NBSIR 74-612

Building and Evaluation of a Second Polluted Air Delivery System

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Fluid Meters Section
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Final Report on PADS 2

Prepared for
Environmental Protection Agency
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Building and Evaluation of a
Second Polluted Air
Delivery System

ABSTRACT

The building and evaluation of a second configuration of a prototype SO_2 and CO polluted air delivery system (PADS) is discussed. The delivery system was built to deliver sulfur dioxide (SO_2) and carbon monoxide (CO) at a rate of 5 liters per minute. The design concentrations by volume were 1.0, 0.5, 0.1, and 0.04 parts per million (ppm) of SO_2 in air and 50, 20, and 2 parts per million of CO in nitrogen. It consists of a diluent air delivery system utilizing a critical flow sonic nozzle and three separate pollutant flow systems utilizing laminar flow porous plugs, one plug for each desired output concentration. The system is contained in a dispatch case and the gases are delivered to it from pressurized containers through detachable supply lines.

By maintaining specific upstream pressures on the critical flow nozzle and the laminar flow porous plugs, PADS 2 produced average output concentrations of; 0.95, 0.50, 0.117, and 0.057 ppm of SO_2; and 52.9 and 18.1 ppm of CO. These concentrations were determined by measurements with NBS calibrated analyzers. The expected output concentrations were 0.93, 0.52, 0.103, and 0.05 ppm of SO_2 and 51.2, 18.0, and 1.49 ppm of CO based on flow calibrations of the individual components. The uncertainty of the output concentration is estimated to be about 7 percent.

Polluted Air Delivery System 2

1. Introduction

This report covers the partial evaluation of a second flow configuration of a polluted air delivery system (PADS) designed to produce known concentrations of pollutants in air. The evaluation of the first PADS was covered in reference 1. The gas flow configuration of PADS 2 was designed to be symmetrical about a new gas mixing chamber constructed of Teflon as opposed to stainless steel in PADS 1. This change was to reduce the tube surface area to which the polluted mixture would be exposed. These changes were expected to, and did, improve equilibration time and reproducibility of performance.

2. The PADS

PADS 2 was designed to produce sulfur dioxide (SO_2) pollutant concentrations of 0.04, 0.1, and 1.0 parts per million by volume (ppm) in air. These concentrations were produced by mixing air containing an average initial concentration of 2240 ppm of SO_2 with pure air flowing at a rate of 5.0 liters per minute. PADS 2 was also designed to produce carbon monoxide, CO, pollutant concentrations of 2, 20, and 50 ppm in air. CO concentrations were produced by mixing nitrogen containing 42,100 ppm of CO with pure air flowing at a rate of 5.2 liters per minute.

The dilute mixtures were produced as follows. The diluent air flow of 5 liters per minute, Lpm, for SO_2 and 5.2 Lpm for CO, was metered with a critical flow nozzle having a throat diameter of 0.0396 cm. The nozzle was operated with an upstream pressure, P_1, of 38 and 40 psig, (2.62×10^5 and $2.76 \times 10^5 n/m^2$ gage) for SO_2 and CO respectively. The pollutant was metered through one of three porous plug laminar flow restrictors for any one of the desired output concentrations. The porous plugs were operated at upstream pressures of 13, 14.3, and 11.2 psig (8.96×10^4, 9.86×10^4, and 7.72×10^4 n/m^2 gage) for SO_2 and 12 psig(8.27×10^4 n/m^2 gage) for CO. Pollutant flow rates at these pressures are 0.11, 0.23, and 2.1 cubic centimeters per minute, cc/min, for SO_2 and 0.19, 2.2, and 6.4 cc/min for CO.

Figure 1 is a schematic of PADS 2. This piping configuration was chosen in order to shorten the flow path of pollutant gas between its flow restrictor and the mixing chamber. It was expected that this reduction of surface area in contact with the metered pollutant would reduce the amount of metered pollutant adsorbed. The mixing chamber and outlet manifold is the only part of the system that is made differently than in PADS 1. They are combined in a single piece of Teflon. Improved mixing and reduction of SO_2 adsorbed from the outlet mixture was also expected from this change.

A detailed explanation for choosing the devices and parts used in the PADS is covered on pages 1 and 2 of reference 1.

3. Evaluation of PADS 2

It was hoped that PADS 2 could be evaluated considering all of the performance characteristics as performed for PADS 1 and listed in reference 1, pages 2 and 3. However, due to inadequate time and resources, it was not possible to complete the program. A limited amount of data was obtained using the unit with both SO_2 and CO which will be the basis for the evaluation.

The purchased pollutant gases used in the tests, SO_2 and CO, and the SO_2 analyzer were calibrated by the Air Pollution Analysis Section, Analytical Chemistry Division of NBS. The SO_2 pollutant was analyzed twice by titration with standarized sodium hydroxide. On August 1, 1973, the concentration was 2230 ppm at a bottle pressure of 2000 pounds per square inch (psi) (1.379×10^7 n/m^2 gage) and on February 27, 1974, the concentration was 2250 ppm at a bottle pressure of 1300 psi. (8.963×10^6 n/m^2 gage). The CO pollutant was analyzed by comparison with two standards containing 3.95 and 4.06 percent of CO in Nitrogen. The analysis was made by gas chomatography which yielded a concentration of 4.21 percent. Both gas analyses have a relative uncertainty of 1 percent of concentration. The calibration of the SO_2 analyzer was performed by using air containing known amounts of SO_2, supplied by NBS standard reference material permeation tubes, and measured flows of air. The concentration indicated by the voltage output, not the visual dial, was within ± 2 percent full scale of the calibration values. The CO analyzer was a gas chromatograph, which was calibrated at least twice each day, whenever data was taken for PADS 2, with two standard samples of 8.29 and 50.1 ppm of CO in N_2.

Referring to Section 3.1 of reference 1, the characteristics evaluated are numbers 1 and 4, kinetic behavior (equilibration time) and reproducibility. The results for PADS 1 for the remaining performance characteristics, except factor number 3, would apply equally well to PADS 2.

1. The time required for PADS 2 to achieve an equilibrium state was 30 minutes or less for all concentrations with either pollutant. The time period for 95 percent of final concentration varied from 20 minutes down to one. The higher concentrations gave shorter equilibration times. An insert was installed in the mixing section, figure 2 and 3, to improve equilibration time and mixing efficiency. Although it did not shorten the equilibration time for PADS 2, it did improve the uniformity of concentration across the outlet flow.

4. Reproducibility was based on the standard deviation of the constant K, (equation 3, in reference 1) as determined from the measurements, where

$$K = \frac{C_1}{C} \quad \frac{P_2(1+P_2/2B)}{P_1+B}$$

and C_1 is the known inlet concentration of SO_2 in air supplied to the porous plugs, ppm.

C is the output concentration of the system, ppm.

P_1 is the inlet gage pressure for the critical nozzle in psig.

P_2 is the inlet gage pressure for the porous plugs in psig.

B is the barometric pressure in psia.

These values for the constant K apply only at the conditions which existed during evaluation at NBS. Any other evaluation of the unit at different conditions would need different values of K derived by application of equation 1 page 3 of reference 1. The average barometric pressure during evaluation of PADS 2 was 14.55 ± 0.02 psia ($1.003 \times 10^5 \pm 138$ n/m^2) and the temperature was 24.9 ± 2.2°C. Barometric pressures and temperatures for each concentration are included in table 1. The gages used for measuring P_1 and P_2 were calibrated and are accurate within the readability of the gage. The pressures used and mentioned in this report were in a range where no correction to the readings was necessary.

For the desired output concentrations of 0.04, 0.1, and 1.0 ppm of SO_2 the value of K is 14000, 7770, and 693 with actual output concentrations of 0.057, 0.117, and 0.95 ppm. The estimate of standard deviation, S, for each of these K values is ± 3.3, ± 3.9, and ± 0.8 percent, of K, respectively. An extra concentration and K value was determined by operating the highest concentration porous plug flow restrictor at 1/2 of the original pressure. The desired concentration was 0.5 ppm and it had K and S values of 647 and ± 0.7 percent of K and the actual concentration was 0.50.

For the desired output concentrations of 2, 20 and 50 ppm of CO, the values of K and S are; 8685 ± 0.3 percent of K, 723 ± 4.6 percent of K, and 247 ± 2.9 percent of K. The value of K at the lowest concentration is based on flow calibrations of the porous plug and nozzle because a standard sample of low CO concentration was not available at the time the tests were run for calibration of the CO analyzer.

A comparison can be made between the resulting output concentration chemically measured and the expected output concentration based on relative flow rates through the porous plugs and nozzle as determined by flow calibrations and equation 2, page 4 of reference 1. The average output concentrations of SO_2, measured chemically, were 0.95, 0.50, 0.117, and 0.057 ppm, compared to expected concentrations of 0.93, 0.52, 0.103, and 0.050 ppm. The average output concentrations of CO were 53 and 18 ppm, compared to expected outputs of 51 and 18 ppm. All of the evaluation results are presented in table 1. The results are the averages of from four to ten separate tests.

4. Conclusions

The changes in the design of the PADS did make an improvement. Improvement in equilibration time appears at the highest and lowest concentrations of SO_2 in air. The time required to attain 95 percent of the equilibration value reduced from 4 minutes to 1 minute at 1 ppm and from 25 to 11 minutes at the lowest concentration. Of course the lowest concentrations are not the same for both PADS. The low concentration in PADS 2 was designed to be higher than in PADS 1 to improve total performance.

Comparing the standard deviations of the value K for PADS 1 and 2 indicates a marked improvement for PADS 2: from ± 4.4 percent to ± 0.8 percent at 1 ppm; ± 4.6 percent to ± 0.7 percent at 0.1 ppm; and from ± 61 percent to ± 3.3 percent at the lowest concentration. Comparing the output concentration obtained with expected output concentration gives an average uncertainty of about 7 percent.

No comparisons can be made for CO, since PADS 1 was not used with CO.

5. Reference 1

Building and Evaluation of a Polluted Air Delivery System, NBSIR 73-414, April 1974.

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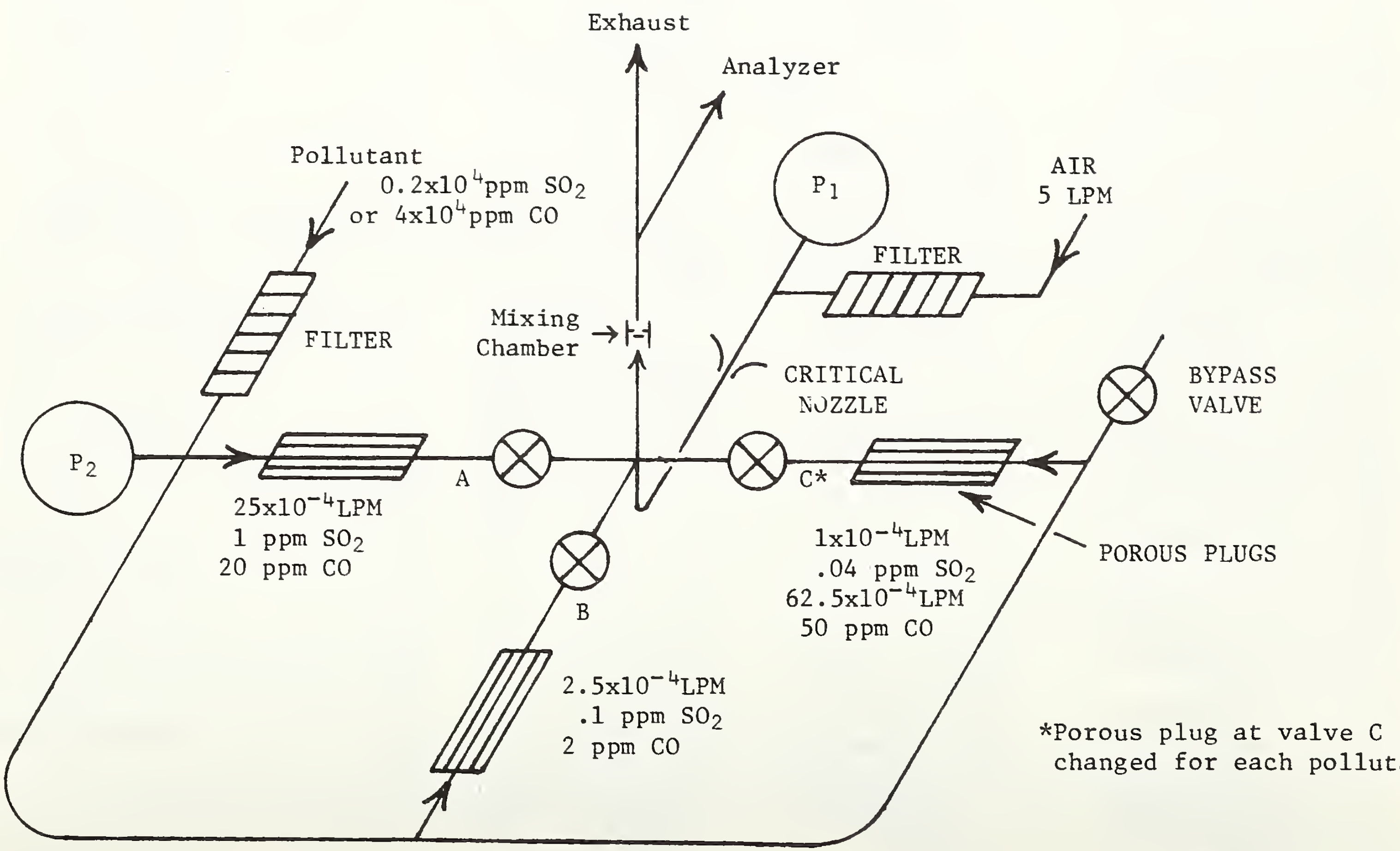
Evaluation Results

	Valve A	Valve B	Valve C***
	SO_2: 1.0 ppm CO : 20 ppm	0.1 ppm 2 ppm	0.04 ppm 50 ppm
Kinetic behavior			
SO_2: 95% of Equilibration time	less than 1 min	11 min ± 7	11 min ± 9
CO : 95% of Equilibration time Estimated	5 min or less	5 min or less	5 min or less
Reproducibility			
SO_2: Value of K ±1S* in percent	693 ± 0.8 647 ± 0.7	7770 ± 0.7	14000 ± 3.3
Avg. Output Conc. @P_1+P_2	0.95 ppm @38 and 11.2 psig 0.50 @38 and 6.2 psig	0.117 ppm @38 and 14.3 psig	0.057 ppm @38 and 13 psig
Expected Output conc. at same pressures	0.93 ppm 0.52 ppm	0.103 ppm	0.050 ppm
Avg. barometric pressure and temp. in laboratory at time of test	14.54 psia and 26.7°C	14.52 psia and 26.8°C	14.53 psia and 26.6°C
CO: Value of K ±1S in percent	723 ± 4.6	8685 ± 0.3**	247 ± 2.9
Avg. output Conc. @P_1+P_2	18.1 ppm @40 and 12 psig		52.9 ppm @40 and 12 psig
Expected output conc. at same pressures	18.0 ppm	1.49 ppm	51.2 ppm
Avg. barometer and temp. in laboratory at time of test	14.56 psia and 22.6°C	14.57 psia and 22.6°C	14.57 psia and 22.4°C

* Estimate of standard deviation
** K and S, for valve B and CO, determined from flow data as discussed on page 5.
*** The porous plug at valve C is changed for each pollutant.

Table 1

PADS 2 FLOW SCHEMATIC



*Porous plug at valve C is changed for each pollutant

Figure 1

MIXING CHAMBER SHOWING INSERT, POLLUTANT CONNECTOR,
AND CRITICAL NOZZLE POSITIONS

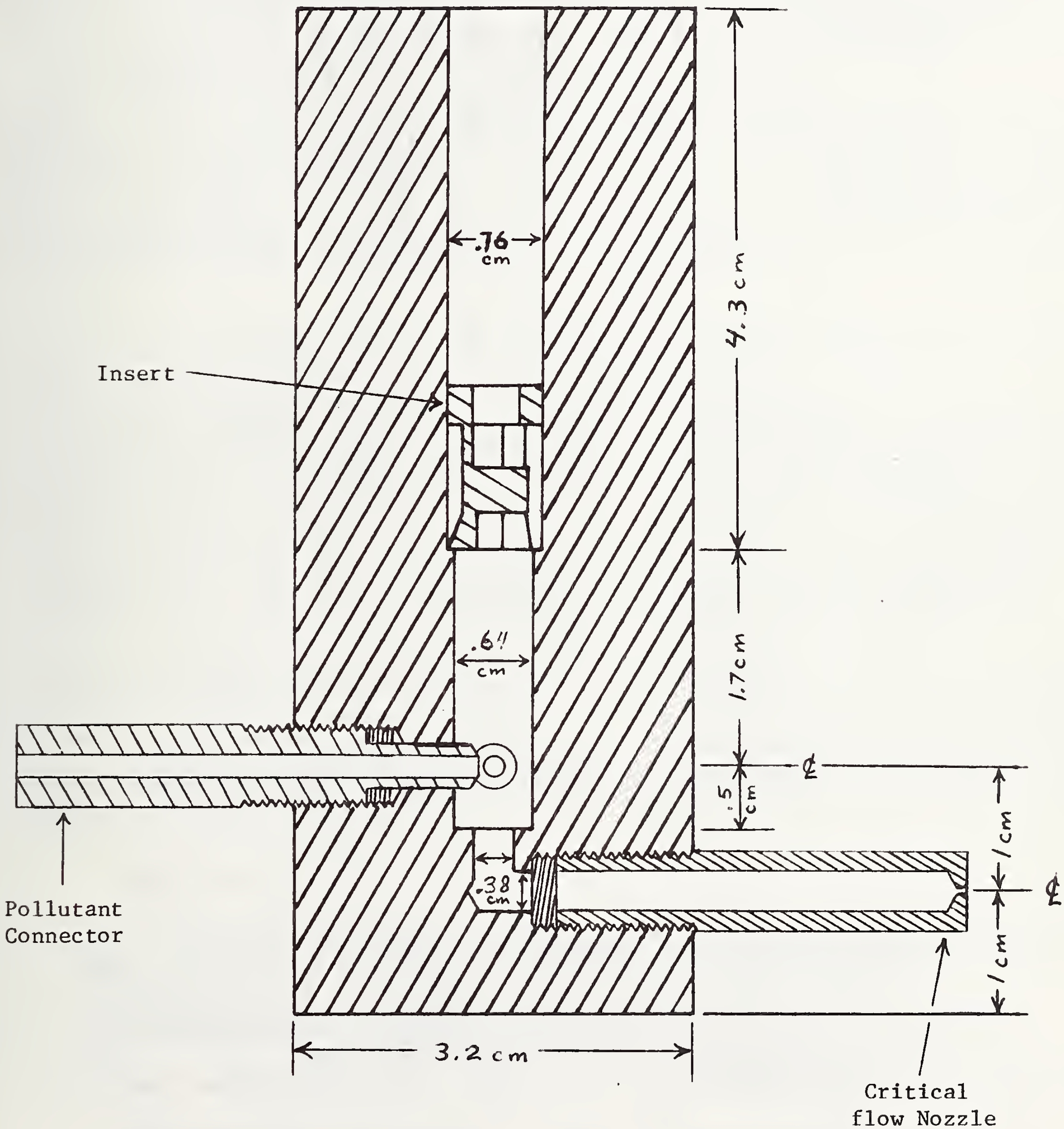


Figure 2

TEFLON INSERT INTO MIXING CHAMBER

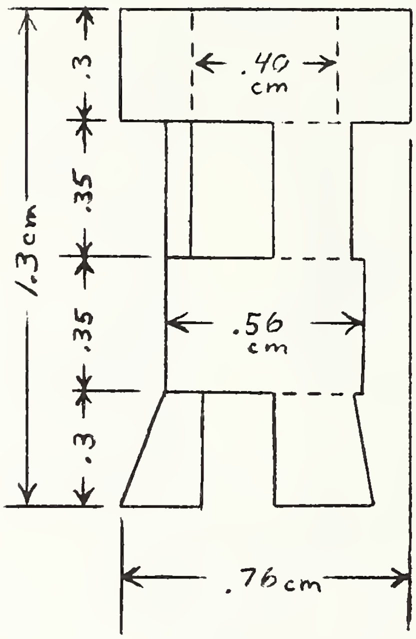


Figure 3

TEFLON POLLUTANT CONNECTOR-VALVE TO MIXING CHAMBER

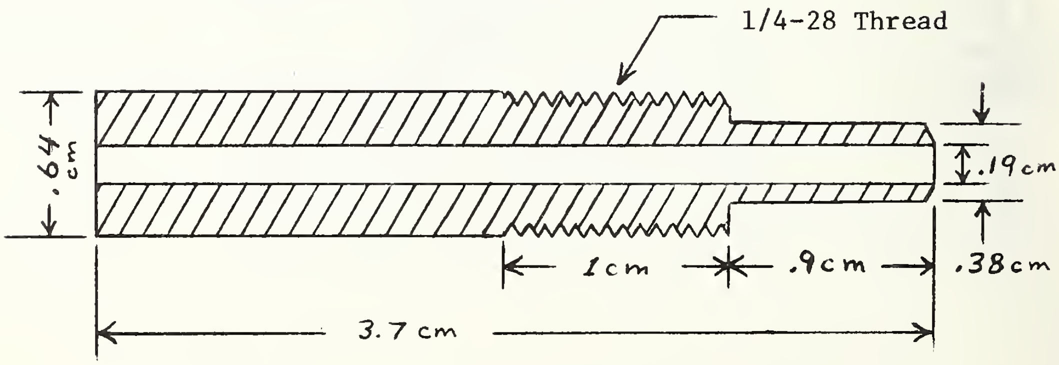


Figure 4

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The building and evaluation of a second configuration of a prototype SO_2 and CO polluted air delivery system (PADS) is discussed. The delivery system was built to deliver sulfur dioxide (SO_2) and carbon monoxide (CO) at a rate of 5 liters per minute. The design concentrations by volume were 1.0, 0.5, 0.1, and 0.04 parts per million (ppm) of SO_2 in air and 50, 20, and 2 parts per million of CO in nitrogen. It consists of a diluent air delivery system utilizing a critical flow sonic nozzle and three separate pollutant flow systems utilizing laminar flow porous plugs, one plug for each desired output concentration. The system is contained in a dispatch case and the gases are delivered to it from pressurized containers through detachable supply lines.

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17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Air pollution; critical flow; laminar flow; nozzle; porous plug; sulfur dioxide concentration; carbon dioxide concentration.

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