Brit. J. industr. Med., 1953, **10**, 142.

THE PRE-IMPINGER

A SELECTIVE AEROSOL SAMPLER

BY

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(RECEIVED FOR PUBLICATION MARCH 11, 1953)

When airborne particles are inhaled it is known that most of those of effective diameter greater than about 5 μ are filtered out by the upper respiratory tract. Current knowledge of this subject as reviewed by Davies (1949, 1952) indicates that the size of particle which has a 50% chance of passing through the upper respiratory tract lies somewhere in the range $3\frac{1}{2}$ μ to 5 μ. Toxic effects from the inhalation of airborne particles are closely related to the size and site of deposition of the particles. With coal dust, for example, it is now generally accepted that danger lies only in the particles which are small enough to reach the alveoli. Other dusts acting as systemic poisons may be absorbed through the nasal mucosa. With airborne anthrax particles a great increase in infectivity has been demonstrated as the particles diminish below 4 μ (Druett, Henderson, Packman, and Peacock, 1953).

An ideal sampling instrument for airborne particles would allow a complete size-distribution of the particles to be obtained quickly from a perfect sample of the cloud. This is usually impossible but, as Davies (1952) points out, for estimating the respiratory hazard much useful information will be given by an instrument which merely discriminates between particles which can and cannot reach the lung. An approximation to this is given by the standard "Porton" impinger shown in Fig. 1a. This device is a development of the Greenburg and Smith impinger (1922) and its impinging jet is an 11-litre per minute critical orifice which gives very high collection efficiency down to the size of single bacterial cells (0·5 to 1 μ). The curving intake tube traps wet particles down to roughly 12 μ, the smaller particle fraction being collected in the liquid of the flask. This cut-off is very much higher than that of the human nose, and when vegetative organisms which can be killed by desiccation are sampled, those which adhere to the dry walls of the intake tube are likely to be lost. It is also possible that the occasional large dry particle will succeed in bouncing through the curved tube, thus giving a highly variable sample in the flask, especially where bacterial clusters are concerned.

To overcome these faults of the impinger our primary requirements were to develop a device which would first divide the bacterial aerosol sample into

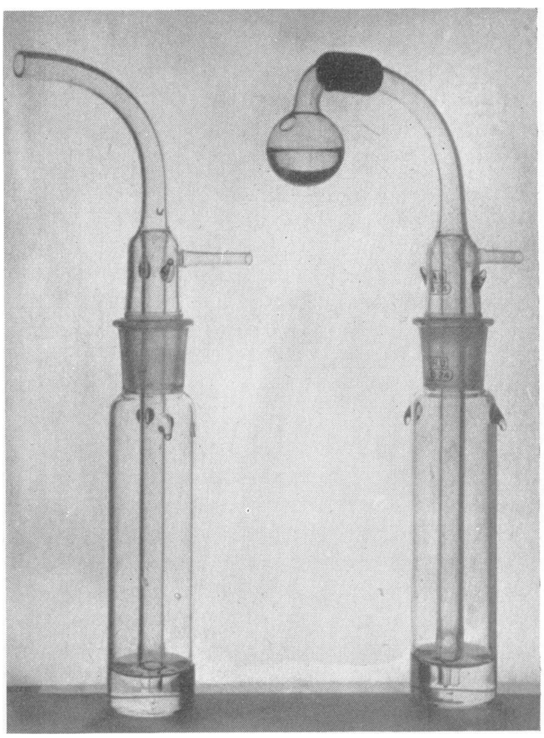


FIG. 1 (a).—Standard "Porton" impinger, (b) pre-impinger on front of impinger.

two fractions, the cut-off being at a specified figure in the $3\frac{1}{2}$ μ to 5 μ range, and second, collect both fractions directly into a suitable liquid with no chance of the penetration of large particles. The "pre-impinger", shown in place in Fig. 1b, performs this function efficiently. It is a spherical glass bulb, half filled with collecting liquid with an air intake hole in the front.

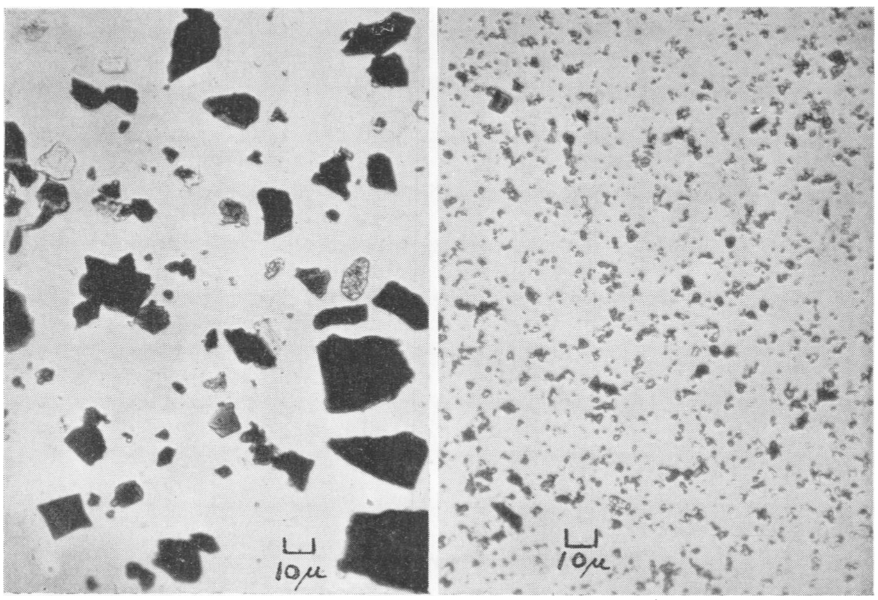
To obtain a good estimate of the total airborne concentration, it is of course necessary to keep all sampling losses as low as possible. In an instrument which sucks in airborne material through a tube and deposits the particles by impingement, physical sampling errors are of four distinct types and the elimination of each is a separate problem.

The types are (1) intake errors, when particles have sufficient inertia to prevent them following sudden directional changes in the sampled streamlines of flow near the orifice. The errors are functions of the velocities of the ambient and intake tube air streams, the dimensions, nature, and orientation of the orifice, and the particle size ; (2) loss from particles striking and being retained by the internal walls of the apparatus, including the walls of the intake tube before reaching the site(s) of impingement ; (3) loss from inefficient adherence or retention of particles on the site of impingement ; (4) loss from the impingement jet having insufficient velocity to throw out the finer particles which are then carried through the instrument with the airstream.

The pre-impinger has been designed to keep these various errors to a minimum, after fulfilling the two primary requirements already given. There is no chance of entirely eliminating type (1) and (2) errors in the case of the pre-impinger in horizontal winds because the entering airstream must be deflected downwards to strike the necessarily horizontal liquid surface, but, as shown by experiment, these losses are never excessive under normal sampling conditions. Type (3) losses appear to be nil with airborne particles consisting, for example, of dye or micro-organisms from a spray of an aqueous solution or suspension. With other particles however, such as dust, this would not necessarily be so unless the particles were immediately wetted on striking the surface of the collecting liquid and removed from it at once by solution or turbulent mixing. Thus coal dust may be inefficiently collected with water in the bulb as it tends to form a dry film on the surface. Kerosene is good for sampling coal dust and Fig. 2 shows the two fractions of a coal-dust cloud recovered from this liquid. The photographs illustrate the completeness of the cut-off.

The cut-off may be set at any desired particle size in the range of nasal penetration by altering the size of the intake orifice, which in turn alters the jet velocity and so the type (4) loss. For our purpose the orifice is made so that 50% of 4 μ particles (density 1·3) penetrate to the impinger operating at 11 litres per minute. This is shown to be so both for spherical particles of dye made by the evaporation of sprayed homogeneous mists of the dye solution and for spherical clusters of micro-organisms similarly obtained from aqueous suspension.

Features of the pre-impinger are that it has an extremely high impingement efficiency in relation to its jet velocity and that the liquid level is not in any way critical. These are due to an interesting and fortunate double impingement process on the



a b

FIG. 2.—The size separation of a coal dust cloud given by the pre-impinger plus impinger unit, both filled with kerosene (× 350) ; (a) pre-impinger sample ; (b) backing impinger sample.

liquid surface, first by the jet and secondly by a tight vortex at the meniscus The liquid surface is only slightly dented by the jet in our standard bulb.

Design Considerations

Various shapes for the pre-impinger were tested and the final forms chosen are shown in Fig. 3. In shape A,

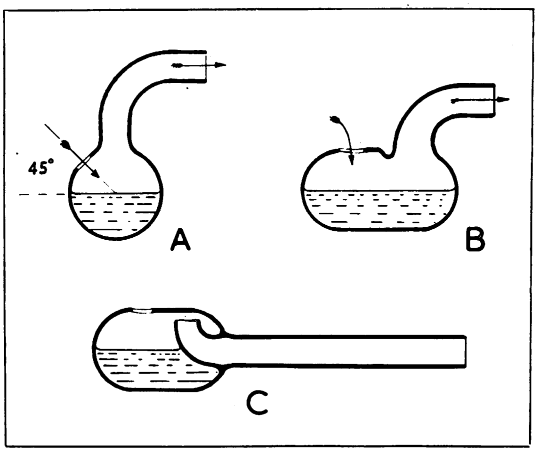


FIG. 3.—Types of pre-impinger.

the most generally useful form, the glass bulb is 30 mm. O.D. × 28–29 mm. I.D. and the smoothly curving neck is 10 mm. O.D. × 8 mm. I.D. The intake hole is ground out in the position shown so that the axis of the air jet strikes the centre of the liquid surface at 45°. The horizontal part of the curving neck is well above the bulb, so that when the unit is handled (with a bung in the intake hole), there is little danger of any of the liquid splashing over into the backing impinger.

To give 50% retention of 4 μ bacterial particles the intake hole is ground out to 6·5 mm. ± 0·25 mm., as checked with a gauge, and lightly chamfered to remove sharp edges. The decision to set the 50% retention at this figure was taken after careful consideration of current knowledge on nasal penetration and lung retention. As we are primarily interested in sampling bacterial aerosols, weight was given to the work of Druett and others (1953) with anthrax particles and Harper and Morton (1953) with radioactively labelled particles. In these experiments a striking agreement was found for the guinea-pig between nasal penetration and infectivity, the particle size where rapid change took place being about 3½ μ.

Shape B in Fig. 3 has a low intake efficiency for windborne clouds but is efficient in static clouds and has rather less danger of spilling when the intake hole is open. The impingement efficiency of shape B is a little lower than that of A (Table 1).

Shape C is an adaptation of B so that samples may be taken inside a vertical duct with a downflowing air-stream by inserting the whole pre-impinger through a hole in the duct wall.

A principal feature of the design was that an intake tube was avoided. Fabrication of the bulb is thereby simplified and intake tube loss of type (2) is eliminated. These considerations were thought to outweigh the fact that the bulk of the bulb round the orifice might cause higher type (1) errors in a windborne cloud than would be given by a more isolated orifice at the end of a tube. On the other hand, in yawing or turbulent wind, type (2) loss in an intake tube would probably make it less efficient overall than the plain hole in the bulb wall.

Test Procedure and Results

Production of Test Aerosols for Measurement of Impingement Efficiency.—Dry spherical particles, homogeneous and rigidly controlled in size, were generated in a vertical wind tunnel (Druett and May, 1952) by a modified form of the Walton and Prewett (1949) spinning disk spray. Solutions of the purified dye "chlorazol sky blue F.F." (I.C.I. Ltd.) were made up in water to strengths of 1% or 0·2% according to the particle size being investigated and 0·1% of "tergitol" was added to the solution to improve the wetting of the disk and therefore the uniformity of the clouds. The solutions were sprayed from a ground-glass surfaced rotor into a dry atmosphere, solid spherical particles of dye (density 1·33) being left after the evaporation of the water. Very uniform clouds of any desired particle size, which are ideally suited for testing the performance of any particle sampling or filtration system, are produced in this way. Pre-impingers backed by standard 11 litre-per-minute impingers were exposed to the test clouds for long enough to give easily measured amounts of dye in each of the two fractions of the sampler. Estimations of dye concentration were made on a Spekker colorimeter. The method is quick and accurate.

To check that the dye cloud results could be applied to the sampling of airborne micro-organisms, aqueous suspension of spores of *B. subtilis* were sprayed in the same way to give dry spherical clusters of spores of the desired diameter. Impinging on water, these immediately disperse to become single organisms. The number in each sample was estimated by the method of Miles and Misra (1938). This procedure is slow and only sufficient bacterial samples were taken to make a valid check on the dye method.

Radioactively labelled spores of *B. subtilis* were sprayed in another experiment and estimated by the Geiger count, using the procedure described by Harper and Morton (1952).

The density of the spore clusters was not measured but we are informed (Powell, 1953) that it would be in the region of 1·3 to 1·4.

Particle Size Measurement.—Samples were withdrawn from the wind-tunnel through the appropriate stage of a Cassella cascade impactor and measured with a microscope eyepiece graticule. As the dye particles are black, spherical, and very nearly uniform in size, the measurement can be made with ease and accuracy. The usual procedure was to measure about 100 particles, arranging them in $\frac{1}{2}$ micron wide size groups. The mean volume diameter $(\Sigma Nd^3/\Sigma N)^{1/3}$ was then found but in practice the overall size range in a given sample was so small that it made little difference whatever statistical mean was taken. Inspection of the sample and measurement of one or two particles of the predominant size (at 5μ for example, 80% of the particles were in the range 4·75 to 5·25 μ) gave a quick and accurate check when setting the cloud to the desired size.

The clouds of spore particles were measured in the same way. Sizing is not so accurate for this type of particle because (*a*) the initial droplets from the spray are not usually quite so uniform for suspensions as for solutions, (*b*) there is a statistical variation in the numbers of spores per droplet which tends to spread out the size range of the dried particles, particularly when the particles are small and contain only a few spores, and (*c*) the dried spore clusters are often lumpy and unspherical. The lower uniformity was a further reason for carrying out the detailed calibration with dye particles, using the spores only as a check.

Estimation of Particle Size Cut-off.—This was carried out in detail for the shape A pre-impinger with 6·5 mm. orifice at 11 litres per minute over the range between just measurable particle retention (at 1·9 μ) to just measurable penetration (at 8 μ). The curve obtained is shown in Fig. 4. In this work six pre-impingers were selected at random from a large production batch and for each particle size three samples were taken with each pre-impinger and impinger unit. Thus each point plotted is the mean of 18 determinations, except for the extreme points where the very long exposure necessary to obtain measurable samples allowed time for only six determinations. The results showed no significant difference between the six pre-impingers. Standard deviations of the full results for the various particle sizes lay between 0·8 and 4%. The two points estimated by the Miles and Misra method from samples from clouds of *B. subtilis* clusters are also shown in Fig. 4. These are the means of one exposure from each of the six pre-impingers and are seen to lie close to the dye curve, confirming the applicability of the latter to bacterial sampling.

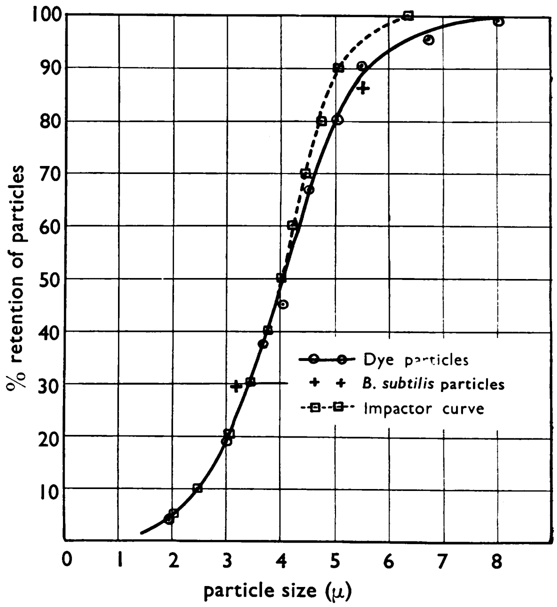


FIG. 4.—Impingement efficiency of pre-impinger with 6·5 mm. orifice at 11 litres per minute.

Further confirmation of this was obtained with the radioactively labelled spore clouds sampled with pre-impingers of shapes A and B with 5 mm. orifices at 11 litres per minute when the following figures were obtained (Table 1).

TABLE 1

	Shape A		Shape B	
	Dye Cloud	Labelled Spore Cloud	Dye Cloud	Labelled Spore Cloud
Cloud particle size (μ)	3·5	3·7	3·5	3·7
Retention (%)	75·5 (by Spekker)	72 (by Geiger count)	49·8 (by Spekker)	49·1 (by Geiger count)

These results also show that shape A pre-impinger is more efficient in retention than shape B, both having the same size of intake hole and flow rate.

The "impactor curve" in Fig. 4 was obtained from the figures given by May (1945) for the performance of impacting jets. The curve is that of a jet-to-dry-plate system with a 50% retention at 4 μ and it is strikingly similar in shape to the pre-impinger curve. The experimental curves of Ranz and Wong (1952) are also similar in shape, but Davies and Alyward's theoretical curves (1951) do not agree so well. The agreement between May's and Ranz and Wong's curves and the pre-impinger curves is in shape only, however, for their empirically

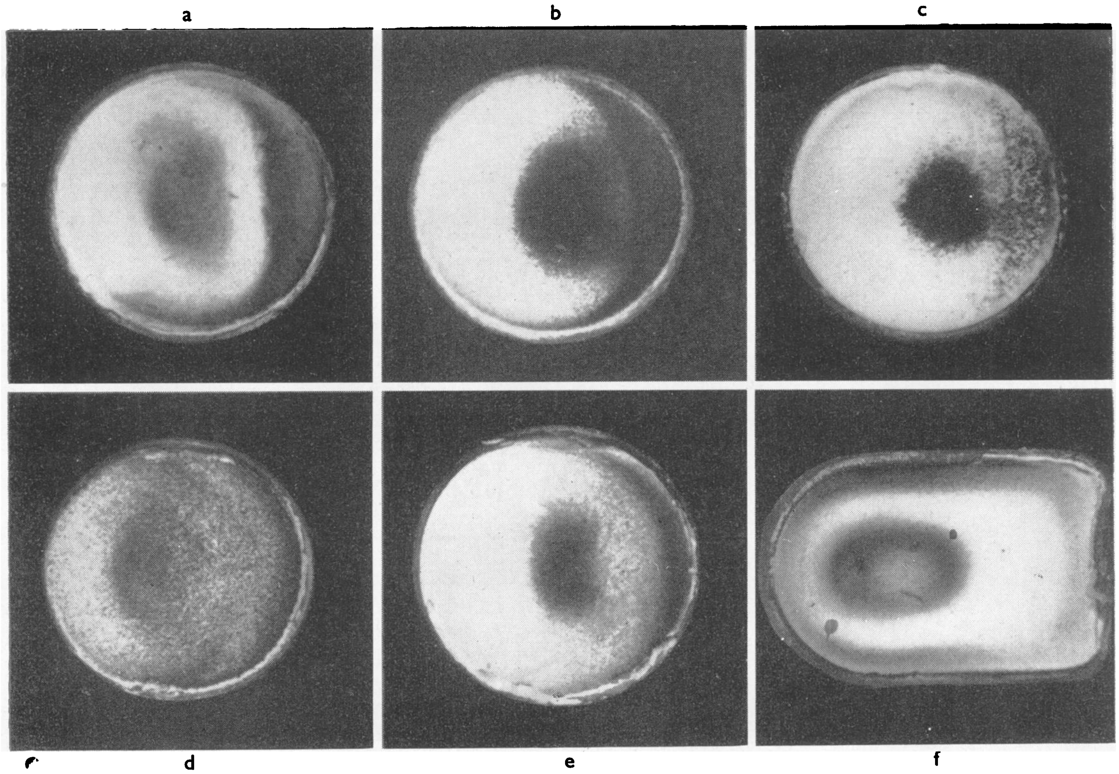


FIG. 5.—Patterns showing sites of impingement on the liquid surface in the bulb : (a), (b), (c), 6·5 mm. intake hole, 11 litres per minute; (a) 4 μ particles ; (b) 7·5 μ, (c) 10 μ, (d) 9 mm. hole, 11 litres per minute, 6 μ particles ; (e) 4·3 mm. hole, 4·6 litres per minute, 4 μ particles ; (f) Shape B pre-impinger with 6·5 mm. hole, 11 litres per minute and 4 μ particles.

evaluated formulae give, for the pre-impinger dimensions, a 50% retention in the $7\frac{1}{2}$ to 9 μ region instead of 4 μ.

Mode of Impingement.—The reason for the exceptionally high particle retention efficiency was not revealed until a study was made of the pattern of impingement on the liquid surface. To do this a bulb was cut in two round the normal waterline and waxed together again. The bulb was then half filled with a thin plaster of paris suspension. Just before the plaster reached setting point a sample of suitable density was taken from the blue dye cloud to give a blue stain on the white plaster at the sites of impingement. If the airflow was continued until the plaster had set, the dent in the liquid surface was " frozen " for study and measurement.

Photographs taken of the plaster surfaces with the upper half of the pre-impinger removed are shown in Fig. 5. In each case the inlet hole was on the left with the exhaust tube on the right (as in Fig. 6c). They show that impingement takes place in two stages, first from the jet as it strikes the liquid surface, giving the dark central spots, and second from a tight vortex at the back of the bulb which gives the crescent-shaped marking. The latter is much more efficient in impingement than the jet as shown by Fig. 5a. Here, 4 μ particles (the size for 50% retention) have been sampled in the standard bulb (11 l./min., 6·5 mm. hole) and it is clear that much the greater mass is deposited by the vortex. The efficiency of the jet alone is as predicted by Ranz and Wong's figures except that there is a slight enhancement due to the denting of the liquid surface. As the particle size increases, the proportion impinged by the jet also increases. This is shown by Fig. 5b where 7·5 μ particles are sampled under the same conditions as Fig. 5a and are about equally distributed between jet and vortex, and in Fig. 5c where at 10 μ the jet impinges much more than the vortex.

The relative importance of the vortex varies with the size of the hole. Fig. 5d shows the pattern in a bulb with a 9 mm. hole which gives a 50% retention size of 6 μ at 11 litres per minute. Here the vortex is predominant and envelops most of the liquid surface. With a small hole, however, the vortex has less effect as shown by Fig. 5e, taken from a bulb with 4·3 mm. hole at 4·6 litres per minute with 4 μ particles (50% retention).

Fig. 5f shows the pattern in the shape B bulb sampling under identical conditions to 5a. Here, the vertical jet makes a greater dent in the liquid than the 45° jet and is thereby more efficient, but the vortex in this shape is of relatively less importance and the overall efficiency is found to be slightly less.

This vortex formation is extremely useful in that it enables the 50% cut-off of the bulb to be achieved with a negligible drop in pressure at a low particle size which, without the vortex, would require a high-velocity, liquid-disrupting jet. It also ensures that there is no chance of over-size particles getting past the pre-impinger. The configuration of the vortex impingement patterns in Fig. 5 would suggest that there would be heavy impingement on the wall of the bulb also. In fact this is not so and such wall deposition as there is takes place just above the meniscus. It is therefore important to ensure that the glass is clean and well wetted by the liquid so that the meniscus reaches as high as possible.

Effect of Varying Intake Hole Diameter and Sampling Rate.—The performance of geometrically similar jet-to-dry-plate particle impactors may be given by an equation of the form

$$I_n = \rho V d_n^2 / \eta l \quad \ldots \quad (1)$$

where I is the dimensionless impaction parameter which varies with n, the impaction efficiency, i.e., the chance of a particle of diameter d and density ρ striking the plate. V is the jet velocity, η the gas viscosity, and l a characteristic length of the system, usually the jet width. For a circular jet nozzle Ranz and Wong (1952) found I = 2·7 at n = 0·5.

It was thought that an equation of similar form might hold for the pre-impinger enabling the dimensions of bulbs to be calculated when used at other flow rates or as selective filters with other apparatus. To test this, bulbs were made at the standard diameter only, with intake holes over a range from 2·65 mm. to 9 mm. diameter and tested at sampling rates between 1·20 litres per minute and 39 litres per minute. From each test the dye particle diameter giving 50% retention ($d_{0\cdot5}$) was obtained.

It was found that there was an inverse relationship between I and l (the intake hole diameter) and that for a given l, I remained nearly constant for any jet velocity which could be used for that size of hole. These effects are explained by the relative magnitude of the vortex and jet impingements, for, as already shown, a large hole gives a large vortex and vice versa (Figs. 5d and 5e). As l diminishes below 3·5 mm. I becomes equal to, then exceeds, Ranz and Wong's value for a plain jet, showing that the vortex effect disappears when we have a long, thin, diffusing jet of air. The vortex could no doubt be reintroduced by scaling down the bulb in proportion to the hole provided that the jet velocity is not high enough to disrupt the liquid surface. $I_{0\cdot5}$ ought then to be nearly constant at about 1·0 for all values of l.

The experimentally determined relationship between I and l showed variations beyond the range of experimental error. This is perhaps not surprising in view of the lack of geometrical similarity in the experiments and the variable importance of the vortex. Nevertheless a plot of

$$I_{0\cdot5} = (\cdot 307/l) + 0\cdot53 \quad \ldots \quad (2)$$

passes fairly well through the experimental points and substitution in equation (1) will give $d_{0\cdot5}$ to better than ± 10%. At l = 6·5 mm. and above, the error in $d_{0\cdot5}$ is very small.

Values of d for other values of n may be found from Fig. 4 by proportion, the efficiency curves being quantitatively similar in all cases.

The validity of equation (1) in respect of ρ and η was not tested. When the pre-impinger is adjusted to give a similar cut-off to the human nose the similarity should apply regardless of the density and shape of the particles, for a process of inertial impingement on to wet surfaces occurs in both cases.

Available Range of Cut-off.—The lower end of the range with the standard 3 cm. bulb is limited to the point where the jet velocity becomes so high that the liquid in the bulb is disrupted and entrained in the air stream into the backing impinger. For any combination of l and V this limit is reached when $d_{0\cdot5} \approx 2\cdot25\ \mu$. The upper limit of cut-off size is set by the increasing proportion of particles trapped in the connecting tube and on the back of the bulb as $d_{0\cdot5}$ increases. Without an extravagant increase in bulb and tube size it is on this account impracticable to set $d_{0\cdot5} > 8\ \mu$.

Streamlines of Flow into the Orifice.—Fig. 6 shows a selection from photographs of pre-impingers in a streamlined-flow wind tunnel sampling in winds of various speeds. The lines of flow into the orifice are made visible by filaments of smoke introduced from fine jets upstream of the orifice. The photographs were taken to study the effect of various wind speeds on the entry conditions and it was also possible to observe, but not photograph, the initiation of vortex circulation within the bulb at low suction rates. In Fig. 6a, where the wind speed

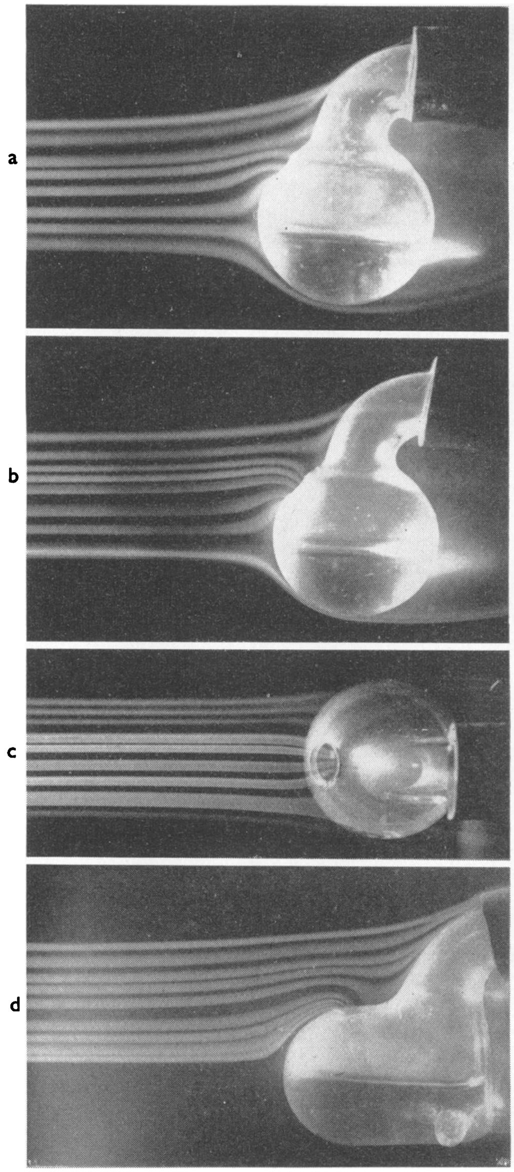


FIG. 6.—Streamlines of flow past pre-impingers: (a) 12 m.p.h. wind; 11 litres per minute suction; (b) 4 m.p.h. 11 litres per minute; (c) 4 m.p.h. 11 litres per minute; (d) 8 m.p.h. 11 litres per minute.

(12 m.p.h.) is about the same as that in the orifice, it will be seen that the streamlines entering the orifice do not bunch together as they do in the lower wind speed of Fig. 6b. This sudden bunching in front of the orifice throws out the larger particles from their "carrier" streamlines of flow into the orifice and the particles are lost on the exterior of the bulb. Fig. 6c shows the horizontal pattern of flow into the orifice. Fig. 6d shows a shape B pre-impinger and demonstrates its unsuitability for horizontal air streams.

Estimation of Sampling Errors

Intake (Type 1) Errors.—For this purpose an extensive series of samples was taken in a horizontal wind tunnel in the mouth of which a spinning disk sprayer dispersed uniform droplets of dibutyl phthalate dyed with the red dye "B.1" for colorimetric estimation. The tunnel had a 6 ft. long expanded turbulent mixing section followed by a contraction to smooth out the flow into the "open-jet" type of working section. Flow was maintained through the tunnel by a suction fan of controllable speed. The open jet was 4 in. by 8 in., which allowed room for four samples to be taken simultaneously. The procedure was to compare the recovery from the inside of two pre-impinger plus impinger units mounted alternately with two standard impinger units equipped with knife-edged isokinetic orifices designed to give the best possible estimate of the cloud concentration. All the sampling orifices face upwind and were placed as close together as possible, consistent with the avoiding of mutual interference. Experiments were made at droplet sizes of 10, 15, 20, 25, and 30 μ at 2, 4, 6, 8, 12, and 16 m.p.h. wind speed at each droplet size and all runs were triplicated in the first instance. A survey of the curves so obtained then indicated doubtful or key points which were finally established by tenfold repetition of the point in question. The coefficient of variation of the latter determinations averaged 4·5%.

To obtain the intake efficiency in a static cloud, (0 m.p.h.) the spinning-disk spray was set up over a hole at the top of a 33 in. square and 4 ft. high chamber. The sprayed droplets settled down through the hole and were mixed at the top of the chamber by a low-speed multiple air-jet. Sampling took place at about 12 in. from the floor of the chamber, the absolute sample being taken by a knife-edged and externally streamlined nozzle of 1·56 cm. diameter whirling horizontally at 30 r.p.m. at the end of a 30 cm. radius arm. This nozzle is isokinetic because at 11 litres per minute suction air enters it at the same velocity as the rotational velocity. Six equally spaced pre-impingers were set up just outside the path of the whirling nozzle and at the same level. To obtain the intake efficiency, the mean of the six samples was compared to the nozzle sample. Good agreement was obtained in replicated experiments (coefficient of variation, 4·3%). At the sampling level there was some turbulence of low velocity relative to the intake velocities of the sampling orifices due to the mixing jets, but the mean horizontal velocity was zero. A mean downward movement of the cloud, in addition to the sedimentation velocity of the droplets, of 0·19 cm. per second was due to the withdrawal of 77 litres per minute through the samplers. Experiments were done at 20 μ and 30 μ only, the results being so close together as to enable the efficiencies at other sizes to be estimated without the possibility of appreciable error.

The results are plotted in Fig. 7 in which the " % intake efficiency " is the ratio between the pre-impinger and isokinetic orifice samples, the latter being assumed absolute.

The accepted picture of the sampling errors of an orifice facing upwind is that when the ambient wind speed is lower than that in the orifice, particles overshoot the streamlines converging into the orifice (cf. Fig. 6b) resulting in a deficient sample, and conversely when the wind speed exceeds the orifice speed, particles undershoot the diverging streamlines giving an excessive sample. These effects should increase with the inertia of the particles. At zero wind speed when the particles settle freely into the sampling zone, the intake efficiency should be high.

These effects are well shown by the Fig. 7 curves from which we see at zero wind speed the intake efficiency is high for all particles (an additional determination at 50 μ gave 85·5% intake). At 12 m.p.h. the wind speed is the same as the orifice speed, and in this region intake efficiencies are again high for all particles, in spite of the bulk of the bulb around the orifice and the 45° angle of the orifice. The drop in efficiency due to the particles overshooting the streamlines is greatest at 6 m.p.h. for all particles >10 μ and the drop increases with the particle size. At 30 μ the intake is only about 58% at 6 m.p.h. and for still larger particles, say 50 μ, the intake is probably below 50% at this speed. At wind speeds higher than the orifice speed the intake tends to exceed 100% for all particles >10 μ. Particles smaller than 10 μ are sucked in with virtually 100% efficiency under all conditions within the limits of the experiment.

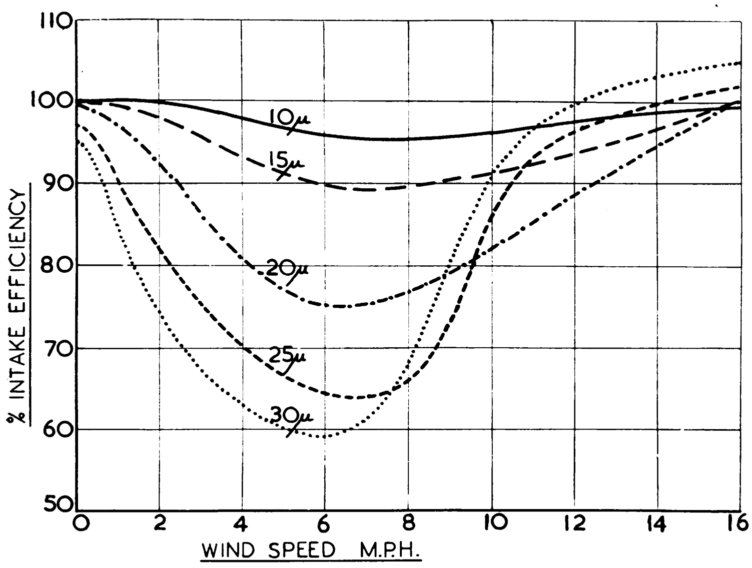


FIG. 7.—Effect of wind speed and particle size on intake efficiency of standard pre-impinger.

Lack of time and certain experimental difficulties have so far delayed the extension of the curves beyond 30 μ and 15 m.p.h. and for negative wind velocities, but the range investigated should cover most practical cases.

The saddle shape of the efficiency curves agrees well with those of Hirst (1952) who performed experiments on the intake efficiency of an impactor device sampling lycopodium spores.

The effect of yaw on the intake efficiency has not been investigated but this should be small because there is no intake tube.

Internal Wall and Tube (Type 2) Losses.—Deposition on the back of the bulb can take place from two causes ; first from the vortex, or second from large windborne particles which have sufficient horizontal momentum when sampled to carry them out of the air jet before the liquid surface is reached.

Deposition from the first is close to the liquid surface unless there is a large intake hole, when the large vortex (cf. Fig. 5d) tends to spread particles over the whole of the back of the bulb. Deposition from the second is a function of d^2v and in practice begins at 30 μ and 8 m.p.h., 20 μ and 16 m.p.h., and so on.

The back wall deposit is only likely to be lost in the case of viable particles sensitive to drying as it is very easy to wash off by shaking the bulb with the intake closed. This should be done as a routine before withdrawing the liquid. The estimation of the back wall deposit has not been made but the conditions in which it is likely to give appreciable loss in our work are rarely encountered.

The small particles surviving the initial impingement in the bulb are subject to deposition in the curving tube connecting the bulb to the backing impinger. This, again, is only a loss with viable particles sensitive to drying as the tubes can be washed through. The magnitude of the particle deposition in these tubes was estimated during the course of the determination of the detailed cut-off curve of the standard bulb (Fig. 4). It was found that below the 50% retention size no measurable dye could be found in the tubes, but as the particle size increased an increasing proportion of the penetrating cloud was retained in the tube. Thus at 5·03 μ, 5·5% of the total of particles entering the pre-impinger were recovered from the tubes, this being 28% of the particles penetrating the pre-impinger. At 6·75 μ the recovery was 2·25% of the total, being 50% of the penetrating cloud. In drawing the cut-off curve of Fig. 4 the tube recovery was added to the impinger sample. If the tube recovery is added to the pre-impinger sample, or neglected, the effect is to raise the upper half of the curve slightly so as to lie about midway between the existing curve and the impactor curve.

Because the tube loss forms only a small proportion of the total sample and the size range at which loss takes place is only 4 to 8 μ, there is no doubt that in the typical cloud of particles of widely dispersed sizes the tube loss in the standard bulb can be ignored. A narrower tube would, of course, give higher losses.

Discussion

The results obtained show that at wind speeds from zero to at least 16 m.p.h. the pre-impinger and impinger unit is capable of giving a good estimate of total cloud concentration of all airborne particles below about 30 μ plus a quantitative measure of the proportion of the aerosol capable of reaching the lung.

The sigmoidal shape of the cut-off curve in Fig. 4 has been found to apply to bubbler sampling devices as well as to impingers and impactors and it seems very likely that such a shape would apply to the nose. Although the nose cut-off curve may be less steep than that in Fig. 4, the cloud reaching the impinger should resemble in size-distribution that which would reach the lung.

It might be thought that the size fractionation of the aerosol could be extended further by employing several liquid impingement stages in series in the manner of the " cascade " impactor. It is, however, scarcely practicable to do this for large particles because the air stream must be made to turn 180° (or nearly so) between each liquid stage and the large particles cannot be made to do this without being thrown out on the bend. The present work shows that the available range of cut-off sizes is limited to 2·5 μ to 8 μ and a complete re-design would be necessary to extend this. In its present form the unit described in this paper is thought to be the simplest way of obtaining the really essential information when sampling toxic aerosols. The high intake efficiency found for still air sampling suggests that for a continuous windborne cloud a more accurate sample of large particles might in some circumstances be obtained by bringing the cloud to a standstill before sampling, e.g. at the stagnation point of a baffle, rather than attempting the usually impossible task of obtaining continuously isokinetic sampling. For example, at 30 μ in a 6 m.p.h. wind the intake of the bulb is 58% (Fig. 7). This may be increased to about 80% with the bulb sampling through the centre of a 4 in. diameter baffle normal to the wind direction. This consideration would apply to sampling devices in general.

Particle size-separation as given by the pre-impinger can, of course, also be achieved by (i) a jet-to-dry-plate impaction device, or (ii) an elutriator or settling chamber. We have given reasons why collection into liquid is to be preferred for viable organisms but in the case of say, dust samples, the pre-impinger has an advantage over (i) above in that no overloading or clogging up at the site of impaction can take place and there are no type (2) losses, and over (ii) in compactness and ease of recovery of the sample. The pre-impinger is also inexpensive and easy to make. A disadvantage of the standard shape is that the liquid can be fairly easily spilt when the orifice is open so that the device is not very suitable for sampling from the hand. This fault could not be overcome without seriously affecting the windborne cloud intake efficiency, though in still air the alternative shape B gives high intake efficiency with little chance of spilling. The assembly shown in Fig. 1b could, of course, be made more compact by sacrificing the curving neck of the impinger and leading an internal-sealed tube straight down from a modified pre-impinger bulb into the impinger flask.

Summary

A simple device is described which, when fitted to the front of an impinger, divides the total aerosol sample into two particle-size fractions by means of

size-selective impingement into liquid. The cut-off between the two fractions is set at 4 μ to simulate nasal penetration.

The curve of efficiency of impingement of particles into the liquid against particle size shows that the pre-impinger has a very high efficiency in relation to its jet velocity. This is due to a double impingement process on the liquid surface.

The particle intake efficiency at various wind speeds is given in detail and is shown to be good for particles smaller than 30 μ. Empirical equations are given to show the relation between cut-off size, intake hole diameter, and jet velocity so that the cut-off may be set to any other desired figure in the range $2\frac{1}{2}$ μ to 8 μ. Internal losses were evaluated and shown to be small. Streamlines of flow into and around the device were investigated by means of smoke filaments in a wind tunnel.

It is concluded that the particle retention of the pre-impinger is similar to that of the nasal passages, while the material in the backing impinger is similar to that reaching the lungs. The pre-impinger appears to have some important advantages over other devices for selective sampling such as dry impaction systems, elutriators, and settling chambers.

Valuable assistance in the large amount of colorimetric work was given by Mr. R. Clifford and Miss M. Gregory. Acknowledgement is made to the Chief Scientist, Ministry of Supply, for permission to publish this paper.

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