Submitted for
publicati 5782
Indoor

MEASUREMENT OF TRACER GAS AND SUSPENDED PARTICLES IN ROOMS

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ABSTRACT

The work described in this paper is concerned with measurement of the flow of tracer gas and suspended particles in rooms. Measurements were carried out in single and two-zone systems using SF_6 tracer gas and oil-smoke particles. The airflow rates estimated from tracer gas measurements were generally higher than those obtained using smoke particles. The coefficients of discharge for the opening connecting the two-zone system were in the range 0.4-0.96 for tracer gas measurements and 0.15-0.42 for smoke particle measurements.

KEY WORDS - Tracer-gas Particles Airflow Single-Zone Multi-Zone Doorways

INTRODUCTION

The study of particulate pollutants in buildings is important as they can have damaging effects on the health of the occupants (1). The development of techniques which could be used to remove particulate pollutants requires knowledge of particle sources, sizes and concentrations. Particles contained in indoor air can be classified into plant, animal, mineral, combustion, home and radioactive aerosols (2). Commonly occurring particles such as pollen, bacteria, viruses, asbestos, tobacco smoke and radon, have sizes in the range 0.1 to 1000 μm. Indoor particles can deposit on surfaces or remain in suspended form; the maximum size of particle that can remain suspended in still air is in the range 0.1 to 100 μm (3).

The concentration of suspended particles can be reduced by mechanical ventilation, e.g. using extract fans, or by natural ventilation which allows air to exchange between the indoor and outdoor environment via windows and doorways. Air exchange is an effective means of reducing the concentration of pollutants in buildings provided that the outside air is cleaner. In the case of polluted air, cleaning methods such as filtration, absorption and electrostatic precipitation can be used to reduce the concentration of particles. The pharmaceutical and micro-electronic industries require clean working environments with very low particle concentrations; high efficiency filters, e.g. heapa filters, are usually employed to provide clean air (4). The control of particle movement in buildings such as hospitals is also necessary to prevent flow of contaminated air to other rooms.

The concentration of particles in the indoor environment is influenced by the flow rate of air supplied to the building; the airflow can be estimated using tracer-gas techniques such as concentration-decay, constant-injection and constant-concentration (5). The purpose of this investigation is to determine the way in which suspended particles and tracer gases are dispersed in buildings. Measurements of the flow of SF_6 tracer gas and oil-smoke particles were carried out using single and two-zone systems. Tests were conducted using different arrangements of window and doorway opening.

THEORY

In this section we describe the fundamental theory of tracer gas and particle movement in single and two-zone systems.

Single-Zone System

Figure 1 shows a single-zone system. The concentration-decay technique was used to estimate the rate of tracer gas and particle exchange in a room. The method involves an initial injection of a tracer gas (e.g. SF_6) and particles (e.g., oil-smoke) into a zone and is followed by a period of mixing to establish a uniform concentration in the zone. 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 SF_6 tracer gas and smoke-particle concentration is given by the following equations:

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

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

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.

Two-Zone System

Figure 2 shows a schematic diagram of a two-zone system. SF_6 tracer gas and smoke particles can infiltrate from outside into each zone (F_{01} and F_{02}) and exfiltrate from each zone to the outside (F_{10} and F_{20}). In addition, SF_6 tracer gas and smoke particles can exchange between the two zones in both directions (F_{12} and F_{21}).

The concentration-decay technique can also be used to determine the movement of tracer gas and particles in a two-zone system. In this case, SF_6 tracer gas and smoke particles are released first in zone 1 while the door between the two zones is closed. After allowing a period for mixing of the tracer gas and smoke particles with air, the communication door is opened and the concentration evolution is measured in both zones. If one applies the material balances in each zone, assuming that a steady state exists, the following equations will apply:

The rate of change of tracer gas (or particle) concentration in zone 1 at time t is given by:

$$V_1\, dC_1/dt = -C_1\,(F_{10} + F_{12}) + C_2\, F_{21} \quad (3)$$

Similarly, the rate of change of tracer (or particle) concentration in zone 2 at time t is given by:

$$V_2\, dC_2/dt = C_1\, F_{12} - C_2\,(F_{21} + F_{20}) \quad (4)$$

The other flow rates can be then determined using the continuity equations as follows:

$$F_{01} = F_{12} + F_{10} - F_{21} \quad (5)$$

$$F_{02} = F_{20} + F_{21} - F_{12} \quad (6)$$

Equations 3-6 can be solved using one of the analysis methods described by Riffat (6). The Sinden (7) method was used to analyse the present data as this produced smallest errors.

A theory based on the application of the Bernoulli equation was used to estimate the coefficient of discharge for the doorway between the two zones. For steady flow conditions, the volumetric-flow rate of air through one half of the opening is:

$$F = (C_D\, W/3)\,(g\, H^3\, \Delta T/T)^{0.5} \quad (7)$$

EXPERIMENTAL

Experimental work was carried out in our laboratory using the single-zone and two-zone units shown in Figures 1 and 2. The single-zone was 5.5m x 4.6m x 2.85m and had three sliding windows (maximum opening = 0.7m x 0.44m each) and a doorway 0.75m x 1.98m.

The two-zone unit consisted of two rooms; room 1 had the dimensions 4.5m x 5.5m x 2.85m and room 2 had the dimensions 6.9m x 5.5m x 2.85m. The rooms were separated by a partition containing a single-sliding door of height 2.45m and a maximum width of 1.5m. Room 1 was heated using a convector electric-heater while room 2 was unheated. Temperatures were measured at the centre of the rooms at mid-height locations using Ni/Cr/Al thermocouples.

The experimental procedure involved injection of tracer-gas and oil-smoke particles into the room and was followed by a mixing period during which a desk fan was used. Multipoint-sampling units were then used to collect tracer gas and particle samples from the room for subsequent injection into gas and particle analysers.

Tracer gas measurements were carried out using an infra-red gas analyser, type BINOS 1, made by Leybold-Heraeus GMBH, Germany. The accuracy of the measurements was estimated to be within ± 5%.

RESULTS AND DISCUSSION

Single-Zone System

Experiments were performed in the single-zone system to determine air and particle exchange rates produced by opening windows. These measurements were carried out simultaneously using SF_6 tracer gas and oil-smoke particles. Measurements were carried using particles 0.3-1.5 μm diameter. Figures 3 and 4 show the variation of the concentration of tracer gas and smoke particles (diameter = 0.3-0.5 μm) with time for different window-opening arrangements. The tracer-gas decay curves were found to be simple exponential functions for each of the air change rates used. The decay curves for smoke particles were found to be simple exponential functions for low air-change rates and a sum of two or more exponential functions for high air-change rates. Table 1 shows tracer gas and particle exchange rates for different window-opening arrangements.

It is clear from Table 1 that the tracer gas and particle exchange rates are generally similar if half or one window is open. When two or three windows are open, the tracer gas exchange rates are 9.29 and 12.95 h^{-1}, respectively and the particle exchange rate vary with time. For example, when two windows are open the particle reduction rate (d = 0.3-0.4μm) is 7 h^{-1} in the first 10 minutes 2.02 in the second 10 minutes and 0.63 h^{-1} in the last 10 minutes. The tracer gas exchange rates for the condition of two and three windows open are higher than the corresponding particle exchange rates for all measurements. The results given in Table 1 are based on room and outside temperatures of 20 and 13.5^{o}C, respectively.

TABLE 1

Tracer gas and particle exchange rates for the single-zone system

Condition	Tracer Gas Exchange Rate (h^{-1})	Particle Exchange Rate (h^{-1}) (d=0,3-0,5μm)	(0.5-1μm)	(1-1.5μm)
Half-window open	5.01	4.33	4	4.02
One-window open	5.72	5.9	4.1	5.85
Two-windows open	9.29	0.63-7	0.6-6	5.85-8.4
Three-windows open	12.95	1.6-7.9	1.7-7.75	4.1-11.67

Two-Zone System

A number of tests were carried out to estimate the flow of SF_6 tracer gas and smoke-particles through openings of different sizes between two rooms. The experimental procedure involved heating room 1 to a temperature of 25-27°C using a convector electric-heater. The initial temperature in room 2 was approximately 23°C. Simultaneous injection of tracer gas and smoke particles in zone 1 then took place. After the mixing of tracer gas and smoke particles with air, the heater in room 1 was switched off and the doorway separating the two zones was opened at a specific position. Simultaneous sampling of SF_6 tracer gas and smoke particles in the two zones then commenced and was continued for 1 hour. The temperature at the centres of the two rooms were measured at 1 minute intervals.

Figures 5 and 6 show typical plots of SF_6 tracer-gas and smoke particle (diameter = 0.3-0.5 μm) concentration with time for a 400mm wide opening. Figures 7 and 8 show schematic diagrams of the flow of tracer gas and particles in the two zones for an average temperature difference of 0.9 °C. Results obtained from the measurements are given in Table 2.

Table 2 indicates that the tracer gas exchange rates across the doorway connecting the two zones were generally higher than the particle exchange rates. Equation (7) was used to estimate the coefficients of discharge, C_{Dg} and C_{Dp}. The values of C_{Dg} and C_{Dp} (for the different sizes of opening) were in the range 0.4-0.96 and 0.15-0.42, respectively. The values of C_{Dg} obtained in this investigation are similar to those published by other researchers (8). Measurements of interzone flow rates for particles 0.5-1.5 μm diameter were similar to those obtained using particles 0.3-0.5 μm diameter. Our measurements provide a clear indication that the behaviour of tracer gas and particles are different as a result of the effects of parameters such as particle

TABLE 2

Tracer gas and particle flows in the two-zone system

Opening Size	Interzone Tracer Gas Flow (m^3/min)	Interzone Particle Flow (m^3/min)	C_{Dg}	C_{Dp}
0.2m x 2.45m	3.348	0.646	0.96	0.19
0.3m x 2.45m	2.164	2.050	0.45	0.42
0.4m x 2.45m	5.354	1.622	0.5	0.15
0.5m x 2.45m	3.578	1.824	0.4	0.21

concentration and mixing. The deposition of particles on the building material can also have a significant effect on concentration/time curves.

CONCLUSIONS

The following conclusions are drawn:

1. The results showed that the tracer gas and particle exchange rates for the single-zone cell were similar for low-ventilation rates. The tracer-gas exchange rate was higher than the particle reduction rate for high-ventilation rates.

2. The interzone airflow rate based on tracer gas measurements was generally higher than the airflow rate based on smoke particle measurements.

3. The coefficient of discharge of the opening connecting the two-zone system was in the range 0.4-0.96 for tracer gas measurements and 0.15-0.42 for smoke particle measurements.

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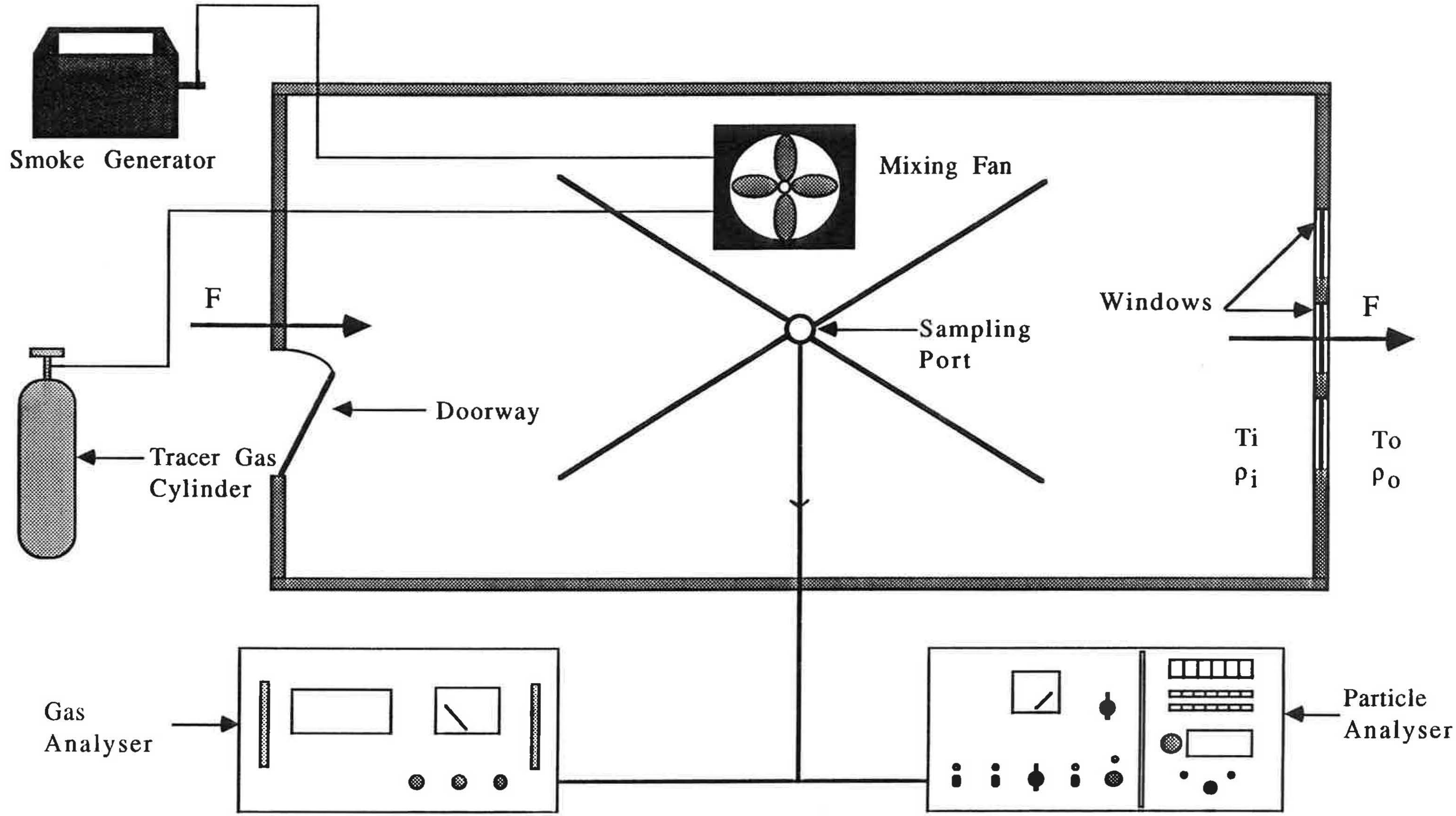
FIGURES


Smoke Generator
Mixing Fan
F
Windows
F
Sampling
Port
Doorway
Tracer Gas
Cylinder
Ti
ρ_i
To
ρ_o
Gas
Analyser
Particle
Analyser

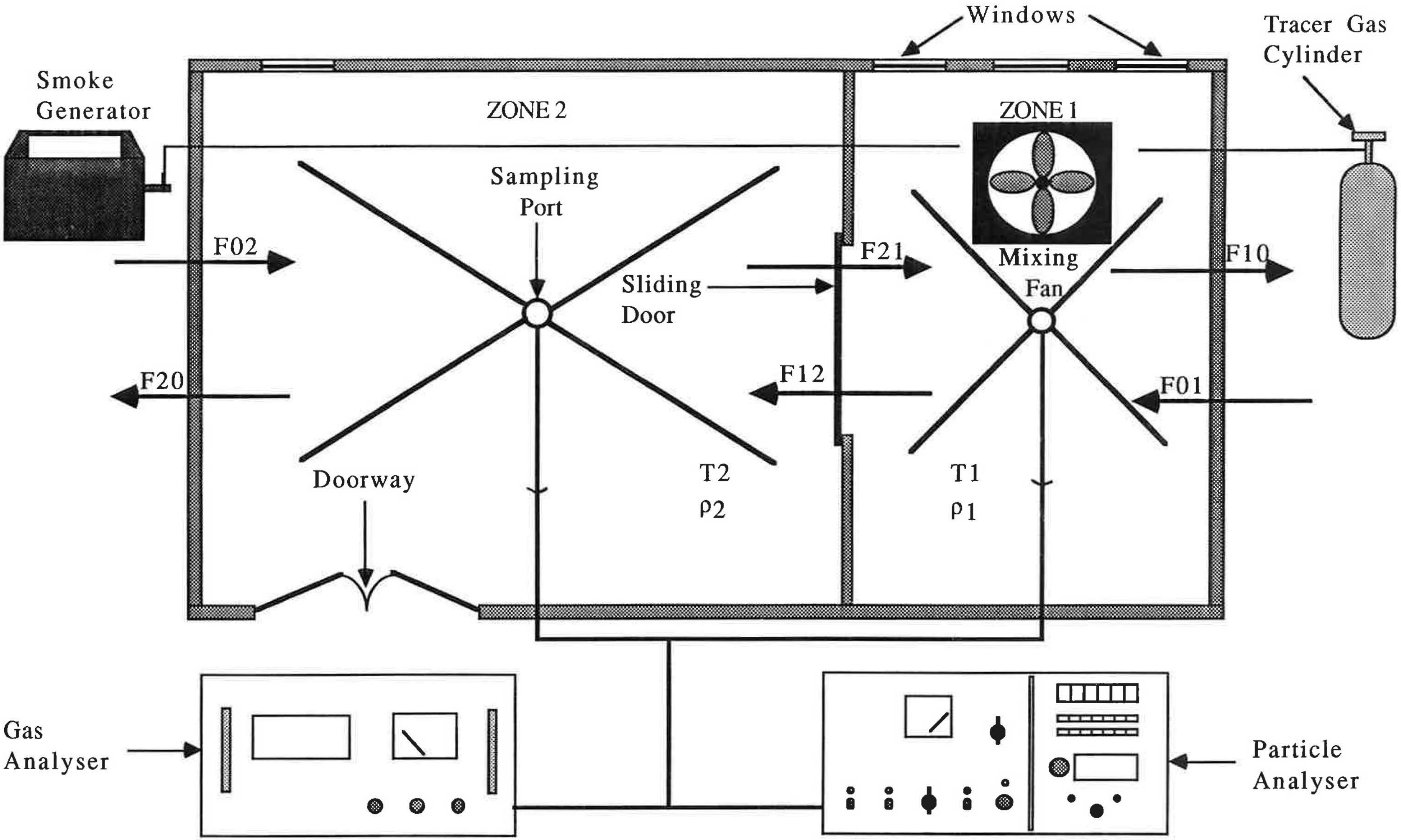
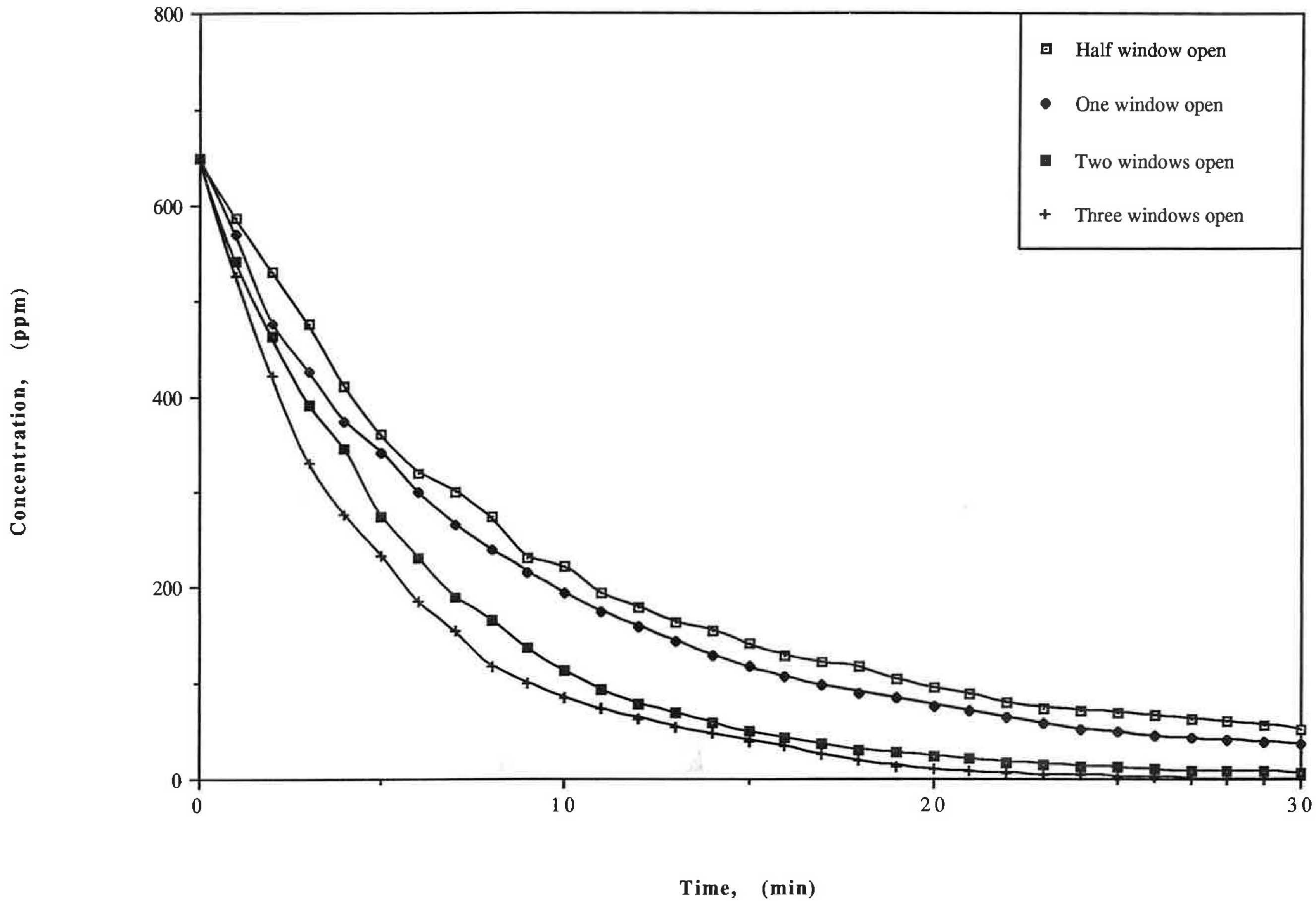
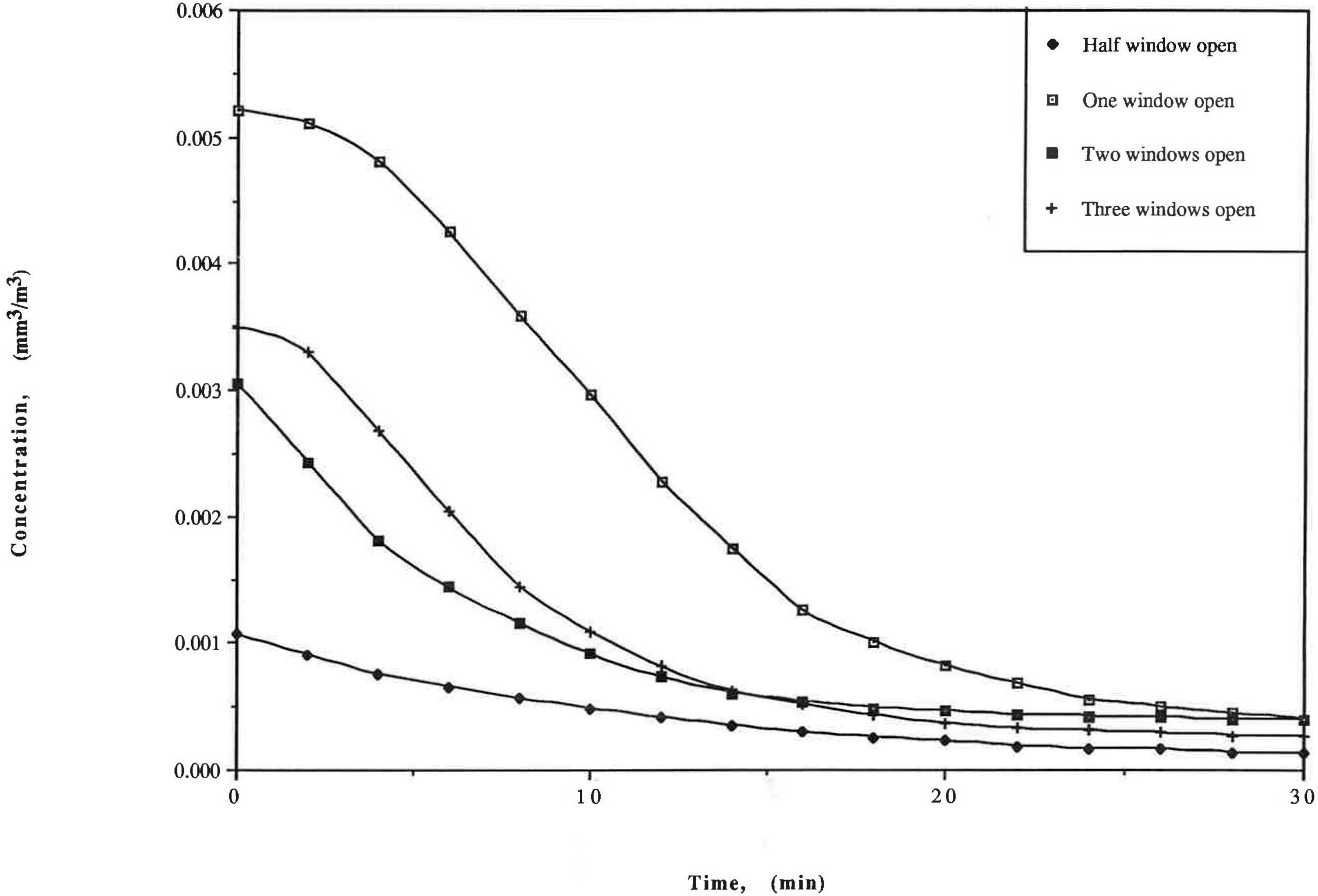

Windows
Tracer Gas Cylinder
Smoke Generator
ZONE 2
ZONE 1
Sampling Port
F02
F21
Mixing Fan
F10
Sliding Door
F20
F12
F01
Doorway
T2
ρ2
T1
ρ1
Gas Analyser
Particle Analyser

Fig 2



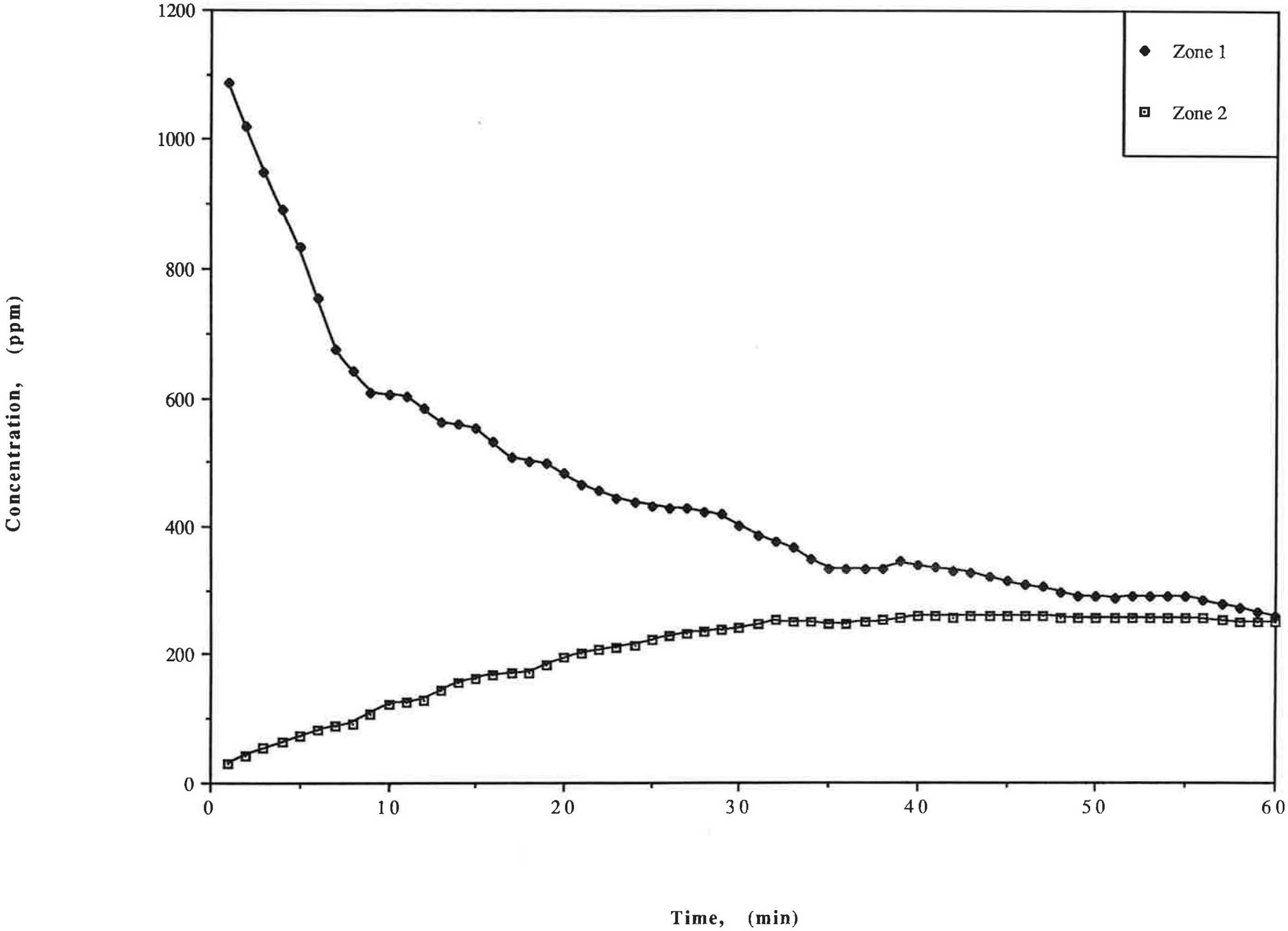
800
600
400
200
0
0
10
20
30
Concentration, (ppm)
Time, (min)
Half window open
One window open
Two windows open
Three windows open



Concentration, (mm3/m3)
Time, (min)
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
10
20
30
Half window open
One window open
Two windows open
Three windows open

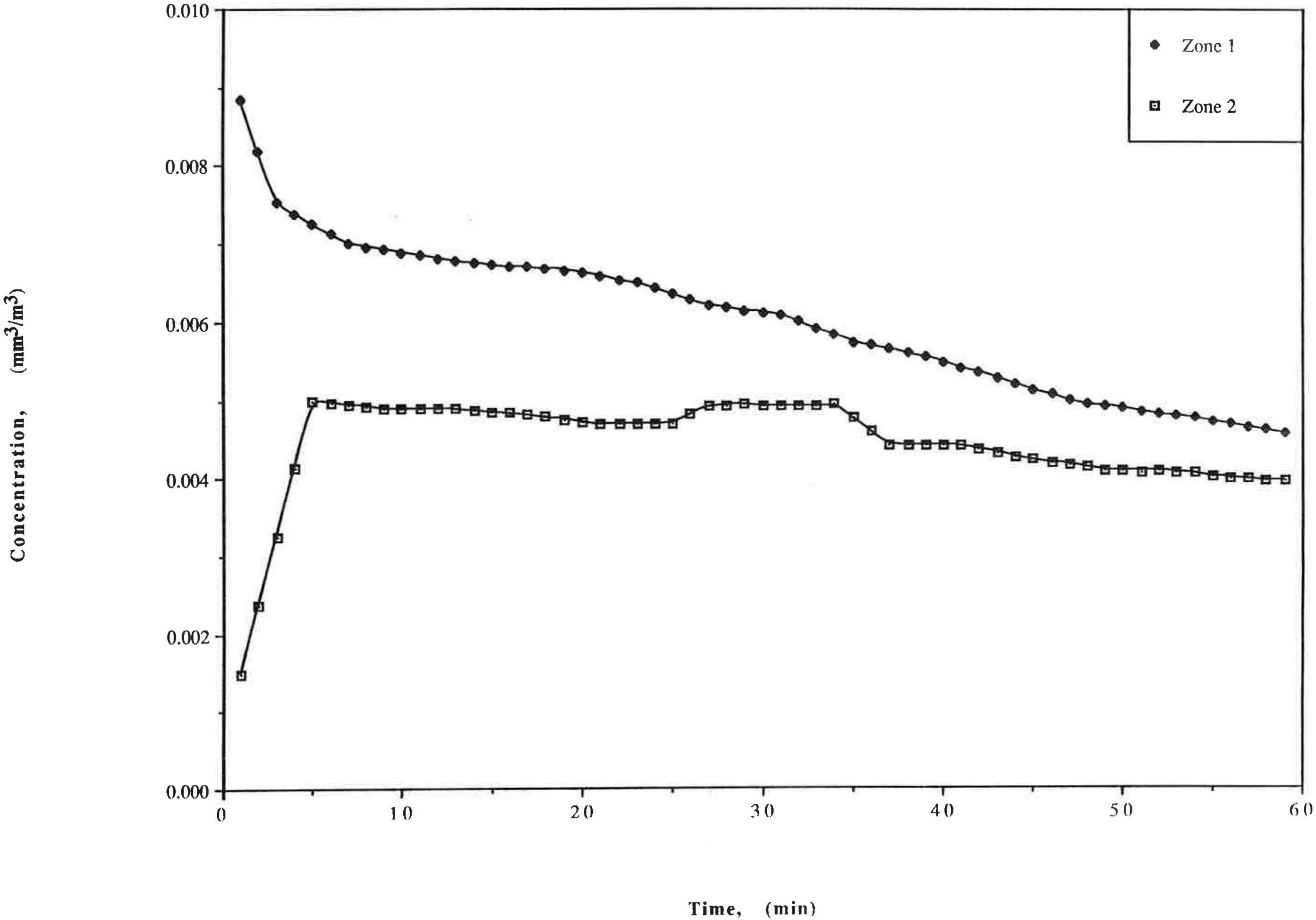
t1

Fig 4



Zone 1
Zone 2
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Concentration, (ppm)
Time, (min)

b)


Zone 1
Zone 2
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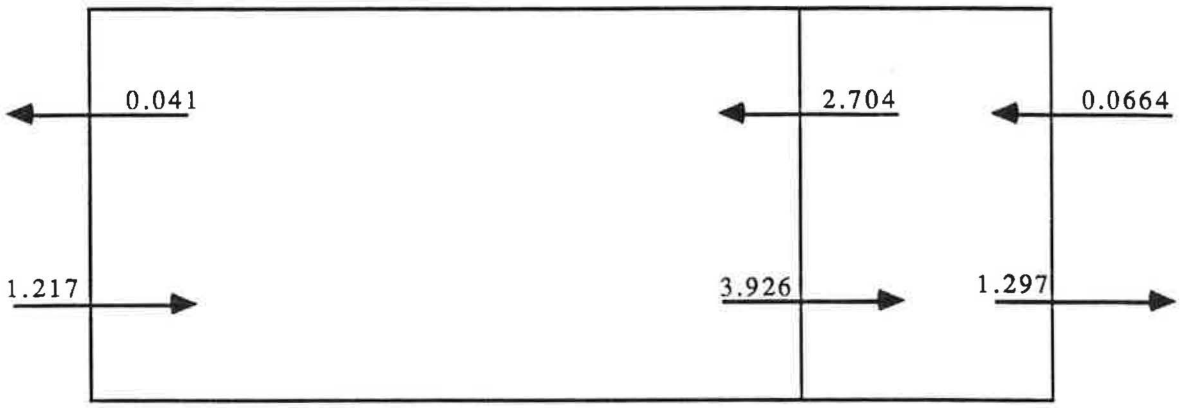
0.008
0.006
0.004
0.002
0.000
0
10
20
30
40
50
60
Concentration, (mm^3/m^3)
Time, (min)

Fig 6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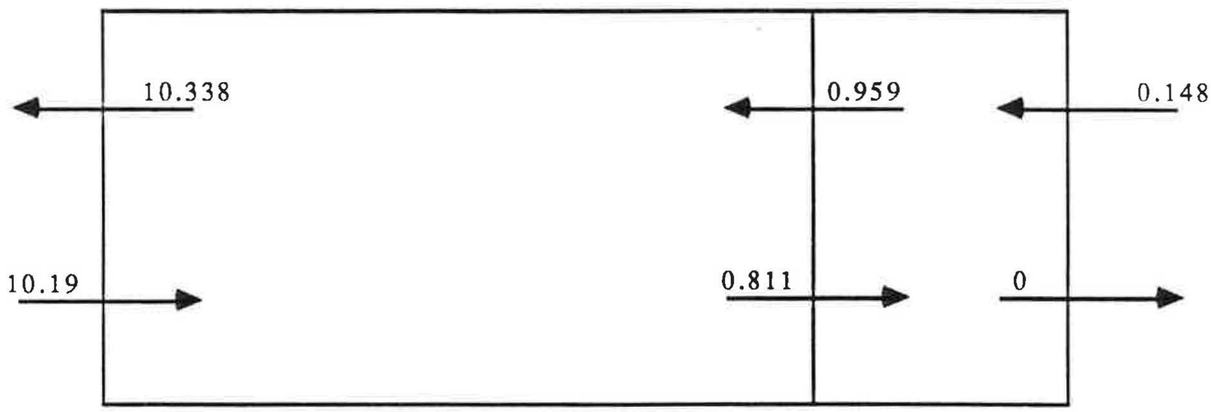
3.926
1.297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0.811
0