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JET ENHANCED LOCAL EXHAUST VENTILATION

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Abstract—Local exhaust ventilation hoods are limited in their application by the fact that the flow induced by a suction opening drops very rapidly with distance from it. By using a radial blowing jet the flow can be greatly enhanced and capture can be effected at distances several times that which would normally be expected. Results of capture efficiency measurements on two jet assisted hoods are presented. The ratio of the momentum fluxes of the blowing jet and the suction is shown to be an important factor in characterizing the capture distance. Variation of capture distance with the momentum flux ratio is determined.

INTRODUCTION

Local exhaust ventilation (LEV) hoods are widely used in industry to capture pollutants which are emitted over a restricted area close to their point of production. The hoods can basically be divided into two types, depending on their method of operation, namely receptor and captor hoods. Receptor hoods use the natural movement of the pollutant to drive it into the hood. The hood is then 'emptied' by the extract system at least as quickly as the process is filling it. Captor hoods on the other hand are required to pull the pollutant into the system. This is achieved by inducing a sufficiently strong air flow at the contaminant source to draw the pollutant towards the exhaust opening.

Captor hoods suffer from a number of restricting features. Whereas it is usually the intention to draw air from a selected region it is in fact drawn into an exhaust opening from all directions. To some extent this can be countered by fitting a flange to the hood which will at least reduce the amount of air being drawn from behind the hood, where ventilation is seldom required. However the great weakness of local exhaust ventilation is that the velocity induced drops very rapidly with increasing distance from the hood face, being approximately inversely proportional to the square of the distance from the hood. As a rule of thumb, for a square hood the velocity at a distance of one hood side will have fallen to one tenth of its value at the hood face, so that to capture efficiently a hood must be very close to the pollutant source. This will often not be feasible and other solutions must be sought.

JET ENHANCEMENT

In 1987 two conference papers were presented on the enhancement of the capture characteristics of an exhaust opening by the use of radial jets. Hyldgard (1987) and Hogsted (1987) described work carried out at Aalborg University and the Jutland

Technological Institute, respectively, both in Denmark. The principle is shown in Fig. 1. A radial jet entrains air as it is ejected at a relatively high speed from a narrow slot surrounding a circular exhaust opening. The movement of air induced by the radial jet is principally in the direction of the longitudinal axis of the hood. This means that not only is air drawn towards the suction opening from relatively large distances by the action of the radial jet, but that the flow is now directional.

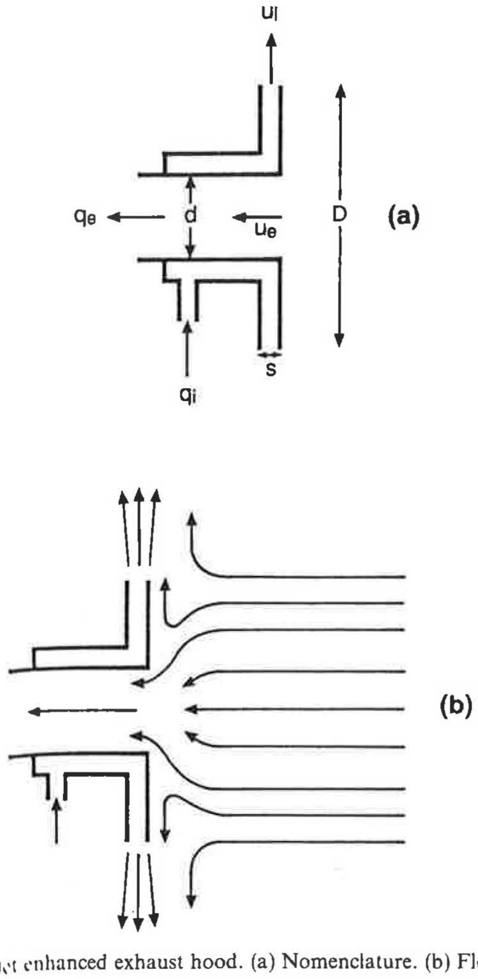

FIG. 1. Jet enhanced exhaust hood. (a) Nomenclature. (b) Flow field.

HYLDGARD (1987) found that if the ejection was too weak the radial jet could be drawn into the suction opening whereas if it were too strong, the effective suction area could be small although the capture distance might be large. Because of the large number of parameters involved, Hyldgard found it difficult to summarize the effects on the capture efficiency, though high efficiencies could be obtained. It was noted that for very small air supply openings and high ejection velocities the noise levels could be high, and high pressures were required for the ejection.

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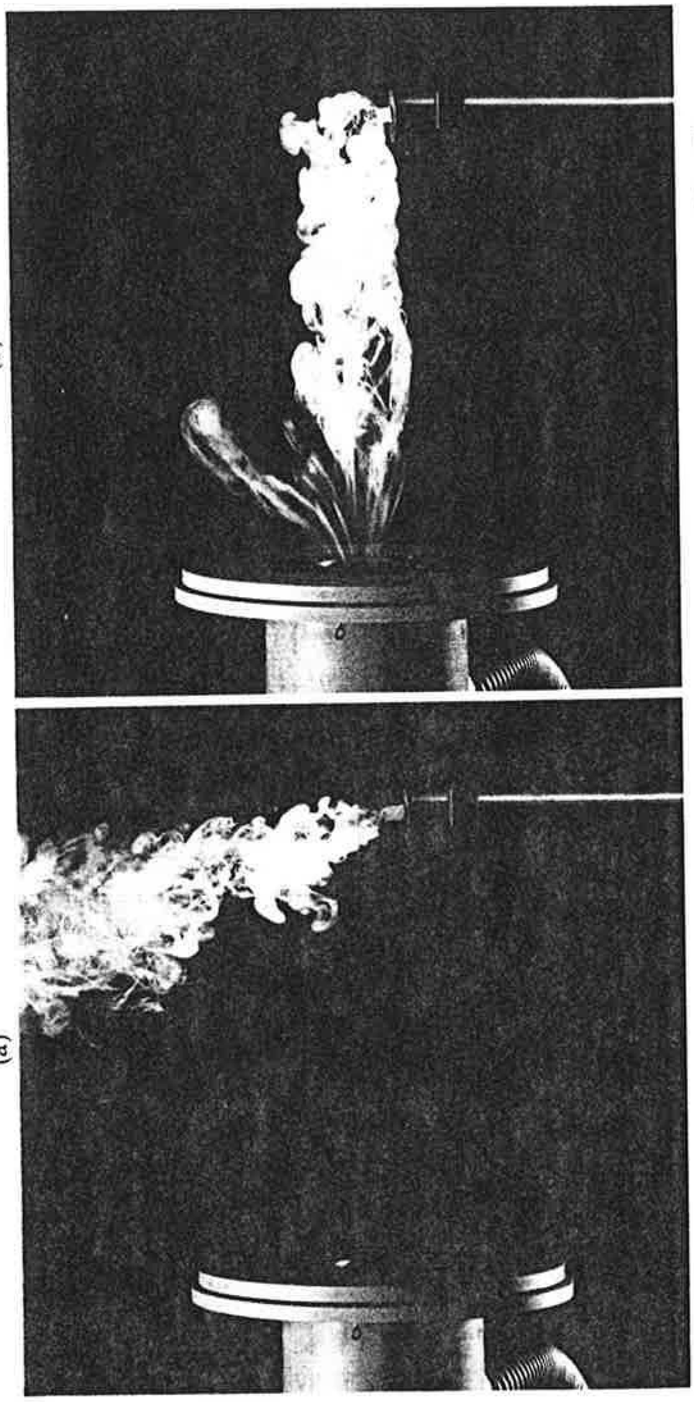
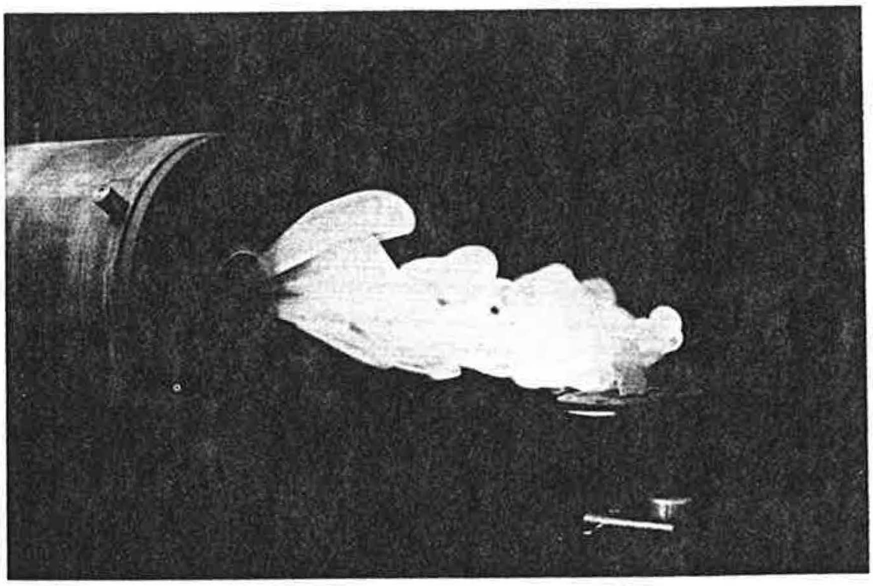


FIG. 2. Capture of smoke from five diameters at a face velocity of 12.7 m s^{-1}. (a) Without ejection. (b) Ejection at 13.9 m s^{-1}.



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similar hood with a 70 mm diameter exhaust opening. By releasing smoke at various positions in front of the hood Hogsted showed that a well-defined region existed where the capture was virtually 100% whilst outside this region the capture was zero. PEDERSON and NIELSEN (1992) state that "the form and working depth of the efficient area is determined by the ratio I between the momentum flow (momentum flux) in the inlet and exhaust where

$$I = \frac{u_i q_i}{u_e q_e}."$$

u and q are the average velocities and volume flow rates and the suffices i and e refer to the ejection and exhaust, respectively. It was found that the critical velocity to prevent the ejected air being taken into the exhaust opening was, for the given geometry, proportional to the exhaust flow rate. However this would be influenced by the proximity of the inlet to the exhaust and, by separating these two, a lower ejection velocity and hence lower noise level should be possible.

MEASUREMENTS

In the present work a series of experiments was carried out on hoods of two different sizes. Both the flow fields and the capture efficiency envelopes were measured. Flow fields were plotted from results obtained using an omnidirectional probe to measure air speeds over a rectangular grid in front of the hoods. Capture efficiencies were measured using a tracer gas technique. The tracer, a neutrally buoyant mixture of sulphur hexafluoride in helium, was released through a porous stone at a constant rate at a matrix of points in front of each hood. The concentration of gas captured was measured in the exhaust, well downstream of the inlet. To determine the 100% capture value, tracer gas was fed directly into the inlet. This was done after the measurement at each point on the matrix to detect and correct for any build-up in the background concentration.

The first hood had an exhaust opening 74 mm in diameter and the radial jet was emitted from a flange 303 mm in diameter. Figure 2 shows the effect of the ejected air on the ability of the hood to capture smoke emitted by a pellet at five diameters in front of the hood. In Fig. 2(a), only suction is applied to give a face velocity of 12.7 m s^{-1}. It can be seen that only occasional wisps of smoke are entrained into the suction opening; the vast majority escapes into the background. In Fig. 2(b), the same amount of suction has been applied but air is also being ejected from the slot (of width 2.0 mm) at a speed of 13.9 m s^{-1}. The capture of the plume is virtually complete. It should be noted that the values of the extract and ejection flow rates, slot width, etc., were not chosen to maximize the effectiveness of the hood for the purpose of these photographs.

Measurements of air speeds around the hood for a face velocity of 15.5 m s^{-1} without ejection are shown in Fig. 3(a). Similar measurements were made but with the addition of ejection at a speed of 7.7 m s^{-1} through a slot of width 7.5 mm; these are shown in Fig. 3(b). It should be remembered that these contours are of positions of equal air speed and that there will be some ambiguity in the profiles in the region of interaction with the jet of ejected air. However it can be seen that in the region adjacent to the suction opening the profiles with and without ejection are very similar, that is the flow is dominated by the suction. At distances greater than two diameters along the

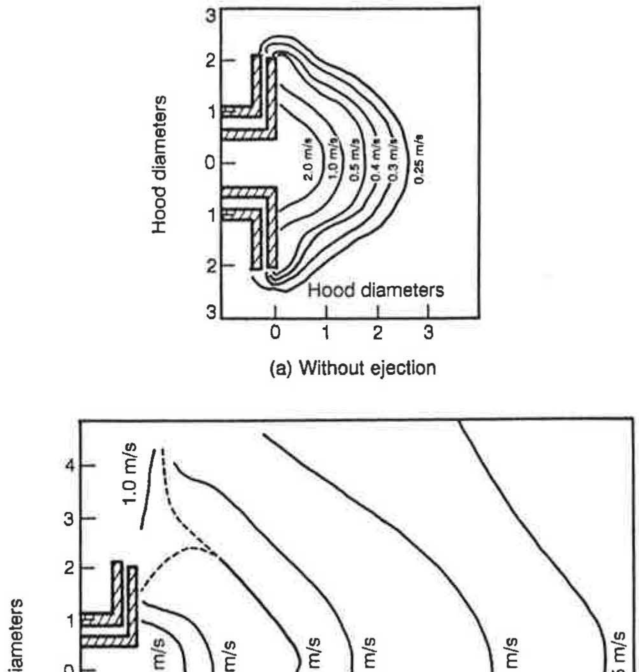


FIG. 3. Speed contours around a hood with face velocity of 15.5 m s^{-1}. (a) Without ejection. (b) With ejection.

centre-line the effect of the radial jet becomes apparent. The air velocity falls much more slowly than it does without ejection and the increased potential for capture in clear.

Figure 4 shows the percentage capture on the centre-line of the hood for a face velocity of 7.7 m s^{-1} and different volume flow rates of air ejected through a slot width of 2 mm. Two features in particular should be noted: (a) with suction only the capture efficiency dropped off rapidly for distances greater than two opening diameters from the hood. However for a face velocity of 7.7 m s^{-1}, the centre-line velocity at a distance of two diameters would be in excess of 0.2 m s^{-1} and this would exceed the general air movements under the test conditions; (b) as the volume of air ejected was increased, the capture distance increased to a maximum and then fell. Similar measurements were also made for slot widths of 1.0, 4.0 and 7.5 mm. From the results plotted, as in Fig. 4, the distance to any selected capture efficiency (e.g. 90%) could be estimated for each ejection flow rate. The ratio of the momentum fluxes is given by:

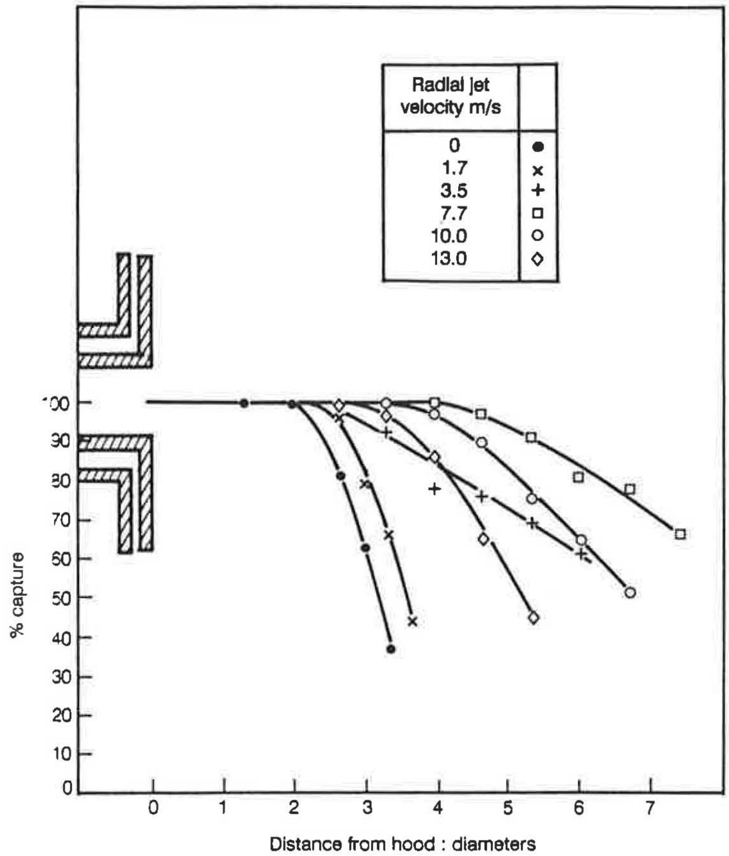


FIG. 4. Percentage capture for a face velocity of 7.7 m s^{-1} and a slot width of 2 mm.

$$I = \frac{4Ds}{d^2}\left[\frac{u_i}{u_e}\right]^2,$$

where s is the slot width, d is the exhaust opening diameter and D is the flange diameter. If the exhaust opening diameter, the flange diameter and the exhaust rate are fixed, then $I \propto su_i^2$. If the depth of the efficient area is determined by I, then under these conditions the distance along the centre-line to a given capture efficiency should be a function of su_i^2. Figure 5 shows the variation of the distances along the centre-line to 90% capture plotted against su_i^2, where s is in mm and u_i is in m s^{-1}. This shows: (i) that when plotted in this form the capture distance is independent of the slot width; (ii) that capture distance initially increases rapidly with increasing values of su_i^2; and (iii) that the capture distance reaches a maximum for a value of su_i^2 of about 65 and thereafter decreases relatively slowly as su_i^2 increases.

The second hood (see Fig. 6, p. 18), although of slightly different design, was geometrically very similar to the first. The exhaust opening and flange diameters were 30 and 114 mm, respectively. Air was extracted to give a face velocity of 15.5 m s^{-1}. Tests were carried out for slot widths of 1.25, 2.0, 4.0 and 6.5 mm for ejection velocities between 2 and 13 m s^{-1}. Figure 7 shows the distance to 90% capture plotted against I,

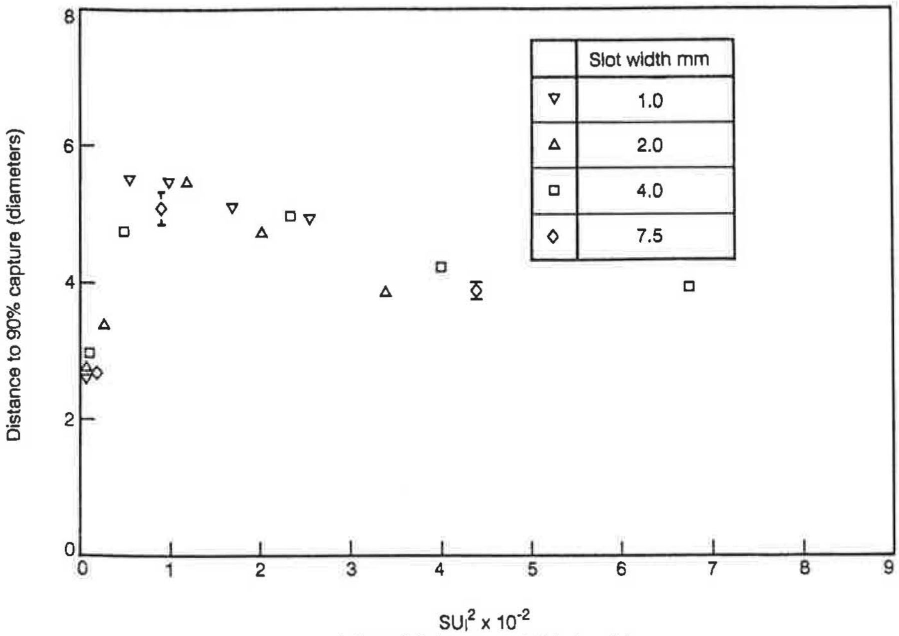


FIG. 5. Distance to 90% capture for the large hood.

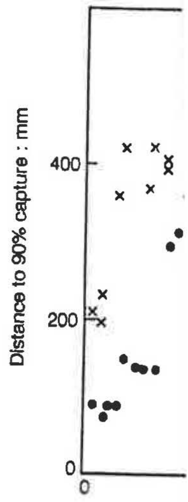
for the two hoods. It can be seen that the values for both hoods follow similar patterns, although at small values of I the capture distances for the smaller one are less; as I increases the differences become smaller.

DISCUSSION

If the amount of air ejected through the flange is so small that it has relatively little effect on the airflow towards the hood, then the capture of a contaminant released at a point in front of the hood will take place mainly as a result of the suction alone. That is, the hood will act as an ordinary LEV hood and the positions of given percentage capture profiles for hoods of different sizes can be expected to be at the same non-dimensionalized distance (with respect to the suction opening diameter) for each of the hoods.

As the amount of ejected air is increased, air is drawn towards the hood under the influence of the expanding radial jet, and the hood will hence capture from greater distances. However, a point will be reached where the amount of contaminated air drawn towards the hood will be greater than the amount of air being removed by the suction opening. At this point the capture distance will begin to fall and, as the effect is no longer driven by the suction opening, non-dimensionalizing with respect to the opening size may not be relevant.

This is borne out by the results plotted in Figs 7 and 8. Figure 8 shows that, for values of $I<0.3$, capture distances expressed in diameters are the same for both large and small hoods. It is clear that for $I>0.4$, the results are not unified. However Fig. 7



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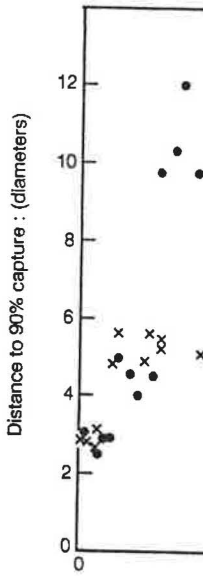

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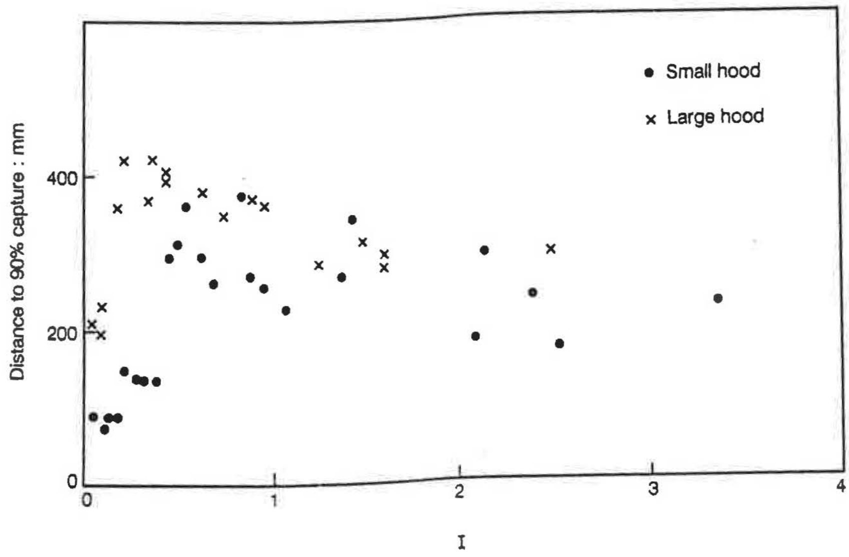

FIG. 7. Distance to 90% capture for large and small hoods.

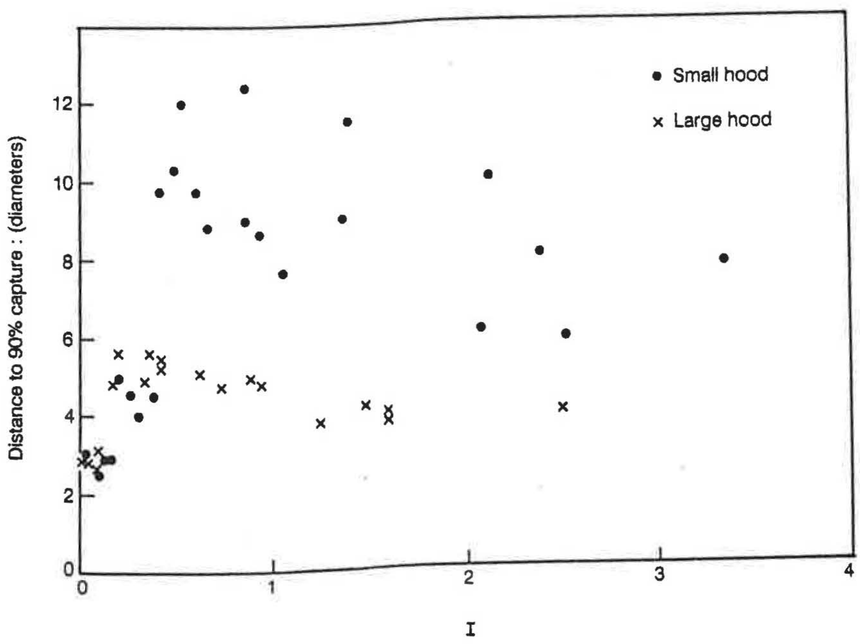

FIG. 8. Distance to 90% capture for large and small hoods.

shows the similarity of the distances when expressed in mm at these larger values of I. For both hoods, a value of I of about 0.6 would be acceptable to give a large capture distance; for $I>0.6$ the distance to 90% capture decreases only slowly with increasing I, whereas for $I<0.6$ the capture distance soon begins to decrease rapidly with I.

CONCLUSIONS

(1) By using an LEV hood with a radial blowing jet, capture can be effected at much larger distances from the hood than with an unassisted hood.

(2) I, the ratio of the momentum fluxes of the radial jet and the suction, can be used to characterize the distance over which capture takes place.

(3) Initially capture distance increases rapidly with increasing values of I, reaches a maximum and then slowly decreases.

(4) A value of 0.6 for the ratio of the momentum fluxes gives a large capture distance whilst being clear of the region of rapid changes.

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