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Investigation of the parameters that influence the effectiveness of a bench top partial enclosure

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Research Report

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Investigation of the parameters that influence the effectiveness of a bench top partial enclosure

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Bench top partial enclosures are frequently used in industry to control airborne contaminants. These hoods tend to be of basic design and often consist of nothing more than a box like structure with an open front to allow worker access and extraction at the rear to remove contaminated air. With this type of design the worker is forced to stand at the face of the enclosure and by doing so presents a blockage to the airflow that creates a 'wake' in front of the worker. Any release of contaminant into the recirculating wake region has the propensity to enter the worker's breathing zone.

This aim of this study was to investigate the design parameters that influence the control effectiveness of an open fronted small partial enclosure. similar to those used in industry, and in particular to identify key variables of small partial enclosure design and to identify how key variables interact.

The results showed that eddies were created against all four walls of the enclosure. These interacted with the wake in front of the test manikin leading to contamination of the breathing zone. Reduction in the breathing zone of the manikin was best achieved by the addition of an offset flange to the entry of the enclosure. This design allowed air to enter between the flange and the enclosure walls and thus eliminated the wall eddies and consequently led to a reduction in the breathing zone concentration. The report also includes a number of other recommendations for design and use of partial enclosures.

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EXECUTIVE SUMMARY

Aims and objectives

The aim of this project was to study the design parameters that influence the control effectiveness of small partial enclosures. To achieve this aim the following objectives were investigated:

- to identify key variables of small partial enclosure design
- to identify how key variables interact

Main Findings

If complete enclosure of a process is not possible then partial enclosure should be considered. Partial bench top enclosures are commonly used in industry and by their very nature have an opening for worker access. An inwards air flow generated at the opening is required to contain the contaminant within the enclosure interior to provide worker protection. Generally, the smaller the opening, the less likely a breach of containment will be. In addition, as the opening is reduced so is the air volume required.

The ideal design of a bench top partial enclosure would be to include a transparent screen between the between the worker's breathing zone and the interior of the enclosure, similar to a fume cupboard sash. The presence of a physical barrier between the workers breathing zone and the contaminated air within the enclosure can significantly reduce worker exposure and should be considered if full enclosure is not possible.

It is however, recognised that this approach is not always practical and an open faced, rear extracted, bench top partial enclosure is often used.

With such an enclosure one would intuitively expect the airflow to move as a plug of air from the front to the rear. In reality the airflow patterns within the enclosure are much more complex. For enclosures with sharp edges at the face of the opening, the airflow will separate from the surface of the walls at the leading edge and create large areas of recirculation against all four walls. The airflow patterns are further complicated by the presence of the worker at the open face of the enclosure.

There are a number of parameters that affect the exposure of the worker. This study has focused on the addition of flanges at the face of the enclosure, but has also considered the effect of face velocity, a rear baffle and the presence of a manikin positioned at the face of the enclosure. From this study the following conclusions can be made:

1. The addition of a rear baffle, or increasing the depth of the enclosure, improved the uniformity of the air velocities measured at the face of the enclosure. However, face velocity measurements give no information of the airflow patterns within the enclosure and no indication of worker exposure.

2. For the enclosure design studied, eddies were found against all four internal walls of the enclosure. Flow visualisation tests using smoke showed that these protruded beyond the plane of the opening when no flange was fitted, and any disturbance resulted in the escape of smoke into the test room.

3. The presence of a manikin at the face of the enclosure caused a ‘wake’ region of highly turbulent air to form in front of it. This ‘wake’ interacted with the eddy against the floor of the enclosure.

4. Moving the release position into the enclosure, further away from the manikin, reduced the concentration of tracer gas in the breathing zone of the manikin.

5. Leaning the manikin into the enclosure increased the concentration of tracer gas in the breathing zone of the manikin.

6. Increasing the face velocity did not necessarily reduce the breathing zone concentration. For example, with the circular rear baffle and the Omnidirectional source the breathing zone concentration increased with increasing face velocity. However with the slotted baffle and the Directional source the breathing zone concentration decreased with increasing face velocity.

7. The addition of a 125 mm 45^o flange to the entry of the enclosure reduced the size of the wall eddies and also pushed them back into the enclosure. However, the flange protruded by approximately 88 mm, making it difficult to position the manikin in a realistic working position. As a result limited data is available for this large flange.

8. Addition of each of the remaining 3 original flanges tested (medium and small 45^o flanges and the half round flange) failed to reduce the concentration of tracer gas in the breathing zone of the manikin when compared to the no flange condition. In fact some of the flanges produced breathing zone concentrations that were higher than the no flange condition. This may be because the manikin had to be leaned forward to ensure the breathing zone remained in the default position.

9. The modified half round flange that was introduced partway through the study considerably reduced the concentrations in the breathing zone of the manikin when compared to the no flange condition. This flange was considered to be the most practical design for bench top partial booths.

Implications of the study

The addition of the correct design and size of flange to the face of an enclosure can reduce the size of eddies that are created against the enclosure walls and thus the exposure of the worker. The incorrect design can increase exposure, as shown by the addition of the medium and small 45^o flanges and the half round flange.

Initial work with the large 45^o flange showed that this design considerably reduced the size of the wall eddies and helped to push them back into the enclosure. However, it was difficult to locate the manikin in a realistic working position whilst keeping the breathing zone at the default position and therefore it is likely that a worker would have to lean forward. As a result the authors believe that the addition of a large flange along the base of a bench top enclosure, may force a worker, who needs to work with their hands and arms inside the enclosure, to lean forward leading to an increase in personal exposure. If a worker was able to work slightly away from plane of the opening – for example processes where the worker tends to stand with their breathing zone outside the plane of the enclosure such as paint spraying – then a large 45^o flange would likely improve containment. Furthermore, the large 45^o flange would be a useful addition to larger walk in enclosures, which have no lower edge.

Only the modified half round flange, which allowed air to pass between the wall of the enclosure and the flange, thus guiding air along the enclosure wall and effectively eliminating the wall eddies, significantly reduced the concentration in the breathing zone of the manikin. Where workers need to stand at the face of an enclosure the modified half round flange (or a similar design) should improve containment and reduce worker exposure.

Recommendations

1. Where full enclosure is not practical, partial enclosures should be considered.

2. Ideally a partial enclosure should include a transparent screen fitted between the operator breathing zone and the interior of the enclosure. This physical separation greatly reduces worker exposure.

Where this is not practical and an open fronted bench top enclosure is chosen, the following recommendations apply:

1. The source should be moved as far back into the enclosure as possible.

2. Leaning into the enclosure is highly likely to increase worker exposure and if this is unavoidable the work practices and enclosure design should be changed.

3. Designers and testers can often become fixated with the ‘correct’ face velocity (in this study, increasing the face velocity did not always reduce the concentrations measured in the manikin’s breathing zone). The enclosure design is of equal importance, particularly the enclosure entry conditions; enclosure design should be carefully considered.

4. The offset half round flange virtually eliminated the wall eddies and out performed the other flanges (including the no flange condition). In addition, it was the least obstructive. The authors think that this is the most practical flange design for small bench top enclosures.

5. The control performance of enclosures, particularly during commissioning, should be assessed with the worker present. Smoke is very useful for visualising air movement within the enclosure interior and assessing exposure of the worker and is therefore recommended.

1 INTRODUCTION

It is generally regarded that local exhaust hoods can be divided into 3 different types [1] [2]; enclosing, receiving and capturing hoods. It is also widely accepted that enclosing hoods are the most effective at reducing inhalation exposure to the worker as the process takes place inside the hood, making them less susceptible to external air disturbances, such as cross flows. Enclosing hoods are also more suited to controlling airborne contaminants with varying release energies, from processes that gently release contaminant laden air to process such as paint spraying where the release is very energetic.

Enclosing hoods vary in shape and size, ranging from large walk-in enclosures to smaller tabletop enclosures. A common enclosure encountered in an industrial setting is a small bench top partial enclosure, where the worker stands at the front of the open face in order to undertake the work task. These hoods tend to be of basic design and often consist of nothing more than a box like structure with an open front to allow worker access and extraction at the rear to remove contaminated air. With this type of common design the worker is forced to stand at the face of the enclosure and by doing so presents a blockage to the airflow. As the air flows around the worker a phenomenon known as boundary layer separation occurs. This manifests itself as a region of recirculation downstream of the worker. This region is often referred to as the ‘wake’. Since the worker faces downstream, any release of contaminant into the recirculating wake region has the propensity to enter the worker’s breathing zone. It is thought that this mechanism of exposure is frequently overlooked for this type of enclosing hood.

Given that these types of hoods are commonly used in industry and are frequently depicted in HSE guidance [1], there has been surprisingly little research carried out on their effectiveness at preventing worker exposure. In fact, from the literature survey carried out by the authors, only two studies were found that considered a bench top fully open fronted enclosure. The most relevant was a study carried out by Guffey et al [3] who investigated the effect of flanges and manikin position at a small bench top hood at half scale. The enclosure used in the study had a fully open face with a square cross-section. With the manikin positioned at the face of the enclosure, Guffey found that the face velocity was the dominating factor that affected breathing zone concentration. Essentially increasing the enclosure face velocity always decreased breathing zone concentrations. He also found that the flanges he considered, which were fitted to the face of the enclosure, did not lower breathing zone concentration. Jun (2003) [4] who studied both a capture hood and an enclosing hood, also found that as face velocity increased exposure decreased.

As well as the small number of studies carried out on small open fronted enclosures, the literature search highlighted a large number of references to studies on laboratory fume cupboards. Ahn (2008) [5] carried out a review of published quantitative experimental studies on factors affecting laboratory fume cupboards and identified 43 published studies between 1966 and 2006. To some extent it is not surprising that fume cupboards have received such a great deal of interest as they are widely used to control airborne contaminants in the laboratory setting and are particularly good at controlling airborne contaminants and reducing worker exposure to very low levels. The published studies cover a wide range of variables, but at first glance it is difficult to compare laboratory fume cupboards to those of the simpler small partial enclosures found in industry, mainly due to the differences in design and how they are used. However, there are a number of important findings from the many fume cupboard studies that should be considered as these findings may translate to open fronted enclosures. For example, studies have shown that; (1) the presence and position of a manikin in front of a fume hood increased leakage; (2) higher leakages were associated with the lack of good hood design – included non-aerodynamic design of the elements at the entry to the hood; (3) the face velocity (except in the extremely low or high range) was not the most important factor (noting that this conflicts with Guffey's and Ahn's findings), (4) the distance between the source and the breathing zone is important in reducing worker exposure and (5) lowering the height/area of sash opening reduced exposure. The latter point marks an important difference between the fully open fronted enclosure found in industry and a laboratory fume cupboard, which is the presence of a transparent sash that separates the worker's breathing zone from the process being carried out inside the fume cupboard. It is well understood and accepted (HSG 258) that this single addition to the industrial enclosure would have the greatest impact on reducing worker exposure.

However, it is also recognised that due to work processes it is often not possible to install a transparent 'sash' between the worker and the process. Therefore, the aim of this study was to investigate the design parameters that influence the control effectiveness of an open fronted small partial enclosure similar to those used in industry, and in particular to:

- identify key variables of small partial enclosure design
- identify how key variables interact
- produce design guidance for small partial enclosures

To meet these objectives the following parameters and their effect on breathing zone concentration were studied; face velocity, rear baffle design, flanges to alter the enclosure entry geometry and the presence of a manikin at the face of the enclosure. It is noted that Guffey concluded that flanges did not lower breathing zone concentrations, however, the flanges considered in this study are smaller, relative to the enclosure and the manikin, and include geometries other than those studied by Guffey.

2 METHOD

2.1 GENERAL

All tests were carried out in a purpose built, free standing, partial enclosure with overall dimensions of 1950 mm high by 1500 mm wide by 1000 mm deep. The open face was full width of the enclosure and positioned 950 mm from the floor giving an open face area of 1.5 m^2 as shown in Figure 2.1. This size is typical of a partial enclosure found in industry, although the test enclosure was manufactured from wood rather than sheet metal, so as to allow easy retrofitting and modification. It also had glass panels fitted to the sidewalls and ceiling to permit flow visualisation tests to be observed and filmed.

Air was extracted from the interior via a 250 mm circular opening positioned centrally in the rear of the enclosure. The design allowed for rear baffles to be fitted inside the enclosure and tests were carried out with baffles fitted at 250 mm from the rear panel, effectively making the enclosure 750 mm deep.

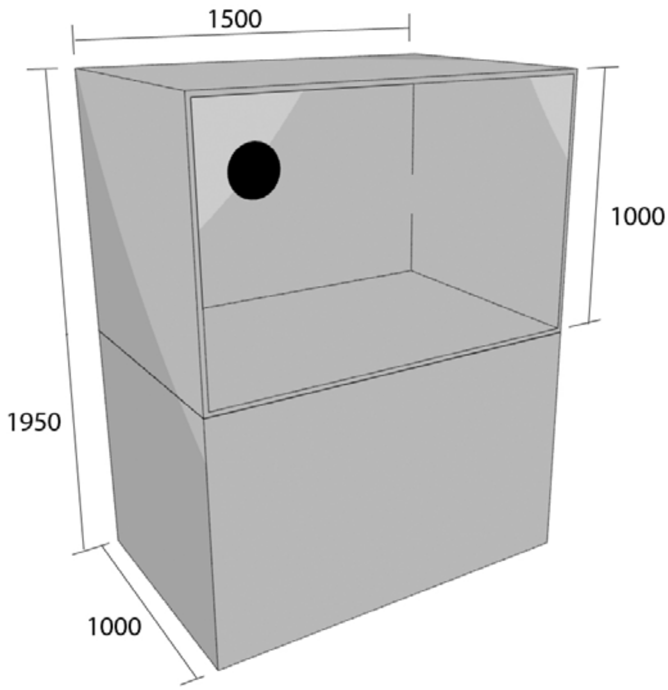


Figure 2.1 *Schematic of the enclosure with no baffle fitted*

To reduce the effects of disturbing draughts, the enclosure was placed inside a test room with a floor area of 4 m by 4 m and a height of 3 m, which was itself located within a larger laboratory. The enclosure was positioned centrally within the room 0.25 m from the rear wall of the test room.

Air extracted from the test room by the enclosure was replaced with air from the larger laboratory. To minimise draughts within the test room, the wall opposite the enclosure face was fully open. Measurements made at the plane of the open wall indicated that air speeds entering the test room were approximately 0.1 ms^{-1}.

The enclosure face velocities were derived from the volume flow rate through the enclosure, which was measured by a Wilson flow grid connected to a calibrated micromanometer. This was positioned in the duct between the enclosure and the fan. The fan speed, and hence the airflow rate through the enclosure, was adjusted by means of an inverter fitted to the fan. The extracted air was discharged to atmosphere to prevent re-entrainment of tracer gas laden air back into the test room. The default face velocity used during this study was 0.5 ms^{-1} (0.75 m^3s^{-1}) although some measurements were carried out at a lower face velocity of 0.3 ms^{-1} (0.45 m^3s^{-1}) and higher face velocity of 0.6 ms^{-1} (0.9 m^3s^{-1}) and 0.7 ms^{-1} (1.05 m^3s^{-1}).

Two different rear baffle designs were used during the study; a circular hole, identical in size and position to the one in the rear of the enclosure that represented a poor design, and one with slots (4 slots, each 30 mm high by 1300 mm long) that was designed to give a more uniform velocity at the face of the enclosure and therefore represented a better design. Both baffles were tested at 750 mm from the face of the enclosure. As the circular hole design in the baffle was identical to the opening in the in the rear of the enclosure, it meant that the effect of enclosure depth at 750 mm and 1000 mm could be compared with the circular baffle. The presence of the slotted baffle increased the hood static pressure, making it impossible to achieve the highest face velocity of 0.7 ms^{-1} (1.05 m^3s^{-1}) with the fan used in the study, and therefore some tests with the slotted baffle were carried out at 0.6 ms^{-1} (0.9 m^3s^{-1}).

In an attempt to improve the performance of the enclosure four flanges, designed to fit around the perimeter of the enclosure opening, were studied. Three flanges were constructed from different widths of flat panels, which when fitted to the enclosure face produced a surface at an angle of 45^o relative to each wall of the enclosure. The widths of the flanges studied were; 125 mm, 60 mm and 30 mm (i.e. the size of each flange was approximately half the width of the next larger flange). The fourth flange studied was semicircular in profile and was manufactured by cutting a 70 mm outside diameter plastic tube along its length. This formed a half round plastic flange. The outside edge of each flange was designed to fit flush to the inside walls of the enclosure. Duct tape was used to cover the joint and therefore fill any slight gap between the flange and the enclosure wall. The consequence of fitting each flange to the enclosure was that they protruded beyond the plane of the opening. The large 45^o flange protruded 88 mm, the medium and small flanges protruded 42 mm and 21 mm respectively and the half round flange protruded 35 mm. An illustration of the four flanges, showing the large flange fitted to the enclosure, is shown in Figure 2.2.

Partway through the study a further flange design was introduced, which was constructed from the same half round section as described above, but the overall width and height of the four sided flange was manufactured 70 mm shorter. This meant that when fitted the flange was offset by 35 mm and so created an air gap between the inside of the flange and the wall of the enclosure. Whilst it was more difficult to fit, it could be made to sit closer to the front edge of the enclosure walls and therefore did not protrude as far as the other flanges. This modified half round flange is discussed in more detail in Section 3.2.4.

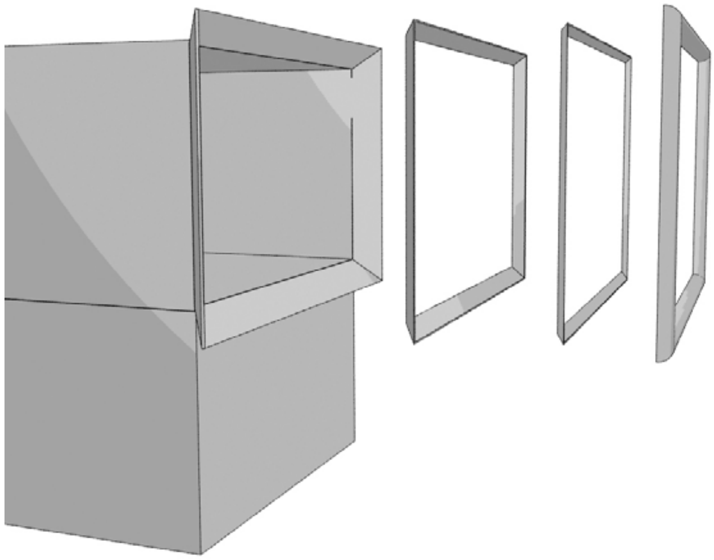


Figure 2.2 *Illustration showing the three 45^o flanges and the half round flange (The large flange is shown fitted to the enclosure)*

Assessment of the effectiveness of the enclosure was determined by carrying out tracer gas measurements. The tracer gas selected for the tests was a mixture of 17% sulphur hexafluoride (SF_6) with the remainder helium (He), which gave a neutrally buoyant tracer gas mixture. The tracer gas was released at various flow rates via three different ejectors detailed in Table 2.1 below and shown in Figure 2.3. The tubing to the ejectors passed through the floor of the enclosure so as to minimise disruption to the airflow. Air samples were taken from a number of positions from within the enclosure and pumped to a calibrated infrared spectrometer (Miran 1A) for gas analysis. The analogue signal from the instrument was connected to a data logging system which stored the data to a laptop computer. The exhaust from the Miran was discharged into the enclosure exhaust duct, which in turn was discharged to the outside.

Table 2.1 *Description of the ejectors used*

Ejector	***Description***	***Flow rate (l/min)***	***Comments***
Omnidirectional source 1	*Brass sintered diffuser used as the ejector in the fume cupboard EN 14175 standard*	*0.04*	*Used only to 'tag' the air in the enclosure whilst minimising disruption to the flow field*
Omnidirectional source 2	*40 mm diameter plastic sphere with 24 holes, each of 5.5 mm diameter*	*5.2*	*Low energy release*
Directional source	*28 mm internal diameter open tube*	*5.2 tracer gas plus 2.2 air Total=7.4*	*28mm diameter tube. Calculated discharge velocity of 0.2 m s^{-1} used to release tracer vertically, and with a cap fitted, to release tracer horizontally*

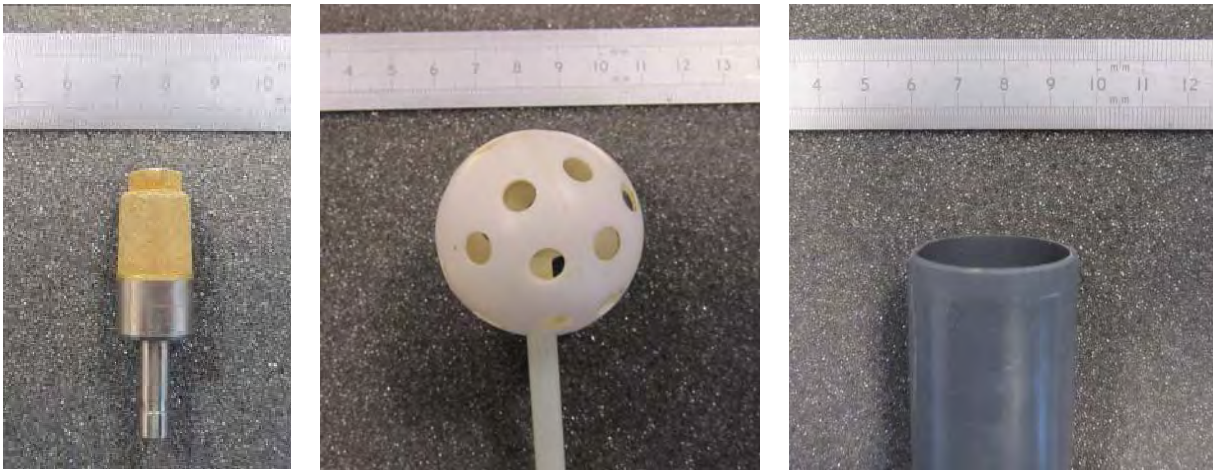


Figure 2.3 *Photographs of the three ejectors used.*
(From L to R: Omnidirectional source 1, Omnidirectional source 2 and the Directional source)

2.2 NO MANIKIN PRESENT AT THE FACE OF THE ENCLOSURE

2.2.1 Flow visualisation

Smoke pencils, which produce a fine filament of smoke, were used to visualise the flow around the face of the enclosure. In addition, a smoke machine, which produced large quantities of smoke, was used to study the larger ‘global’ movement of air around and within the enclosure.

2.2.2 Tracer gas tests

Tracer gas measurements using the Omnidirectional source 1 were carried out to quantify the flow visualisation and to gain a better understanding of the flow patterns within the enclosure with and without the large 45^{o} flange fitted and no rear baffle fitted. The ejector was positioned midway along the width of the enclosure, 20 mm from the base and 150 mm in from the open plane of the face. Whilst tracer gas was released, air samples were taken along the symmetry plane (front to rear) of the enclosure so as to build-up a concentration profile. Test duration was 360 s, with the average concentration measured at each sample position calculated based on the data gathered between 60 s and 360 s, thus allowing 60 s for the airflow patterns in and around the enclosure to stabilise. Measurements were taken along the centreline of the floor of the enclosure with and without the large 45^{o} flange. All tests were performed at the default face velocity of 0.5 ms^{-1}.

In addition to the above, further tests were also carried out to investigate the lateral spread of the tracer gas. The release position remained in the same position while air samples were taken across the width of the enclosure. Tests were carried out for all three flanges and with no flange fitted. The test duration and flow rate though the enclosure remained the same.

2.2.3 Velocity measurements

Air velocity measurements were made at the face of the enclosure with no flange fitted using an array of three calibrated hot wire anemometers connected to a data logging system and laptop computer. The objective of the measurements was not to calculate the flow rate through the enclosure, as this was determined based on the Wilson flow grid measurement, but rather to study the uniformity of the air velocity at the face for each rear baffle. The measurement positions were established by dividing the open face of the enclosure into 50 imaginary rectangles (10 across the width of the face by 5 high). Velocity measurements were then made at the centre of each of the imaginary rectangles. The air velocity was logged every second for 60 s and the mean velocity was then calculated. Measurements were made at face velocities of 0.3 ms^{-1} and 0.5 ms^{-1} with both rear baffles and with no baffle fitted.

2.3 MANIKIN POSITIONED AT THE FACE OF THE ENCLOSURE

2.3.1 The manikin

The manikin used in the study was 1.83 m (6 ft) tall and had a shoulder width of 0.45 m. The arms were straight, but were moveable at the shoulder joint. The manikin was positioned centrally at the face of the enclosure with the arms positioned inside and close to the floor of the enclosure, either side of the tracer gas release position.

2.3.2 Tracer gas tests and flow visualisation

Smoke was also used to visualise the airflow patterns in and around the enclosure with the manikin present, as described in Section 2.2.1.

Tracer gas tests were also carried out with both the Omnidirectional source 2 and the Directional source. The Omnidirectional source 2 was used with the 45^{o} flanges, the half round flange and with no flange fitted. The default release position was 150 mm in from the front edge of the open face and 50 mm to the centre of the source from the floor of the enclosure, although other positions were also tested. The directional source was used with the modified half round flange and with no flange fitted. The default release position was 150 mm in from the front of the enclosure, although tests were carried out at distances of 300 mm and 450 mm. The release heights were 18, 35, 70 and 140 mm above the floor of the enclosure.

The breathing zone sampling point was positioned at the end of the manikin’s nose in the plane of the open face. Figure 2.4 shows the manikin positioned at the face of the enclosure. Note that when a flange was added, the manikin’s position was adjusted so that the sample position remained in the plane of the opening. However, to achieve this it was necessary to lean the manikin forward slightly (as a worker would have to). This will have resulted in a slightly lower sample position. For the large 45^{o} flange the manikin position was such that measurements were only made with the sampling position 60 mm from the plane of the opening.

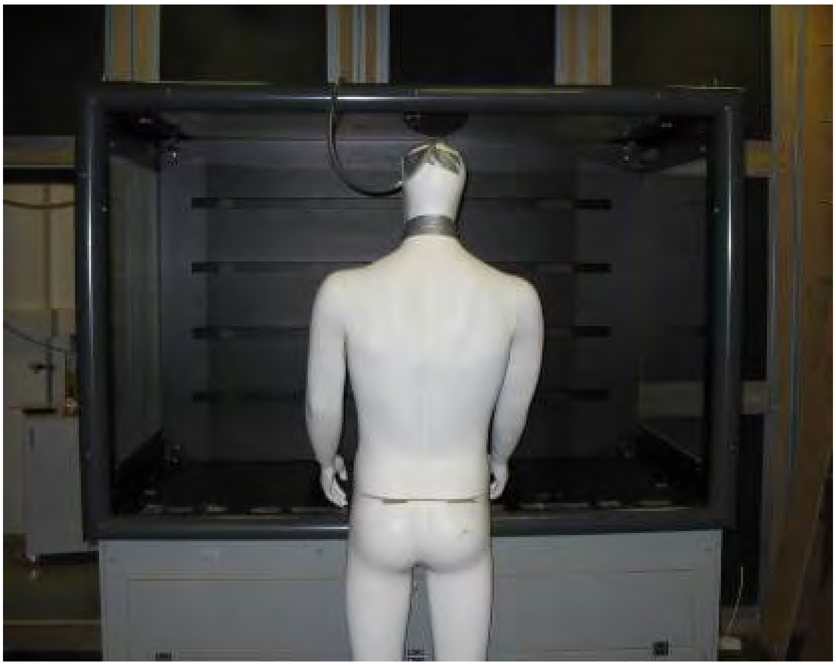


Figure 2.4 *Shows the manikin positioned at the face of the enclosure (Note the slotted rear baffle and half round flange fitted)*

Preliminary tests were carried out with the manikin clothed, but test results were not repeatable, therefore all tests included in this report are with the manikin unclothed. In addition, tests were carried out where the manikin was replaced by a volunteer.

The tracer gas tests were 540 s in duration with each test repeated three times (unless specified) and the average concentration of the three tests reported. For all tests a period of 60 s was allowed to lapse to allow the flow patterns in and around the enclosure to stabilise before tracer gas was released and logging commenced.

3 RESULTS

3.1 MEASUREMENTS AND AIRFLOW OBSERVATIONS WITHOUT THE MANIKIN

3.1.1 Velocity measurements

Table 3.1 below summarises the velocity data taken at the open face of the enclosure.

Table 3.1 *Summary of the velocity measurements made at the open face of the enclosure at 0.3 and 0.5 ms^{-1} for both rear baffles and with no rear baffle fitted*

Baffle	*Volume flow rate m^{3}s^{-1}(ms^{-1})*	*Distance from open plane to the baffle mm*	*Mean velocity ms^{-1}*	*Min velocity ms^{-1}*	*Max velocity ms^{-1}*	*Std dev velocity ms^{-1}*
Slotted	*0.45 (0.30)*	*750*	*0.30*	*0.15*	*0.36*	*0.04*
Circular	*0.45 (0.30)*	*750*	*0.30*	*0.09*	*0.37*	*0.06*
Circular	*0.45 (0.30)*	*1000*	*0.30*	*0.09*	*0.38*	*0.06*
Slotted	*0.75 (0.50)*	*750*	*0.50*	*0.33*	*0.59*	*0.06*
Circular	*0.75 (0.50)*	*750*	*0.51*	*0.22*	*0.68*	*0.09*
Circular	*0.75 (0.50)*	*1000*	*0.48*	*0.28*	*0.61*	*0.07*

From Table 3.1 the following can be noted; the lower flow rate gave a more uniform face velocity; the average of each velocity profile could accurately be used to calculate the actual volume flow rate. Whilst the velocities at the face of the enclosure were relatively uniform for all baffles, the slotted baffle gave the best uniformity, followed by the circular opening positioned at 1000 mm.

For a graphical comparison, Figures 3.1 and 3.2 show the flooded velocity contour plots for the circular and slotted rear baffle respectively, both fitted at 750 mm from the open plane of the enclosure to the rear baffle and at a flow rate of 0.75 m^{3}s^{-1}. It can be seen the slotted rear baffle gave a more uniform face velocity, with the circular baffle producing a lower velocity close to both vertical walls of the enclosure. This pattern was repeated at the lower volume flow rate and with no baffle fitted. Appendix 1 contains all the graphs, together with plots showing the velocity data labels.

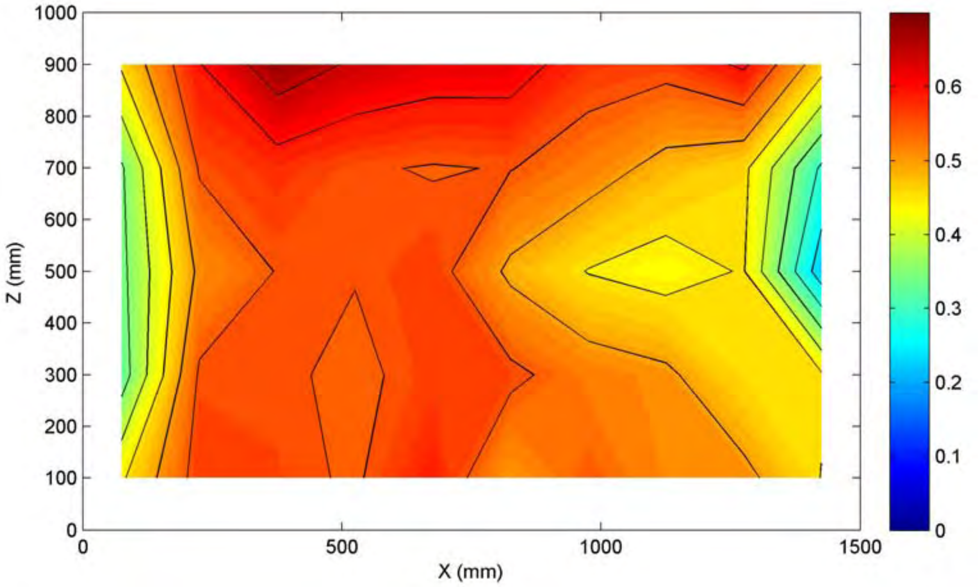


Figure 3.1 *Flooded velocity contour plot at the face of the enclosure.*
Circular rear baffle at 750 mm (0.75 m^3s^{-1}) Note: units of right hand scale are ms^{-1}

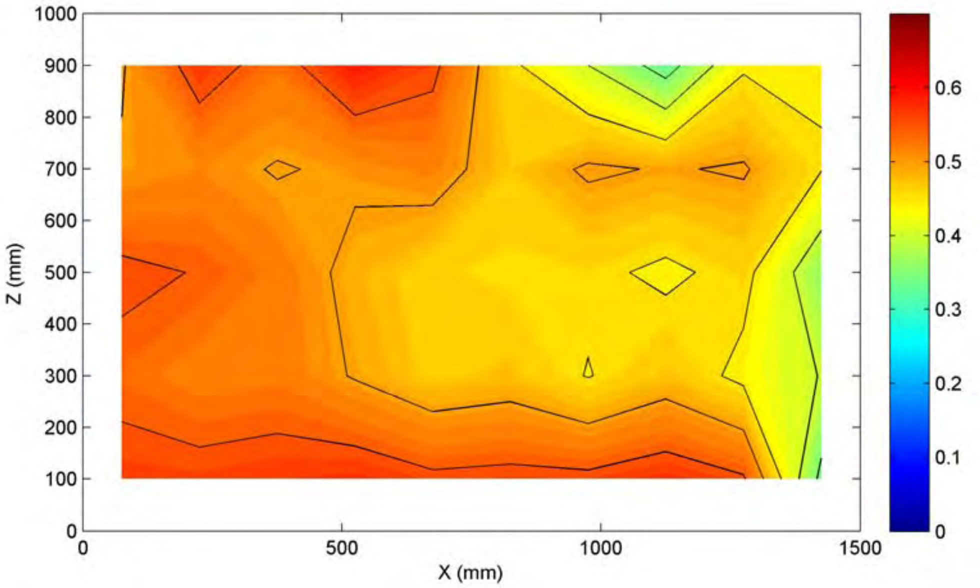
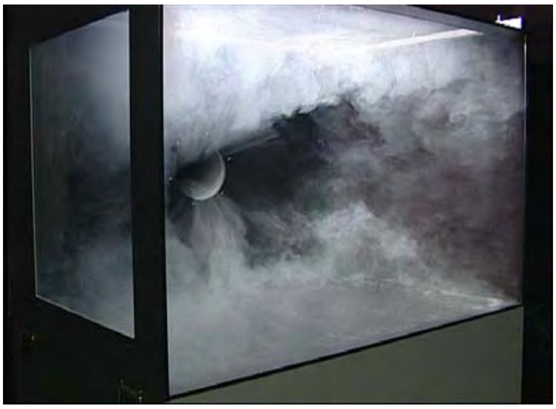


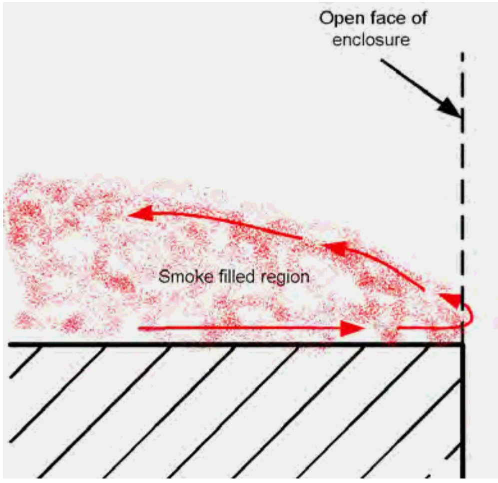
Figure 3.2 *Flooded velocity at the face of the enclosure.*
Slotted rear baffle at 750 mm (0.75 m^3s^{-1}) Note: units of right hand scale are ms^{-1}

3.1.2 Flow visualisation

The flow visualisation work showed that without a flange fitted large areas of recirculation were apparent against all four walls of the enclosure. The areas of recirculation were largely independent of the rear baffle design, but linked more to the entry conditions of the enclosure. As the air entered the enclosure it was noted that that the airflow was unable to follow the relatively angular geometry of the walls. This resulted in the flow separating at the front edge and creating an area of slightly lower pressure. This in turn caused flow reversal as the air was drawn into this low pressure region.

Figure 3.3a is a screen grab from a video clip where the smoke machine was used to fill the enclosure. The screen grab was taken 5 seconds after smoke production ceased. The large areas of recirculation are picked out by the presence of the smoke. Figure 3.3b shows an illustration of the wall eddy with no flange fitted. In addition, the smoke tests highlighted that the wall eddies extended beyond the plane of the opening, as can be seen from Figure 3.4, which shows the enclosure viewed from the side. It was noted that any disturbing draught close to the face of the enclosure was sufficient for the smoke to escape into the test room.





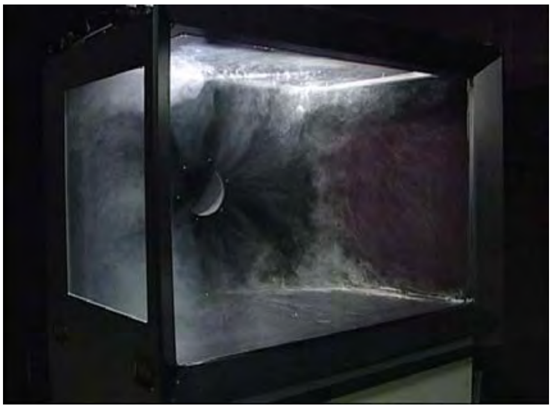
(a) (b)

Figure 3.3 *Enclosure with no flange fitted (a) Wall eddies made visible using smoke 5 seconds after smoke production was halted (b) illustration of wall eddies based on flow visualisation – side view of the floor of the enclosure*

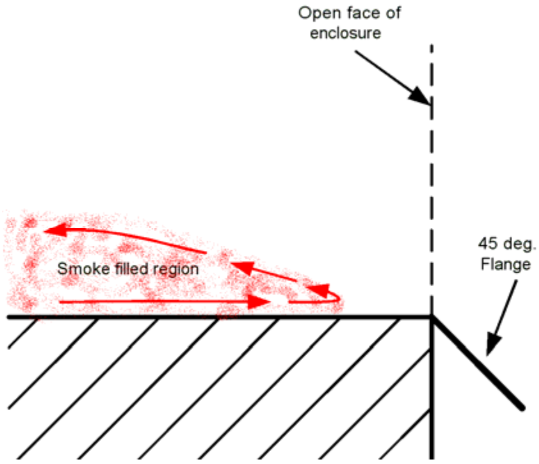
Figure 3.4 *Enclosure viewed from the side showing wall eddies protruding beyond the plane of the enclosure opening (see right of picture)*

With the large 45° flange fitted, the wall eddies were noticeably smaller and did not extend as far from the enclosure wall, as shown schematically in Figure 3.5b.

It was evident from the flow visualisation tests that the enclosure cleared of smoke quicker with the large flange fitted than without. This effect is shown to some extent when comparing Figure 3.3a and 3.5a, which show the enclosure with and without the large 45^{o} flange fitted 5 s after smoke production ceased. It can be seen that there is noticeably less smoke after 5 seconds with the flange fitted.



(a)



(b)

Figure 3.5 *Enclosure with large 45^{o} flange fitted (a) Wall eddies made visible using smoke 5 seconds after smoke production was halted (b) illustration of wall eddies based on flow visualisation – side view of the floor of the enclosure*

3.1.3 Tracer gas tests

Results of the tracer gas tests made along the symmetry plane (front to rear) of the enclosure are shown in Figure 3.6. The Figure shows the measured tracer gas concentrations results represented as a flooded contour plot. (Note the tracer gas release position is represented by the black cross). The tracer gas concentrations give an indication of the size of the eddy against the floor of the enclosure, and showed that the eddy extended close to 200 mm above the floor of the enclosure only 150 mm into the enclosure. Tracer gas concentrations upstream of the release point were higher than any measurement downstream, showing that the tracer gas was transported from the release position (150 mm in from the front edge of the enclosure) towards the face of the enclosure, against the predominant flow direction. Compare this with Figure 3.7, which shows the same experimental conditions but with the large 45^{o} flange fitted. It can be seen that the tracer gas concentrations do not extend as far from the floor of the enclosure and the eddy is pushed back from the front plane, resulting in higher concentrations extending further into the enclosure. It is clear that the tracer gas is again transported upstream of the release position, indicating that an eddy, although smaller, still exists. However, the concentrations upstream are considerably lower (24.8 ppm measured 20 mm in from the face of the enclosure compared to 8.6 ppm at the same position with the large 45^{o} flange fitted).

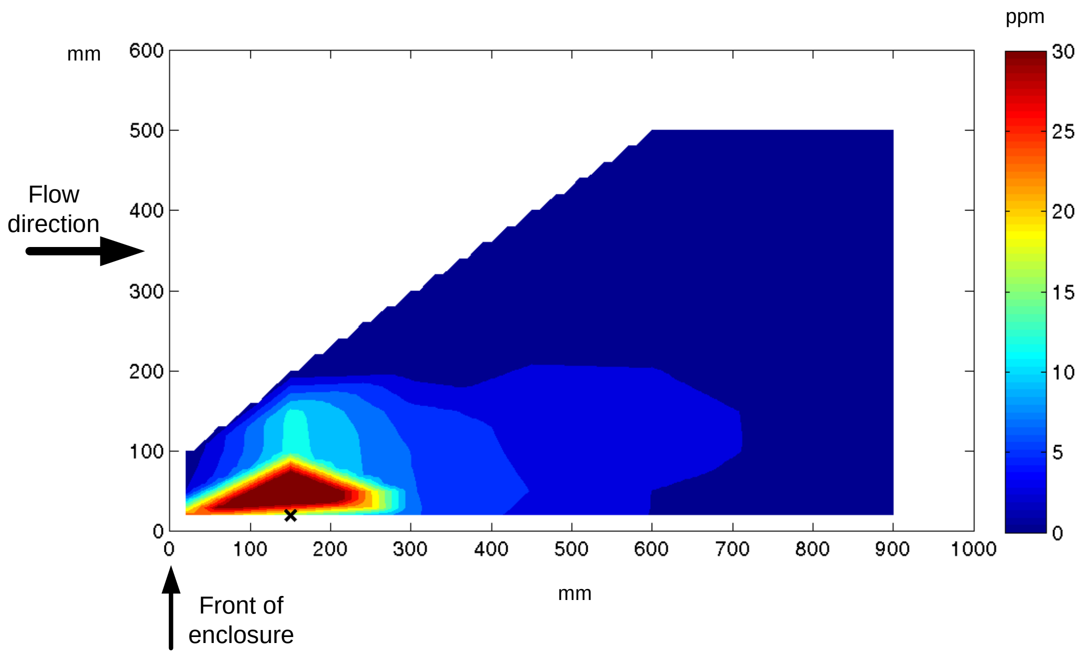


***Figure 3.6** Flooded concentration contour plot along the centre-line (front to rear) of the enclosure with no flange fitted (0.75 m^3s^{-1})*

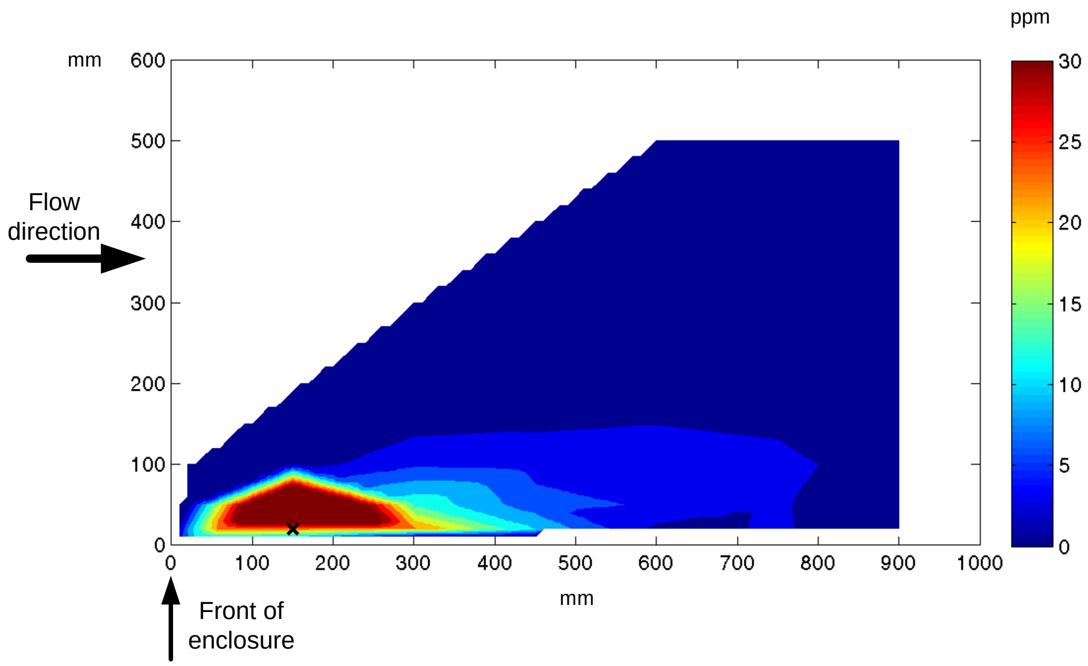


***Figure 3.7** Flooded concentration contour plot along the centre-line (front to rear) of the enclosure with the large 45^o flange fitted (0.75 m^3s^{-1})*

To explore the spread of the tracer across the width of the eddy, air samples were taken either side of the release position (same height and distance into the enclosure). Figure 3.8 below shows the concentrations measured across the width of the enclosure with no flange and the 3 different 45° flanges fitted.

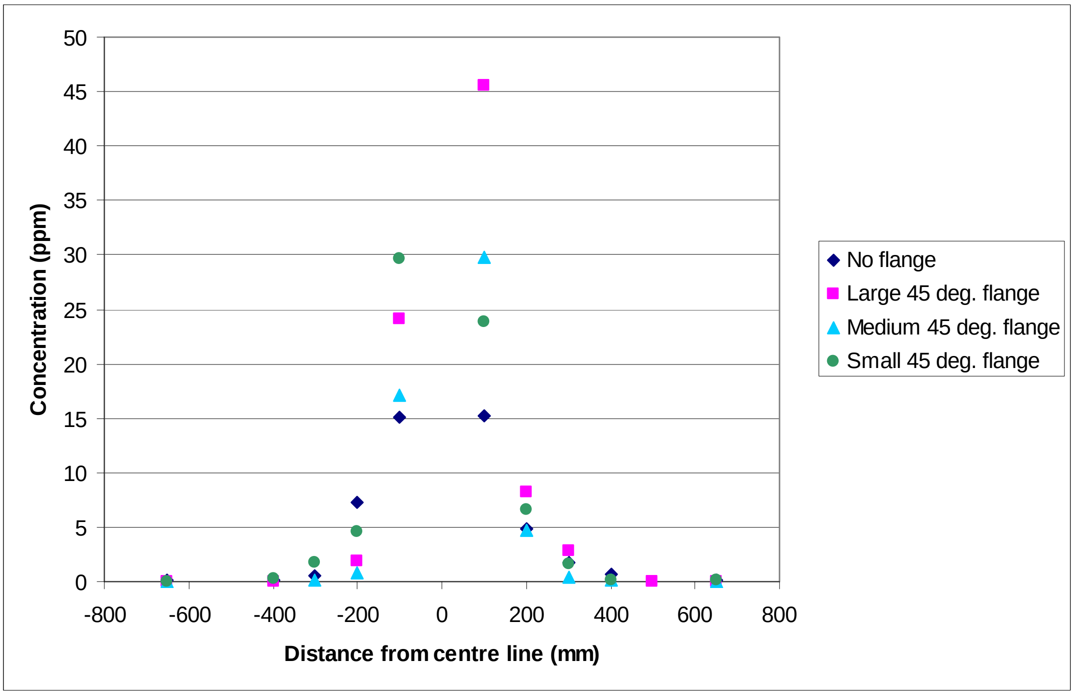


Figure 3.8 *Tracer gas concentrations either side of the release position*

Figure 3.8 shows that the tracer does not spread uniformly throughout the eddy and fails to reach the side walls of the enclosure, but does demonstrate some lateral spread from the source caused by mixing within the eddy.

There is the suggestion of a slight asymmetry to the data, therefore, where data was available, the concentration measurements equally spaced about the release position have been averaged and are given in Table 3.2 below. From the table it can be seen the presence of the flanges creates a higher concentration at the measurement position closest to the release position, with the largest flange creating the highest concentration. Overall the flanges do not dramatically affect the fall in tracer gas concentration with distance, although it could be argued that the large and medium flanges have a marginal effect.

Table 3.2 *Average of the equidistant concentration measurements from the release position*

Dist. from release point (mm)	*Average of measured concentration (ppm)*			
	No flange	*Small 45° Flange*	*Medium 45° Flange*	*Large 45° Flange*
100	*15.5*	*26.7*	*23.4*	*34.8*
200	*6.1*	*5.6*	*2.7*	*5.0*
300	*1.2*	*1.7*	*0.0*	*1.5*
400	*0.4*	*0.2*	*0.1*	*0.1*
500	*0.1*			*0.0*
650	*0.1*	*0.1*	*0.1*	*0.0*

3.2 MEASUREMENTS AND AIRFLOW OBSERVATIONS WITH THE MANIKIN PRESENT

3.2.1 Flow visualisation

With no flange fitted the large recirculating eddies were visible against the walls of the enclosure, however, immediately in front of the manikin the airflow was highly turbulent due to the presence of the manikin in the airstream. An interaction between the turbulent wake and the eddy against the floor of the enclosure was observed. When tests were repeated with a person present rather than a manikin, significantly more smoke appeared to enter the breathing zone of the person. The authors could not replicate this with the manikin present. However, a number of tracer gas tests were carried out with a volunteer in order to compare the difference between a person and the manikin. These are reported in Section 3.2.2.

3.2.2 Tracer gas tests with Omnidirectional Source 2

3.2.2.1 Volunteer versus manikin

As mentioned above, flow visualisation tests with a manikin present produced significantly different flow patterns compared to when the enclosure was unobstructed and interestingly there were some differences compared to the presence of a person. To explore this further a small number of tests were carried out with the sample position fixed at the breathing zone position in the plane of the enclosure opening, with (i) the manikin present, (ii) a person present and (iii) no obstruction. The enclosure had no baffle fitted and the face velocity was set to 0.3 ms^{-1} with the tracer gas release at the default position (150 mm in and 50 mm to the centre of the perforated ball). The average of three repeat tests with the manikin present was 1.54 ppm, with a person present the breathing zone concentration was 102 ppm. With no obstruction the Miran infrared analyser did not detect any gas at all.

The zero reading with no blockage present at the face of the opening is understandable as there is no obvious mechanism for the tracer gas to reach the breathing zone position. The large concentration difference between the manikin and the volunteer is interesting and this could be due to a combination of factors, such as (i) temperature effects as the manikin was unheated, (ii) the manikin was unclothed and had smooth surfaces, which was likely to reduce air friction and may have affected the amount of mixing within the wake region, and (iii) the manikin was quite slim around the midriff and presented less of a blockage than the person. It is the latter which is thought to be the main factor.

Whilst the large measured differences in concentration between the presence of a person and the manikin are noted, it was not realistic to conduct the whole study using a person.

3.2.2.2 Effect of flanges and rear baffle on breathing zone concentration

Figure 3.9 shows data for the slotted baffle fitted at 750 mm at face velocities of 0.3 and 0.5 ms^{-1}. Data with the large flange is included, although it should be noted that the sample position was 60 mm away from the plane of the opening. The results are a little mixed with no clear pattern to the data. For example, it is difficult to state how the breathing zone concentration is influenced with increasing face velocity as 3 flanges appear to cause an increase, whilst the small flange and the no flange condition cause a decrease. With the sample position at the plane of the opening, the half round flange performed the best, giving the lowest breathing zone concentrations. The highest breathing zone concentration was recorded (>12 ppm) at 0.3 ms^{-1} face velocity with no flange fitted. However, when the face velocity was increased to 0.5 ms^{-1} the breathing zone concentration fell to approximately 1.5 ppm.

The data for the large flange is difficult to interpret as the sample position was not at the plane of the opening. For example the results show that the average concentrations are the lowest, but it is not clear if this is due to the presence of the large flange or that fact that the sample position was further from the plane and the tracer release position, although the position of the breathing zone is considered further in Section 3.2.3.3.

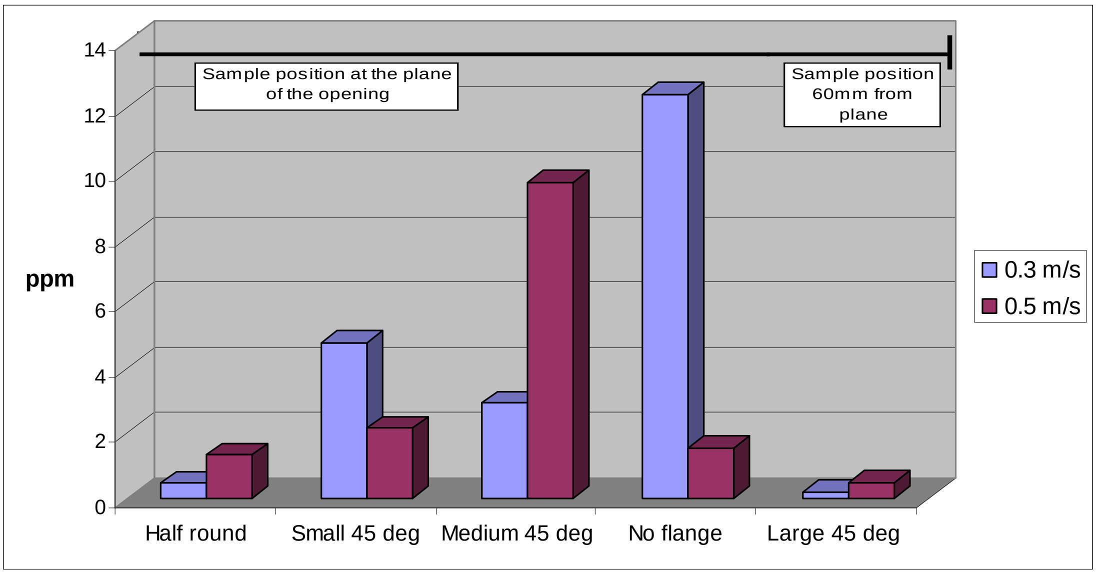


Figure 3.9 *Breathing zone concentration for four flanges and the no flange condition at two face velocities (slotted baffle fitted)*

Figure 3.10 shows the measured breathing zone concentrations for three different flanges and the no flange condition at three different face velocities with the circular baffle fitted at 750 mm.

For all flanges it can be seen that as the face velocity was increased the breathing zone concentration also increased. In addition, all the flanges produced an increased breathing zone concentration when compared to the data with no flange fitted. Data for the large 45^{o} flange is not included as, previously mentioned, the sampling position was 60 mm away from the plane of the opening and this makes it difficult to compare the data.

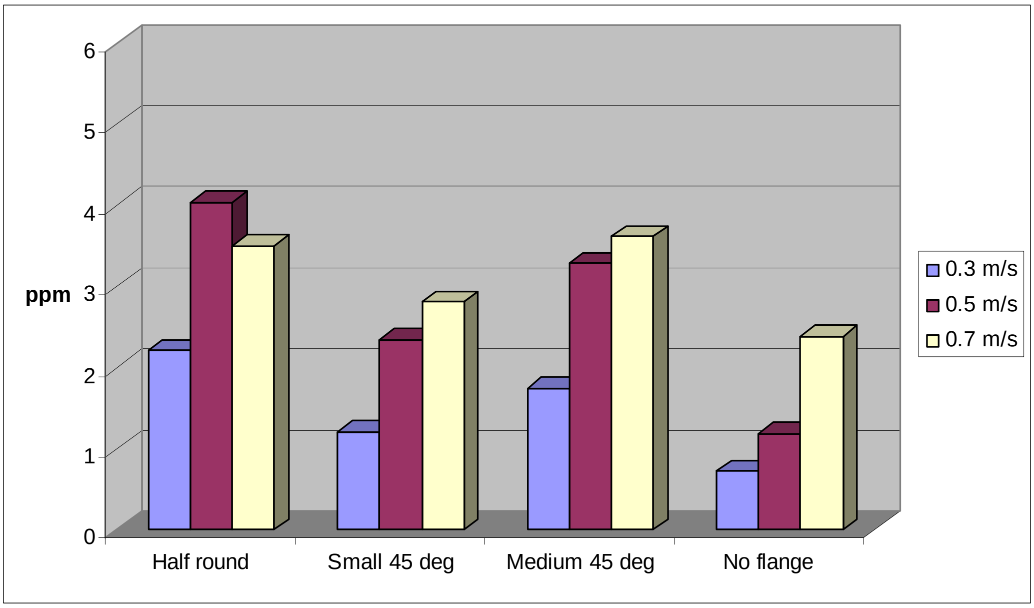


Figure 3.10 *Breathing zone concentration for three flanges and the no flange condition at three face velocities (Circular baffle fitted at 750 mm)*

With no baffle fitted the geometry of enclosure was essentially the same as with the circular baffle, but an additional 250 mm deeper. Data for three of the flanges are shown below in Figure 3.11. The graph shows that the half round and small 45^{o} flanges gave similar results, although the small 45^{o} flange performed slightly better. Nevertheless, both flanges produced a reduction in the breathing zone concentration as the face velocity was increased. This is contrary to the data with the baffle at 750 mm. The medium 45^{o} flange gave the lowest breathing zone concentration at 0.3 ms^{-1} face velocity, however, the data for the medium 45^{o} flange was generally higher than the comparable data when the baffle was at 750 mm. Further comparisons of both sets of data show that the best results are produced with no flange fitted.

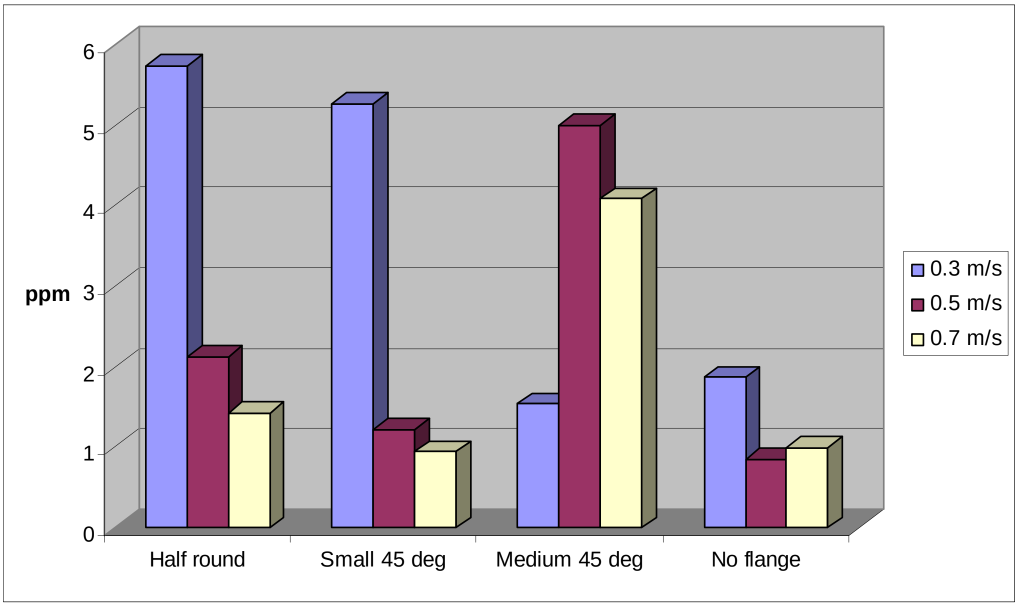


Figure 3.11 *Breathing zone concentration for three flanges and the no flange condition at three face velocities (Circular extraction opening at 1000 mm)*

3.2.3 Tracer gas tests with Directional Source

3.2.3.1 Effect of release direction close to the floor of the enclosure

The 28 mm diameter tube was passed through the floor of the enclosure floor. This minimised disruption to the airflow and allowed the discharge height to be easily altered. The tracer was released vertically for most of the tests, however, a number of tests were carried out with a horizontal release close to the floor of the enclosure. This was achieved by positioning the top of the tube 18 mm from the floor of the enclosure and placing a 52 mm diameter cap over the open end. The cap sat on the floor of the enclosure and had four openings around its perimeter, each 90^{o} to one another (the front and rear openings were approximately 36 mm wide by 18 mm high whilst the side openings were approximately 24 mm wide by 18 mm high). By covering one or more of the openings the release direction relative to the manikin and the enclosure could be altered. See Figure 3.12.

Tracer gas tests were carried out with the rear slotted baffle fitted and the face velocity set to 0.3 ms^{-1}. No flange was fitted. The centre of the directional ejector was positioned 150 mm from the face of the enclosure and the concentration in the manikin's breathing zone measured for different source release directions. The average breathing zone concentrations, based on three repeat tests are presented in Table 3.3.

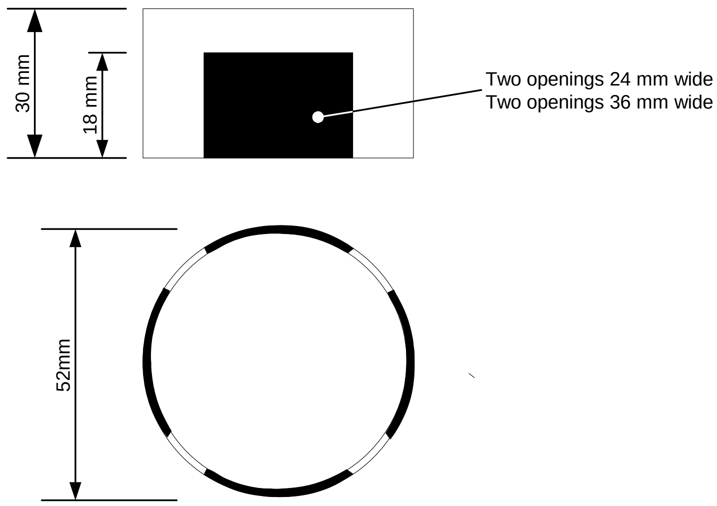


Figure 3.12 *Geometry of the cylindrical cap placed over the open end of the 28 mm tube*

Table 3.3 *Effect of release direction on the manikin breathing zone concentration*

Release direction	***Breathing zone concentration (ppm)***
Vertical release 18 mm from floor of enclosure (no cap fitted)	*6.1*
Horizontal release in all directions (all four slots open)	*10.8*
Horizontal release away from the manikin (Slot facing rear of enclosure open, 3 remaining slots covered)	*7.3*
Horizontally towards the side walls and the rear of the enclosure (1 slot facing manikin covered)	*3.2*

Instinctively one would expect the highest breathing zone concentration to be measured when the tracer gas was released vertically towards the breathing zone. In fact the highest concentration measured was when the tracer gas was released horizontally in all directions. The release would have entered the eddy, which would have been present on the floor of the enclosure, and subsequently into the wake region in front of the manikin before entering the breathing zone. With a portion of the tracer directed toward the manikin one can see why this arrangement produced the highest breathing zone concentrations.

With tracer released via the opening facing the rear of the enclosure, the mean breathing zone concentration was measured to be 7.3 ppm. This is high considering that the tracer was directed away from the manikin's torso. Again it is likely that the tracer would have been caught in the eddy and recirculated back towards the manikin and into the wake region. The lowest mean concentration measured was with all slots open except the one facing the manikin. In this configuration approximately two thirds of the tracer laden airflow would have been directed towards the sides of the enclosure and possibly outside of the wake region.

This data demonstrates that when the release is directly in front of the manikin the eddy against the floor of the enclosure interacts with the wake region, created by the presence of the manikin, resulting in the tracer gas reaching the manikin's breathing zone.

To explore this further the release point was moved sideways both to the left and right by 375 mm i.e. positioned a quarter of the width from the centre line and to the side of the manikin. The release height and distance into the enclosure remained the same, as did the other variables. For these tests the discharge direction was vertical. Table 3.4 summarises the data.

Table 3.4 *Comparisons of breathing zone concentrations with lateral position of the source*

Release position relative to the centre of the enclosure (mm)	***Breathing zone concentration (ppm)***
0	*6.1*
-375	*0.4*
375	*0.8*

When the release is to one side of the manikin, tracer gas is still detected in the breathing zone but at a much lower concentration. This is probably because the tracer does not spread uniformly throughout the wall eddy, as shown in Figure 3.8, and demonstrates that once the release position is outside of the wake region, the breathing zone concentrations are much lower.

3.2.3.2 Release height and distance from the manikin

A series of measurements were carried out with the directional source positioned at different heights above the floor of the enclosure at the default position (150 mm), 300 mm and 450 mm in from the plane of the opening. The slotted baffle was fitted, but the no flange was fitted.

Figure 3.13 and 3.14 below show the data for face velocities 0.3, 0.5, and 0.6 ms^{-1}.

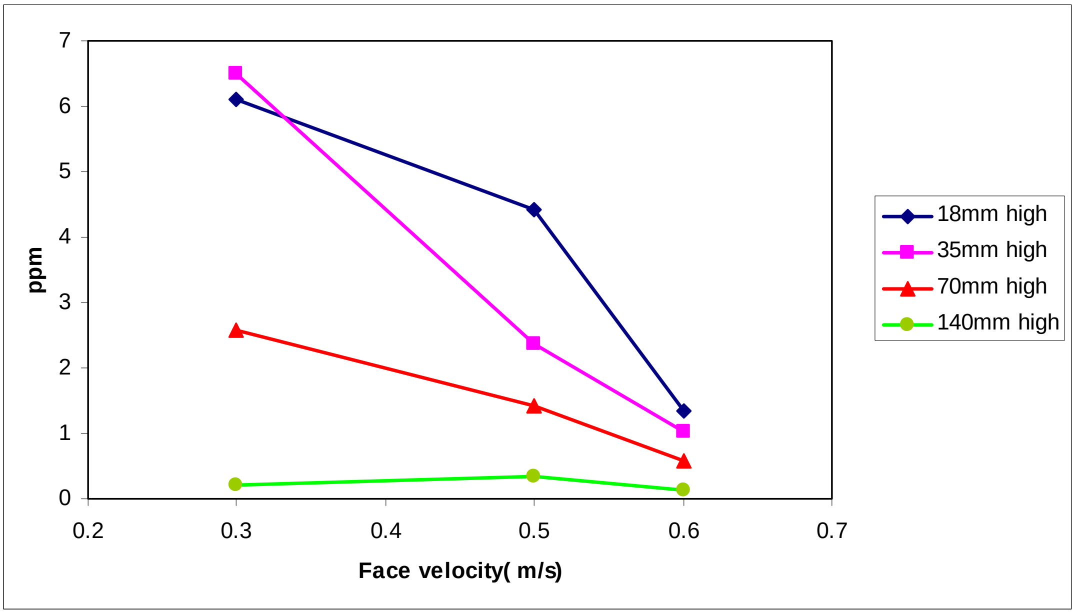


Figure 3.13 *Breathing zone concentration plotted against enclosure face velocity for various release heights*
(Tracer gas released 150 mm from plane of the opening)

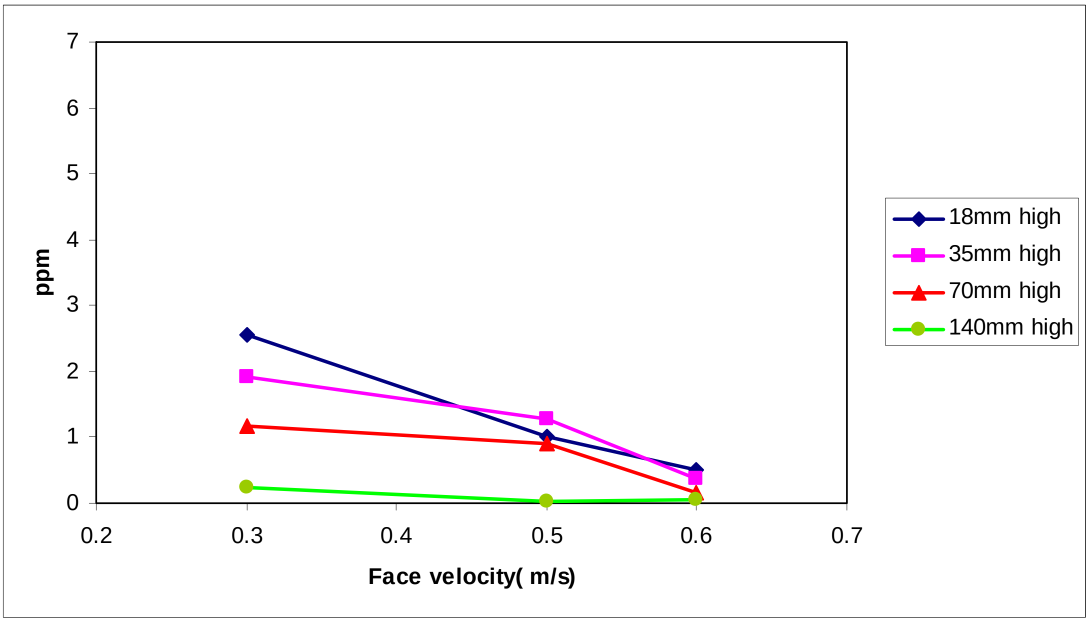


Figure 3.14 *Breathing zone concentration plotted against enclosure face velocity for various release heights*
(Tracer gas released 300 mm from plane of the opening)

Figure 3.13 shows that for all release heights, as the face velocity is increased the breathing zone concentration decreases. In addition, as the release position is raised, the concentration in the breathing zone also decreases. It is likely that at the three lower release heights, as supported by the flow visualisation tests, the tracer gas is recirculated within the eddy on the floor of the enclosure and that in turn interacts strongly with the wake in front of the manikin resulting in a higher breathing zone concentration.

When the release position was positioned 300 mm from the face of the enclosure, and therefore further from the manikin, (Figure 3.14) a similar pattern is observed, i.e. increasing face velocity results in decreasing breathing zone concentration and as the release position is raised the breathing zone concentration falls. However, comparing the data at 300 mm to that at 150 mm, it is evident that the breathing zone concentrations are lower with the release position at 300 mm.

The release position was moved in a further 150 mm to 450 mm from the face of the enclosure. At all three face velocities and all four heights, the concentrations measured were less than 0.1 ppm.

Therefore, moving the release position further from the manikin reduces breathing zone concentration. In this scenario moving the source from 150 mm from the face of the enclosure to 300 mm gave, on average, a 40% lower breathing zone concentration.

3.2.3.3 Position of manikin breathing zone relative to the plane of the enclosure

In a real situation it is likely that a person will lean into an enclosure, particularly if they are carrying out a task below head height. To investigate this, tests were carried out with the manikin at the default position and leaned into the enclosure so that the breathing zone was 50 mm beyond the plane of the opening.

Tests were carried out at the default face velocity of 0.5 ms^{-1} with the slotted baffle in place and the Directional source positioned at the default position, 150 mm from the face of the enclosure. Tests were repeated with no flange and with the half round flange fitted at two tracer gas release heights; 35 mm and 70 mm. The data is summarised in Table 3.5 below.

Table 3.5 *Effect of manikin position on breathing zone concentrations*

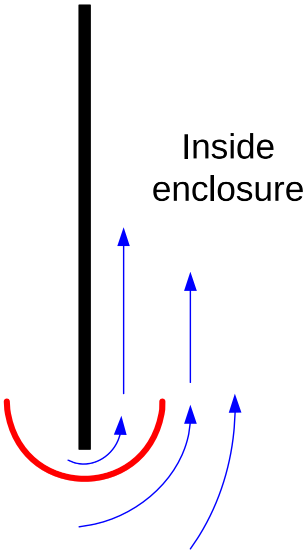
	No flange		***Half round flange fitted***	
Tracer release height (mm)	***Breathing zone in the plane of the opening (ppm)***	***Breathing zone 50 mm beyond the plane of the opening (ppm)***	***Breathing zone in the plane of the opening (ppm)***	***Breathing zone 50 mm beyond the plane of the opening (ppm)***
35	*0.69*	*1.26*	*2.8*	*47.7*
70	*0.41*	*0.94*	*2.45*	*26.8*

With no flange fitted and the tracer gas release height at 35 mm, the breathing zone concentration approximately doubled when the manikin was leant 50 mm beyond the plane of the opening. The same occurred when the release height was raised to 70 mm from the floor of the enclosure, although the mean concentrations were lower.

With the half round flange fitted, the same trend was noted. However, the breathing zone concentrations increased dramatically when the manikin leaned 50 mm into the enclosure (more than a 10 fold increase). A possible reason for this is the difference in the angle of the manikin relative to the vertical plane. The half round flange protruded 35 mm outwards from the plane of the opening, this meant that the manikin had to be leant further forward in order to achieve the same breathing zone positioning than for the no flange condition. Therefore the angle to the vertical plane would have been greater with the half round flange fitted. Flow visualisation tests using smoke with a small flat panel placed against the face of the enclosure showed that as the panel was leaned forward into the enclosure an increase in smoke drawn up the front of the panel was noted. It is suspected that a similar process was occurring when the manikin was learned forward.

3.2.4 The modified half round flange

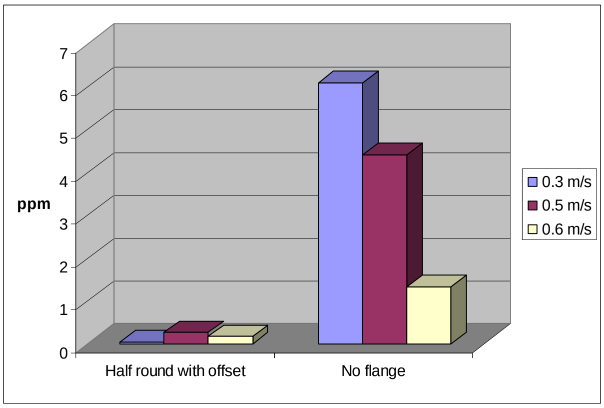
It was apparent that the addition of a flange did not produce a reduction in the breathing zone concentration of the manikin. Therefore a modification was made to the design of the half round flange as described in Section 2.1. By offsetting the flange by 35 mm an air gap was created between the edge of the enclosure and the inside of the flange. Air entering this gap was guided into the enclosure and directed parallel to the face of the walls, thus purging the wall eddies. Flow visualisation showed that this new design virtually eliminated the wall eddies. In addition, it allowed the flange to be mounted closer to the edge of the enclosure and also ensured there was a gap for air to pass between the front edge of the enclosure and the torso of the manikin. In should be noted that as the enclosure had a vertical panel from the base of the enclosure to the floor, the size of the flange needed to be reduced in order to maintain the gap along lower edge. This is shown in a Figure 3.15a below, which shows the lower left hand corner of the face with the flange fitted. Figure 3.15b shows an illustration of the flange and the flow in the immediate vicinity (a video clip is also available).



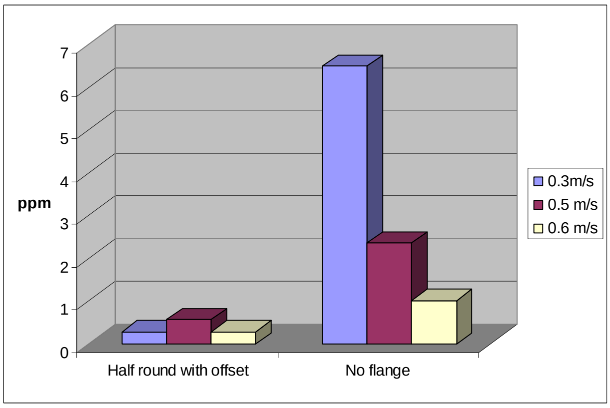
(a) (b)

Figure 3.15 *(a) Photograph of the modified half round flange fitted showing the lower left hand corner – note the modification required to maintain a gap along the base. (b) Illustration of the air flow around the modified half round flange (shown in red) based on flow visualisation tests*

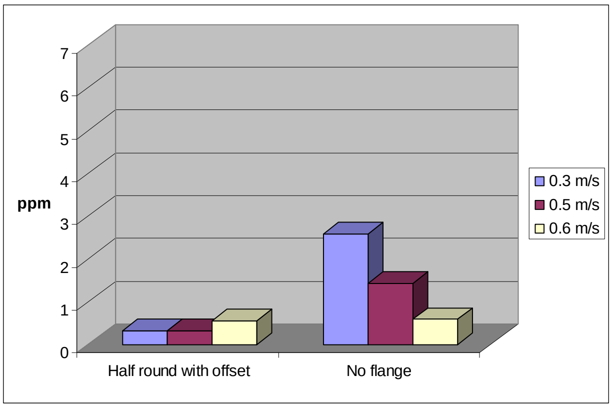
With the slotted rear baffle fitted, tracer gas tests with the modified half round flange were carried out for a range of face velocities. The Directional source was used to release tracer at the same heights as reported in Section 3.2.3.2. Figure 3.16 shows four graphs that compare the data with the modified half round flange to that of the no flange condition (reported earlier in Section 3.2.3.2) at the four tracer release heights with the release positioned 150 mm from the front edge of the enclosure. Figure 3.17 shows the data recorded with the directional source moved to 300 mm from the face of the enclosure.



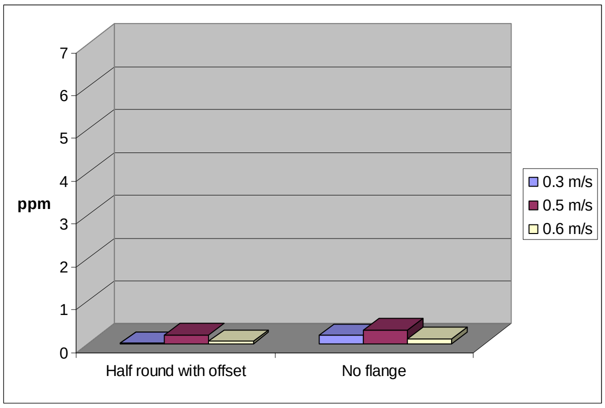
(a) Source height 18 mm



(b) Source height 35 mm

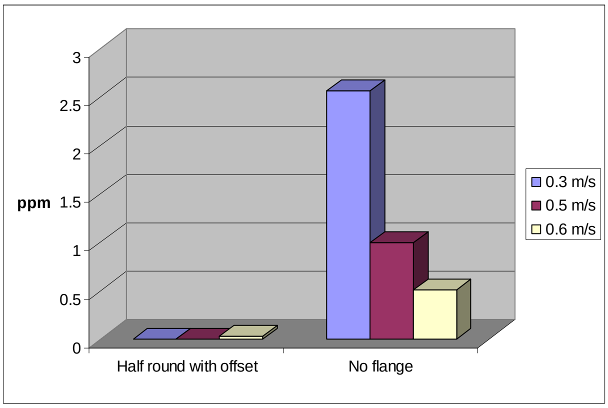


(c) Source height 70 mm

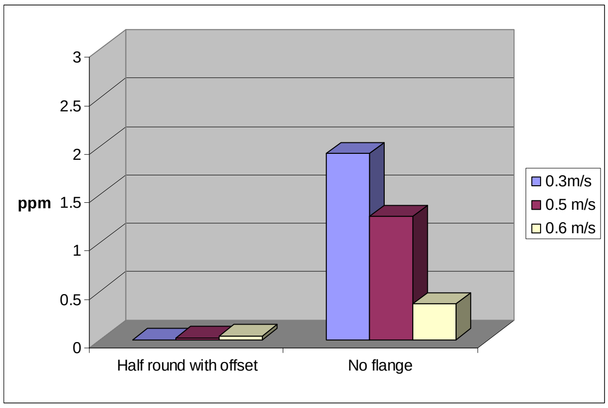


(d) Source height 140 mm

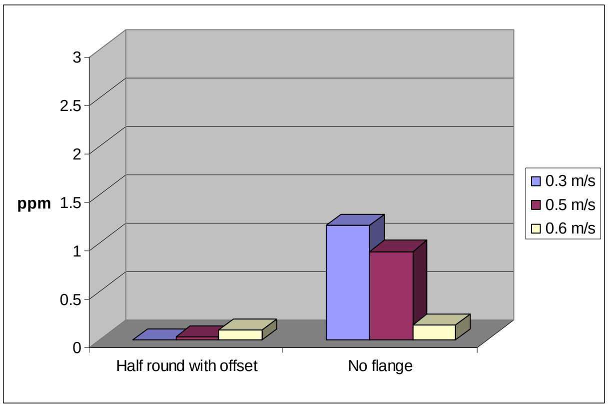
Figure 3.16 *Comparison of the performance of the modified half round flange to the no flange condition at different tracer release heights*
(Directional ejector positioned 150 mm into the enclosure)



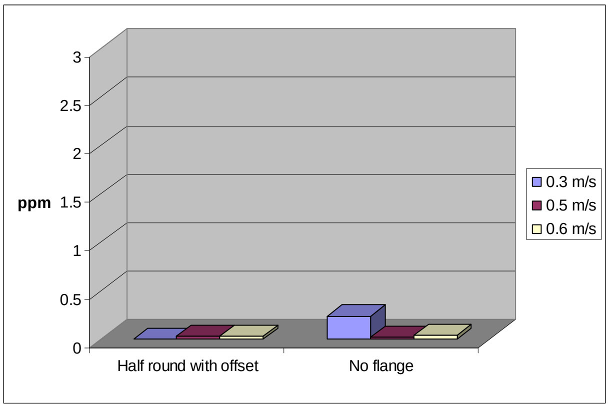
(a) Source height 18 mm



(b) Source height 35 mm



(c) Source height 70 mm



(d) Source height 140 mm

Figure 3.17 *Comparison of the performance of the modified half round flange to the no flange condition at different tracer release heights*
(Directional ejector positioned 300 mm into the enclosure)

The addition of the modified flange produced a significant decrease in the manikin breathing zone concentrations. With the ejector positioned 150 mm from the front of the enclosure the breathing zone concentrations were consistently lower regardless of the face velocity and the source position. In fact all the results were much lower than the no flange condition, except when the source was positioned 140 mm above the floor of the enclosure when both the no flange condition and the modified flange performed equally well.

When the ejector was moved to 300 mm from the face of the enclosure, the breathing zone concentrations with the modified flange fell further, with the mean concentrations for all heights and face velocities less than 0.1 ppm.

4 DISCUSSION

The performance of partial enclosures is often judged by the magnitude of the air velocity and its uniformity as measured at the face of the opening (e.g. HSG 258 states that no velocity reading taken at the face of an enclosure should vary by more than 20% from the average). The introduction of a slotted baffle at the rear of the enclosure or increasing the depth of the enclosure improved the uniformity of the face velocity as demonstrated by the data in Section 3.1.1. However face velocity data does not provide any information on the flow structure within the enclosure, which can influence worker exposure. Instinctively one would assume that air drawn into the enclosure used in this study would move in a unidirectional manner from the front opening to the rear, where extraction took place. However, flow visualisation and tracer gas tests have demonstrated that eddies are created against all four internal walls of the enclosure, creating large areas of recirculation. The size and shape of these eddies are largely governed by the entry conditions of the hood and by improving the aerodynamics of the entry geometry, the wall eddies can be significantly reduced in size and pushed back into the enclosure. Flow visualisation and tracer gas tests carried out without the manikin present showed that the wall eddies could be reduced significantly in size and pushed back into the enclosure by the addition of a large 45^{o} flange. This also led to a reduction in the clearance time of the enclosure.

However, the airflow patterns within a bench top partial enclosure are complicated further by the presence of the worker who is forced to stand at the face of the opening and effectively creates a blockage to the airflow. In this study the presence of a person has been simulated by a manikin positioned centrally at the face of the enclosure. The presence of the manikin created an area of recirculation in front of the torso extending into the enclosure, often referred to as the 'wake effect'. Flow visualisation tests have shown that the eddy against the floor of the enclosure interacts strongly with the wake region in front of the manikin. Tests have shown that tracer gas released into the eddy against the floor of the enclosure, directly in front of the manikin, can enter the wake region and from here enter the breathing zone of the manikin, therefore reducing the wall eddies should help to reduce exposure. It should be noted that reducing the wall eddies will not eliminate the wake region, but may reduce its effect on breathing zone concentrations. Interestingly, increasing the face velocity did not always reduce the concentrations measured in the manikin's breathing zone.

Using the 'Omnidirectional source 2' as the ejector, tests with a variety of different flanges showed that only the modified half round flange, which created an air gap between the flange and the wall of the enclosure, reduced the concentration in the breathing zone of the manikin when compared to the no flange condition. This suggests that, for the enclosure studied, the size and design of the flange is important; in fact with the circular rear baffle fitted, tracer gas concentration measured in the breathing zone of the manikin actually increased with the addition of the two smaller 45^{o} flanges and the half round flange. The presence of the slotted rear baffle did not improve matters and the flanges, except the half round, again resulted in an increase in the tracer gas concentration in the manikin's breathing zone. It would appear that if the flanges are too small they do not significant improve the entry conditions of the enclosure and only serve as an obstruction to the positioning of the manikin, forcing the manikin to be leant forward to ensure the sampling position was in the plane of the opening and thereby increasing the flow of air up the torso of the manikin.

With the large 45^{o} flange fitted, it was difficult to place the manikin in a realistic working position and this resulted in the breathing zone sampling position being 60 mm away from the plane of the enclosure opening. Whilst data showed that the breathing zone concentration was reduced it was not clear whether this was due to the presence of the flange or the different sample position. Although it is possible that the flange could have contributed to a reduction in the concentration, it is probably due more to the fact the sample position was 60 mm from the plane of the opening. The authors are unsure how workable the large (125 mm) 45^o flange fitted to the face of a bench top enclosure would be, as it may force a worker who needs to work with their hands and arms inside the enclosure to lean forward beyond the plane of the opening. Leaning the manikin beyond the plane of the opening increased the measured breathing zone concentrations without a flange fitted and significantly increased the concentrations with a flange fitted. If the worker did not lean forward they may move the process closer to the front of the enclosure, which again is very likely to increase the worker's exposure as demonstrated by the data given in Section 3.2.3.2. If a worker was able to work slightly away from plane of the opening without moving the process – for example paint spraying where the worker tends to stand with their breathing zone outside the plane of the enclosure – then a 45^o flange is likely to improve containment. Furthermore, the 45^o flange would be a useful addition to larger walk-in enclosures, which have no lower edge.

The introduction of the redesigned half round flange partway through the study had a dramatic effect on the concentration in the breathing zone of the manikin. Comparison of this flange to the no flange condition, using the directional source, gave significantly lower breathing zone concentrations regardless of release height, with many measurements close to zero. The gap created between the wall of the enclosure and the flange allowed air to pass between, effectively scouring the walls of the enclosure and virtually eliminating the wall eddies. In addition, the flange could be fitted closer to the opening of the enclosure, reducing the need for the manikin to be leant forwards. Furthermore, even with the torso of the manikin pressed against the flange, it did not block the flow of air between the manikin's torso and the enclosure, thus ensuring that the floor of the enclosure was continually swept with clean air.

Whilst it has been demonstrated that the modified half round flange reduced the breathing zone concentration significantly, the best method to virtually eliminate airborne contaminants in the breathing zone is by the addition (where practical to do so) of a screen between the worker's breathing zone and the interior of the enclosure.

In addition it should be noted that face velocity measurements carried out on real partial enclosures found in industry are not performed with a person present and so give little information on the effectiveness of the enclosure when in use. Flow visualisation with a person present and study of the design of the enclosure provides much more information on likely exposure.

5 CONCLUSIONS

5.1 SUMMARY

If complete enclosure of a process is not possible then partial enclosure should be considered. Partial bench top enclosures are commonly used in industry and by their very nature have an opening for worker access. An inwards air flow generated at the opening is required to contain the contaminant within the enclosure interior to provide worker protection. Generally, the smaller the opening, the less likely a breach of containment will be. In addition, as the opening is reduced so is the air volume required.

The ideal design of a bench top partial enclosure would be to include a transparent screen between the between the worker's breathing zone and the interior of the enclosure, similar to a fume cupboard sash. The presence of a physical barrier between the workers breathing zone and the contaminated air within the enclosure can significantly reduce worker exposure and should be considered if full enclosure is not possible.

It is however, recognised that this approach is not always practical and an open faced, rear extracted, bench top partial enclosure is often used.

With such an enclosure one would intuitively expect the airflow to move as a plug of air from the front to the rear. In reality the airflow patterns within the enclosure are much more complex. For enclosures with sharp edges at the face of the opening, the airflow will separate from the surface of the walls at the leading edge and create large areas of recirculation against all four walls. The airflow patterns are further complicated by the presence of the worker at the open face of the enclosure.

There are a number of parameters that affect the exposure of the worker. This study has focused on the addition of flanges at the face of the enclosure, but has also considered the effect of face velocity, a rear baffle and the presence of a manikin positioned at the face of the enclosure. From this study the following conclusions can be made:

1. The addition of a rear baffle, or increasing the depth of the enclosure, improved the uniformity of the air velocities measured at the face of the enclosure. However, face velocity measurements give no information of the airflow patterns within the enclosure and no indication of worker exposure.

2. For the enclosure design studied, eddies were found against all four internal walls of the enclosure. Flow visualisation tests using smoke showed that these protruded beyond the plane of the opening when no flange was fitted, and any disturbance resulted in the escape of smoke into the test room.

3. The presence of a manikin at the face of the enclosure caused a 'wake' region of highly turbulent air to form in front of it. This 'wake' interacted with the eddy against the floor of the enclosure.

4. Moving the release position into the enclosure, further away from the manikin, reduced the concentration of tracer gas in the breathing zone of the manikin.

5. Leaning the manikin into the enclosure increased the concentration of tracer gas in the breathing zone of the manikin.

6. Increasing the face velocity did not necessarily reduce the breathing zone concentration. For example, with the circular rear baffle and the Omnidirectional source the breathing zone concentration increased with increasing face velocity. However with the slotted baffle and the Directional source the breathing zone concentration decreased with increasing face velocity.

7. The addition of a 125 mm 45^{o} flange to the entry of the enclosure reduced the size of the wall eddies and also pushed them back into the enclosure. However, the flange protruded by approximately 88 mm, making it difficult to position the manikin in a realistic working position. As a result limited data is available for this large flange.

8. Addition of each of the remaining 3 original flanges tested (medium and small 45^{o} flanges and the half round flange) failed to reduce the concentration of tracer gas in the breathing zone of the manikin when compared to the no flange condition. In fact some of the flanges produced breathing zone concentrations that were higher than the no flange condition. This may be because the manikin had to be leaned forward to ensure the breathing zone remained in the default position.

9. The modified half round flange that was introduced partway through the study considerably reduced the concentrations in the breathing zone of the manikin when compared to the no flange condition. This flange was considered to be the most practical design for bench top partial booths.

5.2 IMPLICATIONS OF THE STUDY

The addition of the correct design and size of flange to the face of an enclosure can reduce the size of eddies that are created against the enclosure walls and thus the exposure of the worker. The incorrect design can increase exposure, as shown by the addition of the medium and small 45^{o} flanges and the half round flange.

Initial work with the large 45^{o} flange showed that this design considerably reduced the size of the wall eddies and helped to push them back into the enclosure. However, it was difficult to locate the manikin in a realistic working position whilst keeping the breathing zone at the default position and therefore it is likely that a worker would have to lean forward. As a result the authors believe that the addition of a large flange along the base of a bench top enclosure, may force a worker, who needs to work with their hands and arms inside the enclosure, to lean forward leading to an increase in personal exposure. If a worker was able to work slightly away from plane of the opening – for example processes where the worker tends to stand with their breathing zone outside the plane of the enclosure such as paint spraying – then a large 45^{o} flange would likely improve containment. Furthermore, the large 45^{o} flange would be a useful addition to larger walk in enclosures, which have no lower edge.

Only the modified half round flange, which allowed air to pass between the wall of the enclosure and the flange, thus guiding air along the enclosure wall and effectively eliminating the wall eddies, significantly reduced the concentration in the breathing zone of the manikin. Where workers need to stand at the face of an enclosure the modified half round flange (or a similar design) should improve containment and reduce worker exposure.

5.3 RECOMMENDATIONS

1. Where full enclosure is not practical, partial enclosures should be considered.

2. Ideally a partial enclosure should include a transparent screen fitted between the operator breathing zone and the interior of the enclosure. This physical separation greatly reduces worker exposure.

Where this is not practical and an open fronted bench top enclosure is chosen, the following recommendations apply:

1. The source should be moved as far back into the enclosure as possible.

2. Leaning into the enclosure is highly likely to increase worker exposure and if this is unavoidable the work practices and enclosure design should be changed.

3. Designers and testers can often become fixated with the ‘correct’ face velocity (in this study, increasing the face velocity did not always reduce the concentrations measured in the manikin’s breathing zone). The enclosure design is of equal importance, particularly the enclosure entry conditions; enclosure design should be carefully considered.

4. The offset half round flange virtually eliminated the wall eddies and out performed the other flanges (including the no flange condition). In addition, it was the least obstructive. The authors think that this is the most practical flange design for small bench top enclosures.

5. The control performance of enclosures, particularly during commissioning, should be assessed with the worker present. Smoke is very useful for visualising air movement within the enclosure interior and assessing exposure of the worker and is therefore recommended.

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7 APPENDIX

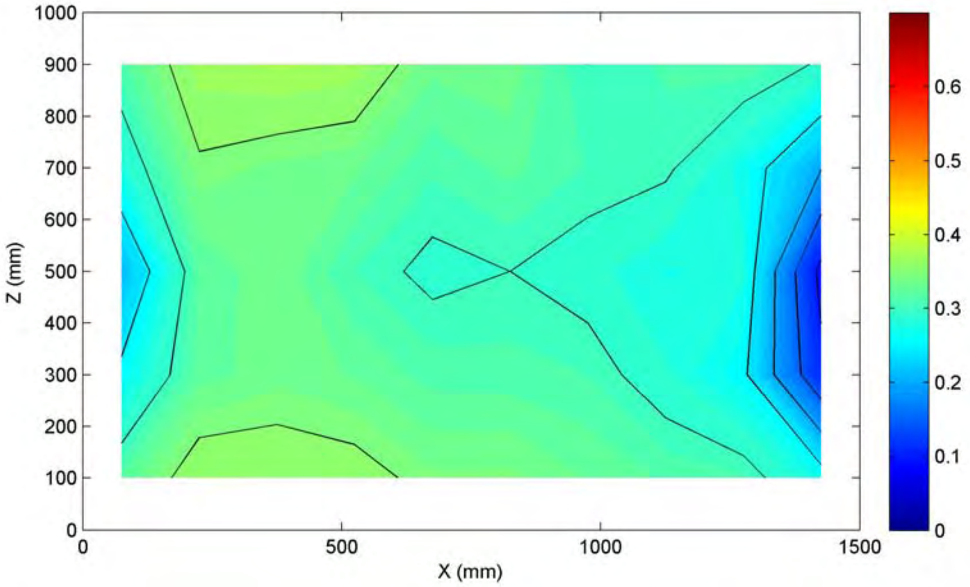

Figure A.1 *Flooded velocity at the face of the enclosure.*
No baffle (0.45 m^3s^{-1}) Note: units of right hand scale are ms^{-1}

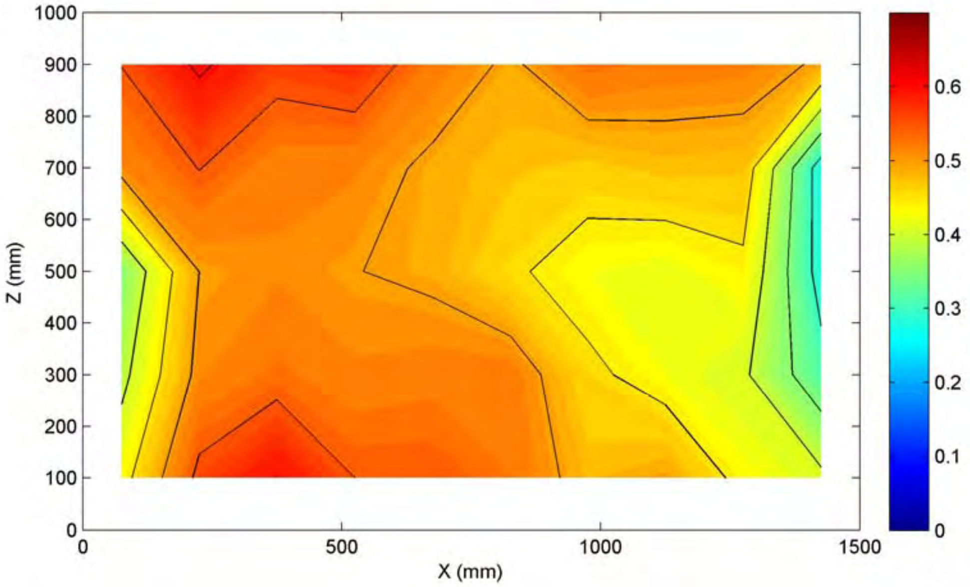

Figure A.2 *Flooded velocity at the face of the enclosure.*
No baffle (0.75 m^3s^{-1}) Note: units of right hand scale are ms^{-1}

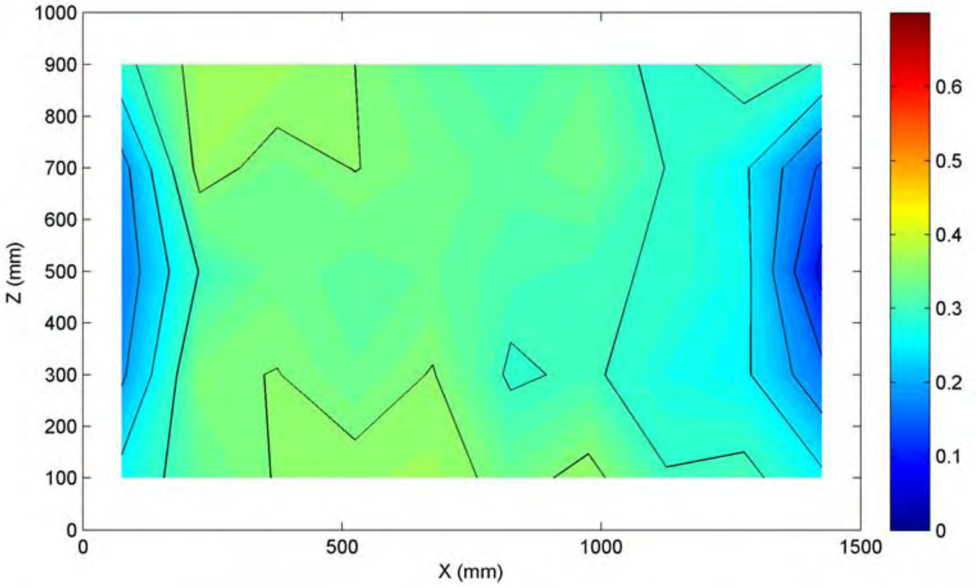

Figure A.3 *Flooded velocity contour plot at the face of the enclosure. Circular rear baffle at 750 mm (0.45 m^3s^{-1}) Note: units of right hand scale are ms^{-1}*

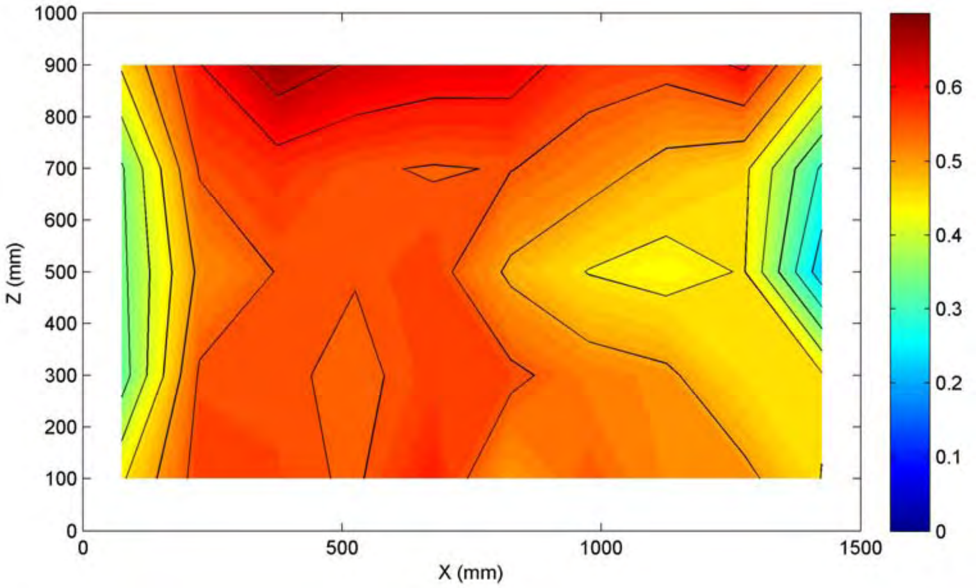

Figure A.4 *Flooded velocity contour plot at the face of the enclosure. Circular rear baffle at 750 mm (0.75 m^3s^{-1}) Note: units of right hand scale are ms^{-1}*

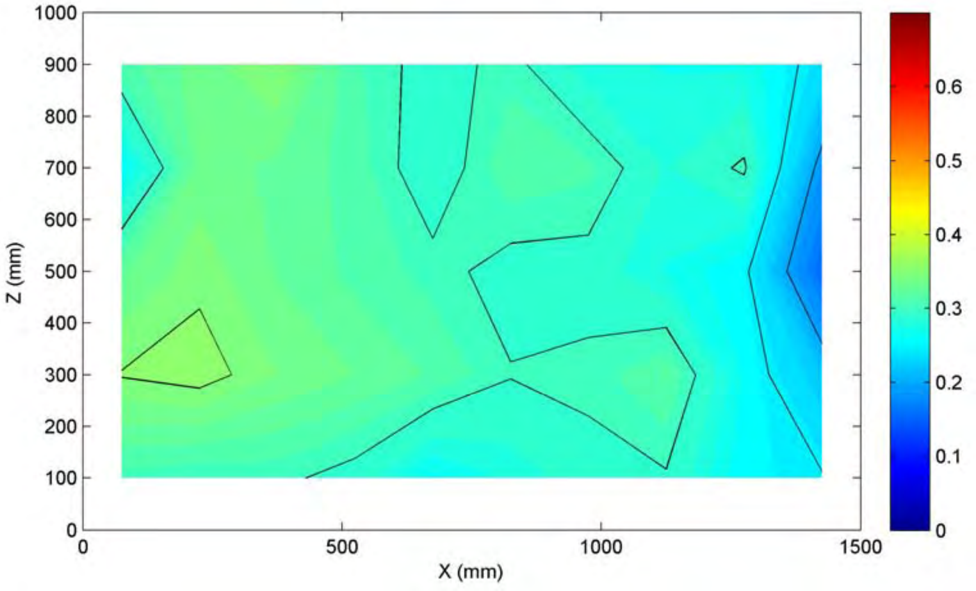

Figure A.5 *Flooded velocity at the face of the enclosure.*
Slotted rear baffle at 750 mm (0.45 m^3s^{-1}) Note: units of right hand scale are ms^{-1}

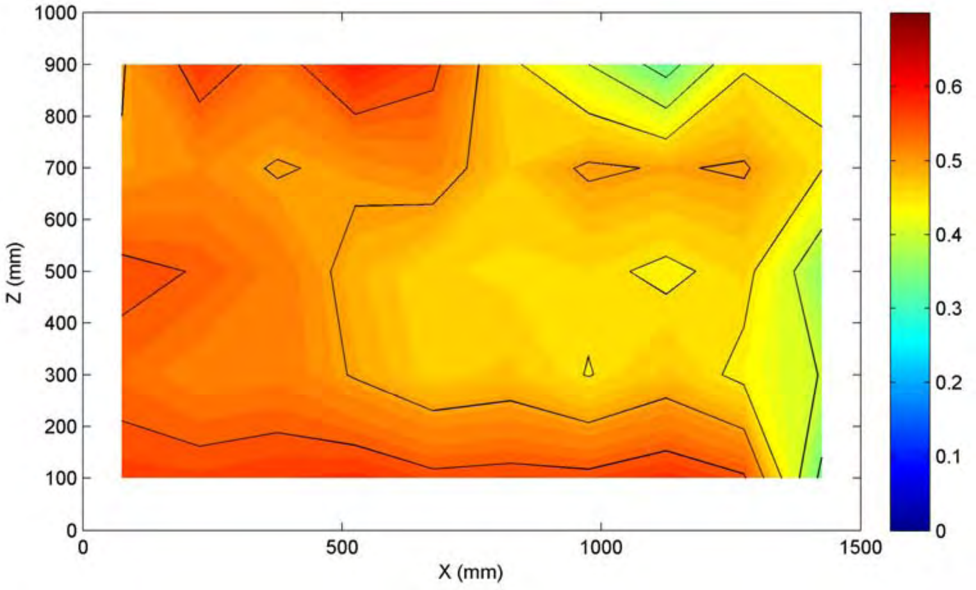

Figure A.6 *Flooded velocity at the face of the enclosure.*
Slotted rear baffle at 750 mm (0.75 m^3s^{-1}) Note: units of right hand scale are ms^{-1}

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Investigation of the parameters that influence the effectiveness of a bench top partial enclosure

Bench top partial enclosures are frequently used in industry to control airborne contaminants. These hoods tend to be of basic design and often consist of nothing more than a box like structure with an open front to allow worker access and extraction at the rear to remove contaminated air. With this type of design the worker is forced to stand at the face of the enclosure and by doing so presents a blockage to the airflow that creates a 'wake' in front of the worker. Any release of contaminant into the recirculating wake region has the propensity to enter the worker's breathing zone.

This aim of this study was to investigate the design parameters that influence the control effectiveness of an open fronted small partial enclosure. similar to those used in industry, and in particular to identify key variables of small partial enclosure design and to identify how key variables interact.

The results showed that eddies were created against all four walls of the enclosure. These interacted with the wake in front of the test manikin leading to contamination of the breathing zone. Reduction in the breathing zone of the manikin was best achieved by the addition of an offset flange to the entry of the enclosure. This design allowed air to enter between the flange and the enclosure walls and thus eliminated the wall eddies and consequently led to a reduction in the breathing zone concentration. The report also includes a number of other recommendations for design and use of partial enclosures.

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