A WIND TUNNEL FOR THE STUDY OF AIRBORNE INFECTIONS

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(With Plates 6–9 and 2 Figures in the Text)

INTRODUCTION

In a previous paper, Henderson (1951) has referred to the methods used in the study of airborne micro-organisms. In general, liquid suspensions of organisms have been sprayed from a fine spray into a static chamber, or through a continuous flow tube as described in detail in the previous paper. It is characteristic of sprays which disperse liquid by shattering (typically by an air blast) that a very wide spectrum of droplet size is produced, and mass ratios of a million to one between the largest and smallest droplets are commonly found. A fine spray giving water droplets of between 20 and 0·2 μ could, when spraying a suspension of organisms, give dried airborne particles varying from clusters of hundreds of organisms down to single organisms. The alternative to having a wide range of particle sizes is to dilute the suspension to be sprayed to such an extent that the largest droplets formed are unlikely to contain more than a single organism. In this way a cloud of single organisms is produced on the evaporation of the droplets. The fact that the conventional spray can only be used to produce either clouds of single organisms, or clouds of heterogeneous particle size, is a severe limitation. For example, it is well known that the site of deposition of a particle in the respiratory system is governed by the size of the particle, but little was known of the importance of this effect where viable particles are concerned. The heterogeneous spray enables 'finer' or 'coarser' clouds to be produced by the adjustment of the suspension concentration, spray pressure, nozzle dimensions, etc., but it is not possible to correlate any particular effect with a particular particle size. A cloud of single organisms is not thought likely to occur commonly in nature. In practice, airborne organisms are known to occur in clusters or groups of widely variable number usually in association with a variable amount of mucus or saliva, or with dust particles in any of their innumerable forms.

It is clear that a whole field of knowledge remains to be explored in respect of the hazard associated with a given size of viable particle. In addition to the particle size aspect, we may expect that the viability and/or infectivity of the particles may be affected by variables such as radiation (heat, light, and ultra-violet), the possible mutual protective effect of clusters of organisms, the presence of inert, protective, enhancing or suppressive agents in the particle, the temperature and humidity of the atmosphere, etc. Further we may expect that the effect

of these factors and of the time of exposure to them will vary with different organisms.

The introduction of the high-speed spinning disk spray as a source of mists of nearly homogeneous droplets by Walton & Prewett (1949) has now made possible the individual study of the above-mentioned variables. In this form of spray the liquid to be dispersed is fed continuously through a fine jet on to the centre of the upper surface of a rapidly spinning disk. When the disk is uniformly wetted by the liquid the latter is flung off the edge in the form of a ring of nearly homogeneous droplets, the sizes of which are controlled by the speed of the disk. When spraying suspensions of micro-organisms with this apparatus, the size of the final dried particle can be controlled both by the size of the initial wet droplet and by the concentration of the suspension. One can then cover a range from a cloud consisting of particles of single organisms to one of particles containing thousands of organisms.

In putting up a cloud of organisms for detailed study a choice must be made between the commonly used static chamber method and the dynamic system represented by a wind tunnel. The latter system is strongly to be preferred for the following reasons:

(*a*) In a wind tunnel it is possible to obtain a constant cloud concentration using a spray source of constant output. In a static chamber, on the other hand, it is necessary either: (i) to produce initially the concentration required by means of a short spray period and accept the resulting concentration decay; or (ii) to boost the concentration at intervals, which is difficult in practice owing to the lack of any method of instantaneous assay of viable particles.

(*b*) In a static chamber, owing to the sedimentation of particles, a vertical concentration gradient will exist. Fanning will nullify this temporarily but will remove particles by impaction. These considerations become more serious as the particle size is increased, and are particularly relevant in the case of the spinning disk sprayer which produces quite large initial droplets. In a vertical dynamic system, on the other hand, the droplets can be supported by a rising air stream until evaporation is complete; the concentration at any point is not a function of time and sedimentation loss does not occur.

(*c*) At a given point in the dynamic system all cloud particles are continuously of the same age. This can be of great importance in studying the infectivity of delicate organisms and is a condition which cannot be realized in a static system.

(*d*) A dynamic system can be run at a pressure slightly below the ambient, and the particle concentration can be made constant across a given section of the apparatus to a point within a few millimetres of the walls. This means that only the muzzle of the experimental animals need be exposed, and animals can be safely and easily interchanged. Therefore, during the course of an experiment, a large number of animals can be exposed to a cloud of constant concentration, particle size and age. It seems impossible to realize all these conditions simultaneously in a static system.

PRELIMINARY EXPERIMENTS

In view of the preceding considerations, it was decided to construct a tunnel in a manner suitable for the incorporation of a modified spinning top sprayer (May, 1949). A vertical tunnel possesses considerable advantages over any other type for the study of particulates. In a horizontal tunnel, or in one possessing an appreciable amount of horizontal section, losses due to sedimentation across the wind direction increase with the square of the particle size. With a heterogeneous cloud this implies that the size distribution at the emergent end of the tunnel is a function of tunnel diameter and tunnel wind speed, while with a homogeneous cloud the same consideration would set a lower bound to the tunnel wind velocity for any chosen particle size. Further, due to sedimentation, it would be impossible to maintain a constant cloud concentration across the working section in the vertical sense.

The vertical tunnel removes these difficulties, and, in addition, if used with a rising air stream, allows the rate of upward movement of the particles to be controlled by varying the cross-sectional area. This property is of great value when using sprayed aqueous suspensions of organisms as homogeneous droplets, since the upward velocity can be adjusted in a given cross-section to be very slightly greater than the droplet sedimentation rate. This causes any 'oversize' droplets—of which a few are known to occur—to be lost by elutriation, while the 'working size' droplets are given time to evaporate and to disperse in the air stream to give a uniform cloud concentration, before being carried into the more rapidly moving air stream in the sampling section. Besides these inherent advantages, a circular vertical wind tunnel is ideally suited to the requirements of the spinning top sprayer, since the latter produces a ring of droplets in a horizontal plane. The utilization of a tunnel of this type for animal experiments would require the use of two platform levels, separated by several feet in order to allow time for the sprayed droplets to evaporate. The apparatus controlling the cloud would be operated from the lower platform, while the upper level would be used by personnel exposing the animals. This consideration prevented the use of the simple tunnel, as described above, until a two-story building became available.

As an approximation to the ideal, it was decided to construct a tunnel of the general shape of an inverted U which would be capable of withstanding internal vacuum, would be easy to sterilize, safe to handle, and which would be of such dimensions that water droplets of up to 60 μ could be produced inside it from a spinning top sprayer.

Preliminary experiments made in a vertical straight tunnel showed:

(*a*) That to a close approximation, the theoretical size of a dried particle could be obtained from a wet droplet of known initial size produced from a suspension of known concentration.

(*b*) That a time interval longer than 1 sec. was needed for a particle with a final dry size of 10–15 μ to come to equilibrium in the atmospheric humidity.

A prototype tunnel of the inverted U type, with a general shape similar to that shown in Text-fig. 1, was constructed in tin-plate. The essential features of this tunnel were:

(*a*) An entry section below the plane of emission.

(*b*) A central supporting column for the spinning top sprayer.

(*c*) A cloud emission section fitted with Perspex doors to allow access to the spray.

(*d*) A 'mixing and drying' section.

(*e*) A section fitted with Perspex doors which simulated the section for the exposure of animals.

With this tunnel it was found that:

(*a*) An entry section with parallel sides gave satisfactory results if (i) the incoming air was passed through fine gauzes; (ii) the upward velocity of the air was sufficient to buoy the wet particles at the time of their formation.

(*b*) To minimize wall losses the internal surface of the tunnel must be smooth, and the cross-sectional area of the tunnel must either be kept constant or must be a monotonically decreasing function of the distance along the path of the air stream.

(*c*) The access to the tunnel provided by the Perspex doors was more than adequate. It was decided that if the section immediately above the opening were made of glass, the opening could be restricted to the dimensions necessary for the entry of the operator's hands and forearms.

(*d*) To render visible the small droplets produced by the spinning top sprayer it was necessary to use the Tyndall beam effect. It was found experimentally that illumination with a powerful beam along the plane of emission gave the best result.

(*e*) The setting up of the hypodermic needle of the spinning top necessitated vision in two planes at right angles and passing through the vertical axis of the spray, the direction of vision being downwards at about 45 degrees.

(*f*) To check various mechanical settings it was necessary to view the spray along the plane of emission.

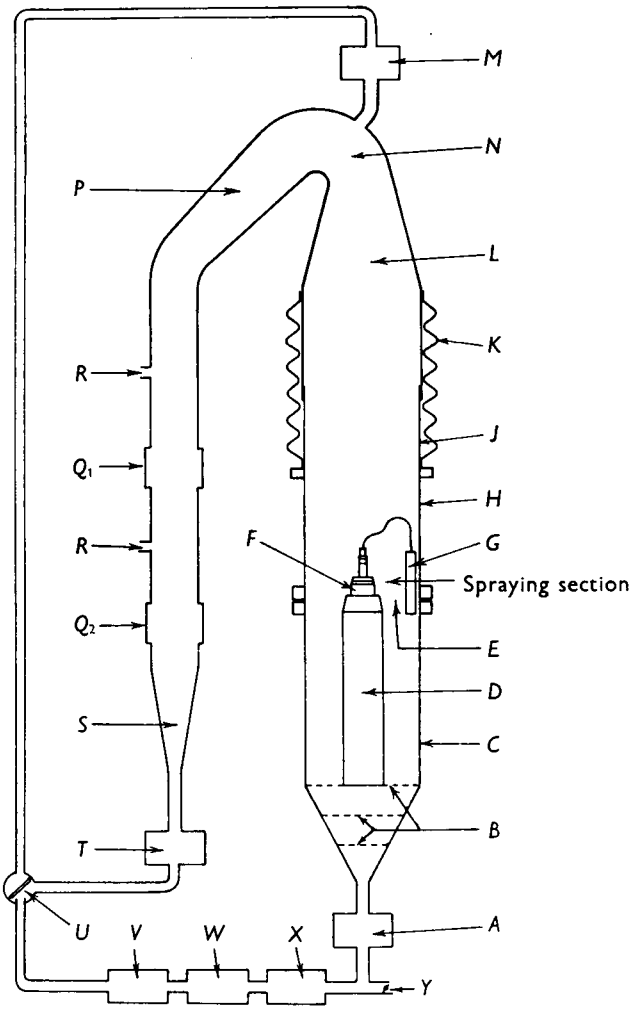
In view of these findings it was decided that a lifting cylinder (Text-fig. 1, *H*) about 1 ft. long, and made of heat-resisting glass, would be the most suitable arrangement to provide both access and visibility.

A few experiments were carried out to investigate the uniformity of the concentration in the animal exposure section, using a cloud of dye particles, and to obtain an estimate of the efficiency of the prototype tunnel. These indicated that the uniformity of concentration across the exposure section was satisfactory, and that an overall efficiency of recovery of 30–50 % might be expected. This efficiency figure was acceptable in view of the losses known to occur in and around the sprayer.

THE TUNNEL PROPER

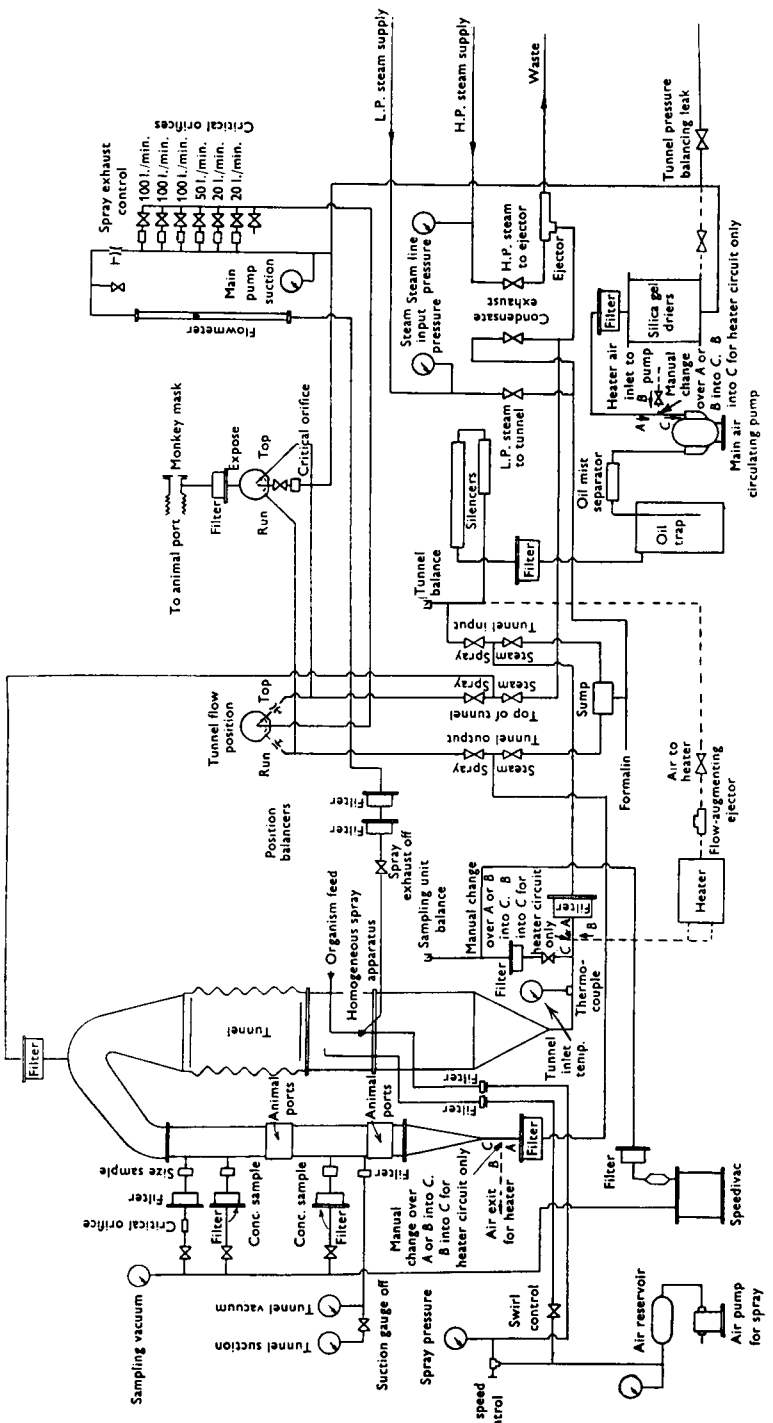
It was decided that the first tunnel for use with pathogens should be of circular cross-section, since not only is this shape more convenient for use with the spinning top sprayer, but also the symmetry simplifies the problem of making a structure which will withstand the considerable stresses that arise during the

partial evacuation which precedes sterilization (see below). Text-fig. 1 is a section of the tunnel drawn to scale to show the principal air circuits. Details of the major parts and the practical use of the controls mentioned in the ensuing description will be found later in this paper.



Text-fig. 1.

In order to accommodate the 60 μ water droplets produced by the spinning top sprayer, an internal diameter of 12 in. at the spraying section is necessary. Air enters through the filter, *A*, and is spread over the spraying section by means of the three fine horizontal gauzes, *B*. These gauzes also reduce the turbulence of the incoming air. The air is passed from here into a parallel-walled elutriating section between the outer wall of the tunnel, *C*, and the spray supporting pillar, *D*. At *E* the air encounters the cloud produced by the spinning top sprayer, *F*, which derives its liquid feed from a motorized hypodermic syringe, *G*. The production



Text-fig. 2.

of the cloud can be observed through the glass-lifting section, *H*, which provides access to the spray before the commencement of the experiment. As the air passes *E* the cross-sectional area is increased slightly by the termination of the spray column, and this gives rise to some vorticity which helps to ensure uniformity of concentration. The telescopic section, *J*, is covered by a reinforced rubber bellows, *K*, and in passing up this section the mixing of the cloud continues. It then passes into the upper conical section, *L*, which increases the upward velocity of the cloud, and reduces turbulence. From this point, two alternative routes are provided for the air stream, and these are selected by means of a two-way cock, *U*. With the control cock in the 'Top' position, the cloud is drawn off through the filter, *M*. With the cock in the 'Run' position, the cloud is accelerated round the bend, *N*—the centrifugal effects acting in opposition to gravity—into the smooth working section, *P*, in which the ports for animal exposure, Q_1, Q_2 and for sampling, *R*, are situated. Finally, the cloud passes through the conical section, *S*, into the filter, *T*. From the filters *M* and *T* the air passes to the two-way cock, *U*, and on to the venturi type critical orifices, *V* (Druett, in preparation). These orifices were designed to function at a suction of 12 cm. or more of mercury, and serve to control and stabilize the tunnel flow rate. From here the air passes through the silica gel drier, *W*, to the pump, *X*, whence it returns to the filter, *A*, via the 'Blow-off' valve, *Y*, which determines the positive pressure in the return pipe with respect to the atmospheric pressure, and thereby determines the working pressure in the tunnel (see below).

A general view of the apparatus is shown in Pl. 6, and a circuit diagram is given in Text-fig. 2. In addition to the tunnel air flow already described, it is necessary to extract air through filters from the spinning top sprayer, both to withdraw the satellite droplets and to remove the spent working air. After filtering, this air is metered through a rotameter (Pl. 1, *A*). The rate of air removal is adjusted manually by means of a screw clip whose control knob is shown at *B* in Pl. 6.

As mentioned above, the tunnel is operated below atmospheric pressure. This is necessary to prevent the escape of the bacterial aerosol into the surrounding air. Since it is undesirable that the animals should breathe against suction, it was decided to operate at not more than 1 in. water below atmospheric pressure.

To sterilize the tunnel, the internal pressure is first reduced to half atmospheric by means of a steam ejector, to ensure the subsequent penetration of the steam into all parts of the apparatus. Steam containing a metered amount of formalin from a motorized hypodermic syringe (see below) is introduced through the filters *T* and *A* (Text-fig. 1) and is drawn out through the filter *M* by means of a steam ejector. At the end of sterilization the condensate is removed from the tunnel by means of the same ejector, and the tunnel dried with air at 160° C. Details of the procedure for sterilization are described below.

FACTORS CONTROLLING PARTICLE SIZE AND CONCENTRATION.

The methods by which the cloud characteristics of the tunnel are altered are:

(*a*) Change in the rate of feed of the suspension of organisms to the rotor surface of the spray. This affects only the concentration. In practice, with the

standard spray the rate of feed can only be chosen between the limits of 0·16 and 1 ml./min. Lower rates of feed cause 'dripping' from the feed needle and consequently an intermittent cloud, with a heterogeneous particle size, due in part to drying of the rotor surface. Higher rates of feed tend to give heterogeneous particles with the entrainment of satellite droplets, and instability of the rotor.

(*b*) Alteration of the concentration of the suspension fed to the rotor surface. This affects both particle size and concentration.

(*c*) Change in the rate of the flow through the tunnel. This gives a corresponding change in concentration without alteration of the particle size; but the variation in flow rate that can be used depends on the size of wet particle being produced, since the flow rate must give a linear velocity in the spray section of the tunnel sufficient to buoy up these particles.

(*d*) Change in the angular velocity of the rotor. This alters the particle size but does not affect the concentration.

ANCILLARY APPARATUS

(*a*) *The gate*

In practice, an insufficient percentage variation is given by the above methods to meet the biological requirements for cloud concentration. In order to overcome this, a circular gate mechanism is fitted around the spray which cuts off any desired fraction of the droplet output (Pl. 7). In addition, the gate control can be operated from outside the tunnel, and thus affords a simple method of varying the cloud concentration during a run.

(*b*) *The swirl*

Since the use of a gate mechanism results in the production of an asymmetric cloud in the tunnel, a device is incorporated to produce vorticity about a vertical axis. This consists simply of a glass jet drawn down to give an air-flow of about 3–4 l./min. at whatever working pressure is needed. The jet is directed chordially to the tunnel walls about 9 in. above the plane of emission.

(*c*) *The motorized hypodermic syringe feeds*

Two hypodermic syringes driven by clock motors are employed in this apparatus, one of which controls the rate of feed of suspension to the spinning top sprayer, while the other meters formalin into the steam supply during sterilization.

(i) *The formalin feed*

The piston of the 20 ml. syringe is driven by means of a screw mechanism working inside a non-rotating thrust block. The torque is provided by a powerful clock motor which runs at 1 r.p.m. The gearing is arranged to give a rate of feed of 1 ml./min. As this syringe does not need to be sterilized, a 'metal-in-glass' type is used. The whole mechanism is built as a unit.

(ii) *The spray feed*

In principle this is the same as the formalin feed, but for safety the 20 ml. spray-feed all-glass syringe is mounted inside the tunnel. The thrust block

mechanism is driven from the outside of the tunnel by means of a rotating vacuum seal. A set of change wheels is provided to give rates of feed from the syringe of from 0·16 to 1 ml./min.

CONTROLS

Controls are grouped according to their function on the various panels on the front of the machine (Pl. 6). Controls for operating the tunnel during a spray run are mounted on the upper two panels, while those on the lower panels are concerned with subsequent sterilization and drying.

ANIMAL EXPOSURE FITTINGS AND CLOUD SAMPLING TECHNIQUES

These are similar to those described by Henderson (1951) in the previous paper.

(*a*) *Guinea-pigs*

Considerable difficulty was experienced in developing an animal port whose cover was rapid in action, and free from the danger of cross-threading when handled by operatives wearing gloves. The arrangement finally adopted is shown in Pl. 8. The caps, which are machined with a 8 T.P.I. free thread carry a fully floated seal disk. The rubber diaphragm *U*, which seals over the animal's snout, is moulded with a thick ring at the edge, which grips over the brass insert ring. The guinea-pig boxes are shown in the figure.

In experiments in which guinea-pigs are used the cloud concentration is estimated by means of a modified impinger. The standard impinger *W* is fitted with a glass extension tube of sufficient length to pass into the centre of the animal exposure side of the tunnel, and the end of this tube is bent to face upwind. The cross-sectional area of the tube is made to give a sampling velocity of the same order as the air velocity in the tunnel.

(*b*) *Rabbits*

At the time of writing, modified boxes and trays are being constructed to enable experiments to be made with rabbits. Procedure otherwise will be as for guinea-pigs.

(*c*) *Monkeys*

An attachment for monkeys has been developed and is shown in Pl. 9. A conveniently situated rubber diaphragm is removed and a modified cap screwed on in place of the normal cap, *A*. A length of 2¼ in. bore flexible non-collapsible tube, *B*, is led away to a monkey mask, *C*. To expose an animal, a suitable fraction (100 l./min.) of air from the tunnel is by-passed through the mask, and subsequently through the filter, *F*. This operation is controlled from an additional panel, *D*. In monkey exposure experiments, cloud samples are taken in the position occupied by the monkey's nose, and not in the main tunnel as shown in Pl. 8. The type of box used for holding monkeys is shown, *E*.

(*d*) *Particle size*

When required, size measurements of the airborne particles of dried organisms are made with a single stage of a cascade impactor (May, 1945), stage four being used when the particles are 1–3 μ and stage three for 3–7 μ. With particles greater than 7 μ it is generally best to insert a horizontal slide into the tunnel, on which the particles settle. In this way the tendency for the large and rather soft particles to flatten, when sampled by an impactor, is avoided. Before use, sampling slides are coated with a very thin film of grease by spreading a carbon tetrachloride solution with a glass rod. Time of sampling is judged by experience.

With pathogens special precautions are needed to avoid outside contamination, and samples are demounted from the impactor unit and examined under a Perspex canopy equipment with sealed-in gauntlets of the type familiar in bacteriology. Fitted under the canopy is a microscope with calibrated eye-piece scale. Only the eye-piece projects through a sealing diaphragm in the canopy.

The size of the wet droplets projected from the spray may be adequately judged by observing the distance of projection from the disk centre. Thus 60 μ droplets are projected 6 in. and just strike the walls of the surrounding glass cylinder. 50 μ droplets are projected 5 in.; 40 μ, 4 in. and so on. These distances will be somewhat less if the spray suspension has a low surface tension.

WORKING EFFICIENCY

Before quantitative experiments could be carried out, it was necessary to minimize leakage into the tunnel. No attempt was made to attain the degree of leak freedom required by high vacuum workers, since such a refined standard would be quite unnecessary, either from the experimental viewpoint, or on grounds of safety. A rate of fall of differential pressure not exceeding 1 cm. Hg in 10 min. with the tunnel evacuated to 70 cm. below atmospheric was found to be an adequate standard for our purpose. The most troublesome leaks were due to porosity in the metal castings used in the lifting section, and these were considerably reduced by tinning and painting the castings.

The overall working efficiency is defined as the ratio of the amount of airborne material recoverable in the working section, to the amount fed to the spray, and multiplied by 100; therefore this efficiency figure is dependent on the efficiency of the sprayer as well as that of the tunnel. Preliminary experiments were made using dye solutions estimated colorimetrically. Initially a red dye (*p*-nitroaniline-azo-β-naphthylamine) in dibutyl phthalate was sprayed, and estimated in toluene; but later, aqueous solutions of purified Chlorazol Sky Blue F.F. (sodium salt of dimethoxy-diphenyl-disazo-bis-8-amino-1-naphthol-5:7-disulphonic acid, colour index 518) were used. A value for the overall working efficiency of a little over 50 % was obtained. Little of the loss could be accounted for by losses on the tunnel walls, most of it occurring on the inside and outside of the spray. The tunnel efficiency remained effectively constant for flow rates through the tunnel in excess of 150 l./min. but fell off at lower rates. The findings were in keeping with the bacteriological results obtained later. A slight rise in efficiency with particle size

was observed in the range 5–20 μ. Below 5 μ there is a rather steeper gradient, probably due to the high extraction rate from the spray when it is running fast and to the close proximity of the emitted cloud to the spray body. A summary of these results is given below:

Dry particle size (μ)	Overall efficiency (%)
20	63
15	63
12	57·5
6	47
2·5	40

The vital question of the constancy of cloud concentration across the working section was settled by emplacing a wide grid of Perspex strips ($\frac{3}{16}$ in. in breadth) across the working section at the height of the animal ports. The tunnel was then run for a suitable length of time while fairly large (10–15 μ) dried particles were produced. The particles settled on the Perspex strips which were then carefully removed and individually examined under a travelling microscope. Particle counts were made across the strips at 1 cm. intervals, the time of exposure and traverse width having been judged to give approximately 100 particles per traverse. The counts showed no systematic trend of particle density and the differences between the counts were attributable to random fluctuations. As confirmatory evidence, strips of glass wool of similar width were exposed to dye particles, and after being cut up into six equal portions, were estimated colorimetrically. This method of course gives less detail than the counting method, as it was not practicable to cut up the 4½ in. long strips into more than six equal pieces; but, on the other hand, the results are based on many more particles. Maximum variation was of the order of 10%, many runs being very much better than this. Again no systematic density trends were observed.

EXPERIMENTS WITH ORGANISMS

A large number of experiments were carried out using aerosols produced from suspensions of *Bacillus subtilis* spores in water, in order:

(*a*) To provide data for setting up the tunnel under varying conditions of flow and feed rates, etc.

(*b*) To investigate the safety of operatives using pathogenic aerosols under working conditions.

(*c*) To determine the most efficient division of duties amongst the team of operatives (three in number) under working conditions, and to give the team practice in these duties.

(*d*) To investigate the efficiency of the sterilization process.

(*e*) To determine the coefficient of variation of cloud concentration using viable particles. Over the whole series of experiments a value of 13% was obtained.

(*f*) To investigate the overall efficiency of the apparatus using viable particles. These results confirmed those obtained with dye particles, and will be discussed in a subsequent paper.

SAFETY

An extensive series of swabs and air samples was examined to test the tunnel for safety in use. During the periods in which *B. subtilis* was sprayed in the tunnel, samples taken from the ambient air showed no increase above the normal background concentration. When animals were exposed, contamination was detected by swabbing in the neighbourhood of the animal trays and the exposure ports. This contamination arises either from eddies caused by the removal of the animals' snouts from the tunnel, or more probably from particles falling off the heavily contaminated snouts of the animals. Washing the animal ports and trays with 3 % Chloros was found to be effective in killing these organisms, and this procedure is carried out at the termination of each experiment. To increase the margin of safety, the washing process has been extended to all parts of the apparatus handled during the experiment, and at the termination of each run, the floor is damped down with a disinfectant spray.

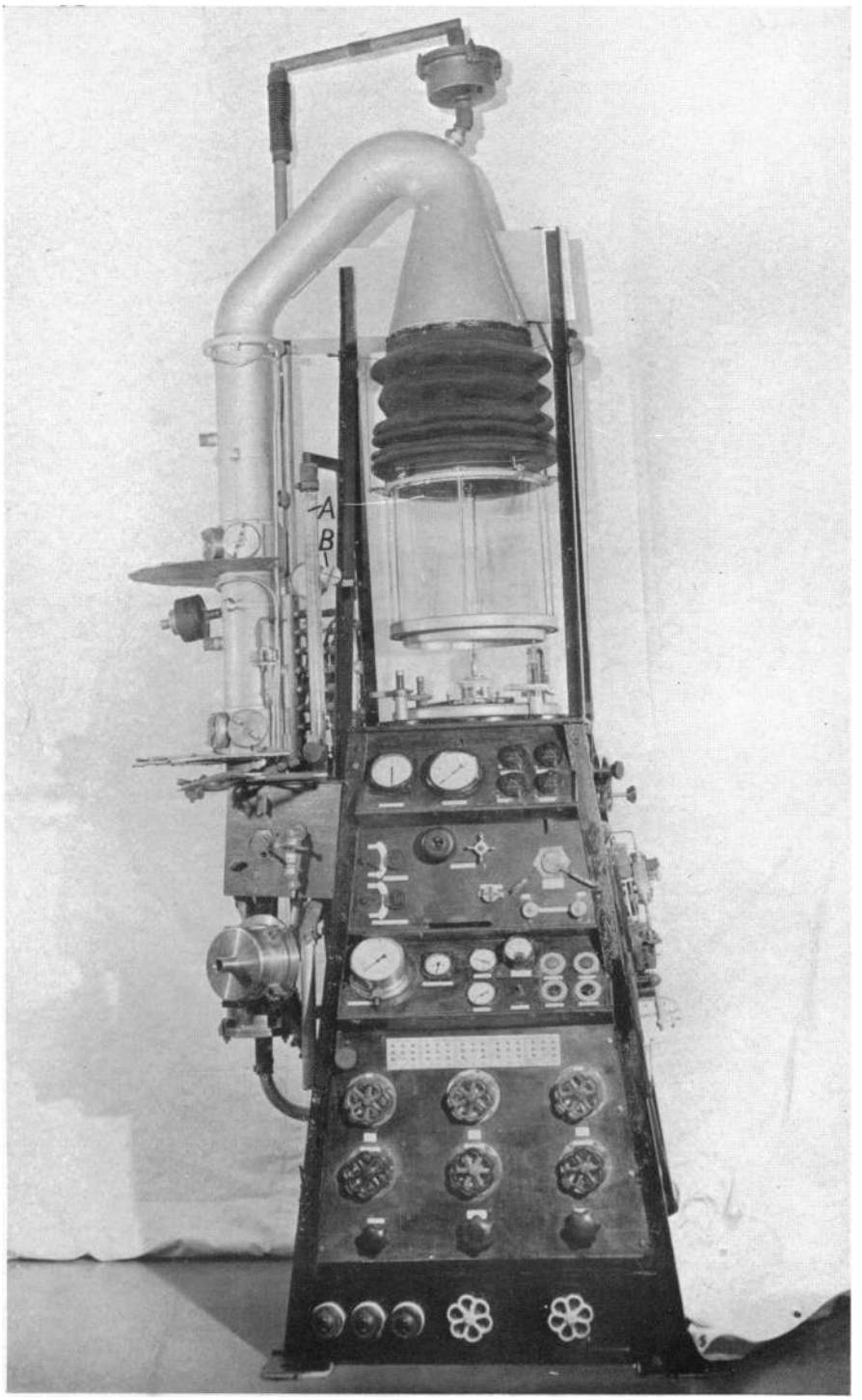
A large series of experiments with *B. anthracis* was carried out using the procedure mentioned above. At no time was *B. anthracis* detected in the ambient air, nor was it detected on the animal trays or ports after the termination of any experiment.

As a safeguard against the possibility of accidents, and to give a further degree of safety, the operatives wear protective clothing, and a well-fitted mask with a particulate filter of high efficiency (Henderson, 1951).

STERILIZATION

After some preliminary consideration of gaseous disinfectants it was decided to use live steam-formalin as the disinfectant medium. The quantities used were 1 ml. 40 % formaldehyde/min. and 10 cu.ft. live steam/min. for a 20 min. period. The tunnel pressure is first reduced to about half an atmosphere by means of a steam ejector coupled to the sterile side of the top filter (Text-fig. 1, *M*). Steam containing formalin metered in by the motorized hypodermic syringe is introduced through the sterile side of the two filters attached to the bottom of both arms of the tunnel (Text-fig. 1, *A* and *T*). The internal pressure in the tunnel is allowed to rise until it is only slightly below atmospheric, where it is maintained constant by manual control for the remainder of the sterilization time. The motorized hypodermic syringe, which is of 20 ml. capacity, acts as an automatic timing device for this operation. At the end of the spraying period the piston of the spray feed syringe is retracted slightly to allow the entry of steam, and this process is repeated once during the sterilization process.

Swabs taken in the tunnel at the end of the sterilization period showed complete sterility on all occasions, with the exception of the inside of the feed syringe, which was usually sterile, but on occasions showed the presence of a Gram-positive bacillus, believed to be an airborne contaminant. On no occasion was the survival of any *B. anthracis* detected, but at the end of an experiment the routine autoclaving of the syringe has been adopted. The filters used on the tunnel are repacked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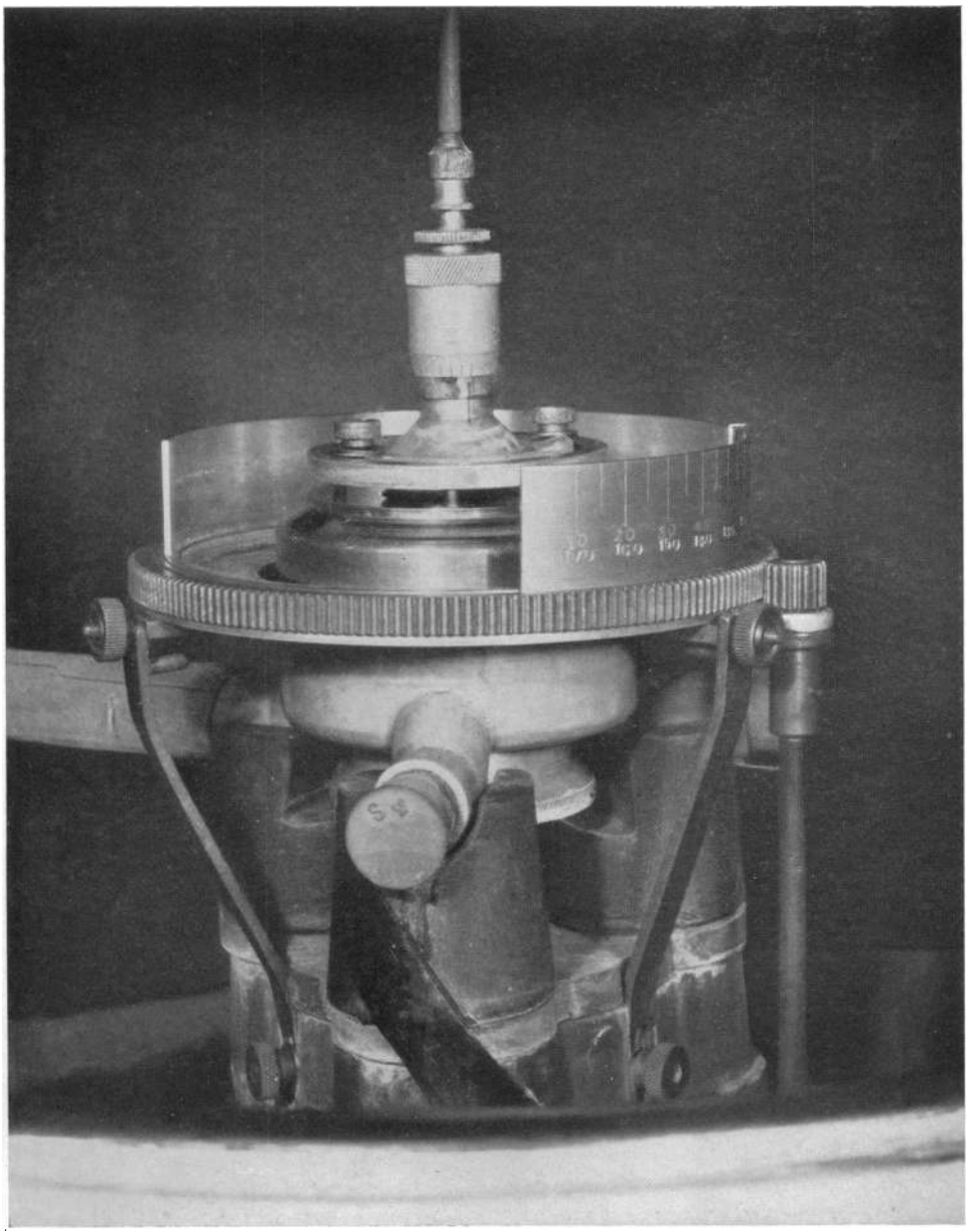

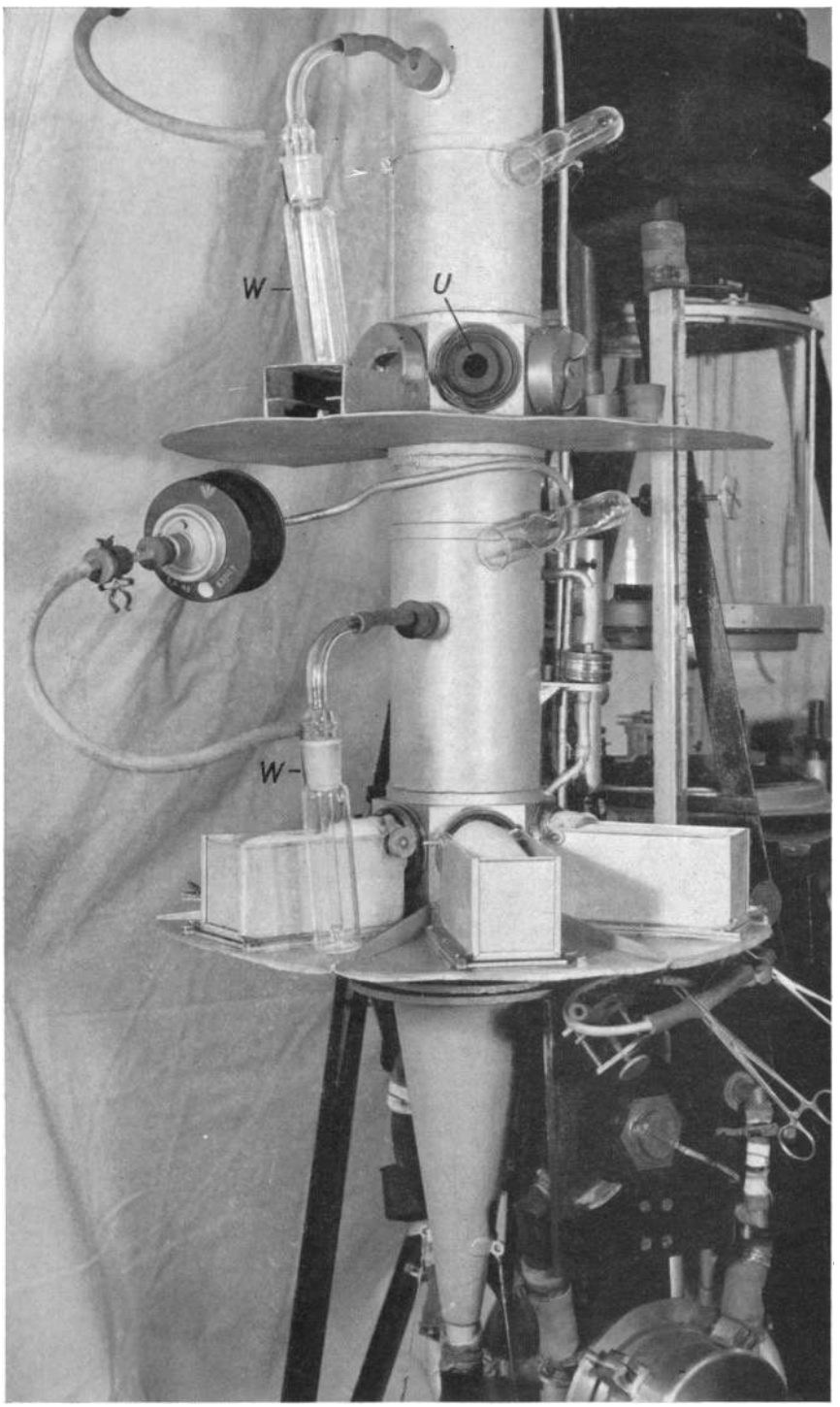
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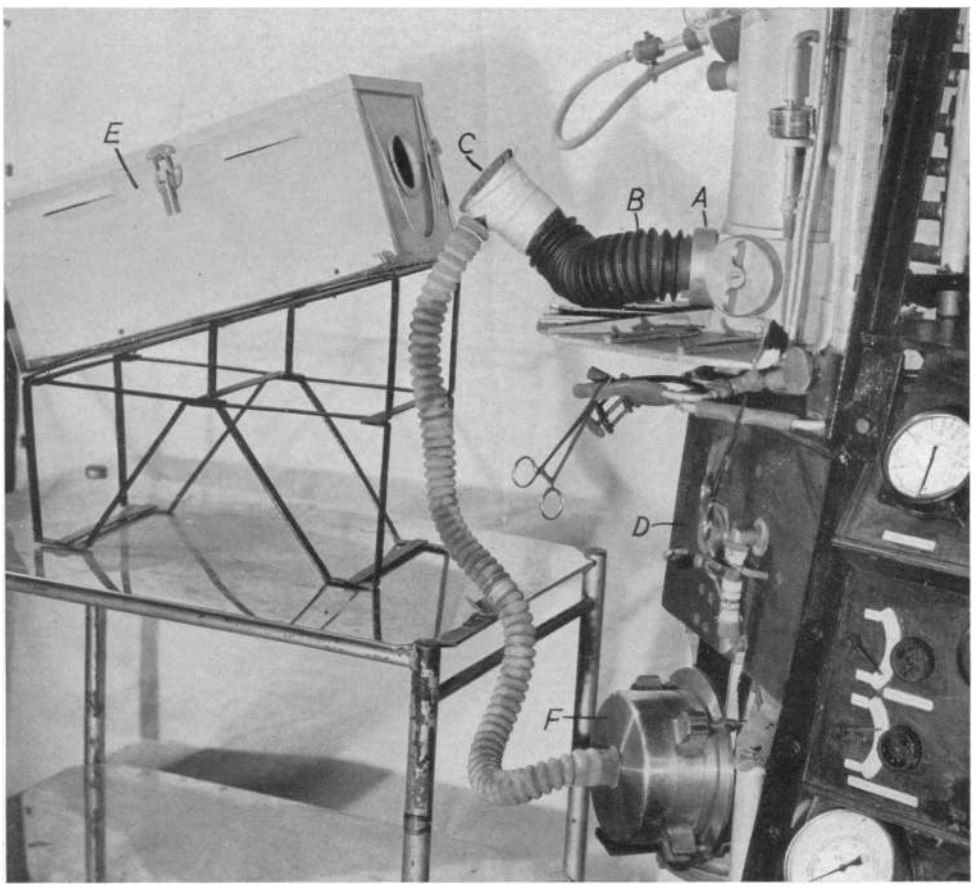
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with wool-asbestos after each sterilization. Samples from the effluent pipe during and after the sterilization period have been shown to be sterile.

At the termination of the sterilization period, the tunnel contains about 4 gallons of condensate. To remove this, the lower filters (Text-fig. 1, *A* and *T*) are connected by a suitable system of globe valves to the steam ejector, and the liquid withdrawn through them. To dry the tunnel after sterilization, air at 160° C. is passed round the circuit. This is made to take place, while the tunnel is still hot from the steam, by decoupling the intake into the main air circulating pump, and passing the output through a 5 kW. heater. From here the air is led into the bottom of the main arm of the tunnel with the filter (Text-fig. 1, *A*) removed. The hot air is allowed to escape from the open end of the cone below the animal exposure arm (Text-fig. 1, *S*). Drying is completed in 10–15 min.

FURTHER WORK IN PROGRESS

The tunnel described has been in continuous operation for 16 months and has given satisfactory service. Bacteriological data will be given in a subsequent paper. As a result of the experience gained, further models of the apparatus have been constructed which incorporate a number of refinements intended to improve the constancy of the cloud output, ease of operation and safety margin, and general versatility.

SUMMARY

A vertical closed circuit wind tunnel is described in which a spinning top sprayer is used as a source of homogeneous particles of pathogenic organisms. The dry particle size may be set at any figure between 1 and 20 μ, and the cloud concentration can be varied over wide limits. Provision is made for humidity control. Animals may be exposed to the cloud, and samples taken from it. The apparatus can be sterilized with flowing steam and formalin.

An appendix giving details of the operational technique is available on request.

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