Compact Sampling Systems for Measuring Atmospheric Trace Gas Profiles

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ABSTRACT

Obtaining trace gas profiles using a single analyzer requires a valve/manifold system that can sample the atmosphere at multiple levels. Ideally, the entire profile would be sampled at the same instant, but because this is not possible, averaging volumes are often installed on the intake lines. A more representative profile can be obtained and averaging volumes eliminated, however, by cycling through all the intakes quickly. To achieve this, the time required for the analyzer sample to equilibrate to the selected intake must be minimized. This shortens the profile cycle time and uses a greater portion of the time for measurements. The sampling systems described here use small, manifold-mounted valves, minimizing the internal volume of the manifold. Two examples are described. The first has four intakes and one analyzer outlet; the second has 16 intakes and four analyzer outlets. Performance test results are given for these systems, including pressure drops at various flow rates, equilibration times, pressure transients, and zero-gradient tests using a tunable diode laser trace gas analyzer.

KEYWORDS

sampling system, trace gas profile, valves, equilibration time

INTRODUCTION

Measuring multi-level atmospheric profiles, multi-site gradients, or multiple open-top chamber fluxes using a single trace gas analyzer requires a valve/manifold system to switch between intakes. Trace gas concentrations change over time; therefore the time interval between measurements when multiplexing between several intakes can lead to errors. These errors can be minimized by cycling through all of the intakes quickly, but this requires short equilibration times following the selection of a new intake. If the internal volume of the sampling system is large, a high flow rate is required to equilibrate quickly. However, for tightly spaced gradients close to the ground and inside vegetation canopies a low flow rate is necessary to avoid disturbing the ambient conditions. Also, splitting a vacuum pump's finite capacity among several intakes lowers the flow rate in each one. The sampling system could be designed to pull air through only one intake at a time, but it is desirable to maintain flow in all intake lines, even when not selected, to minimize equilibration time and to minimize pressure transients in the analyzer. The sampling systems described here use small manifold-mounted valves and have a small mixing volume that provides a rapid equilibration even with low flow rates. The sampling systems have been tested with the TGA100 Trace Gas Analyzer manufactured by Campbell Scientific, but can be used with other analyzers as well.

DESIGN FEATURES

The sampling system design is based on small, manifold mounted three-way valves (model LHDA1223211H, The Lee Company, Westbrook, CT). These valves were selected for their small size (0.3" x 0.3" x 1.25") low power consumption (750 mW @ 12 Vdc) and long lifetime (250,000,000 cycles minimum). The valves are mounted on a custom manifold designed so that each intake tube connects to the common port of a three-way valve. The normally closed ports of all of the valves connect to the analyzer manifold, and the normally open ports connect to a vacuum bypass manifold. The control electronics energize one valve at a time, connecting one of the intakes to the analyzer, and leaving all of the other intakes connected to the vacuum pump via the bypass manifold. This design pulls air through all of the intakes all of the time to minimize pressure transients in the intake lines and the analyzer.

Typically the intake tubes will have a filter and orifice at the intake. The orifice determines the intake flow and drops the pressure in the tubing. This is a convenient and cost-effective way to ensure equal flow in all intakes, and to avoid condensation in the tubing. The sampling system is mounted close to the analyzer to reduce equilibration time.

In the case of a single-analyzer design, the sampling system can easily be mounted inside the TGA100 enclosure. A four-intake version of this design was built and tested, but the design is easily adapted to any number of intakes. The manifold length can be increased by 0.3" per intake and additional holes drilled to accommodate the additional valves and intake fittings. The internal volume of the four-intake manifold is 0.27 ml. The sampling system requires less than 100 mA @ 12 Vdc (regardless of the number of intakes), which can be drawn from TGA100 power supply. It includes relay modules to drive the valves from the control signal provided by the TGA100. The relay driver modules include indicator lights and manual override switches for testing.

Control signals are provided directly from the TGA100 Trace Gas Analyzer. The TGA100 operating system includes a table editor to set the timing parameters, and it controls the valves, and computes and stores the mean concentration and the concentration slope (time derivative of concentration) at each intake. The concentration slope allows for correction of the error introduced by the multiplexing the intakes when the overall concentration is changing over time.

In the case where more than one trace gas species is to be measured, multiple analyzers and a multiple-analyzer sampling system are required. The 16-intake x 4 sampling system was designed to measure four-level profiles at four towers, one on each side of the flux source. The sampling system has four analyzer outlets to support four trace gas analyzers, each measuring a different species. The internal volume is 0.64 ml. This system is housed in a 17.5" x 19.6" x 9.0" enclosure that contains 32 three-way valves mounted on the manifold, two relay modules, a universal-input AC power supply, and manual valves for testing. One of the TGA100s attached to this system is designated as the master and the other three are designated slaves. The master TGA100 controls the sampling system, and computes and stores mean concentrations from all four analyzers.

PRESSURE DROPS

The small valves used in these sampling systems have an effective orifice of approximately 0.026" (0.66 mm), so the pressure drop in the valves limits the upper range of acceptable flow rates. In the single analyzer design, the air sample flows through one valve. In the multiple analyzer design, the air sample flows through two valves: one to select the intake line, and the other to select the analyzer outlet. Figure 1 shows the pressure at the inlet of the sampling system, as a function of flow rate, for the two designs. The outlet pressure was low enough to maintain sonic flow in the valves for these data. The inlet pressure varies from one valve to another by a range of approximately 5%, for the same flow rate, indicating some variability in the flow restriction of the valves.

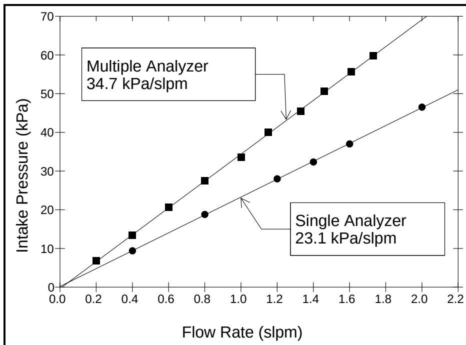

Figure 1. Pressure drop as a function of flow rate.

PRESSURE TRANSIENTS

In this sampling system design, the vacuum pump always receives the flow from all of the intakes. This tends to maintain a constant pressure at the analyzer even if the flow rate is slightly different for each intake. There will be pressure transients in the intake lines as they switch from the vacuum bypass to the analyzer, especially for multiple analyzer design. This is because the flow goes through two valves if selected, and one valve if bypassed. These pressure transients can be minimized by adjusting a needle valve between the vacuum manifold and the vacuum pump. For a flow rate of 0.575 slpm , the pressure at the sampling system inlets varied from 19.7 to 20.8 kPa due to the different flow restriction from one valve to another. The corresponding pressure transients in the TGA100 were less than 0.001 kPa.

EQUILIBRATION TIME

The small internal volume of the manifold has no noticeable effect on equilibration time. This was verified by connecting the odd-number intakes to a compressed nitrogen gas supply, and the even-number intakes to a compressed air supply. The TGA100 short sample cell, which has a volume of 30 ml, was used for this test. The

50% and 99% equilibration times were measured at flow rates from 0.06 to 0.98 actual liters per second, and were found to be as expected for the sample cell volume and the actual flow rate. There was no observable effect from the sampling system.

ZERO GRADIENT TESTS

Zero gradient tests have been run on the sampling systems to verify there were no biases in the concentration gradients. In a typical test of the 16-intake x 4 system, it cycled through all 16 intakes every 2 minutes, and the mean concentration and slope were computed every 30 minutes. The 16 intakes sampled room air at approximately the same position to provide a known zero-gradient. For each 30-minute period, the 16 means were corrected for slope, and averaged to get a mean of all intakes. This mean was subtracted from each of the individual intake means to give the gradient for each intake. Figure 2 shows the means and standard deviations of the 38 half-hour gradients. The standard deviations average 560 pptv. Dividing this by the square root of 38 samples gives the standard error of the mean, 90 pptv. The means are all within 168 pptv of zero (less than two sigma), demonstrating there are no statistically significant biases.

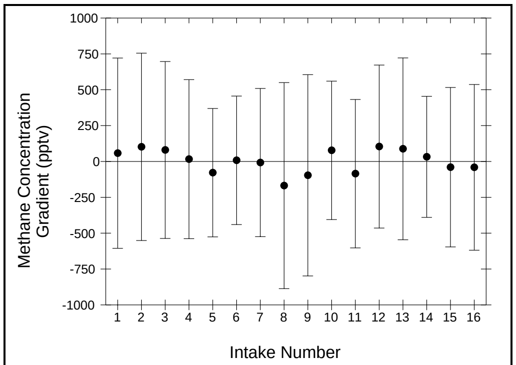

Figure 2. Gradient bias and resolution.

SUMMARY AND CONCLUSIONS

Designing sampling systems for multiple-intake trace gas analysis involves difficult tradeoffs. The design approach described here uses small, manifold-mounted valves to minimize equilibration time. It is well suited for applications where low flow rates are required because the vacuum pump capacity is split between many intakes or where high flow rates would disturb the ambient conditions, and where a small amount of leakage can be tolerated. Their mounting configuration enables them to be integrated into complex multiple-analyzer systems as well as single analyzer systems with an arbitrary number of intakes.