput

Nozzle Ref.	Throughput 5 gal./hr.				Throughput 9 gal./hr.				Throughput 14 gal./hr.			
	Water Pressure	Dust Concentration p.p.c.c.		Efficiency	Water Pressure	Dust Concentration p.p.c.c.		Efficiency	Water Pressure	Dust Concentration p.p.c.c.		Efficiency
	p.s.i.	Before Spray	After Spray	per cent	p.s.i.	Before Spray	After Spray	per cent	p.s.i.	Before Spray	After Spray	per cent
An	17.6	726	980	-	64.0	925	750	18.8	156	1010	960	4.95
In	22.5	731	1056	-	79.5	936	854	8.54	169	766	661	13.70
K	38.5	664	847	-	128	745	697	6.45	325	850	744	12.50
V	121	906	888	1.99	400	812	520	36.0	960	856	425	50.3
D	360	716	495	30.9	1160	995	695	30.2	2900	975	350	64.0
B	1090	920	546	40.6	3850	1625	833	48.8	-	-	-	-

(viii) The effect of solid cone (drowned spray). Tests were made using the same nozzle cups as with the hollow cone sprays, with the original plug drilled with an 0.02 inch centre hole. The results are shown in Tables 24 (a), (b) and (c).

(ix) Airborne dust suppression was also tried by spraying simultaneously at two points - commonly known as "two-stage air cleaning". For this, the present spraying unit was modified to take another spray nozzle. A gap of 4.5 ft. was kept between the two spray nozzles which were arranged in tandem down the axis of the tunnel. The nozzles in this case gave a hollow cone spray and were arranged to be at either end of the perspex window, and this helped to keep visual check on nozzles when working. The results obtained are shown in Tables 25 (a) and (b).

(x) Two stage cleaning was also tried by setting the first spray nozzle to face downstream and the second spray nozzle to face upstream. The results are shown in Table 26 for four pairs of hollow cone nozzles all tested at 500 p.s.i.

(xi) Two hollow cone spray nozzles were arranged to face each other across the wind tunnel. Dusty air was allowed to flow through the spray curtain so produced and dust concentrations were measured before and after. When the sprays were operating it appeared that the water droplets were hitting each other and causing intense turbulence. Part of the

TABLE 24 (a)

Solid cone sprays

Variation of Water Pressure

Nozzle: V Air Velocity: 120 ft/min.

Water Pressure lbs/sq.in.	Dust Concentration p.p.c.c. Before Spray	After Spray	No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
200	1202	965	337	28.0	1.47
400	1578	705	873	55.20	2.68
600	1520	519	1001	65.80	2.51
800	1340	342	998	74.50	2.17

Note: Dust-Water Ratio - No. of particles removed per c.c. of water x 10^6

TABLE 24 (b)

Variation of throughput at the same pressure

Water pressure: 600 p.s.i. Air Velocity: 120 ft/min.

Nozzle Ref.	Water flow rate gals/hr.	Dust Concentration p.p.c.c. Before Spray	After Spray	No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
B	8.1	1065	776	289	27.10	2.79
D	26.0	1206	878	428	35.50	1.29
K	34.1	1125	859	364	32.30	0.83
An	42.2	1425	749	781	54.75	1.45

Variation of dust concentration

TABLE 24 (c)

Nozzle: V Water Pressure: 1000 p.s.i.

Water Throughput: 40.1 gal./hr. Air Velocity: 120 ft./min.

Dust Conc. Ref.	Dust Concentration p.p.c.c. Before Spray	After Spray	No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
B	690	234	456	66.10	0.89
A	1221	514	707	58.0	1.38
C	3140	1219	1921	61.20	3.75
D	3341	1419	1922	57.60	3.75

TABLE 25 (a)

Effect of increased pressure and throughput

Nozzle: 'D' pair Air Velocity 120 ft./min.

Water Pressure lbs./sq. in.	Water Through-put gals/hr.	Dust Concentration p.p.c.c. Before Spray	After Spray	No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
280	9	946	670	276	29.2	2.40
600	13	975	487	488	50.00	2.93
1000	16.6	1525	680	845	55.40	3.20
1500	20.1	1815	670	1145	63.00	2.61

TABLE 25 (b)

Effect of dust concentration

Nozzle: 'V' (pair) Water Pressure: 600 p.s.i.
Water Throughput 23.0 gal/hr. Air Velocity 120 ft./min.

Dust Conc. Ref.	Dust Concentration p.p.c.c. Before Spray	After Spray	No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
B	392	115	277	70.70	0.94
A	1138	164	974	85.60	3.32
C	3508	1169	2339	65.40	7.98
D	3646	1340	2306	63.30	7.85

TABLE 26

Effect of variation of throughput at constant pressure

Water Pressure: 500 p.s.i. Air Velocity: 120 ft/min.

Nozzle Ref.	Water Through-put gals/hr.	Dust Concentration p.p.c.c. Before Spray	After Spray	No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
B pair	6.4	1463	570	893	61.10	10.85
D pair	11.8	1580	520	1060	67.00	7.05
V pair	21.2	1092	585	507	46.50	1.89
An pair	50.6	1338	572	766	57.20	1.18

wind tunnel looked as if it were full of a white mist. The dust suppression results are shown in Tables 27 (a) and (b).

TABLE 27 (a)

Varying distance between the two nozzles

Nozzles 'V' pair. Water Pressure = 600 p.s.i.
Water throughput = 23 gals/hr. Air Velocity = 120 ft./min.

Distance between the nozzles ins.	Dust Concentration p.p.c.c.		No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
	Before Spray	After Spray			
2	975	417	558	57.5	1.90
6	1015	437	578	57.0	1.97
10	644	471	173	26.90	0.59
16	890	467	423	48.00	1.44

TABLE 27 (b)

Nozzles 'V' pair. Air Velocity 120 ft./min.
Distance between the Nozzles: 6 inches

Water Pressure lbs/sq.in.	Water Throughput gals/hr.	Dust Concentration p.p.c.c.		No. of Dust particles removed	Efficiency per cent	Dust-Water Ratio
		Before Spray	After Spray			
280	15.2	1240	710	530	42.7	2.73
600	23.0	1250	580	670	53.5	2.28
1000	29.0	1430	493	937	65.50	2.53
1500	35.4	775	218	557	72.0	1.23

(xii) Effect of water sprays on the size-distribution of the airborne dust particles under different working conditions. Typical dust slides from the above group of experiments were sized to give size-distributions in the following form :-

Size-ranges: 0.5 - 1; 1.0 - 2.0; 2.0 - 4.0;
(microns)
4 - 5; Above 5.

The size-distributions of the airborne dust particles before and after each spray are shown in the form of histograms in Figure 25. (For details please refer to the note given in sub-section 5 (i)).

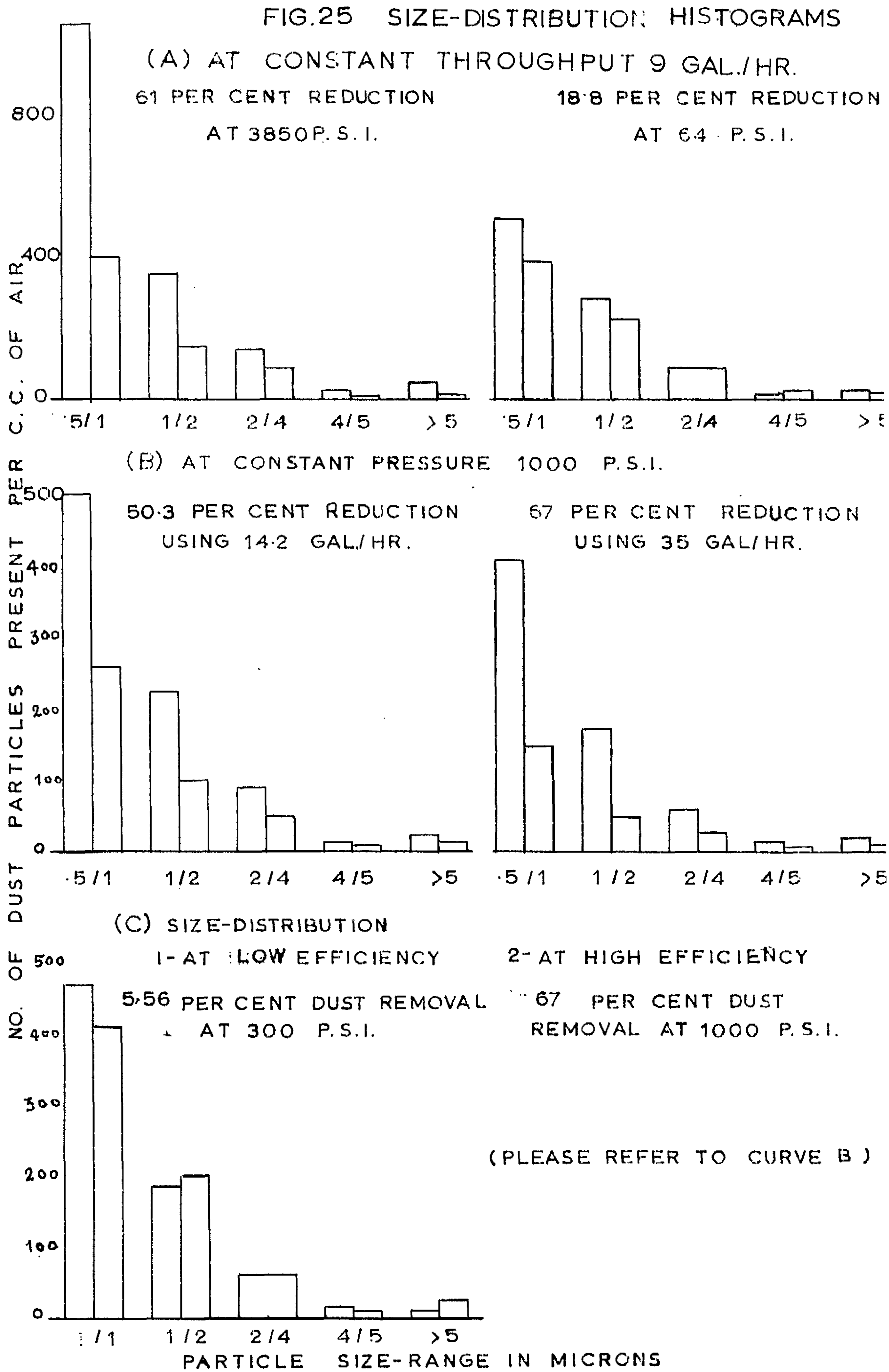


FIG.25 SIZE-DISTRIBUTION HISTOGRAMS
(A) AT CONSTANT THROUGHPUT 9 GAL./HR.
61 PER CENT REDUCTION
AT 3850 P.S.I.
18·8 PER CENT REDUCTION
AT 64 P.S.I.
(B) AT CONSTANT PRESSURE 1000 P.S.I.
50·3 PER CENT REDUCTION
USING 14·2 GAL./HR.
67 PER CENT REDUCTION
USING 35 GAL./HR.
(C) SIZE-DISTRIBUTION
1- AT LOW EFFICIENCY
5·56 PER CENT DUST REMOVAL
AT 300 P.S.I.
2- AT HIGH EFFICIENCY
67 PER CENT DUST
REMOVAL AT 1000 P.S.I.
(PLEASE REFER TO CURVE B)
NO. OF DUST PARTICLES PRESENT PER C.C. OF AIR
PARTICLE SIZE-RANGE IN MICRONS
·5/1
1/2
2/4
4/5
>5
0
100
200
300
400
500
800

FIG.25 (CONTD.)

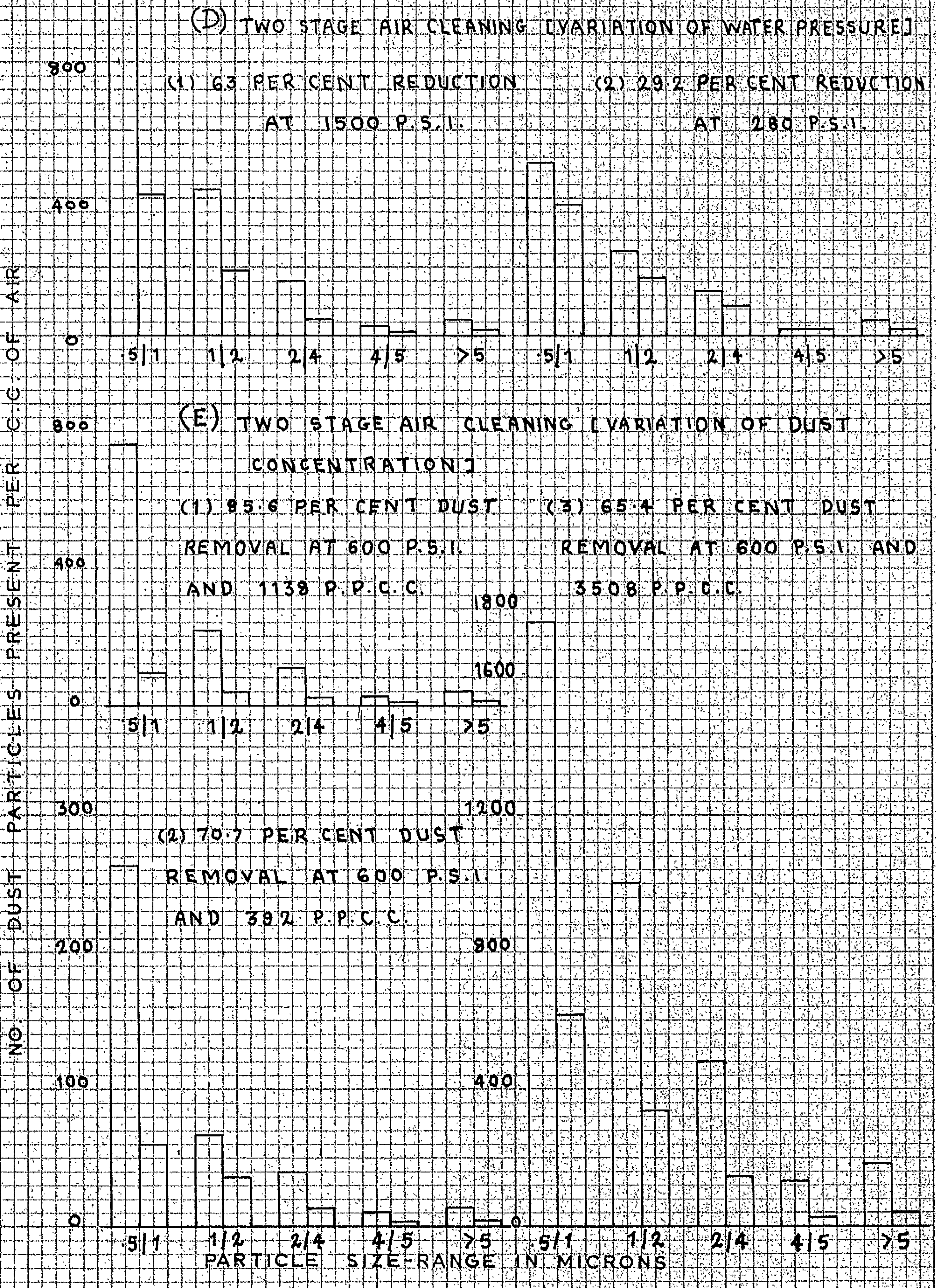
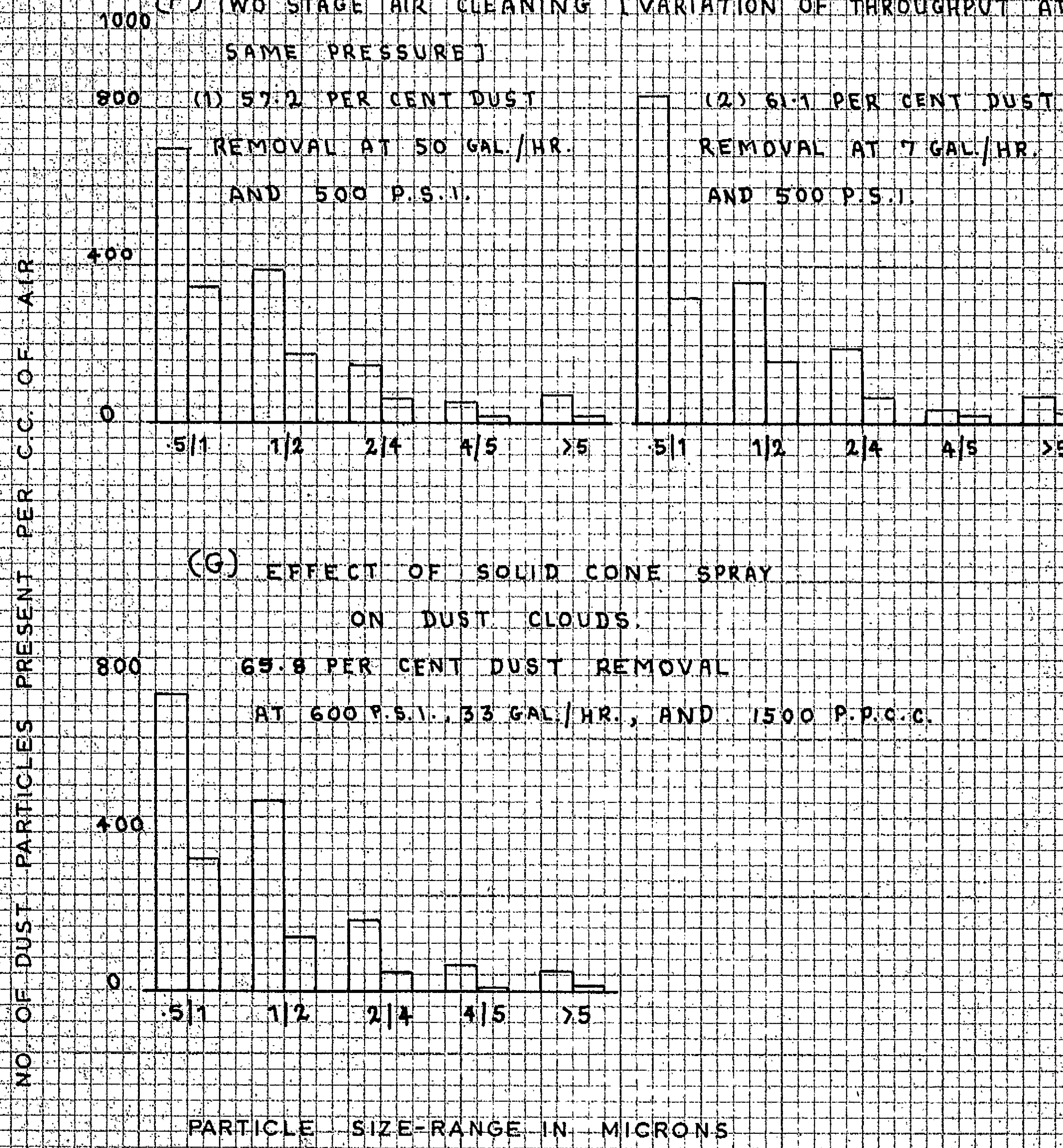

(D) TWO STAGE AIR CLEANING [VARIATION OF WATER PRESSURE]
(1) 63 PER CENT REDUCTION AT 1500 P.S.I.
(2) 29.2 PER CENT REDUCTION AT 280 P.S.I.
(E) TWO STAGE AIR CLEANING [VARIATION OF DUST CONCENTRATION]
(1) 85.6 PER CENT DUST REMOVAL AT 600 P.S.I. AND 1139 P.P.C.C.
(3) 65.4 PER CENT DUST REMOVAL AT 600 P.S.I. AND 3508 P.P.C.C.
(2) 70.7 PER CENT DUST REMOVAL AT 600 P.S.I. AND 392 P.P.C.C.
NO. OF DUST PARTICLES PRESENT PER C.C. OF AIR
800
400
0
300
200
100
1800
1600
1200
800
400
·5|1
1|2
2|4
4|5
>5
PARTICLE SIZE-RANGE IN MICRONS

FIG 25 (CONTD)


(F) TWO STAGE AIR CLEANING [VARIATION OF THROUGHPUT AT
SAME PRESSURE]
(1) 57.2 PER CENT DUST
REMOVAL AT 50 GAL./HR.
AND 500 P.S.I.
(2) 61.1 PER CENT DUST
REMOVAL AT 7 GAL./HR.
AND 500 P.S.I.
1000
800
400
0
·5|1
1|2
2|4
4|5
>5
(G) EFFECT OF SOLID CONE SPRAY
ON DUST CLOUDS.
65.8 PER CENT DUST REMOVAL
AT 600 P.S.I., 33 GAL./HR., AND 1500 P.P.C.C.
800
400
0
·5|1
1|2
2|4
4|5
>5
NO OF DUST PARTICLES PRESENT PER C.C. OF AIR
PARTICLE SIZE-RANGE IN MICRONS

6. Discussion of Results

It appears in general that these small high pressure sprays have been able to remove a considerable proportion of < 10 micron suspended coal dust from the air in the tunnel. The results are best considered under their appropriate subsection headings.

Effect of spray pressure (i) and (v). Tables 14, 15, 21, 22, 23, 24(a), 25(a), 27(b). As might be expected, increase in spray pressure generally causes an increase in dust suppression. Some of the results in Table 15, however, appear at first sight to be anomalous. The two nozzles with the larger orifice diameter (An and In) show a decrease in efficiency at higher pressures and even nozzle V does not show much increase in efficiency after a pressure of 2500 p.s.i. The results in Table 21 which are for the dust suppression test carried up to 5000 p.s.i. indicate that for this particular orifice diameter there is not much change in efficiency between 1000 p.s.i. and 5000 p.s.i. When all the results from the above tables are plotted together, as has been done in Fig. 26A, an approximate proportionality appears to exist between the dust suppression efficiency of the nozzle and the logarithm of the water pressure. This would suggest that there is not much to be gained in increasing water pressure above about 2000 p.s.i. The amount of energy required to produce

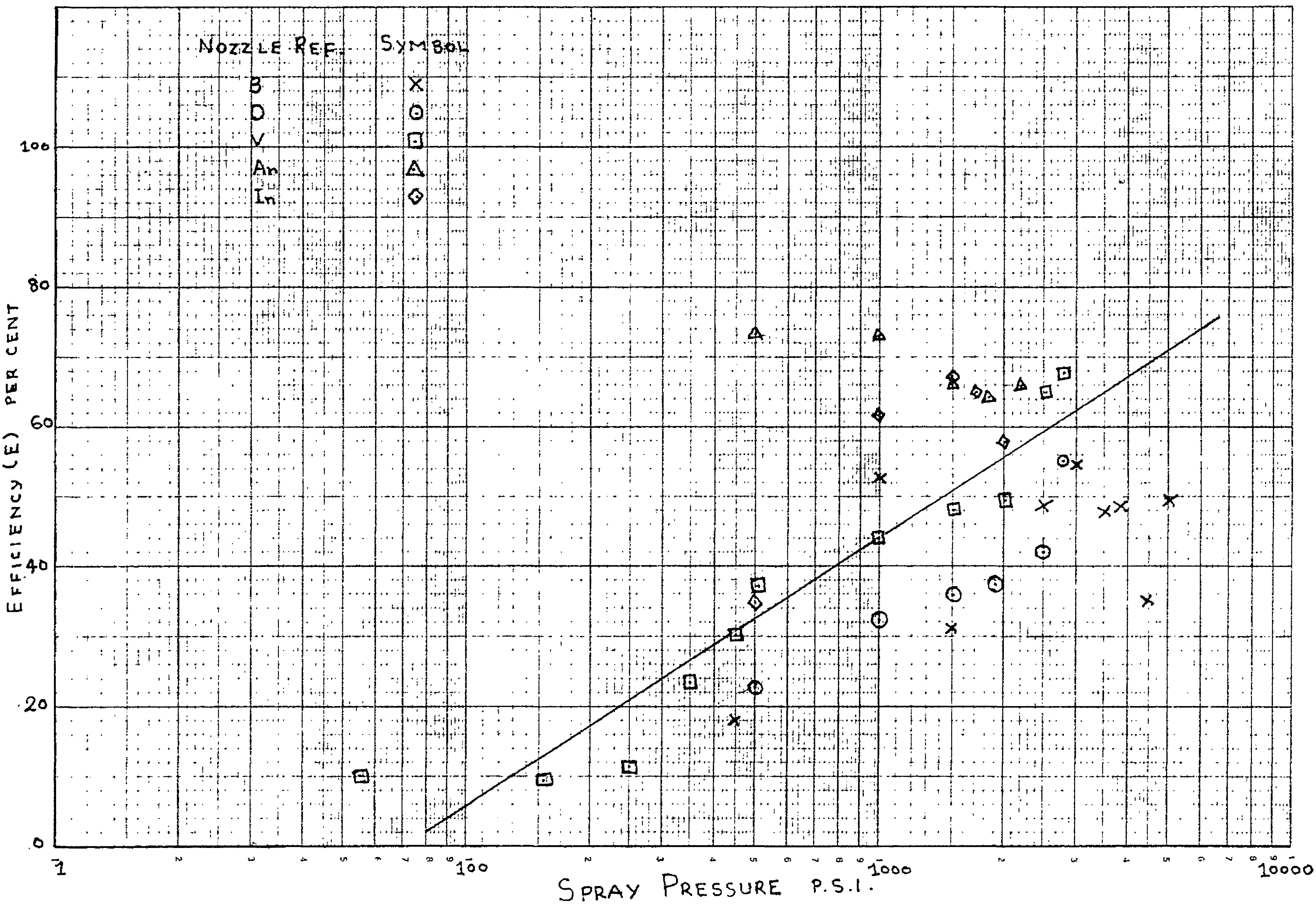


FIG 26(A) EFFECT OF SPRAY PRESSURE ON AIRBORNE DUST SUPPRESSION the spray is not commensurate with the return in dust suppression.

The spray variables that are dependent on the pressure at which the water is applied to a given orifice are :-

(a) the angle which the spray cone subtends at the orifice (the cone angle),

(b) the water flow-rate, which is known to increase as the square root of the water pressure,

(c) the initial velocity and penetration of the spray droplet, and

(d) the droplet diameter.

It has been shown elsewhere (24) for these nozzles that the cone is fully developed at a pressure of about 100 p.s.i. and does not change greatly at higher pressures. Although, as shown in Table 12, there is a wide variation in fully-developed cone angle among the various nozzles, when the nozzles were spraying water in the tunnel contra- to the air flow a certain amount of deformation of the cone took place so that in practice there was little difference between the cone angles.

If the increased dust suppression at increased pressure were merely due to the increased flow rate one might expect the dust suppressing efficiency to vary approximately as the square root of the applied pressure. In Fig. 26B the

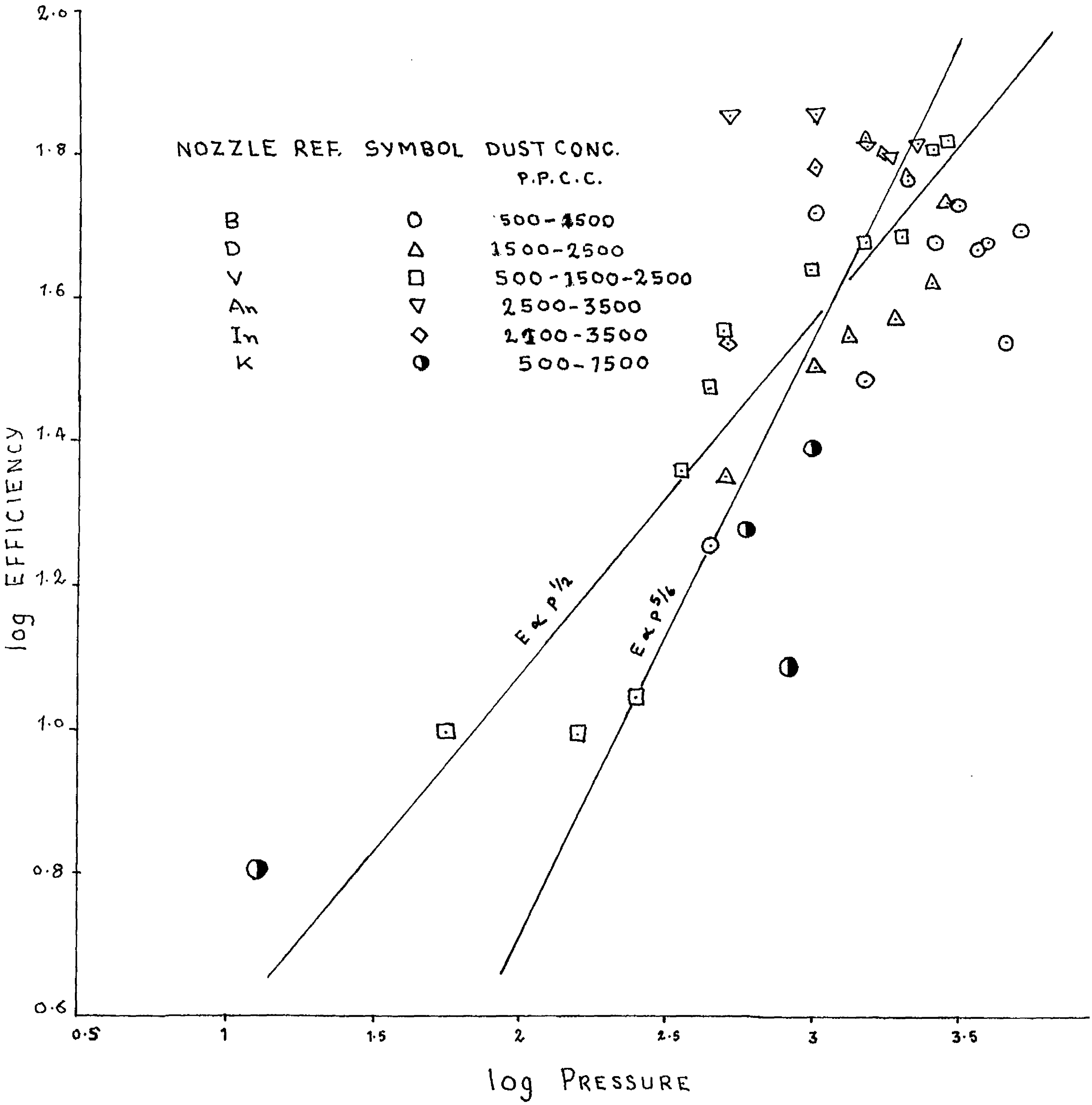


FIG.26(B) LOGARITHMIC RELATIONSHIP OF DUST SUPPRESSION EFFICIENCY AND SPRAY PRESSURE.

logarithms of all pressure variation results are plotted against the logarithm of the efficiency and a "0.5 power" straight line drawn through the points. While the general trend of the results would appear to be in the direction of this line, the spread of values is such that no definite conclusion can be drawn. The main reason for this spread was the fact that the results plotted in Figure 26B corresponded to a wide range in initial dust concentration. It is interesting to note that points relating to initial dust concentrations less than 2500 p.p.c.c. in general lie below the $E \alpha \Delta P^{1/2}$ line and points relating to dust concentrations great than 2500 p.p.c.c. in general lie above the line, indicating, as might be expected, that efficiency increases with initial dust concentration.

The results of Tables 22 and 23 where the six spray nozzles are compared at constant pressure and constant water flow rate are not very conclusive. The range of nozzle diameter thus studied (0.0139 - 0.1608 inches) is perhaps too great for safe efficiency comparisons to be made. Nozzles B, D, and V in Table 22 appear to behave differently to nozzles An, In and K. These results are plotted in Fig. 26C.

The constant water throughput results are plotted in Fig. 26D and again an approximate $E \alpha \log \Delta P$ relationship can be seen to exist. Three only of the nozzles would

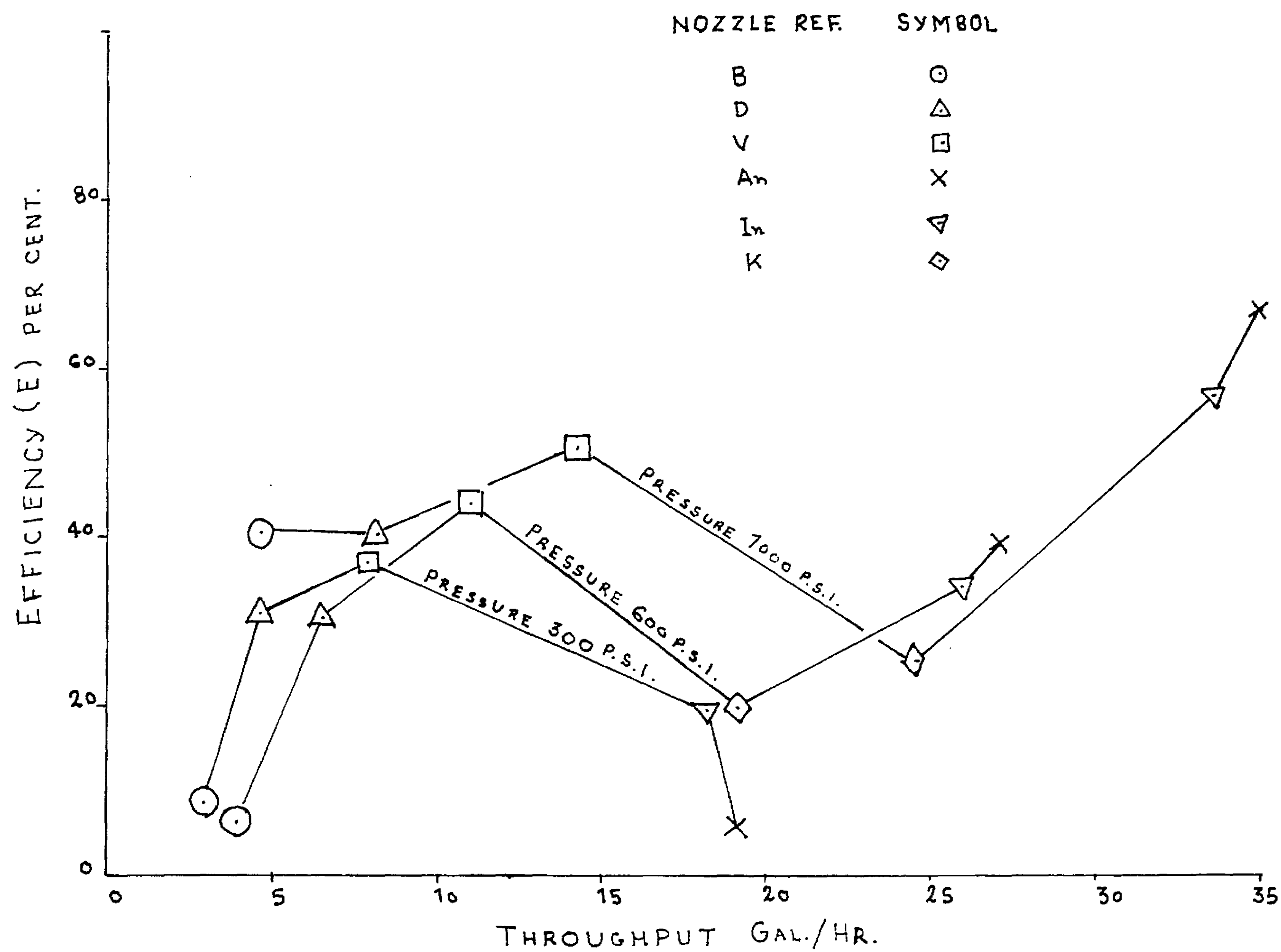


FIG. 26 (C) EFFECT OF THROUGHPUT AT CONSTANT SPRAY PRESSURE ON DUST SUPPRESSION.

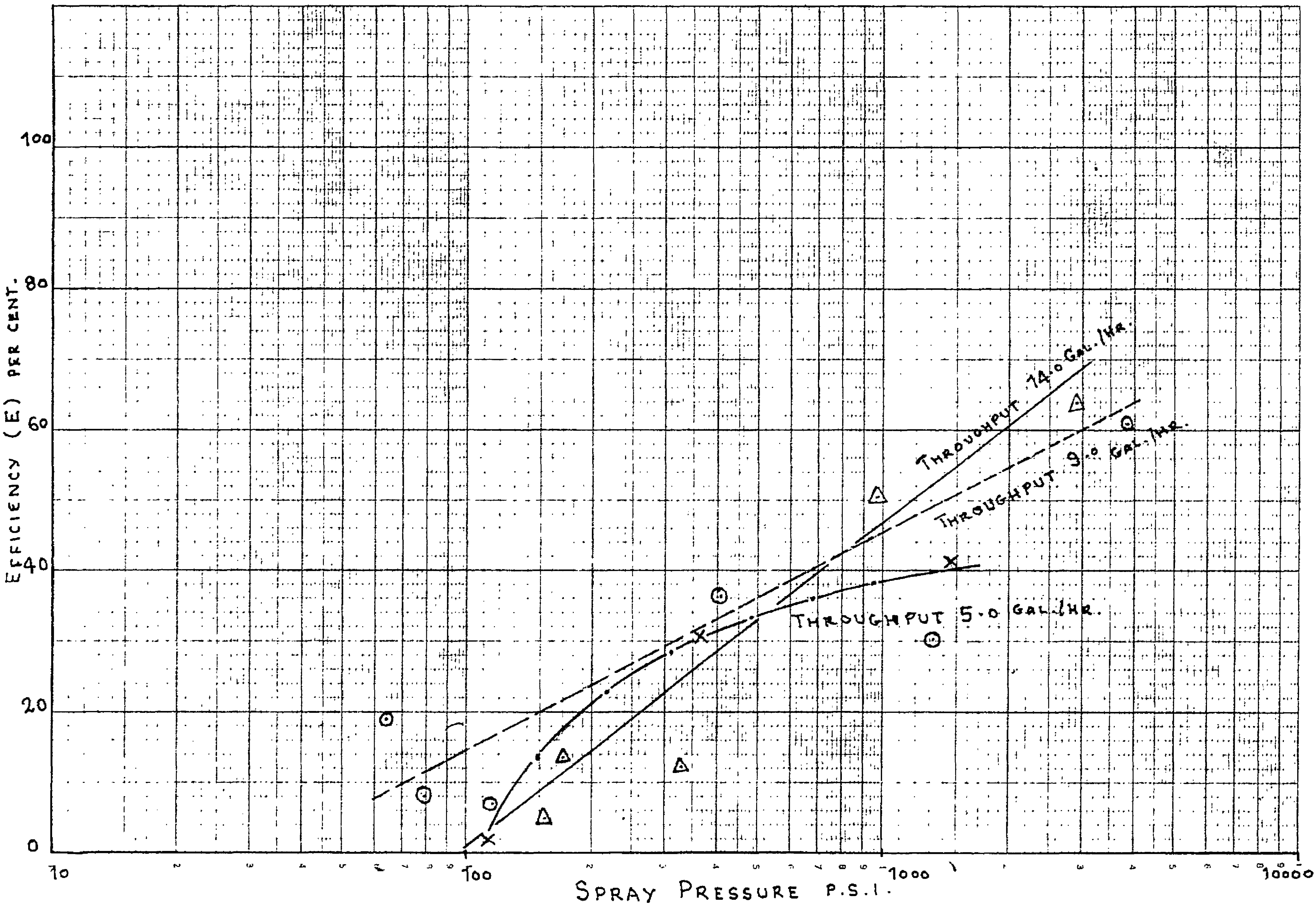


FIG.26 (D) EFFECT OF SPRAY PRESSURE AT FIXED THROUGHPUT.

operate at the low water rate of 5.0 gal./hr., and therefore insufficient data could be obtained at this rate to check the curve obtained. The increasing gradient of the straight lines with increasing throughput of water, is also apparent.

The increased initial velocity and penetration at higher pressures should have a positive influence on the dust suppressing efficiency. Owing, however, to the preferred arrangement of the spray nozzle in the tunnel (i.e. spraying upstream), the water droplet will decelerate rapidly to zero velocity and, if it has not reached the tunnel wall, will then be accelerated downstream with the air. Thus for quite a small proportion of its life will it have a velocity controlled by the water pressure.

It has been shown by dimensional analysis(43) and by experiment that the average droplet diameter is inversely proportional to the cube root of the spray pressure. Hunter(25) obtained this relationship for the spray nozzles used in this work up to 500 p.s.i. and Bauchop has recently verified it for the same nozzles up to about 3000 p.s.i.(44) There will be, of course, a distribution of droplet sizes, but it is known that at the higher pressures the range of sizes is not great. Both Glen(24) and Hunter found that a decrease in the average droplet size at higher pressures was brought about by an increase in the number of smaller sized droplets rather than by a decrease in the smallest size. If one make take as a measure of the number of water droplets produced per minute the ratio

$$\frac{\text{Volume flow rate}}{\text{Average droplet size}},$$

$$\text{and since volume flow rate} = k_1 \Delta P^{1/2}$$

$$\text{and average droplet size} = k_2 \Delta P^{-1/3}$$

$$\text{Number of droplets per minute} = k_1 \Delta P^{1/2} / k_2 \Delta P^{-1/3}$$

$$= k_3 \Delta P^{5/6}$$

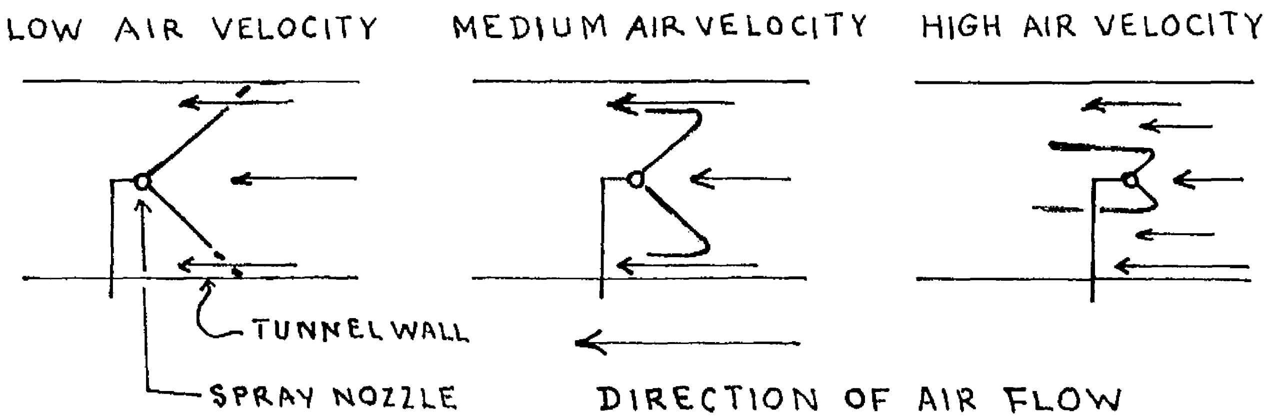
Thus if the dust suppressing efficiency were dependent on the number of droplets produced per minute it should increase as the $5/6^{th}$ power of the water pressure. In Fig. 26B a straight line has been plotted whose gradient follows such a relationship. Again the scatter of points make it difficult to decide whether $E \alpha \Delta P^{5/6}$ is nearer the truth than $E \alpha P^{1/2}$.

The size of the water droplet will also influence the probability of its contact with a dust particle. The smaller the droplet the more difficult does it become for it to make a successful capture of a dust particle owing to the nature of the flow pattern of the air around the droplet. This subject will be dealt with more fully later in this thesis. It has been suggested elsewhere(45) that there may be a decrease in the efficiency of atomisation by the spray nozzles at very high pressure due to pressure deformation of the orifice.

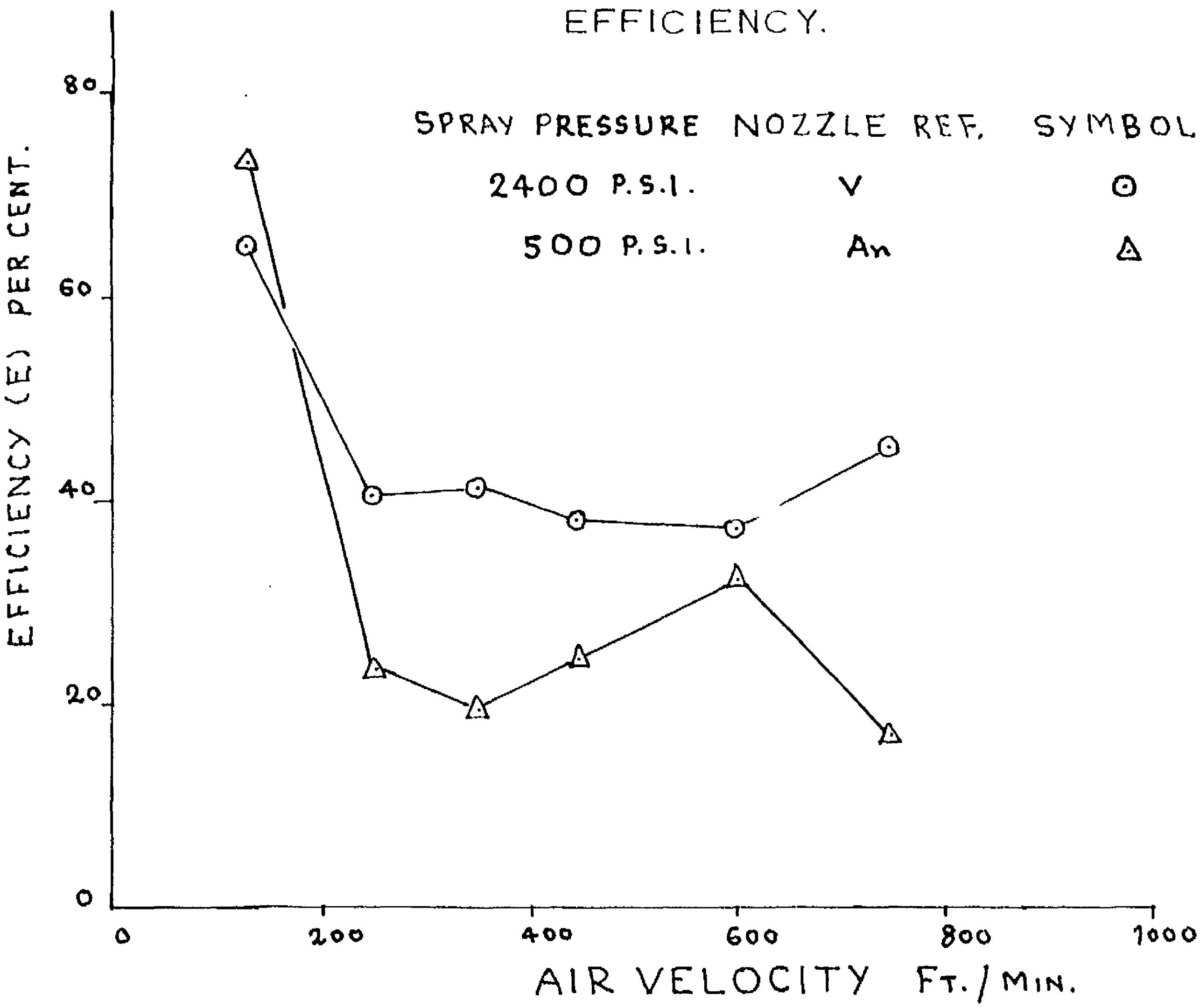
<u>Effect of velocity of air in tunnel</u> (ii). Tables 18(a) and 18(b). With the water sprayed upstream one might expect that increase in air velocity, since it thereby increases the relative velocity between dust particle and water droplet should increase the dust suppressing efficiency. The results of Tables 18(a) and 18(b) show that in the wind tunnel this did not in fact happen and are plotted in Fig. 26E(B). It would appear that after an initial drop in efficiency, increased air velocity did not on average markedly affect its value. Inspection of the effect of the flowing air on the spray cone provided a clue to this odd variation. It could be seen that the deformation of the spray cone shortened the forward travel of the droplet so that the overall size of the cone was reduced. This effect is sketched in Fig. 26E(A). Owing to this deformation dusty air was able to by pass possibly the high velocity droplets near the cone. If this were the only factor operating, one might expect an even greater drop in efficiency than was found but the enhanced turbulence resulting from increased air velocity will tend to counter the effect of the above-mentioned deformation so that water droplets carried down the tunnel with the air will have more chance of capturing a particle missed by the smaller spray cone. Thus the dust suppressing efficiency may tend to become relatively constant over a range of air velocity as was evidenced in Fig. 26E(B).

FIG. 26(E)

(A) EFFECT OF AIR VELOCITY ON SPRAY CONE.



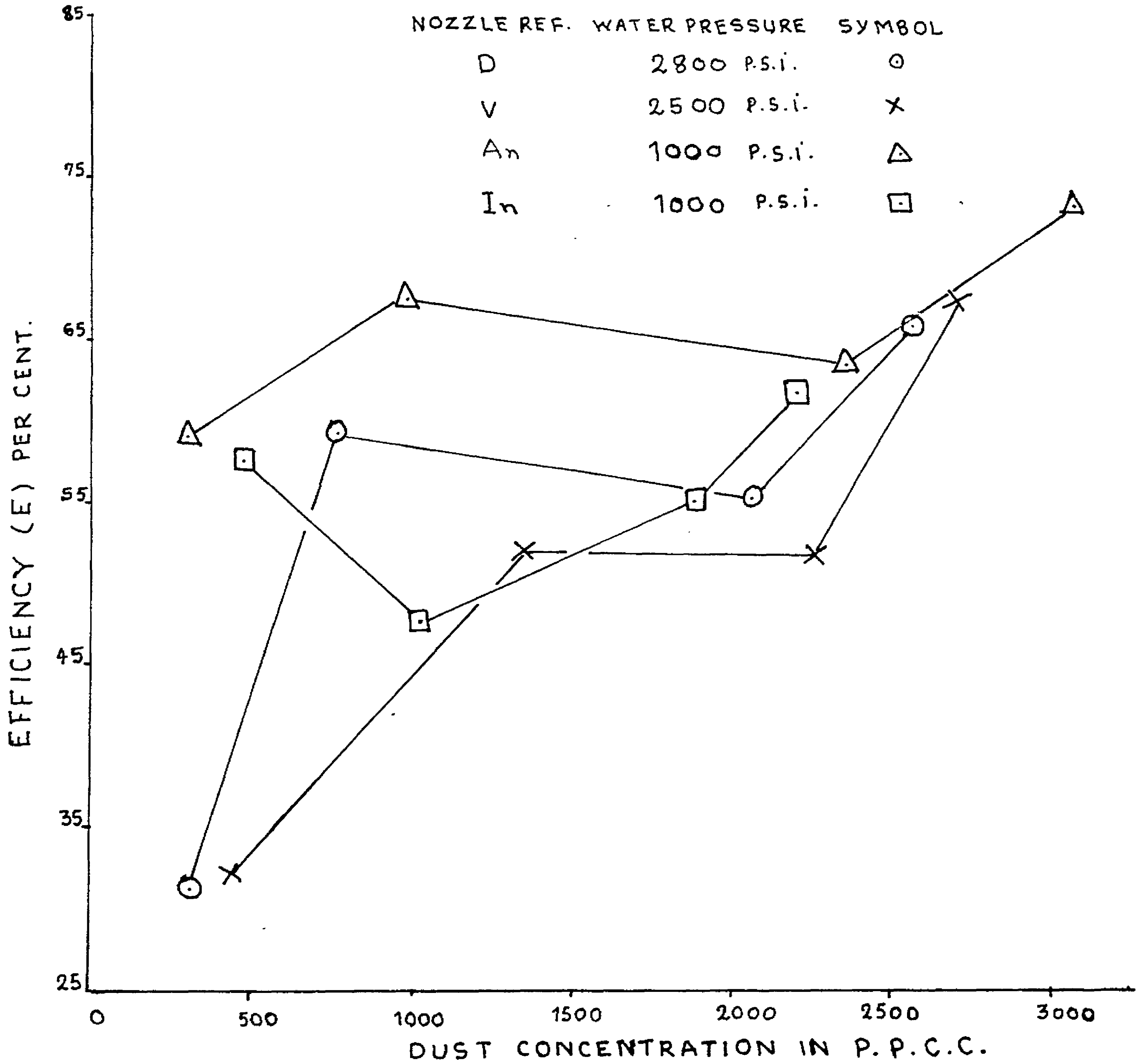
(B) EFFECT OF AIR VELOCITY ON DUST SUPPRESSION EFFICIENCY.



<u>Effect of dust concentration</u> (iii). Table 19. The results showing the influence of initial dust concentration in the tunnel on the efficiency of dust suppression are plotted in Fig. 26F for the four nozzles tested. It can be seen that there is in general an increase in efficiency with dust concentration. This is of course due to the increased probability of impact between water droplets and dust particles at higher dust concentrations and suggests that under the conditions of these tests there was a sufficient number of water droplets available in the tunnel to knock down all the "removable" dust from the air, i.e. the efficiency values obtained represent the best that can be obtained for this type of spray nozzle set in this particular way in the tunnel at this particular air velocity and dust concentration.

It is of interest to note that the overall increase is greater for the low throughput nozzles D and V than for the higher throughput nozzles An and In. This may suggest that at sufficiently high throughput the dust suppression efficiency becomes virtually independent of dust concentration over the range 300 - 3000 particles per c.c.

<u>Dust-Water Ratio</u> A knowledge of the volume of water required to remove a certain amount of dust from air is of value when spray capacities have to be decided upon and when taking into consideration the nuisance created by wet conditions in a particular mining operation. The volume


NOZZLE REF. WATER PRESSURE SYMBOL
D 2800 P.S.I.
V 2500 P.S.I.
An 1000 P.S.I.
In 1000 P.S.I.
85
75
65
55
45
35
25
EFFICIENCY (E) PER CENT.
0
500
1000
1500
2000
2500
3000
DUST CONCENTRATION IN P.P.C.C.

of water required may be assessed by calculating a dust-water ratio. The ratio chosen in this work was the number of particles of coal dust knocked down per c.c. of atomised water. This seeming inconsistence of units may appear objectionable, but to use any larger, more practical volume unit, e.g. the gallon, results in a very large number for the final ratio value. If a density is selected for the coal substance together with an average particle diameter, one may calculate the weight of coal dust removed from air suspension per gallon of water sprayed. These dust-water ratios are given in Table 16 for the hollow cone spray tests of Table 15, and the results are plotted in Fig. 26G against the water throughput corresponding to each value of applied pressure. The results group conveniently into those for the smaller orifice diameters (D and V) and those for the larger (An and In). For the smaller orifice diameters the dust-water ratio can be seen to be approximately constant over the range, while the value for the larger diameters behave more erratically. If the results for all the nozzles are considered together, the overall trend is towards a decrease in dust-water ratio as the throughput increases. This would appear to indicate that under the existing conditions increased water usage does not result in an equivalent increase in dust suppression and that there is little to be gained (from the point of

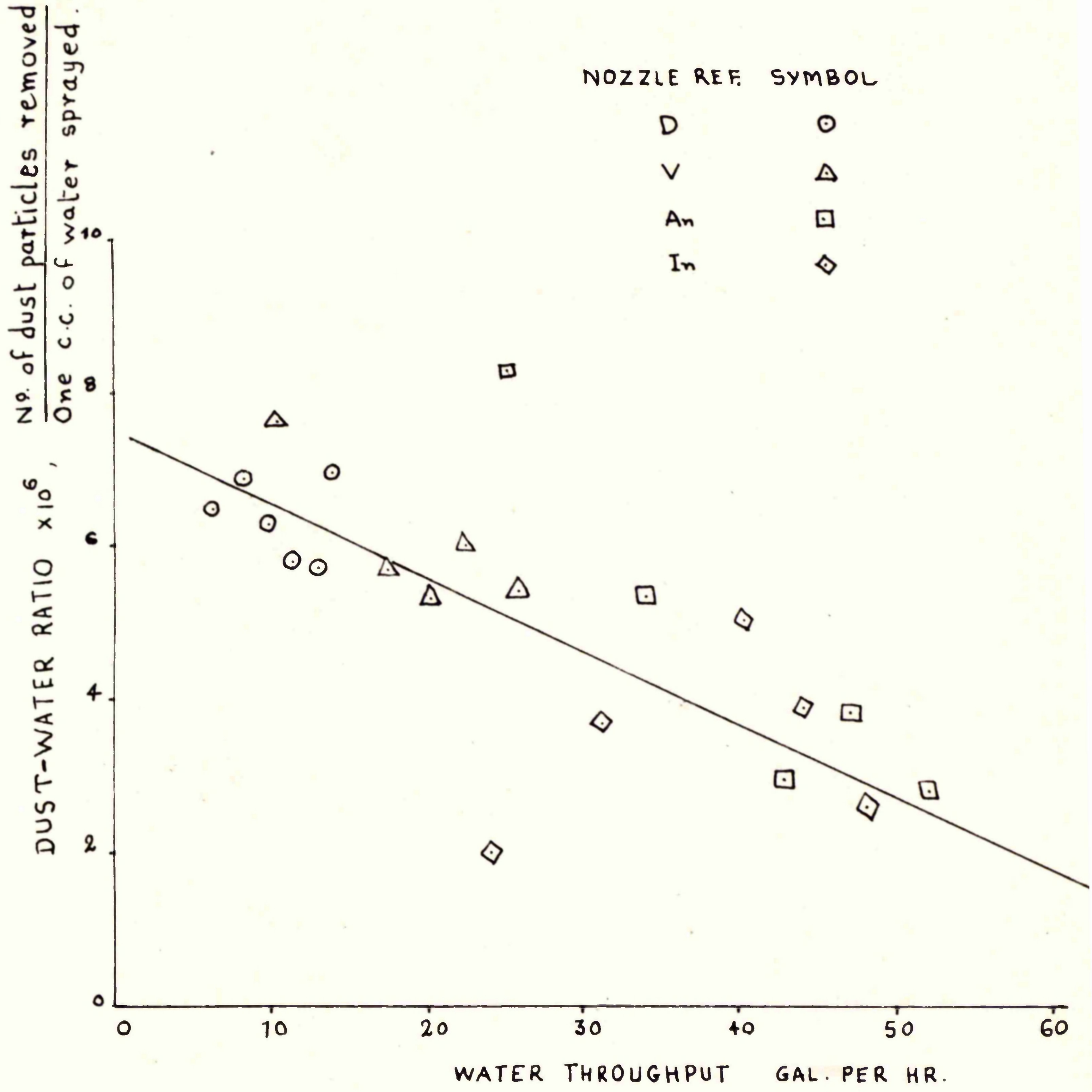


FIG.26(G) EFFECT OF WATER THROUGHPUT ON DUST-WATER RATIO.

view of dust-water ratio) by increasing the orifice diameter of the nozzle to obtain high throughput at high pressure.

Effect of Nozzle orientation (iv) Table 20. The results in Table 20 for three positions of the spray nozzle cover a range of water throughput and, since it was not possible to keep the initial dust concentration at the same value from test to test, a range of dust concentration was us. To smooth out the effects of these changes the dust concentrations and efficiencies have been averaged for each nozzle position and these values are placed at the foot of the table. The average efficiencies thus obtained show a remarkable constancy from nozzle position to position. This constancy would appear to indicate that the orientation of the spray cone in the tunnel has been relatively unimportant for dust suppression. This is somewhat surprising as one would have expected that the enhanced relative velocity obtained when the nozzle faced upstream would produce higher efficiencies, and perhaps indicate that a considerable proportion of the dust suppression takes place after the mixture of dusty air and water droplets has left the cone.

The effect of the solid cone spray (viii). Tables 24(a),(b), and (c). As already indicated a solid cone spray was produced by drilling a small axial hole through the plug fitted within the spray nozzle cup. The combined flow from this central hole and the normal swirl groove of the plug produced a distribution of water droplets generally known as a "drowned spray".

As before, the dust suppression efficiency was found to increase with water pressure and when these results were compared with results already obtained for the same nozzle cup (V) arranged to give a hollow cone (taken from Tables 14, 15, 22, and 23) as in Fig. 26H, it could be seen that the solid cone spray had produced a marked increase in dust suppression. Part of this increase would be due to the higher initial dust concentrations of Table 24(a) but even allowing for this difference the solid cone spray had produced a better result. The results of variation of throughput, by using a series of nozzle cups, at the same pressure showed the expected result, with nozzle K in an anomalous position. Variation of dust concentration appeared to have little effect on dust suppressing efficiency for the range of concentration tested. This might well suggest that once again the spray was providing sufficient droplets to suppress all "removable" dust over the range of dust concentration tested.

Dust-water ratios, i.e. particles removed per c.c. of water atomised, have been calculated and included in Tables 26(a). (b) and (c). Comparison with the results in Table 16

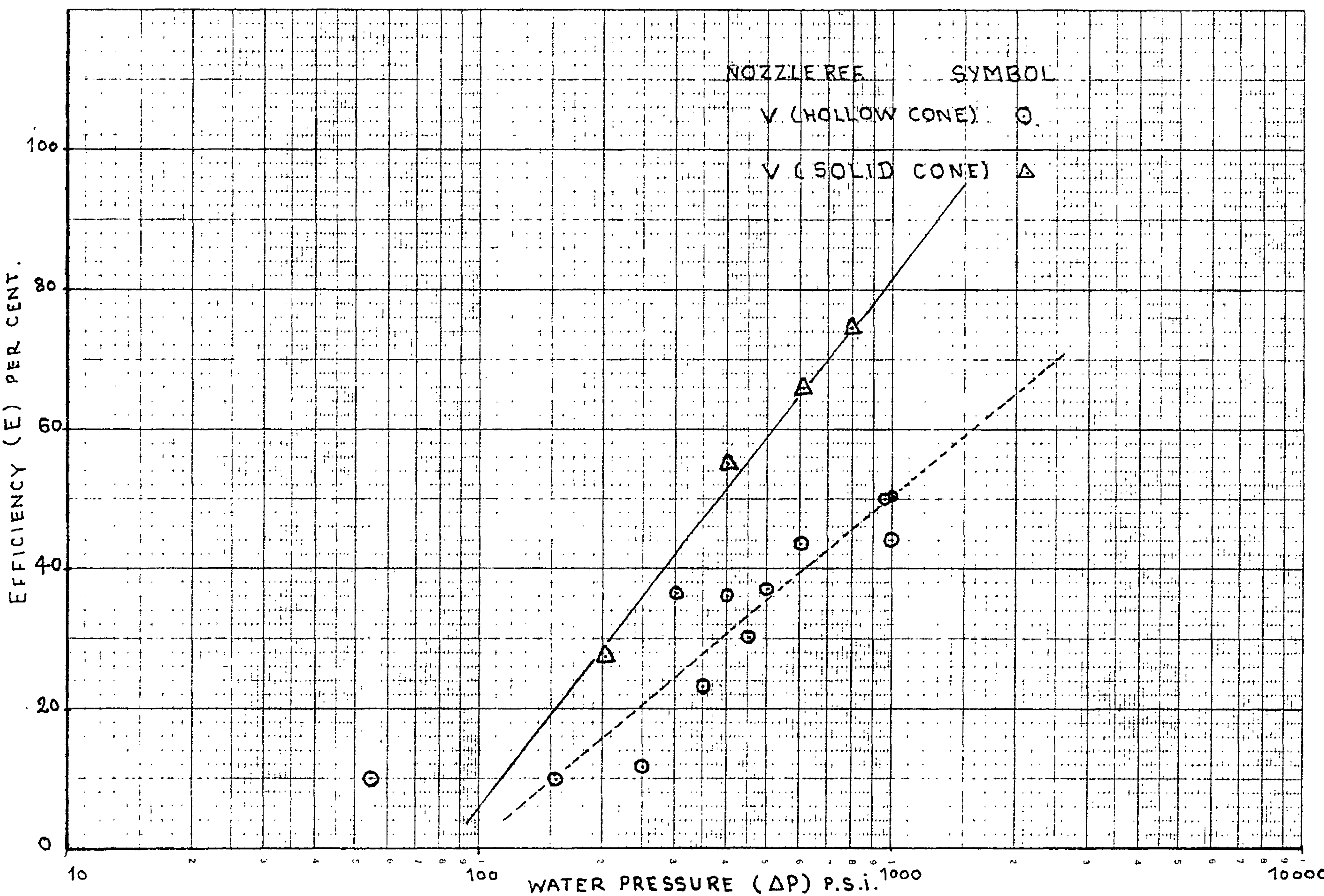


FIG 26(H) DUST SUPPRESSION WITH SOLID AND HOLLOW CONE SPRAYS shows that the increased efficiency of the solid cone spray has been gained at the expense of very high water usage. The values of the ratio are less than half that obtained by the hollow cone nozzle under similar conditions. In practice a decision would have to be made as to whether the gain in efficiency was worth the extra water involved.

<u>The effect of two spray nozzles</u> (ix),(x),(xi). Tables 25(a) and (b), 26, and 27(a) and (b). The effect of spraying upstream with two nozzles 4.5 ft apart is shown in Table 27(a) and (b). When the results are compared with those given by a single nozzle under the same conditions of pressure and dust concentration, a marked increase in efficiency due to the use of two nozzles is evident. An increase in efficiency of about 20 - 25% has been obtained.

The dust-water ratios included in the tables should be compared with those for the solid cone spray since the water usage is of the same order. It may be seen that although the ratio values are less than for a single hollow cone nozzle, they tend to be higher than those for the solid cone. This is particularly noticeable at high dust concentrations where the two nozzle arrangement gives much better values of dust-water ratio than the solid cone.

Once again it may be seen (Table 24(c)) that increased initial dust concentration does not result in an overall increase in dust suppression efficiency.

Efficiencies and dust-water ratios of the same order as before were obtained when the first spray nozzle was set to face downstream and the second, separated by 4.5 ft from the first, facing upstream.

When the airborne dust was made to pass through two sprays facing each other and set in the tunnel perpendicular to the air flow and a small distance apart, above 57 per cent dust removal was obtained when the distance between the nozzle was 2 - 6 inches, but dust suppression decreased progressively as the nozzles were set further apart. Comparison of the results of Table 27(a) with the value for the same nozzles at a similar dust concentration in Table 25(b) indicate that this transverse spraying does not give as high an efficiency of dust suppression as the former two stage spraying test and the dust-water ratios also are lower.

The two nozzles were set to face each other at a distance of 6 inches apart and with dusty air flowing in the tunnel spraying was again carried out perpendicular to the air flow. The effect of increasing water pressure was tested and the results are given in Table 27(b) An increase in efficiency with pressure was once again obtained together with an increase in dust-water ratio, but the increase was not such that this arrangement of nozzles was to be preferred to the two-stage spraying arrangement tested earlier.

One might well continue to multiply the number of spraying stages and determine if further efficiency increase could be obtained. Unfortunately, this would require a much longer tunnel and a high pressure water pump of much larger capacity than was available at this time.

Effect of dust suppression on size distribution of residual dust. Table 17 and Figs. 24 and 25. As can be seen in the Table 17 the residual dust was, like the initial dust, counted in four size ranges. In general about 75 per cent of the particles greater than 5 microns in diameter could be removed and about 60 - 65 per cent of the particles of sizes from 0.5 to 5 micron. The comparative histograms of Figs. 24 and 25 indicate that the sprays over a range of pressures, throughputs, arrangements and dust concentrations do not appear to be selective in suppressing any particular size of dust within the range counted.

Extension of spray tests to the coal pit

Since one of the objects of this work was to suppress dust under mining conditions, it had been hoped to test these small, high pressure spray nozzles in mine roadways and at various dust producing points underground. It was found, however, that the water pressure available underground was no greater than 120 p.s.i. and a high pressure pump suitable for mining conditions was not available. Since it had been found already, as shown in Table 14, that only a small dust suppressing efficiency was possible with these small nozzles at pressures as low as 120 p.s.i. it was decided that no useful purpose would be served by testing the small nozzle underground. As an alternative extension of the spray work it was decided to test a number of N.C.B. full-size spray nozzles in the present wind tunnel to determine whether their much greater water throughput even at relatively low pressures would give reasonable dust suppression. The values obtained could then be compared with the dust suppression obtained under actual mining conditions.

SECTION V

Spray production of full-size nozzles

1. Nozzles to be studied: Water sprays are extensively used for the reduction of airborne dust concentration at most of the dust producing operations in British Collieries. Spraying is popular because of its easy installation and more practical nature and because it appears possibly to the miner that something tangible is being dust to reduce dust. Richmond(46) made a series of measurements of the dust concentration in air at loading points before and after water spraying. The nozzles tested by him were made available to us. It was therefore decided to study systematically the relative merits of these nozzles by the technique described by Glen(24) and Hunter(25) and using the methods applied to the small nozzles in Section IV.

The study, for convenience, is conducted under three sub-headings.

(i) A study of the spray characteristics of the spray nozzles.

(ii) The sedimentation of airborne dust by the spray nozzles under laboratory conditions.

(iii) Application of the spray nozzles to the suppression of dust in a coal mine.

The complete data for the nozzles used in these tests are given in Table 28. Orifice diameters of the nozzles varied from 1.0 - 6.0 m.m. and only the Porter sprays were equipped with filters so as to avoid blockage of the liquid passage and damage to the orifice by dirt carried along with the water.

2. <u>Description of spray testing unit</u>: A line diagram of the spray testing unit built for these full-size nozzles is shown in Figure 27, and Plate No.3 shows the actual testing of the spray nozzle.

The apparatus consisted of a high pressure rubber hose fitted to the main water line through a needle valve to vary the outlet pressure. A three phase electric motor powered a centrifugal pump which enabled one to increase the available water pressure above 80 p.s.i.g. A by-pass valve was provided to improve flow regulation and the outlet end of this valve was connected by a rubber hose to the nozzle socket through a pressure gauge which was fixed rigidly to a wooden stand.

The nozzle socket was clamped between the two retort stands. This allowed free movement of the spray nozzle to give varying height, different angles, etc. The motor, the gauge, and the pressure controlling valve were mounted on a table.

A pulley was fixed in the ceiling right above the nozzle and was used for lifting up a baffle plate and for

TABLE 28

Data on full-size nozzles

Trade name of nozzle	Orifice diameter m.m.	Using filter or not	Remarks
Porter Sprays No. 1 - 4	1.0-2.5	Yes	Tangential feed filters, easily cleaned.
Ledward and Beckett Spray	3.50	No	Tangential feed, disadvantage is high water consumption.
Hayden Niles Spray	2.25	No	Easily cleaned, helical groove imparts rotary motion to spray cone.
Korting Spray	6.00	No	Wide span due to helical groove, but very high water consumption.
Morris Spray	1.50	No	Simple orifice nozzle, not very easily cleaned.

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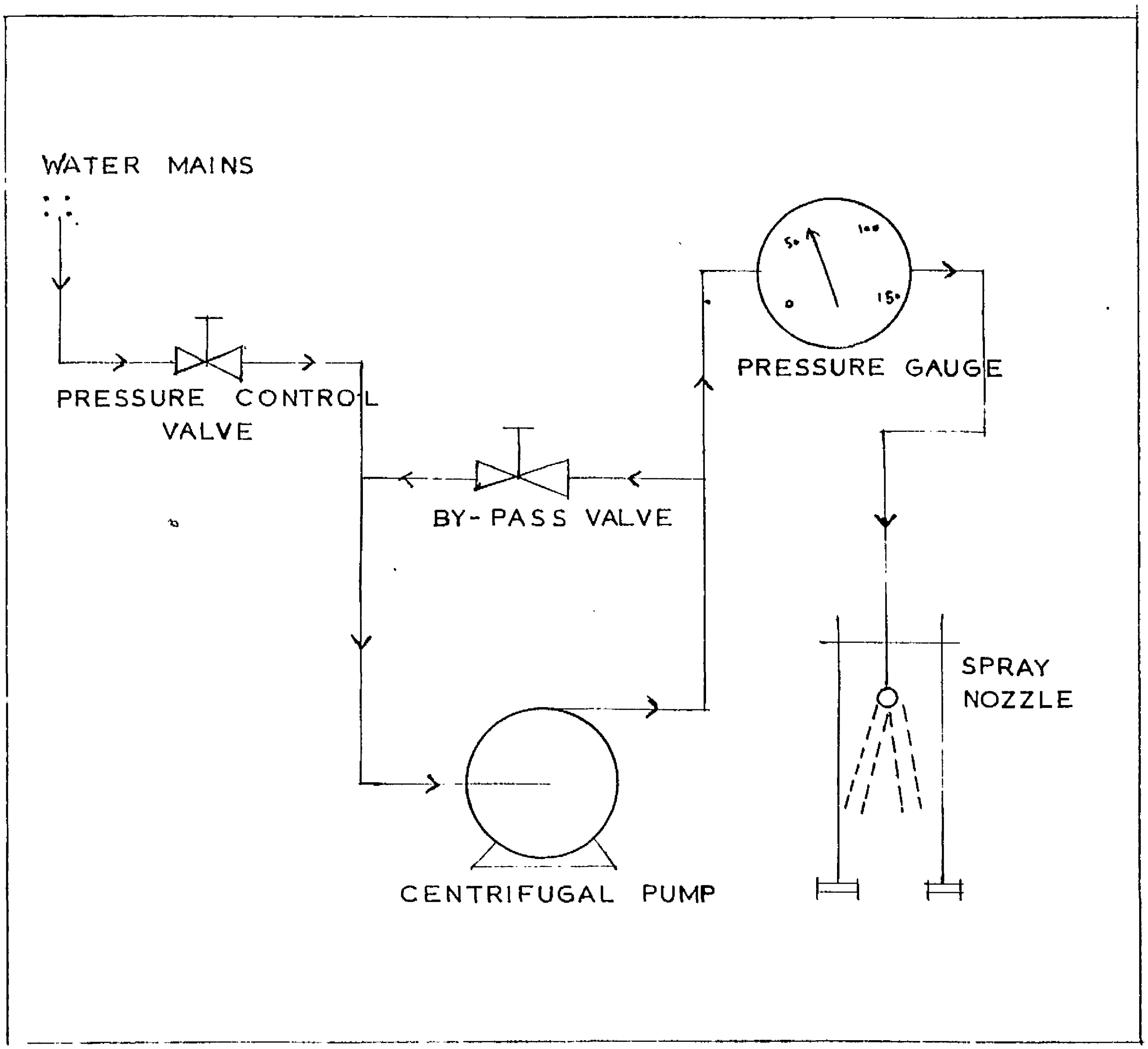


FIG. 27 LINE DIAGRAM OF THE SPRAYING UNIT.

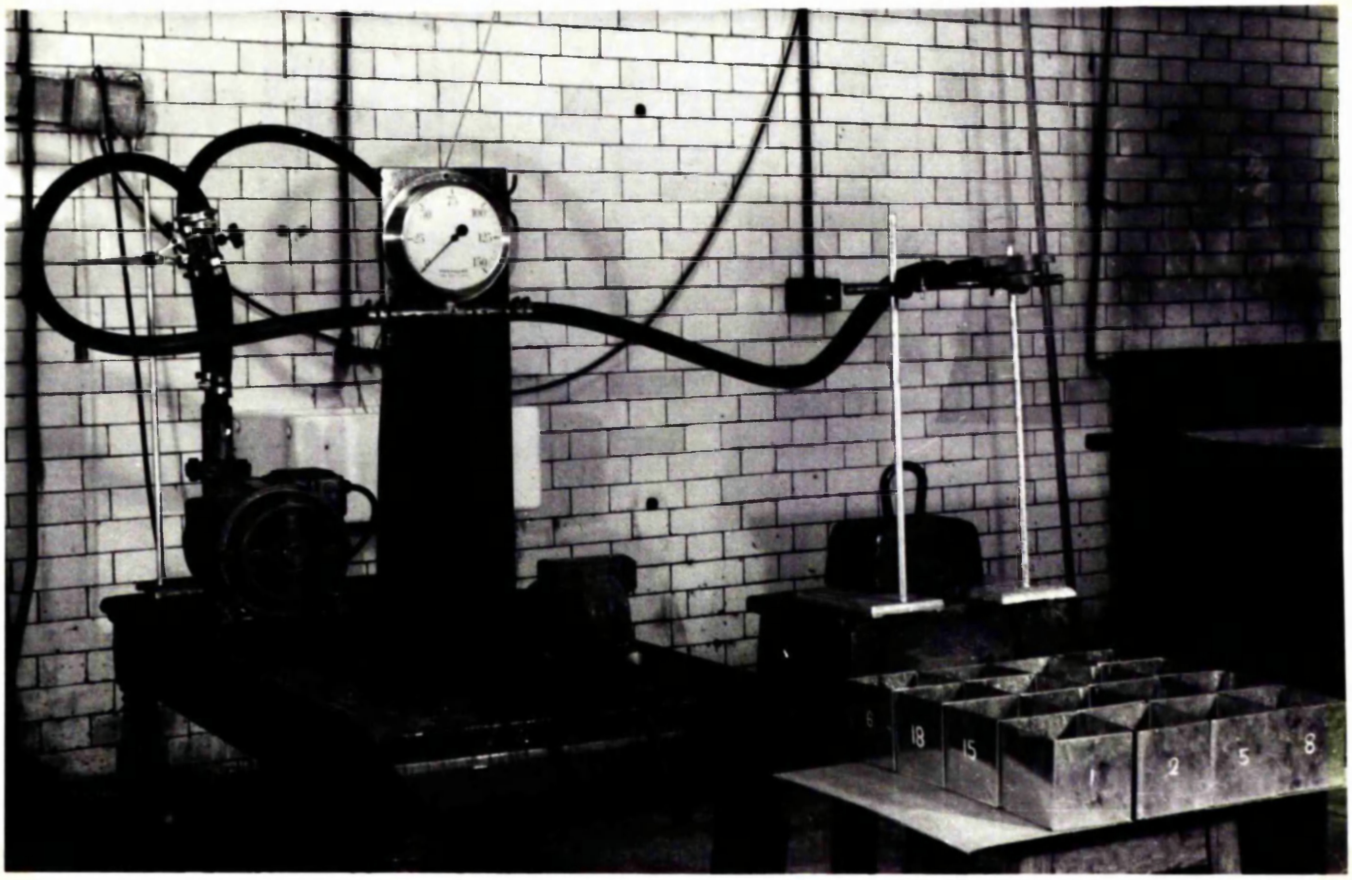


PLATE III

Spray Testing Unit

measuring the vertical height of the spray.

3. Experimental: The following spray characteristics were studied.

(i) The effect of applied pressure on throughput,

(ii) the relationship between the spray cone angle and the injection pressure,

(iii) the area wetted when sprayed horizontally,

(iv) the air swept volume when sprayed vertically,

(v) the arithmetic mean diameter of the droplets and the size distribution of droplets in the spray, and

(vi) the spatial dispersion of the spray and its deposition on a target.

(i) Throughput: Throughput for each nozzle at pressures ranging from 20 - 150 lbs/sq.in. was determined and a graph was drawn of the throughput in gal./hr. against the square root of pressure. The gradient of the straight line obtained is the flow number (Fn).

Fn is generally expressed as imperial gallons per hour/$\sqrt{\text{lbs}}$. per square inch.

$$\text{i.e. } Fn = Q/\sqrt{\Delta P}$$

Throughput curves for the full-size nozzles are shown in Figure 28(a) and 28(b).

The flow number which is in a sense a measure of water delivered by a nozzle for a given energy input is

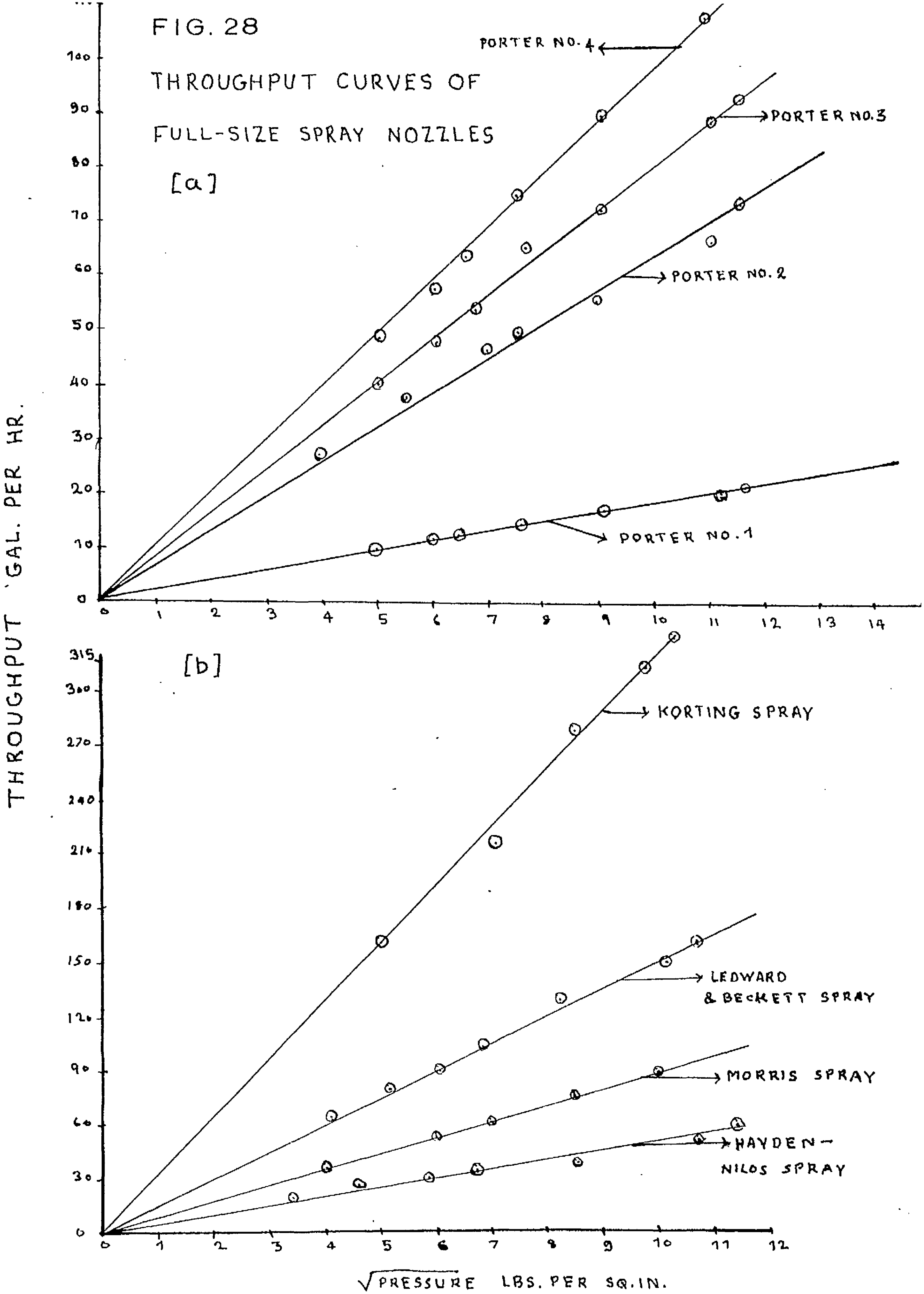


FIG. 28
THROUGHPUT CURVES OF
FULL-SIZE SPRAY NOZZLES
[a]
PORTER NO. 4
PORTER NO. 3
PORTER NO. 2
PORTER NO. 1
[b]
KORTING SPRAY
LEDWARD
& BECKETT SPRAY
MORRIS SPRAY
HAYDEN-
NILOS SPRAY
THROUGHPUT GAL. PER HR.
√PRESSURE LBS. PER SQ. IN.

greater for the tangential feed type of spray nozzle, e.g. Porter No.3, than for the helical groove type of spray nozzle of the same diameter, e.g. Haydon Nilos Spray.

Because the flow number is a function of throughput it is in effect dependent on the density of the liquid

$$\therefore \quad Fn = kCA/\sqrt{\rho_l}$$

Other properties of the atomised liquid such as viscosity affect the flow number through their influence on the discharge coefficient.

(ii) <u>The spray cone angle</u>: This tends to vary somewhat with the distance from the atomiser, and the spray angle is usually taken to mean the angle subtended by the spray cone at the atomiser orifice. This is shown in Figure 29. For continuous sprays the spray angle can be determined by obtaining a magnified silhouette of the spray on a screen by frontal illumination.[47]

Due to many complications involved in the silhouette method, a simpler and fairly accurate method was used to measure the spray cone angle. The spray was directed downwards and the pressure was carefully controlled. The spray cone angle was then measured by means of callipers for seven different pressures from 20 - 140 p.s.i. For each pressure a set of five determinations was made and

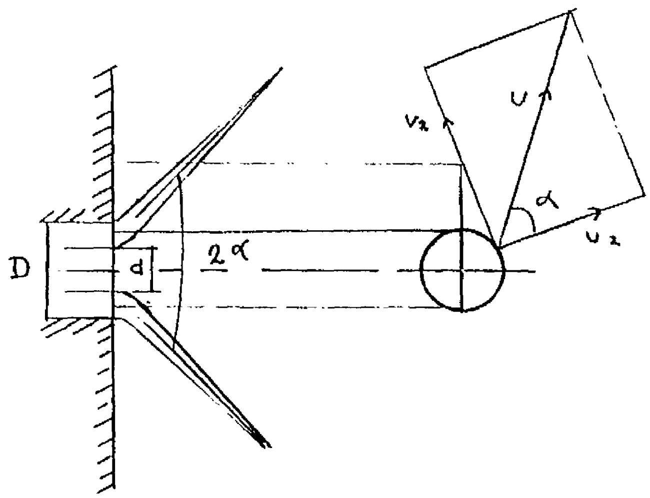


FIG 29 SPRAY PROFILE FOR SWIRL ATOMISER

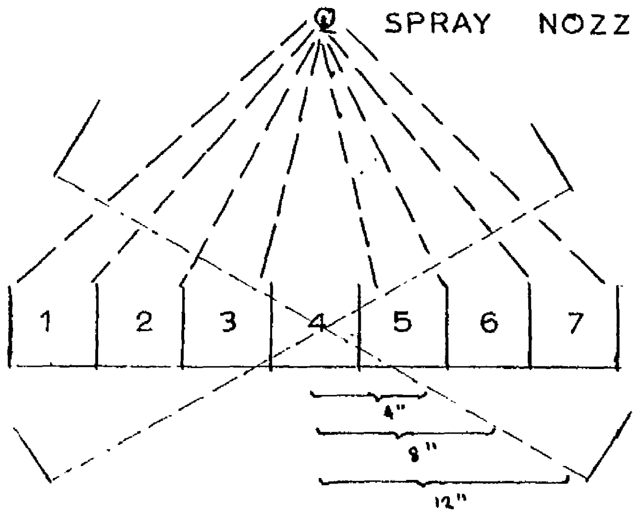


FIG. 32 SPATIAL DISPERSION OF SPRAY

the mean was taken as the spray cone angle for that pressure.

For all nozzles tested, the spray cone angle increased with applied pressure up to about 80 p.s.i. pressure and above that pressure the spray angle was almost constant. The results are shown in Tables 29 : 1 to 29 : 7.

The spray cone angle for the tangential-feed type of nozzle is of the order of 23° – 77°, and that for helical groove type of nozzles is 54° – 69°. The spray cone is better developed for the helical groove type of nozzle than for the tangential feed type. The helical groove also appears to give a better rotary action to the spray cone than the cyclone chamber of tangential feed nozzles. For swirl atomisers of helical groove type, the cone angle is generally less than for the swirl chamber type. This is clearly indicated by Ledward and Beckett and Korting Sprays. For the helical groove type of nozzle, the spray cone angle may beexpressed as a function of groove helix angle.[48]

(iii) Wetted area when sprayed horizontally: Each nozzle was set parallel to the floor and the pressure was adjusted to the required value while the ejected water was diverted by means of a baffle plate. The baffle plate was then

Characteristics of full-size nozzles

Table 29 : 1 Spray : Porter No.1 Flow No. = 1.80

Water Pressure lbs/sq.in.	25	35	42	60	80	125	132
Cone angle °	23	27	39	40	41	41	41
Area wetted when sprayed horizontally in sq.ft.	-	15.95	-	22.10	22.79	-	28.80
Air-swept volume when sprayed vertically in cu.ft	-	11.80	-	34.79	57.03	-	83.60
Average droplet size in microns	-	-	-	129.4	-	-	86.0

Table 29 : 2 Spray : Porter No.2 Flow No. = 6.4

Water Pressure lbs/sq.in.	15	35	47	60	80	120	132
Cone angle °	47	52	52	52	52	52	52
Area wetted when sprayed horizontally in sq.ft.	-	73.9	-	74.80	76.25	-	65.0
Air-swept volume when sprayed vertically in cu.ft	-	65.0	-	100.4	146.8	-	240.0
Average droplet size in microns	-	-	-	106.2	-	-	89.20

Table 29: 3 Spray : Porter No.3 Flow No. = 8.1

Water Pressure lbs/sq.in.	25	35	45	60	80	120	130
Cone angle °	47	49	50	53	53	58	59
Area wetted when sprayed horizontally in sq.ft.	-	61.25	-	70.40	70.40	-	71.30
Air-swept volume when sprayed vertically in cu. ft.	-	56.75	-	116.0	153.5	-	332.0
Average droplet size in microns	-	-	-	115.4	-	-	91.38

Table 29: 4 Spray : Porter No.4 Flow No. = 10.00

Water Pressure lbs/sq.in	25	35	43	60	80	120	130
Cone angle °	47	49	51	54	61	65	68
Area wetted when sprayed horizontally in sq.ft.	-	81.4	-	95.0	96.10	-	88.10
Air-swept volume when sprayed vertically in cu. ft.	-	87.4	-	135.2	241.5	-	797.5
Average droplet size in microns	-	-	-	124.0	-	-	88.4

Table 29 : 5 Spray : Ledward & Beckett. Flow No. = 15.0

Water Pressure lbs/sq.in	25	35	45	60	80	112.5	132
Cone angle °	62	65	68	69	72	75	77
Area wetted when sprayed horizontally in sq.ft.	-	90.4	-	103.8	109.5	-	114.1
Air-swept volume when sprayed vertically in cu. ft.	-	160.8	-	292.0	386.50	-	950.0
Average droplet diameter in microns	-	-	-	117.0	-	-	98.5

Table 29 : 6 Spray : Hayden Niles. Flow No. = 5.36

Water Pressure lbs/sq.in	20	35	45	60	80	125	132
Cone angle °	50	55	56	57.5	60	62	64.5
Area wetted when sprayed horizontally in sq.ft.	-	43.6	-	59.0	77.0	-	84.0
Air-swept volume when sprayed vertically in cu. ft.	-	112.0	-	153.5	207.5	-	339.0
Average droplet size in microns	-	-	-	110.6	-	-	100.9

Table 29 : 7 Spray : Korting Flow No. = 31.80

Water Pressure lbs/sq.in.	25	35	50	60	80	100
Cone angle °	58	60	62	63	66	69
Area wetted when sprayed horizontally in sq.ft.	-	178.0	-	186.8	188.9	208.0
Average droplet diameter in microns	-	-	-	110.2	-	97.9
Air swept volume when sprayed vertically cu.ft.	-	155.9	-	268.0	364.0	605.0

Table 29 : 8 Spray : Morris Flow No. = 9.09

Water comes out as a liquid jet with very high velocity.

removed and the spray was allowed to fall on the floor which had been covered with white paper. After about a minute the spray was stopped and the area of the wet stain on the paper was measured. As was to be expected the stain was elliptical in form. To simulate mining conditions, the height of the nozzle was set at two feet from the floor. The major and the minor axes of the ellipse were measured and the area calculated. The results are shown in Tables 29:1 to 29:7. The test was repeated at four different pressures.

The area wetted depends on the cone angle and the distance travelled by the droplets. The minor axis is controlled by the cone angle and the major axis by the cone angle and the kinetic energy distribution of the droplets. The area wetted by tangential feed and by the helical groove type of nozzles do not differ greatly.

Theoretically, with the increase in applied pressure, the area wetted should also increase because the axial component of the velocity of the liquid flowing through the nozzle increases with pressure. It may be seen, however, from Tables 29:2 to 29:4 that for the Porter type Nos. 2, 3 and 4, the wetted area did not increase appreciably with applied pressure. Instead, it was found to decrease with increase in pressure.

(iv) <u>The air-swept volume when sprayed vertically</u>: Each nozzle was set pointing upwards with the orifice axis exactly perpendicular to the floor. A horizontal aluminium disc of 2.0 ft. in diameter was lowered from the ceiling to a height where most of the droplets in the spray cone made contact with the disc. The height (h) was recorded and the air-swept volume was calculated assuming that spray volume was that of a cone, i.e.

$$\text{Air-swept volume} = \pi\, h^3 \tan^2\alpha/3$$

Air-swept volume could be expected to depend on the applied pressure and cone angle.

The accurate measurement of the spray height was difficult. Therefore a number of observations were made and the mean was taken as the spray height for that pressure. Air-swept volumes of the nozzles tested were of the order of 12.0 - 950.0 cu.ft. for 60 - 135 p.s.i. pressure.

(v) <u>Average size and size-distribution of droplets</u> The arithmetic mean diameter of the spray droplet and droplet size-distribution in the spray zone was measured. Hunter[25] describes work on sampling techniques for measuring spray droplet diameter. Hunter's method was adopted here. White paraffin oil was used as the immersion liquid instead of light Kerosene.

The spray was directed horizontally and a petri dish $2^1/2$ inches in diameter, covered with 2.0 m.m. uniform layer of vaseline and about 5.00 m.m. layer of white paraffin was taken through the spray zone for a very short interval at such a distance that the spray droplets had lost most of their kinetic energy and were falling under gravity. The captured droplets were at once sized under a microscope with a calibrated eye-piece. Each time about 50 drop diameters were recorded in a period of about ten minutes. Aggregation was later apparent among the captured droplets. The procedure was repeated six times making it possible to record a total of about 250 - 300 drop diameters in each test. From the observations, the arithmetic mean diameter of the spray droplets was calculated and size-distribution curves drawn.

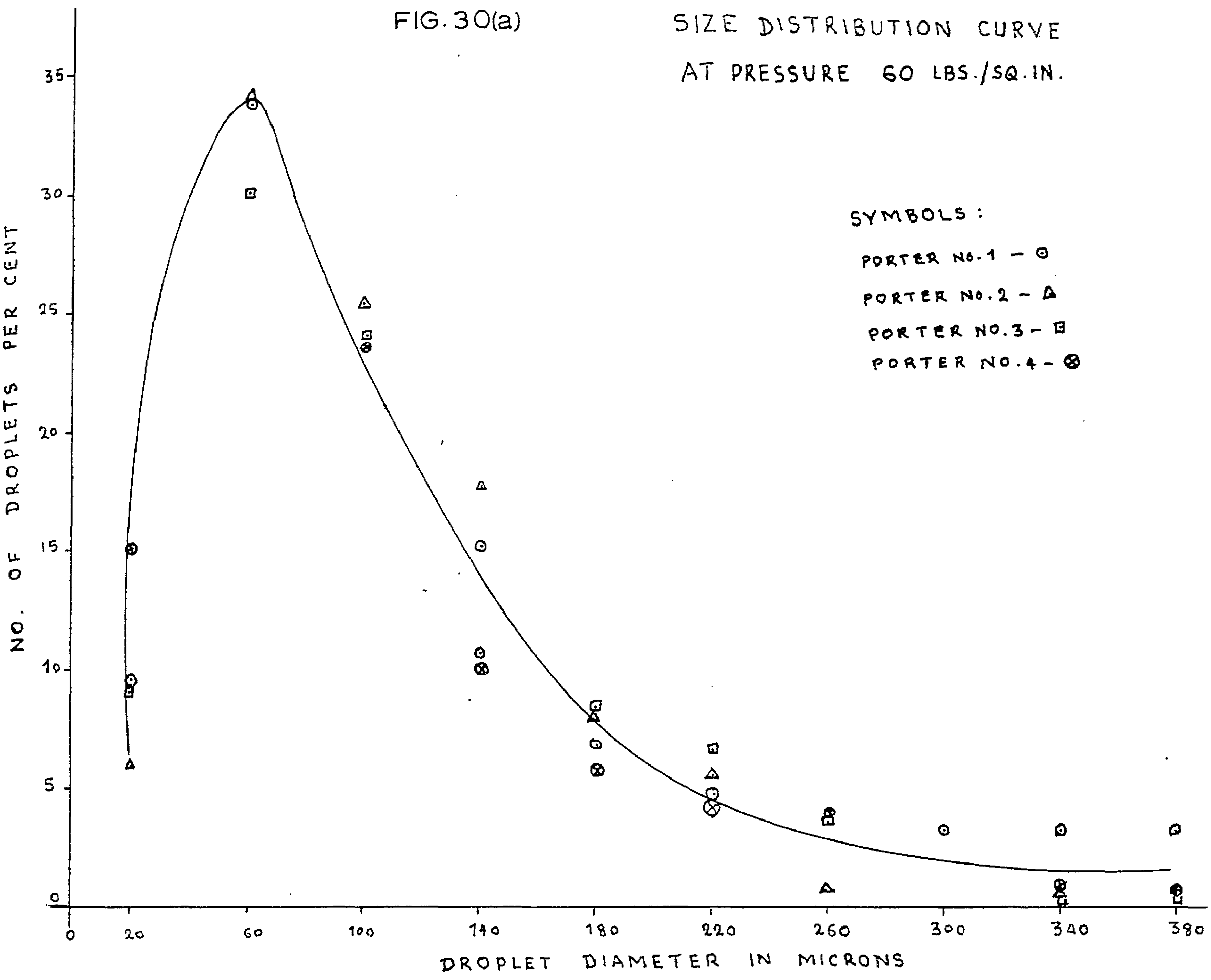
The results are shown in Tables 29:1 to 29:7 and in Figures 30(a), 30(b), 31(a) and 31(b).

For all the nozzles, the average droplet diameter varies between 86 - 130 microns at 65 - 135 p.s.i. pressure.

For Porter spray nozzles, though their orifice diameters differ from 1.0 - 2.5 m.m., a common skew curve can be drawn to represent the size distribution of the droplets.

For Porter sprays 60 per cent of the drops are of 41 - 120 microns size-range, but for the rest of the nozzles this figure is slightly higher, With Hayden Nilos sprays the maximum number of spray droplets lies in 81 - 120 microns size-range.

FIG. 30(a)


SIZE DISTRIBUTION CURVE
AT PRESSURE 60 LBS./SQ.IN.
SYMBOLS :
PORTER No.1 – ⊙
PORTER No.2 – △
PORTER NO.3 – ⊡
PORTER NO.4 – ⊗
NO. OF DROPLETS PER CENT
DROPLET DIAMETER IN MICRONS
0
5
10
15
20
25
30
35
0
20
60
100
140
180
220
260
300
340
380

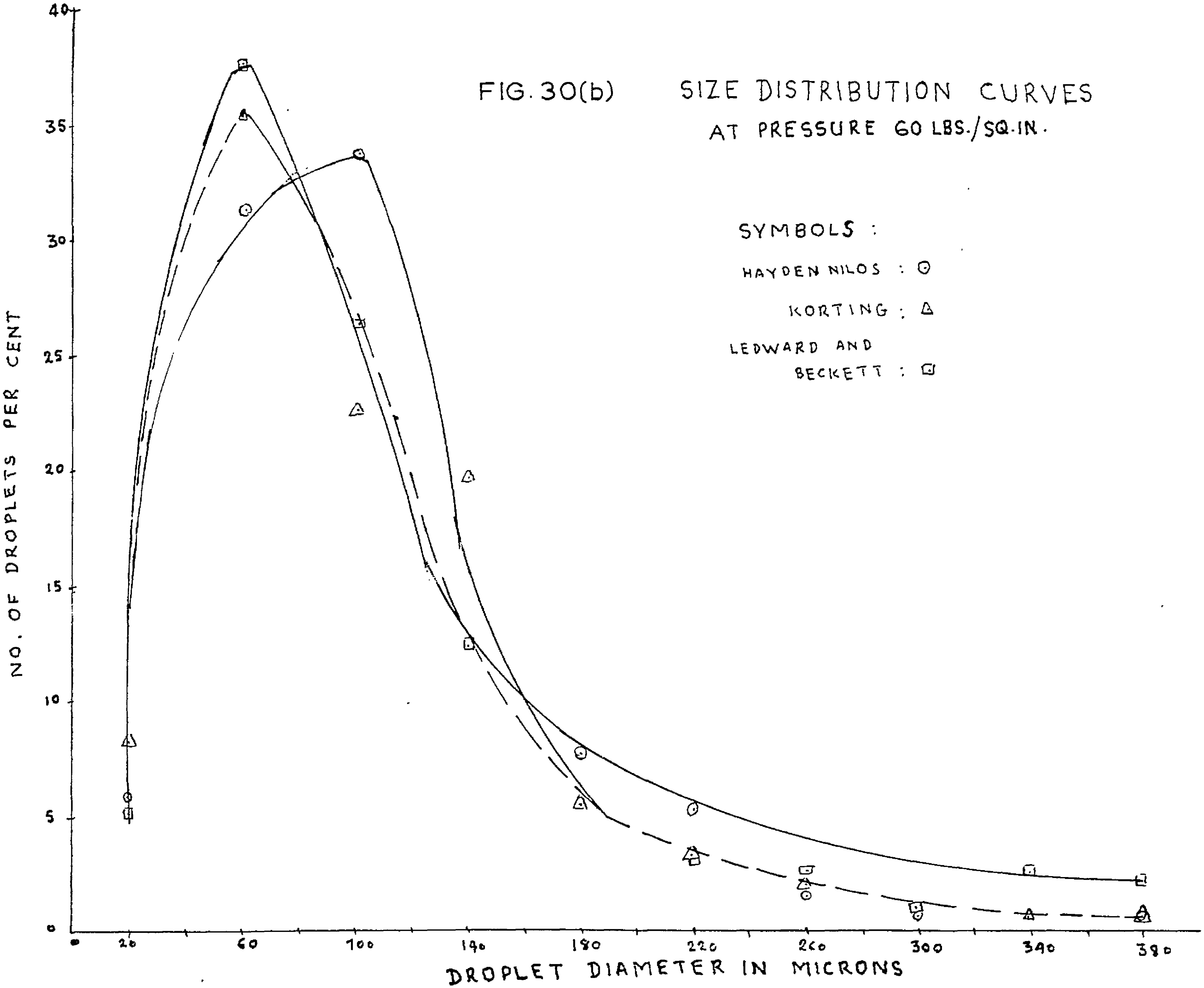


FIG. 30(b) SIZE DISTRIBUTION CURVES AT PRESSURE 60 LBS./SQ.IN.

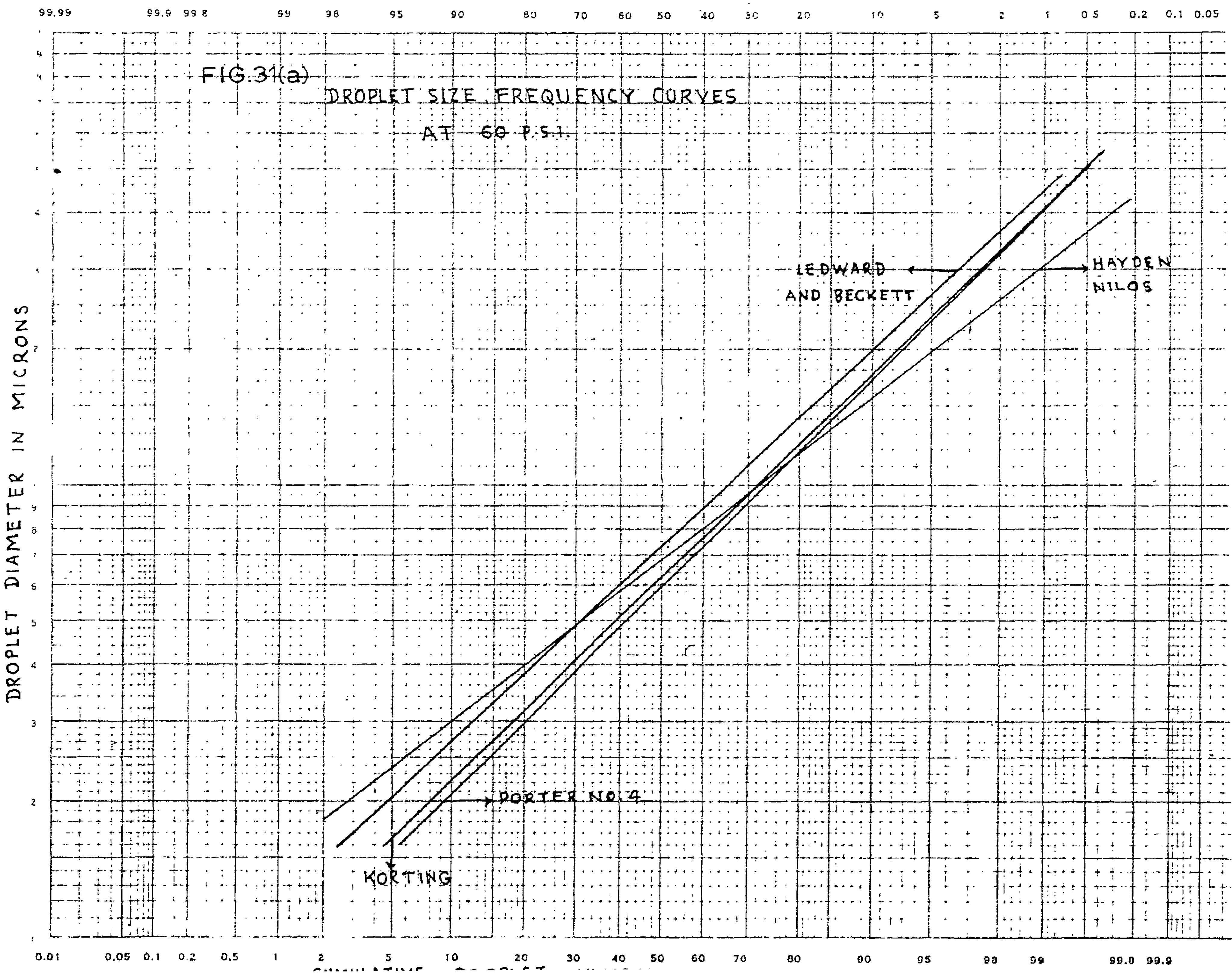

DROPLET SIZE FREQUENCY CURVES
AT 60 P.S.I.
LEDWARD AND BECKETT
HAYDEN NILOS
PORTER NO. 4
KORTING
DROPLET DIAMETER IN MICRONS

FIG.31(a)

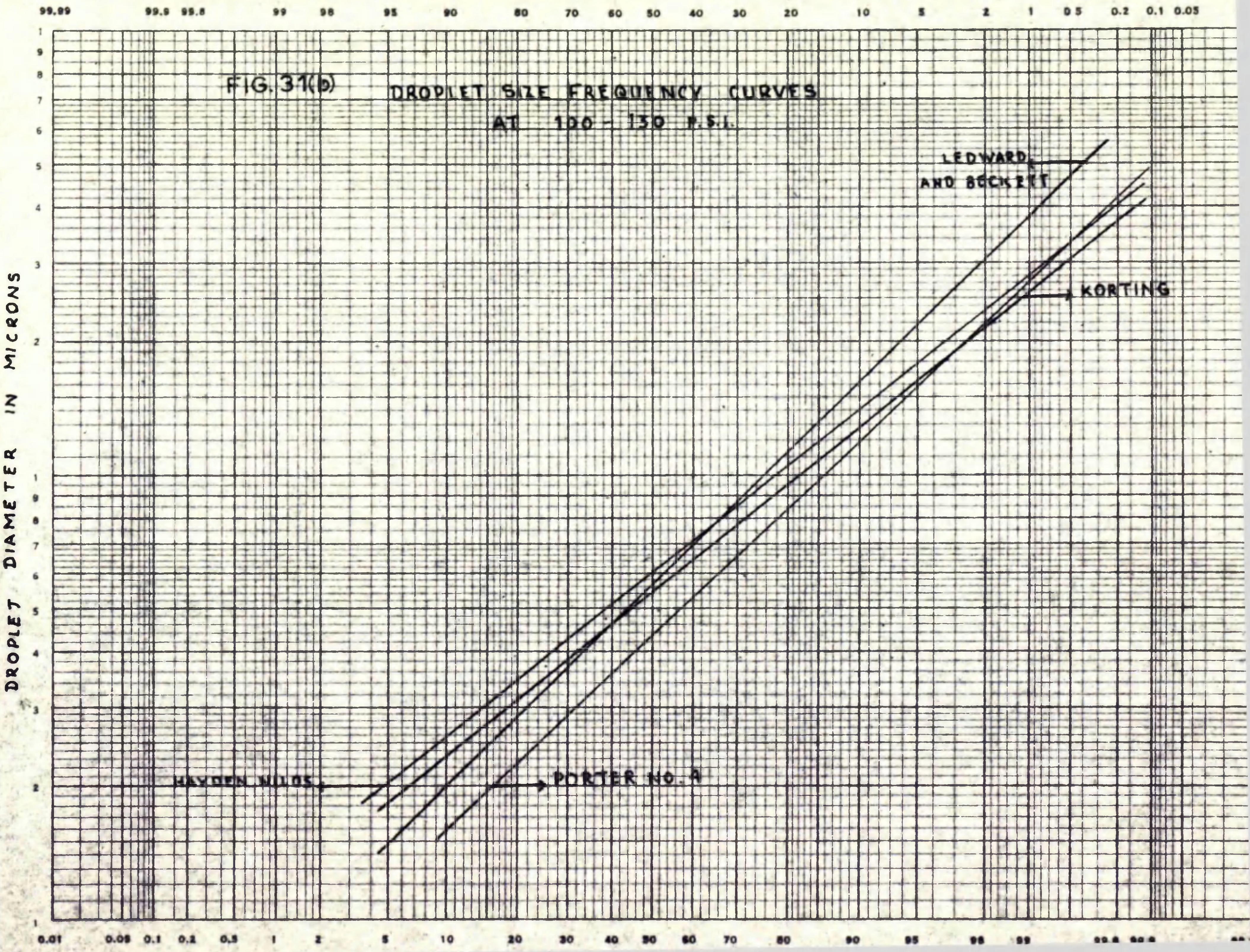


FIG. 31(b)
DROPLET SIZE FREQUENCY CURVES
AT 100 - 130 P.S.I.
LEDWARD AND BECKETT
KORTING
HAYDEN NILOS
PORTER NO. 4
DROPLET DIAMETER IN MICRONS
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99

<u>Spatial dispersion and target deposition:</u> If the volume distribution of water, in a horizontal plane, issuing downwards from a vertically mounted swirl spray nozzle is studied, it is to be expected that the hollow cone character of the spray sheet will tend to concentrate most of the water into a fairly narrow ring. The diameter and thickness of this ring will of course depend on the sampling distance from the orifice. Abnormal distribution of water will throw light on orifice machining errors, blockages of nozzle passages, damage to nozzle tip, or even faulty nozzle design.

It was important to compare the water spatial dispersion of the various full size nozzles and for this purpose the arrangement of collecting boxes shown in Figure 32 and Plate III was prepared. The tests were carried out as follows :-

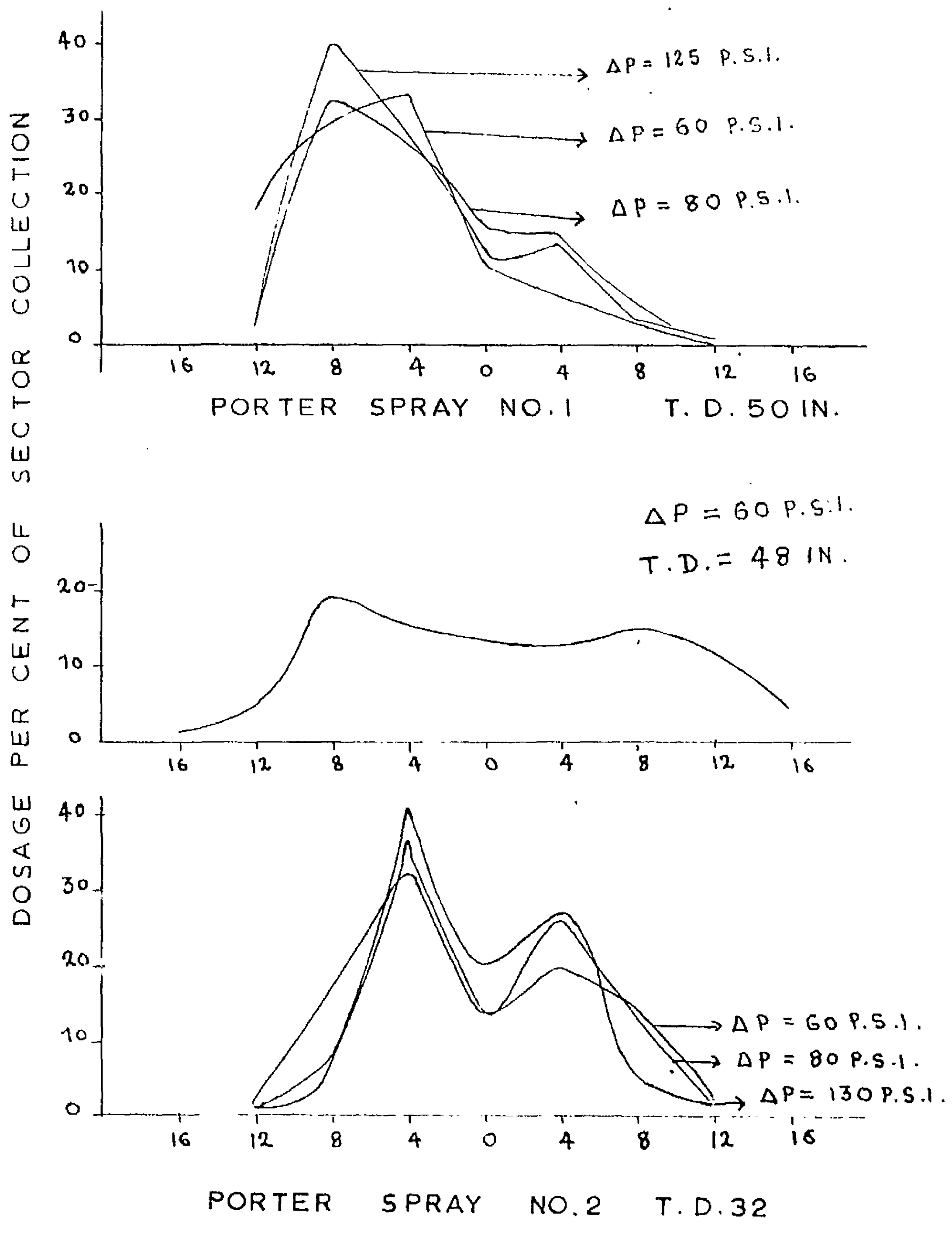
A number of tin boxes of dimensions 4" x 4" x 4" were specially constructed. The nozzle was fixed pointing downwards from a suitable height and the diameter of the spray circle was noted by spraying water on the floor. The boxes were arranged to form a diameter to this circle. The sprayed water was collected in this strip - (28 in. - 44 in. x 4 in. x 4 in.)

The procedure was repeated at two other diameters at 45° to the first one tested. Observations were made at a fixed height and at three different pressures, and again at a fixed pressure with varying target distance. A deposition curve was drawn showing the relationship between the distance from the nozzle axis and the percentage spray deposition. These deposition curves are shown in Figures 33 (a), (b), (c) and (d), and are quite comparable to those given by others[43][49][50] for swirl atomisers used for spraying, combustion studies etc.

Spatial dispersion of spray mainly depends on the mechanical design. Even then increasing the target distance also helps to increase the spray uniformity. However, increase in the injection pressure does not seem to have much effect on the distribution of the spray. At high injection pressure spray losses in transit, which these deposition curves do not take into account, are quite considerable. The chief reason for transit losses is that the resulting spray droplets are so fine that they are prone to drift away in local air currents.

4. <u>Spray Penetration:</u> By penetration of a spray is understood the shortest distance between the atomiser and a plane perpendicular to the atomiser axis, which has been reached by droplets at any given moment. This has been calculated for swirl atomisers while estimating air-swept volumes.

FIG. 33 SPRAY DEPOSITION CURVES
[a]



DISTANCE (IN) FROM THE CENTRE OF THE NOZZLE

T.D. = TARGET DISTANCE

ΔP = PRESSURE (SPRAY)

FIG.33 (CONTD)

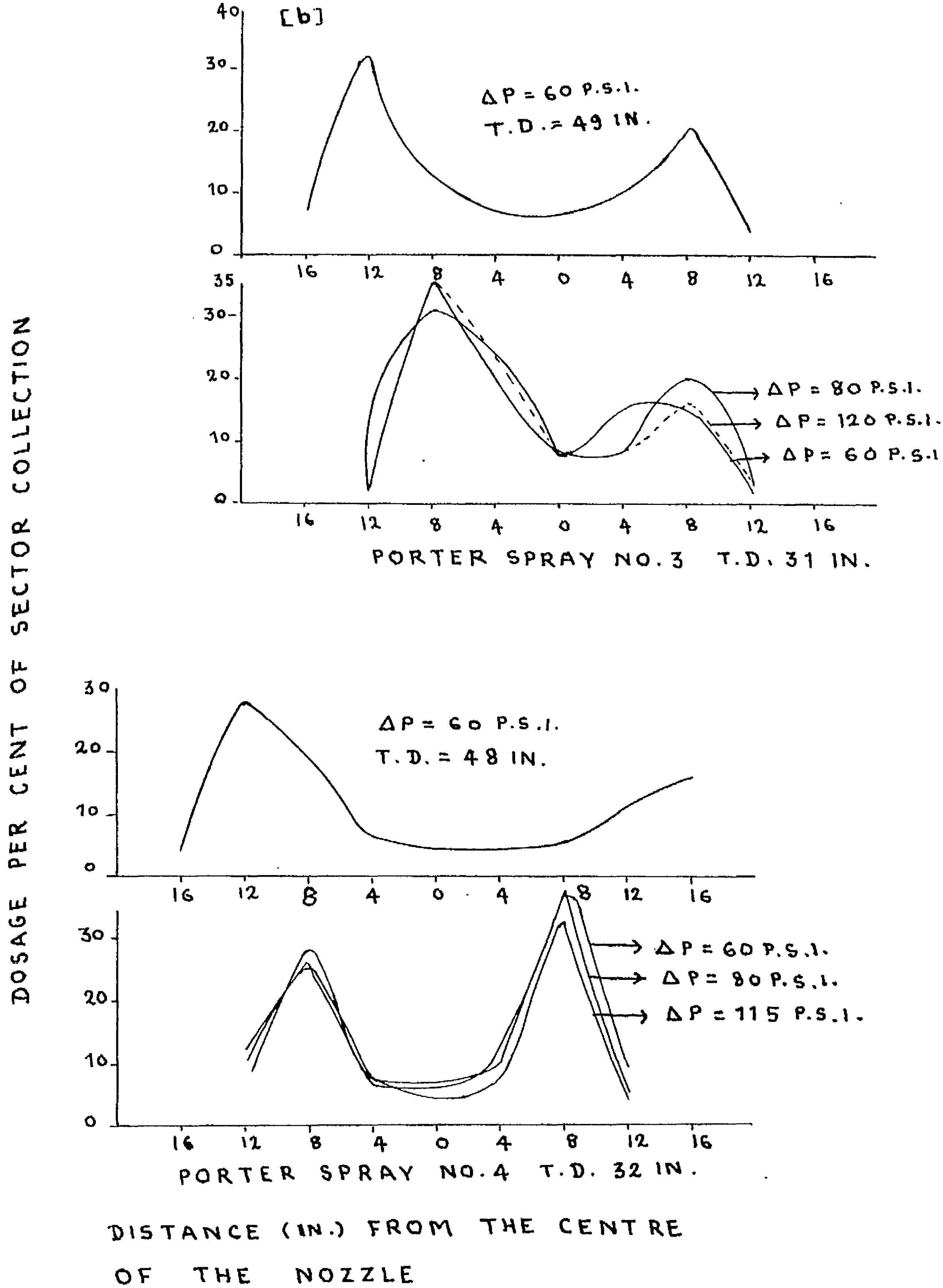

[b]
ΔP = 60 P.S.I.
T.D. = 49 IN.
ΔP = 80 P.S.I.
ΔP = 120 P.S.I.
ΔP = 60 P.S.I.
PORTER SPRAY NO.3 T.D. 31 IN.
ΔP = 60 P.S.I.
T.D. = 48 IN.
ΔP = 60 P.S.I.
ΔP = 80 P.S.I.
ΔP = 115 P.S.I.
PORTER SPRAY NO.4 T.D. 32 IN.
DOSAGE PER CENT OF SECTOR COLLECTION
DISTANCE (IN.) FROM THE CENTRE OF THE NOZZLE

FIG. 33 (CONTD)

[C]

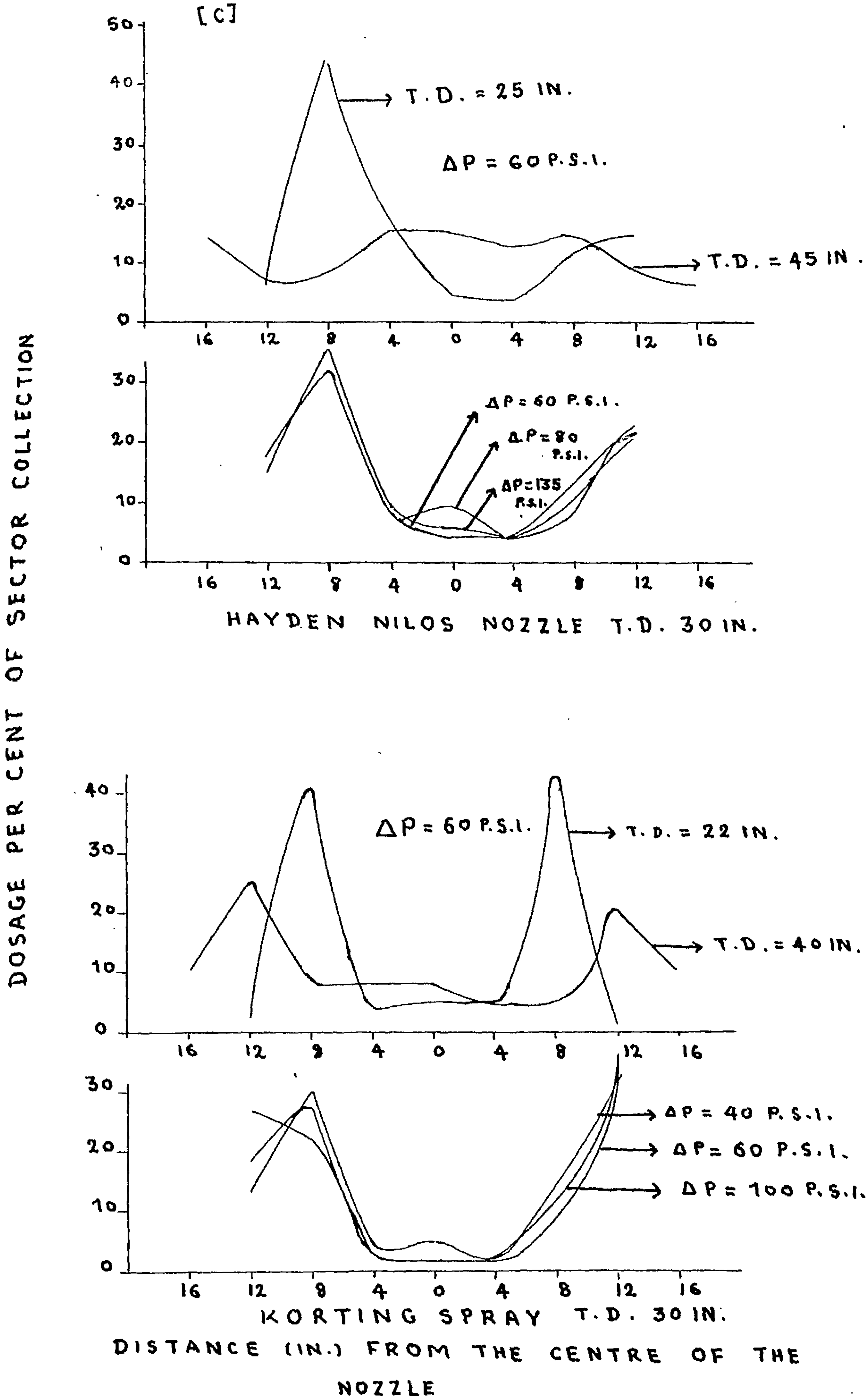
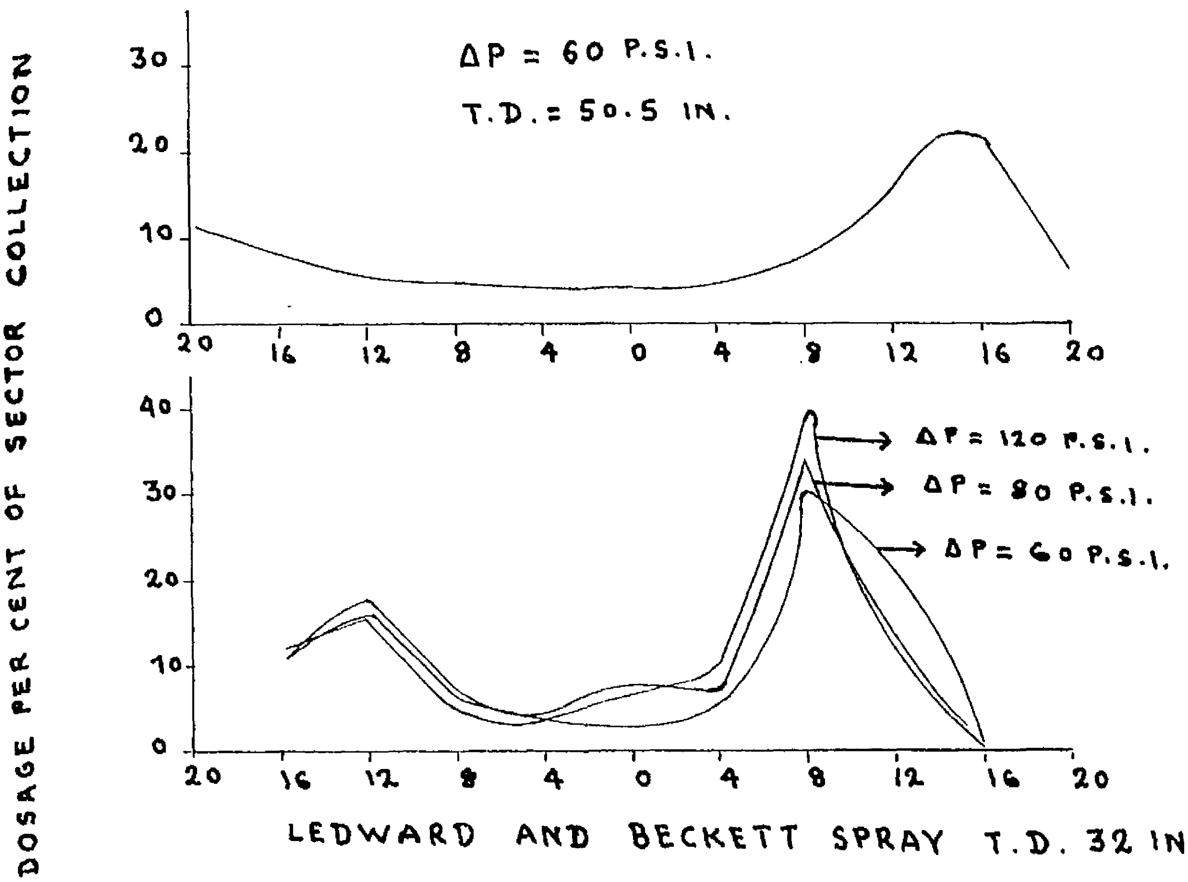


FIG. 33 (CONTD)

[D]



LEDWARD AND BECKETT SPRAY T.D. 32 IN.

DISTANCE FROM THE CENTRE OF THE NOZZLE (IN.)

Average droplet diameter of a swirl-spray nozzle also enables one to calculate theoretical penetration for a single droplet. For simplicity the Hayden Nilos nozzle was selected and the results at 60 p.s.i. applied pressure were used in al the calculations given below.

5. Calculation of the projection velocity and spray penetrati

Projection velocity for a spray droplet could be obtain by using two different methods.

(i) The projection velocity of a droplet fired vertically into still air can be determined from the equation[51

$$2\,g\,x / k^2 = \log\left(V_o^2/k^2 + 1\right)$$

where it is assumed that the air resistance varies as the square of the velocity, and that x is the height above the nozzle at which the droplet comes to rest before falling again. The constant k depends on the air resistance and was taken to be 16 in this case[51].

Therefore for the Hayden Nilos spray at 60 p.s.i. with $x = 10.87$ ft., and $g = 32.2$ ft/sec.^{2}, the projection velocity, $V_o = 60.6$ ft/sec.

(ii) Projection velocity from coefficient of discharge and injection pressure[52]

$$V_o = C(2g\Delta P/\rho_1)^{1/2}$$

If C, the coefficient of discharge is taken as 0.6 for this type of spray nozzle

$$\therefore \; V_o = 56.75 \text{ ft/sec.} = 1760 \text{ cms./sec.}$$

For example:- Penetration of a 110 micron diameter droplet at 60 p.s.i. applied pressure. Swirl-spray nozzle:- Hayden Nilos Spray (helical groove type). Orifice diameter = 2.25 m.m., injection pressure = 60 p.s.i Density of liquid = 62.4 lbs/cu.ft. Air density = $1.293 . 10^{-3}$ g./c.c. and Air Viscosity = $1.79 . 10^{-4}$ poise., and

$$\therefore \; \text{Reynolds Number, Re} = \rho_a V_o D_p / \eta_a$$

$$= 140.0$$

Projection velocity of the droplet = 1760 cms./sec.

This shows that the flow is initially in a semi-turbulent region, i.e. Re. No. between 2 and 500, therefore the velocity of the droplet, V_1, at the end of the semi-turbulent region is given by the equation,(53)

$$V_1 = 2\,V_o/\text{Re} = 2\,V_o/140 = 25.14 \text{ cms./sec.}$$

The time (t) for the velocity to fall to this value is given by the equation,(54)

$$V_1 = [(0.01\,D_p\rho_a/\eta_a + 1/V_o)\,\exp\,(30\eta_{at}/D_p^2\rho_1) - 0.01\,D_p\rho_a/\eta_a]$$

By substituting appropriate values and solving the equation, $t = 0.0785$ seconds.

The penetration (S) of the droplet is given by the equation[54]

$$S=(D_p\rho_1/0.3\rho_a)\log_e\left\{1+(0.01\ D_p\rho_a/\eta_a)V_o[1-\exp(-30\eta_a t/D_p^2\rho_1)]\right\}$$

$$\therefore\quad S = 24.35 \text{ cms. or } 0.794 \text{ ft.}$$

For laminar flow, the initial velocity is 25.14 cms./sec. and the velocity V_2 and penetration S_1 at any time (t) from the beginning of this stage is given by the equation,[54]

$$V_2 = V_1 \exp(-18\eta_a\ t/D_p^2\rho_1)$$

and $$S_1 = (D_p^2\rho_1/18\eta_a)[1 - \exp(-18\eta_a t/D_p^2\rho_1)]V_1$$

Where $V_1 = 25.14$ cms./sec., and at $t = \infty$,

$$S_1 = (D_p^2\rho_1/18\eta_a)V_1$$

since $\exp(-18\eta_a t/D_p^2\rho_1) = 0$,

$$S_1 = 1.03 \text{ cms.}$$

Thus the total penetration of a 110 micron water droplet when projected at an initial velocity of 1760 cms./sec. is equal to $25.35 + 1.03 = 25.38$ cms. or 0.8278 ft.

But in practice most of the droplets reach the vertical height of about 10.87 ft.

Therefore the ratio of actual penetration to theoretical penetration is $\dfrac{10.87}{0.8278} = 13$

Giffen and Muraszew have calculated the actual penetration of droplets using a stroboscopic technique when working on the atomisation of low pressure fuel sprays.(55) They have also given the size distribution of fuel spray droplets. From the given data, the theoretical penetration of a fuel droplet of about 80 microns in diameter has been calculated using the same procedure as indicated above. The total theoretical penetration comes out to be 9.16 cms. while the experimental observation by the stroboscopic method, leaving the shutter open indefinitely, was 4 ft.

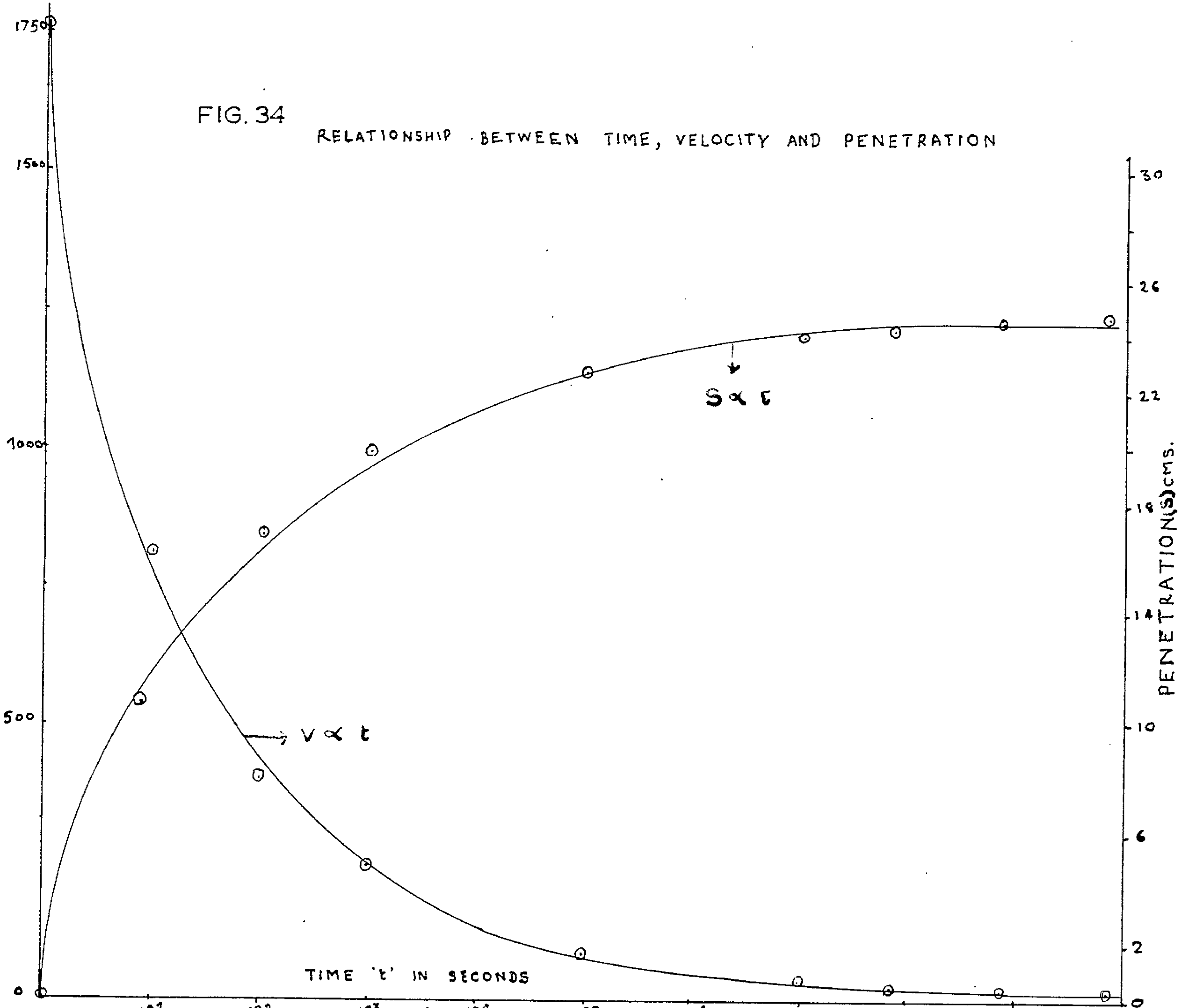
$$\therefore \text{The ratio} = \frac{\text{Actual Penetration}}{\text{Theoretical Penetration}} = 13$$

The relationship between time, velocity and penetratio for the 110 micron water droplet is shown in Figure 34 and that between penetration, velocity and Re. No. for the same droplet is shown in Figure 35.

The high value of the above ratio of penetration is the result of the difference between the conditions of motion of a single water droplet projected into still air and of a complete spray of many droplets. Each droplet within the air-swept volume of the spray is influenced by the air movement produced by droplets ahead of it which

FIG. 34

RELATIONSHIP BETWEEN TIME, VELOCITY AND PENETRATION



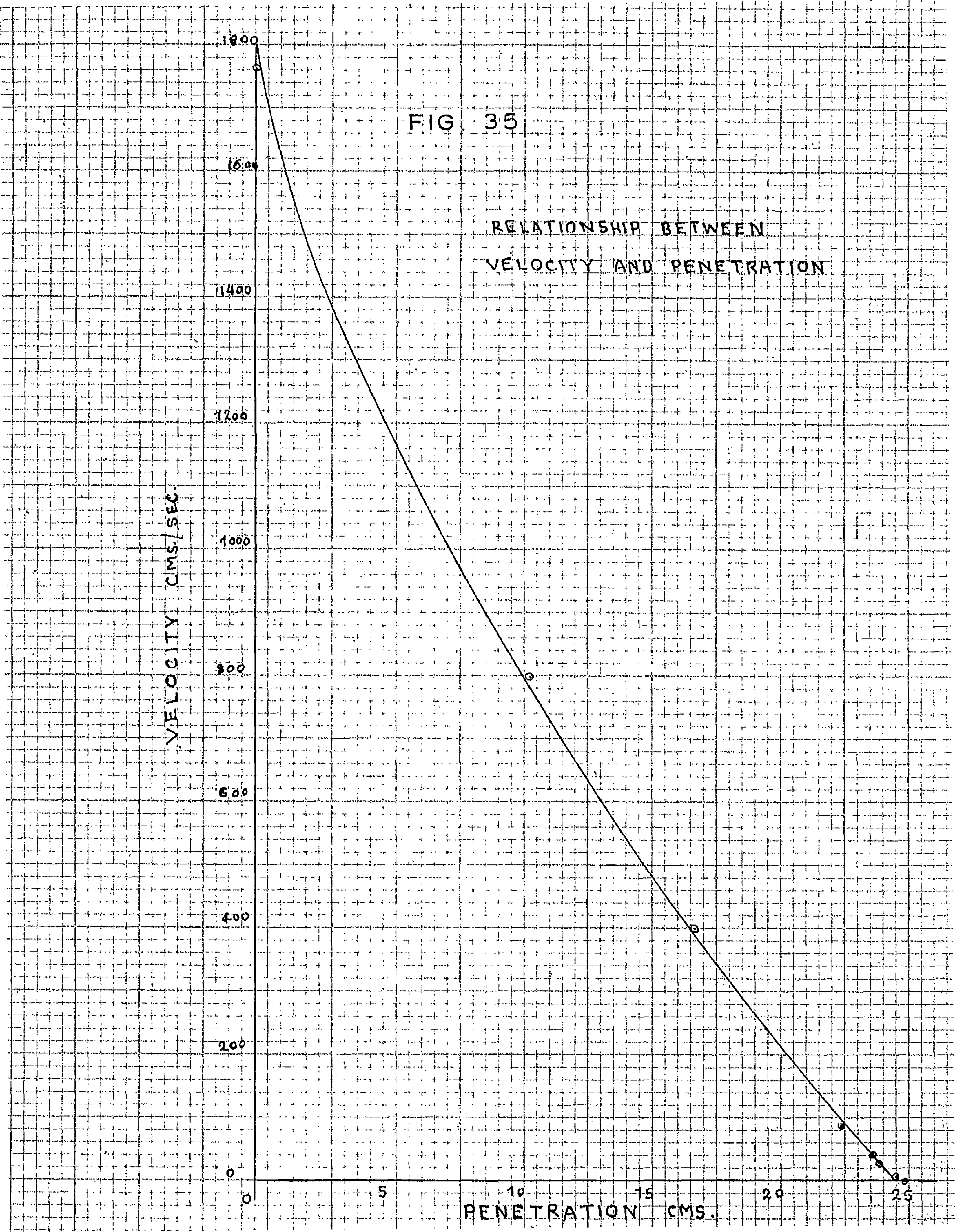
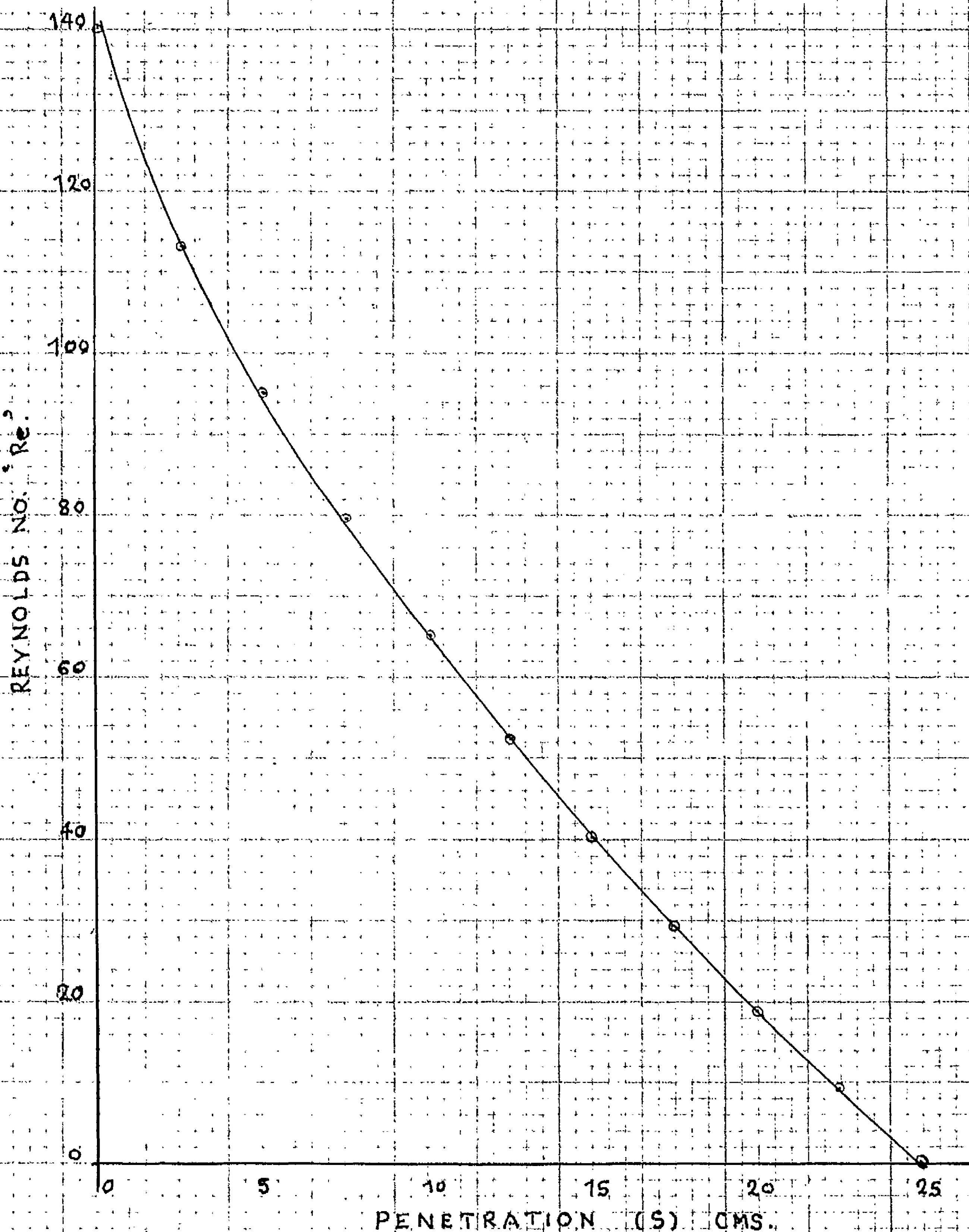


FIG. 35
RELATIONSHIP BETWEEN
VELOCITY AND PENETRATION
VELOCITY CMS./SEC.
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
PENETRATION CMS.

FIG. 35 (CONTD)

RELATIONSHIP BETWEEN REYNOLDS NO. AND PENETRATION



effectively reduce the air resistance and allow the droplet to penetrate much further than the small distance shown by the above calculations.

6. Representation of droplet size-distribution

Another aspect worth considering is the representatio of various drop sizes. This is usually done on rectangular co-ordinates and gives a skew shape curve. Because of the peculiar shape, the curve does not give full information. Therefore various workers have tried to use different techniques and mathematical expressions to obtain more information from such data.(56)(57)

For dust suppression two most useful diameters are (1) arithmetic mean projected diameter, and (2) Sauter mean diameter, (S.M.D.), and their values for Hayden Niles spray at 60 p.s.i. applied pressure are :-

1. Mean projected diameter = $\Sigma nD_p/\Sigma n$ = 105.8 microns
   (calculated from size-distribution)
2. Sauter mean diameter = $\Sigma nD_p^3/\Sigma nD_p^2$ = 137.0 microns
   (calculated from size-distribution)

The usual curves of skew type give no clue to the average droplet diameter. Therefore "log probability" paper was used to represent the same data. The number and volume per cent curves are plotted on the "log probability" paper for (a) normal size-distribution data,

TABLE 30

Size-distribution data for Heyden Nilos Spray at 60 p.s.i.

Particle size-range in microns	0-40	40.1-80	80.1-120	120.1-160	160.1-200	200.1-240	240.1-280	280.1-320	320.1-360	>360
Mean Size (microns)	20	60	100	140	180	220	260	300	340	-
Number per cent of droplets at 60 p.s.i.	5.71	31.21	33.62	15.43	6.05	5.25	1.39	0.67	-	0.67
Cumulative number per cent	5.71	36.92	70.54	85.97	92.02	97.27	98.66	99.33	99.33	100.(
Volume per cent of droplets at 60 p.s.i.	0.0175	2.5999	12.88	16.59	13.56	21.25	9.37	7.075	-	16.58
Cumulative volume per cent	0.0175	2.617	15.50	31.09	41.65	65.90	75.27	82.34	-	98.92
$U = \frac{D_p}{D_{pm} - D_p}$	0.022	0.064	0.112	0.165	0.22	0.28	0.353	0.428	0.516	0.613

and (b) using the special upper limit equation data described later. This is shown in Figure 36(a).

The size-distribution data is given in Table 30.

Log probability volume distribution function is given by the equation

$$dv/dy = \delta\pi^{-1/2} \exp(-\delta^2 y^2)$$

where $y = \log e \, (D_p/\overline{D_p})$

The Saunter Mean Diameter can be calculated for such a distribution from the equation as follows:-

$$S.M.D. = \overline{D}_{p50} \exp(-1/4\delta^2)$$

In this case S.M.D. was found to be 130 microns.

This result is quite close to 137 microns obtained from experimental data. One important point to note is that the graph shows a slight deviation from the straightline relationship at high values of droplet diameters.

To overcome this difficulty, a special upper limit equation(56) was applied to the log probability distribution function. The assumptions were as before except that now

$$y = \log e \, (U/U_{50})$$

where $U = D_p/(D_{pm} - D_p)$

D_{pm}, a maximum droplet diameter, was taken to be 1000 microns in this case.

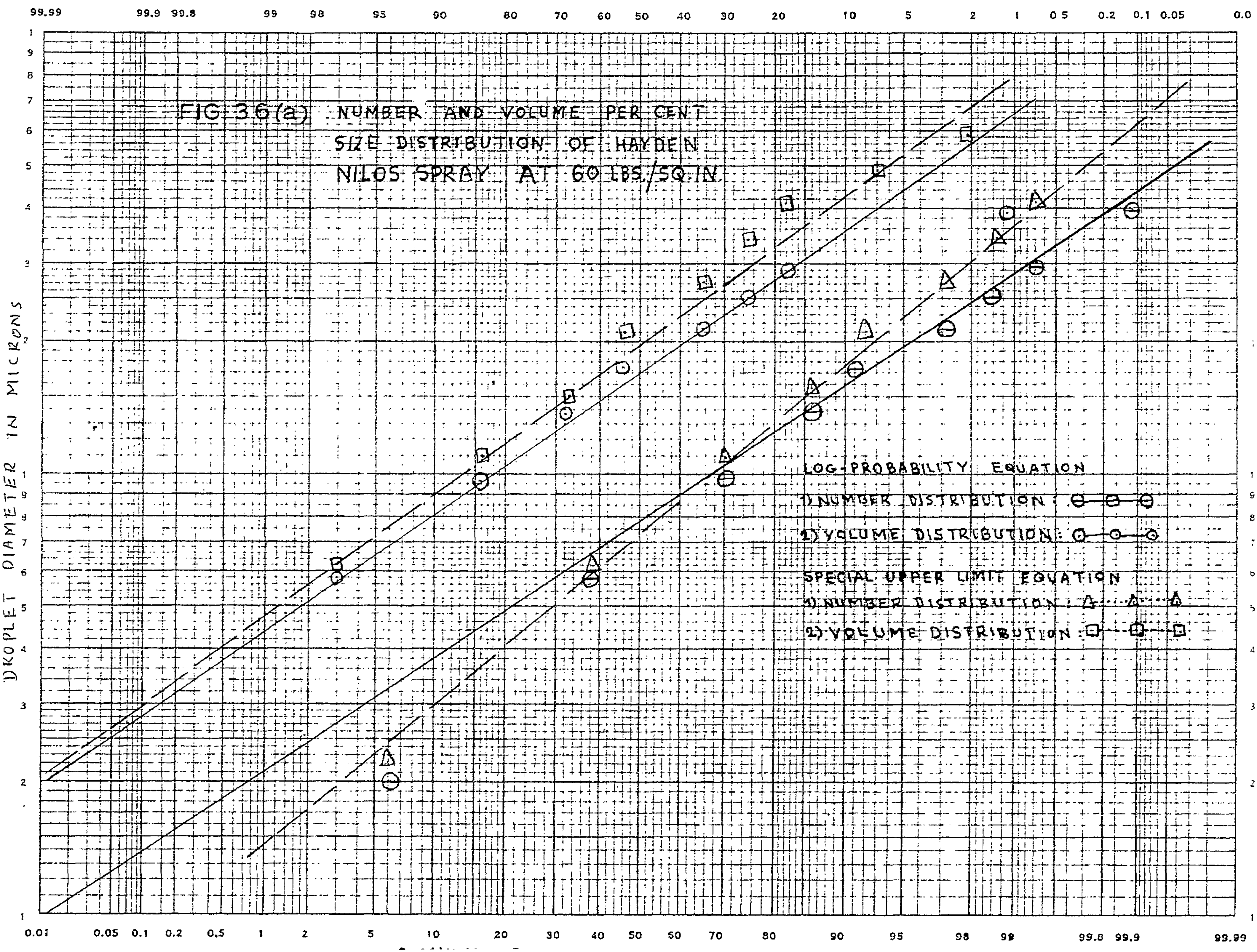


FIG 36(a) NUMBER AND VOLUME PER CENT
SIZE DISTRIBUTION OF HAYDEN
NILOS SPRAY AT 60 LBS./SQ.IN.
LOG-PROBABILITY EQUATION
1) NUMBER DISTRIBUTION:
2) VOLUME DISTRIBUTION:
SPECIAL UPPER LIMIT EQUATION
1) NUMBER DISTRIBUTION:
2) VOLUME DISTRIBUTION:
DROPLET DIAMETER IN MICRONS

U_{50} is the value of U at 50 per cent of the total volume of spray droplets.

The S.M.D. was calculated from the equation

$$S.M.D. = D_{pm}/[1 + (U_{50})^{-1} \exp (1/4\delta^2)]$$

and the value obtained was 141.0 microns.

This value is nearer the result obtained from the experimental data than the value given by the simple log probability equation. This would appear to indicate that this upper limit equation represents well the size-distribution obtained from swirl-spray nozzles used in our experiments.

SECTION VI

Laboratory dust suppression studies on full-size nozzles

Experiments on the airborne dust suppression were carried out in the experimental wind-tunnel described in Section I of this thesis, with the swirl spray nozzles used by Richmond.(46)

1. Spraying test unit: Line diagram of the spraying unit is shown in Figure 36b. The spraying unit consisted of a water tank of 25-gallon capacity, a centrifugal pump, a pressure gauge for recording pressures up to 0 - 150 p.s.i., and a nozzle socket which was fitted in the wind-tunnel in such a way that the spray nozzle was pointing upstream exactly on the axis of the wind-tunnel. All the connections were made by high pressure rubber hose and the unit operated in conjunction with a water recirculation system. The coal dust swept down with the sprayed water was first allowed to settle in a small narrow mouthed settling tank and the clear overflow was run back into the main tank. The settling tank was emptied from time to time. A fine wire mesh filter was also fixed on the outlet pipe from the tank which also helped to keep unsedimented coal particles from passing into the centrifugal pump and thereby choking the spray nozzle.

2. Experimental Procedure: Tests were performed on moving dust clouds by spraying water against the flow of airborne dust. The spray nozzle was set at the axis of the wind-tunnel

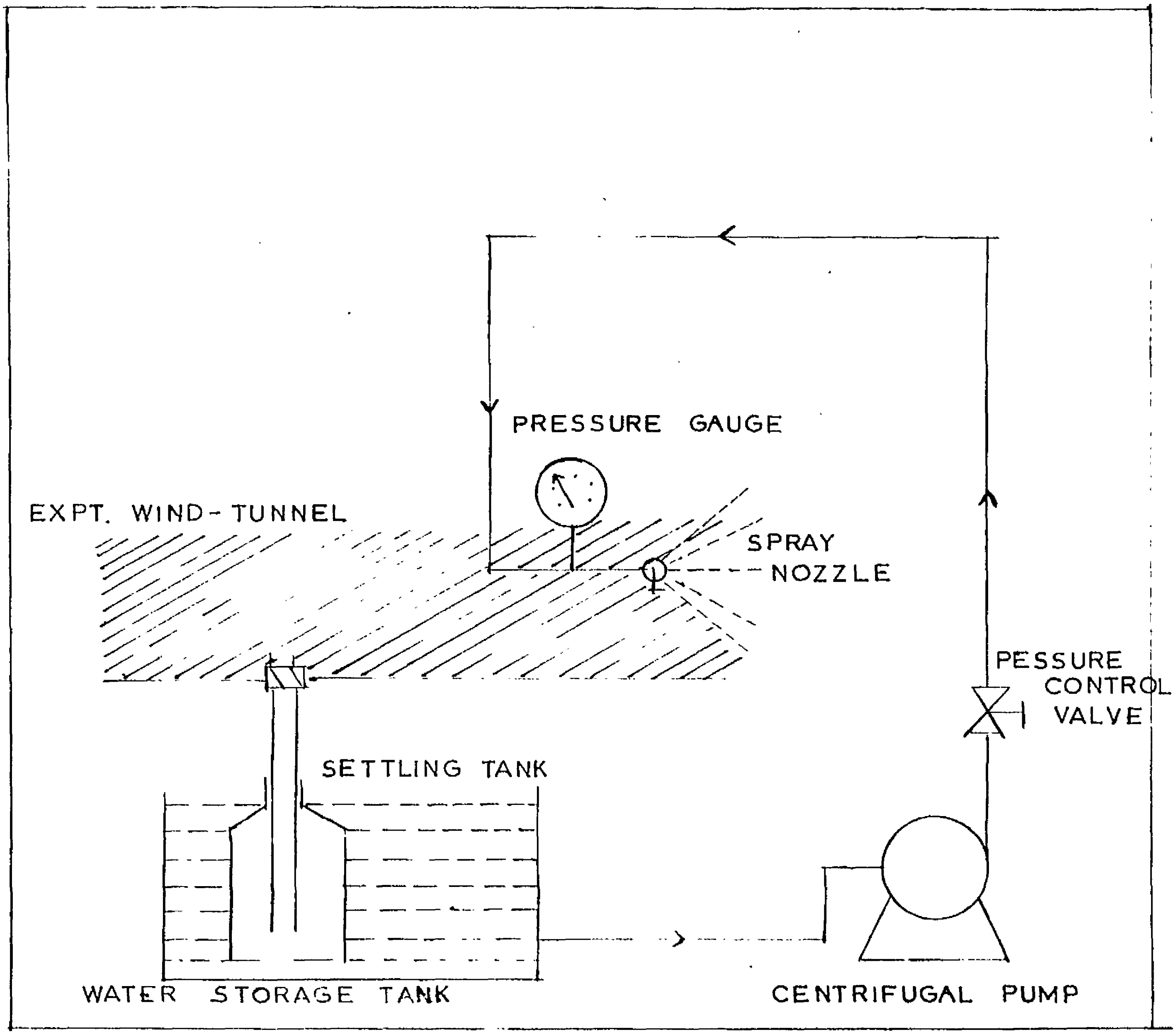


FIG.36(b) SPRAYING SYSTEM FOR DUST SUPPRESSION EXPTS.

near the perspex window. The velocity of the air down the wind-tunnel was adjusted to the desired value. The dust machine was then switched on and the spray started. A short period of time was allowed to stabilise the conditions in the wind-tunnel, and then the sampling of the air before and after the spray was started by switching on the two thermal precipitators simultaneously. The test run was continued until a suitable volume of air had been sampled.

When the test run was in progress, a close check was kept on all the instruments, and when completed everything was switched off and the cover glasses with the dust strips were mounted on a standard microscope slide 3" x 1" in the usual manner. (N.C.B. system of mounting dust sampled from thermal precipitator).

The particle counting was carried out at Isleworth Laboratory, N.C.B. under a projection microscope fitted with N.C.B. graticule, owing to the fact that the automatic particle counter was not available at this time. A specimen calculation of this method of determining dust concentration has been given in Appendix II.

This procedure was repeated at a number of water pressures, and air velocities, and using different swirl-spray nozzles. The speed of the dust machine was kept constant throughout the test.

All the spray nozzles were tested for their dust removal efficiency at 40 p.s.i. injection pressure on dust clouds moving at velocities from 150 - 900 ft./min. The effect of increase in the applied pressure was also determined by increasing the water pressure to 55 lbs/sq. inch on dust clouds moving at 150 ft./minute. The results are shown in Tables 31:1 to 32:3.

3. Discussion of Results: From the results plotted in Figures 37(a) and 37(b) it may be seen that in all cases increased dust suppressing efficiency is obtained at increased air velocity. This is in direct contradiction to the results of Tables 18(a) and (b), and Fig. 26E for the small high pressure nozzles.

For these small nozzles it has been explained that high velocity air was able to deform the spray cone and allow dust particles to bypass it. For such previous nozzle tests water had been atomised at a rate of 10.1 gal./hr. at 500 p.s.i. and 22.0 gal./hr. at 2400 p.s.i. With the large N.C.B. nozzles at 40 p.s.i. the water throughput ranged from 34.3 gal./hr. for the Hayden Niles nozzle to 201 gal./hr. for the Korting nozzle. Porter No.1 nozzle with a throughput of only 11.7 gal./hr. at 40 p.s.i. could only remove a small amount of dust at normal air velocity and at higher velocities could remove no dust. It is suggested therefore that for the higher throughput N.C.B. nozzles the increased droplet size (e.g. 120 microns as against < 40 microns for the small high pressure

TABLES 31 : 1 to 32 : 3

Results of Airborne Dust Suppression Tests

Table 31 : 1 Porter Spray No.1 (Flow No. 1.853)

S.No.	Air Velocity ft./min	Water Pressure lbs/sq.in	Dust conc. before spray ppcc	Dust conc. after spray ppcc	No.of dust particles removed by spray	Efficie per cent
1	150	40	1635	1562	73	4.47
2	150	55	1635	1432	203	12.42
3	400	40	842	850	8	-
4	900	40	654	778	124	-

Table 31 : 2 Porter Spray No. 2 (Flow No. 6.456)

S.No.	Air Velocity ft./ min	Water Pressure lbs/sq.in	Dust conc. before spray ppcc	Dust conc. after spray ppcc	No.of dust particles removed by spray	Efficier per cent
1	250	55	1316	860	456	34.70
2	250	40	1042	625	417	40.00
3	400	40	1087	613	474	43.60
4	900	40	1041	440	601	57.80

TABLE 31 : 3 Porter Spray No. 3 (Flow No. 8.034)

S. No.	Air Velocity ft./ min.	Water Pressure lbs/ sq. in.	Dust conc. before spray ppcc	Dust conc. after spray ppcc	No. of dust particles removed by spray	Efficiency per cent
1	150	55	1525	1131	394	25.85
2	150	40	1660	1280	380	22.90
3	400	40	1231	702	529	43.10
4	900	40	787	400	387	49.25

TABLE 31 : 4 Port Spray No. 4 (Flow No. 10.0)

S. No.	Air Velocity ft./ min.	Water Pressure lbs/ sq. in.	Dust conc. before spray ppcc	Dust conc. after spray ppcc	No. of dust particles removed by spray	Efficiency per cent
1	150	55	2330	1178	1152	41.50
2	150	40	2330	1372	958	37.90
3	400	40	973	596	377	38.80
4	900	40	820	328	492	60.00

TABLE 32 : 1 Korting Spray (Flow No. 3184)

S. No.	Air Velocity ft./ min.	Water Pressure lbs/ sq. in.	Dust conc. before spray ppcc	Dust conc. after spray ppcc	No. of dust particles removed by spray	Efficienc per cent
1	150	25	1870	1075	795	42.50
2	150	40	2440	845	1595	55.00
3	400	40	1840	648	1192	64.80
4	900	40	1642	490	1152	70.25

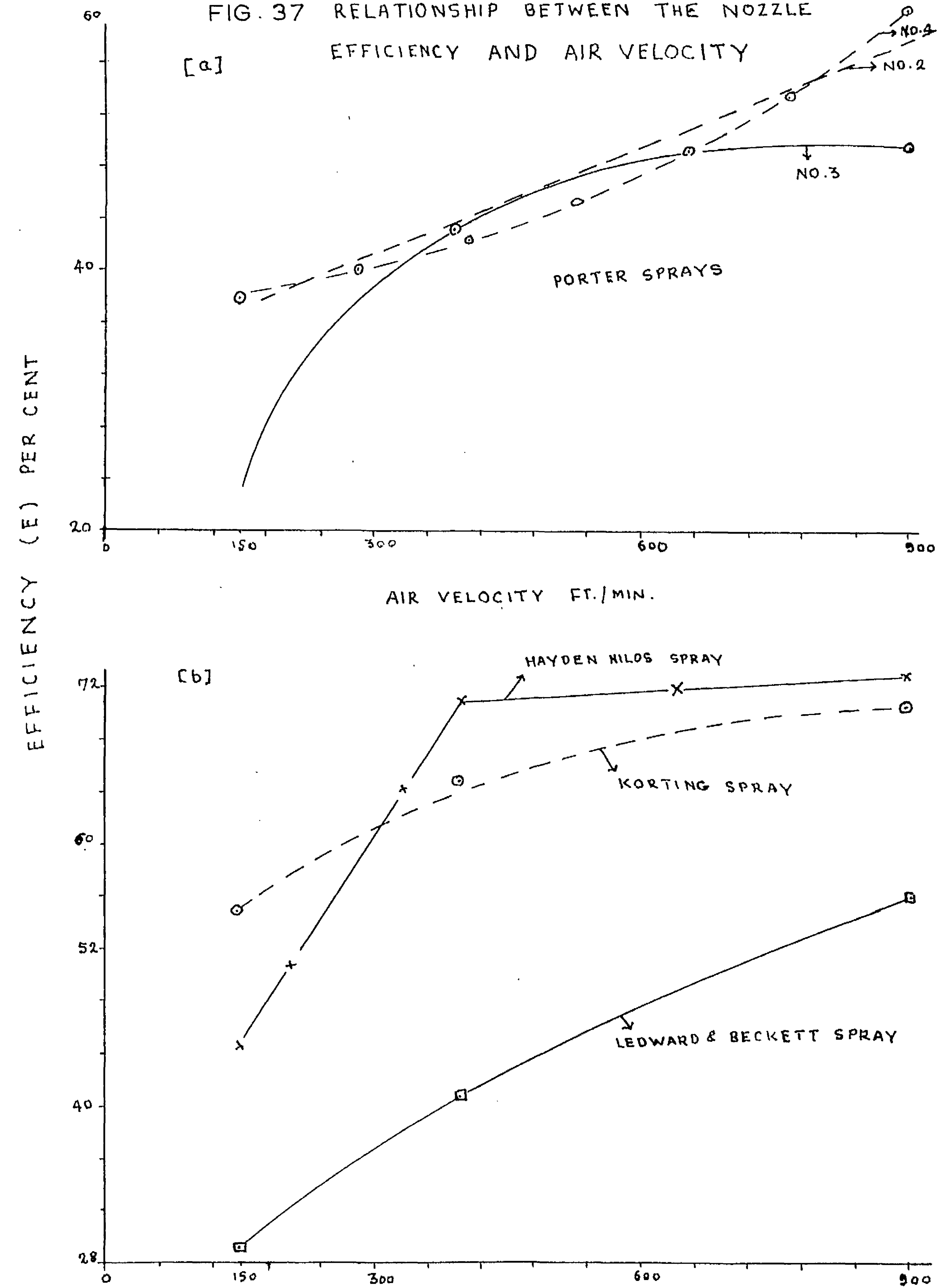
TABLE 32 : 2 Hayden Nilos Spray (Flow No. 5.424)

S. No.	Air Velocity ft. / min.	Water Pressure lbs/. sq. in.	Dust conc. before spray ppcc	Dust conc. after spray ppcc	No, of dust particles removed by spray	Efficiency per cent
1	150	55	1192	626	566	90.00
2	150	40	2700	1480	1220	44.50
3	400	40	1827	532	1295	71.00
4	900	40	1314	360	954	73.00

TABLE 32 : 3 Ledward & Beckett Spray (Flow No.1495)

S. No.	Air Velocity ft./ min.	Water Pressure lbs/ sq. in.	Dust conc. before spray ppcc	Dust conc after spray ppcc	No. of dust particles removed by spray	Efficie per cent
1	150	50	1542	1000	542	35.2
2	150	40	1660	1179	481	29.0
3	400	40	924	551	373	40.5
4	900	40	995	440	555	56.0

FIG. 37 RELATIONSHIP BETWEEN THE NOZZLE EFFICIENCY AND AIR VELOCITY



nozzles) and increased throughput of water (e.g. 55 gal./hr. and upwards) was able to prevent damaging deflection of the spray cone, and the increase relative velocity of dust particle and water droplet at higher air velocities caused greater dust suppression.

Tables 31:1 to 32:3, also indicate that even an increase of water pressure from 40 p.s.i. to 55 p.s.i. is sufficient to bring about a noticeable increase in dust suppressing efficiency with these nozzles (Porter No.2 result is anomalous)

Again in comparing the efficiencies of the Porter group of sprays, it would appear that the trend is towards an increase in dust suppressing efficiency with increasing flow number.

The difference between the efficiencies of Hayden Nilos and Ledward and Beckett seems to be decreasing at higher air velocities (See Fig. 37(b)). Considering all the factors it can be said that Porter No.4, Korting Spray, and Hayden Nilos Spray give about 70 per cent dust suppression at higher air velocities, but owing to very high water throughput the Korting spray might well cause uneasy environmental conditions.

The effectiveness of sprays from the above-mentioned nozzles is shown in Table 33. A 111 micron spray droplet ejected at 40 p.s.i.g. from Hayden Nilos nozzle knocks down 11.85 coal dust particles ($^1/2$ - 5 micron size) with the air moving at 900 ft./minute.

TABLE 33 - EFFECTIVENESS OF SPRAYS

Type of Nozzle	Air Velocity ft./min.	Water Pressure lbs/sq.in.	Throughput gals/hr.	Average Droplet size microns	No. of water droplets ejected per sec. x 10^6	No. of dust particles removed per second x 10^6	Effectiveness of spray $= \frac{\text{No. of dust particles}}{\text{No. of water droplets}}$
Porter No.4	150	40	63.0	124	79.6	119.8	1.505
Porter No.4	400	40	63.0	124	79.6	126.0	1.582
Porter No.4	900	40	63.0	124	79.6	369.0	4.64
Hayden Nilos	150	40	33.8	111.0	60.5	152.3	2.525
Hayden Nilos	400	40	33.8	111.0	60.5	433.0	7.16
Hayden Nilos	900	40	33.8	111.0	60.5	717.5	11.85
Korting Spray	150	40	201.5	102.0	464.0	199.2	0.43
Korting Spray	400	40	201.5	102.0	464.0	398.0	0.857
Korting Spray	900	40	201.5	102.0	464.0	866.0	1.865

It has already been shown that the theoretical penetration of a 110 micron diameter droplet ejected from a nozzle at a pressure of 60 p.s.i. into still air is about 25.4 cms. Under these conditions it will sweep out a volume of air of

$$\pi/4\ (110)^2 \times 10^{-8} \times 25.4 = 0.00241 \text{ cm}^3.$$

This volume of air will contain on average, (S.No.4. Table 32:2), a total of 0.00241 x 1314 dust particles.
i.e. = 3.2 dust particles.

On the other hand when the Heydon Hiles nozzle was operated vertically upwards at 40 p.s.i. the water droplets reached a height of 225 cms. above the nozzle (calculated from the results of Table 29:6. Under these conditions the volume of air swept by one 110 micron droplet becomes

$$\pi/4 \times (110)^2 \times 10^{-8} \times 225 = 0.0212 \text{ cm}^3.$$

and this volume of air should contain

$$2.12 \times 10^{-2} \times 1314 \text{ dust particles}$$

i.e. = 27.8 dust particles.

In the wind tunnel the ejected water droplet is neither a single droplet in still air nor one of a large number of droplets ejected into initially still air. It is one of a large number of droplets which are ejected against a strong air current. At a cone angle of 56° it will traverse a distance to the tunnel wall given by 9/sin 28° i.e. 46.3 cms., and thus will sweep through a volume of air containing 5.65 particles. On reaching the tunnel wall the droplet is most likely to cling there and wet the wall with other droplets forming a continuous flow of water down the tunnel to the outl point.

On the other hand, if the droplet comes to rest (with respect to the tunnel) under the influence of the counter-flow velocity of the air before it reaches the wall, it will revers and move downstream with the turbulent air and in the process it will capture further dust particles until it finally hits the wall. It would appear that in the case of Hayden Nilos spray a large amount of dust suppression must have taken place downstream from the spray cone proper.

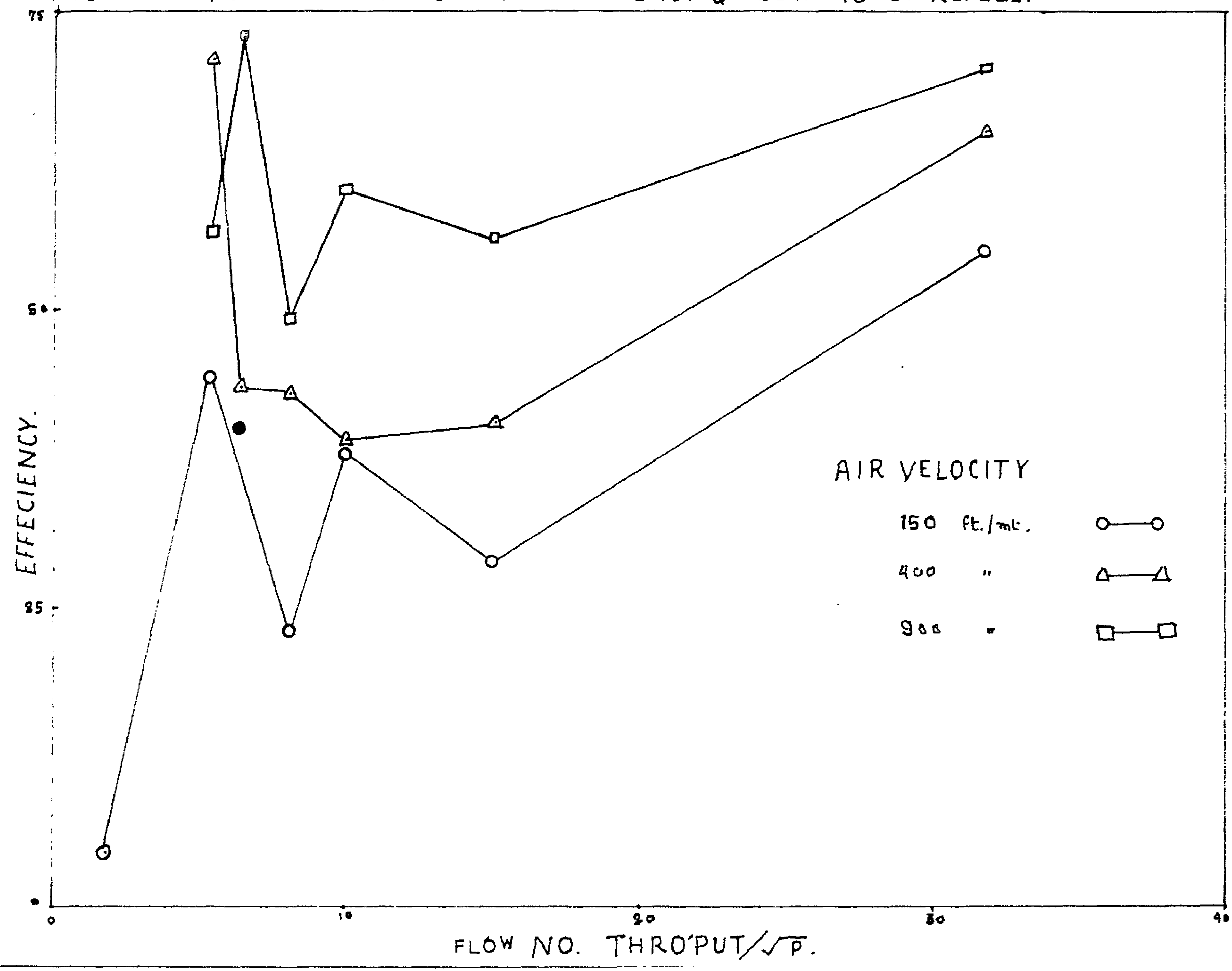
The relationship between the nozzle efficiency and the flow number for the full-size nozzles is shown in Fig. 38. The trend towards an increase in efficiency with increasing flow number would appear to be reduced with increasing air velocity.

Table 33 indicates, in agreement with Richmonds finding[46] that the Heyden Nilos nozzle, as far as mining conditions are concerned, is the most suitable nozzle. One may summarise its advantages as follows,

(a) The throughput of water is much less than that of other spray nozzles of comparable dust suppressing efficiency. (Porter No.4 and Korting Spray).

(b) The cone angle is high (about 56° at 40 p.s.i.)

FIG. 38 RELATIONSHIP BETWEEN EFFECIENCY & FLOW NO. OF NOZZLE.



(c) The spray distribution is seen to be more uniform than that of the other two high efficiency nozzles.

(d) The droplet size-distribution is good, e.g. 70 per cent of the droplets are less than 110 microns in diameter.

SECTION VII

Dust suppression studies on full-size nozzles under mining conditions

All efforts to reduce dust concentration in mines are designed to produce as near as possible dust free conditions in the working environment of all underground personnel.

A preliminary survey was made to determine dust concentration of mine air during normal operations and the findings of this survey are summarised below.

1. Selection of site for tests: Cardowan Colliery, located in Stirlingshire, Scotland, was selected for the test work. It had two pits in operation and about seven sections were being worked every day from four seams - (1) Possil, (2) Meirlehill, Main, (3) Meirlehill Wee, and (4) Kilsyth Coking Coal. The output of the coal amounted to about 1400 - 1600 tons per day.

After reviewing previous dust records and consulting the N.C.B. Dust Survey Officer, it was decided to make a dust survey of "2 - Plough" and"6 - West" sections in No. 2 pit, as they were known to have the highest dust concentrations. These two sections are sketched in Figures 39 and 40.

2. Existing methods of dust suppression: Both coal seams were water infused, but no water was used during coal

FIG.39 PLAN OF 2-PLOUGH SECTION

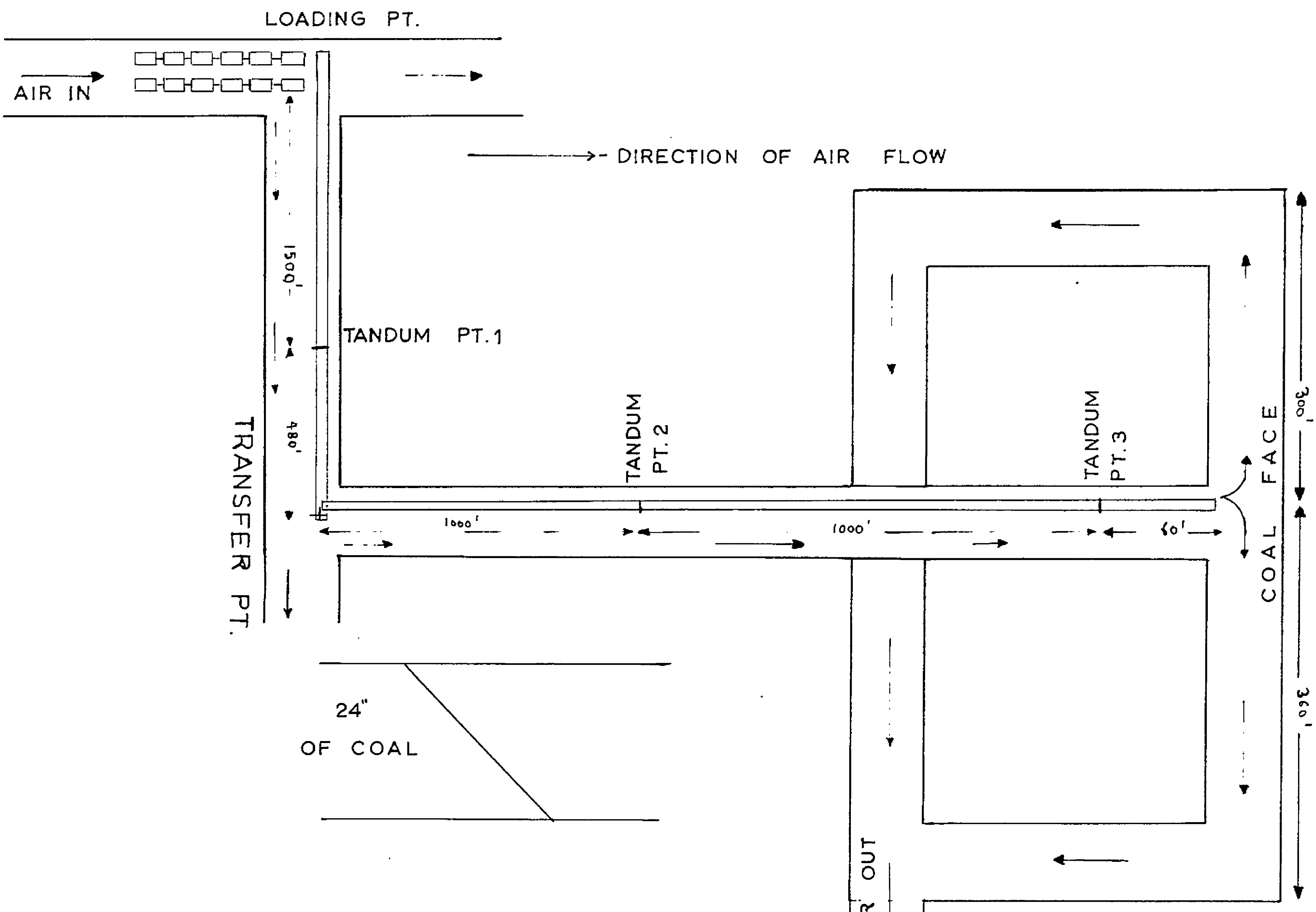
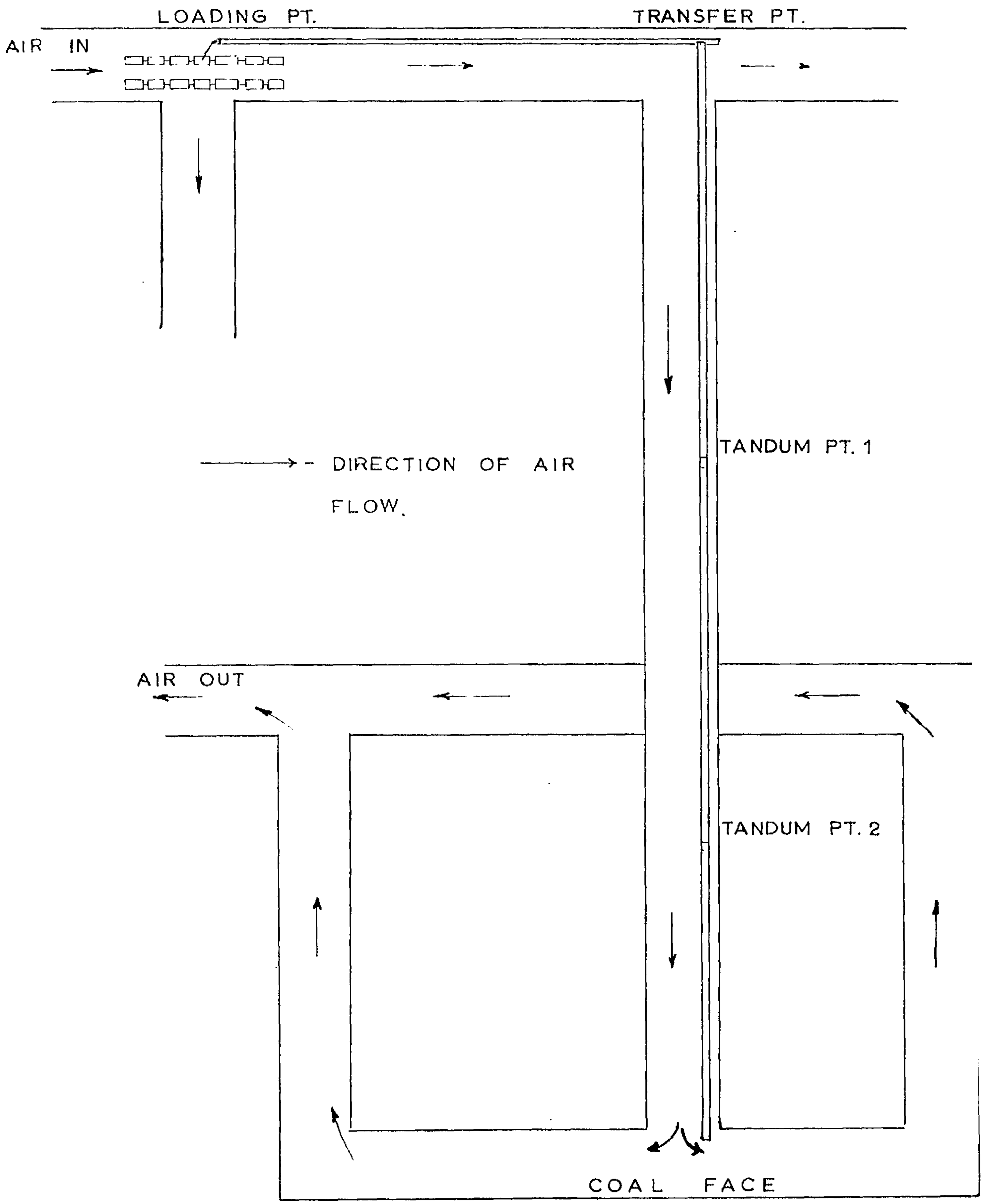


FIG. 40 PLAN OF 6-WEST SECTION



winning operations and no sprays were fitted to the plough blades.

In "2 - Plough" section water sprays could be used to wet the coal and suppress the dust produced at all transfer and loading points, but in fact the sprays were seen to be working only at face transfer point and at the loading point.

In "6 - West" section water sprays were used at every transfer point and at loading point. The water pressure used varied from operator to operator, but was in general found to be about 25 - 50 p.s.i.

Haydon Nilos spray nozzles and some twin orifice simple nozzles were used to atomise the water.

3. <u>Dust sampling position and concentration</u>: In general the sample was taken at a height of 5 ft from the floor and with the thermal precipitator's suction end facing towards the floor. The sampling distance was always maintained within 25 ft. to 50 ft. from the dust source. The air velocity was between 100 ft. and 500 ft./minute. The dimensions of the mine roadways were approximately 10 ft. x 8 ft. but at loading points they were nearly 20 ft. x 20 ft. to allow for the rise of conveyor belts to top of the hopper under which hutches were filled. (See photograph of loader arrangements Plate 4).

Table 34 shows typical dust contents of the air in the return air ways of Nos. 1 and 2 pits of Cardowan

TABLE 34

Dust content of surrounding air and the comparison between visual counting and automatic counting techniques

Type of operation	Dust concentration p.p.c.c.			Remarks
	Above $^1/2$ microns A.C.M/c.	1 - 5 microns		
		A.C. M/C	V.C.	
Stripping:- 3 spray nozzles working on cutting blades	1) 397	180	233	Samples taken
Scraper chain conveyor system. (Trepanner Section)	2) 486	250	Range 155-355	Simultaneously
Brushing:- wet boring and water	1) 1735	594	1059	Dry boring
capsule used for shot firing.	2) 418	212	294	Wet boring
Under cutting:- No sprays, coal	1) 192	72	105	Samples taken
face water infused.	2) 279	143	143	Simultaneously.

A.C. M/c : Automatic Counting Machine.

V.C. : Visual counting.

Colliery during stripping, brushing and undercutting operations. It would appear that water infusion keeps the dust content down during stripping operations in spite of the fact that there are no sprays fitted on the under-cutting blades. Same is the case with wet and dry drilling operations. It is, however, claimed that wet drilling produces relatively more fine dust than dry drilling.(58) The dust concentration rises from 400 p.p.c.c to 9,000 p.p.c.c. immediately after blasting, and no measures, except the use of water capsule(59) in some places, are used to keep it down.

Table 35(a) and (b) show the increase in the dust content of ventilating air as one passed from the loading points towards the coal face. A marked increase in dust concentration may be noted as the air moves from the loading point towards the face.

4. <u>Comparison of visual and automatic particle counting</u>: It was possible during this survey to compare the counting of the dust in the thermal precipitator samples by using (a) the automatic particle counting machine, and (b) a visual counting technique, using a projection microscope. Unfortunately, owing to different methods of mounting the slides, it was not possible to evaluate the same thermal precipitator sample strips by both techniques, but simultaneous dust sampling was carried out using two thermal precipitators at the same dust spot, and the dust

TABLE 35 (a)

Dust content of the intake air at transfer and loading points in 2 - Plough Section

Position	Dust concentration p.p.c.c. (microns)				
	> ½ A.C. M/c	½ - 5 A.C. M/c	½ - 5 V.C.	1 - 5 A.C.M/c	1 - 5 V.C.
Loading point	178	168	176	38	74
Tandum Point I	270	253	218	138	103
Transfer Point	278	215	275	90	122
Tandum Point(II)	511	459	384	242	211
Tandum Point (III)	602	545	451	292	29

Remarks: Coal is won by means of plough which is operated electrically

TABLE 35 (b)

Dust content of the intake air at transfer and loading points in 6 - West Section

Position	Dust concentration p.p.c.c. (microns)				
	> ½ A.C. M/c	½ - 5 A.C. M/c	½ - 5 V.C.	1 - 5 A.C.M/c	1 - 5 V.C.
Loading Point	203	199	230	55	84
Transfer Point	211	191	182	126	138
Tandum Point (1)	417	376	400	176	141
Tandum Point (11)	497	-	-	233	251

Remarks: Coal winning is done by pneumatic picks

1 - A.C. M/c. - Automatic particle counting machine.

2 - V.C. - Visual counting

slides evaluated independently by each technique. In most cases the results are fairly close. One must remember that dust concentrations in mines vary abruptly with time and place, etc. Insufficient samples were available to enable the "Student 't'" test to be applied to the results.

5. Test Procedure: After considering the dust content of the intake air in both sections and weighing the facilities available to carry out all experimental work without affecting normal working schedule, it was thought that 2-Plough section was best suited for the tests. The analyses of the coal mined and the water sprayed are given in Appendix IV.

Tests were started at the loader shown in Plate 4 and Fig. 39. Sampling position and procedure was the same as described in the dust survey. Sampling was temporarily stopped when the conveyor belts were stationary. Humidities and air velocities were recorded regularly at the sampling positions. In each case the air velocity value recorded was the average of five readings taken with an accurate vane anemometer at points evenly spaced over the cross-section of the roadway.

Dust content of the intake air was found for two positions,(a) 50 ft. before the loader, and (b) 50 ft.

PLATE IV - View of the Loader

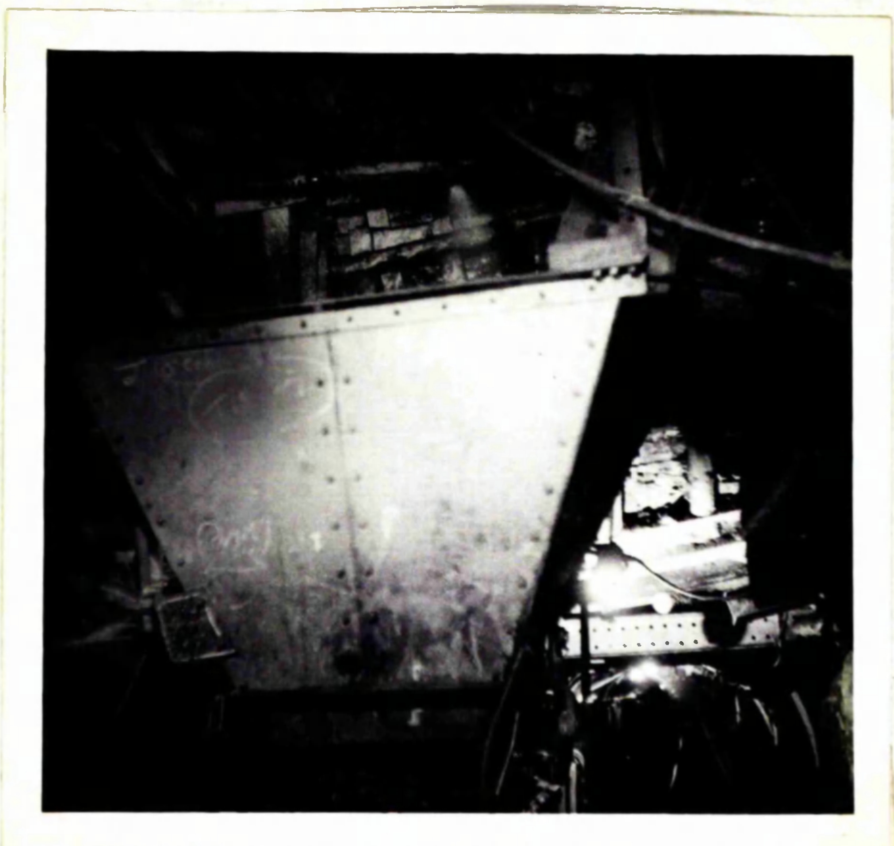


PLATE V - Spray Set up at the Loader

past the loader in the direction of Tandem point I. Position (a) served as a monitor for intake air and any abnormalities were quickly noticed. About 3 - 4 monitor samples were taken during each shift. At sampling position (b) more or less continuous sampling was carried out except for the time required for unloading and recharging of the thermal precipitator. This enabled one to take anything from 7 - 10 samples during each shift. About 30 samples were taken in position (b) to determine the dust content of the air when no sprays were used at the loading point.

After making sure that the dust concentration was fairly steady at the loader, testing of the swirl-spray nozzles began. A combined instrument for recording water pressure and flow (throughput) was fitted to the water line feeding the spray. After setting the spraying apparatus, it was checked by running water for leaks and the effect, if any, on normal working. The spray nozzle setting at the loader is shown in Plate 5.

Ledward and Beckett, Korting, Porter No.4 and Hayden Nilos nozzles were tested. Each nozzle was tested at 50 p.s.i. and about 15 - 16 dust samples were taken when the spray was on. The quantity of water used and the weight of coal passed over the conveyor belt were recorded.

Similar tests were performed using a Hayden Nilos spray nozzle at tandem point (I), transfer point, and tandem point (II). These positions when the spray was working are shown in Plates 6 and 7.

Finally a special test was made by setting spray nozzles at all the four dust producing positions and determining the dust content of the intake air 50 ft. before the loader and 50 ft. past tandem point (II) with sprays working at all the four positions at about 50 p.s.i.

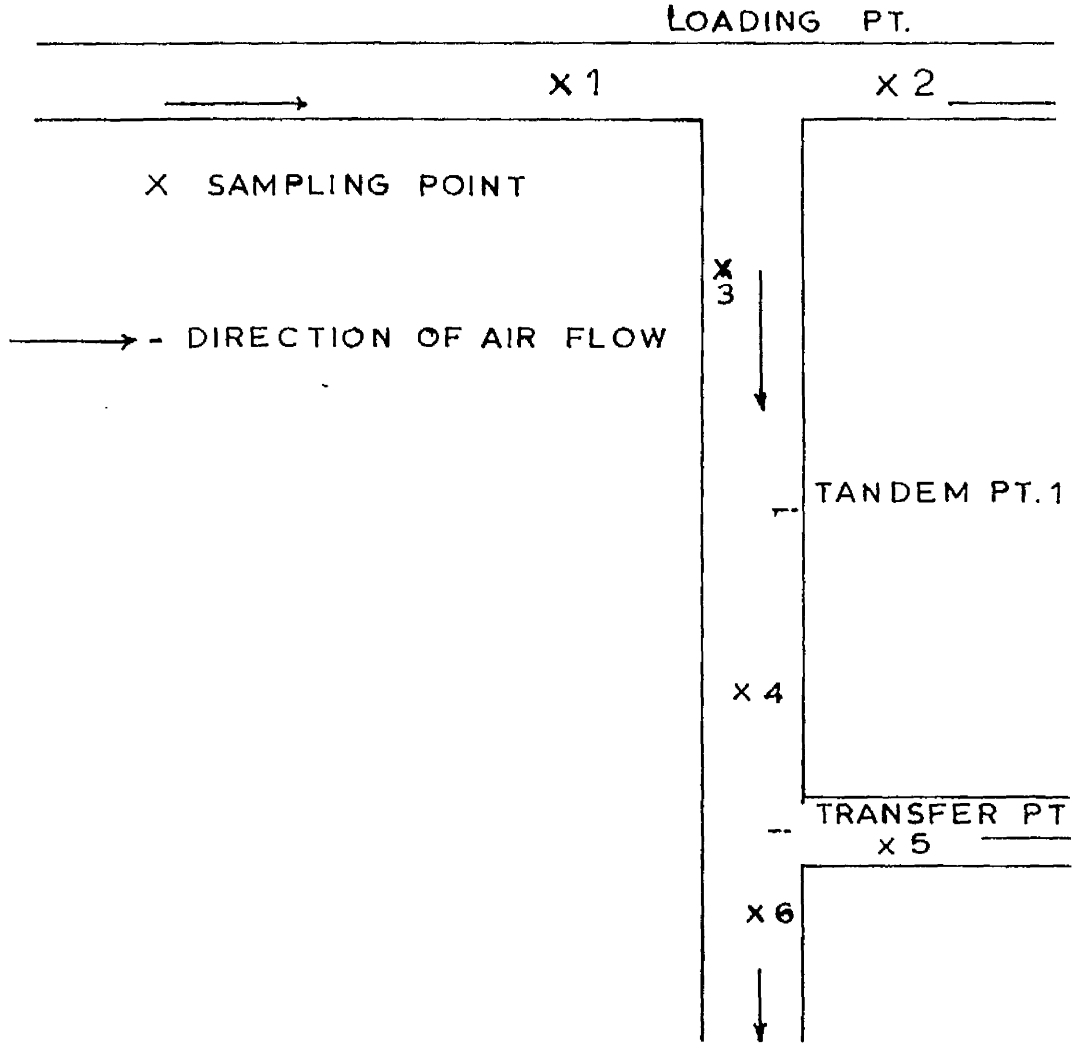
6. Test Results: Due to the fact that the loader was situated at a tee junction, it was necessary to determine the distribution of dust in the air of the various roadways. The measurement was made when the pit was idle by simultaneous sampling air at all the three positions. The details of sampling positions etc. are shown in Figure 41. The results of this test are tabulated in Table 36 (a) and 36 (b).

It appears from Table 36 (b) that about 20 per cent of the dust particles are unaccounted for at the right angle bend. This may be due to impingement and deposition of dust particles on the wall, on conveyor belt and on the loader itself, by virtue of the sudden change in direction of the greater part of the air.

PLATE VI - Spray set up at tandum point I

PLATE VIII - Spray set up at transfer point

FIG. 41 DISTRIBUTION OF DUST AT LOADING AND TRANSFER POSITIONS.



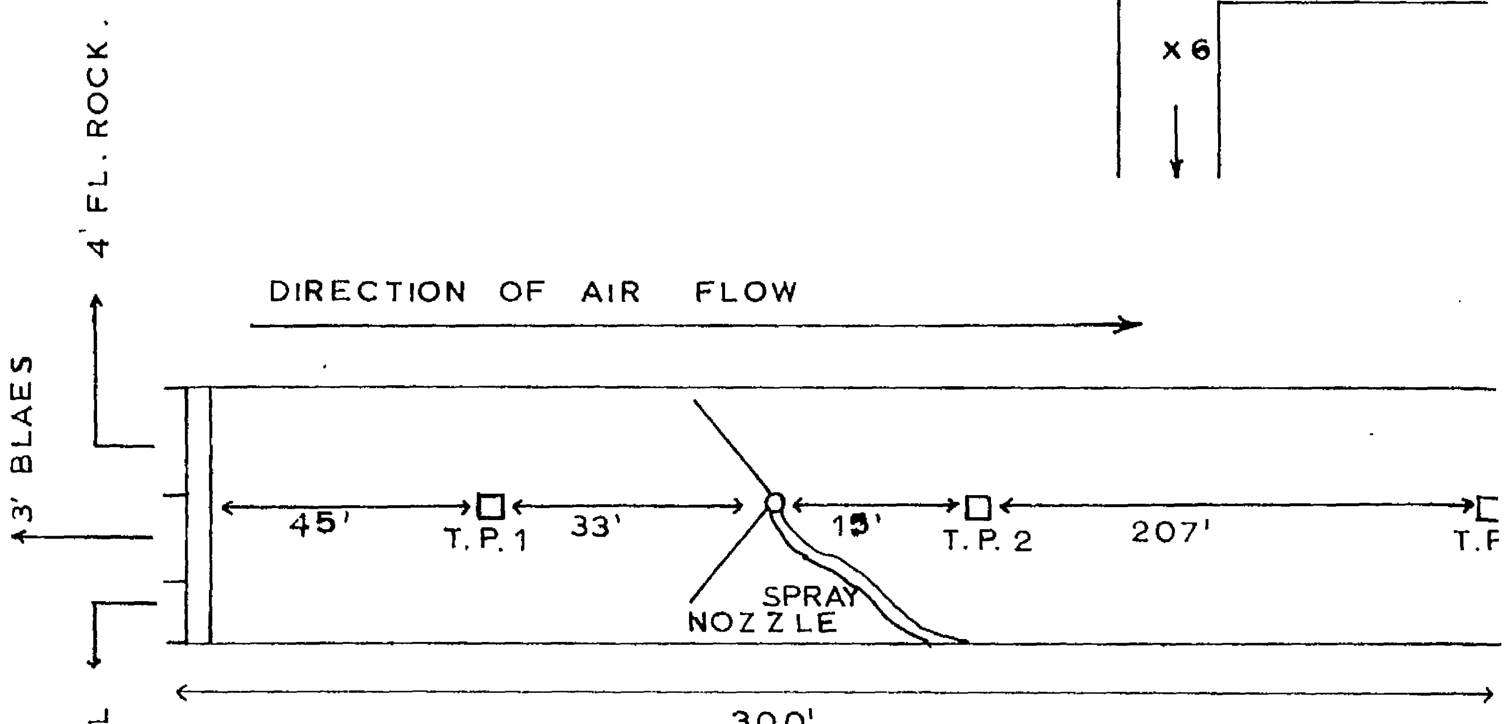


FIG. 42(A) ELEVATION OF RETURN AIR ROAD SHOWING DUST SAMPLING POSITIONS.

TABLE 36 (a)

Dust concentration at loader

Reference No.	S.P. I (50ft before loader)ppcc	S.P. II (20ft behind loader)ppcc	S.P.III (50ft after loader)ppcc
Run 1	535	494	400
Run 2	238	237	179

TABLE 36 (b)

Distribution of dust at loader

Reference	S.P. I	S.P. III	S.P. II
Road dimensions	15ft x 12ft	12ft x 10ft	10ft x 8 ft
Area sq.ft.	180	120	59
Air velocity ft./min.	214	315	43
Total dust passing per min.(Number of particles)	Run 1. 58.15×10^{10} Run 2. 25.90×10^{10}	42.20×10^{10} 19.10×10^{10}	3.54×10^{10} 1.70×10^{10}
per cent distribution	1) 100	72.47	6.08
" "	2) 100	73.80	6.55

The effect of spraying the moving coal with water from the four different nozzles during the loading operation is shown in Table 37 (a) and 37 (b).

TABLE 37(a)

Environmental Conditions at Loader

Position		50 ft. Before Loader	50 ft. After Loader
Relative Humidity without Spray working.		71.0	72.0
Temperature:	Dry	60°F	62.5°F
	Wet	55°F	57°F
Relative Humidity with Spray working.		71.0	82.0
Temperature:	Dry	62°F	61°F
	Wet	55°F	57°F
Air Velocity ft./min.		320.0	401.0

TABLE 37 (b)

Effect of Sprays on Dust at Loader

Spray Used	Water Pressure p.s.i.	Flow Rate gals/ min.	Dust Concentration p.p.c.c. 50 feet Before Loader	50 feet After Loader No Spray	50 feet After Loader With Spray	Total Dust Suppression at Loader (%)	Airborne dust sup -pression of nozzle [Efficiency %]	Dust Wat Ratio. Particle removed per c.c. water.
1. Ledward and Beckett	50	1.555	277	328	204	37.8	26.4	16.8 x 1
2. Korting Sprays	50	2.630	348	413	219	47.1	37.1	17.35 x
3. Hayden Nilos Spray	50	0.508	241	286	197	31.2	18.3	31.1 x 1
4. Porter No.4	50	1.007	a) 576	684	447	34.6	22.4	46.25 x 1

When no sprays are used the dust in the air after the loader will be the sum of the dust in the air passing over the loader plus the dust created at the loader. On the other hand, when sprays are in use at such a location where the moving, dust-producing coal is actually wetted with the sprayed water, the dust content of the air leaving the loader is the result of two factors which operate in parallel. These are:

(a) Less dust becomes airborne from the wet coal, and

(b) A proportion of the dust carried in the air over the loader, together with some of the dust rising from the wet coal, is knocked down by the spray droplets.

Thus the dust concentration difference produced in the air after the loader by the use of sprays at the loader cannot be taken as a true measure of the nozzle efficiency in suppressing airborne dust. If one could spray the air without wetting the coal, the efficiency could be calculated from a comparison of results after the loader.

An approximation to the efficiency may be obtained by assuming that the sprayed water in wetting the coal suppresses <u>all</u> the dust actually produced <u>at</u> the loader. If it is assumed also that the dust concentration 50 ft before the loader is maintained in the air passing over the loader one may calculate the dust suppressing efficiency from the difference between the dust concentration before the loader and that after the loader with the spray in operation.

e.g. In Table 37(b) Hayden Nilos Spray.

Dust concentration in air 50 ft before loader = 241 p.p.c.c.

With no spray, dust concentration in air 50 ft after loader = 286 p.p.c.c.

With spray, dust concentration in air 50 ft after loader = 197 p.p.c.c.

Thus percentage of total dust leaving loader suppressed by spraying air and coal $= \frac{(286 - 197)100}{286}$

$= 31.2\%$

Assuming wetted coal produces little dust, airborne dust suppressing efficiency of nozzle $= \frac{(241 - 197)100}{241} = 18.3\%$

When the airborne dust suppressing efficiencies of the nozzles calculated in this way are plotted against the nozzle throughput of water the points are seen to lie close to a straight line (Fig. 42B). This indicates that over this range of water flow the efficiency of the nozzles is directly proportional to water usage. The low values of efficiency obtained are due to the fact that only a fraction of the dust laden air passing around the loader comes within the zone swept by the spray droplets.

When the nozzles are compared in the basis of the number of particles of airborne dust suppressed per c.c.

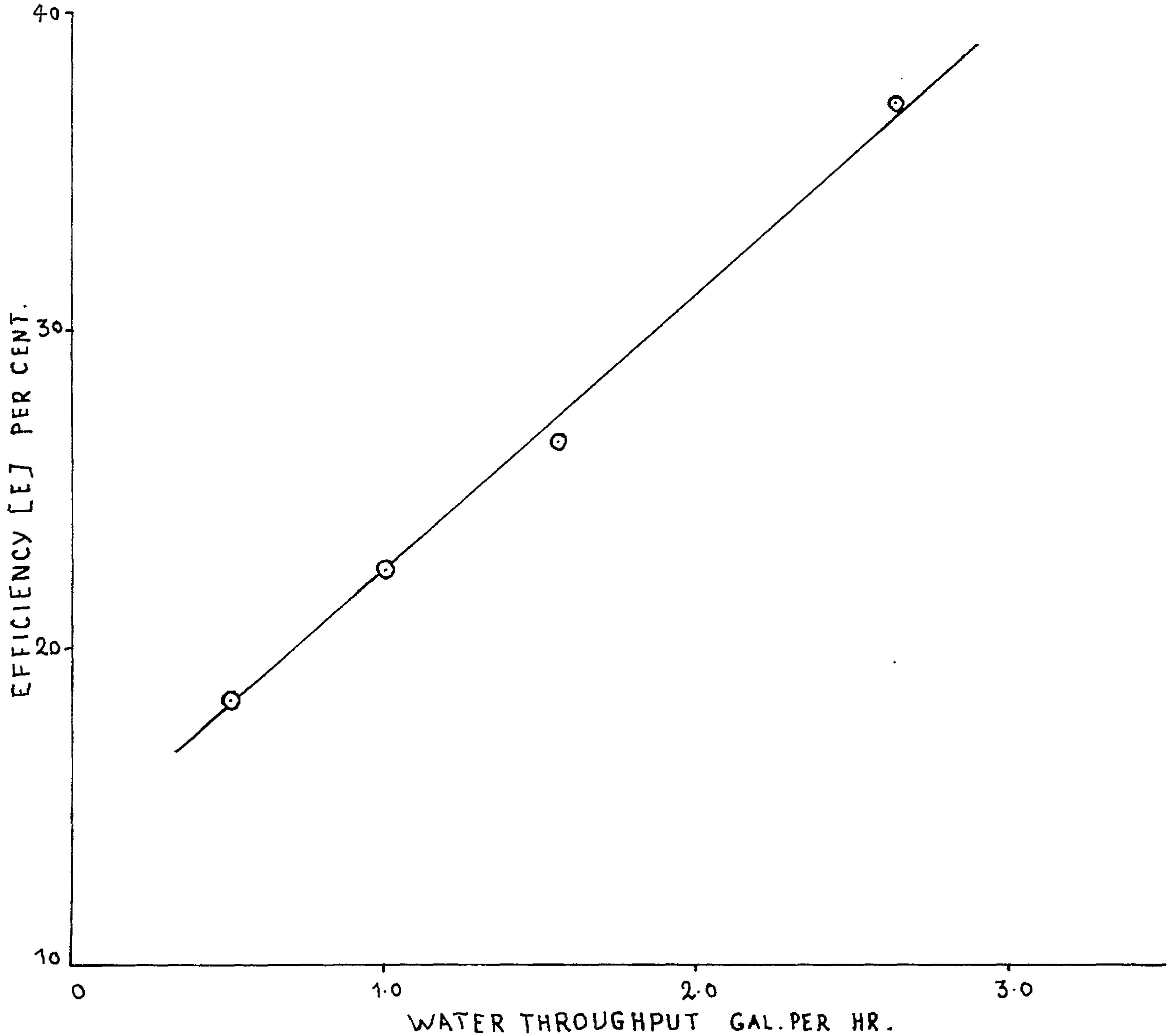


FIG. 42(B) RELATIONSHIP BETWEEN WATER THROUGHPUT AND DUST SUPPRESSION of water atomised, as in the last column of Table 37(b), it may be seen that the best nozzles from this point of view are the Hayden Nilos and Porter No.4. The fact that the water throughput at 50 p.s.i. for the former nozzle is just half that of the latter would suggest that from an environmental point of view the Hayden Nilos is the better nozzle.

The Hayden Nilos spray nozzle was used for the tests at the tandem and transfer points. The results for the remaining three tests are given in Tables 38, 39 and 40. The values of dust suppression are calculated.

TABLE 38(a)

Environmental Conditions at Tandem Point I.

Reference		50 ft. before Tandem	50 ft. after Tandem
Relative Humidity without Spray working.		73.5	73.5
Temperature:	Dry	64°F	64°F
	Wet	59°F	59°F
Relative Humidity with Spray working.		73.5	77.0
	Dry	64°F	65°F
	Wet	59°F	61.5°F
Air Velocity ft./min.		393.0	443.0

TABLE 38(b)

Effect of Water Sprays on Dust at Tandem Point I

Water Pressure p.s.i.	Flow Rate gals./min.	Dust Concentrations p.p.c.c.			Total Dust Suppress %
		Before Tandem	After Tandem No Spray	After Tandem With Spray	
50.0	0.508	182	384	198	48.4

In Table 38(b) the concentration of airborne dust after the tandem point was higher than before it, even althoug the spray was in operation. This is presumably due to insufficient wetting of the coal so that on balance more dust was produced by the coal than was suppressed in the air by the spray. For this reason the dust suppression efficiency of the nozzle cannot be calculated.

Again due to the peculiar setting of the transfer point at a tee junction, the dust distribution experiment was repeated in the same way as at the loader.

Distribution of the Dust at Transfer Point

Reference	50ft. before Transfer	50 ft. after Transfer	30 ft. behind Transfer
Road dimensions	12ft. x 9 ft	12ft x 10ft	10ft x 8ft.
Area sq.ft.	93.0	104	68.0
Air Velocity ft./min.	464.0	251.0	152.0
Total dust content No.of dust particles passing per minute	26.0×10^{10}	20.95×10^{10}	6.16×10^{10}
% Distribution	100.0	80.65	23.72

It can be seen that there appeared to be an excess of 4.37 per cent number of dust particles in the total air passing from the transfer point. This may well have been due to persons walking in between the sampling positions and thereby dispersing some of the settled dust.

TABLE 39(a)

Environmental Conditions at Transfer Points

Reference		50 ft. before Transfer	50 ft. after Transfer
Relative Humidity without spraying		74.0	74.0
Temperature:	Dry	66°F	66°F
	Wet	61°F	61°F
Relative Humidity with spraying		74.0	79.0
Temperature:	Dry	66°F	67°F
	Wet	61°F	62°F
Air Velocity ft./min.		371.0	223.0

TABLE 39(b)

Effect of Water Sprays on Dust at Transfer Point

Water Pressure p.s.i.	Flow Rate gals./min.	Dust Concentrations p.p.c.c.			Total Dust Suppression (%)	Air-borne dust Sup. Effcy. of nozzle	Dust Water Ratio Partic remove per c water
		Before Transfer	After Transfer No Spray	After Transfer With Spray			
50	0.508	280	368	214	41.9	23.6%	4.24×10^6

The final test with Hayden Nilos spray nozzle was made at Tandem Point No.II. Here the water pressure was increased to 75.0 p.s.i. to improve the wetting of the coal, and because of a big drop between the conveyor belts.

TABLE 40(a)

Environmental Conditions at Tandem Point II.

Reference		50 ft. before Tandem	50 ft. after Tandem
Relative Humidity without Spray		70.5	71.0
Temperature:	Dry	69°F	69.75°F
	Wet	63°F	64°F
Relative Humidity with Spray		71.0	75.0
Temperature:	Dry	69°F	69°F
	Wet	63°F	64°F
Air Velocity ft./min.		223.0	211.0

TABLE 40(b)

Effect of Water Sprays on Dust at Tandem Point II

Water Pressure p.s.i.	Flow Rate gals./min.	Dust Concentrations p.p.c.c. Before Tandem	After Tandem No Spray	After Tandem With Spray	Total Dust Suppression (%)	Air-borne dust Supp. Effcy. of nozzle	Dust Water Ratio. Particle remove per cc Water
75	0.814	230	291	217	25.4	5.7%	1.78×10^6

The low nozzle efficiency calculated in Table 40(b) may indicate that even at 75 p.s.i. at this tandem point the water is insufficient to wet adequately the coal.

For the overall test, spray nozzles were set at all coal transfer positions and dust measurement was carried out in the intake air 50 ft. before loader and 50 ft. after tandem point II. Spraying time was controlled from the loader and simultaneous sampling was done at both places. The details of the test are shown in Table Nos. 41(a) and 41(b). Again on balance the air leaving the tandem point II has a higher dust concentration than that going to the loader so an overall airborne dust suppression efficiency for the nozzles could not be calculated.

TABLE No. 41(a)

Experimental Particulars

Position	Type of Spray	Flow Rate gals/min.	Water Pressure p.s.i.
Loading	Korting	2.6300	50
Tandem Point I	Ledward and Beckett	1.5550	50
Transfer Point	Hayden Niles	0.5080	50
Tandem Point II	Hayden Niles	0.8140	75
Total water used per minute		5.5070	

TABLE 41(b)

Environmental Conditions

Ref:	Conditions at Loader		Conditions at Tandem Pt. II	
	Relative Humidity and Temp. °F	Air Velocity ft./min.	Relative Humidity and Temp. °F	Air Velocity ft./min.
Normal conditions	71.0 per cent Dry 60 Wet 55	320.0	71.0 per cent Dry 69.75 Wet 64.0	384.0
Run I	65.0 per cent Dry 59.0 Wet 55.0	320.0	72.50 per cent Dry 69.0 Wet 64.0	211.0
Run II	65.0 per cent Dry 59.0 Wet 55.0	320.0	72.50 per cent Dry 71.0 Wet 65.0	211.0

Results of the Test

Ref:	Water Pressure p.s.i.	Total water used (gals)	Wt. of coal passing during test (tons)	Dust concn. at Loader p.p.c.c	Dust concentration after Tandem point(II) p.p.c.c.	Per cent reduction in dust concn. from Loader to Tandem pt (II)
Run I	50 (approx)	991	106.25	233	No Spray -510 With Spray -274	46.30
Run II	50 (approx)	743	81.00	207	No Spray -452 With Spray +253	44.10

7. <u>Full-size tunnel test</u>: To determine directly the actual airborne dust suppression efficiency of a nozzle under mining conditions an experiment similar to that carried out in the Laboratory was performed in the return air-road of 3-South Ball Coal section. The operations being carried out during the experiment were (1) dry boring, (2) shot-firing, (3) "redding" dirt on conveyor belts, and (4) putting new girders. Three thermal precipitators were set at (1) 45 ft. from the coal-face, (2) 93 ft. from the coal-face, and (3) 300 ft. from the coal-face. A Ledward and Beckett spray was used for spraying because of its good coverage on the 10 ft x 8 ft road. The water was sprayed at 75 p.s.i. pressure. The nozzle was set at the centre of the road and about 15 ft. before the second thermal precipitator. The spray drops practically covered all the road area and some drops were even hitting the roof. Simultaneous dust sampling was made taking into consideration the time taken by the dust cloud to reach each thermal precipitator.

The sketch of the roadway is shown in Figure 42 and the results are shown in Table Nos. 42(a) and 42(b).

Environmental Conditions at Sampling Points

Volume of Air-borne Dust passing per min. cu.ft.	Water Pressure p.s.i.	Volume of water sprayed per minute (Galls.)	At 45 ft. from Coal Face T.P.(1) (Before Spray)		At 93 ft from Coal Face T.P.(2) (15ft. After Spray)		At 300 ft. from Coal Face T.P. (3) (225 ft. After Spray	
			Air Velocity ft./min.	Relative Humidity and Temp. °F	Air Velocity ft./min.	Relative Humidity and Temp. °F	Air Velocity ft./min.	Relative Humidity and Temp. °F
3332	75.0	2.01	49.0	84 Dry 68 Wet 66	42.0	90 Dry 69 Wet 67	53	90 Dry 69 Wet 67

TABLE 42(b)

Dust concentrations during mining operations

1. Dry Boring

Reference No. (R)	Dust Concentration p.p.c.c.			Per Cent Dust Removed
	1st T.P. Before Spray	2nd T.P. 15 ft. after Spray	3rd T.P. 225 ft. after Spray (fall out)	
1	1403	1376		1.93
2	1333	1067		19.90
3	1947	1419		27.10
4	757	517	405	31.50
5	1488	1056	1252	29.30
	Average per cent dust removal for R2 - R5			26.9

TABLE No. 42(b) Cont'd.

(2) Shot-firing

Run No.	Dust Concentration p.p.c.c.			Per Cent Dust removed
	1st T.P.	2nd T.P.	3rd T.P. (fall out)	
1	5696	6032	-	Nil
2	9584	12608	-	Nil
3	6560	8944	3632	Nil
4	2896	2736	-	5.53

(3) Redding Dirt on Belts

Run No.	Dust Concentration p.p.c.c.			Per Cent Dust reduced
	1st T.P.	2nd T.P.	3rd T.P.	
1	278	240	300	13.70
2	285	186	243	34.70
3	283	251	176	11.30
4	195	224	176	Nil
5	314	282	269	10.20
6	248	380	220	Nil

(4) Putting New Girders

Run No.	Dust Concentration p.p.c.c.			Per Cent Dust reduced
	1st T.P.	2nd T.P.	3rd T.P.	
1	189	243	170	Nil
2	280	284	204	Nil
3	344	388	348	Nil
4	347	163	115	52.20

8. <u>Variation of Results of spraying moving coal.</u>

As already mentioned in the survey, the dust concentratic of the intake air increases from 178 p.p.c.c. to 602 p.p.c.c. as it flows towards the coal face. This increase in the dust concentration must be due to 160 tons of coal passing over the conveyor belt during the shift. These transfer positions are the main source of dust as the coal drops from one belt to another.

It was noticed that the dust concentration of the air past the loader was varying quite a bit because there was much activity taking place near the loader throughout the stripping shift. It was therefore thought necessary to apply some sort of statistical check before calculating mean dust concentrations.

To determine the variations in the dust concentration within and between the shifts at loading point, the observed results were put through the "F" test (statistical method to find out the significance of the variations) which showed that at 5% probability the variations in the dust concentration between the shifts were insignificant. This means one sample out of 20 samples collected may lie outside the two times standard deviation confidence limit.

The mean dust concentration was found to be 244 p.p.c.c. and the standard deviation at the loader was 136. Therefore the standard error of the mean for an average of 10 samples taken within the shift is 43 p.p.c.c.

It is believed that this holds good at all other dust sources selected for this set of experiments. So all the observations of dust concentration taken during the course of the investigation were taken to be true and normal.

The 'F' test calculations are shown in Appendix 3.

When sprays were in use, a quantity of coal 'gum' was found to cling to the belt and was later removed by a scraper. Samples of the material were collected from underneath the belt and its content of particles less than 5 microns in diameter was determined. Standard sieving and centrifugal sedimentation techniques were used to separate dust below 5 microns size from the bulk. It was found that 9.95 per cent by weight of particles below 5 microns were present in the sample.

Size distribution of the dust sample below 5 microns was determined and is given below :-

Size range: (microns)	$^1/_2$-1	1 - 2.5	2.5 - 5	Above 5	Total
Per cent present:	69.23	23.72	7.05	-	100.00

No particle above 5 micron size was found on the slide. This confirms that no aggregates were formed in the preparation of the slide. About 0.00346 per cent fine dust below 5 microns by weight was present in the total 'gum' sample. This shows that dust below 5 microns was prevented from becoming airborne by wetting the coal with a water spray.

9. <u>Results of spraying dusty air.</u>

Looking at the results obtained in the experiment on airborne dust suppression (Table 42(b)), one finds that the effect of water sprays is not very promising. Dusts produced during dry boring were reduced on average by 27 per cent by water sprays. But when the dust concentration increased to 6,000 - 10,000 p.p.c.c. during shot-firing, the water spray seemed to have no large effect on the dust cloud and instead the dust concentration was found to have increased after it had been sprayed. A similar state arose in the "redding dirt" and putting in new girders. These are manual operations and here the settled dust is redispersed giving fairly low dust concentrations of about 200 - 350 p.p.c.c. When these dust clouds were sprayed, out of the 9 good runs, the dust concentration, after the spray, was reduced by 10 - 30 per cent in 5 runs. In the rest of the runs it showed an increase

It would be rather unwise to draw any definite conclusions from this last experiment. However, the water sprays improved the visibility in the section by removing most of the coarse dust particles.

10. Effect of sprays on size distribution of residual dust:

Size distribution histograms for dust produced during transportation of coal, boring, shot-firing, redding dirt, and girdering, are shown in Figures 43-1, to 43-8 and 44-1 to 44-16.

In the intake air before the loader nearly 98 per cent of the particles are below 2.5- 5 micron size, and in the air past the loader this is reduced to 93 per cent. This indicates that the dust produced during loading operations is very fine indeed. As was already found in the laboratory tests on the small nozzles the water sprays do not appear to be specific for any one range of sizes. Sometimes a particular size range is reduced after the spray, while at other times it shows an increase. Generally all the dust size ranges are suppressed with equal efficiency. If anything, the 1/2 - 1 micron size range seems to be reduced slightly more than the other size ranges. This might well be due to the fact that there were many more 1/2 - 1 micron size dust particles present in the air as compared to other sizes.

In boring, shot-firing, redding dirt and girdering, the size distribution of the airborne dust is nearly as shown below:

Size-range: (microns)	1/2 - 1	1 - 2.5	2.5 - 5	Above 5
Per Cent:	37.0	39.8	18.82	4.38

FIG. 43 SIZE-DISTRIBUTION OF DUST AT LOADER

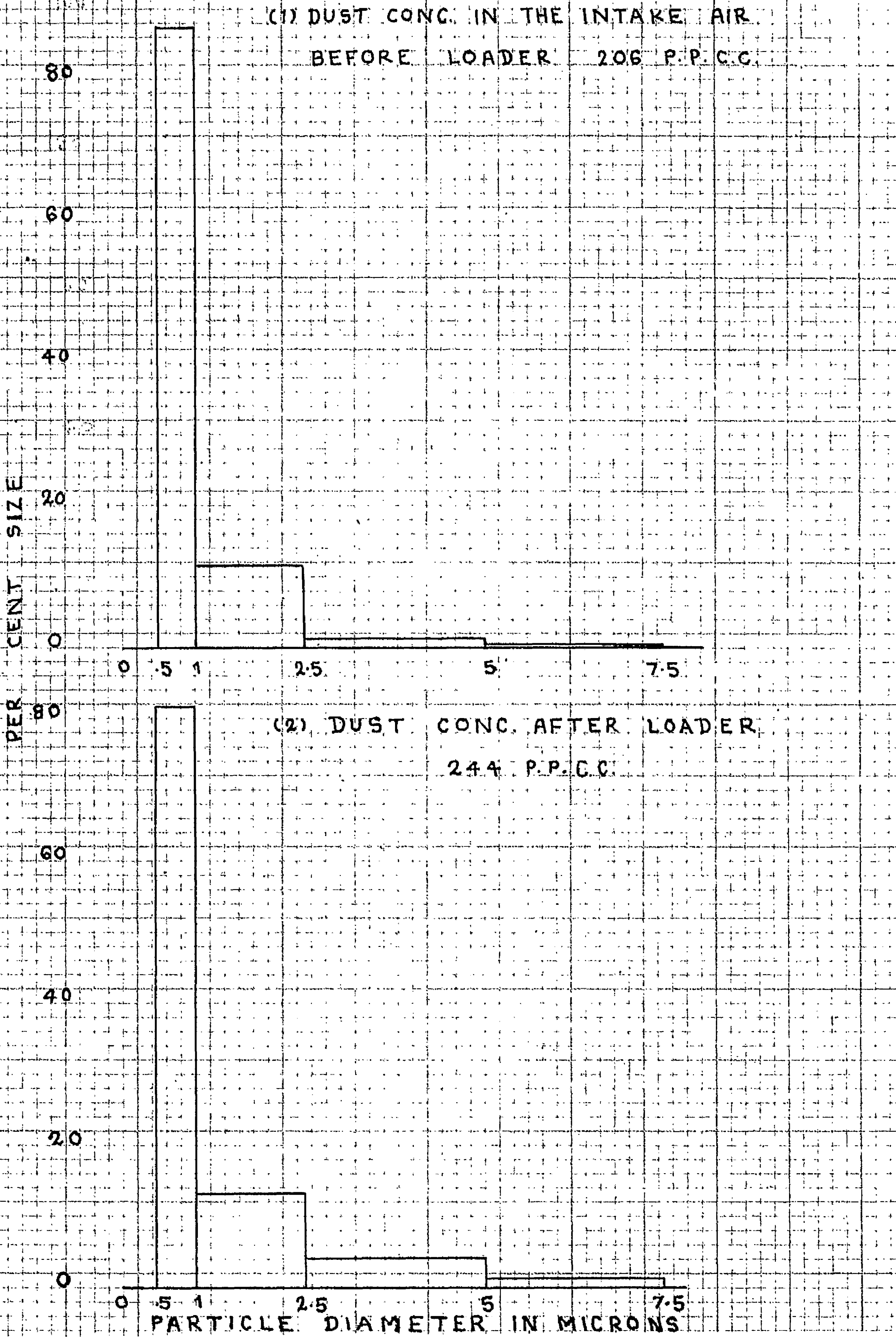
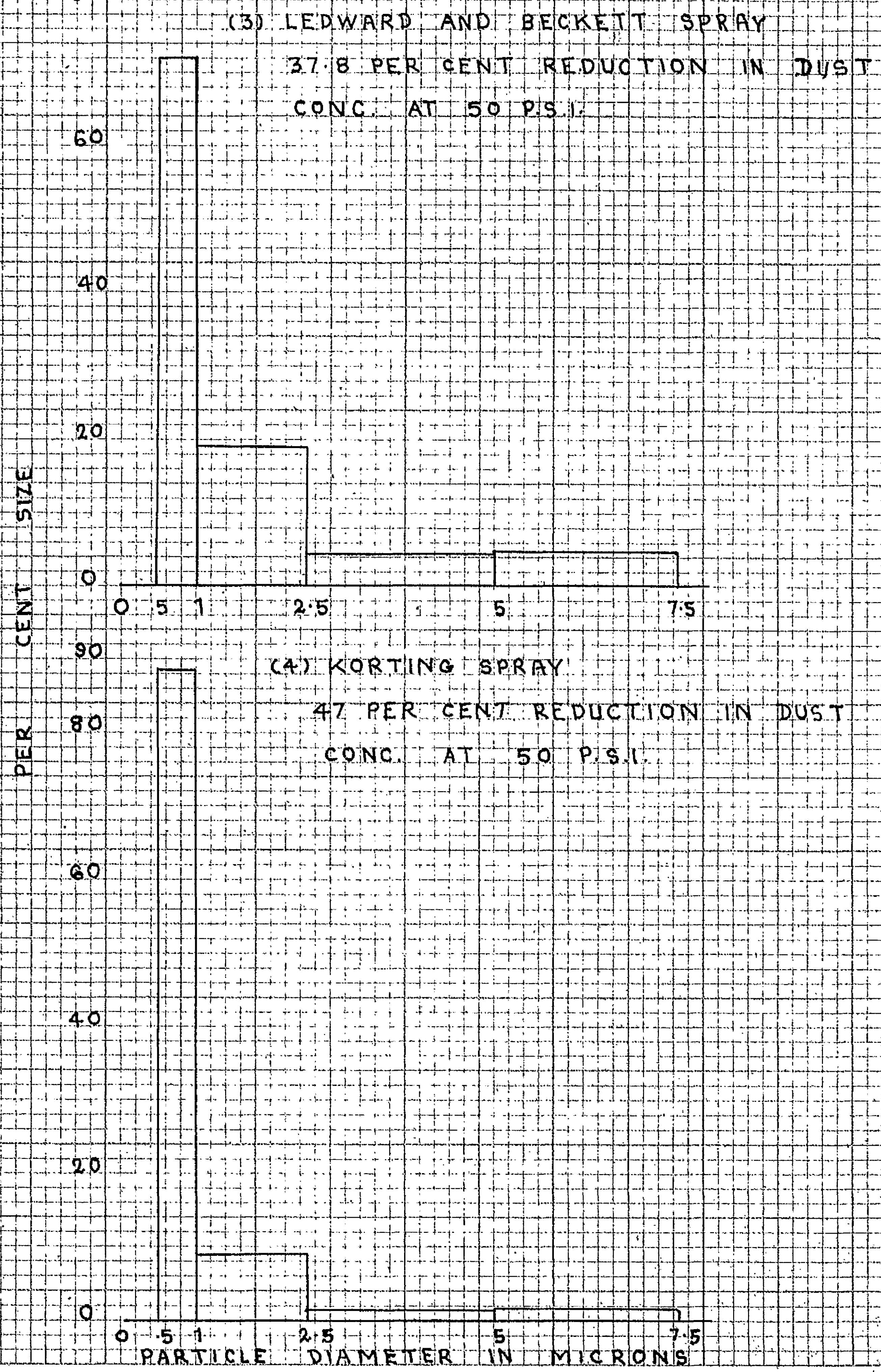
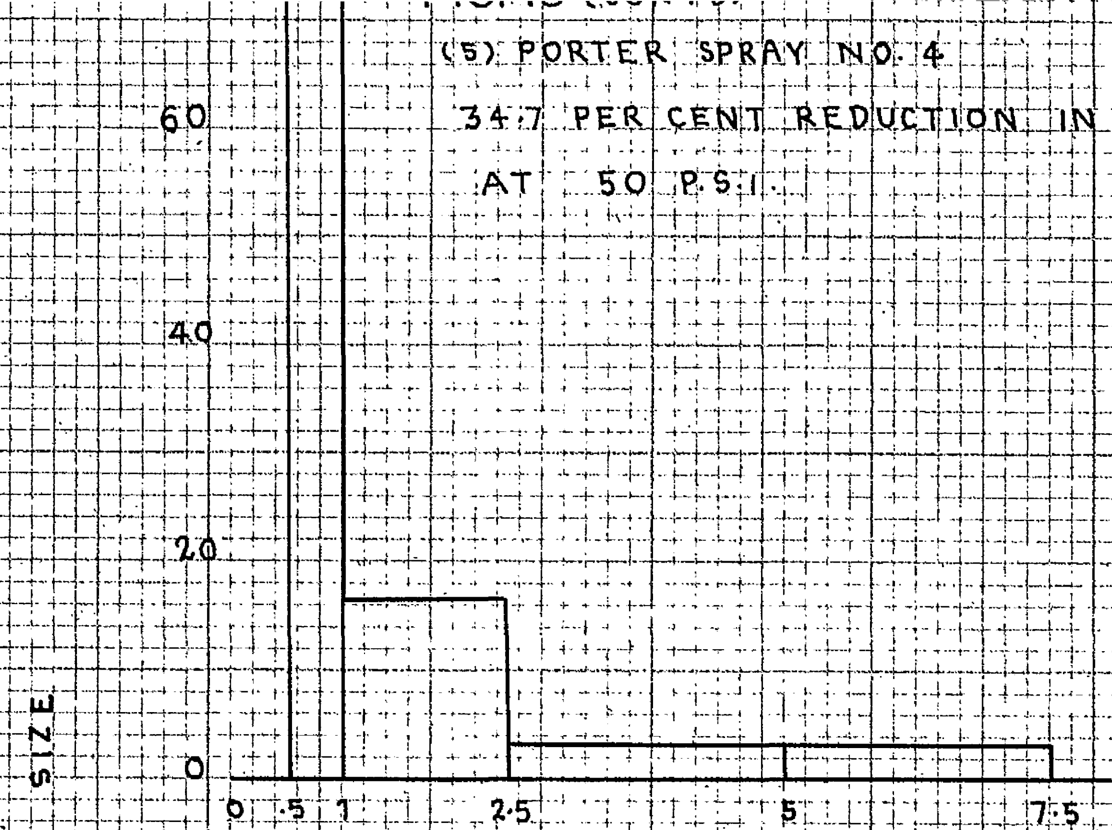
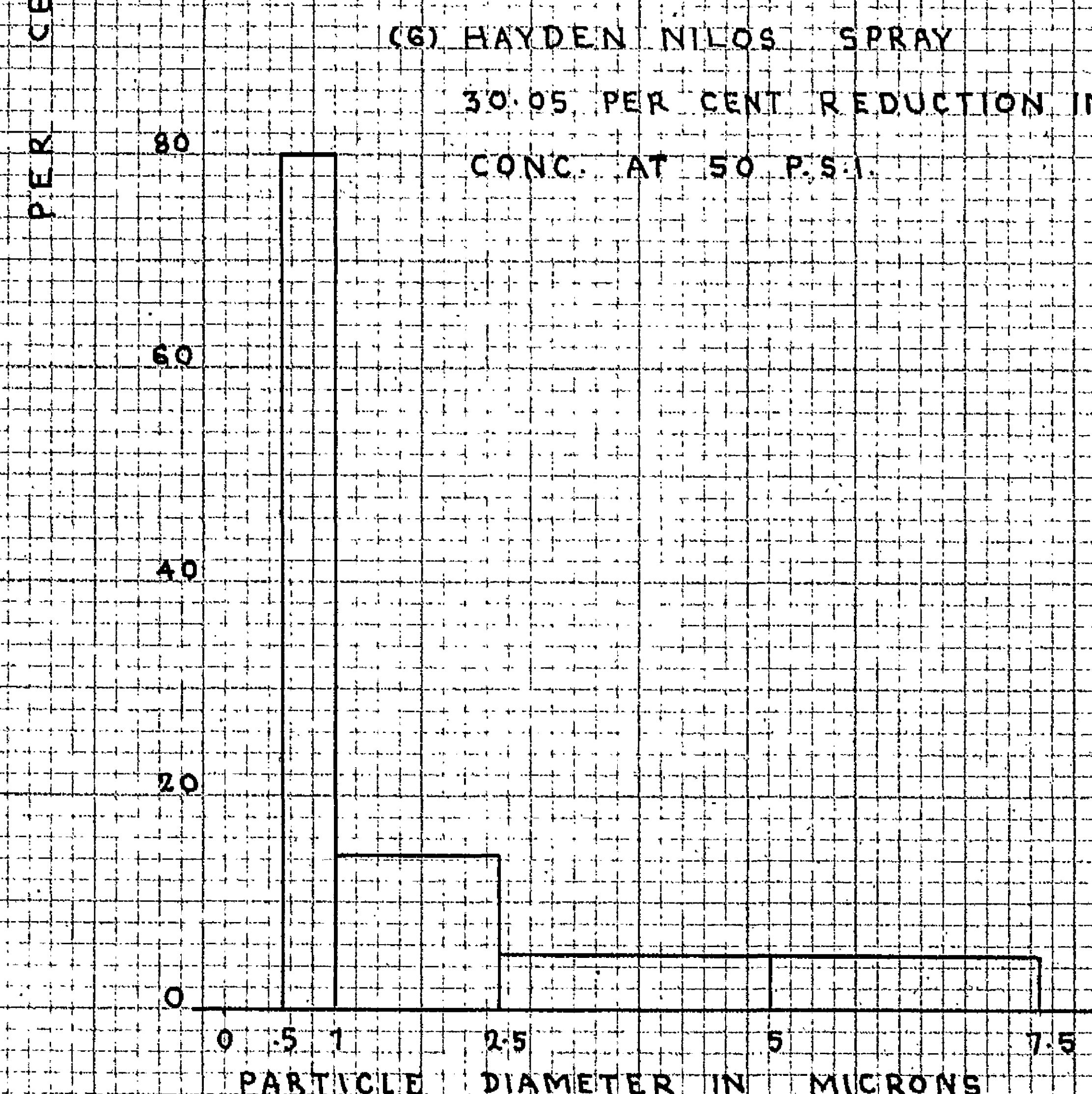


FIG 43 (CONTD)


(3) LEDWARD AND BECKETT SPRAY
37·8 PER CENT REDUCTION IN DUST
CONC. AT 50 P.S.I.
80
60
40
20
0
0 ·5 1 2·5 5 7·5
PER CENT SIZE
(4) KORTING SPRAY
47 PER CENT REDUCTION IN DUST
CONC. AT 50 P.S.I.
90
80
60
40
20
0
0 ·5 1 2·5 5 7·5
PARTICLE DIAMETER IN MICRONS



(5) PORTER SPRAY NO. 4
34.7 PER CENT REDUCTION IN DUST CONC. AT 50 P.S.I.
60
40
20
0
0 .5 1 2.5 5 7.5

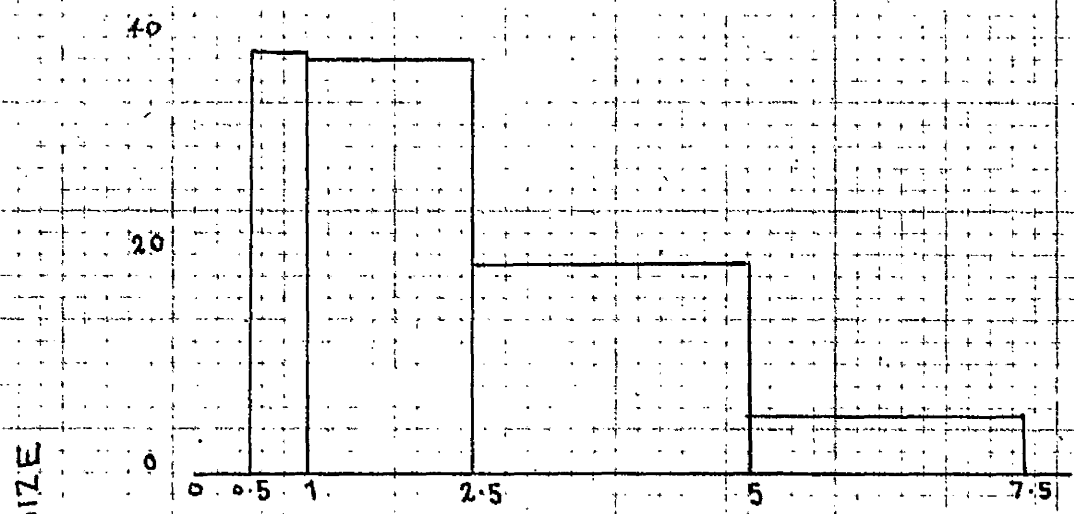


PER CENT SIZE
(6) HAYDEN NILOS SPRAY
30.05 PER CENT REDUCTION IN DUST CONC. AT 50 P.S.I.
80
60
40
20
0
0 .5 1 2.5 5 7.5
PARTICLE DIAMETER IN MICRONS

SIZE-DISTRIBUTION OF DUST

BORING BLACE (DRY)

(1) BEFORE SPRAY DUST CONC. 1403 P.P.C.C.



(2) AFTER SPRAY 1.93 PER CENT REDUCTION IN DUST CONC.

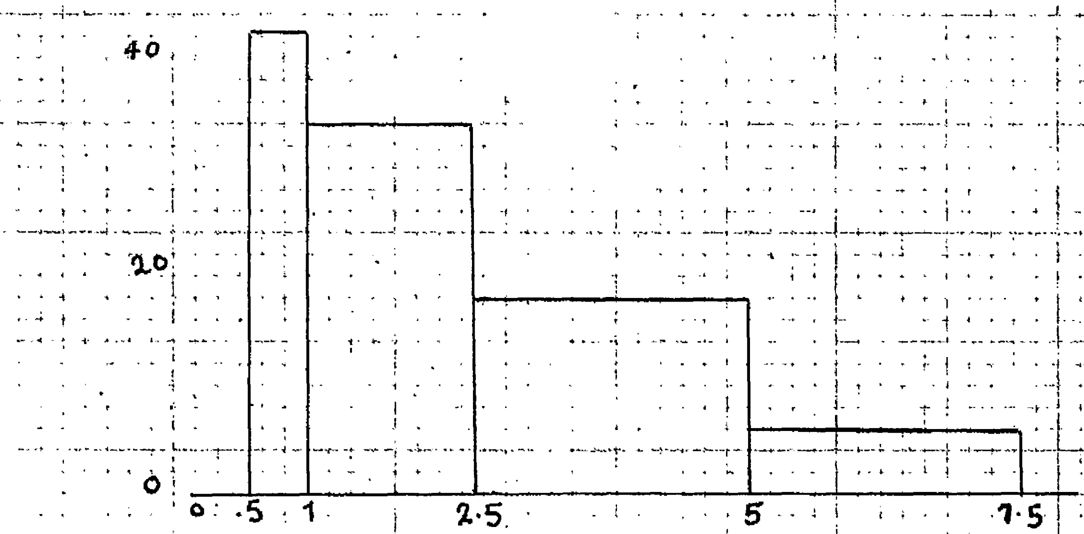


FIG. 44 (CONTD)

BORING FLAKY ROCK (DRY)

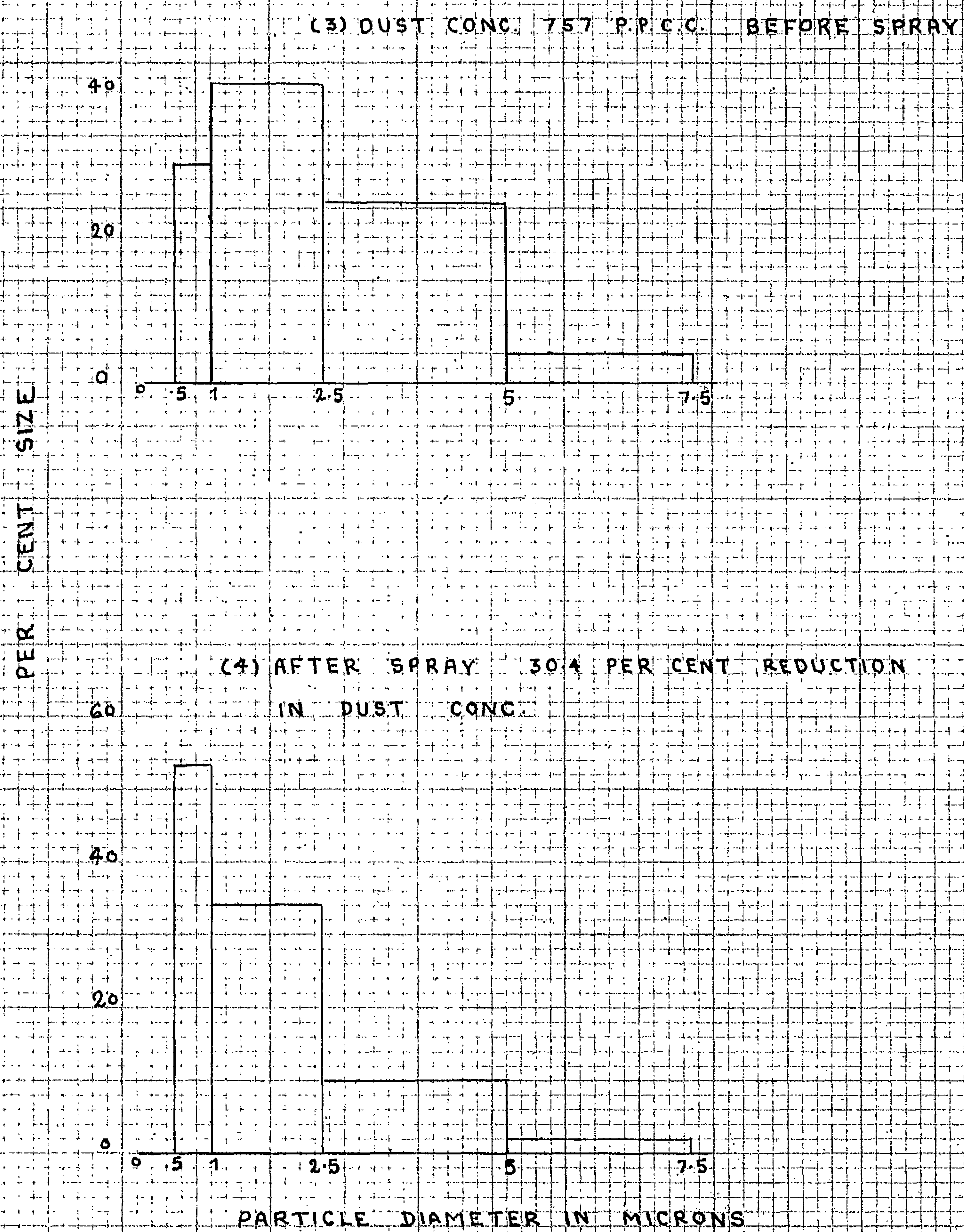


FIG. 44 (CONTD)

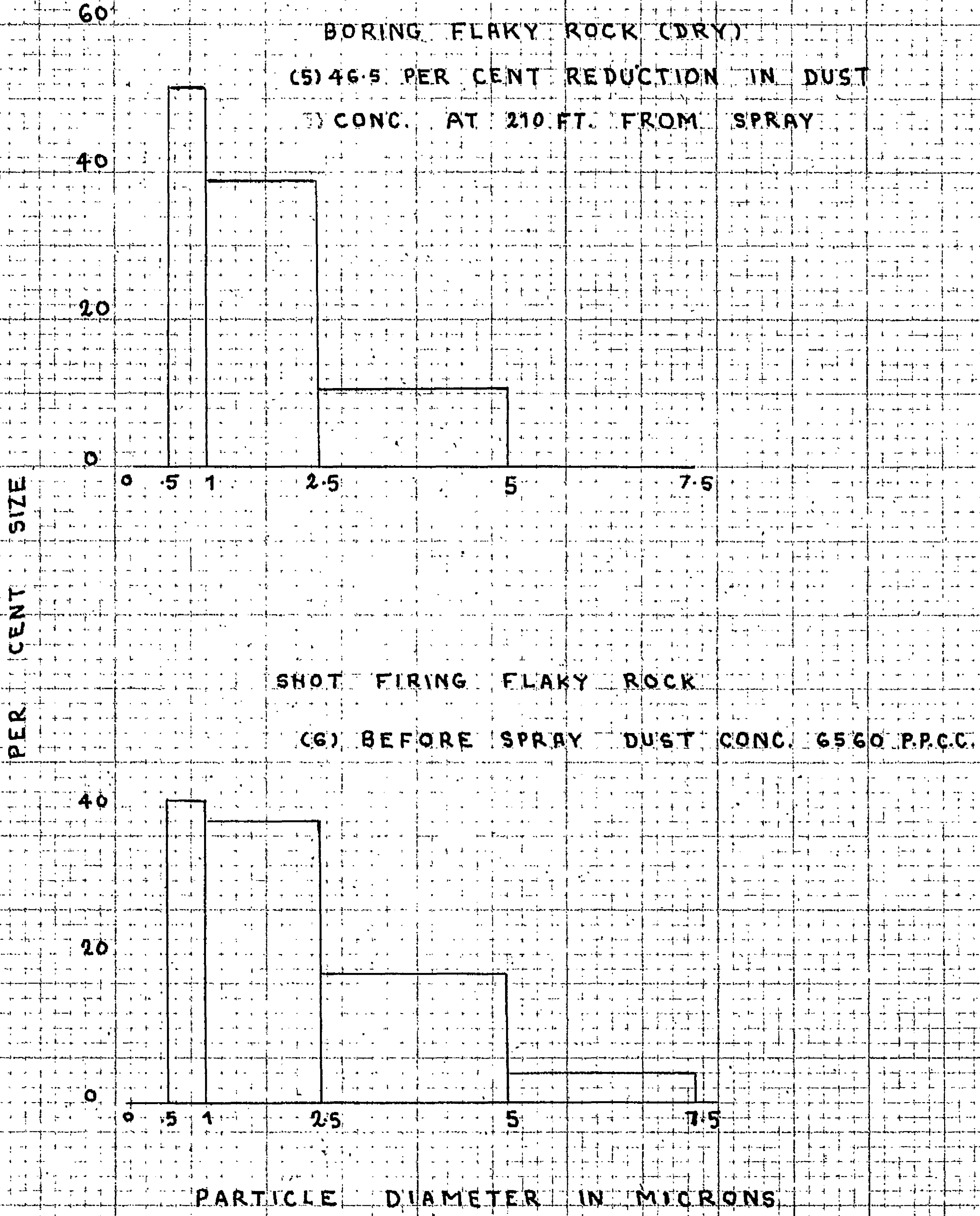

BORING FLAKY ROCK (DRY)
(5) 46·5 PER CENT REDUCTION IN DUST CONC. AT 210 FT. FROM SPRAY
60
40
20
0
0 ·5 1 2·5 5 7·5
PER CENT SIZE
SHOT FIRING FLAKY ROCK
(6) BEFORE SPRAY DUST CONC. 6560 P.P.C.C.
40
20
0
0 ·5 1 2·5 5 7·5
PARTICLE DIAMETER IN MICRONS

FIG. 44 (CONTD)

SHOT FIRING FLAKY ROCK

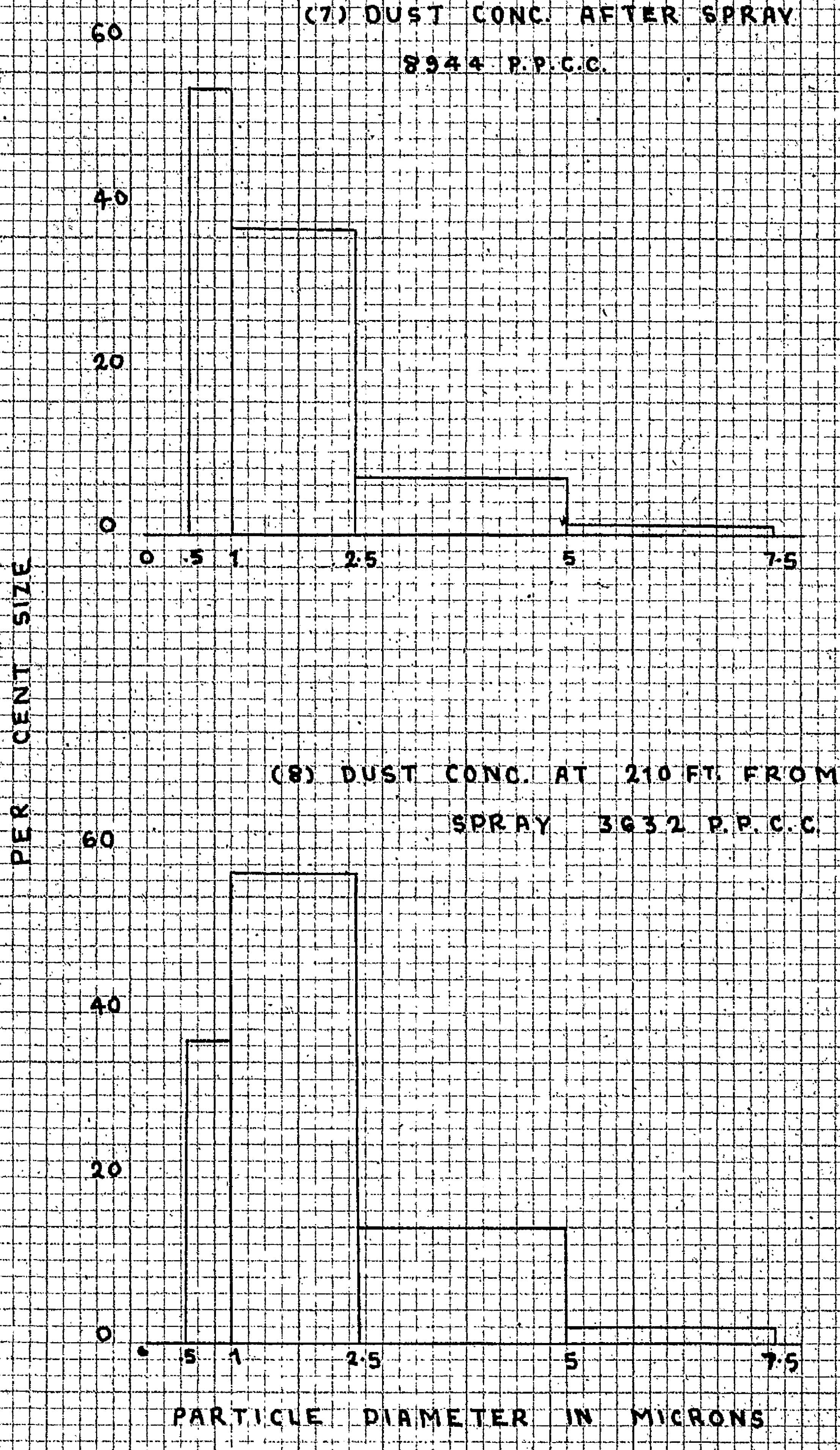
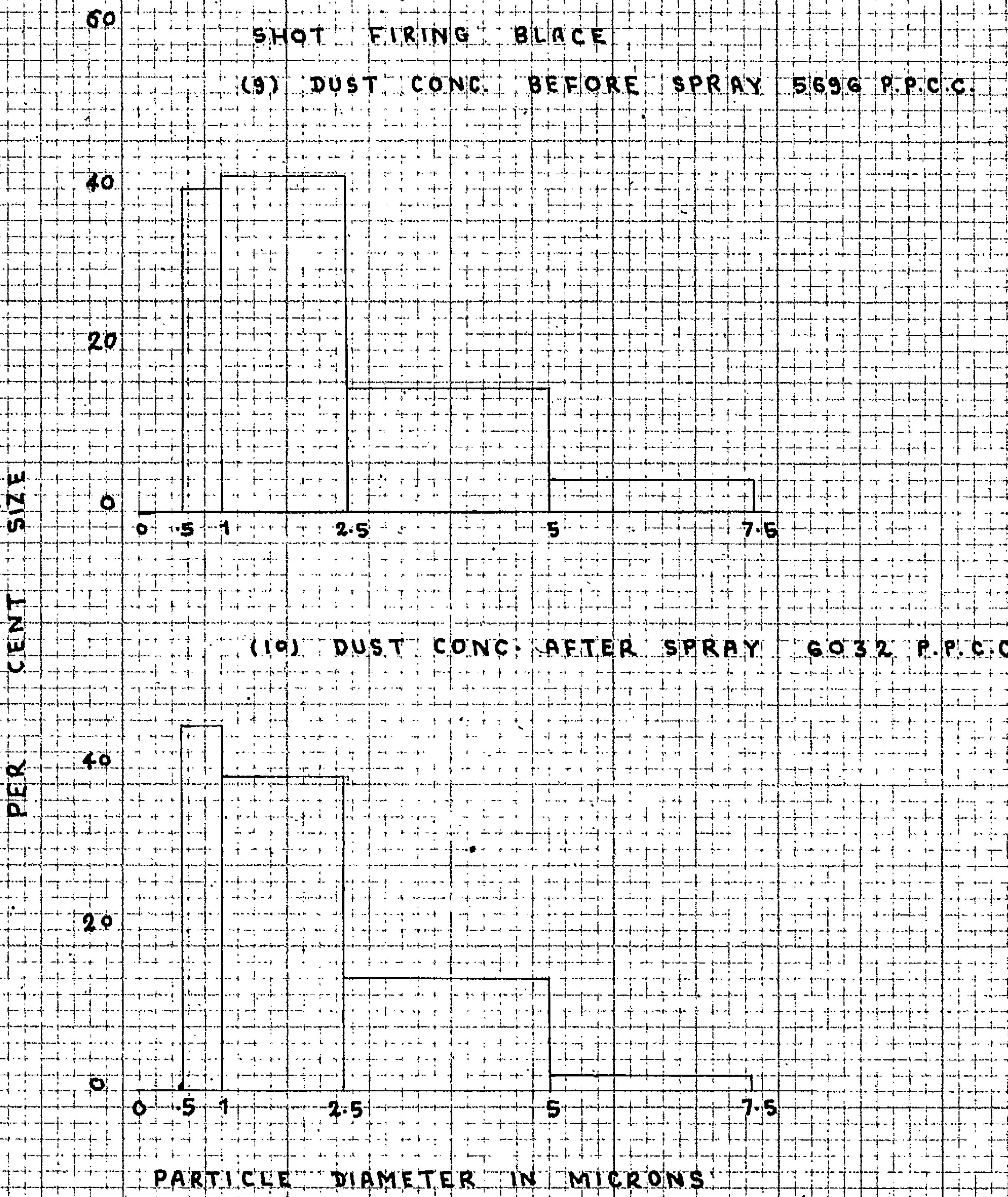


FIG. 44 (CONTD)



SHOT FIRING BLACE
(9) DUST CONC. BEFORE SPRAY 5696 P.P.C.C.
60
40
20
0
0 ·5 1 2·5 5 7·5
PER CENT SIZE
(10) DUST CONC. AFTER SPRAY 6032 P.P.C.C.
40
20
0
0 ·5 1 2·5 5 7·5
PARTICLE DIAMETER IN MICRONS

FIG. 44 (CONTD)

REDDING DIRT ON BELTS

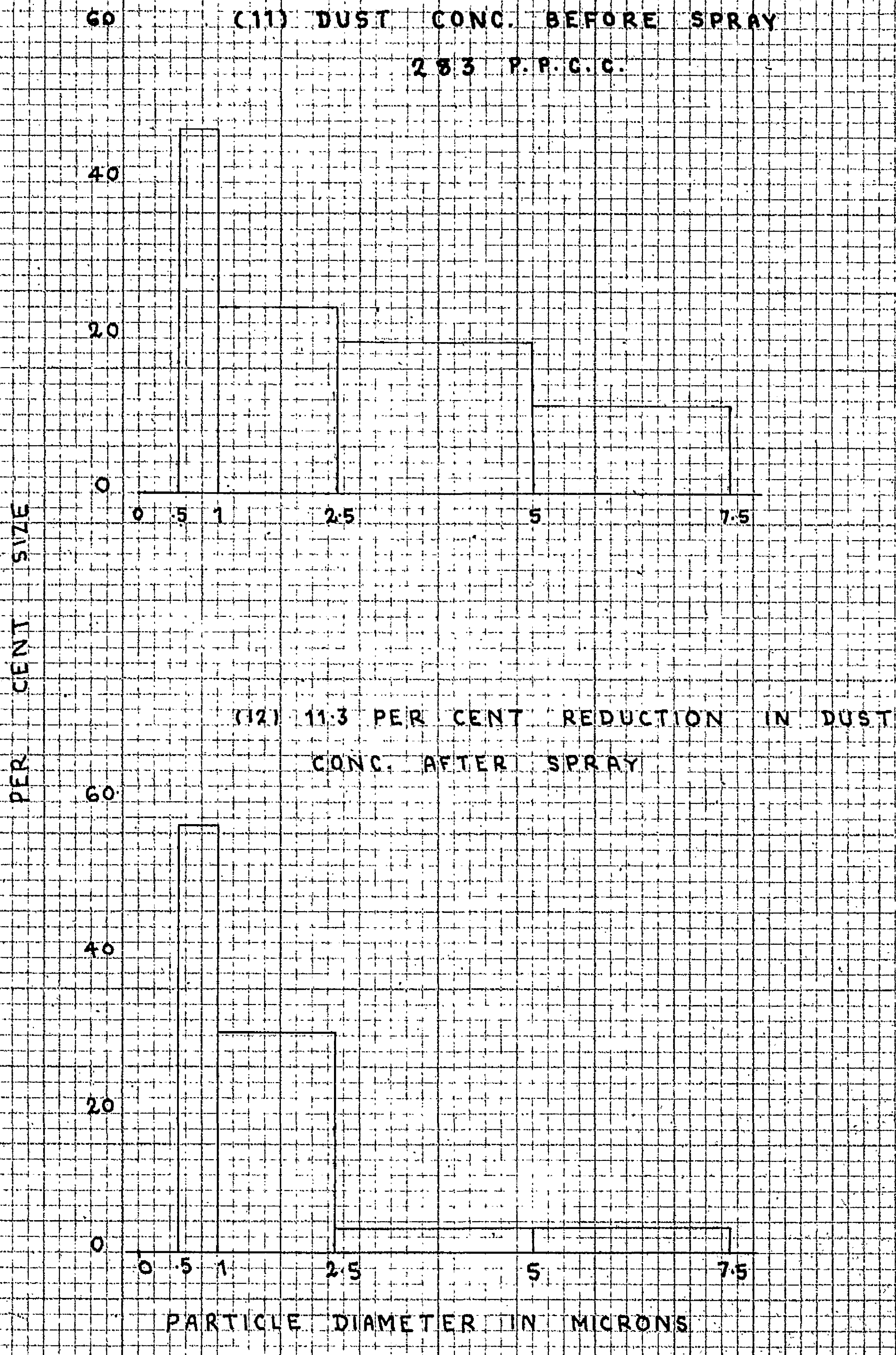
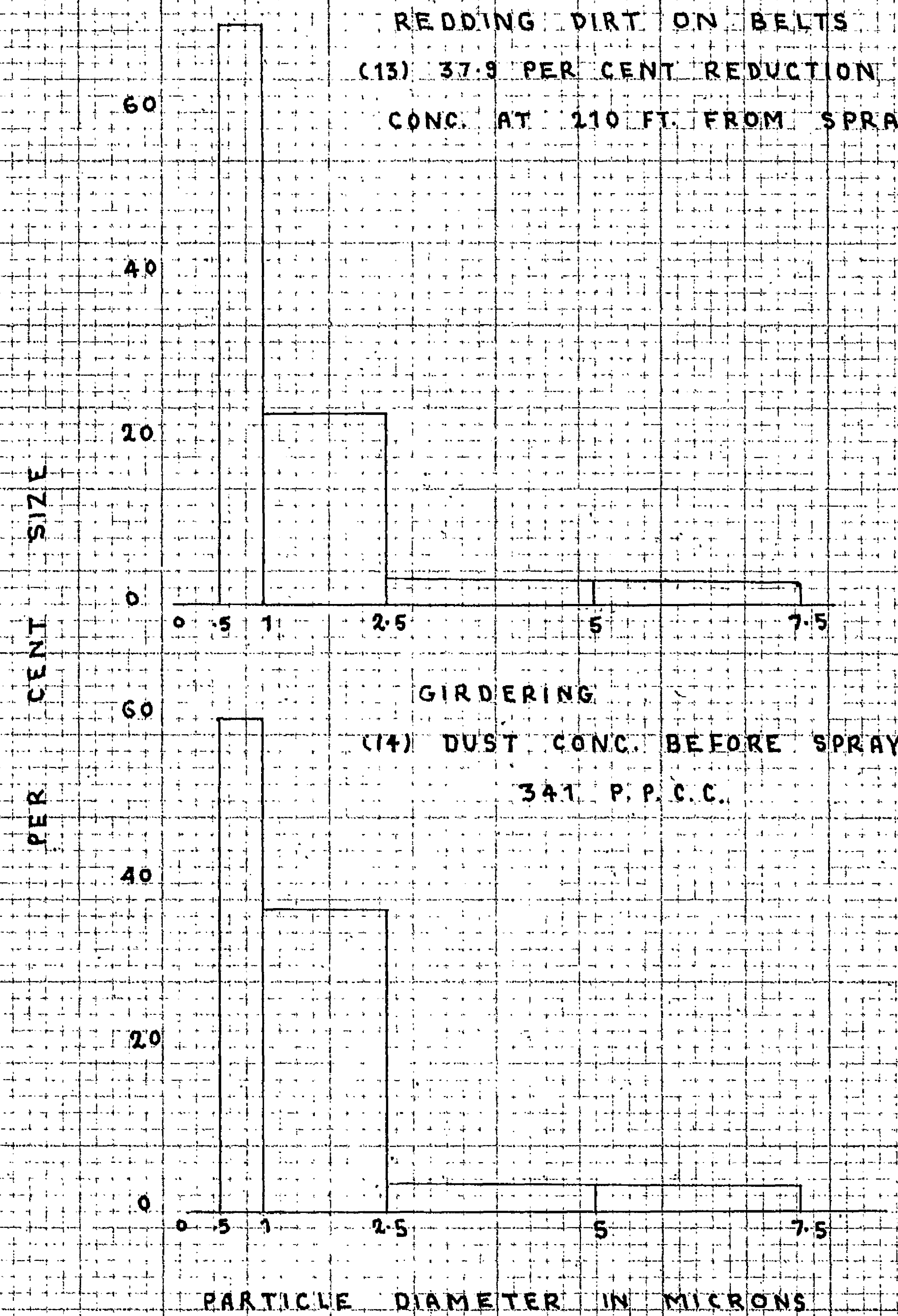


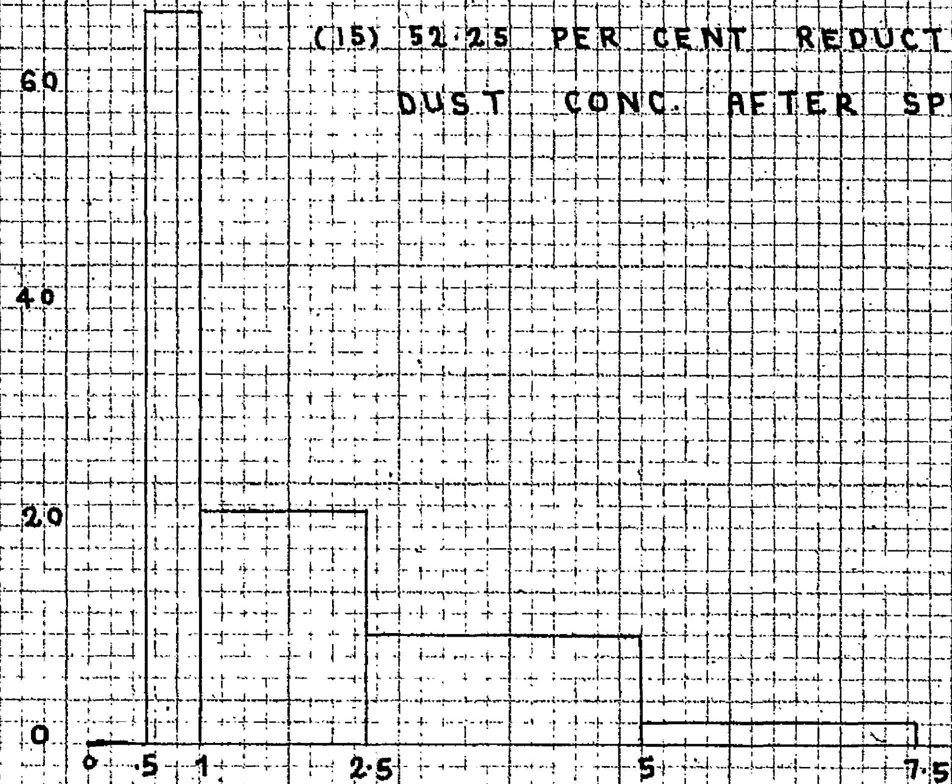
FIG. 44 (CONTD)



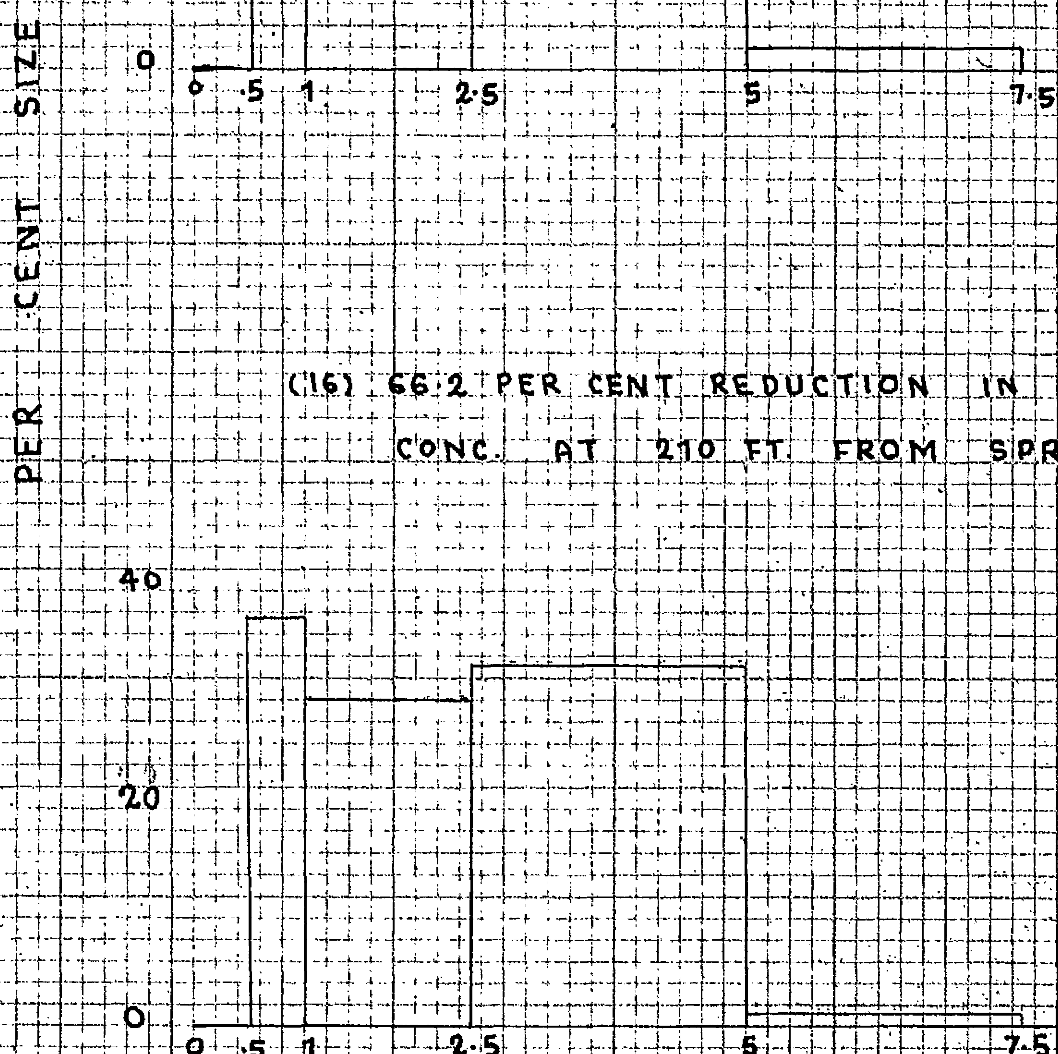
REDDING DIRT ON BELTS
(13) 37·9 PER CENT REDUCTION IN DUST CONC. AT 210 FT. FROM SPRAY
GIRDERING
(14) DUST CONC. BEFORE SPRAY 341 P.P.C.C.
PER CENT SIZE
60
40
20
0
0 ·5 1 2·5 5 7·5
PARTICLE DIAMETER IN MICRONS

FIG. 44 (CONTD)

GIRDERING



(15) 52·25 PER CENT REDUCTION IN DUST CONC. AFTER SPRAY



(16) 66·2 PER CENT REDUCTION IN DUST CONC. AT 210 FT. FROM SPRAY.

PARTICLE DIAMETER IN MICRONS

This is more uniform distribution when compared with the dust produced during transportation of coal. Here again also no specific size-range was suppressed by water sprays, but the reduction in the dust concentration after the sprays would appear to be brought about by roughly equal removal of all the particle size ranges.

The size distribution histograms are self-explanatory.

11. Effect of water usage on air humidity:

The air temperature increased as it flowed towards the coal-face. At the loader it was 60°F but at tandem point II it was 65°F. The relative humidity of the air was fairly constant between 70 - 75 per cent. However, when sprays were working, it increased by about 4 - 6 per cent near the sampling position. When sprays were used at all transfer positions, the relative humidity increased from 65 to 72.5 per cent.

Underground personnel have generally a strong objection to the use of water sprays. The chief reason for this is that through the use of excessive amounts of water, the conveyor belt slips and is likely to break. Thus the amount of water to be sprayed must be such that it should not affect the conveyor belt and at the same time remove the airborne dust particles. It was found that the Hayden Niles spray is therefore best suited under the circumstances. One definite advantage of using water sprays is the improved visibility in the section due to the partial removal of the airborne dust.

SECTION VIII

General discussion and conclusions

The precise mode of the action of spray droplets on suspended dust particles is as yet uncertain. It has been claimed that they actually wet the dust particles and cause them to settle more rapidly by increasing their size and weight. Terrel[60] has suggested that, in addition, the mechanical sweeping action of the descending droplets brings down particles which may be too small to be efficiently wetted. Nelson[61] claims that when using water in the form of mists, airborne dust particles are wetted and deposited by impingement on surrounding surface or because of increased particle size settle near the source instead of being widely dispersed.

The wetting of fine particles of dry coal dust is difficult because of high interfacial tension between coal and water. The contact wetting of a dust particle by a water droplet is explained by Greenwald[62] on the basis of the change in the surface free energy.

By adding wetting agent to the water, the surface tension is lowered, and this would tend to decrease the contact wetting power of water, except that contact angle is reduced and thus the adhesion tension is increased.

Dust removal efficiency has not been found to be greatly increased by the use of wetting agents in sprayed water.[63,64,65,66]

No matter the final means of removing the dust particle from suspension, it is generally recognised that the initial step involves a collision between a water droplet and a dust particle. The probability of such an impact under a given set of conditions is difficult to estimate theoretically due to incomplete information on the relative influence of viscous and inertial forces on the dust particle trajectory in the vicinity of the water droplet.

The flow pattern around such a spherical body is related to the Reynolds number which is itself a measure of the balance of inertial and viscous forces. When the Reynolds number is very low the characteristic viscous flow pattern is obtained[67] and when large a so called potential flow pattern is obtained[67], at these two extremes the Navier-Stokes equation can be linearised and solved for flow around a sphere. Unfortunately this is not possible at practical intermediate values of Reynolds number and approximations become necessary. A number of workers have produced approximate equations and solved them for suitable values of Reynolds number[68] but in most cases their results have relatively limited application.[69,70,71,72,73,74,75,76,77] A review of their relative merit as an aid to the solution of the problem of particle capture is given by Herne.[78]

In treating the hydrodynamic capture of the dust particle by the water droplet from a theoretical point of view a number of simplifying assumptions are made. For convenience it is considered that only the two bodies under study, the water droplet and the dust particle, are present in the air. Both bodies are assumed to be spherical and the water droplet is considered to be appreciably larger than the dust particle, so that the flow pattern under consideration is that of the air and the dust particle around the water droplet.

The water droplet has a motion relative to the air due to the action of gravity or by virtue of being ejected from a spray nozzle, while the dust particle is initially at rest relative to the air and is so small that, under all conditions, the Reynolds number of any motion it has relative to the air is so much less than unity that Stokes law applies.

Under these conditions the droplet will sweep out through the air a tube of cross-section equal to its diameter and in so doing may capture, sweep against, or sweep just past the dust particle. The probability of capture of the particle by the droplet depends on the balance of the viscous and inertial forces governing the motion of the smaller body relative to the larger. If viscous forces are neglected and only inertial forces are considered, collision leading to capture will occur if the dust particle lies within the tube swept out by the water droplet. If the dust particle is considered to have a dimension, the diameter of the tube has to be increased to allow for the diameter of the particle, i.e. the particle will just make contact with the droplet if its centre follows a path that passes within a particle radius of the droplet. On the other hand if viscous forces only are considered the smaller body although within this tube will follow the path of the streamlines and will be carried around the droplet.

In practice, the smaller body is influenced by both viscous and inertial forces and collision efficiencies lie between zero and one hundred per cent. Theoretical treatment moreover can only concern itself with impact. It takes no account of the fact that such impact may not necessarily lead to capture, the smaller body "bouncing off" after impact. A sketch of the flow pattern is given in Fig. 45.

Under conditions in which the fluid forces on the small particle obey Stokes law, the equations of motion

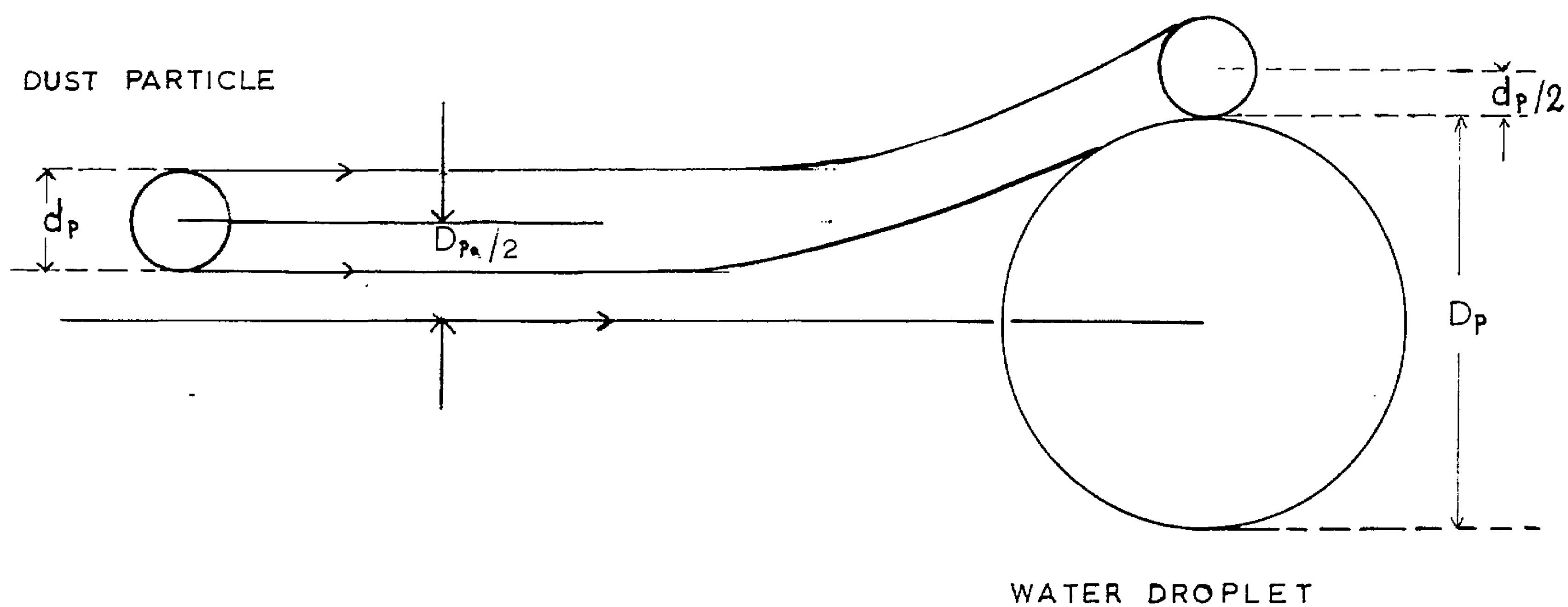


FIG. 45 GRAZING TRAJECTORY OF DUST PARTICLE AND WATER DROPLET.

can be reduced to a dimensionless form and are found to depend on a dimensionless group, the so-called "particle parameter", K, where

$$K = \rho_s d_p^2 \, u / 9\eta D_p$$

The non-linear equations of motion of the particle necessitated numerical methods for their solution, which involve step-by-step plotting of each possible trajectory of the dust particle. The trajectory which corresponds to a grazing collision is thus found by trial and error. This is the trajectory whose distance of nearest approach to the droplet surface is $d_p/2$ and whose distance from the line through the centre of the droplet when still at a large distance from it is $D_{po}/2$. The circular area corresponding to the distance $D_{po}/2$ from the centre line is known as the "capture cross-section", and the "collection efficiency"(79) is defined as

$$\bar{E} = \pi(D_{po}/2 + d_p/2)^2 / \pi(D_p/2)^2$$

$$= (D_{po} + d_p)^2 / D_p^2$$

It can also be defined as the ratio of the number of particles striking the droplets to the number which would strike it if the streamlines were not deflected around the droplet. Computations are normally made of the collision efficiency as a function of K for a series of values of d_p/D_p.

A number of workers have computed values of E in terms of K. Of lesser importance is the early work of Sell(80) and the limited study by Vasseur[81]. Das computed a few trajectories[82], but was not concerned with grazing trajectories. Stairmand reports calculations of Bosanquet[83] but only a small number of values are given. Pearcey and Hill[84] superimposed the flow pattern of two individual particles to enable the evaluation of the flow pattern around two approaching spheres of comparable size. This last approach is of doubtful merit and has been criticised[85]. Hocking has studied a similar system for comparable spheres ranging from 38 - 60 μ diameter using the Stokes linearisation of the Navier-Stokes equations.[77] His results would appear to indicate that collision is impossible if the diameter of the water droplet (the larger sphere) is less than 36 microns. Langmuir and Blodgett[86][79] have evaluated collision efficiencies for potential flow and for viscous flow. A differential analyser was used as an aid to computation.

Fonda and Herne[87] made use of a digital computer to evaluate particle trajectories in viscous and in potential flow pattern around spheres and are considered to have obtained the most accurate results to date. Their work has been extended by Mason[88] for a range of values of the particle parameter in the viscous flow pattern.

Employing the diameter of the droplet as the unit of length, Fonda and Herne derive a dimensionless capture cross-section (y_o^2) and plotted curves relating y_o^2 to K for various nearest distances of approach, r_m (measured as a fraction of $D_p/2$) of the trajectory to the centre of the sphere, for both viscous and potential flow. Collision will take place where

$$r_m = (d_p + D_p)/D_p.$$

It was of interest to discover the range of capture cross-section covered in the experimental work described in this thesis. The ranges were conveniently separated into three groups, i.e. small high pressure nozzle in the tunnel, large N.C.B. nozzle in tunnel, and N.C.B. nozzle in the coal pit. Using the data and diagram provided by Herne and Fonda[87] and applying Langmuir's interpolation formula for conditions of finite Reynolds number, the range of capture cross-section was calculated for the appropriate range of nozzle pressure and for typical values of droplet diameter (D_p) and dust particle diameter (d_p). The results of these calculations are shown in Tables 43(a), (b) and (c).

The wind tunnel capture cross-sections are in general high and thus good dust suppression should have been achieved. It must be remembered, however, the values calculated correspond to the initial velocity of the droplet. On entering the air stream the water droplet is rapidly decelerated by the resistance of the air and finally comes to a halt in the counter current air flow. It then moves

TABLE 43 (a)

Small high pressure nozzles in the wind tunnel

Pressure range	50 ——— 5000 p.s.i.
Initial Velocity	1572 ——— 15,720 cms./sec.
Counter flow air Velocity	60 ——— 380 cms./sec.
Reynolds Number Range	
for D_p = 20 microns	23.65 ——— 231.0
for D_p = 40 microns	47.30 ——— 458.0
for D_p = 60 microns	70.90 ——— 692.5
Range of particle parameter K (for average dust particle diameter 1.59 microns.)	
for D_p = 20 microns	15.50 ——— 151.5
for D_p = 40 microns	7.75 ——— 75.80
for D_p = 60 microns	5.16 ——— 50.50
Theoretical Capture Cross-section	
for r_m = 1.038	0.835 ——— 1.06
for r_m = 1.016	0.726 ——— 1.02
for r_m = 1.012	0.657 ——— 0.99

TABLE 43(b)

Full-size N.C.B. nozzles in the wind-tunnel.

Pressure Range	40 ------ 60 p.s.i.
Initial Velocity	1394 ------ 1760 cms./sec.
Counter flow air Velocity	610 ------ 458 cms./sec.
Reynolds Number Range	
for D_p = 80 microns	80.1 ------ 126.3
for D_p = 100 microns	105.0 ------ 159.4
for D_p = 120 microns	126.0 ------ 190.0
Range of particle parameter K (for average dust particle diameter 1.54 microns)	
for D_p = 80 microns	2.455 ------ 5.475
for D_p = 100 microns	2.760 ------ 4.150
for D_p = 120 microns	2.300 ------ 3.490
Theoretical Capture Cross-section	
for r_m = 1.02	0.625 ------ 0.769
for r_m = 1.0154	0.575 ------ 0.678
for r_m = 1.011	0.545 ------ 0.683

TABLE 43(c)

Full-size N.C.B. nozzles in the mine-roadway

Pressure range	50 ------ 75 p.s.i.
Initial Velocity	1572 ------ 1931 cms./sc
Counter flow air Velocity	30 ------ 210 cms./sec
Reynolds Number Range	
for D_p = 100 microns	115.6 ----- 155.0
for D_p = 120 microns	139.0 ----- 186.0
Range of particle parameter K (for average particle size 1.109 μ)	
for D_p = 100 microns	1.54 ------ 2.055
for D_p = 120 microns	1.28 ------ 1.71
Theoretical Capture Cross-section	
for r_m = 1.0154	0.455 ------ 0.520
for r_m = 1.01	0.422 ------ 0.485

downstream with the air. Under these conditions the capture cross-section decreases rapidly, and if one calculates a capture cross-section for a 40 micron water droplet brought to momentary rest in a counter flow of air moving at 120 ft/min. a value as low as 0.005 is obtained. The mean capture cross-section will then lie somewhere between the maximum values given in Tables 43(a), (b) and (c) and the minimum value. Giffen[54] provides formulae which enable the projection velocity to be calculated at various distances from the nozzle to the end of the droplet penetration range. As it has been shown already that the experimental values of penetration exceed by many times the values calculated from the theoretical formulae, Giffen relationships cannot be easily applied to our work to enable calculation of capture cross-section to be made at various distances from the nozzle and an average value of y_o^2 obtained.

Walton and Woodcock[89] have utilised the results of Fonda and Herne[87] to predict the collection efficiencies of gravity sprays and projected sprays on static and moving dust clouds. Their reasoning has been applied to our experimental conditions to enable the calculation of dust suppression efficiencies resulting from the continuous spraying of a moving dust cloud in our cylindrical tunnel.

If a small interval of time Δt is considered during which water is sprayed in droplets of D_p diameter at a total volume throughput rate of Q and the penetration of the droplets is S, the number of water drops produced will be equal to $6Q\Delta t/\pi D_p^3$

If $\overline{y_o^2}$ is the average capture cross-section over the range S.

Effective volume of air denuded of dust will be

$$= (6Q\Delta t/\pi D_p^3)(\overline{y_o^2} \times \pi D_p^2 \times S/4)$$

$$= 3\,\overline{y_o^2}\,Q\Delta tS/2D_p$$

If the rate of air flow in the tunnel is G, the volume of air passed in time Δt will be $G\Delta t$.

Thus fraction of the total dust removed

$$= 3\,\overline{y_o^2}Q\Delta tS/2D_pG\Delta t$$

and if n is the dust concentration

$$\therefore\ \Delta n/n = 3\,\overline{y_o^2}Q\Delta tS/2D_pG\Delta t$$

Thus for a logarithmic diminution in dust concentration

$$n_1 = n_o \exp(-3\overline{y_o^2}QS/2D_pG)$$

Where n_o and n_1 are the initial and final dust concentrations

$$\log_e n_1/n_o = -3\overline{y_o^2}QS/2D_pG$$

$$\text{i.e. } 2.3 \log_{10} n_1/n_o = -3\overline{y_o^2}QS/2D_pG$$

$$\therefore \log_{10} n_1/n_o = -1.5\overline{y_o^2}QS/2.3 D_pG$$

and nozzle efficiency $(E) = \dfrac{n_o - n_1}{n} \; 100 = (1 - n_1/n_o)^{100}$

To compare the value of $\overline{y_o^2}$ calculable by this equation from the experimental values of nozzle efficiency with the value obtained from the particle parameter using Herne and Fonda's data a set of experimental conditions were selected from our earlier work and the two calculations made.

The conditions selected for this comparison were :-

Water Pressure = 500 p.s.i.
Water throughput = 25.0 gals./hr.
Average droplet diameter = 40.0 microns
Air velocity = 130 ft./min.
Initial dust concentration (n_o) = 3285 p.p.c.c.
Final dust concentration (n) = 880 p.p.c.c.
Nozzle Efficiency (E)= 73.25 per cent.
Spray cone angle = 112°

From this data the following values were obtained :-

Q = water flow rate = 31.5 c.c./sec.

G = air flow rate = $1.085 \quad 10^5$ c.c./sec.

S = penetration = $9 \quad 2.54/\sin 56 = 27.5$ cms.

$$\therefore \log_{10} 880/3285 = -\frac{1.5 \times 31.5 \times 27.5}{2.3 \times 1.085 \times 10^5 \times 40 \times 10^{-4}} (\overline{y_o^2})$$

$$\therefore -\overline{y_o^2} = \log_{10} 0.268/1.3$$

$$\therefore -\overline{y_o^2} = -0.5719/1.3$$

$$\therefore \overline{y_o^2} = 0.44$$

The value of y_o^2 was also calculated for the water droplet of 40 micron diameter under the same conditions using Fonda and Herne's technique and Langmuir's[79] interpolation formula.

A value of 24.45 was obtained for the particle parameter, resulting in a value of 0.93 for the capture cross section (y_o^2). This however is a value calculated from the initial velocity whereas the value calculated from the nozzle efficiency is an overall average value. It has already been shown that the value of y_o^2 drops to 0.005 when the 40 micron droplet comes to rest with respect to the tunnel. Therefore if an average value for y_o^2 is taken over the range S, we obtain 0.935/2, i.e. 0.468 which is very close to the value calculated from experiment.

Walton and Woolcock have estimated the total effective swept volume per c.c. of spray based on theoretical capture cross-section for various drop sizes from 0.1 - 0.5 m.m. and dust particle sizes from 1 - 10 microns.

They used the relationship $3\overline{y_o^2}S/2D_p$ to calculate the swept volume and related this figure for 90 per cent removal of dust per 1000 cu.ft. of dusty air assuming that the dust concentration fell logarithmically.

When this theory is applied to our work reported in section VII Table 42(b) - "boring operation", the results obtained are shown in Table 44.

In our calculation we have assumed as an approximate mean value, a capture cross-section $(\overline{y_o^2})$ of 0.27 which is quite close what we would have obtained from Fonda and Herne's particle parameter. Calculations shown in Table 43(c) over the whole penetration range.

TABLE 44

Average dust particle size	2.0 microns
Average drop size at 75 p.s.i.	100 microns
Initial velocity of the droplet	1931 cms./sec.
Dust cloud velocity	60 cms./sec.
Relative velocity	1991 cms./sec.
Average capture cross-section $(\overline{y_o^2})$	0.27
Actual distance travelled by the droplet	2080 cms.
Total effective swept volume per c.c. of spray	8.4 litres
Volume of water required to remove 90 per cent of the dust (3332 cu.ft. of dusty air/min.)	5.7 gallons/min. at 75 p.s.i.

Walton and Wooldock used the theoretical penetration value for S calculable from Giffen and Muraszew[54]. In our calculation we have used actual experimental distance travelled by the drops (calculated from cone angle and dimensions of the roadway). This gives a required water rate of 5.7 gallons/min. at 75 p.s.i. to remove 90 per cent of the dust of average particle size of 2.0 micron (approximately) from 3332 cu.ft. of dust cloud moving at a counter velocity of 60 ft./min.

In the tests carried out in the return air way of the coal pit with a Ledward and Beckett nozzle only 2 gallons of water was used to treat 3,332 cu.ft. of air (as shown in Table 42(a)). This perhaps helps to explain the low nozzle efficiencies obtained in our tests in the coal pit.

<u>Results obtained under mining conditions</u>

From Table No. 37(b) it appears that the airborne dust concentration at the loading point can be reduced by a maximum of 30.35 per cent, by both wetting the coal and partially suppressing the incoming airborne dust by the use of water sprays. This maximum reduction in the dust concentration obtained from the four nozzles tested varied from 30 to 47 per cent, but after considering the amount of water used and the inconvenience caused by spraying to normal working conditions, the Hayden Nilos spray nozzle is possibly the most suitable at this point. It consumes only 0.5 gallons of water per minute at 50 p.s.i. pressure and the airborne dust knocked down by every c.c. of water sprayed equals $\underline{31.1 \times 10^6}$ particles in the range 1/2 - 5 microns. This dust-water ratio is much bigger than that given by the Korting Spray and Ledward and Beckett Spray. However, Porter No.4 Spray nozzle has even better dust-water ratio, $\underline{46.25 \times 10^6}$ but it takes double the amount of water used by the Hayden-Nilos Spray at 50 p.s.i.

Hayden Nilos Spray when used at tandem point I and transfer point gave 48 and 42 per cent overall reduction in the airborne dust concentration.

When all the transfer positions were simultaneously sprayed with water at 50 p.s.i. pressure, a total dust concentration reduction of 45.0 per cent was achieved.

The dust removal efficiencies obtained by Richmond[46] for the same nozzles, i.e. 75.7 per cent for Porter No.4, 74.0 per cent for Korting Spray, 53.1 per cent for Hayden Niles Spray, and 46.1 per cent for Ledward and Beckett Spray, were much higher than those obtained by us in the mine tests. The reason for this difference may well lie in the difference in dust concentration measurement. Richmond calculated dust concentrations in the particle size range 1 - 5 microns while the work reported here is based on a 0.5 - 5 micron range of diameters.

It is of interest to note that the Monmouthshire Coal Owners[90] claimed 85 per cent dust removal efficiency by using the South Wales mist projectors under controlled conditions in a wind tunnel. 50 per cent dust removal was obtained in a very dusty seam by using water sprays at the coal face. It appears from their size distribution results that the spray droplets are not selective in suppressing any particular size and the same size distribution is obtained even after spraying. Our size distribution results are in close agreement with those obtained by Monmouthshire workers.

Johnson[91] claims 90 per cent dust removal when using solid cone sprays at coal loading positions and 30 per cent at coal unloading positions.

Merwitts[92] claims 95 per cent dust removal for the dust generated during cutting, loading of coal etc. by using water at high pressure up to 800 p.s.i. and swirl spray nozzles having flow rates similar to those used in high pressure dust suppression work reported in this thesis. Burnes[93] concludes that on the whole the effect of water in dust suppression is only 50 per cent, and suggests that more study should be devoted to effective application of water as a suppressive measure, the design, location and efficiency of the spray nozzle and coarsing the ventilation through areas where dust is generated.

We would agree with Harrington[94] that the probable benefits of using water to allay coal dust under mining conditions are :-

(1) decrease in the explosion hazard;

(2) decrease in ill health of miners;

(3) increase in working efficiency and comforts of workers; and

(4) increase morale.

CONCLUSIONS

Utilising the findings of Glen[24] and Hunter[25] that the average droplet diameter in the sprays from small swirl-spray nozzles varied inversely as the cube root of the applied pressure, the following general conclusions have been drawn from the work reported here.

We obtained very low dust suppression efficiencies for these small swirl-spray nozzles at pressures below 500 p.s.i. Efficiencies were increased from 22.5 to 73.5 per cent with increase in the applied pressure from 500 p.s.i. to 2800 p.s.i. For a low throughput nozzle (i.e. Nozzle B - hollow cone) the dust suppression efficiency did not change much between 1000 p.s.i. and 5000 p.s.i.

The dust-water ratios for the smaller orifice diameters (nozzles D and V - hollow cone) were approximately constant over the pressure range tested, but the larger orifice nozzles give somewhat anomalous results.

If the results for all the nozzles are considered together, the dust-water ratio seems to decrease with increased water throughput. The total dust removed per unit volume of water sprayed increases with spray initial velocity.

Dust suppression efficiencies for nozzles V and An were found to decrease with increase in the tunnel air velocity up to a certain range and then seemed to be almost constant. This was found to be due to the deformation of the spray cone and later capture of some of the dust-particles during the downstream motion of the water droplet.

For all nozzles tested, the dust suppression efficiency generally increased with increase in dust concentration but the results are more marked for hollow cone, low throughput, nozzles D and V than for An and In.

It appears that at sufficiently high water throughput the dust suppression efficiency may become almost independent of dust concentration over the range 300 - 3000 p.p.c.c.

The position of the nozzle in relation to the air-borne dust flow was found to be relatively unimportant for dust suppression in our wind tunnel.

By using solid cone sprays instead of hollow cone sprays, a marked increase in the dust suppression efficiency was obtained at the same pressure. But the dust-water ratios were less than half that obtained by the hollow cone spray under similar conditions.

Up to 86.0 per cent of the dust particles were removed when the air was cleaned with the second nozzle located a few feet further down the wind tunnel and working under similar conditions. A general increase of about 20 - 25 per cent in dust suppression over that obtained from one nozzle was achieved when two nozzles were used in this way.

The results also indicated that high pressure sprays did not seem to be very selective in suppressing any particular size-range of the dust particles from the air. The size-distribution of the dust particles remaining in the air was almost the same as that determined before spraying.

Test work on a range of designs of full-size spray nozzles proved that the spray cone angle increased with the increase in the applied pressure and then remained fairly steady. This critical value of pressure varied with each nozzle tested.

All Porter type of sprays had nearly the same droplet size-distribution. This could be shown by the common 'skew' curve given in Figure 30. Their average droplet diameters also differed very little. The Sauter mean diameter of the Hayden Niles Spray calculated from a log-probability equation and size distribution data was found to be in close agreement (Section V). The droplet size distribution fitted well the log-probability expression (see Figure 31(a) and (b)).

Spatial dispersion was found satisfactory for Porter No.4, Hayden Nilos and Korting spray nozzles. Increase in the target distance helped to increase spray uniformity but increase in the applied pressure did not seem to have any effect on spray uniformity.

The ratio of the actual and theoretical penetration was calculated and found to be 13 for Hayden Nilos spray when used at 60 p.s.i. pressure.

When the full size nozzles were tested in the wind tunnel under controlled conditions it was found that :-

(a) The nozzle efficiency increased with increase in the applied pressure.

(b) At the same pressure, increase in the air velocity also increased the nozzle efficiency.

(c) About 70 per cent dust removal was achieved with Porter No.4, Hayden Nilos and Korting nozzles when used at 40 p.s.i. applied pressure. Under these conditions 70, 35 and 210 gallons of water was sprayed respectively to clean 260 cu.ft of dusty air moving at 150 ft/min. to 1321 cu.ft. of dusty air moving at 900 ft/min.

(d) The dust-water ratio was found to be maximum viz. 11.85 in the case of Hayden Nilos spray.

(e) The dust suppression efficiency of the nozzles was found in general to increase with flow number, but the increase was dependent on air velocity in the tunnel.

When the same nozzles were tested under mining conditions the Hayden Nilos spray was found to be the most efficient of the nozzles tested in reducing the dust produced during coal transportation. A total reduction of only up to 50 per cent in the dust content of the air leaving such a point was achieved when this spray was used at a pressure of 50 p.s.i. The dust-water ratio under these conditions for the Hayden Nilos spray worked out to be 31.1×10^6 particles per c.c. of water sprayed.

The nozzle efficiency for suppressing airborne dust was found to increase linearly with increase in the water throughput of the nozzle.

Relative humidity of the mine air was increased by 6 - 10 per cent when sprays were working. On the whole the sprays tested were not very effective in reducing the dust concentration to a very low value when operating under mining conditions.

<u>Suggestions for future work:</u>

(a) The effect of sprays of uniform droplet size on dust clouds of constant particle size should be studied. This will enable the theoretical calculations of Herne and Fonda to be utilised further and the work of Walton and Woolcock to be extended.

(b) Experimental studies should be made of the velocity of water droplets within a spray over the range from initial ejection to the limit of the experimental penetration. This would enable suitable practical values of average capture cross-section to be obtained.

(c) The use of wetting agents in suppressing airborne dust should be studied under controlled conditions and in greater detail.

(d) The possible use of the process of artificial nucleation to remove fine dust particles from the air should be studied.

APPENDIX I

Theoretical concentration of the coal dust in the wind tunnel at different air velocities, calculated from dust machine dimensions and size-analysis of coal-dust.

No. of particles below 5μ size per c.c. of air in the wind tunnel.

	Air Velocity ft./min.	No. of particles per c.c. of air Groove (middle) Plate A	No. of particles per c.c. of air Groove (outer) Plate A
(1)	150.0	3,000	2,980
(2)	250.0	1,810	1,792
(3)	400.0	1,130	1,119
(4)	900.0	502	488

APPENDIX II

Specimen calculations for T.P. slides counted using projection microscope.

Reference:- Slide for Porter No.2

Length of the strip = 9.55 m.m.

Width of the strip = 0.55 m.m.

Cover Glass A

Traverse	Bottom	Centre	Top
No. of particles (1)	184	169	191
" " (2)	171	170	184
" " (mean)	178	170	187

$$\therefore \quad N_1 = 535$$

Similarly for Cover Glass B: Length = 9.55 m.m.

Width = 0.55 m.m.

N_2 = 446

$$\therefore \quad \frac{N_1 + N_2}{3} = \frac{981}{3} = 327$$

$$\therefore \quad \text{No. of Particles per c.c.} = \frac{981}{3} \times \frac{9.575}{30} \frac{10^3}{100}$$

$$= 1042 \text{ p.p.c.c.}$$

APPENDIX III

'F' TEST

Dry Tests at Loader

Date:	13.2.61	14.2.61	15.2.61	16.2.61	27.3.61	28.3.61	Total
Ref:			N = 28 Samples				
Si	812	738	1322	1007	1847	1101	6827 = S
$\Sigma \frac{S_i^2}{n_i}$	164836	136161	436921	253512	568568	202033	1762031
							1664569
$\frac{S^2}{N}$							2163861
Σx_{ij}^2							
$\bar{x}$							244

Analysis of Variance Table

Source of Variance	Sum of Squares		Degrees of freedom		Variance
Between Shifts	$\Sigma\left[\frac{S_i^2}{n_i}\right]^2 - \frac{S^2}{N}$	97462	(k-1)	5	19422
Within Shifts	$\Sigma x^2 - \Sigma \frac{S_i^2}{n_i}$	401830	(n-k)	22	18265
Total	$\Sigma x^2 - \frac{S^2}{N}$	499292	n-1	27	

Application of 'F' test to V_1 and V_2 gives:

$$\frac{V_1}{V_2} = \frac{19422}{18265} = 1.0633$$

at 5% level = 2.2

at 1% level = 3.0

The observed value in both cases is only 1-0.
The variation between the shifts is insignificant.

From this we can estimate Variance V and Standard Error of the Mean S.E.

$$\text{Variance (V)} \quad = \quad \sigma^2 \quad = \quad \Sigma x^2 - \left(\frac{\Sigma x}{n}\right)^2 \quad = \quad 18492$$

$$\text{Standard Deviation} \quad = \quad \sigma \quad = \quad 136$$

$$\text{Standard Error of the Mean} \quad = \quad S.E. \quad = \quad \frac{\sigma}{\sqrt{n}} \quad = \quad \frac{136}{\sqrt{10}} \quad = \quad 43.07$$

where 10 = Number of samples per shift.

APPENDIX IV

The water used for spraying came from the pit bottom. Therefore a water sample was collected directly from the spraying device and analysed for the following physical and chemical properties.

(1) pH - 8.33

(2) Surface tension - 71.80 dynes/sq.cm.

(3) Suspended solids - 16.00 p.p.m.

(4) Dissolved solids - 575.00 p.p.m.

As expected the water is slightly alkaline in character with surface tension slightly lower than that of distilled water. Though the water percolates through about 2,200 ft. from surface and different stratas, the amount of total solids present in it is surprisingly low. The low value of suspended matter helps for better atomisation and frequent cleaning of nozzle is not required.

Analysis of the coal produced in 2-Plough section was made to find out the constituents of the airborne dust.

(a) Proximate Analysis

Rank	Total Moisture %	Ash %	Volatile Matter %	Fixed Carbon %	Sulphur Content %	Calorific Value BTH/lb	Coking Value	Swelli Inde
602	6.60	3.00	34.75	55.55	0.46	13.590	G_3	4 1/2

(b) Ultimate Analysis

Type of Coal	Carbon %	Hydrogen %	Nitrogen %	Sulphur %	Oxygen (by difference
Mixed Sizes	82.40	5.69	2.10	0.70	9.47

(c) Petrographic Analysis

Type of Coal	Micro Rock Types: Vitrite %	Clarite %	Claro-durite %	Durite %	Fusite %	Macerals: Vitrite %	Exinite %	Inert-tinite %
Mixed Sizes	58.90	16.55	18.75	0.9	5.60	81.60	5.50	10.45

The ash content of this seam is fairly low. The micro-rock type and maceral composition of a coal presents its complete make up. The sum of vitrinite and exinite gives the total proportion of coking material in the coal. The proportion of inertinite in combination with micro-rock type analysis gives the total amount of inert components and their distribution in coal. The available information also indicates that the analysis of macerals is more reliable than micro-rock type.

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