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**A New Method for Determination of Velocity
Pressure Loss-Factors for HVAC System
Components.**

K.W. Cheong, S.B. Riffat

**School of Architecture, University of Nottingham,
University Park, Nottingham, NG7 2RD, United
Kingdom**

SYNOPSIS

This investigation is concerned with the determination of velocity pressure loss-factors for HVAC system components using tracer-gas techniques. Experimental work was carried out using an HVAC system and k-factors for various components such as bends, branches, contractions, expansions and orifice were determined. Results were compared with measurements made using a pitot tube and values given in the CIBSE Guide and ASHRAE Handbook.

The performance of different types of filters used in HVAC systems was also examined. The constant-injection tracer gas technique was used to develop correlations between the pressure drop and face velocity of a synthetic-fibre filter, bag filter and glass-fibre filter. Results were compared with data obtained using traditional instrumentation.

LIST OF SYMBOLS

| | |
|--------------|--|
| A | Cross-sectional area of the duct fittings (m^2) |
| C | Concentration of tracer gas (ppm) |
| F | Volumetric flow rate (m^3/s) |
| q | Injection rate of the tracer gas (m^3/s) |
| k | Velocity pressure loss-factor, dimensionless |
| V | Bulk velocity (m/s) |
| t | Air temperature ($^{\circ}C$) |
| 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) |
| V_f | Face velocity, filter (m/s) |
| ΔP_f | Pressure drop, filter (N/m^2) |
| ΔP_t | Pressure drop based on tracer gas measurement, (N/m^2) |
| ΔP_p | Pressure drop based on pitot tube measurement, (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 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 tube 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 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 ducts 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. The performance for different types of filters used in the HVAC systems was also examined.

2. THEORY

2.1 Constant-Injection Tracer-Gas Technique

The constant-injection technique was used to measure airflow in an HVAC system. SF₆ 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 conditions³:

$$F = (q/C) \times 10^6 \quad (1)$$

The average air velocity is:

$$V = (q/CA) \times 10^6 \quad (2)$$

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:

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

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

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

For standard air (i.e. air at 20°C and 101.325 kPa) ρ is 1.2 kg/m³. For air at other conditions, the loss in total pressure must be corrected using the following equation:

$$\Delta P_T = 0.6(\rho/101.325)[293/(273 + t)] (q/CA)^2 \times 10^{12} \quad (5)$$

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

3. EXPERIMENTAL

Measurement 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 0.3 m³/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.

SF₆ tracer gas was injected into the duct at a constant rate using 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 $\pm 1\%$.

3.1. Determination of k -factors

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 mutli-injection probe should be used.
- iv) Use a mutli-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.

3.2. Development Of Correlation Between Pressure Drop and Face Velocity of Filters

The experimental procedure for determining the correlation between the pressure drop and face velocity of filters are as follows:

- i) Insert a filter into the filter holder on the fan intake.
- ii) Start the fan and adjust the flow (e.g. 20% of main voltage).
- iii) Connect the micromanometer to the tappings on the square filter holder as shown in Figure 3 and measure the pressure drop of the filter, ΔP_s .
- iv) Inject tracer gas into the duct inlet at a constant rate q , using a mass-flow controller.
- v) Measure the concentration of tracer gas at downstream of the duct using the gas analyser.
- vi) Measure the velocity pressure at the downstream of the duct using a pitot-static tube.
- vii) Increase or decrease the fan speed in order to alter the airflow rate through the filter and repeat the measurements.

4. RESULTS AND DISCUSSION

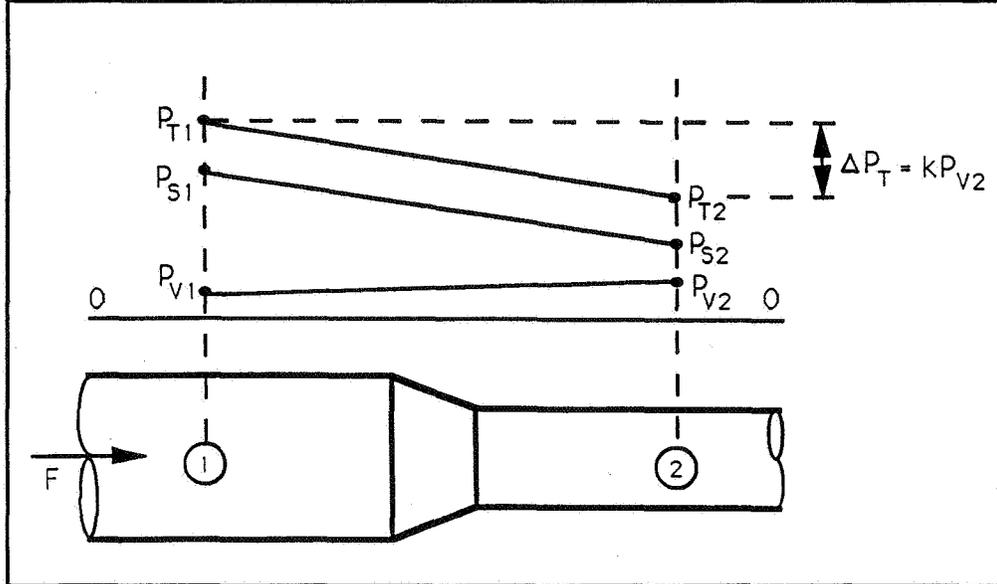
4.1 k-factors For Duct Fittings

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 be 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.

Table 1 Experimental results, based on tracer gas measurements, for determination of the k-factor for a contraction

| Reynolds No. | 1.94×10^5 | 1.90×10^5 | 1.82×10^5 | 1.65×10^5 | 1.38×10^5 |
|-----------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| F | 0.42 | 0.41 | 0.39 | 0.35 | 0.29 |
| V_1 | 13.26 | 12.94 | 12.34 | 11.29 | 9.31 |
| P_{V1} | 104.64 | 100.05 | 91.08 | 75.91 | 51.93 |
| V_2 | 20.73 | 20.22 | 19.28 | 17.64 | 14.54 |
| P_{V2} | 255.46 | 244.25 | 222.35 | 185.34 | 126.79 |
| ΔP_{V1} | -150.82 | -144.21 | -131.28 | -109.42 | -74.86 |
| P_{S1} | 169.00 | 160.00 | 147.00 | 124.00 | 82.00 |
| P_{S2} | 53.00 | 50.00 | 45.50 | 38.50 | 27.00 |
| ΔP_S | 116.00 | 110.00 | 101.50 | 85.50 | 55.00 |
| ΔP_T | -34.82 | -34.21 | -29.78 | -23.92 | -19.86 |



Similar experiments were carried out to determine the k-factors for other components of HVAC system. Figures 4a, 4b, 4c, 4d, 4e and 4f show variation of total pressure loss versus velocity pressure for various duct fittings. The estimated k-factors from the 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, a 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 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.

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 |

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-factor 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.

4.2. Correlations Between Pressure Drop And Face Velocity Of Filters

The correlations between the pressure drop and face velocity of a synthetic-fibre filter, glass-fibre filter and bag filter were developed using the constant-injection technique and pitot-static traverse method. The results indicated that the correlations obtained by these techniques are in close agreement. Tables 3 and 4 show the correlations between pressure drop and face velocity for clean and dirty filters respectively.

Table 3 Correlation between pressure drop and face velocity for clean filters

| Types of Filter | Pitot Tube | Tracer Gas |
|-----------------|------------------------------------|------------------------------------|
| Glass Fibre | $\Delta P_f = -5.698 + 17.791 V_f$ | $\Delta P_f = -5.483 + 19.683 V_f$ |
| Synthetic Fibre | $\Delta P_f = -7.239 + 25.847 V_f$ | $\Delta P_f = -6.123 + 28.094 V_f$ |
| Bag | $\Delta P_f = -6.492 + 45.206 V_f$ | $\Delta P_f = -6.149 + 48.401 V_f$ |

Table 4 Correlation between pressure drop and face velocity for dirty filters

| Types of Filter | Pitot Tube | Tracer Gas |
|-----------------|-------------------------------------|-------------------------------------|
| Glass Fibre | $\Delta P_f = -7.399 + 22.998 V_f$ | $\Delta P_f = -5.576 + 22.307 V_f$ |
| Synthetic Fibre | $\Delta P_f = -24.991 + 76.715 V_f$ | $\Delta P_f = -20.129 + 72.917 V_f$ |
| Bag | $\Delta P_f = -23.609 + 89.326 V_f$ | $\Delta P_f = -19.920 + 91.301 V_f$ |

The pressure drops across the filter varies with the types (see Figure 6) and conditions of the filter used. For example, the pressure drops across the clean-glass fibre filter for a face velocity of 10 m/s were found to be 191.35 Pa (based on tracer gas measurements) and 172.21 Pa (based on pitot tube measurements). For the clean bag filter, the pressure drops measured using the same techniques and face velocity were found to be 477.86 and 445.57 Pa. The difference between pressure drop $[(\Delta P_t - \Delta P_p)/\Delta P_p]$ obtained using constant-injection technique and pitot-static traverse method for the glass fibre, synthetic fibre and bag filters were 7.2%, 9.4% and 11.1% respectively.

5. CONCLUSIONS

- i) The values of k-factors estimated from the tracer technique were lower than those estimated using 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 the 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.

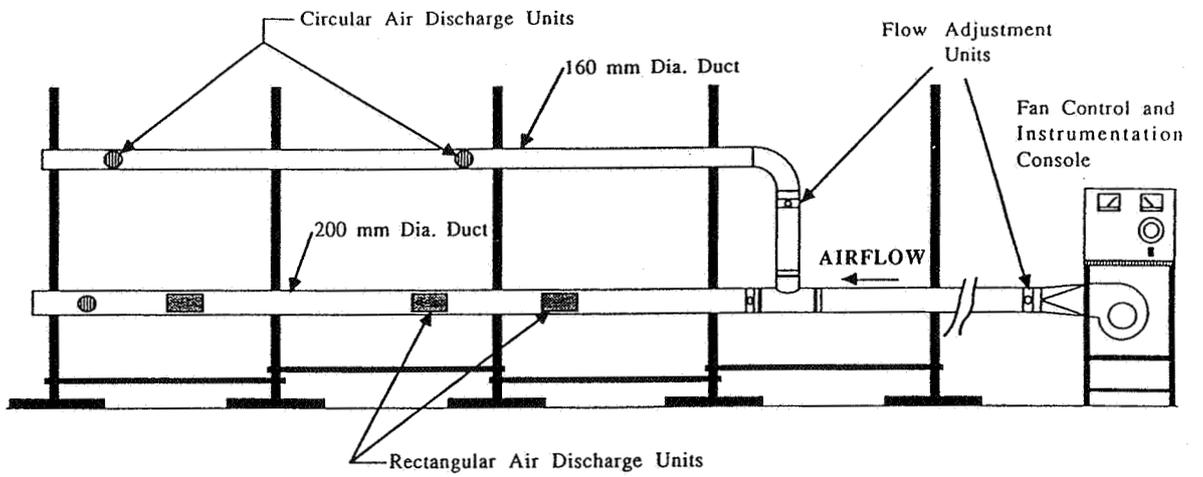


Figure 1 Schematic diagram of the small-scale HVAC system

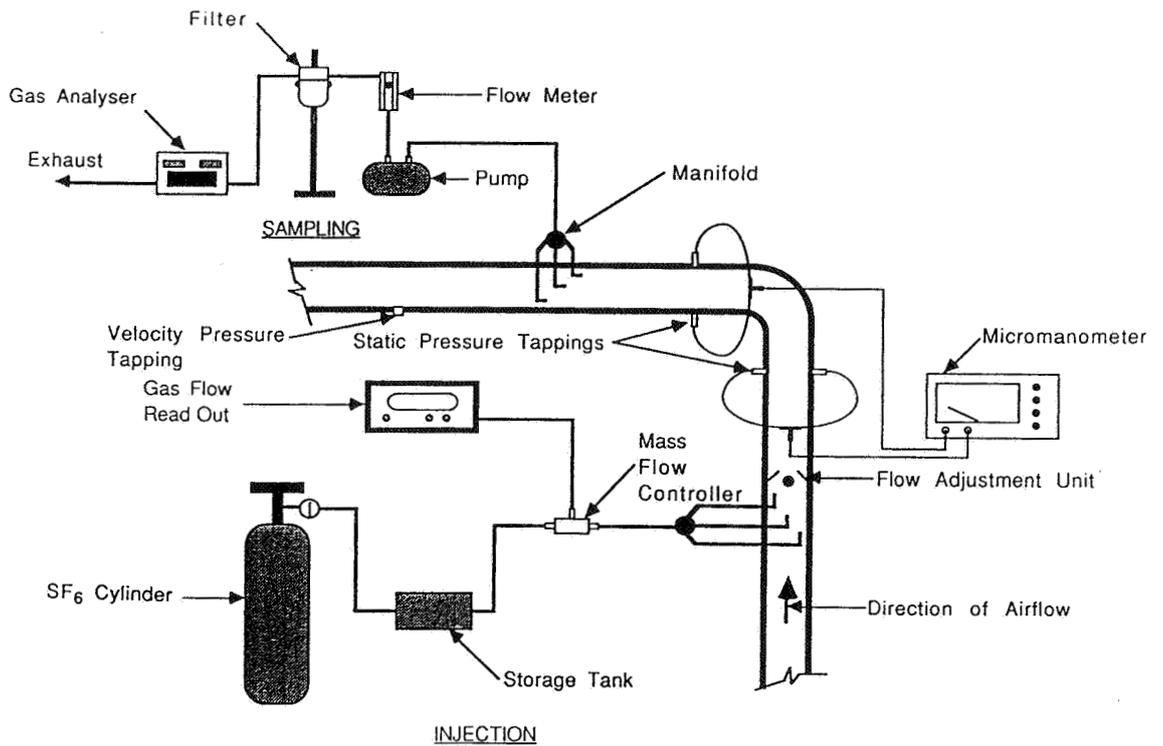


Figure 2 Instrumentation for the constant-injection tracer-gas technique applied to a duct fitting

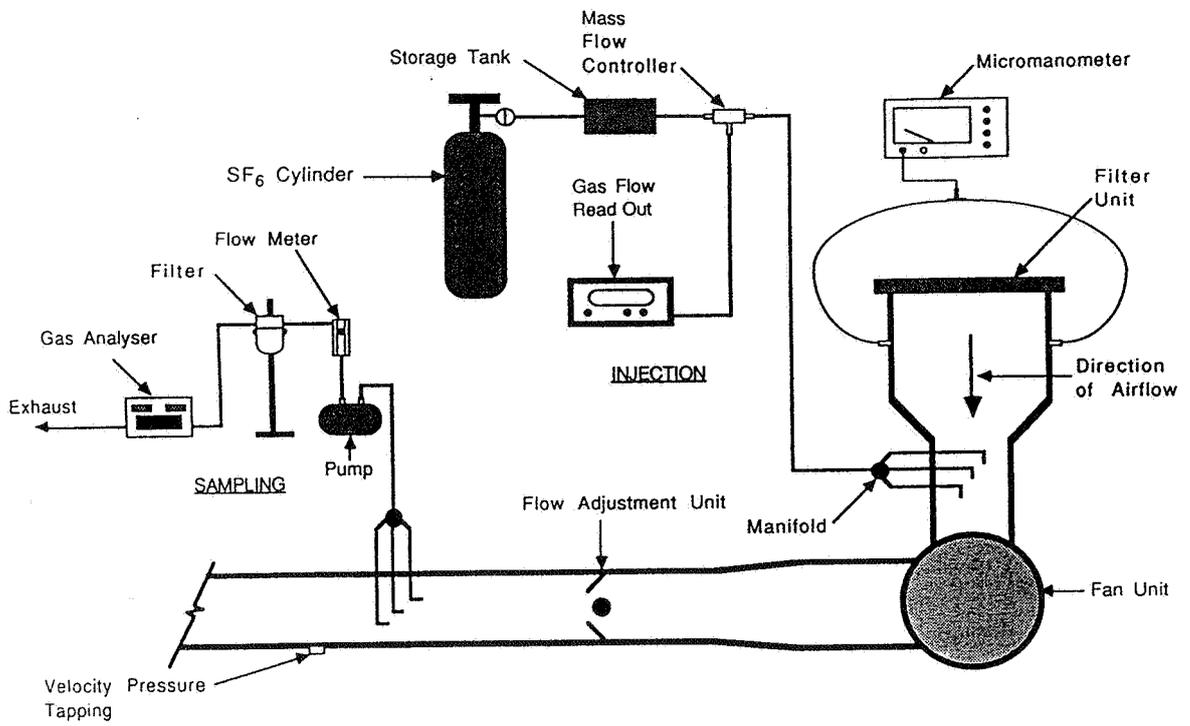


Figure 3 Instrumentation for the constant-injection tracer-gas technique applied to a filter

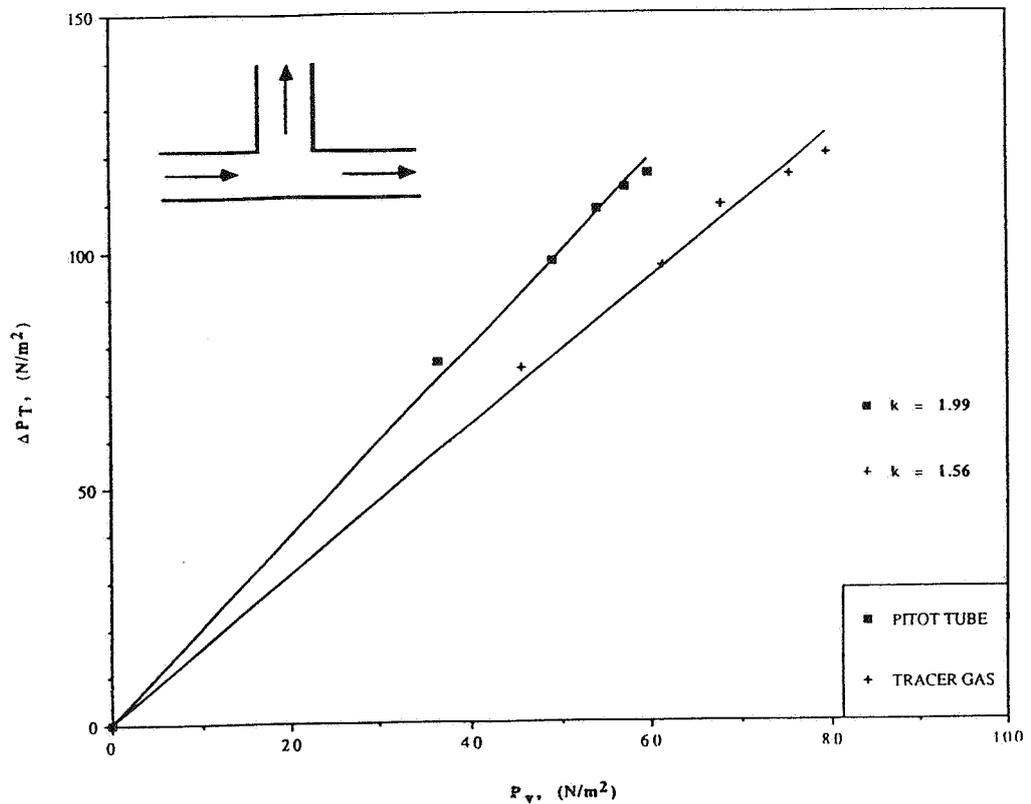


Figure 4a Variation of total pressure loss with velocity pressure, branch

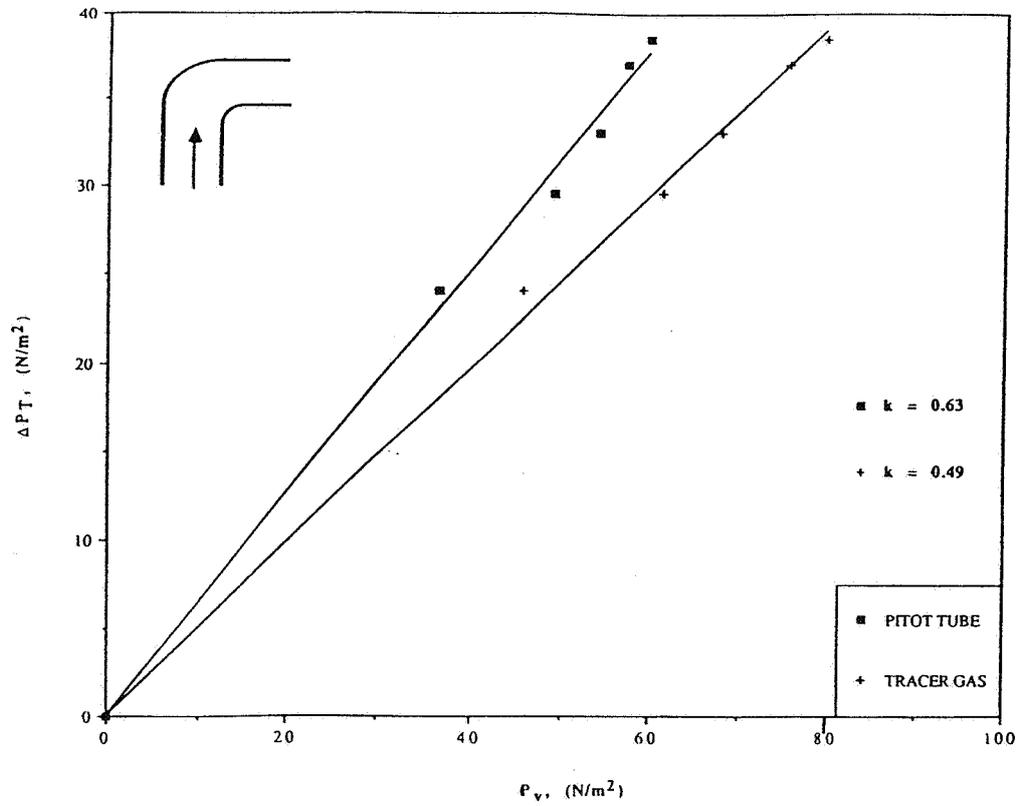


Figure 4b Variation of total pressure loss with velocity pressure, bend

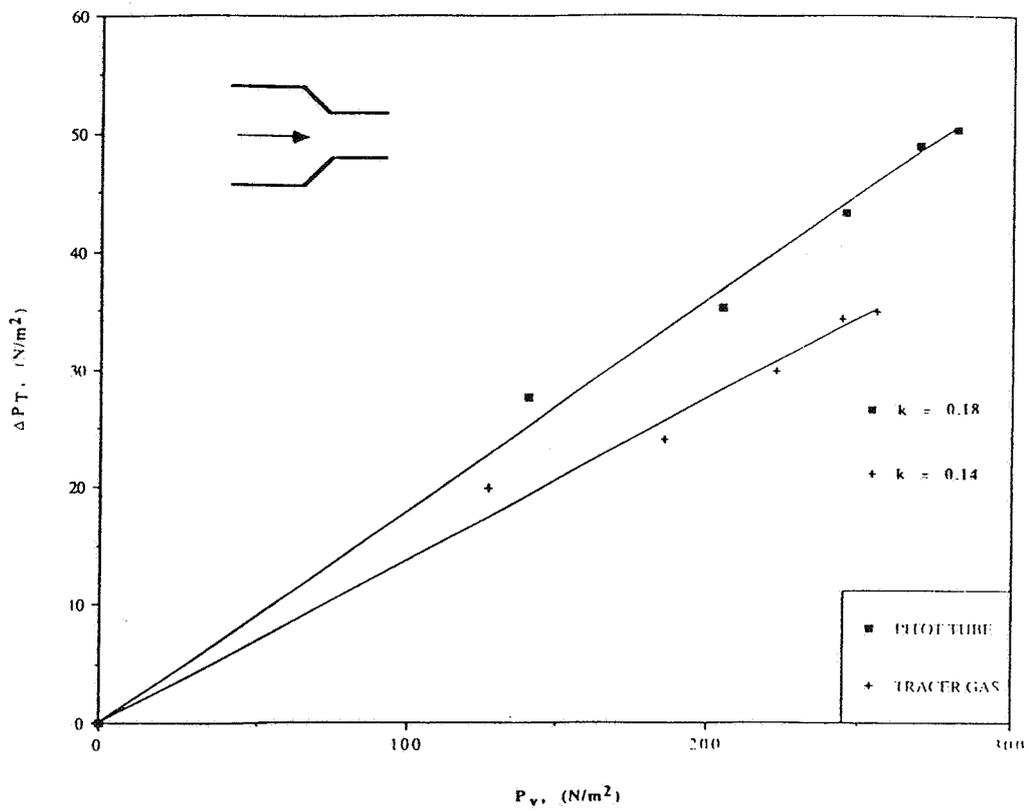


Figure 4c Variation of total pressure loss with velocity pressure, contraction

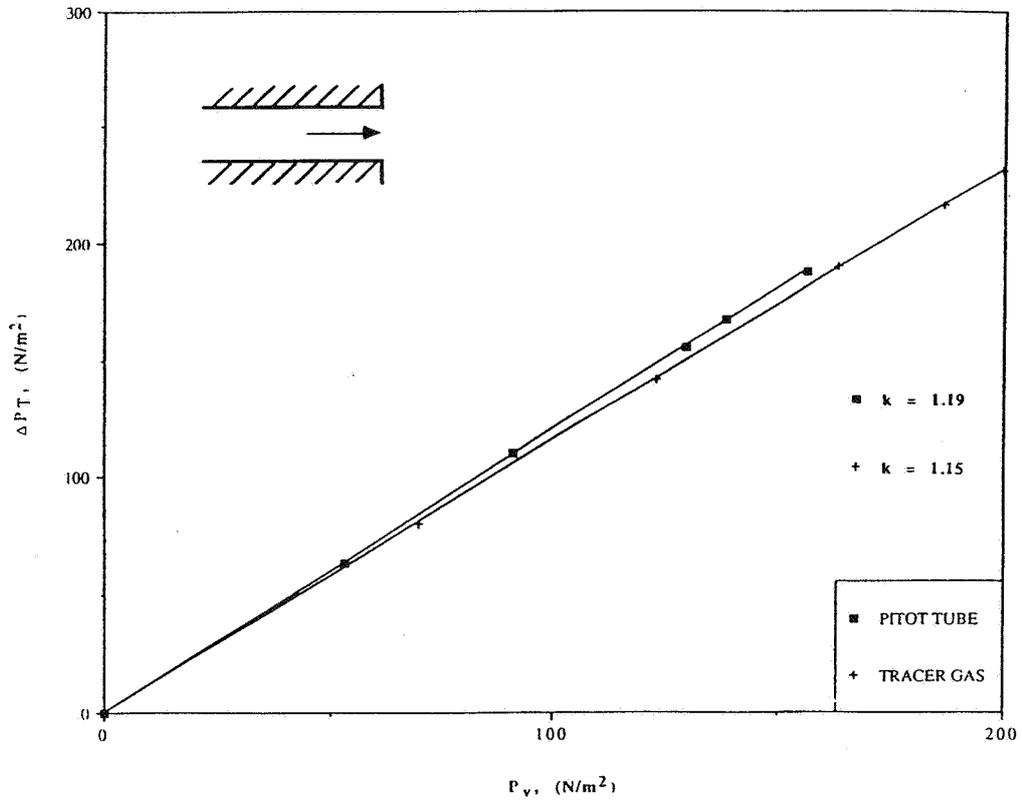


Figure 4d Variation of total pressure loss with velocity pressure, duct exit without bellmouth

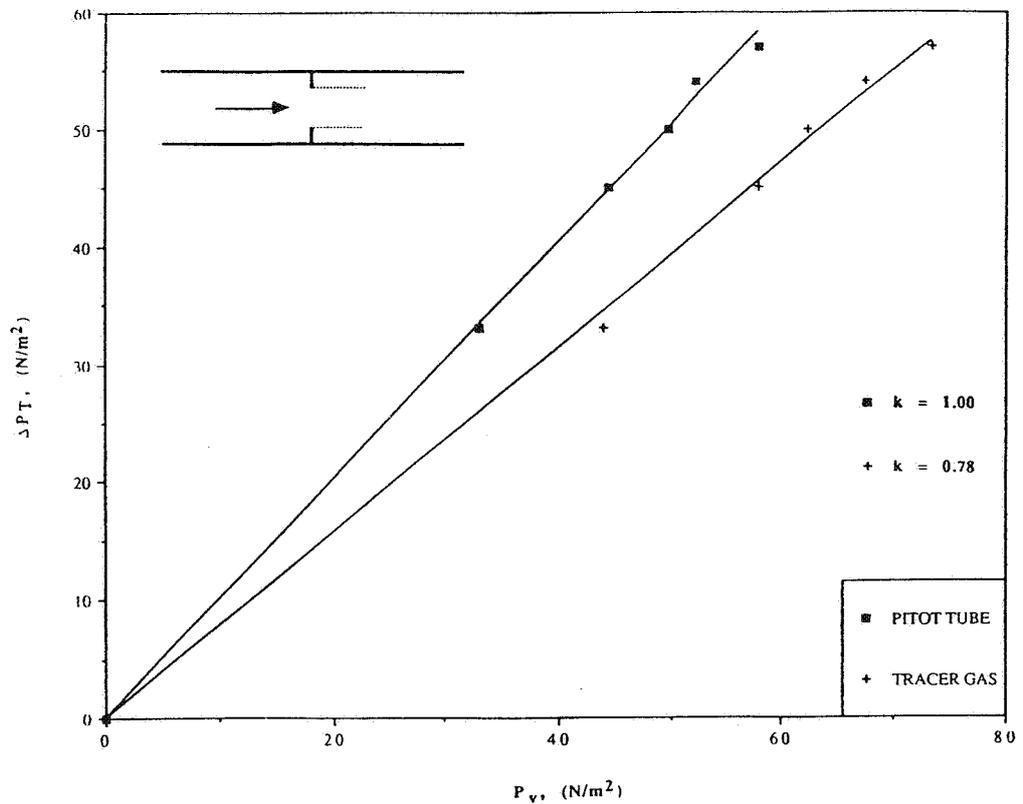


Figure 4e Variation of total pressure loss with velocity pressure, orifice

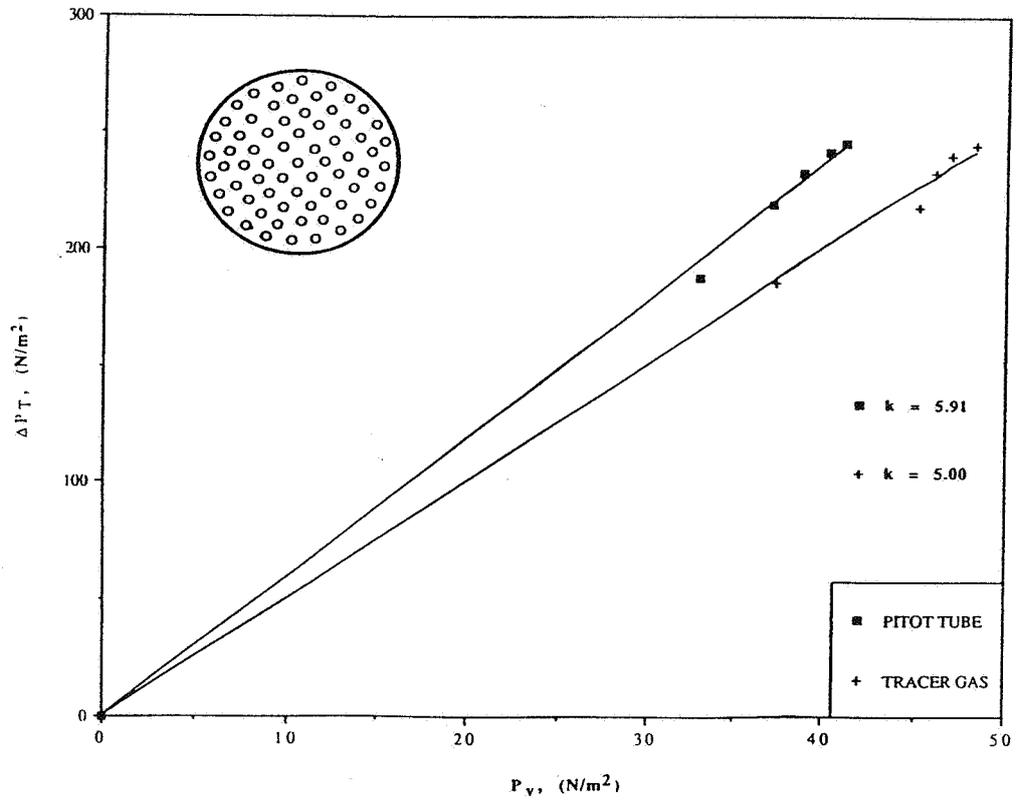


Figure 4f Variation of total pressure loss with velocity pressure, perforated plate

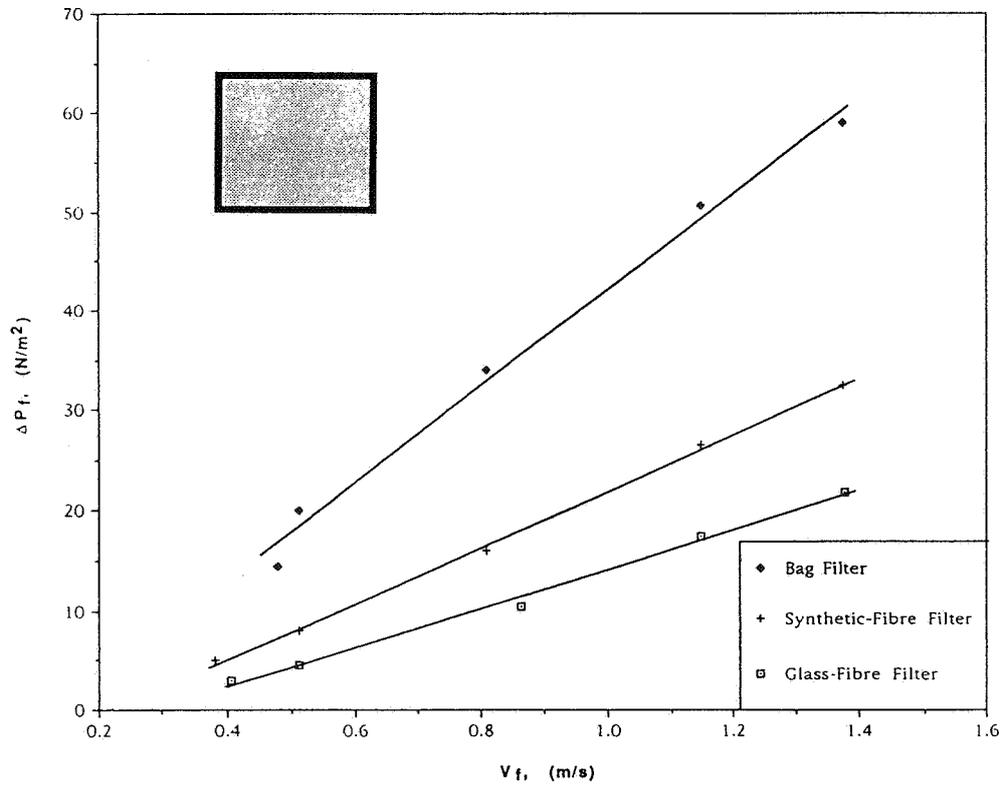


Figure 5 Variation of pressure drop with face velocity, filters

