THE INFLUENCE OF TRACER GASES ON THE ACCURACY OF INTERZONAL AIRFLOW MEASUREMENTS

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ABSTRACT

This paper examines the influence of the tracer gas on the accuracy of the single tracer gas decay method for measurement of interzonal airflow. The use of sulphur hexafluoride (SF_6), nitrous oxide (N_2O) and carbon dioxide (CO_2) is examined for measurement of airflow between two tightly sealed chambers and these measurements are compared with measurements made using a calibrated flowmeter. Tracer gas measurements made using SF_6 were found to be in closer agreement with flowmeter measurements than those made using N_2O or CO_2.

1. INTRODUCTION

Accurate prediction of airflow in buildings is an important factor influencing the design of HVAC systems, energy efficiency, thermal comfort and air quality. Measurement of air flow in buildings can be accomplished using tracer gas techniques, e.g. concentration decay, constant concentration and pulse injection. The concentration decay technique is widely used for measurement of airflow in buildings as it requires

relatively simple equipment[1]. The decay technique involves the injection of a known amount of tracer gas into a building followed by a period of mixing to establish a uniform tracer gas concentration. The decay of gas concentration is then measured. The following experimental methods are commonly used for multizone (N zones) measurements:

i) Multi-tracer gas method: N different types of tracer gas are injected simultaneously, one in each zone of a building and the concentrations of the tracer gases are then measured in all zones. Only one experiment is necessary to obtain all the required data.

ii) Single-tracer gas method: One gas is injected into a single zone (e.g. zone 1) and the concentration of tracer gas is then measured in all zones. The experiment is then repeated carrying out injection of the same tracer gas into each of the other zones (i.e. N-1 zones), sequentially.

Several tracer gases have been used for measurement of ventilation and interzone air movement in buildings[2,3]. Although previous studies[4-5] have indicated that different values in air change rate in the single zone are obtained when different tracer gases are used, they did not address the question of the accuracy of interzone air flow measurements outlined in the methods (i) or (ii) above. The present study evaluates errors in interzone airflow rates derived from measurements made using method (ii). We have chosen to examine the accuracy of measurements made using sulphur hexafluoride (SF_6), nitrous oxide (N_2O) and carbon dioxide (CO_2) as these tracer gases have desirable characteristics in terms of detectability and cost. Furthermore their suitability has been demonstrated previously by their successful use in other air movement studies[6].

2. THE TRACER GAS DECAY TECHNIQUE

The tracer gas decay method can be used for measurement of interzonal airflow within a building. The analysis of this technique involves solving tracer gas continuity and conservation equations. The building is assumed to consist of a number of zones 0, 1, 2, ..., N, which are connected by airflow passages. The test is carried out by first injecting a known amount of tracer gas into each zone. It is assumed that there is no further generation of tracer gas in the zone after time zero and that the air and tracer gas in each zone are perfectly mixed. Applying the continuity equation for the i'th zone, we obtain:

$$V_i \frac{dC_i}{dt} = \sum_{j=1}^{N} F_{ji} C_j (1-\delta_{ij}) - F_{ie} C_i + \sum_{j=1}^{N} F_{ij} C_i (1-\delta_{ij}) \qquad (1)$$

Since there is no net build-up of air in the building, the total flow into the zone i must equal the total flow out of the zone and this is given by the conservation equation:

$$F_{ei} + \sum_{j=1}^{N} F_{ji} (1 - \delta_{ij}) = F_{ie} + \sum_{j=1}^{N} F_{ij} (1 - \delta_{ij}) \qquad (2)$$

where V_i is the effective volume of zone i, C_i is the tracer gas concentration in the same zone, F_{ij} is the volume flow rate of air between zones i and j, F_{ji} is the flow rate from jth to ith zone, F_{ie} is volume flow rate from zone i to the outdoor environment and F_{ei} is the volume flow rate from the outdoor environment into zone i. Zone 0 in the model represents the outdoor environment and is assumed to have an infinite volume. The concentration of tracer gas in this zone is assumed to be zero. The delta function $\delta=0$ when i=j and $\delta=1$ when i=j.

Consider a two-zone model as shown in Figure 1. The single-tracer gas decay method can be applied to each zone in order to determine the infiltration, exfiltration and interzonal airflow rates. Equations 1 and 2 can be solved using one of several analysis methods, such as those adopted by Sinden[7], Penman and Rashid[8], Perera and Walker[9], Wortman and Burch[10] and I'Anson et al[11]. The relative accuracy of these methods has been examined by Riffat[12]. A method based on the Sinden model was found to be the most reliable and has been used for the analysis of our experimental results. This method involves the use of a numerical technique for the analysis of experimental data. The technique considers the multizone system to be a series of cells of known and constant volumes. These are assumed to be coupled to another cell of infinitely large volume, i.e., the outdoor environment. The zone volumetric balance equations are expressed in matrix form with the addition of a discrete time model as follows:

Introducing the notation $G_{j,i} = F_{j,i}/V_i$ we have:

$$dC/dt = GC \tag{3}$$

where

$$C = (C_1 \ldots C_N)^T \tag{3a}$$

and

$$G = \begin{pmatrix} G_{1,1} & G_{2,1} & \cdots & G_{N,1} \\ G_{1,2} & G_{2,2} & \cdots & G_{N,2} \\ & & \cdot & \\ G_{1,N} & G_{2,N} & \cdot & G_{N,N} \end{pmatrix} \tag{3b}$$

The discrete time model is written:

$$C_1(t+1) = D_{1,1}\, C_1(t) + D_{2,1}\, C_2(t) \ldots + D_{N,1}\, C_N$$

$$C_2(t+1) = D_{1,2}\, C_1(t) + D_{2,2}\, C_2(t) \ldots + D_{N,2}\, C_N$$

$$\vdots$$

$$\vdots$$

$$C_N(t+1) = D_{1,N}\, C_1(t) + D_{2,N}\, C_2(t) \ldots + D_{N,N}\, C_N \qquad (4)$$

or, in matrix form:

$$C(t+1) = D\, C(t) \qquad (4a)$$

where

$$D = \exp G \qquad (4b)$$

The exponential of the square matrix G is most conveniently defined by the power series:

$$\exp G = I + G + G^2/2! + G^3/3! + \ldots \qquad (4c)$$

This technique minimises the errors introduced by the uncertainties in tracer gas measurements and estimation of the gradient dC/dt since the variable t is restricted to the values 1, 2, 3, ... S - 1, where S denotes the number of samples taken in each zone.

3. TEST FACILITY AND EXPERIMENTAL PROCEDURE

Interzonal airflows were measured using two identical microprocessor-controlled tracer gas systems, Figure 2 which are capable of taking samples as frequently as every 5 seconds. In essence, the tracer gas sampling system incorporates solenoid valves, tracer gas sampling bags, a pulse pump, a microprocessor-based controller, a manifold and a by-pass valve. The sampling period of the system can be adjusted over a wide range (seconds, minutes, hours, weeks or months). Variable interval sampling is

achieved using a specially designed microprocessor controller. This contains a central processing unit and a programme memory with a capability of 60 input/output.

The system is designed to take up to 40 samples at short or long intervals and allows different sampling periods to be used during the transient and dominant periods of a single experiment. Air/tracer gas samples can be collected from a zone and injected automatically into a portable gas chromatograph/analyser. This allows determination of the concentration of tracer gas in each sample.

To estimate the accuracy of the decay technique using different tracer gases, air flow measurements were carried out using a two-zone test rig, Figure 3. The test rig simply consists of two tightly-sealed chambers each with a volume of $0.225m^3$, a diaphragm pump, a flowmeter and a mixing fan.

The experimental procedure was as follows. At the beginning of each test a tracer gas was injected into chamber 1 where it was mixed with air using a fan. The concentration of tracer gas was then measured at different heights in the chamber in order to check that a good mixing had been achieved. After the mixing period, the two chambers were connected and the pump was turned on. Tracer gas/air samples were then taken from the two chambers for analysis.

4. RESULTS AND DISCUSSION

To minimise the effect of weather conditions on tracer gas measurements, tests were conducted in tightly sealed chambers in which the infiltration air, (F_{01} and F_{02}), and exfiltration air, (F_{10} and F_{20}), were negligible. The interzonal airflows F_{12} and F_{21} are therefore equal.

Air flow rates ranging from 2 to 10 1/min between the two chambers were achieved using a diaphragm pump. The flow rate was measured using a calibrated flowmeter accurate to +5% of measured flow.

The first tests were conducted using SF_6 tracer gas. Figures 4 and 5 show typical variations of tracer gas concentration with time for flow rates of 2 and 10 1/min. The rate of change of tracer gas concentration in the two chambers was small at low air flow rates but increased at higher flow rates. Well-conditioned data were obtained during these measurements as shown by the concentration/time curves. These indicated that uniform tracer gas concentrations had been achieved in the chambers after the mixing period. The minimum and maximum errors in the estimated airflow rates, i.e., $(F_{tracer} - F_{flowmeter})/F_{flowmeter}$ were -3.8 and 35%.

The second tests were carried out using N_2O as the tracer gas. Figures 6 and 7 show the concentration versus time curves for flow rates of 2 and 10 1/min. The general characteristics of these curves are similar to these obtained using SF_6. The minimum and maximum errors in the estimated airflow rates were 17.5 and 39%.

The third set of measurements were carried out using CO_2. Figures 8 and 9 show the concentration versus time curves for airflow rates of 2 and 10 1/min. The minimum and maximum errors in the estimated airflow rate were -7 and -24%.

Figure 10 compares the results of the experiments carried out using SF_6, N_2O and CO_2 with measurements made using a flowmeter. Best linear relationships were obtained as follows:

Airflow rate using SF_6 = 1.056 airflow rate using flowmeter
Airflow rate using N_2O = 1.247 airflow rate using flowmeter
Airflow rate using CO_2 = 0.848 airflow rate using flowmeter

These relationships show that measurements made using SF_6 tracer gas are in closer agreement with the flowmeter measurements than those made using N_2O or CO_2. Comparison of the results obtained using the three tracer gases produces the following correlations:

N_2O airflow rate = 1.176 SF_6 airflow rate
CO_2 airflow rate = 0.794 SF_6 airflow rate

Measurements made using N_2O produced slightly higher values than those made using SF_6. Use of CO_2 resulted in lower values than those obtained using SF_6. These results are similar to those obtained by Basset et al[5] who compare air change rate for the single zone with fan pressurization extract rate.

CONCLUSIONS

The use of SF_6, N_2O and CO_2 tracer gases has been examined for measurement of airflow between two zones using the single tracer gas decay method. Values of interzonal airflow rates derived from tracer gas measurements were found to be dependent on the particular tracer gas used. The agreement between flowmeter and tracer gas measured interzonal airflow rates was closer for SF_6 than for N_2O or CO_2.

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FIGURES

Figure 1 Air movement between two zones

Figure 2 The microprocessor-controlled tracer gas system

Figure 3 Apparatus for testing airflow between two zones using different tracer gases

Figure 4 The variation of SF_6 concentration with time in zone 1 and 2; interzonal airflow rate = 2 l/min

Figure 5 The variation of SF_6 concentration with time in zone 1 and 2; interzonal airflow rate = 10 l/min

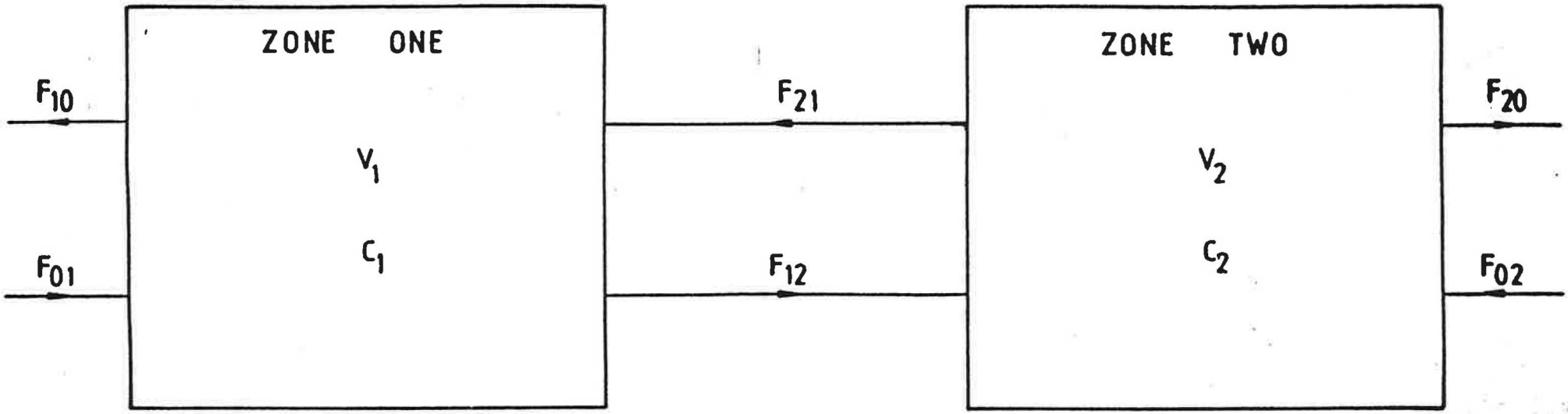
Figure 6 The variation of N_2O concentration with time in zone 1 and 2; interzonal airflow rate = 2 l/min

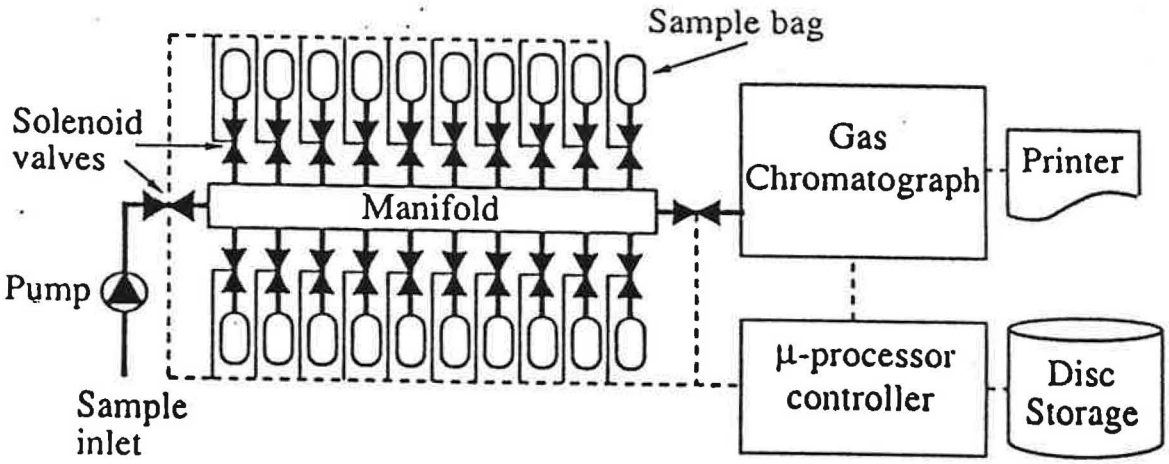
Figure 7 The variation of N_2O concentration with time in zone 1 and 2; interzonal airflow rate = 10 l/min

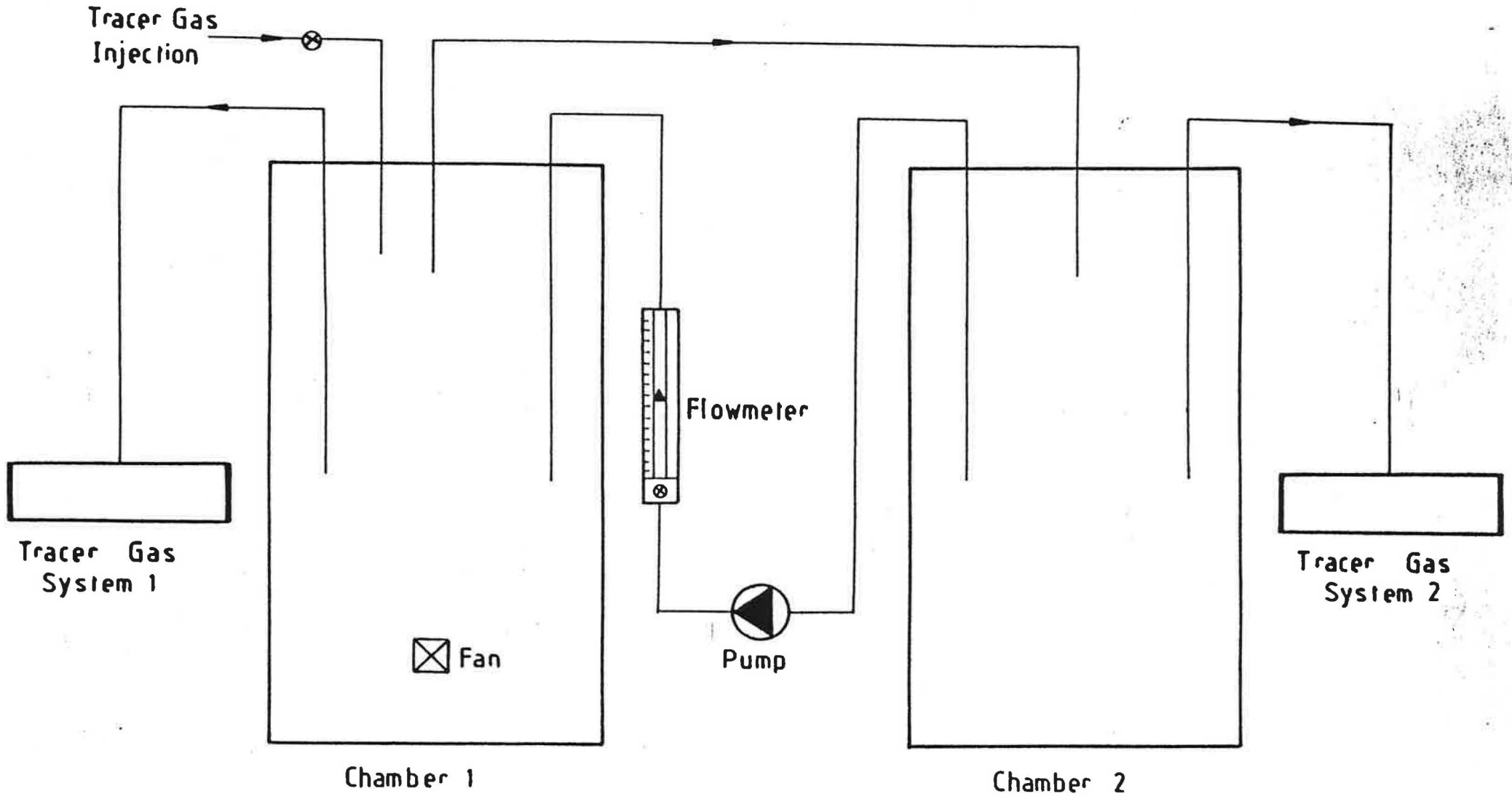
Figure 8 The variation of CO_2 concentration with time in zone 1 and 2; interzonal airflow rate = 2 l/min

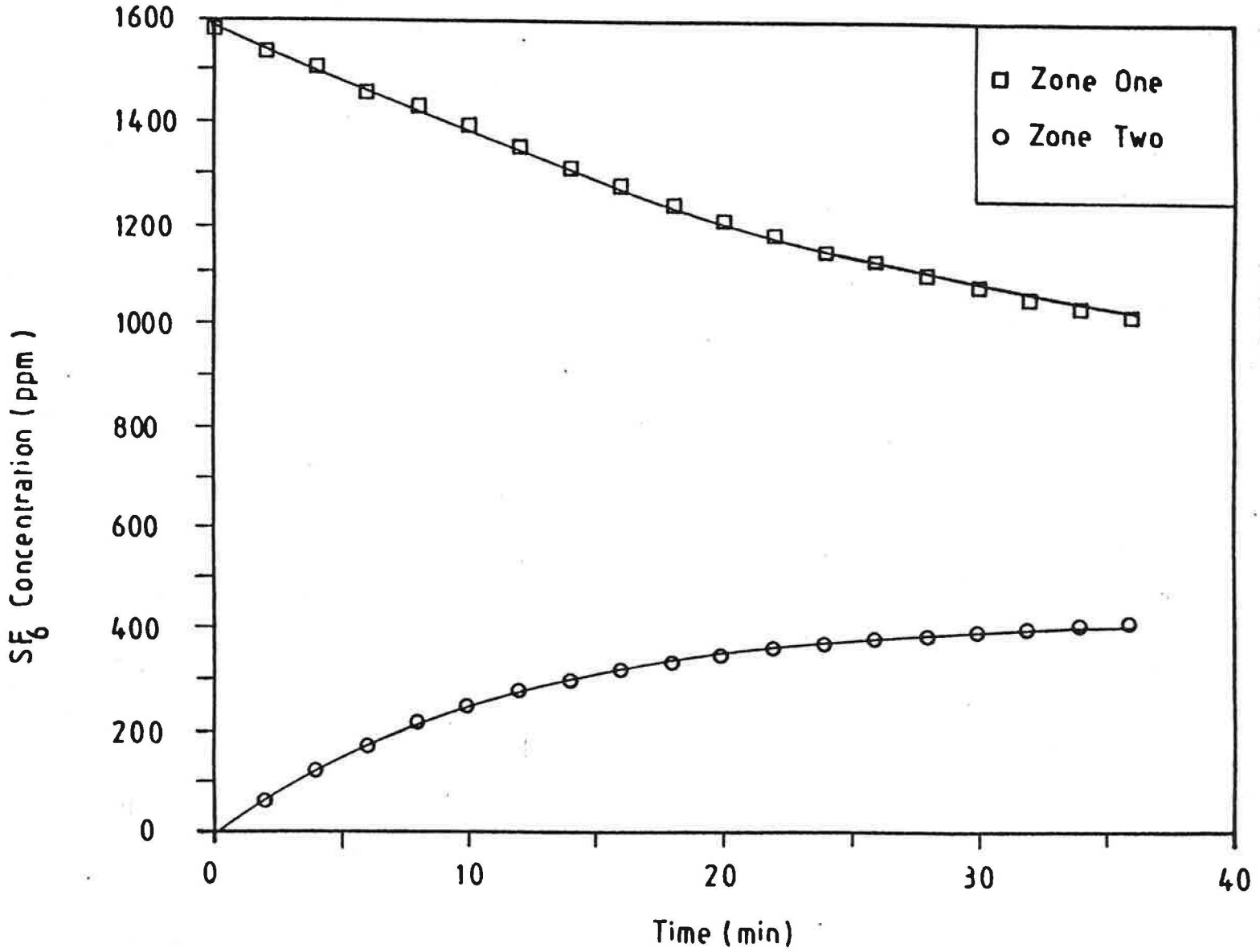
Figure 9 The variation of CO_2 concentration with time in zone 1 and 2; interzonal airflow rate = 10 l/min

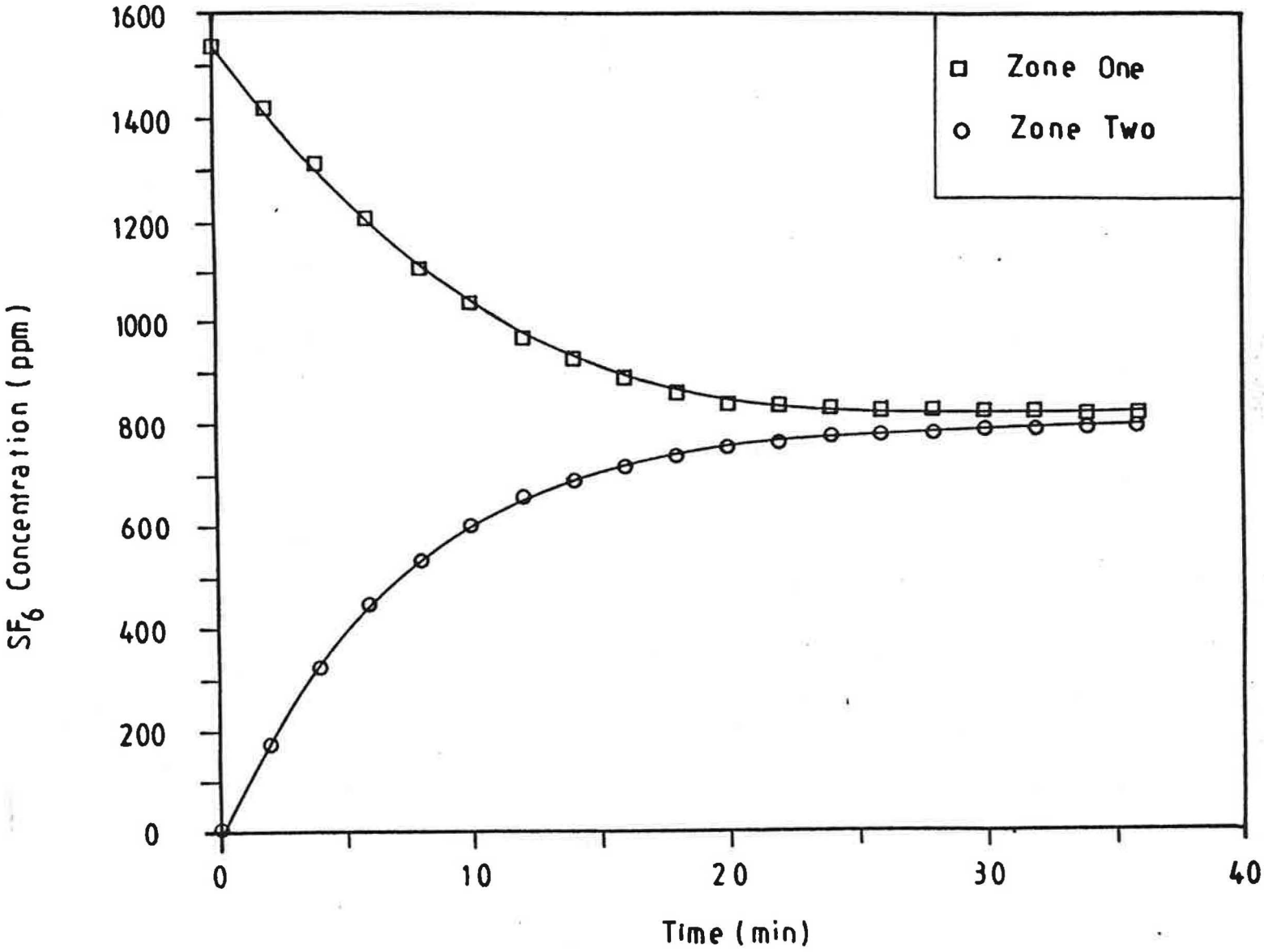
Figure 10 Comparison of airflow measurements made using SF_6, N_2O and CO_2 tracer gases with measurements made using a flowmeter.

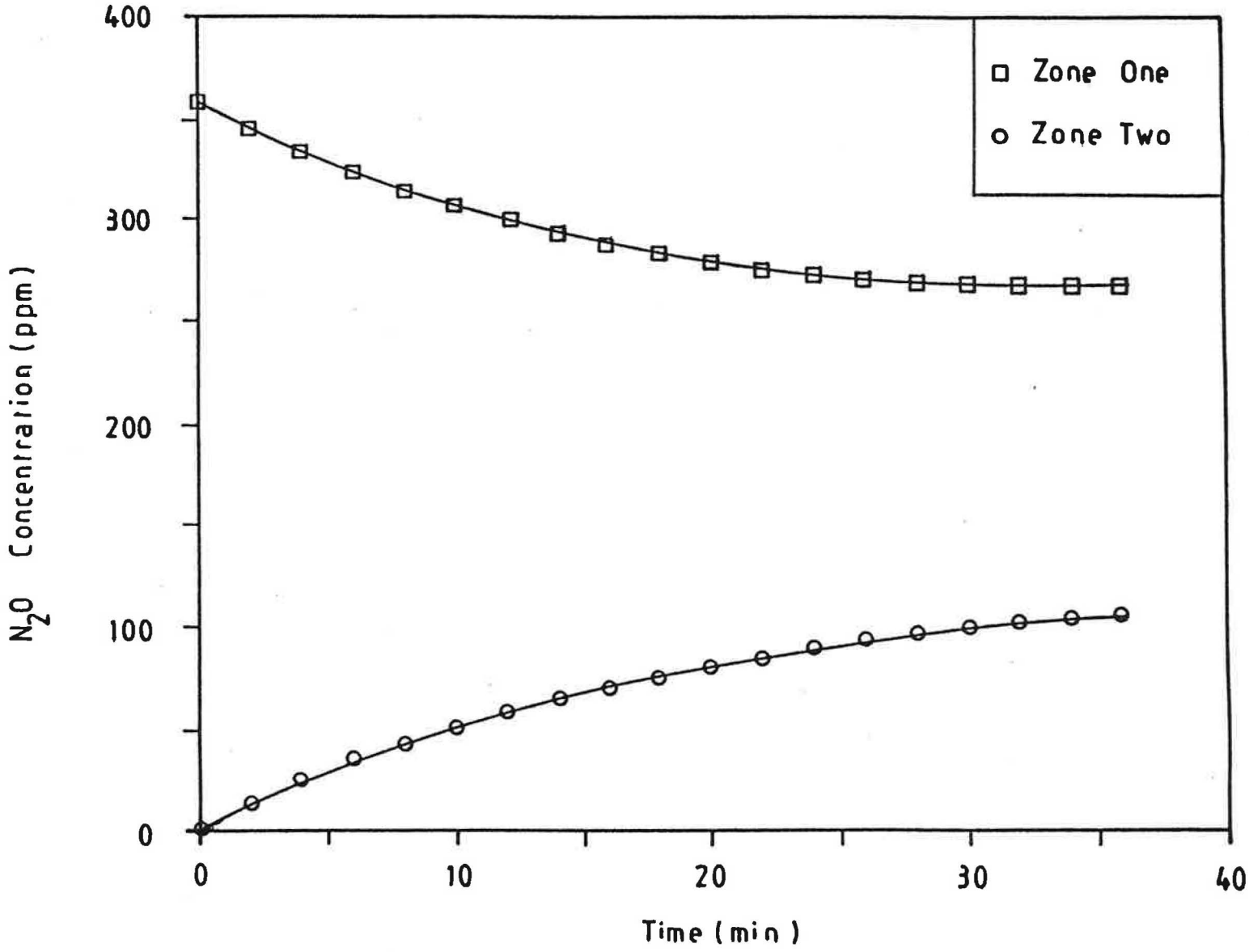

ZONE ONE
ZONE TWO
F_{10}
F_{01}
F_{21}
F_{12}
F_{20}
F_{02}
V_1
C_1
V_2
C_2

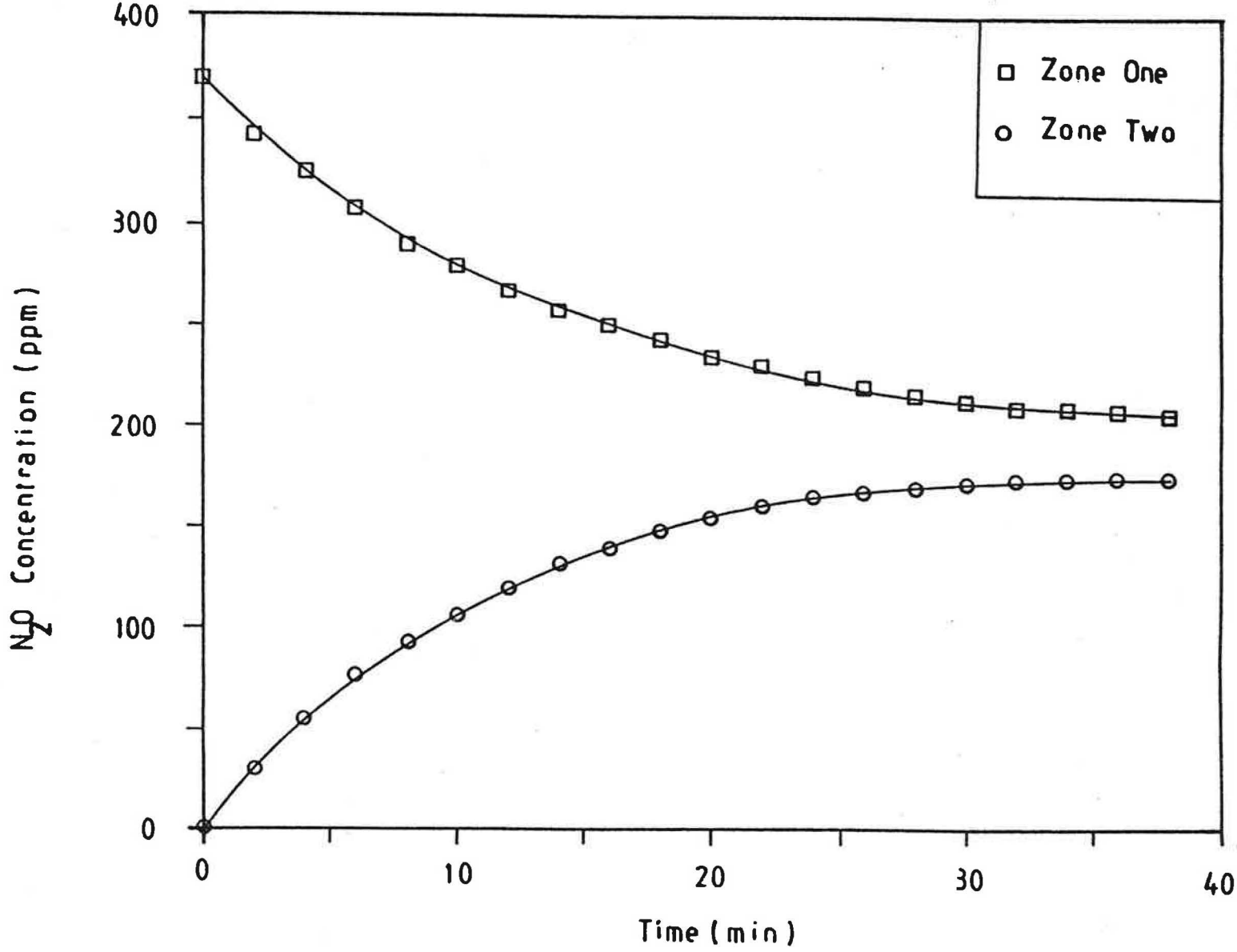

Sample bag
Solenoid valves
Manifold
Pump
Sample inlet
Gas Chromatograph
Printer
μ-processor controller
Disc Storage

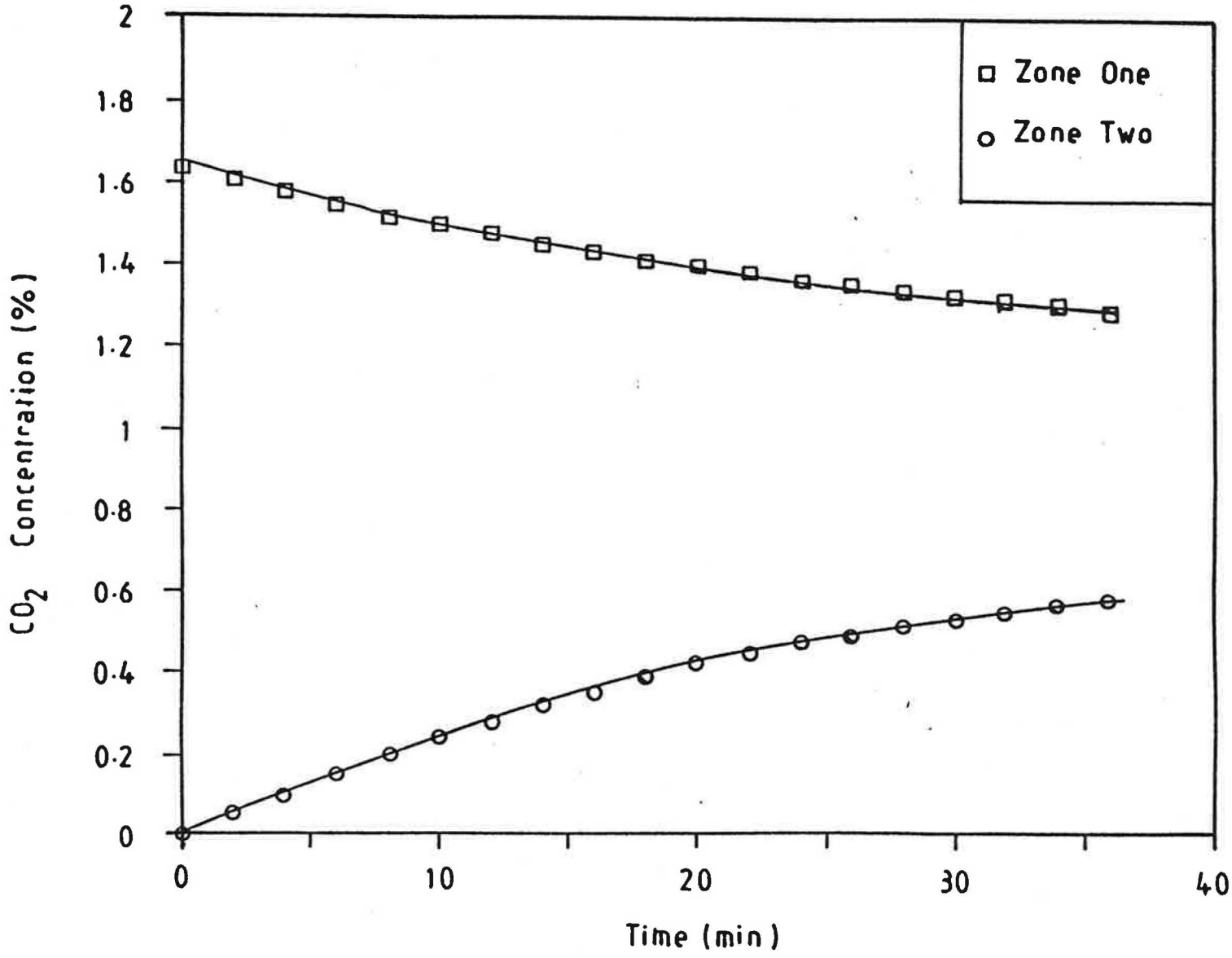

Tracer Gas
Injection
Flowmeter
Tracer Gas
System 1
Fan
Pump
Tracer Gas
System 2
Chamber 1
Chamber 2

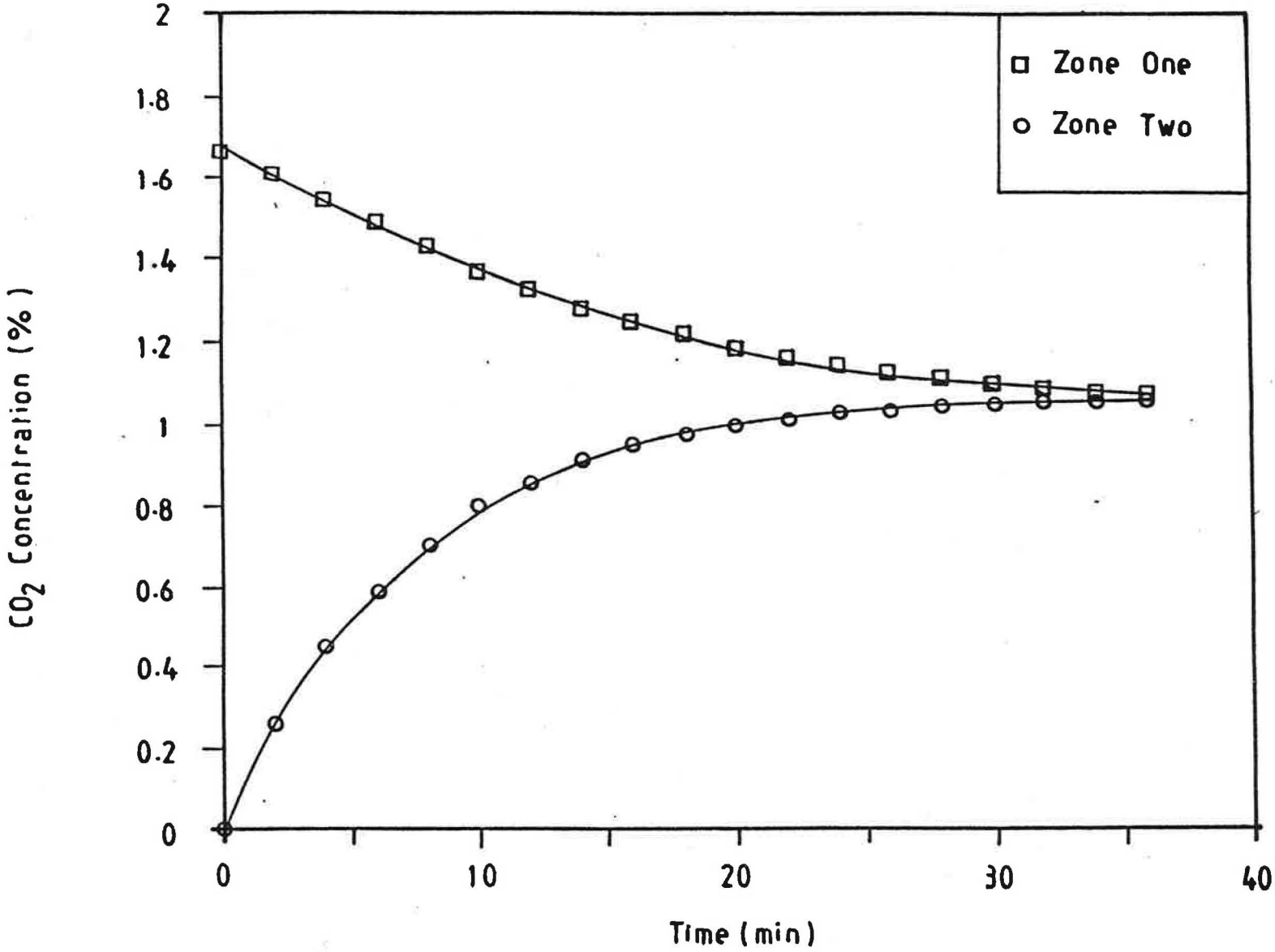

1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
Time (min)
SF_6 Concentration (ppm)
Zone One
Zone Two

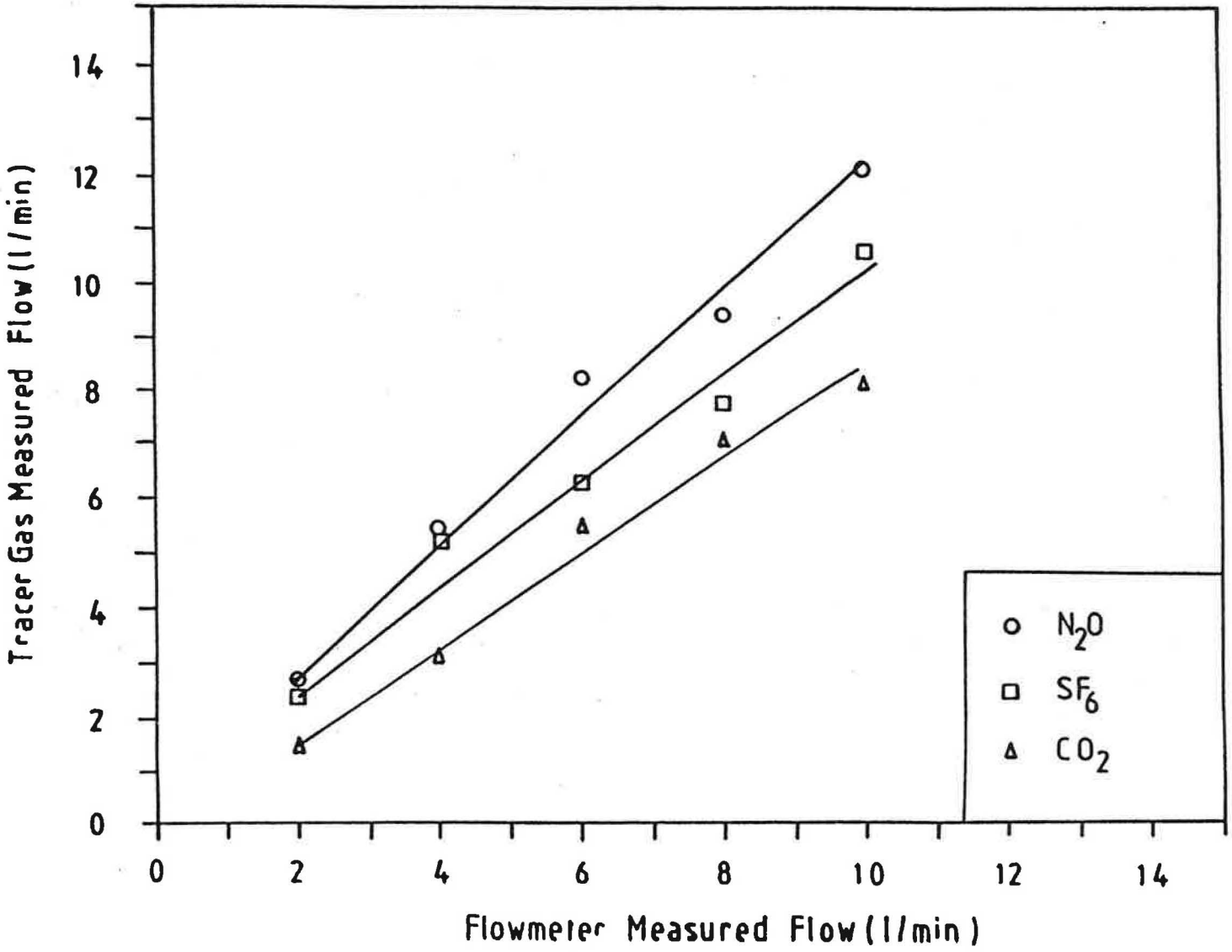

1600
1400
1200
1000
800
600
400
200
0
SF_6 Concentration (ppm)
0
10
20
30
40
Time (min)
Zone One
Zone Two


400
300
200
100
0
0
10
20
30
40
N_2O Concentration (ppm)
Time (min)
Zone One
Zone Two


400
300
200
100
0
0
10
20
30
40
Zone One
Zone Two
N2O Concentration (ppm)
Time (min)


Zone One
Zone Two
CO_2 Concentration (%)
Time (min)
0
0·2
0·4
0·6
0·8
1
1·2
1·4
1·6
1·8
2
0
10
20
30
40


Zone One
Zone Two
CO_2 Concentration (%)
Time (min)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40


Tracer Gas Measured Flow (l/min)
Flowmeter Measured Flow (l/min)
0
2
4
6
8
10
12
14
N_2O
SF_6
CO_2