EFFECT OF VENTILATION RATE ON DEPOSITION OF AEROSOL PARTICLES ON MATERIALS

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Summary This paper describes measurements carried out in a single-zone chamber using aerosol particles and tracer gases. Aerosol particles and a tracer-gas were injected into the chamber and their concentrations with time were monitored. The deposition rate of particles on the surfaces of the chamber were determined for a range of ventilation rates. The chamber was lined with various types of materials e.g. aluminium foil, carpet and the deposition rate of particles of different sizes were examined. Results indicated that particle exchange rates were higher than tracer-gas exchange rates. This was due to the deposition of particles on surfaces of the

chamber. The deposition rate was found to be dependent on the type of lining material and size of particles used.

1. Introduction

Particulate pollutants in buildings can have damaging effects on the health of the occupants and studies have shown that indoor aerosol particles strongly influence the incidence of sick building syndrome [1]. Airborne particles are associated with allergies and it is known that they transport viruses and bacteria. Indoor aerosols are not only associated with outdoor sources (e.g., car exhaust emissions, coal and oil combustion, road dust, etc) but also arise from a number of indoor sources, (e.g., cigarette smoke, building materials, personal products,etc). Aerosol particles can deposit in ventilation ducts and on surfaces of rooms or can be transported between zones; this can have serious effects in hospitals and buildings used by the micro-electronic and pharmaceutical industries [2]. Deposition of airborne particles in museums and galleries can lead to perceptible soiling within a short period and ultimately result in damage to works of art.

The concentration of indoor aerosol particles can be reduced by mechanical ventilation using extract fans or by natural ventilation which allows air exchange between the indoor and outdoor environment via windows and doorways. The airflow, estimated using tracer-gas techniques [3], is not sufficient to describe the removal of particles as particle deposition rate, particle types, sizes, sources and concentrations must be taken into consideration.

The literature contains limited studies of deposition of aerosol particles [4 - 5] but these do not investigate the effect of surface material on deposition. This paper describes measurement carried out in a single-zone chamber using aerosol particles and tracer gases. The deposition rate of particles on the surfaces of the chamber were determined for a range of ventilation rates. The chamber was lined with various types of material, e.g., aluminium foil and carpet and the deposition rate of particles of different sizes were determined.

2. Theory

Figure 1 shows a schematic diagram of the chamber. The concentration-decay technique was used to estimate tracer-gas and particle exchange rates in the chamber. The method involves the initial injection of SF_6 tracer-gas and oil-smoke particles into the chamber and is followed by a mixing period to establish a uniform concentration. The decay of SF_6 tracer-gas and smoke particles is then measured using suitable detectors over a given time interval. The rate of decrease of tracer-gas and smoke-particle concentration is given by the following equations:

$$C_{g(t)} = C_{g(t0)}\, e^{-It} \qquad (1)$$

$$C_{p(t)} = C_{p(t0)}\, e^{-Pt} \qquad (2)$$

where $C_{g(t)}$ is concentration of tracer-gas (µg/m^3 or ppm) at time t, Cg(t0) is concentration of tracer-gas (µg/m^3 or ppm) at time t equals zero; $C_{p(t)}$ is concentration of aerosol particles (µg/m^3 or ppm) at time t, Cp(t0) is concentration of aerosol particles (µg/m^3 or ppm) at time t equals zero. I is the tracer-gas exchange rate (µg/m^{3}h or h^{-1}) and P is the particle exchange rate (µg/m^{3}h or h^{-1}). If the concentrations of the tracer-gas and particles are plotted against elapsed time on semi-log paper, the negative slopes of the lines are equal to I and P respectively.

3. Experimental

Experimental work was carried out in a single-zone chamber as shown in Figure 1. The chamber had dimensions 2m x 1m x 1m and a small access door. A variable speed pump was connected to the chamber and airflow rate was controlled by varying the speed.

The experimental procedure involved injection of SF_6 tracer-gas and oil-smoke particles into the chamber and was followed by a mixing period using desk fans. A multipoint-sampling unit was used to collect tracer-gas samples from the chamber for subsequent injection into an infra-red gas analyser type BINOS 1000, manufactured by Rosemount Ltd, UK. The accuracy of the measurements was estimated to be within ± 5 %.

Particle concentrations and sizes were measured using a laser-particle dust monitor type 1.102, manufactured by Grimm Ltd. Germany. The monitor is capable of measuring particle concentrations in the range 0.0001 - 500 mg/m^3 for particle size range between 0.5 - 10 μm in diameter with an accuracy of ± 5 %.

Aerosol particles were injected into the chamber using a smoke generator. The generator has a microprocessor controlled system capable of producing oil-smoke particles between 0.1 - 2 μm in diameter with a mass median diameter of < 0.3 μm.

4. Results and Discussions

Experiments were performed in the chamber at different ventilation rates.

The chamber was lined with the following materials :

(i) wood (unlined chamber)

(ii) aluminium foil

(iii) carpet

For each material, SF_6 tracer-gas and oil-smoke particles were injected into the chamber. After a mixing period of 1 hour, simultaneous measurements of tracer-gas and oil-smoke particle concentration were performed using the infra-red gas analyser and particle monitor, respectively. Diameters of oil-smoke particles were in the range 0.5 - 2 µm. Figures 2 - 5 show the variation of concentration of tracer-gas and smoke particles (diameter 0.5 - 2 µm) with time for wood (unlined box) at an air change rate of 0.994 h^{-1}. The tracer-gas and particle decay curves were found to be simple exponential functions for all conditions.

Table 1 shows experimental results for conditions (i) to (iii). It is clear from this table that the particle exchange rates were higher than tracer-gas exchange rates. The difference in tracer-gas and particle exchange rate is due to the deposition (or adsorption effect) of particles on the surfaces of the chamber. This was estimated using the following equation:

$$\alpha = [P-I] * V/A \qquad (3)$$

where α is particle deposition rate (µg/m^2h), V is volume of chamber (m^3)

and A is total surface area of chamber (m^2).

Figures 6 - 8 show the variation of deposition rate with flow rate for wood, aluminium foil and carpet respectively. The deposition rate of aerosol particles on all materials was found to be dependent on the size of the particles. Particle deposition rate on wood and carpet was found to increase at air exchange rates above 0.9 h^{-1} and 0.82 h^{-1} respectively. For aluminium, the deposition rate was found to be highest at an air exchange rate of 0.5 h^{-1} and then decreased. Similar results were obtained when R10 (silica oxide, SiO_2, from Particle Technology Ltd.) aerosol particles were used instead of oil-smoke particles.

The deposition rate on wood and carpet was found several orders of magnitude higher than on aluminium foil. The low deposition rate on aluminium indicates that it would be possible to reduce particle deposition in buildings by using highly polished metal surfaces. The results also indicate that ventilation rate in buildings has a strong effect on deposition of particles.

Table 1 also shows the average deposition velocity of the aerosol particles for various tests. The results indicated that the deposition velocity increased with increasing particle size. The deposition velocity in the chamber lined with wood and carpet were significantly higher than an aluminium foil lining was used. For example, the deposition velocities (d > 1 µm) for wood and carpet were in the ranges 0.149×10^{-6} - 11.56×10^{-6} cm/s and 2.16×10^{-6} - 545.9×10^{-6} cm/s respectively compared with 0.036×10^{-6} - 0.146×10^{-6} cm/s for aluminium.

5. Conclusions

i) The results showed that particle exchange rates were higher than tracer-gas exchange rates. This was due to the deposition effect of particles on the surfaces of the room.

ii) The deposition rate was found to be dependent on the type of lining material and size of particle used.

iii) The results also indicate that ventilation rate in buildings has a strong effect on deposition of particles.

6. References

1. Turiel I, Indoor air quality and human health, Stanford: Stanford University Press, California, (1985)

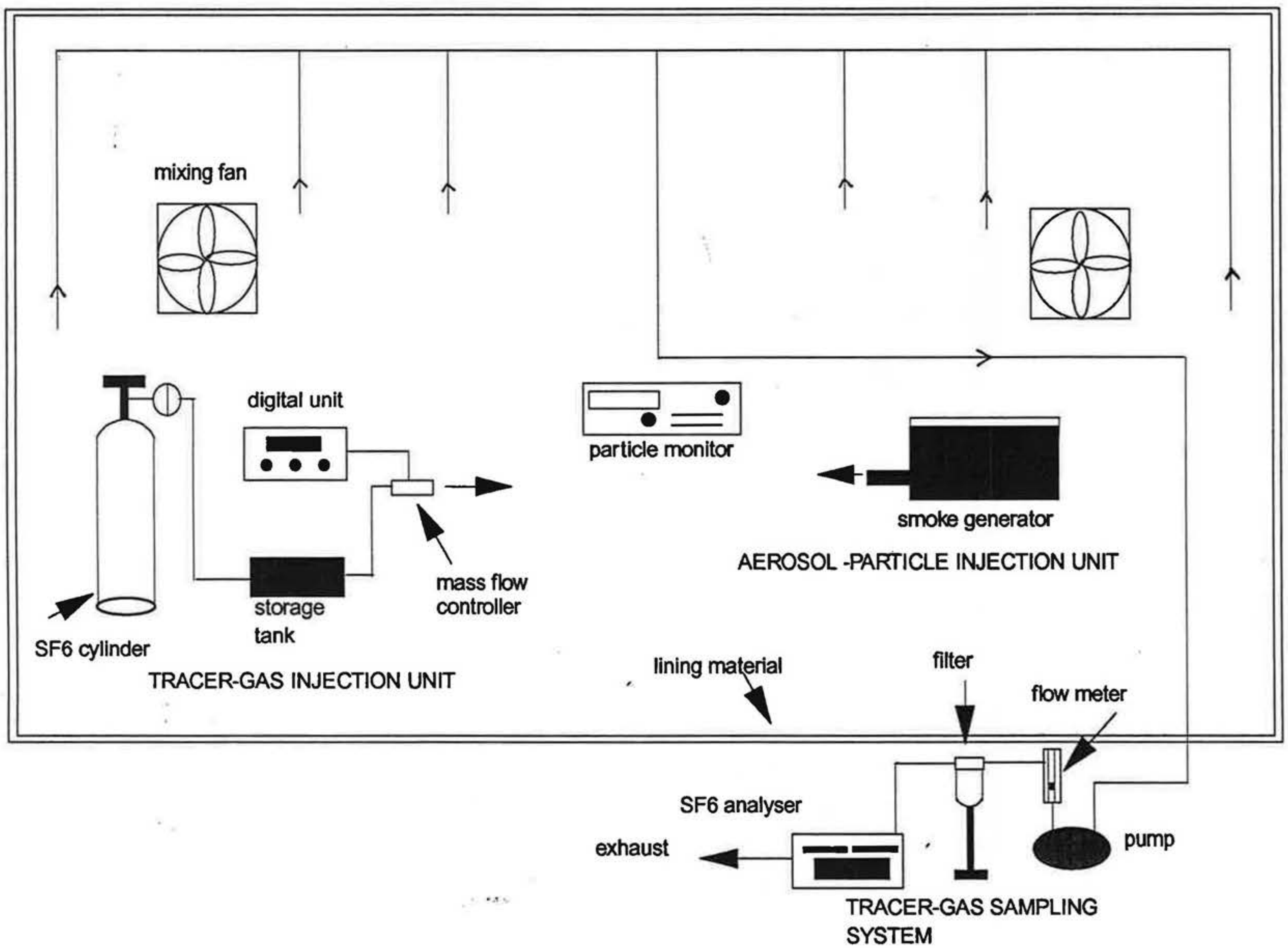
2. Farrance K and Wilkinson J, Dusting down suspended particles Building Services (12), 45-46, (1990)

3. Riffat S B,Comparison of tracer-gas techniques for measuring airflow in a duct J. Institute of Energy, LXIII (545) 18-21,(1990)

4. Adam N M and Riffat S B, Deposition of aerosol particles in buildings, CLIMA 2000 Conference, London, UK, November 1 - 3, (1993), (accepted for publication)

5. Cannell R J Goddard A J H and ApSimon H M, Contamination of dwelling of particulate matter: ingress and distribution witin the dwelling, J. Radiation Protection Dosimetry, 21(1/3), 111-116, (1987)

FIGURES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particle monitor
smoke generator
mass flow
controller
AEROSOL -PARTICLE INJECTION UNIT
storage
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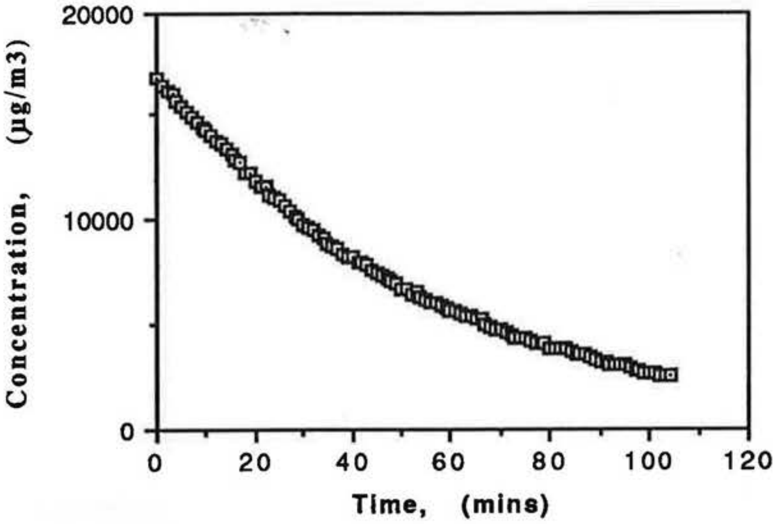
lining material
filter
flow meter
SF6 analyser
pump
exhaust
TRACER-GAS SAMPLING
SYSTEM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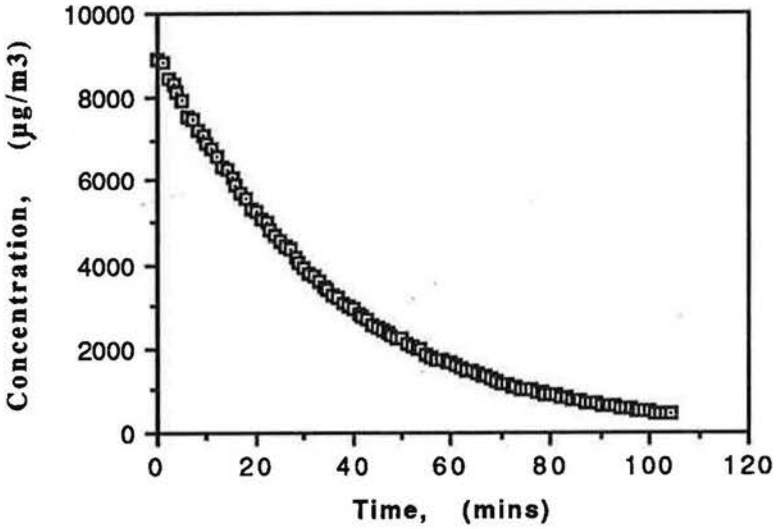
Time, (mins)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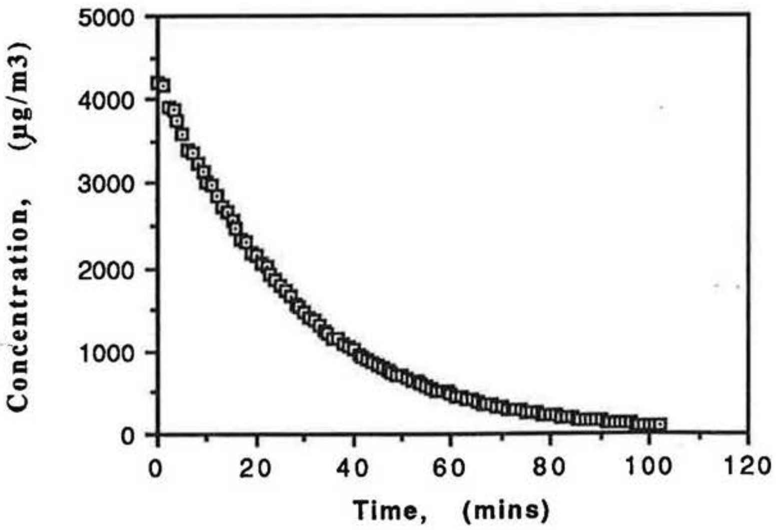
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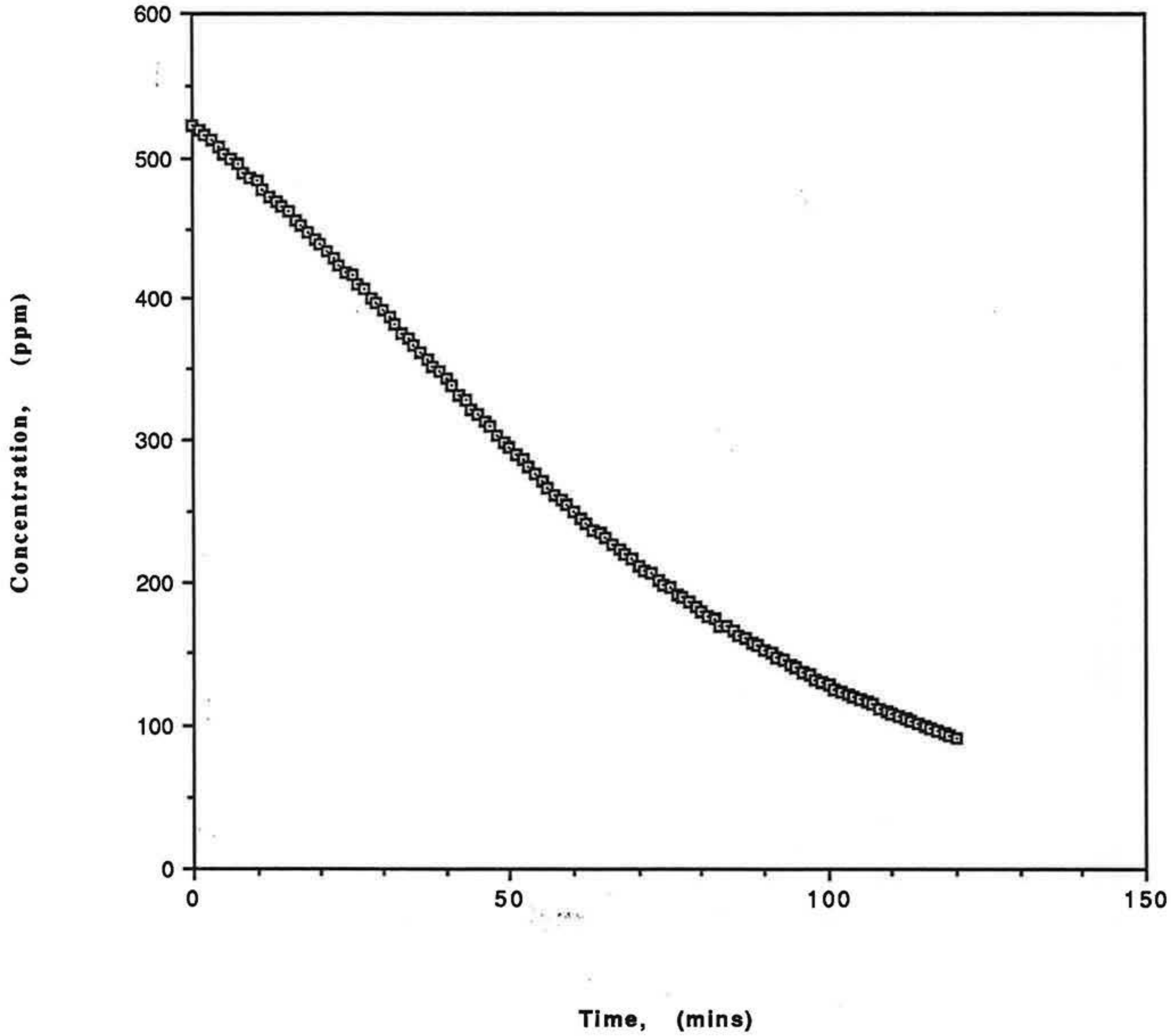
Time, (mins)



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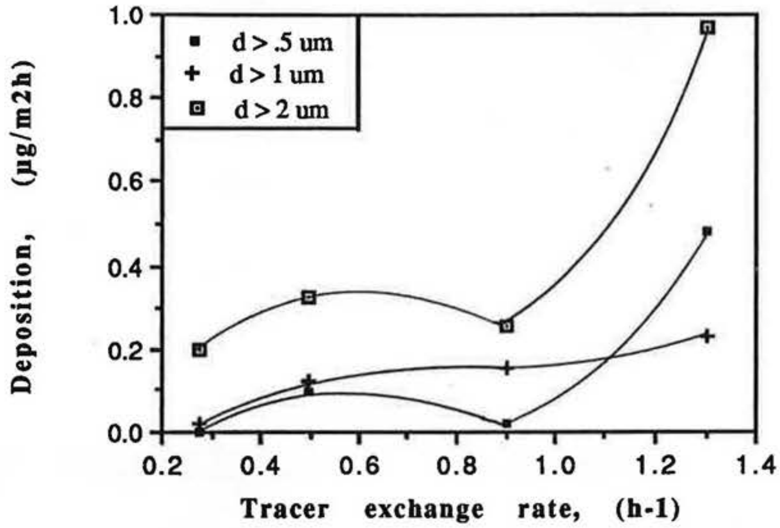
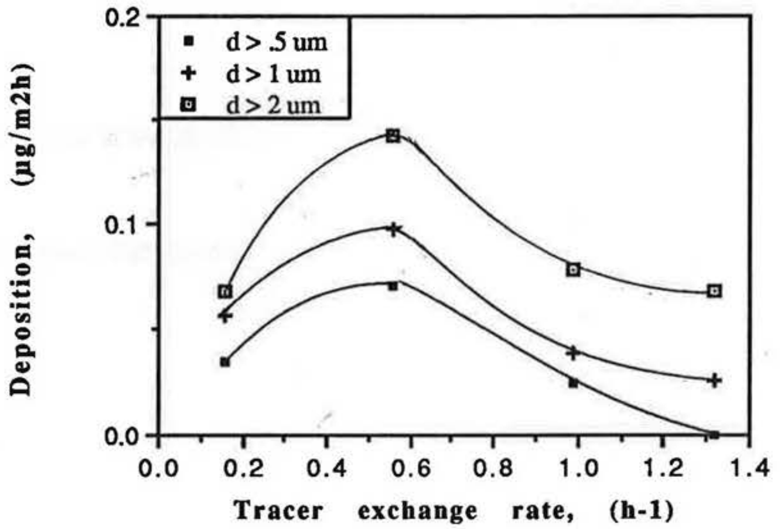
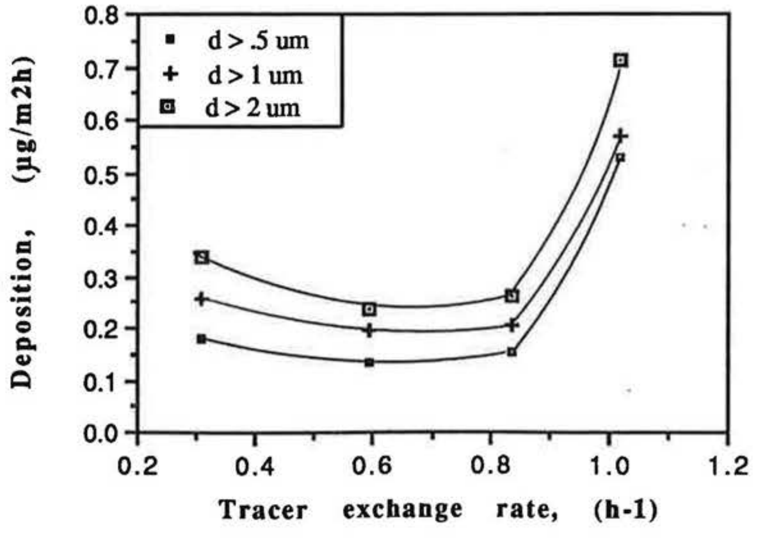
300
200
100
0
0
50
100
150
Time, (mins)



Deposition, (µg/m2h)
Tracer exchange rate, (h-1)
d > .5 um
d > 1 um
d > 2 um



Deposition, (µg/m2h)
Tracer exchange rate, (h-1)
d > .5 um
d > 1 um
d > 2 um



Deposition, (µg/m2h)
Tracer exchange rate, (h-1)
d > .5 um
d > 1 um
d > 2 um

Material	Tracer-gas exchange rate, (h^{-1})	Particle exchange rate, ($\mu g/m^3h$)		
		d>.5μm	d>1μm	d>2μm
wood	0.308	0.313	0.413	1.309
	0.595	1.076	1.203	2.231
	0.994	1.099	1.765	2.280
	1.359	3.773	2.517	6.204
aluminium	0.199	0.369	0.480	0.541
	0.637	0.993	1.129	1.348
	1.020	1.138	1.208	1.411
	1.314	1.146	1.443	1.653
carpet	0.303	1.185	1.572	1.993
	0.583	1.244	1.546	1.766
	0.839	1.597	1.876	2.160
	1.004	3.650	3.853	4.564

Particle deposition rate, α ($\mu g/m^2h$)			Particle deposition velocity, (x 10^{-6} cm/s)		
d > .5μm	d > 1μm	d > 2μm	d > .5μm	d > 1μm	d > 2μm
0.001	0.021	0.200	0.002	0.149	3.740
0.096	0.122	0.327	0.464	4.893	56.46
0.021	0.154	0.257	0.091	2.077	10.49
0.483	0.232	0.969	4.576	11.56	384.6
0.034	0.056	0.068	0.071	0.146	0.219
0.071	0.098	0.142	0.119	0.190	0.342
0.024	0.038	0.078	0.080	0.106	0.257
0	0.026	0.068	0	0.036	0.110
0.177	0.254	0.338	1.289	2.160	4.891
0.132	0.193	0.237	1.683	3.733	7.555
0.152	0.207	0.264	1.026	1.774	3.420
0.529	0.570	0.712	238.4	545.9	989.0

Table 1 Experimental Results