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TRACER-GAS TECHNIQUES FOR DETERMINATION OF VELOCITY PRESSURE LOSS-FACTORS FOR DUCT FITTINGS

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SUMMARY

This investigation is concerned with the determination of velocity pressure loss-factors (k-factors) for duct fittings. The constant-injection tracer-gas technique was used to measure airflow through the components of a small-scale HVAC system. Tracer-gas measurements were compared with measurements made using a pitot tube. The concentration of SF_6 tracer gas, velocity and static pressures in duct fittings were measured for various Reynolds numbers. Results indicated that the k-factors estimated using the pitot static traverse method were generally higher than those obtained using the tracer-gas technique. The estimated k-factors were compared with data published in the CIBSE Guide and ASHRAE Handbook.

LIST OF SYMBOLS

A	cross-sectional area of the duct fitting, m^2
C	concentration of tracer gas, ppm
F	volumetric flow rate, $m^3\ s^{-1}$
q	injection rate of the tracer gas, $m^3\ s^{-1}$
k	velocity pressure loss-factor, dimensionless
V	bulk velocity, $m\ s^{-1}$
t	air temperature, ^oC
P_v	velocity pressure, $N\ m^{-2}$
P_s	static pressure, $N\ m^{-2}$
P_T	total pressure, $N\ m^{-2}$
ΔP_T	total pressure loss, $N\ m^{-2}$
β	barometric pressure, $N\ m^{-2}$
ρ	air density, $kg\ m^{-3}$

1. INTRODUCTION

Accurate determination of duct pressure losses is a necessary prerequisite for design of energy-efficient heating, ventilation and air conditioning (HVAC) systems. The pressure loss of ductwork supplying air to various zones can be calculated using friction charts and tables of pressure loss-factors (i.e. k-factors) for duct fittings. Pressure loss-factors are usually obtained using standard values given in the CIBSE Guide "Reference Data" [1] and ASHRAE Handbook "Fundamentals" [2]. These values have been determined experimentally using traditional instrumentation such as pitot tubes and orifice meters.

Tracer-gas techniques such as constant-injection and pulse-injection allow accurate measurement of airflow in ducts and duct fittings. Unlike traditional instrumentation, tracer-gas techniques do not require a long measuring duct for establishment of fully developed flow and can be used to measure airflow over a wide range of velocities in ducts and fittings of various sizes and shapes. Furthermore, tracer-gas techniques can be used to measure airflow directly and do not require determination of the cross-sectional area of the duct and duct fittings. The present study describes the use of the constant-injection technique for estimation of k-factors of duct fittings. Experimental work was carried out in a small-scale HVAC system and k-factors for various components such as a bend, a branch and a contraction were determined and results were compared with measurements made using a pitot tube and values obtained from CIBSE and ASHRAE data.

2. THEORY

2.1 Constant-Injection Tracer-Gas Technique

The constant-injection technique was used to measure airflow in an HVAC system. SF_6 tracer gas was injected into the duct fittings at a constant rate and the resulting concentration response was measured. Assuming that the air and tracer gas are perfectly mixed within the duct, and the concentration of tracer gas in the outside air is zero, the following equation can be used for steady-state conditions [3]:

$$F = (q/C) \times 10^6 \tag{1}$$

The average air velocity is:

$$V = (q/CA) \times 10^6 \tag{2}$$

2.2 Velocity Pressure Loss-Factors For Duct Fittings

Whenever a change in area or direction occurs in a duct or when the flow is divided and diverted into a branch, losses in total pressure occur. These losses are usually greater than losses in a straight duct and are referred to as separation losses; they can be calculated from:

$$\Delta P_T = k\ P_v = k\ \rho V^2/2 \qquad (3)$$

Substituting equation (2) into equation (3) we have:

$$\Delta P_T = 0.5\ k\ \rho\ (q/C\ A)^2 \times 10^{12} \qquad (4)$$

For standard air (i.e. air at 20°C and 101.325 kPa) ρ is 1.2 kg/m^3. For air at other conditions, the loss in total pressure must be corrected using the following equation:

$$\Delta P_T = 0.6\ (\beta/101.325)[293/(273 + t)]\ (q/C\ A)^2 \times 10^{12} \qquad (5)$$

The loss factor, k, for various duct fittings can be found using the CIBSE Guide "Reference Data" and ASHRAE Handbook "Fundamentals".

3. EXPERIMENTAL

Measurements of airflow and pressure distribution were carried out in a small-scale HVAC system, Figure 1. This consisted of a fan control and instrumentation console. The fan unit had a volumetric flow rate in the range 0.1 to 0.3m^3/s, dependent upon the ductwork resistance and supply voltage. The console contained a variable transformer for fan speed control and a voltmeter and ammeter for measurement of supply voltage and current respectively. A square-to-round fan intake transition also accepted a standard 600 x 600mm filter. The rectangular-to-round fan discharge transition connected to 200mm diameter ductwork using standard push fittings; the duct was manufactured from galvanised mild steel. The HVAC system was fitted with various types of fittings such as bends, branches, expansions and diffusers. Two types of air supply diffusers were used and the discharge was controlled by means of dampers.

The concentration of tracer gas was measured by an infrared gas analyser, type Binos 1000, made by Rosemount GMGH, Hanau, Germany. The velocity was measured using a pitot-static tube. The velocity and static pressure at the inlet and outlet of duct fittings were measured using an electronic micromanometer, type EDM 2500, made by Airflow Development Ltd, High Wycombe, UK.

SF_6 tracer gas was injected into the duct at a constant rate using a mass flow controller, type F100/200, made by Bronkhorst High-Tech BV, Ruulo, Holland. The mass flow controller had a maximum flow capability of 3.9 L/min and a measurement accuracy of $\pm$ 1%.

A typical arrangement for measuring the pressure loss and airflow rate in a duct fitting is shown in Figure 2. The experimental procedure for determining the k-factor was as follows:

i) Start the fan and adjust the flow (e.g. 20% of main voltage).

ii) Connect the micromanometer across the measuring unit as shown in Figure 2 and measure the differential static pressure (i.e. P_S at the inlet - P_S at the outlet of the fitting).

iii) Inject tracer gas into the duct upstream of the fitting at a constant rate q, using the mass-flow controller. To achieve a good distribution of tracer gas in the duct, a multi-injection probe should be used.

iv) Use a multi-point probe to collect tracer-gas samples downstream of the fitting. Measure the concentration of tracer gas using the gas analyser.

v) Measure the velocity pressure at the inlet and outlet of the duct fitting using a pitot static tube.

vi) Increase or decrease the fan speed in order to alter the airflow rate through the duct fitting and repeat the measurements.

4. RESULTS AND DISCUSSION

k-factors of duct fittings were determined using the constant-injection technique and pitot static traverse method. Fittings tested included a branch, a bend, a contraction, duct exits, an orifice and a perforated plate. The total pressure loss for each fitting was measured and was plotted against the velocity pressure ($P_v = 0.5\ \rho\ V^2$) for a range of air velocities. The k-factor was then determined by measuring the gradient.

Table 1 shows typical experimental results, based on tracer-gas measurements, for a contraction. These results are plotted in Figure 4a. The slope, k-factor, of the contraction was found to 0.14 based on tracer-gas measurements compared with 0.18 based on pitot static traverse measurements. The k-factors of the contraction are 0.13 and 0.09 according to data in the CIBSE Guide and ASHRAE Handbook, respectively.

Similar experiments were carried out to determine the k-factors for other components of the HVAC system. Figures 3a, 3b, 4b, 5a and 5b show the variation of total pressure loss versus velocity pressure for various duct fittings. The estimated k-factors from our experimental results and standard data quoted in the CIBSE Guide and ASHRAE Handbook are given in Table 2. The values of k-factors for the branch, contraction and duct exits given in the CIBSE Guide and ASHRAE Handbook were similar. However significant differences in k-factors for the bend and perforated plate were apparent. Although it is not obvious why there is a difference in values quoted for the 90^{o} bend, the difference in k-factors quoted for the perforated plate could be explained by the fact that the CIBSE Guide has not included the effect of plate thickness on k-factor.

The k-factors estimated from tracer-gas measurements were lower than values estimated from pitot tube measurements and in most cases were in closer agreement with the average values of CIBSE and ASHRAE data. Small differences between our data and CIBSE and ASHRAE data may have resulted from variations in quality, construction and testing of the duct fittings.

In order to estimate pressure losses accurately, it is desirable that the designer uses data for k-factors provided by the manufacturers of the HVAC system in question. There is also a need for research work to provide data for k-factors for a wide range of duct fittings not at present given in the CIBSE Guide and ASHRAE Handbook. Parameters such as thickness and angle of obstruction should be included in these tables.

5. CONCLUSIONS

(i) The values of k-factors estimated from the tracer technique were lower than those estimated using the pitot static traverse method.

(ii) The estimated k-factors from tracer gas measurements for the branch, bend, contraction, exits and orifice were similar to those values given in the CIBSE Guide.

(iii) The k-factors estimated from tracer gas and pitot tube measurements for the perforated plate were smaller than values given by CIBSE and ASHRAE data.

(iv) The k-factor for the bend given in the ASHRAE Handbook was significantly lower than values estimated from tracer gas and pitot tube measurements and the value quoted by the CIBSE Guide.

(v) More experimental work is required to estimate the k-factors for a wide range of duct fittings. The effect on k-factor of a number of parameters, such as the thickness and angle of obstruction should be investigated.

REFERENCES

1. CIBSE Guides "Reference Data", The Chartered Institution of Building Services Engineers, London, United Kingdom, 1986.
2. ASHRAE Handbook "Fundamentals", American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, USA, 1989.
3. Riffat, S.B. and Lee, S.F., "Turbulent flow in a duct: measurement by a tracer gas technique", Building Services Engineering Research and Technology, 11(1), 1990, pp.21-26.

TABLE1 Experimental results, based on tracer gas measurements, for determination of the k-factor for a contraction

Reynolds No.	1.94 X 10^5	1.90 X 10^5	1.82 X 10^5	1.65 X 10^5	1.38 X 10^5
F	0.42	0.41	0.39	0.35	0.29
V1	13.26	12.94	12.34	11.29	9.31
Pv1	104.64	100.05	91.08	75.91	51.93
V2	20.73	20.22	19.28	17.64	14.54
Pv2	255.46	244.25	222.35	185.34	126.79
ΔPv1	-150.82	-144.21	-131.28	-109.42	-74.86
Ps1	169.00	160.00	147.00	124.00	82.00
Ps2	53.00	50.00	45.50	38.50	27.00
ΔPs	116.00	110.00	101.50	85.50	55.00
ΔPT	-34.82	-34.21	-29.78	-23.92	-19.86

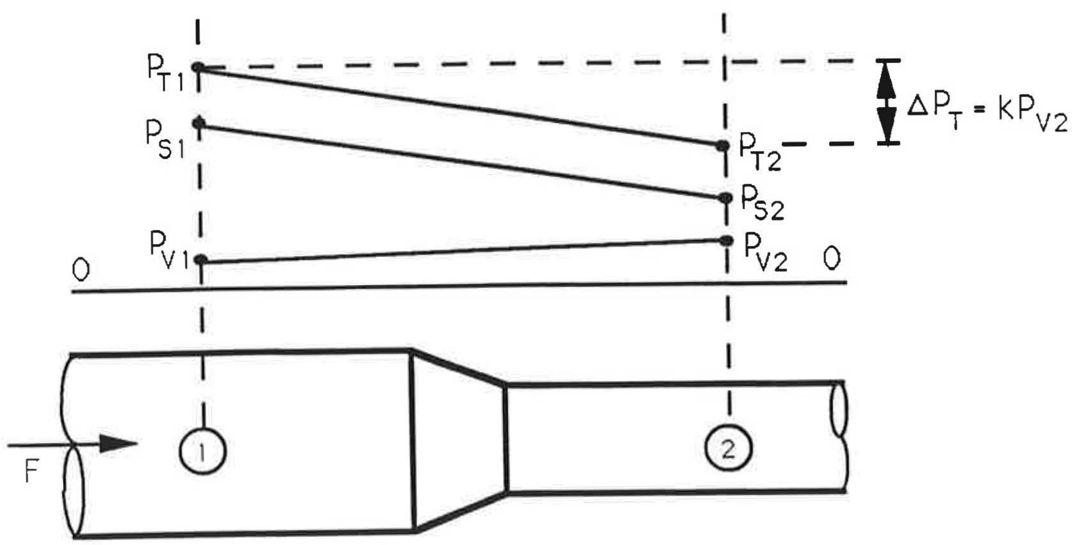


TABLE 2 Velocity pressure loss-factors for duct fittings

TYPE OF DUCT FITTINGS	VELOCITY PRESSURE LOSS-FACTORS (k)			
	CIBSE	ASHRAE	PITOT TUBE	TRACER GAS
90 BRANCH	1.64	1.62	1.99	1.56
90 BEND	0.67	0.24	0.63	0.49
CONTRACTION	0.13	0.09	0.18	0.14
DUCT EXIT WITHOUT BELLMOUTH	1.00	1.00	1.19	1.15
DUCT EXIT WITH BELLMOUTH	1.09	1.00	1.03	1.02
ORIFICE	1.04	Not given	1.00	0.78
PERFORATED PLATE	7.76	6.77	5.91	5.00

FIGURES

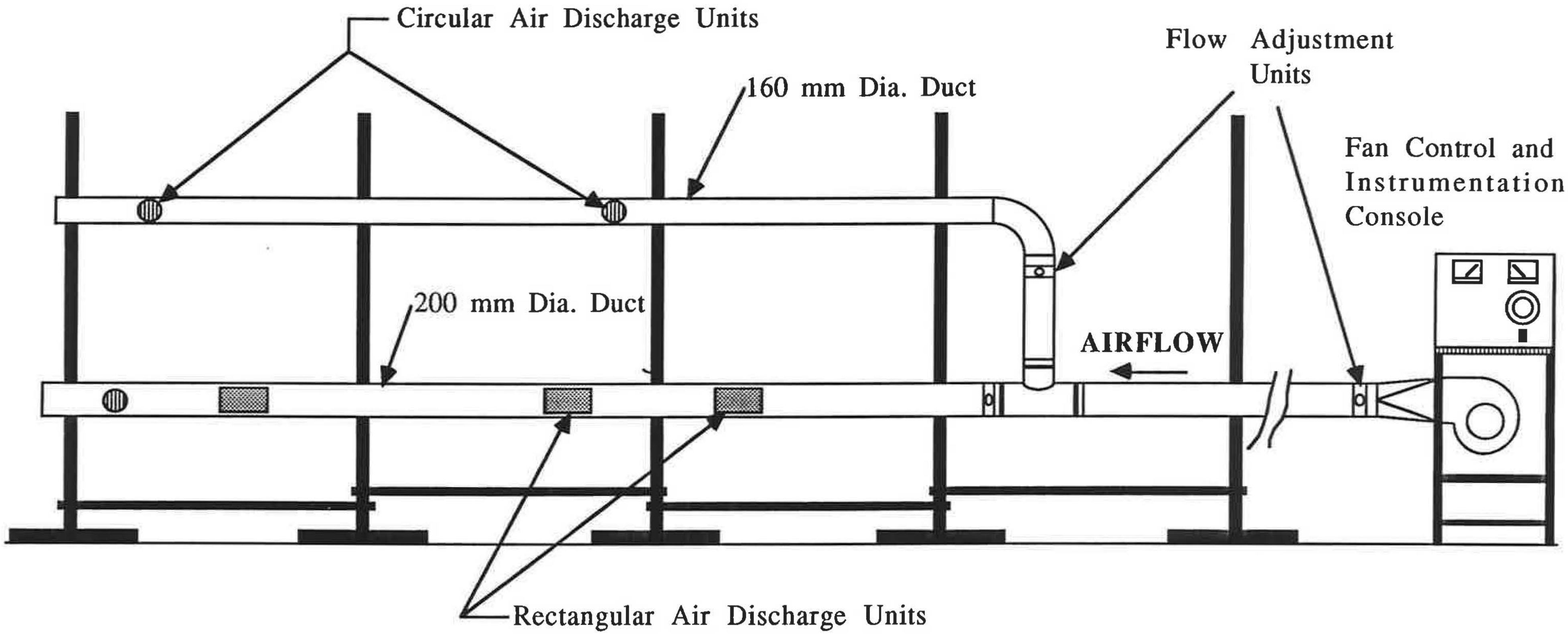

Circular Air Discharge Units
160 mm Dia. Duct
Flow Adjustment Units
Fan Control and Instrumentation Console
200 mm Dia. Duct
AIRFLOW
Rectangular Air Discharge Units

Fig 1

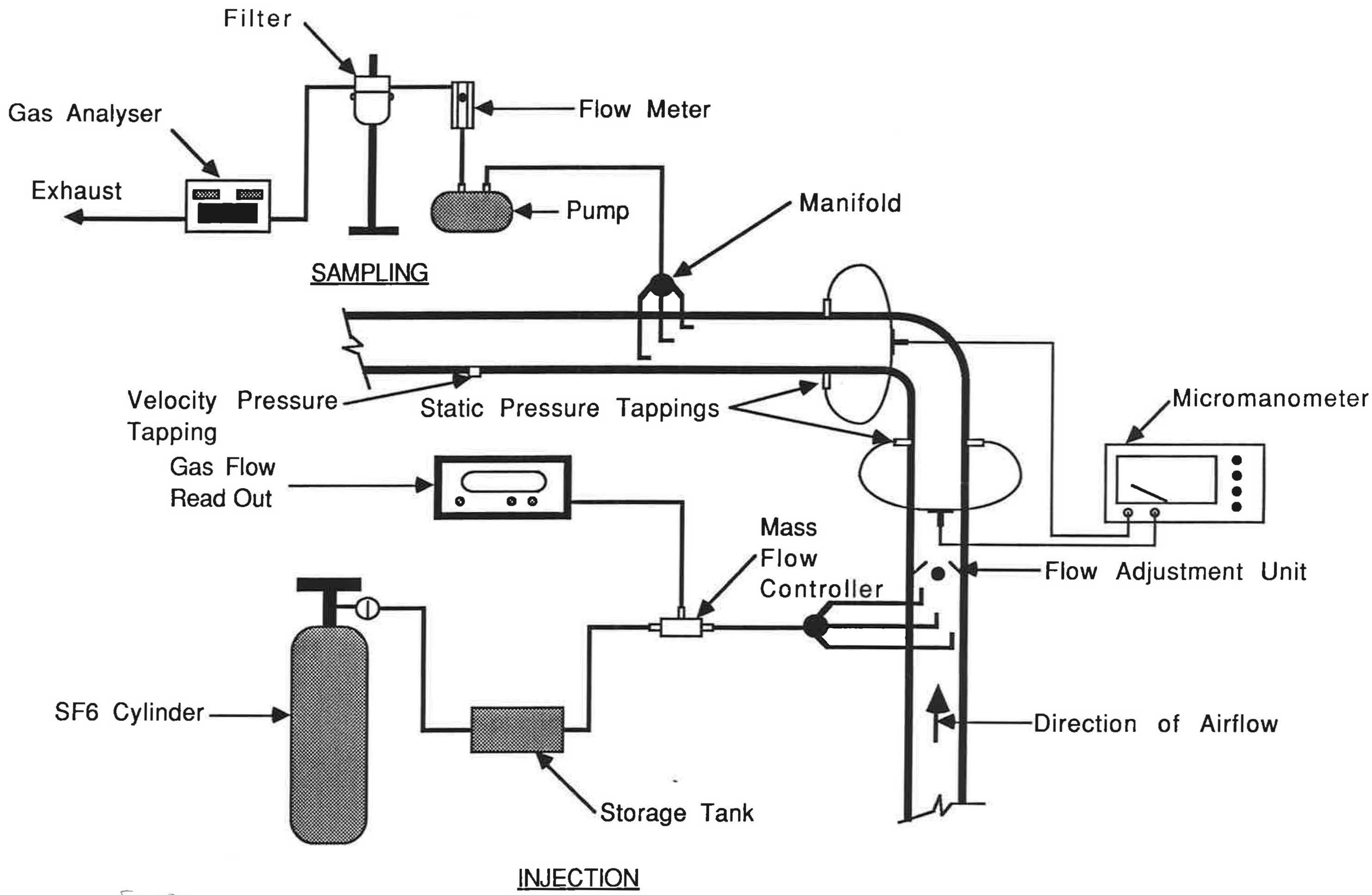

Filter
Gas Analyser
Flow Meter
Exhaust
Pump
Manifold
SAMPLING
Velocity Pressure
Tapping
Static Pressure Tappings
Micromanometer
Gas Flow
Read Out
Mass
Flow
Controller
Flow Adjustment Unit
SF6 Cylinder
Direction of Airflow
Storage Tank
INJECTION

Fig 2

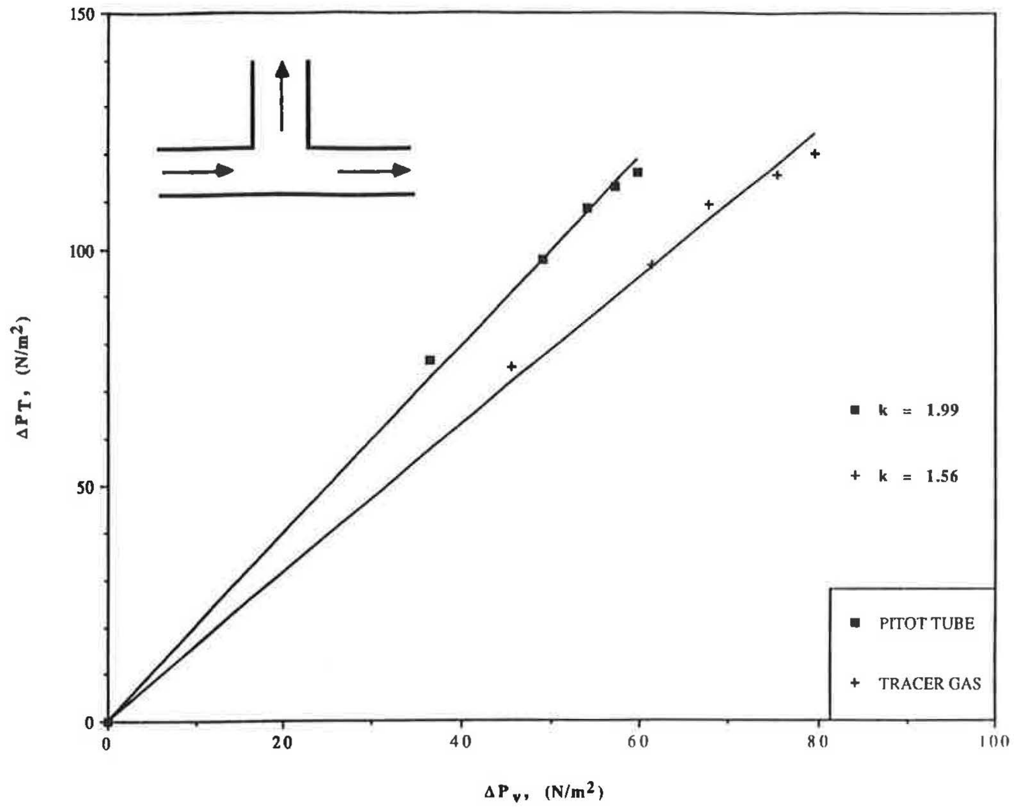

150
100
50
0
0
20
40
60
80
100
ΔPT, (N/m2)
ΔPv, (N/m2)
■ k = 1.99
+ k = 1.56
■ PITOT TUBE
+ TRACER GAS

Fig 3a

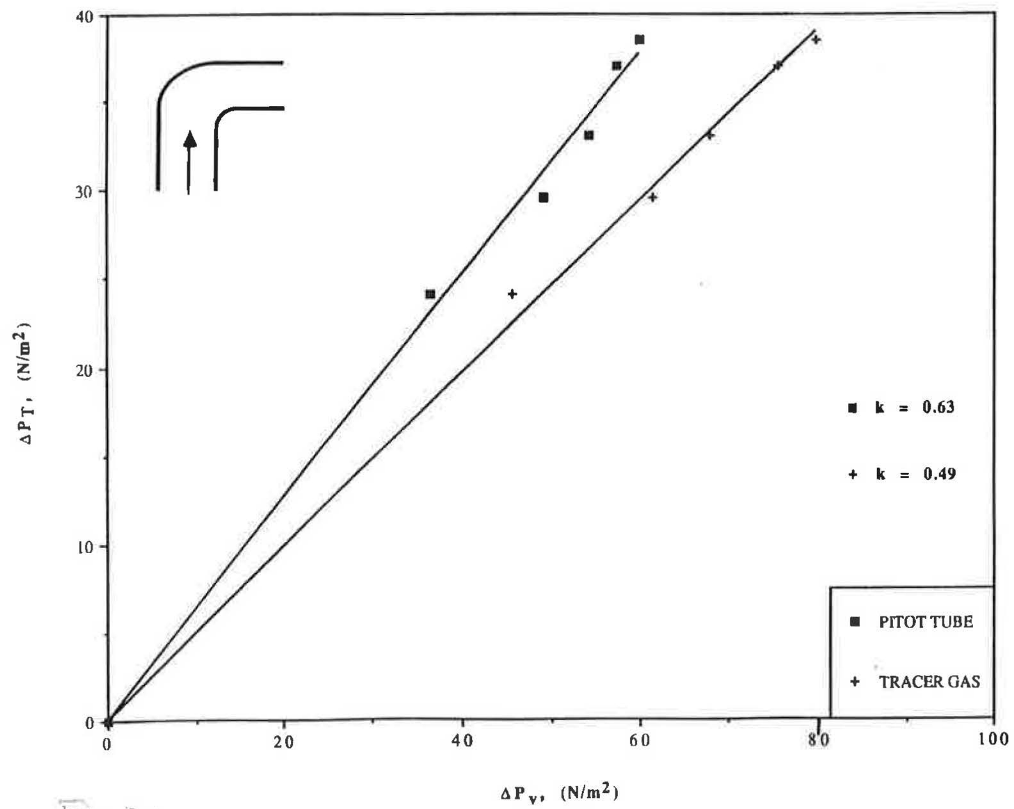
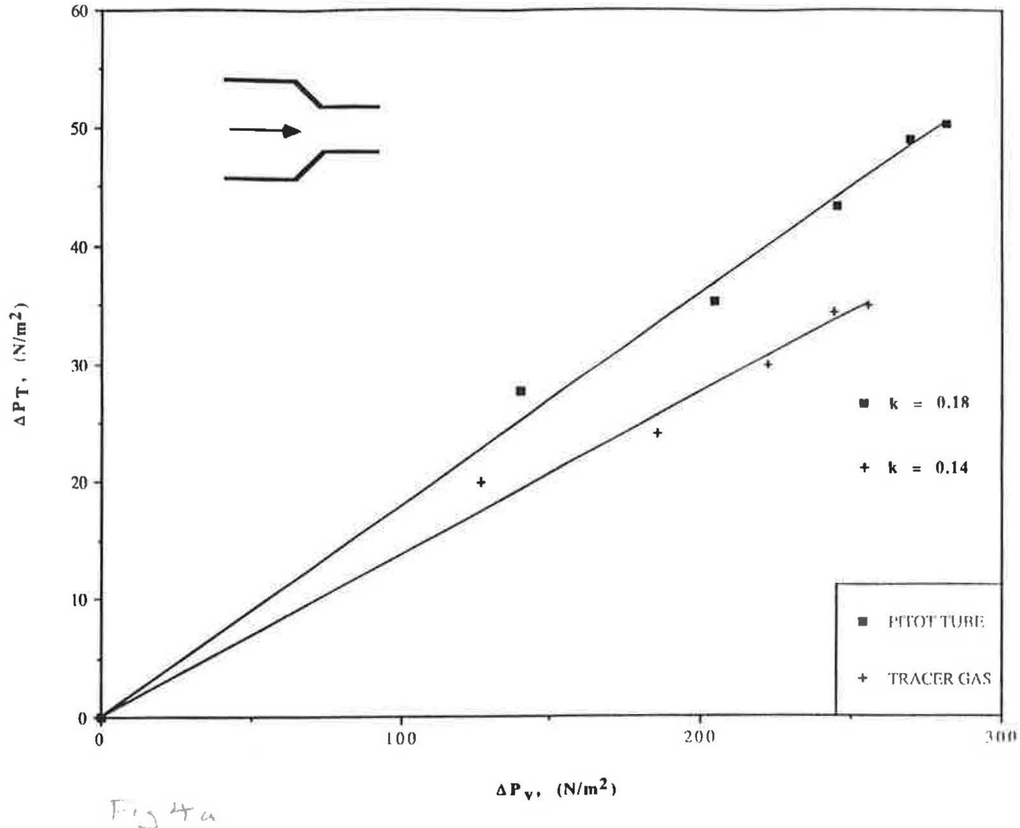
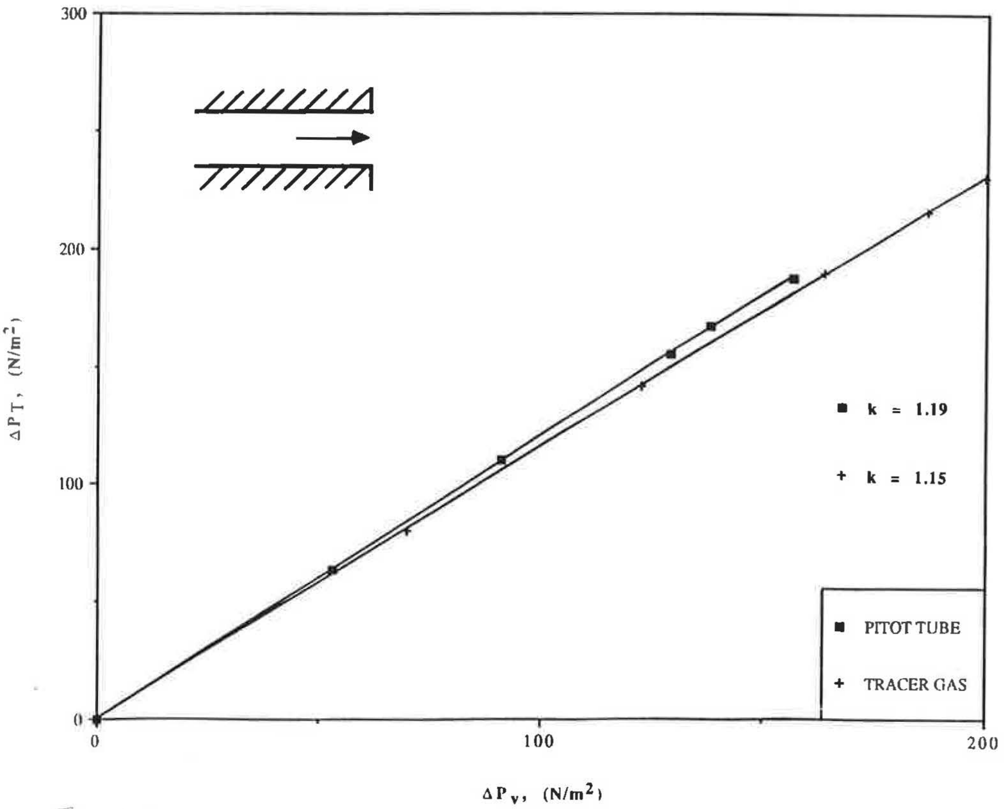

40
30
20
10
0
0
20
40
60
80
100
ΔPT, (N/m2)
ΔPv, (N/m2)
■ k = 0.63
+ k = 0.49
■ PITOT TUBE
+ TRACER GAS

Fig 3b



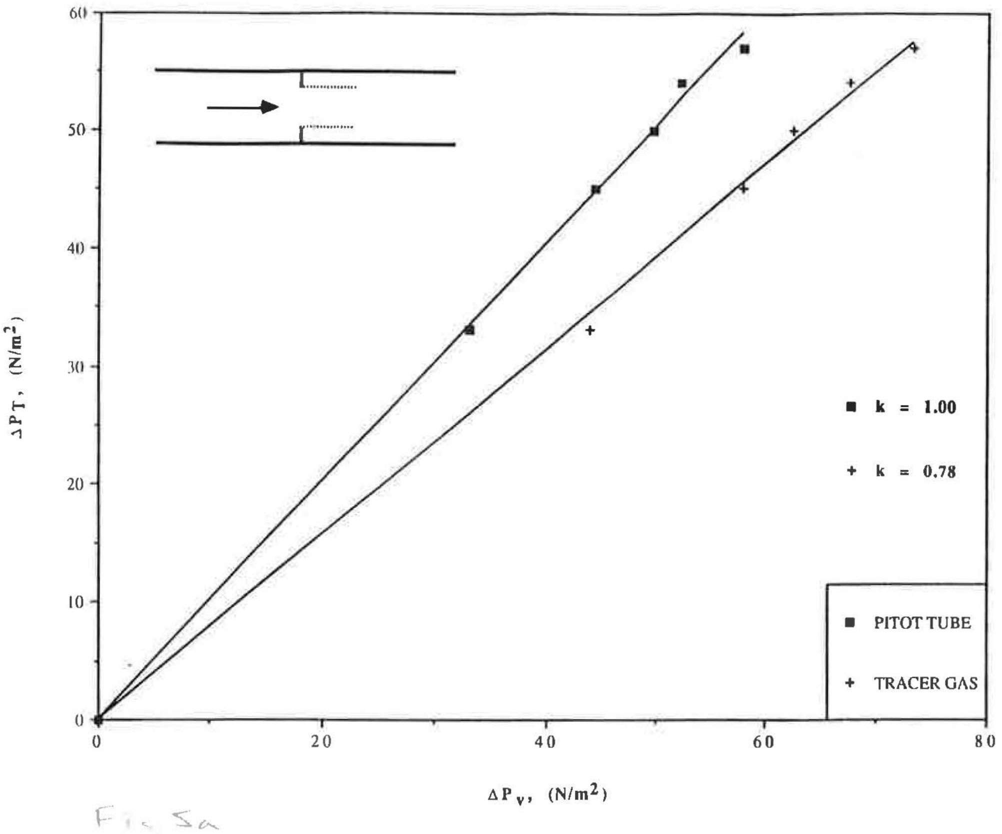
60
50
40
30
20
10
0
ΔPT, (N/m²)
■ k = 0.18
+ k = 0.14
■ PITOT TUBE
+ TRACER GAS
0
100
200
300
ΔPv, (N/m²)

Fig 4a



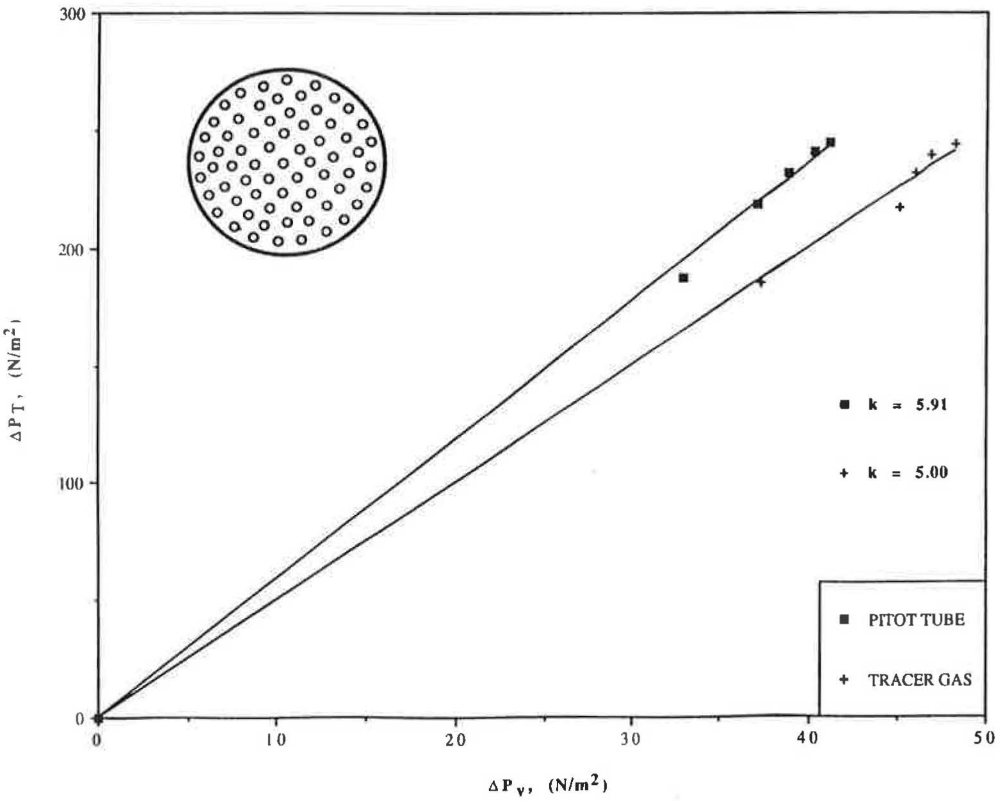
300
200
100
0
ΔPT, (N/m²)
■ k = 1.19
+ k = 1.15
■ PITOT TUBE
+ TRACER GAS
0
100
200
ΔPv, (N/m²)

Fig 4b



ΔPT , (N/m²)
ΔPv , (N/m²)
k = 1.00
k = 0.78
PITOT TUBE
TRACER GAS

Fig 5a



ΔPT , (N/m²)
ΔPv , (N/m²)
k = 5.91
k = 5.00
PITOT TUBE
TRACER GAS

Fig 5b