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AIRFLOW RATE THROUGH A HEAT-EXCHANGER COIL: COMPARISON OF MEASUREMENTS MADE WITH A ROTATING VANE-ANEMOMETER AND A TRACER-GAS TECHNIQUE

S B Riffat
Building Services Group
Department of Civil Engineering
Loughborough University of Technology
Loughborough
Leicestershire LE11 3TU
United Kingdom

ABSTRACT

This work compares measurements of airflow rate through a heat-exchanger coil made with a rotating vane-anemometer and a tracer-gas technique. The two sets of measurements were generally in good agreement. The tracer-gas technique was found to be simpler to use in practice and has additional advantages as it does not require detailed specification of the coil or actual density of air.

NOTATION

v	Specific volume (m^3/kg)
R_a	Gas constant for air, 0.287 kJ/kgK
T	Absolute temperature (K)
P	Total pressure (Pa)
W	Humidity ratio (kg/kg_a)
W_s	Humidity ratio of saturated air at wet bulb temperature (kg/kg_a)
t_d	Air dry-bulb temperature (°C)
t_w	Air wet-bulb temperature (°C)
P_w	Saturated pressure of water vapour at the wet-bulb temperature (P_a)
A	Coil face area, A = L x H, (m^2)
H	Height of the coil (m)
L	Width of the coil (m)
U_s	Corrected velocity for calibrated density (m/s)
U	Measured velocity (m/s)
U_a	Average air velocity for 38 measured coil velocity (m/s)
K	K-factor for coil
R	Number of rows deep of tubes in coil
fp	Fins per 25.4mm for the coil
S_p	Tube spacing at the coil face (mm)
d	Tube outside diameter (mm)
F_s	Volume flow rate at standard density air through the coil (m^3/s)
F_a	Volume flow rate at actual density air through the coil (m^3/s)
F_t	Volume flow rate using tracer gas technique (m^3/s)
C	Tracer-gas concentration (ppm)
q	Injection flow rate of tracer gas (m^3/s)
D	Diameter of the rotating vane-anemometer head (m)

1. INTRODUCTION

Indoor air quality, thermal comfort and energy use in buildings are largely dependent on the performance of heating, ventilation and air-conditioning (HVAC) systems. Incorrect ventilation rate is a common cause of poor indoor climate in office buildings and if this is to be avoided, frequent testing and balancing of HVAC systems must be carried out. Measurements of airflow in HVAC systems are usually performed using traditional instrumentation such as vane anemometers, pitot tubes and hot-wire anemometers. This type of instrumentation can be difficult to employ in practice as access to the duct may be restricted and, even if this is overcome, a long measuring section is required to achieve fully-developed flow. Furthermore, it is difficult to achieve reasonable measurement accuracy with pitot tubes or vane anemometers when flow velocities are less than 3 m/s.

Tracer-gas techniques[1], such as constant-injection, constant-concentration, concentration-decay and pulse-injection, can be used as alternatives to traditional-instrumentation for measuring airflow in HVAC systems. These techniques are not limited by the complexity of duct configurations and, as the concentration of tracer gas can be detected easily using a gas chromatograph , they can be used for measuring airflow over a wide range of values. Furthermore, tracer-gas techniques can be used to measure flow rates directly and do not require determination of the cross-sectional area of the duct or flow profile at the duct wall. Unlike traditional instrumentation, tracer-gas techniques can be used to determine the tightness of air ductwork. This is important if energy losses and noise resulting from air leakage are to be controlled.

A recent, ASHRAE Research Project PR-451, carried out by Howell and Sauer[2], investigated the use of a rotating vane-anemometer to measure airflow rates at coil faces. Results indicated that the measurement accuracy of the vane-anemometer for this application was ±7%. The present work describes the use of the constant-injection techniques for measuring airflow through a heat-exchanger coil and compares the results with those obtained using a vane anemometer. The constant-injection technique was employed in this investigation as it produces a minimum error[3].

2. CALCULATION PROCEDURE

The calculation procedures for the rotating vane-anemometer method[2] and the constant-injection tracer-gas technique are as follows:

2.1 Rotating Vane-Anemometer

i) The heat-exchanger coil should be marked so that standard (D/2, H/4...etc) and offset (D + Sp/2, H-Sp/2,...etc) location readings can be taken on a dry coil on the downstream side.

ii) With the air flowing through the coil, measure the air dry-bulb temperature, the wet-bulb temperature, and the barometric pressure. The specific volume of the air can be calculated using[4].

$$v = \frac{R_a T}{P}(1 + 1.6078\ W) \qquad (1)$$

The humidity ratio, W, can be calculated from:

$$W = \frac{(2501 - 2.381\ t_w)\ W_s - (t_d - t_w)}{2501 + 1.805 t_d - 4.186 t_w} \qquad (2)$$

The humidity ratio of the saturated air at the wet-bulb temperature is given by:

$$W_s = 0.62198 \frac{P_w}{P - P_w} \qquad (3)$$

iii) Using a 100mm rotating vane-anemometer (calibrated to standard density air), take 19 velocity readings at the standard location and 19 readings at the offset location. Measurement of air velocity at each location should be taken after 5-15 seconds in order to allow sufficient time for the anemometer to respond to the velocity at that location.

iv) Correct the measured velocity from step (iii) to standard density air (for which the anemometer was calibrated) using the following:

$$U_s = U\,(0.8333/v)^{0.5} \tag{4}$$

v) Determine the average velocity reading at the coil-surface face using:

$$U_a = \frac{\sum_{o}^{i=38} U_{si}}{38} \tag{5}$$

vi) Determine the K-factor for the coil from the following equation:

$$K = a_o + a_1\,U_a + a_2\,R + a_3\,f_p + a_4\,S_p + a_5\,d + a_6\,U_a^2 \tag{6}$$

For a 100mm vane-anemometer:

$a_o = 0.65204515$, $a_1 = 0.0346653$, $a_2 = 0.000971875$, $a_3 = -0.006745072$,

$a_4 = 0.000186495$, $a_5 = -0.00035727$, $a_6 = -0.00033647$

vii) Calculate the volume flow rate through the coil using:

$$F_s = K\,A\,U_a \tag{7}$$

viii) Calculate the actual volume flow rate using:

$$F_a = F_s\,(v/0.8333) \tag{8}$$

2.2 Constant-Injection Tracer-Gas Technique

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

ii) A multi-point probe is used to collect tracer-gas samples downstream of the coil. Assuming that the concentration of tracer-gas in the outside air is zero, the following equation can be used for steady-state condition[3]:

$$F_t = (q/C) \times 10^6 \tag{9}$$

3. EXPERIMENTAL

The system shown in Figure 1 consisted of a centrifugal fan, a transformation piece, a duct, a heat-exchanger coil and a bell-mouth outlet. The duct was constructed from galvanised mild steel and was 0.965m long and had an internal cross-sectional area of 303mm x322mm. The centrifugal fan, made by Fischback Ventilation Ltd, was driven by an AC motor of 0.15kW.

Figure 1 also shows the instrumentation used to implement the tracer-gas technique. SF_6 tracer-gas was injected at a constant rate into the duct inlet, through a number of small injection tappings. The tappings were connected to a manifold by flexible tubing. SF_6 was supplied to the manifold via a type F100/200 mass-flow controller, which had a maximum flow capability of 1 litre/min and was manufactured by Bronkhorst High-Tech BV, Holland. The measurement accuracy of the mass-flow controller was ±1%; the flow rate was controlled by means of the variable power supply, and the rate of injection of tracer-gas was displayed on a digital unit.

Tracer-gas/air samples were collected using a multi-point sampling probe at a position immediately downstream from the heat-exchanger coil. The concentration of tracer-gas was measured by an Infra-red Gas Analyser, type Binos 1, made by Leybold-Heraeus GMBH, Germany.

The velocity at the coil face was measured using a 100mm rotating vane-anemometer, type DVA30, made by Airflow Development Ltd, UK. The pressure difference across the coil was also measured using a single-tube inclined manometer.

4. RESULTS AND DISCUSSIONS

Separate measurements of airflow rate through the heat exchanger coil were carried out using the rotating vane-anemometer and the constant-injection technique. A calibrated, 100mm diameter, rotating vane-anemometer was used to take 19 velocity readings at the standard location and 19 readings at the offset location in accordance with the method described by Howell and Sauer[2]. The second set of measurements required controlled injection of tracer-gas into the duct at a position upstream from the heat-exchanger coil. The concentration of tracer gas was measured downstream from the coil. The concentration of tracer-gas upstream from the coil was measured at different heights from the duct wall and was found to be uniform. This indicated that good mixing of tracer gas and air had been achieved.

Experiments were carried out for various flow rates through the heat-exchanger coil. Figure 2 compares measurements of airflow rate made with the vane-anemometer and the tracer-gas technique. The tracer-gas results were generally found to be in good agreement with those obtained with the vane anemometer. The best linear relationship was as follows:

$$F_t = 1.083\ F_a \tag{10}$$

This relationship shows that tracer-gas measurements were about 8.3% higher than vane-anemometer measurements. These results are encouraging as the vane-anemometer has an uncertainty (difference between the true value of the quantity measured and the observed value) of ±7% (Ref.2).

Although the vane-anemometer method produced results similar to those derived from the tracer-gas technique, we found that the former is difficult to employ in practice for several reasons. The vane-anemometer method requires detailed specification of the heat-exchanger coil (ie, tube diameter, tube spacing, number of fins and number of rows) and a knowledge of the actual density of air. This may produce difficulties as it is not always possible to have access to the heat-exchanger coil in order to carry out measurements of air velocity at specific locations (ie, offset and standard locations). In addition, use of the vane-anemometer method is time consuming and measurement accuracy depends on the uniformity of air velocity across the coil.

In contrast to the vane-anemometer method, the tracer-gas technique was found to be simple to use and does not require detailed knowledge of the dimensions of the coil or the duct. Airflow disturbances in the duct caused by coils, elbows and dampers act to improve tracer-gas mixing and so increase measurement accuracy.

CONCLUSIONS

The following conclusions can be drawn up from this investigation:

1. Measurements of airflow-rate through the coil made with tracer-gas technique and a vane-anemometer were generally in good agreement.
2. The tracer-gas technique was found to be easier to use in practice and does not require detailed specification of the coil or the actual air density.
3. Unlike the vane-anemometer method, the tracer-gas technique can be used for continuous monitoring of airflow in ducts over a wide range of flow rates (laminar and turbulent flow).
4. The presence of heat-exchanger coils, dampers and elbows in the airflow passages assists tracer-gas mixing the hence improves the accuracy of the technique.

REFERENCE

1. Lagus, L. and Persily, A. K., A review of tracer-gas techniques for measuring airflows in buildings, ASHRAE Trans, 91 Part 2B, HI-B5-22, No.1, (1985), 1075-1087.
2. Howell, R.H. and Sauer, H.J., Field measurements of air velocity: pitot traverse or vane anemometer, ASHRAE Journal, 32(3), (1990), 46-52.
3. Riffat, S.B., A comparison of tracer-gas techniques for measuring airflow in a duct, Journal of the Institute of Energy, LXIII(454). (1990), 18-21.
4. ASHRAE Handbook, Fundamentals, SI Edition, (1989), 6.8-6,9.

FIGURES

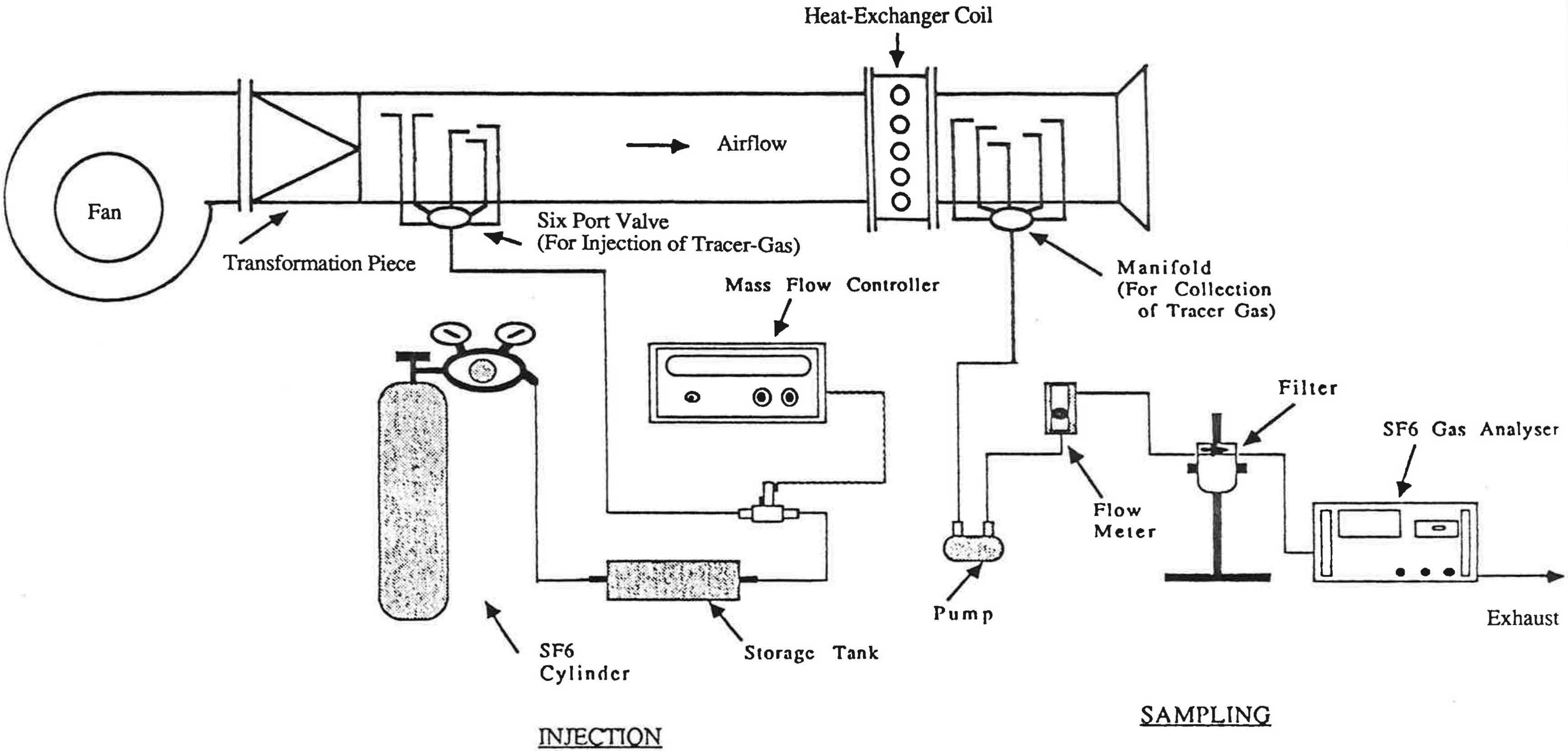
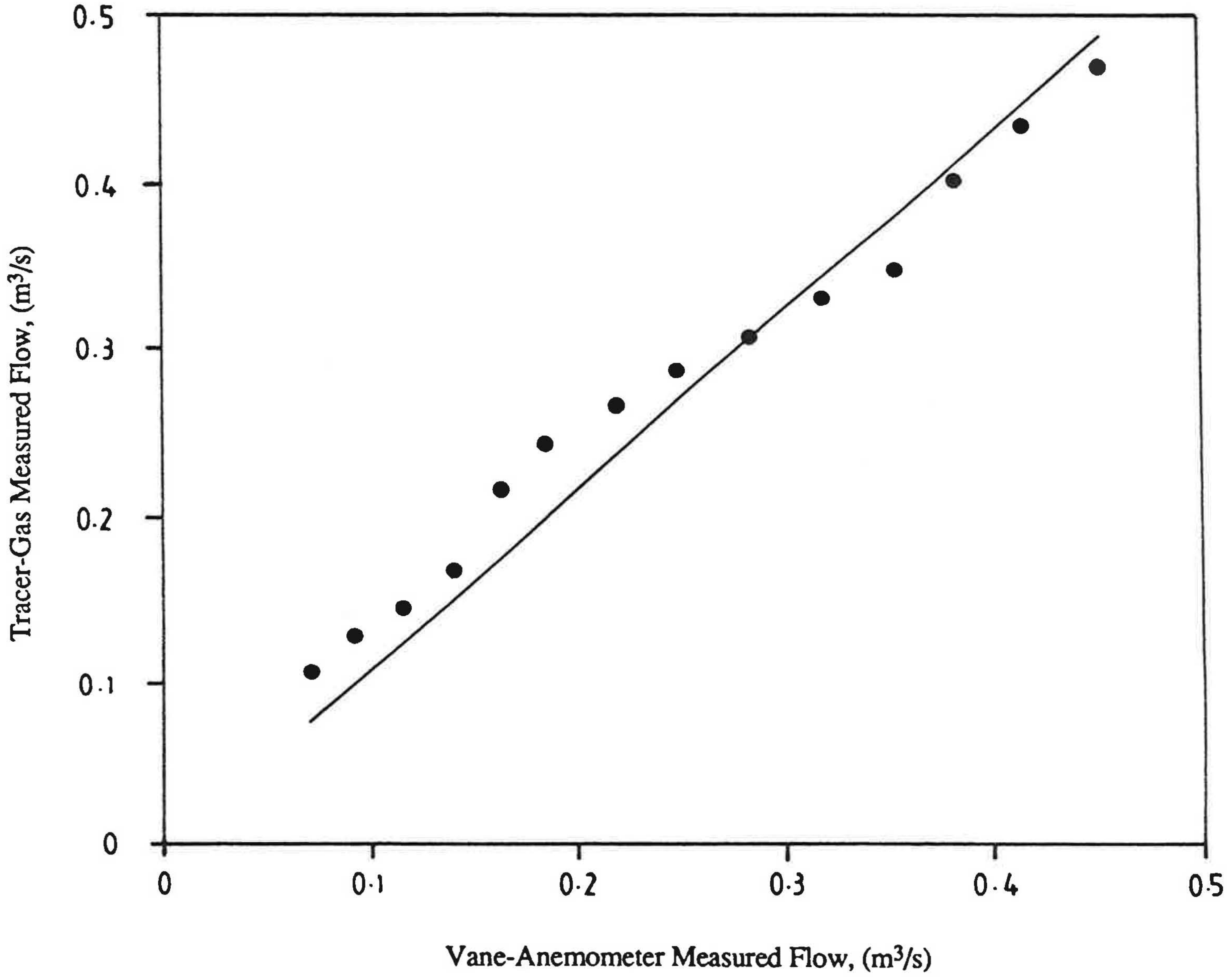

Heat-Exchanger Coil
Airflow
Fan
Six Port Valve
(For Injection of Tracer-Gas)
Transformation Piece
Mass Flow Controller
Manifold
(For Collection
of Tracer Gas)
Filter
SF6 Gas Analyser
Flow
Meter
Pump
Exhaust
SF6
Cylinder
Storage Tank
SAMPLING
INJECTION

Fig 1


Tracer-Gas Measured Flow, (m3/s)
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
Vane-Anemometer Measured Flow, (m3/s)