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Dispersion from SMART Repairs

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Science Group: **Fire and Explosion**

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EXECUTIVE SUMMARY

Objective

To examine the distance over which dilution to 5 μg/m^3, 100-fold dilution, of spray mist from SMART repairs occurs when the repairs are performed outdoors.

Main Findings

Predictions of dispersion of spray mist from SMART repairs have been made using an atmospheric dispersion model, ADMS. A representative spray mist source with a volume of 5 litres and concentration of 500 μg/m^3, based on measured spray mist volumes and concentrations, was specified. The effect of source height, source volume and atmospheric conditions on dispersion were examined.

For the representative source with reasonable assumptions for the flow conditions, the distance to a concentration of 5 μg/m^3, 100-fold dilution, was predicted to be approximately 10 m, 50-fold dilution 6-7 m and 10-fold dilution 2-3 m. These figures are at the release height, concentrations are predicted to decrease rapidly above or below this height. For a constant release rate, dilution at all distances increases with increasing surface roughness, while with constant concentration, increasing source volume reduced the dilution. Atmospheric conditions also affected dilution, with increasing stability decreasing the dilution at all distances. Given the uncertainties and variabilities involved, these figures indicate scales over which dilution occurs, rather than precise figures.

The modelling indicates the distance over which dilution could be expected to occur. In producing these numbers the approach taken was to try to be precautionary or examine the consequences of uncertainty and variability. In particular the calculations were performed for a steady state release and mean concentrations were output. In practice the process is intermittent and the concentration at a point will be affected by fluctuations in the atmospheric flow. The predicted mean concentrations at a point are therefore likely to be precautionary, though observed instantaneous peak concentrations could be higher.

There are uncertainties and natural variability associated with the values of parameters used and the range of conditions under which SMART repairs could be performed. The influence of parameters was examined by looking at the effect of values used. However, the use of an atmospheric dispersion model assumes that a fully developed boundary layer is appropriate. The dispersion scenario used was designed to fit this and give indicative figures. A typical SMART repair will occur in the roughness sublayer of the atmospheric boundary layer. Local topography, including the presence of the vehicle being sprayed, will modify the flow and dispersion.

Recommendations

It is recommended that if further detail of dispersion of spray mist or examination of uncertainty is required, the use of a dispersion model developed for use in the urban roughness sublayer, or CFD (Computational Fluid Dynamics), be considered.

1 INTRODUCTION

SMART repair (small to medium area repair techniques) for motor vehicles includes spray painting small areas for chip and scratch removal. This report concerns the use of two-pack paints containing isocyanates for such repairs. HSE guidance states that the sprayer should always wear air-fed RPE. If done indoors, the job requires either the use of a spray booth, or the vacation of the whole area for 30 minutes. If done outdoors, the area should be kept clear of other people while spraying is performed. The size of this exclusion zone was not clear, but it is proposed that total isocyanate concentration below 5 $\mu g/m^3$ is a suitable target value. This is the limit for jobs of short duration (e.g. less than two minutes), concentrations of 500 $\mu g/m^3$ have been observed during spray painting, implying 100-fold dilution. As bystander exposure may occur, an indication of the potential concentrations that bystanders may be exposed to is necessary to evaluate appropriate controls.

The formation of an isocyanate mist and vapour cloud occurs during use of a spray gun. The aim of the spraying process is to transfer paint to the vehicle. However, fine droplets that are not transferred onto the vehicle surface become available for transport. The use of spray guns involves specified, or at least measurable, air flow rates. The air impinges on the surface being sprayed, most will follow the surface, away from the region where spraying occurs. Air flow will also be induced by the spraying and this may transport the mist and vapour. The result is a cloud of spray mist.

Attempting to model the spray processes would be difficult and not make a useful contribution to the estimation of bystander exposure. Instead, a representative release scenario will be assumed to describe the source term for dispersion. The release scenario is based on the assumption that spraying occurs for 30 seconds, leading to a concentration of 500 $\mu g/m^3$ in a cloud of spray mist with a volume of 5 litres.

2 APPROACH AND ASSUMPTIONS

Repair of damage to vehicles using the SMART approach generally occurs in urban areas. Dispersion of mist and vapour from the repairs will therefore occur within the urban roughness sublayer. The detailed flow within the roughness sublayer is determined by the interaction between the local topography and the meteorological conditions. In addition flow separation and reattachment round a vehicle and its influence on dispersion from a spray repair may be affected by the position of the repair on a vehicle and the direction of wind relative to the vehicle. The position of a vehicle relative to buildings may also be significant.

Dispersion measurements could be made but they would be for specific cases, though any data collected could be useful for checking calculations. Similarly dispersion calculations for specified geometries could be performed using CFD (Computational Fluid Dynamics): again this would give answers for the specific cases, not general answers. Models for dispersion within the urban roughness sublayer are currently being developed but we do not have access or experience of using them at present. Atmospheric dispersion models are, however, available. While these were not developed for this specific purpose they are used here to give an initial indication of dispersion.

If the problem is treated as dispersion from the centre of a car park, a “large flat space with small roughness length”, then if the car park is large enough and smooth enough the dispersion of spray mist will not be occurring with the roughness layer. The problem with this approach is that atmospheric dispersion models are designed for application to fully developed atmospheric boundary layers. These conditions are not likely to occur even for the largest car parks. While the atmospheric dispersion model used, ADMS (CERC 2004), allows heights down to zero to be specified it was not developed for the low height, short distance dispersion of interest here. The dispersion coefficients may not be appropriate, or well defined in this region. Also the results from the model will be of mean quantities, while fluctuations, particularly in concentration, may be significant. ADMS can represent fluctuations but they are not considered here. Nevertheless, ADMS is considered to be the best available model that does not incur high computing costs.

3 CALCULATIONS PERFORMED

A representative spraying process was taken to be 30 seconds spraying, leading to a spray mist cloud of 5 litres volume with a concentration of 500 μg/m^3. As this is based on air sampling of the sprayer this estimate is realistic. In the dispersion calculations the spray mist was assumed to be a "passive tracer", following but not influencing the flow. The concentration at specified distances from the source can be calculated for different source strengths. The calculations were performed for a steady state source. If the stated spray mist concentration is assumed to be the maximum reached, this result will be precautionary. If the volume is greater, than five litres, the result will be understated. During spraying the concentration will increase to the maximum, whereas assuming steady state the concentration will always be at the maximum, this will therefore be conservative.

Spray mists consist of fine droplets formed during spraying that do not get transferred to the surface being sprayed. These droplets mix with the air and are sufficiently fine that they remain suspended in the air after spraying has finished. They are therefore available for transport and dispersion. Initial movement of spray mists may be due to flows induced by spraying, but once spraying ceases the spray mist will be transported by the ambient flow. Since there is no preferred flow or direction associated with the spray mist it was treated as a fugitive emission and modelled with a volume source, a source with no associated plume rise. The source volume was defined as a cube with a specified centre height.

The modelled source is specified as a rate (with units kg/m^3/s), rather than a concentration. During spraying mist will be entering the 5 litre volume from spraying and leaving due to dispersion, the balance of these will determine the concentration of any spray mist cloud that is formed. We do not have direct information on the rates that spray mist enters and leaves the 5 litre volume but we can set some limits on the source term.

<u>No dispersion of spray mist</u> The source term flow rate is that giving a concentration of 500 μg/m^3 after 30 seconds. Obviously if nothing leaves the 5 litre volume there would be no dispersion and the concentration would just keep rising, so this is a non-physical limiting case.

<u>Continuous dispersion of spray mist</u> The source term flow rate is such that the flow from the 5 litre volume has a concentration of 500 μg/m^3, see Appendix. Since the flow concentration is always 500 μg/m^3 this gives conservative source flow rates.

Calculations were performed using a unit rate source term, 1 g m^{-3}s^{-1}. Since the release was passive the magnitude of the release does not affect the flow. The predicted concentrations for any particular source flow rate can be found by multiplying the predicted concentrations by the fraction of the unit flow rate the release represents. Two source volumes were examined, 5 and 10 litres and two source centre heights, 0.5 and 1 m.

The effect of the presence of a vehicle on the flow and dispersion were ignored.

A typical roughness length, z_0, for water or a paved surface of 0.001 m is quoted in the user guide for HGSYSTEM, this would typically be associated with roughness elements with heights between 10 and 30 times the roughness length (Post 1994). Roughness lengths of 0.0002 m, 0.001 m and 0.002 m were examined, with equivalent roughness element heights of 0.006 m, 0.03 m and 0.06 m. The values used cover reasonable roughness heights for a large smooth area. It should be emphasised that using these values for roughness length assumes that the dispersion is not occurring within the urban roughness layer, these values are really only appropriate over a large area of the stated roughness length. As has already been mentioned with respect to the urban roughness sublayer the assumptions about atmospheric boundary layers break down within the roughness sublayer. This applies for all roughness heights, the roughness heights assumed here are such that the releases themselves would not be within the roughness sublayer.

Dispersion calculations were performed for four meteorological conditions. As Pasquill-Gifford stability classes these were from moderately unstable, B2, through neutral, D2 and D5, to moderately stable F2, the letter represents the stability class and the number the windspeed in metres per second at 10 m height. In practice B2 and D5 are conditions that are more likely to occur during daylight while D2 and F2 are more likely to occur at night, when outdoor spraying is unlikely to occur (Post 1994). ADMS actually specifies the atmospheric boundary layer using boundary layer height and Monin-Obukhov length, which is a more precise system than the Pasquill-Gifford stability classes, but the stability classes can be approximated. A limitation of the Pasquill-Gifford stability classes is that they do not apply for values of z_0 less than 0.001 m, so strictly the shortest roughness length considered here is inappropriate.

Concentrations were output at 0.5 m height intervals from 0 m to 2 m and at 1 m horizontal intervals from 1 m to 8 m downwind of the centre of the source.

4 RESULTS

Two types of source conditions were considered:

No dispersion spray mist A source flow rate of 16.7×10^{-6} µg/m^3/s, would give a concentration of 500 µg/m^3 after 30 seconds, if no dispersion occurred. With this source flow rate the highest concentration predicted at 1m from the source was less than 1 µg/m^3. This source is not considered further.

Continuous dispersion of spray mist Source flow rates for a continuous 500 µg/m^3 concentration were calculated for two meteorological conditions, D2 and D5, for a 5 litre volume spray mist cloud. The necessary source flow rates do not vary much between a release height of 0.5 m and 1 m, so a single source flow rate was used for each condition, 4.2 mg/m^3/s and 10.5 mg/m^3/s, for 2 m/s and 5 m/s wind speed at 10 m height respectively. A problem with the specification of source flow rate based on a stated concentration is that the source flow rate must increase with wind speed to preserve the concentration. Increasing wind speed might affect the fraction of sprayed material available to form spray mist but the concentration, or volume of spray mist, or both would probably also vary with the wind speed. The comparisons shown below are made with the D5 related release rate unless otherwise indicated.

The predicted concentrations at all distances decreased with increasing roughness length scale, Figure 1. Further comparisons are made using the middle roughness length scale, 0.001 m, representative of a paved surface.

The different release heights had very little effect on the predicted downstream concentrations at that height, see Figure 2. The predicted spreading, comparing the variation in concentrations above and below the release height, shows predictions of higher concentrations close to the ground for the release at 0.5 m height, Figure 3. The predicted concentrations at the ground approach that at the release height 6 m downwind of the source. The releases at 1.0 m do not show this behaviour, Figure 4. Dispersion models treat contact with the ground by reflection (Blackadar, 1998). Since the releases at 0.5 m height are closer to the ground they reach the ground sooner and start to be reflected sooner, hence the higher concentrations. For a spray mist reflection is likely to be a conservative assumption, as at least some of the mist would probably settle out on contact with the ground. The peak concentrations 0.5 m above and below the release height have been reached within the 8 m plotted, so these heights represent limits on the volume that will have concentrations with less than 100-fold dilution (ie 500 µg/m^3 to 5 µg/m^3).

The different weather conditions had a significant effect on dispersion with the daytime conditions, B2 and D5, showing lower concentrations at all distances than the night conditions, D2 and F2, for the same release rate, Figure 5. Spraying outdoors is more likely to occur during the day. When the release rate was set to produce 500 µg/m^3 concentration at both D2 and D5 conditions the predicted concentrations are much closer, Figure 6.

Larger cloud volumes, with release rates adjusted for the cloud volume, give predictions of increased concentrations, not quite doubling the concentration for a doubling of cloud volume, Figure 7.

4.1 DILUTION

The source concentration and volume are representative and the contaminant is treated as passive, that is not influencing the flow, in the dispersion calculations. Rather than looking at absolute concentrations the dilution at different distances may be considered. At the release height these show 10 fold dilution between 2 and 3 m, 50 fold dilution between 5 and 6 m and 100 fold dilution at greater than 8 m for the 0.001 m roughness length and D5 conditions.

The concentration values are mean predicted downwind concentrations for a steady state release. The actual releases will be intermittent, as spraying is not continuous, and there will also be fluctuations in the concentration at a point due to the atmospheric flow. Both the calculation of source release rate and treatment of the source as steady state are precautionary assumptions.

As the flow is not buoyant the predicted downwind concentrations at the release height will be the maximum concentration at any particular distance. While these concentrations are predicted to show less than 100 fold dilution up to 8 m the spreading around this line show that with the possible exception of near ground concentrations the predicted mean concentration never shows less than 100 fold dilution at 0.5 m above or below the release height. The predicted mean ground level concentrations do approach the release height concentration for the release at 0.5m height due to the assumption of reflection at the ground, which is a conservative assumption for spray mist.

Given the dispersion scenario used the roughness length scale can affect the rate of mixing, however other influences may be more significant. For example, no attempt was made to represent the presence of a vehicle being sprayed or its influence on the flow. Some effects of building on dispersion could be examined in ADMS, but there are other potential limitations. The distances considered are short and heights low, while atmospheric dispersion models were developed and are most often applied to higher, longer dispersion problems. Finally there is the question of the limitations of atmospheric models for a flow in the urban roughness sub-layer. The dispersion scenario used was chosen so that an atmospheric dispersion model was applicable, but this introduces its own limitations.

5 CONCLUSIONS

Predictions of dispersion of spray mist from SMART repairs have been made using an atmospheric dispersion model, ADMS. A representative source, based on volume and spray mist concentrations, was specified. The effect of source height and volume on dispersion were examined. The dispersion is affected by the atmospheric flow field. This was defined by the roughness length scale and the atmospheric stability and their influence on the dispersion was also examined. The quantities affecting dispersion involve uncertainty or variability or both. For example roughness length scale is related to the surface over which flow occurs and may therefore take different values while there will be natural variability in the atmospheric conditions. Examining the influence of the different factors allows both their influence and relative importance to be considered.

For the representative source with reasonable assumptions for the flow conditions the distance to a concentration of 5 $\mu g/m^3$, 100-fold dilution, was predicted to be approximately 10 m, 50-fold dilution 6-7 m and 10-fold dilution 2-3 m. For a constant release rate dilution at all distances increases with increasing roughness length, while with constant concentration increasing the source volume reduced the dilution. Atmospheric conditions also affected the dilution, with increasing stability decreasing the predicted dilution at a given distance. Given the uncertainties and variabilities these figures indicate scales rather than precise figures.

The modelling indicates the distance over which dilution could be expected to occur. In producing these numbers the approach taken was to try to be conservative or examine the consequences of uncertainty and variability. In particular the calculations were performed for a steady state release and mean concentrations were output. In practice the process is intermittent and the concentration at a point will be affected by fluctuations in the atmospheric flow. The predicted mean concentrations at a point are therefore likely to be precautionary though observed peak concentrations could be higher.

There are uncertainties and natural variability associated with the values of parameters used and with the range of conditions under which SMART repairs could be performed. Where possible the influence of parameters was examined by looking at the effect of values used. However, the use of an atmospheric dispersion model assumes that a fully developed boundary layer is appropriate. The dispersion scenario used was designed to fit this, but there are many other possibilities. There are limitations with both the type of model, in this application, and the dispersion scenario, compared to a typical SMART repair. Local topography, including the presence of the vehicle being sprayed, will modify the flow. It is recommended that if further detail of dispersion of spray mist or examination of uncertainty is required the use of a dispersion model developed for use in the urban roughness sublayer, or CFD, be considered.

6 REFERENCES

Blackadar, A K (1998), Turbulence and diffusion in the atmosphere, Springer

CERC (2004), ADMS 3: User Guide, Version 3.2, Cambridge Environmental Research Consultants Ltd.

Post L (1994), HGSYSTEM 3.0 User Guide, Report No. TNER.94.058, Shell Research Ltd

7 APPENDIX

7.1 SOURCE TERM WITH REPLACEMENT

For a log-law velocity profile

$$\frac{U_z}{u_*} = \frac{1}{\kappa} \ln \frac{z}{z_0}$$

where: z is height in m,

z_0 is roughness length scale, m,

κ is von Karman's constant,

U_z is mean velocity at height z, m/s and

u_* is the shear velocity

This can be rearranged:

$$\frac{u_*}{\kappa} = {U_z}\Big/{\ln \frac{z}{z_0}}$$

For a stated velocity at height, z, the velocity at other heights can then be found. So for a stated velocity, U_{10}, at $z = 10$ m,

$$U_z = \frac{\ln \frac{z}{z_0}}{\ln \frac{10}{z_0}} U_{10}$$

The source is treated as a cube of stated volume, V m^3, with sides length $\sqrt[3]{V}$ m. Taking the velocity at the mid-height of the source, z, the volumetric flow rate in m^3

$$Q = U_z \left(\sqrt[3]{V}\right)^2$$

and for a concentration C the mass flow rate, in kg/m^3

$$\dot{m} = C U_z \left(\sqrt[3]{V}\right)^2$$

For a volume source, in kg/m^3/s

$$S = \frac{C U_z \left(\sqrt[3]{V}\right)^2}{V} = \frac{C U_z}{\sqrt[3]{V}}$$

8 FIGURES

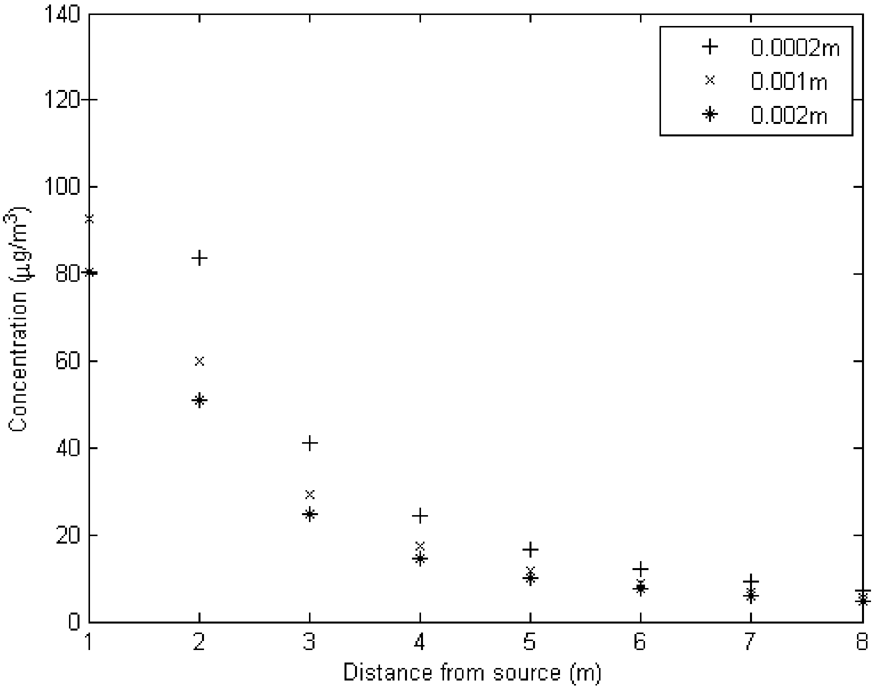

Figure 1 Influence of roughness length scale
D5 conditions, 5 litre volume at 0.5 m height

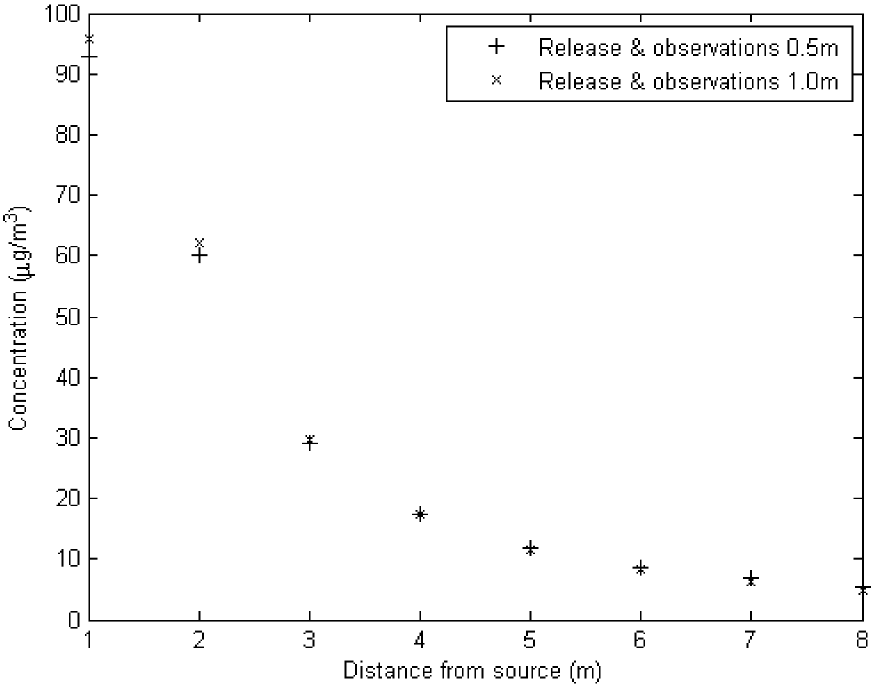

Figure 2 Effect of release height
D5 conditions, 5 litre volume, z_0=0.001 m

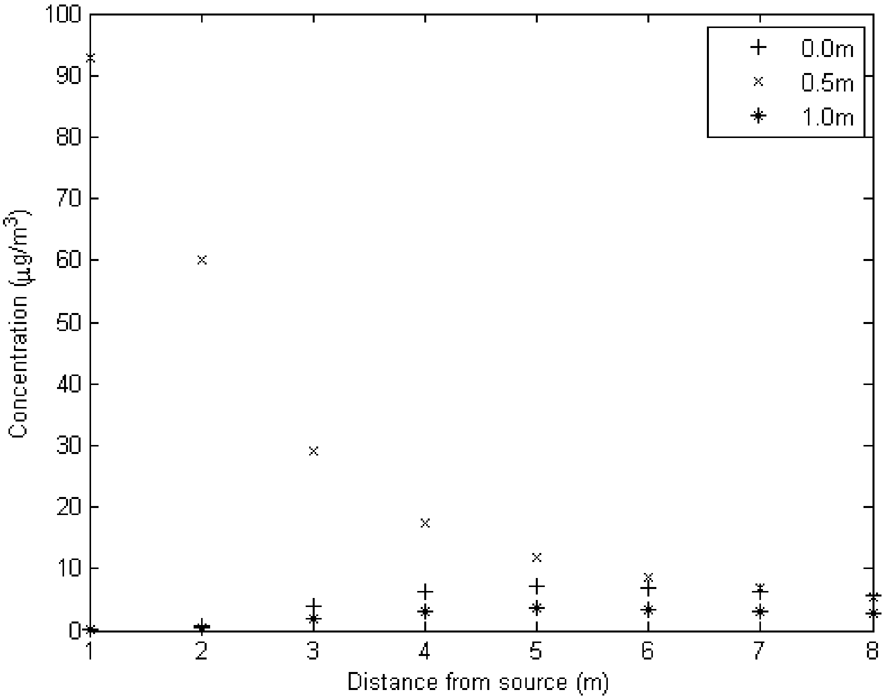

Figure 3 Concentrations at height
D5 conditions, 5 litre volume at 0.5 m height, z_0=0.001 m

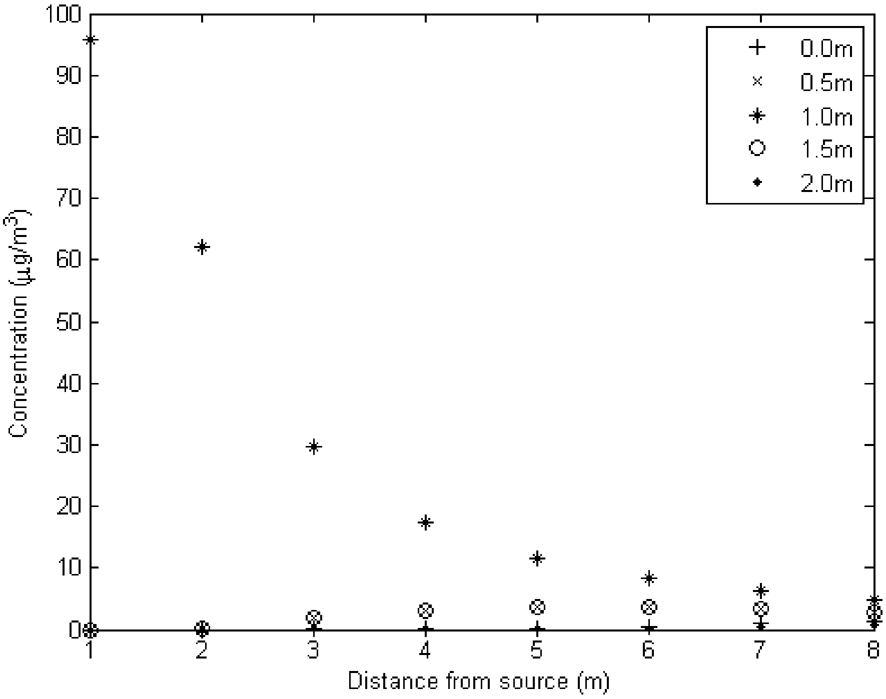

Figure 4 Concentrations at heights
D5 conditions, 5 litre volume at 1 m height, z_0=0.001 m

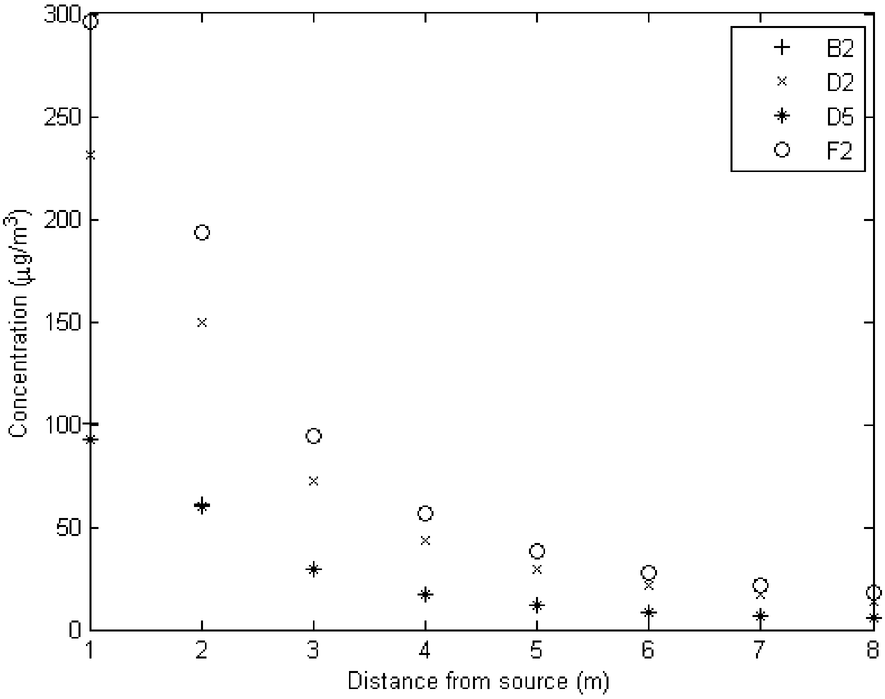

Figure 5 Effect of different conditions, same release rate
5 litre volume at 0.5 m height, z_0=0.001 m

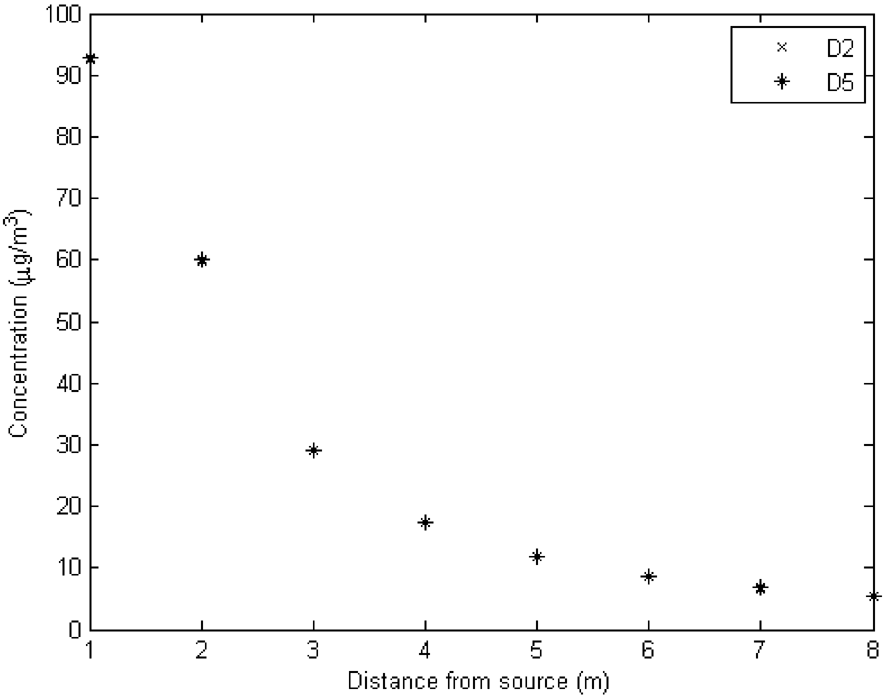

Figure 6 Effect of different conditions, same concentration
5 litre volume at 0.5 m height, z_0=0.001 m

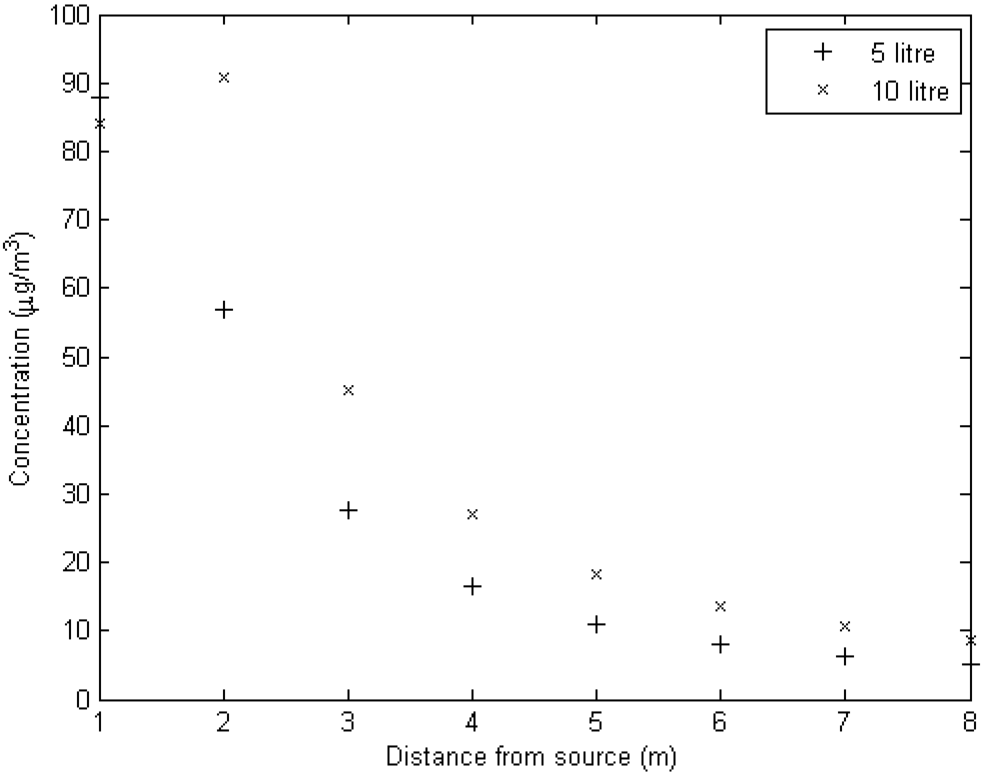

Figure 7 Effect of different source volumes
D5 conditions, source at 0.5 m height, z_0=0.001 m