AEROSOL PARTICLES IN DUCTS

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This paper examines the flow behaviour of tracer gas and aerosol particles in ducts of various aspect ratios. SF_6 tracer gas and smoke particles were injected at a constant rate into the inlet of ducts and their concentrations were monitored at various points downstream. The deposition rate of smoke particles was found to be strongly influenced by the airflow rate and size of the duct.

INTRODUCTION

It is well known that during operation HVAC systems are contaminated with aerosol particles penetrating the filters. Studies have shown that deposition of aerosol particles in ducts contributes to deterioration of indoor air quality (1). Regular cleaning of ducts is recommended but a rationale does not exist. Particle concentration is influenced by the flow rate of air supplied by the ventilation systems. The constant-injection tracer gas technique was used to measure airflow in the ducts. This technique has several advantages over the pitot-tube traversing method as it does not require a long measuring duct to establish fully developed flow. In addition, the constant-injection technique can be used to measure airflow over a wide-range of velocities and does not require determination of the cross-sectional area of the duct.

The purpose of this paper is to establish the relationship between airflow and deposition rate of aerosol particles in ducts.

THEORY

Constant-Injection Technique

The constant-injection technique was used to measure airflow rates. Assuming that the air and tracer gas is perfectly mixed within the duct, the mass balance equation is:

$$V\, dC_{(t)}/dt + F_{(t)}\, C_{(t)} = q_{(t)} \qquad (1)$$

where V is internal volume of the duct, $C_{(t)}$ is concentration of tracer gas, $dC_{(t)}/dt$ is rate of change of concentration of tracer gas, $F_{(t)}$ is volumetric-flow rate of air and $q_{(t)}$ is the injection rate of tracer gas into the duct.
The duct air-exchange rate I is given by:

$$I_{(t)} = F_{(t)}/V \qquad (2)$$

Assuming that the injection rate of tracer gas into the duct and the air exchange rate are constant during the measurement, the solution of equation (1) is:

$$C_{(t)} = q/F + (C - q/F) \exp(-It) \qquad (3)$$

If the system were close to equilibrium, the concentration of tracer gas would change slowly and the rate of change of concentration would be small. After sufficiently long period, the transient term in the equation (3) would die out and the flow rate through the duct would be given by:

$$F = q/C \qquad (4)$$

where F is the volumetric-flow rate of air based on tracer gas measurements.

Deposition of Aerosol Particles

The deposition rate of aerosol particles is estimated using the following equation:

$$N = (Cp_1 - Cp_2) \times F/A \qquad (5)$$

where N is deposition rate of particles, Cp_1 and Cp_2 are steady-state concentrations of aerosol particles at points 1 and 2 in the duct and A is surface area of the duct between point 1 and 2.

EXPERIMENTAL

The experimental work was carried out using ducts with cross-sections of 300mm x 300mm, 600mm x 300mm and 1200mm x 300mm. The ducts were constructed from galvanised mild steel and were 9m long (See Figure 1). The downstream end of the ducts was connected to an axial fan by means of a diffuser. The flow rate through the duct was varied using a speed controller. The fan was driven by an AC motor of 4kW and a maximum speed of 2880 rpm.

Tracer gas and aerosol particle tappings were positioned along the duct. SF_6 tracer gas was injected at a constant rate into the duct inlet using a mass flow controller which had a maximum flow capability of 5 L/min (See Figure 2). The measurement accuracy of the mass flow controller was $\pm 1\%$. The flow rate was controlled using a variable power supply, and the rate of tracer-gas injection was displayed on a digital unit.

The concentration of tracer gas was measured using an Infra-red gas analyser. The accuracy of the measurements was estimated to be ± 2%.

A smoke monitor was used to estimate the concentration of smoke particles. The monitor was capable of measuring particles 0.1 to 10 μm in diameter with an accuracy of ± 5%.

RESULTS AND DISCUSSION

Experiments were carried out to estimate the deposition rate of smoke particles in ducts for different Reynolds numbers. SF_6 tracer gas and smoke particles were injected at the inlet of the duct at constant rates of 2.5 L/min and 50 mg/s respectively. Simultaneous measurements of tracer gas and particle concentration were made at various distances from the duct inlet. The accuracy of tracer gas measurement was ±10% (depends on velocity). Figures 3 and 4 show the variation of tracer gas and particle concentration with X/D_h for the duct of aspect ratio 1:1 while Figures 5 and 6 show the same for the duct with aspect ratio 4:1. The concentration of tracer gas was found to be variable close to the injection point but remained constant afterwards.

Figure 7 shows the relationships of particle deposition rate and air flow rate. The relationships are given in Table 1.

Duct Dimensions (mm)	Aspect-Ratio	Deposition-Rate Equation
300 x 300	1 : 1	$N = 4.653 \times 10^{-2} + 0.208\ F$
600 x 300	2 : 1	$N = -6.315 \times 10^{-3} + 0.196\ F$
1200 x 300	4 : 1	$N = 5.052 \times 10^{-3} + 9.095 \times 10^{-2}\ F$

Table 1 Relationships for deposition rate of aerosol particles in ducts

The deposition rates of particles on the surface of the duct wall varies with duct size and Reynolds number. For example, the deposition rates for aspect-ratio 1:1 and Reynolds numbers, 7.36 x 10^3, 15.44 x 10^4, 24.82 x 10^4 and 36.27 x 10^4 were estimated to be 0.1158, 0.194, 0.2828 and 0.3933 mg/m^2.s respectively. For an aspect-ratio of 4:1, the deposition rates with the same Reynolds numbers were estimated to be 0.0353, 0.0695, 0.1084 and 0.1567 mg/m^2.s. These results clearly indicate that the amount of particles depositing on the duct wall is much smaller at higher aspect-ratios and increases rapidly with Reynolds number. The deposition rate of aerosol particles was found to increase at high flow rates. This was due to the fact that the outside air entering the duct contained a significant concentration of particles. The deposition rate was also found to be influenced by particle sizes, density and shear velocity.

CONCLUSION

The flow behaviour of SF_6 tracer gas and smoke particles was examined in ducts of various aspect ratios. Results indicated that the concentration of tracer gas was variable close to the injection point but remained constant afterwards. Unlike tracer gas, the concentration of smoke particles was found to decrease continuously with X/D_h as a result of deposition of particles on the surface of the duct. At a given Reynolds number, the deposition rate of smoke particles was found to be greater in ducts with smaller aspect ratios. Further research is required to examine the deposition rate of different types of aerosol particles in HVAC systems.

REFERENCES

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2. Riffat, S.B., "A comparison of tracer-gas techniques for measuring airflow in a duct", J Institute of Energy, LXIII, 18-21,1990.

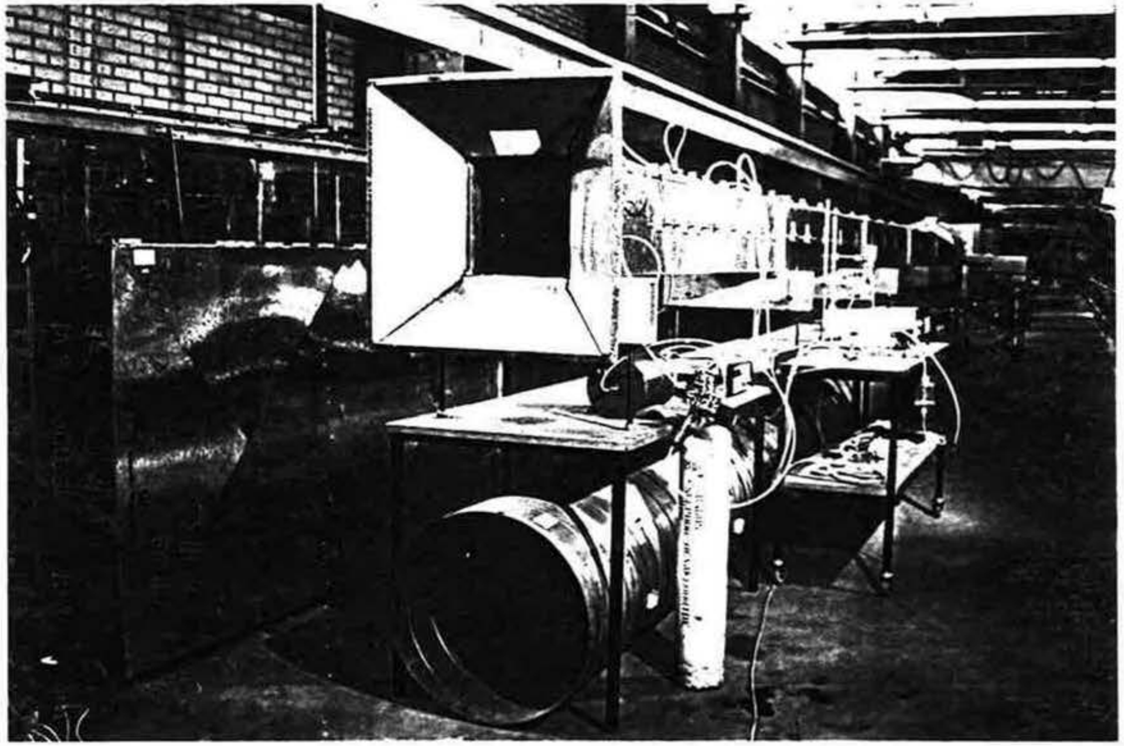

Figure 1 Apparatus for testing tracer gas and aerosol particles

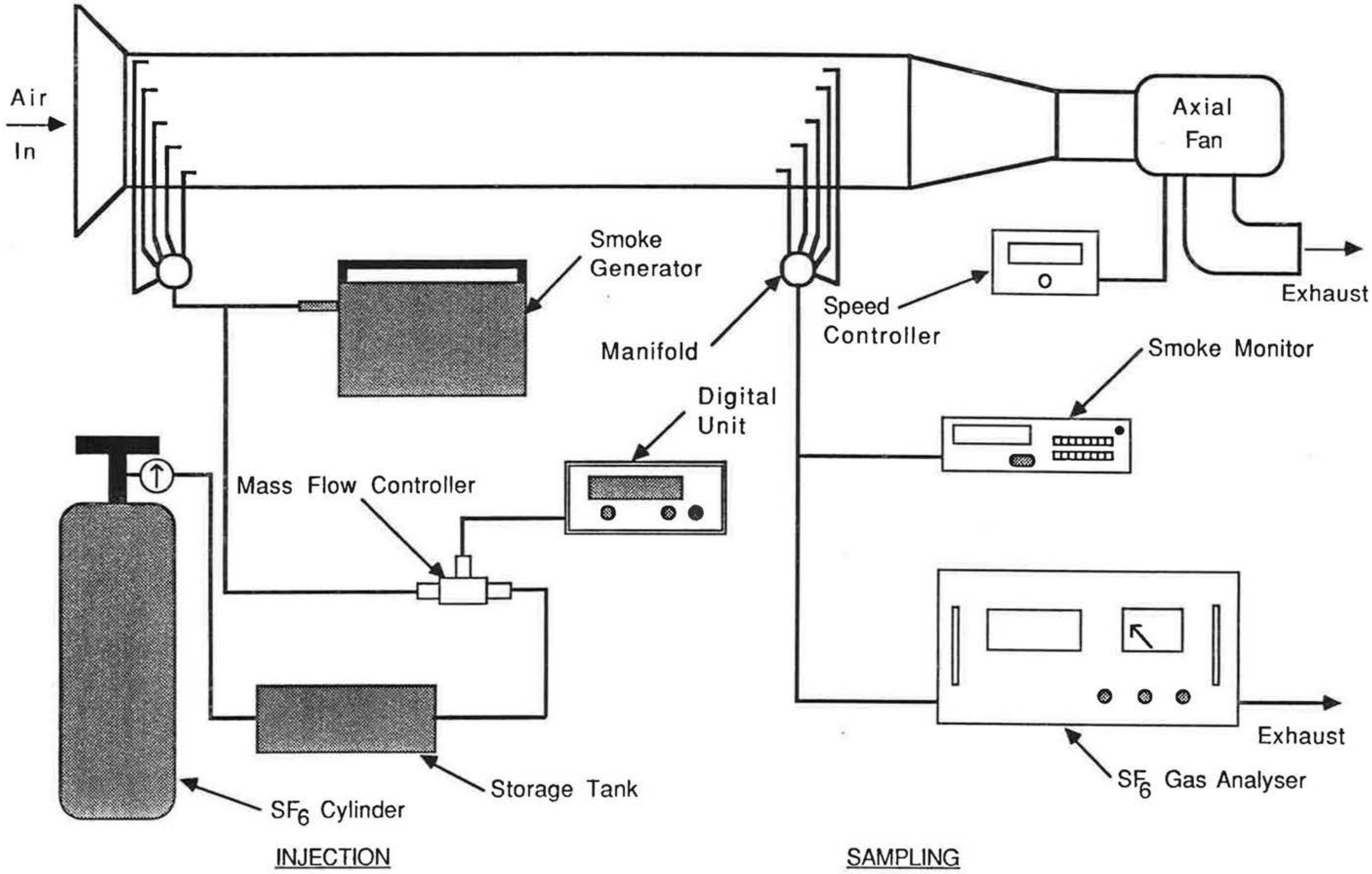

Figure 2 Schematic diagram of the experimental system

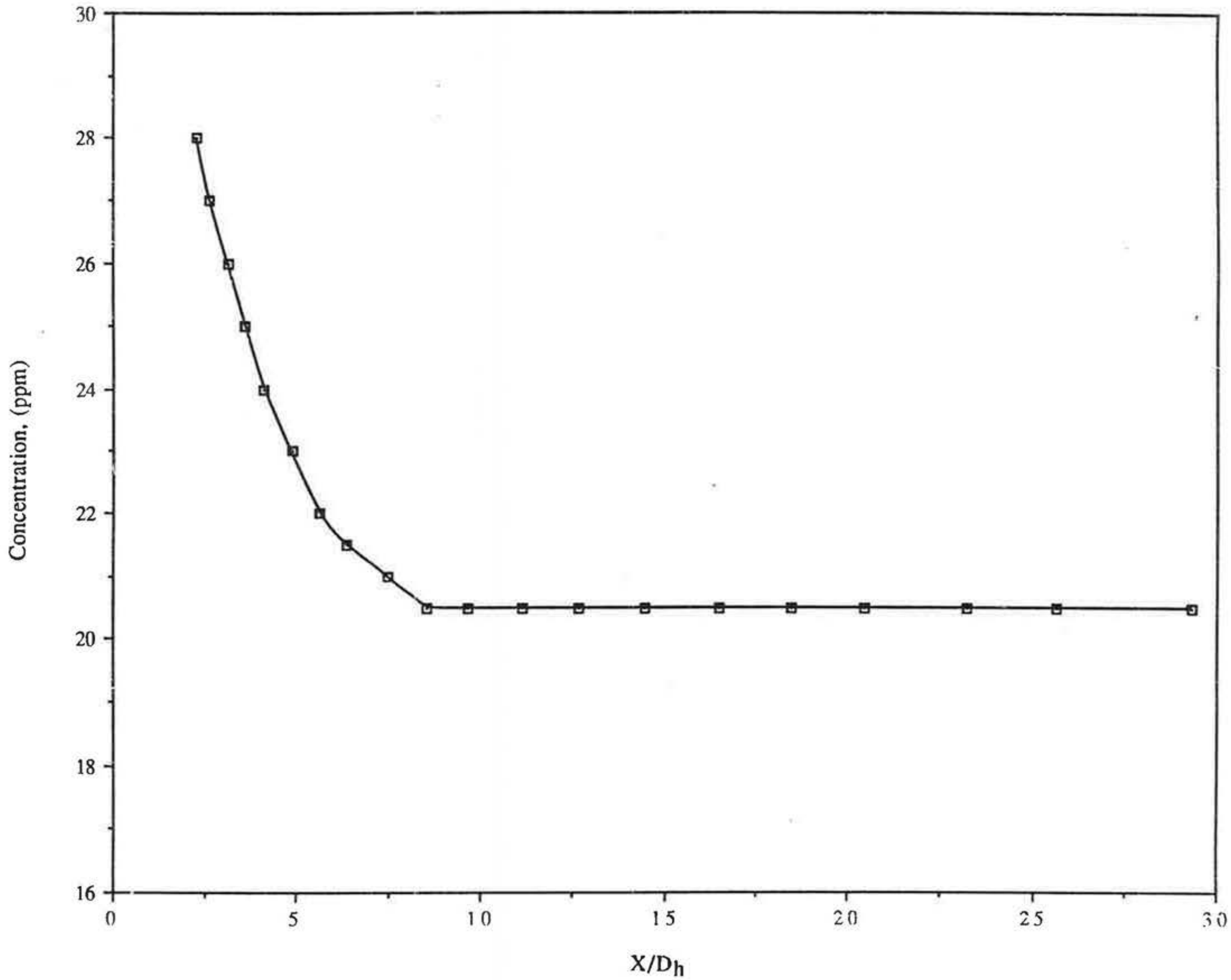

Figure 3 Variation of tracer-gas concentration with X/D_h, aspect ratio = 1:1

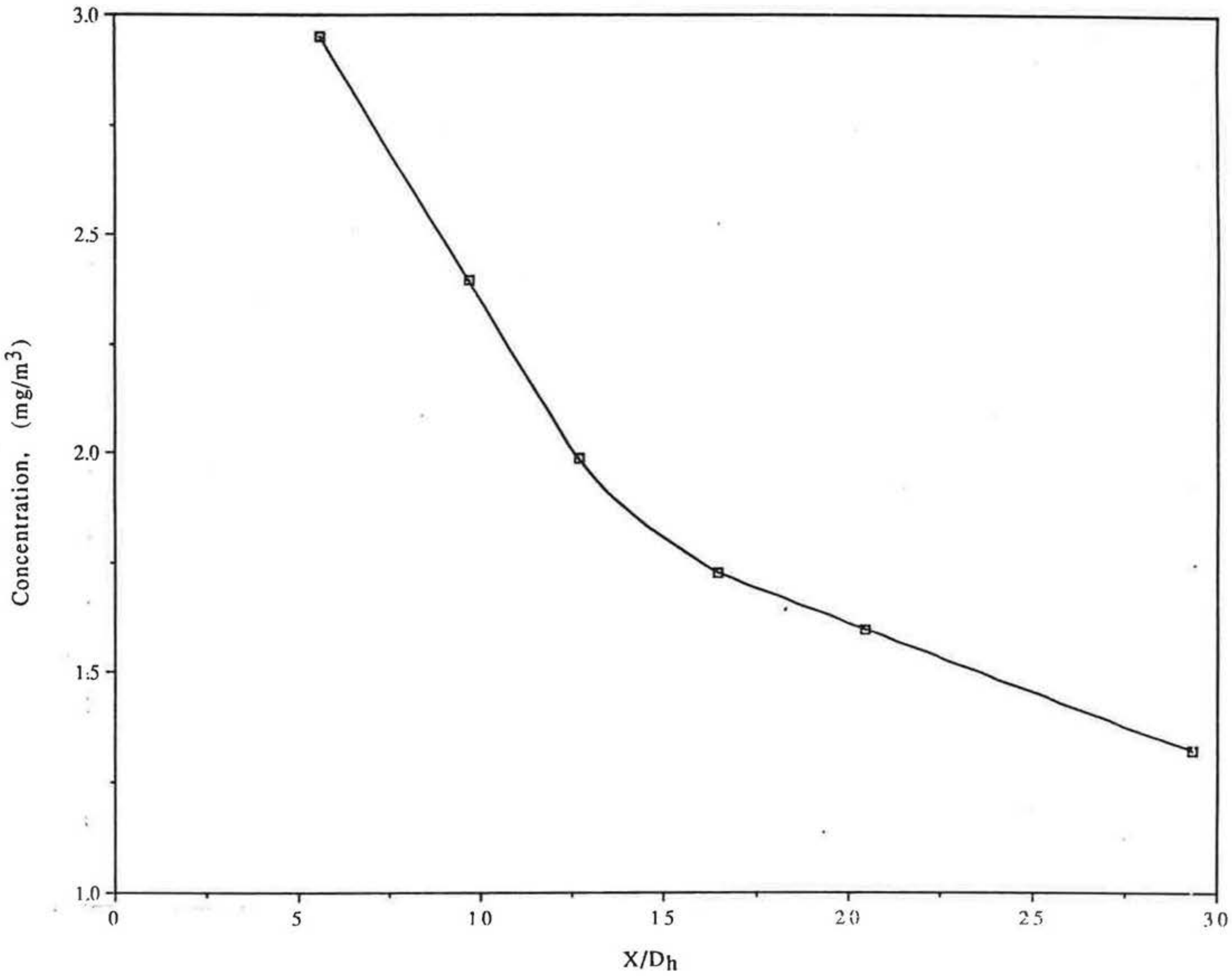

Figure 4 Variation of smoke-particle concentration with X/D_h, aspect ratio = 1:1

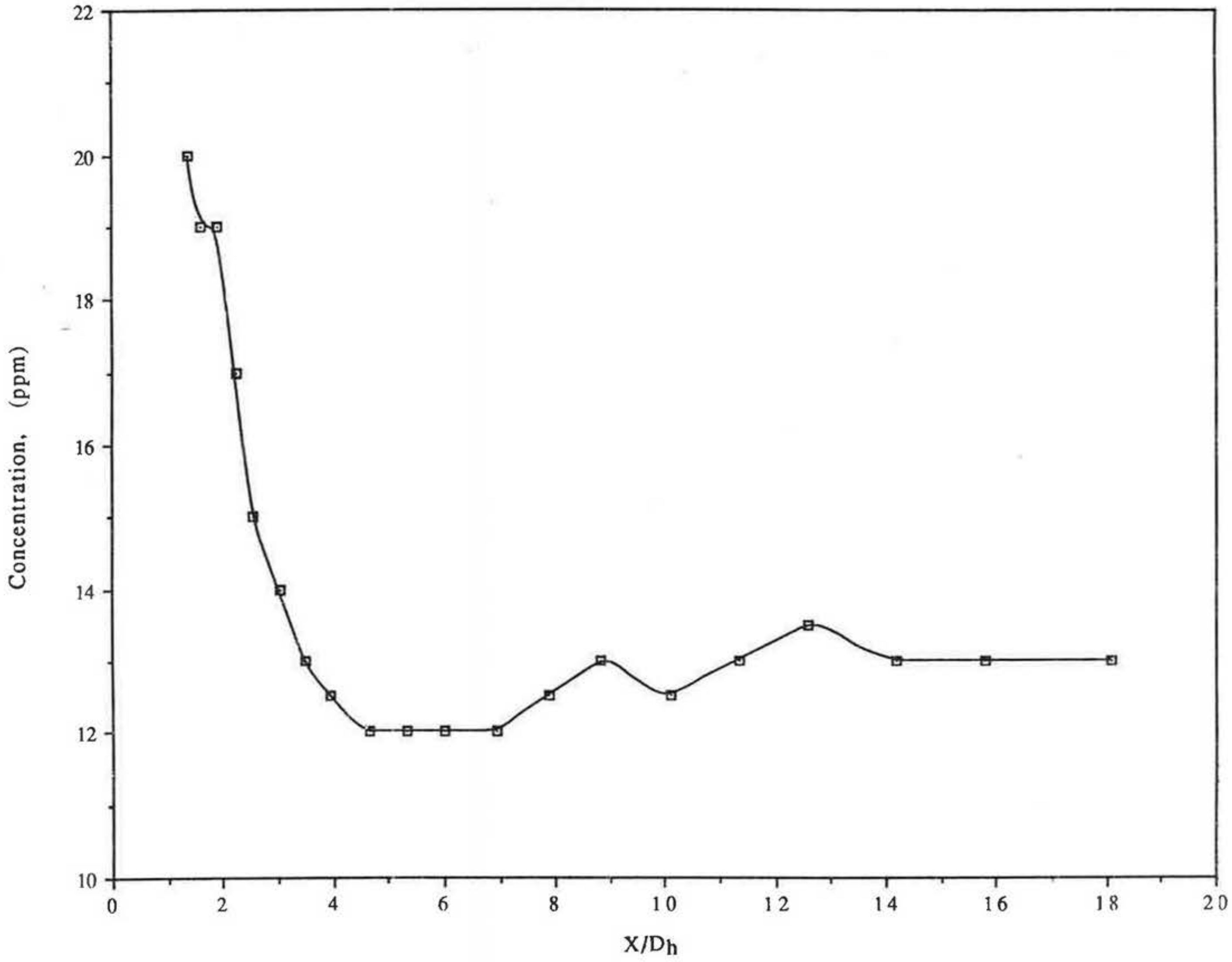

Figure 5 Variation of tracer-gas concentration with X/D_h, aspect ratio = 4:1

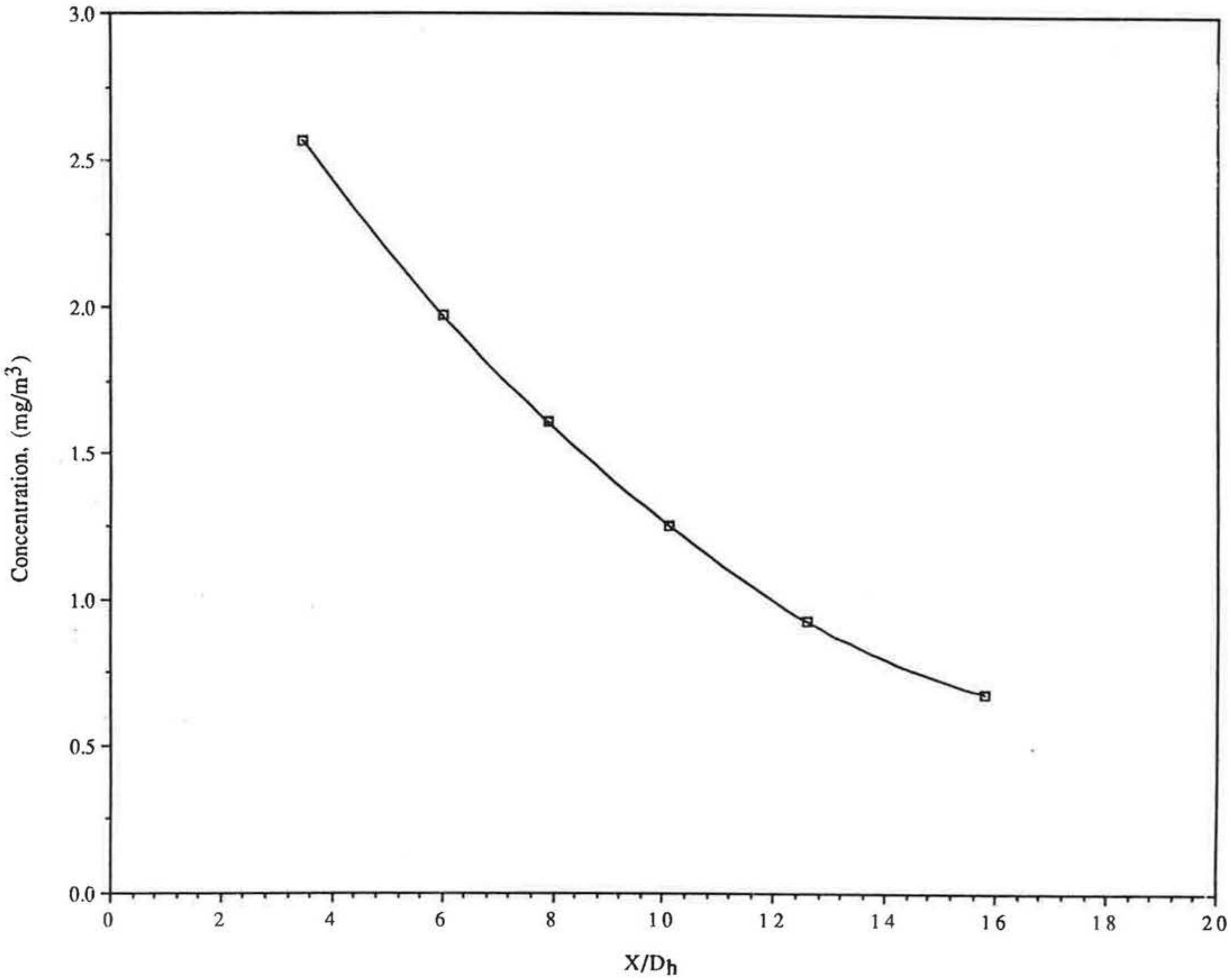

Figure 6 Variation of smoke-particle concentration with X/D_h, aspect ratio = 4:1

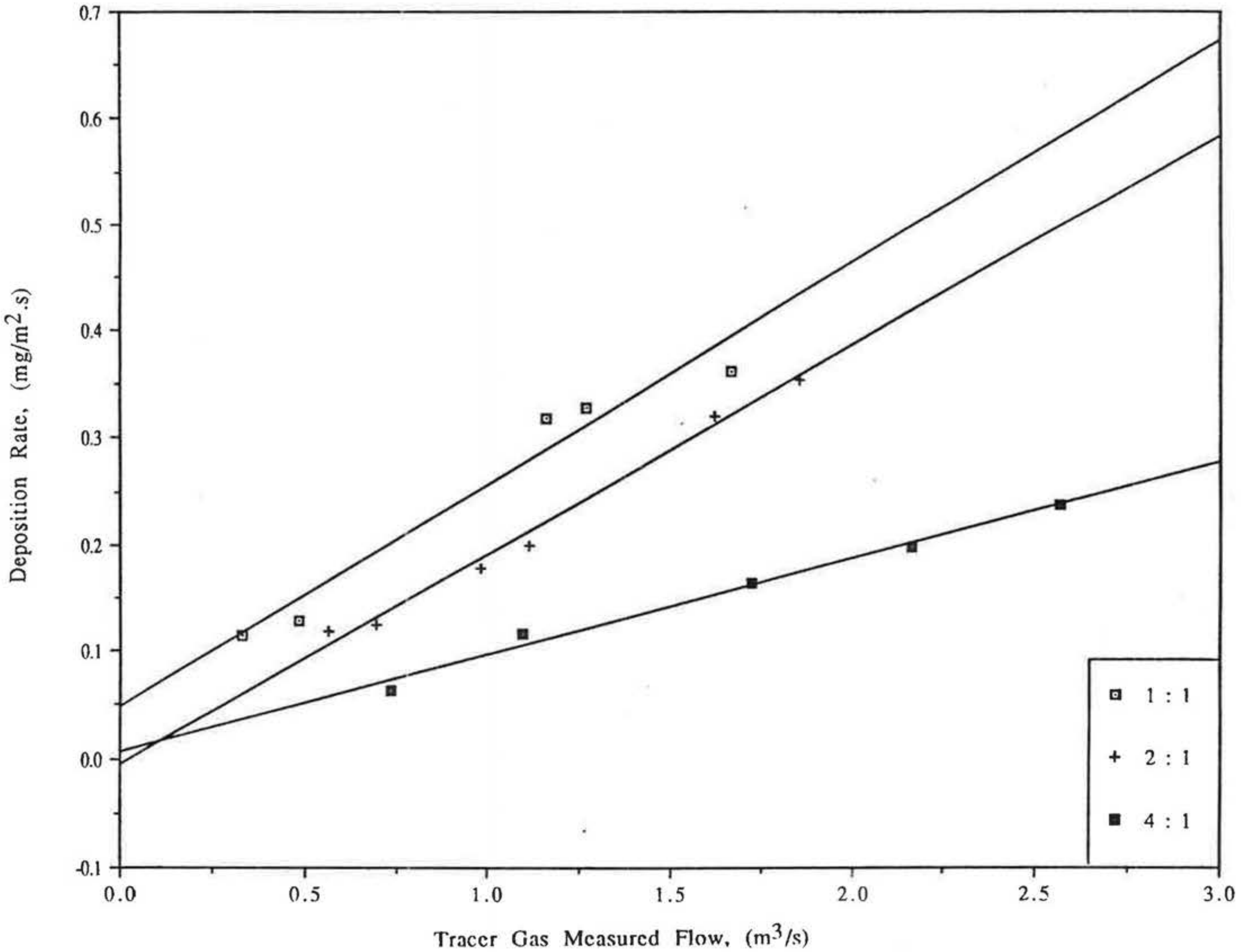

Figure 7 Variation of deposition rate of smoke particle with airflow rate