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MEASUREMENT OF AIRFLOW THROUGH A POROUS MEDIUM

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ABSTRACT

This work examines the application of the constant-injection tracer-gas technique for measurement of airflow in a duct filled with a porous medium. The duct used for this investigation had an aspect ratio of 6.25 and measurements of tracer-gas concentration and pressure distribution along the duct were performed for Reynolds numbers between 1140 and 1790. The work indicated that the concentration of tracer-gas in the porous medium became constant at a distance of approximately 52 hydraulic diameters from the tracer-gas injection point.

NOTATION

C	Concentration of tracer-gas (ppm)
C_o	Concentration of tracer-gas at t=0 (ppm)
$\dot{C}$	Time derivative of tracer-gas concentration (ppm/s)
D_H	Hydraulic diameter of the duct (m)
F	Airflow rate (m^3/s)
I	Air exhange rate (h^{-1})
P_a	Atmospheric pressure (Pa)
P_s	Static pressure (Pa)
q	Injection flow rate of tracer gas (m^3/s)
Re	Reynolds number = $U_b \rho D_H/\mu$ (dimensionless)
t	Time (s)
U_b	Bulk velocity (m/s)
V	Internal volume of the duct (m^3)
X_s	Tracer-gas sampling distance from the duct inlet (m)
X_p	Pressure-sampling distance from the duct inlet (m)
ρ	Air density (kg/m^3)
μ	Dynamic viscosity (Ns/m^2)

INTRODUCTION

Porous media are widely used in engineering applications such as thermal-storage devices, transpiration-cooling systems and muffling devices. They are also used in mining, petroleum processes and chemical and aerospace applications. Mass and energy transport in porous media must be well understood if these materials are to be used effectively and several studies have been carried out with this aim (1-6).

Fluids normally experience a high pressure drop as they pass through a porous medium and the resulting flow velocity is often too small to be measured accurately using traditional instrumentation such as orifice meters, pitot tubes and hot-wire anemometers. In some cases, limited access to the flow passage or the short duct length involved prevents easy deployment of traditional instrumentation. The complex geometries of porous media and the irregular flow patterns associated with them give rise to additional difficulties.

The constant-injection tracer-gas technique offers an alternative approach for measurement of fluid (eg. air) flow through porous media. The tracer-gas technique can be used to measure flow rates over a wide range of values (ie., laminar and turbulent flow) and is not limited by the complexity of the porous media or passage configuration. Moreover, the tracer-gas technique can be used to measure flow rates through porous media directly and does not require determination of the cross-sectional area of the flow passage or the granular size of the porous medium.

This work describes the application of the constant-injection technique for measurement of airflow in a two-dimensional duct filled with a porous medium.

THEORY

This technique is based on the injection of tracer-gas into the duct inlet at a uniform rate. Assuming that the air and tracer gas are perfectly mixed within porous medium and that the external tracer-gas concentration is zero, the mass balance equation is given by:

$$V\dot{C}(t) + F(t)C(t) = q(t) \quad (1)$$

The duct air exchange rate I is given by:

$$I(t) = F(t)/V \quad (2)$$

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

$$C(t) = q/F + (C_o - q/F)\ \exp(It) \quad (3)$$

As the system approaches equilibrium, the concentration of tracer-gas changes slowly and the rate of change of tracer-gas becomes small. The transient equation in equation (3) would die out after a sufficiently long period. The air flow rate through the duct would simplify to:

$$F = q/C \times 10^6 \quad (4)$$

Hence, F can be evaluated, if measurement of tracer-gas flow rate and concentration can be made.

MATERIALS AND METHOD

The apparatus used for this investigation is shown in Figure 1. The rectangular duct was constructed from plywood 12 mm thick. The entrance to the duct consisted of a bell-mouth, and the duct itself was 3 m long with an internal cross-section of 250 x 40 mm. The downstream end was connected to the suction side of a centrifugal fan by means of a diffuser, and the flow rate through the duct was varied by means of a variable speed controller. The centrigual fan was manufactured by Fischbach Limited, Germany. A length of 1600 mm, commencing 400 mm from the duct inlet was packed with gravel of granular size between 5 and 10 mm.

Static pressure tappings was distributed at various positions along the duct. A single tube inclined manometer, made by Air Flow Development Ltd, High Wycomb, UK, was used to measure the static pressure head.

The constant-injection technique was used to determine the air flow rate in the duct and SF_6 tracer gas was used. The tracer-gas was injected into the duct inlet a constant rate via a number of small injection tappings distributed around the perimeter of the duct. These tappings were connected to the manifold using flexible tubing. The SF_6 gas was supplied from a SF_6 gas cylinder via a type F-100/200, mass flow controller which had a maximum capability of 3.9 L/min. The controller was manufactured by Bronkhorst High-Tech BV, Ruurlo - Holland. The measurement accuracy of the mass flow controller was 1%. The flow rate was controlled using a variable power supply and the rate of tracer gas supply was displayed on a digital unit.

Tracer gas/air samples were taken at various points along the duct as shown in Figure 1. The gas analyser was a Binos 1 Infra-red Gas Analyser manufactured by Leybold-Heraeus GMBH, Hanau, Germany.

RESULTS AND DISCUSSION

Airflow rates in the duct were measured using the constant-injection tracer-gas technique. Measurement of tracer-gas concentration and static pressure along the duct were carried out for Reynolds numbers between 1140 and 1790. SF_6 gas was injected at a rate of 0.25 L/min into the duct at X_s/D_H = 21.9 and the concentration of tracer-gas was monitored at various positions downstream. Figure 2 shows the variation of tracer-gas concentration for various X_s/D_H. The concentration of tracer-gas was found to be unsteady close to the injection point but remained constant when X_s/D_H was greater than 74.5 (i.e. 0.9 m from the injection point). The flow rates were found to vary between 35 and 55 m^3/h (i.e., velocities between 0.9 and 1.5 m/s). These velocities are too small to be measured using traditional instrumentation. The porous medium was found to produce good mixing of tracer gas in the duct.

Figure 3 shows the variation of the pressure difference, P_a - P_s, along the duct for various Reynolds numbers. The pressure difference was found to vary non-linearly through the porous material particularly at high Reynolds numbers. The flow rate through the duct was plotted against the static pressure difference across the porous medium as shown in Figure 4. The least squares technique was used to fit an exponential curve through the measurements of F and ΔP_S and the flow rate was found to change in accordance with:

$$F = 4.41(\Delta P_S)^{0.47} \qquad (5)$$

The above equation is similar to that describing air leakage through cracks in building materials (7). The results indicate that the flow rate is approximately proportional to the square root of the pressure drop across the porous medium.

CONCLUSION

The results of this investigation show that the constant-injection tracer-gas technique provides a simple and convenient method for measuring airflow through a porous medium. The tracer-gas method is particularly useful for measuring small volumetric flow rates which cannot be measured accurately using traditional instrumentation.

Additional work is required to examine the application of tracer-gas techniques for measurement of fluid flow through different types of porous media.

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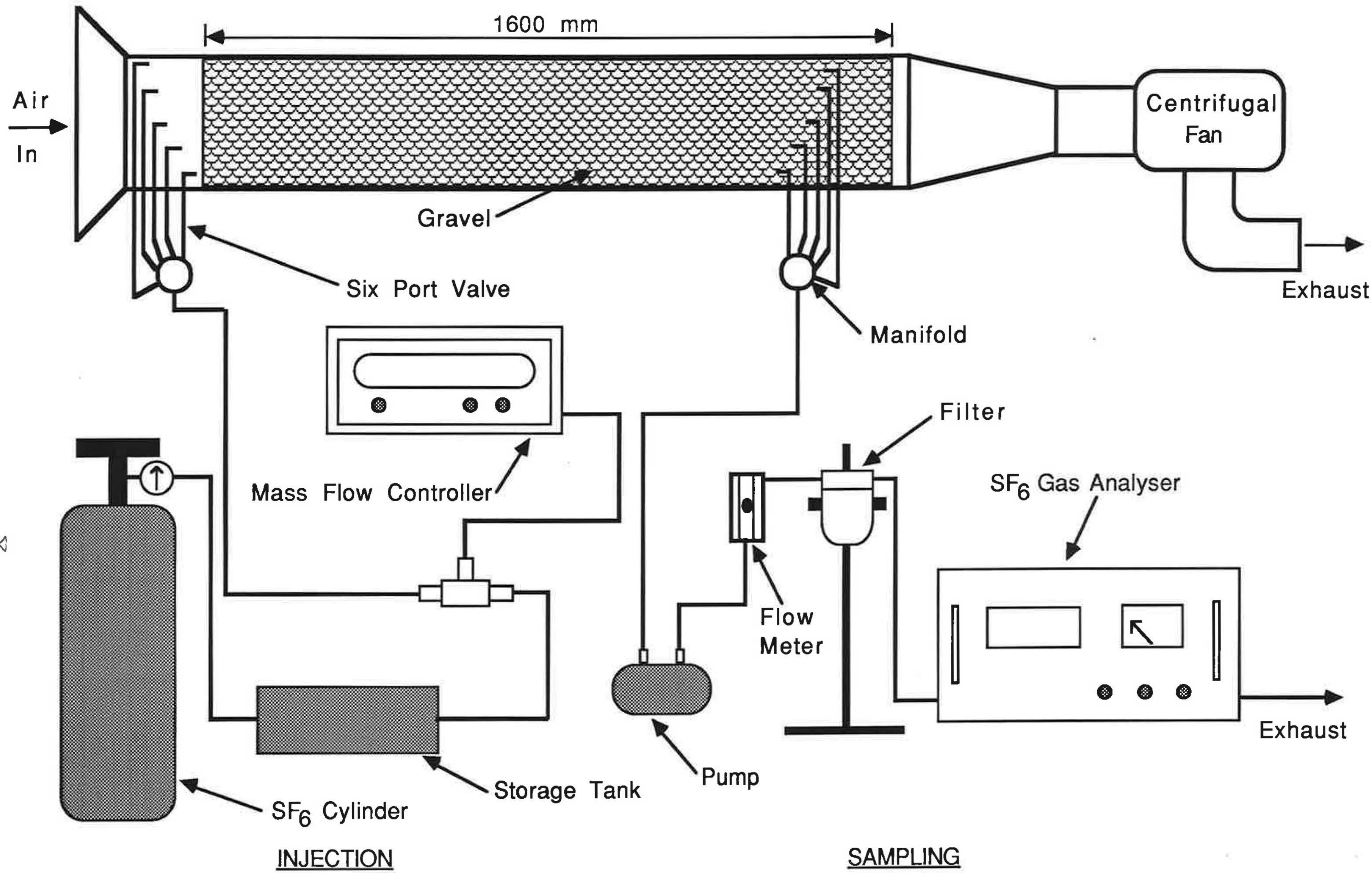
FIGURES

Figure 1 Schematic diagram of the duct system and instrumentation.

Figure 2 Variation of tracer-gas concentration with X_s/D_H.

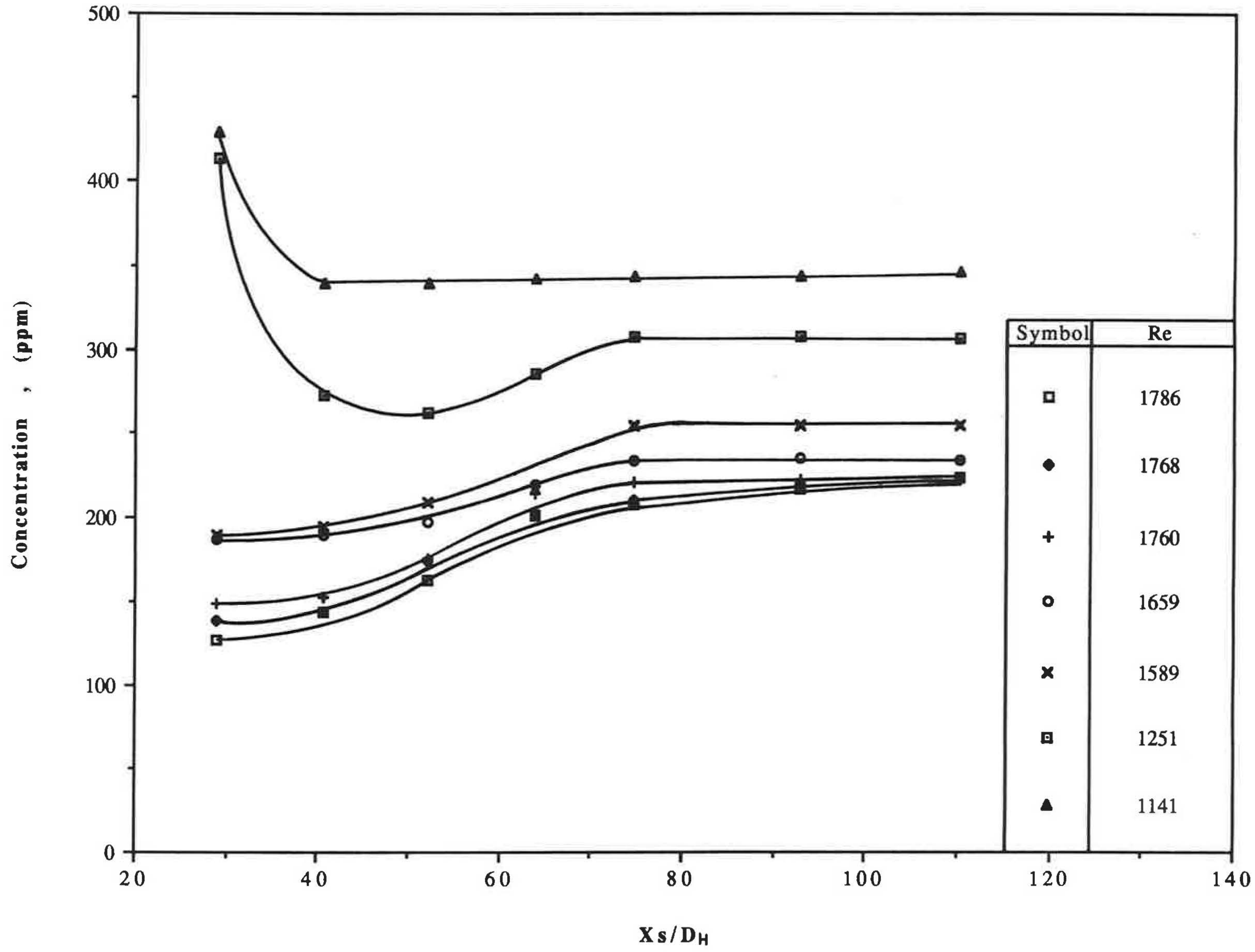
Figure 3 Variation of static pressure with X_p.

Figure 4 Variation of volumetric flow rate with static pressure difference across the porous medium.



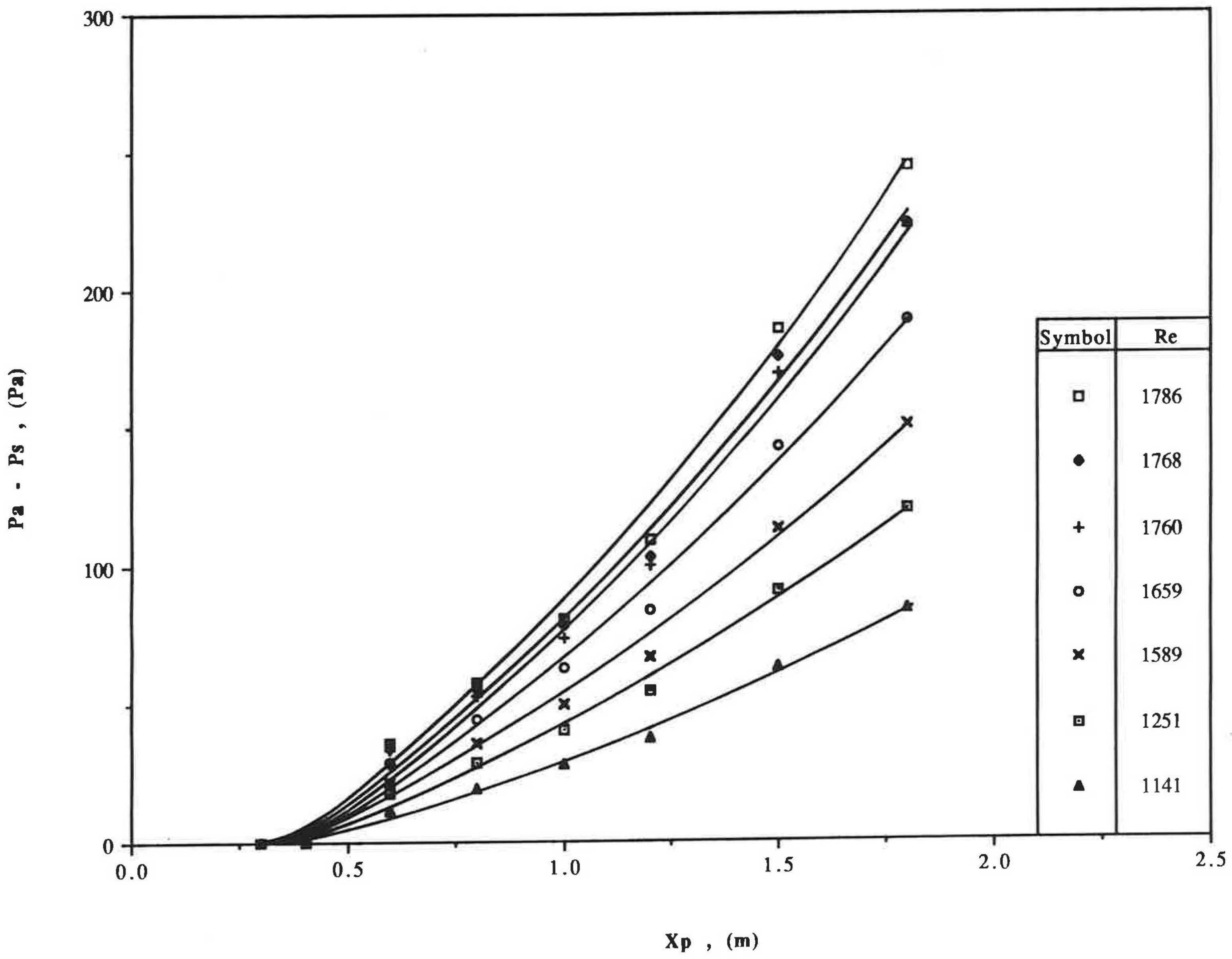
1600 mm
Air
In
Centrifugal
Fan
Gravel
Six Port Valve
Exhaust
Manifold
Filter
Mass Flow Controller
SF6 Gas Analyser
Flow
Meter
Exhaust
Pump
Storage Tank
SF6 Cylinder
INJECTION
SAMPLING

Figure 1



500
400
300
200
100
0
Concentration , (ppm)
20
40
60
80
100
120
140
Xs/DH
Symbol
Re
1786
1768
1760
1659
1589
1251
1141

Figure 2



300
200
100
0
Pa - Ps , (Pa)
0.0
0.5
1.0
1.5
2.0
2.5
Xp , (m)
Symbol
Re
1786
1768
1760
1659
1589
1251
1141

Figure 3

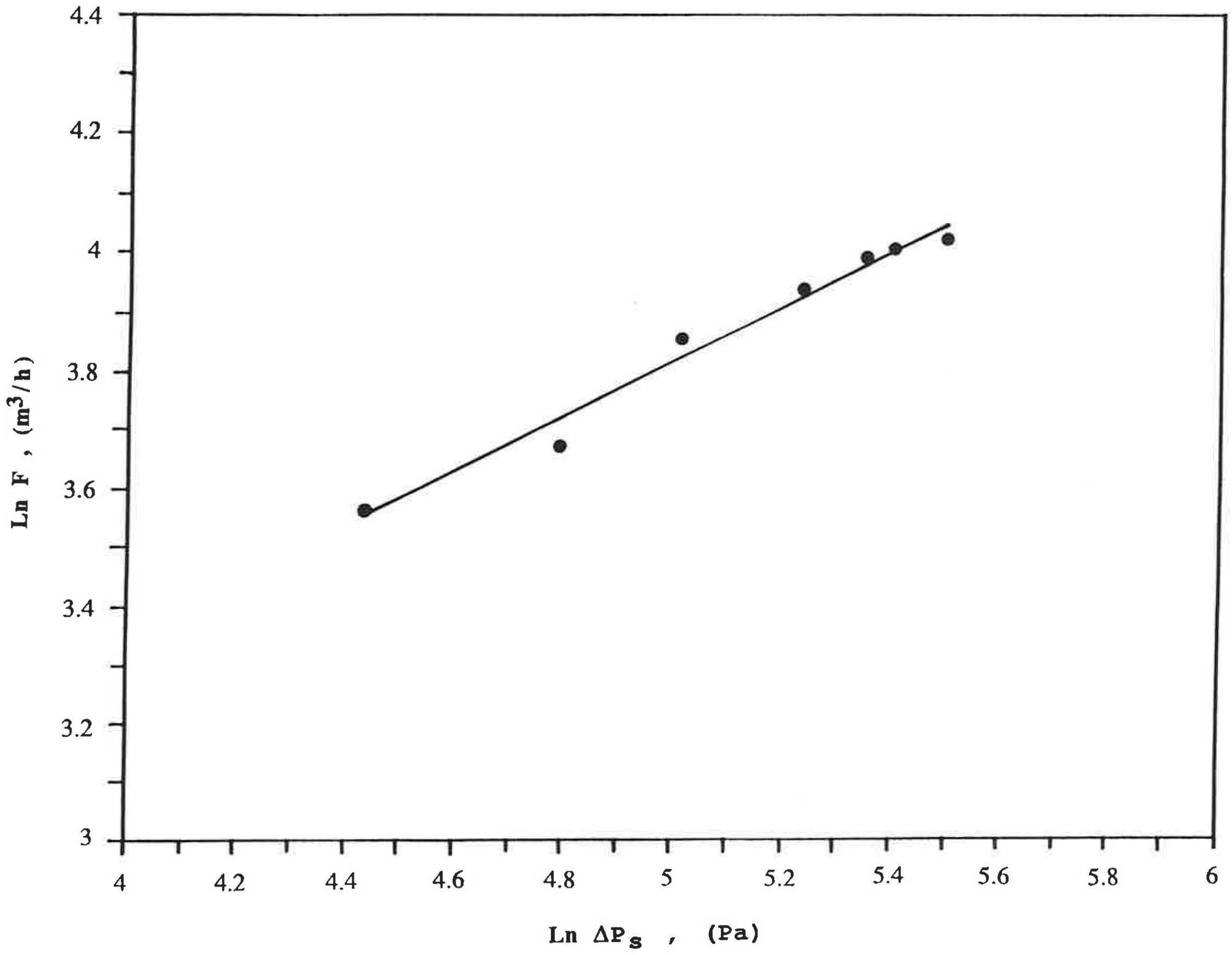


Figure 4