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Model 400 Nitric Oxide Monitor™

The Model 400 Nitric Oxide Monitor™ is designed for the measurement of atmospheric nitric oxide (NO) in the range of 2-2000 ppbv (2 ppmv). In combination with the Model 401 NO_2 Converter, NO_x and NO_2 (by difference) are also measured. The Model 400 shares many of the unique features of the Model 202 Ozone Monitor, including:

- Small size – 3.5 in. x 8.3 in. x 11.6 in. (9 cm x 21 cm x 30 cm)
- Lightweight – 6.4 lb. (2.9 kg)
- Low power – operates on 12V DC, 11 W
- Precision – 2 ppbv or 3%
- Calibration – no cal gas required; annual calibration

2B Technologies has been able to achieve these significant advances as a result of the new NOzone™ technology. This patented technology builds on 2B's ozone measurement expertise and eliminates many of the problems associated with the more familiar chemiluminescence method for NO.

Theory of Operation

The NOzone™ technology employed by the Model 400 Nitric Oxide Monitor™ is based on the quantitative reaction of nitric oxide (NO) with ozone (O_3):

$NO + O_3 \rightarrow NO_2 + O_2 + \text{light}$ (1)

This reaction has long been used as a gas phase titration for the measurement of either NO or O_3 in laboratory kinetics experiments, and the reaction is stoichiometric; i.e., one O_3 molecule is consumed for every NO molecule oxidized to NO_2 in the reaction. In the Model 400 Nitric Oxide Monitor™, a small concentration of ozone (~4 ppm) is added to the gas sample stream and the resulting decrease in concentration of ozone is measured by the absolute method of UV absorption. By providing adequate time for the reaction to go to completion, the decrease in ozone concentration is equal to the original concentration of NO in the gas stream.

Reaction 1 also is used in conventional chemiluminescence analyzers. Instead of measuring the change in ozone concentration, chemiluminescence detects the small amount of light produced in the reaction. That light is emitted by electronically excited NO_2 molecules formed in reaction 1. Chemiluminescence instruments are highly sensitive and have a very fast response time, but require frequent calibration using a gas standard.

Figure 1 is a schematic diagram of the Nitric Oxide Monitor. Here we trace the gas flow through the instrument beginning at the Air Inlet near the bottom of the diagram.

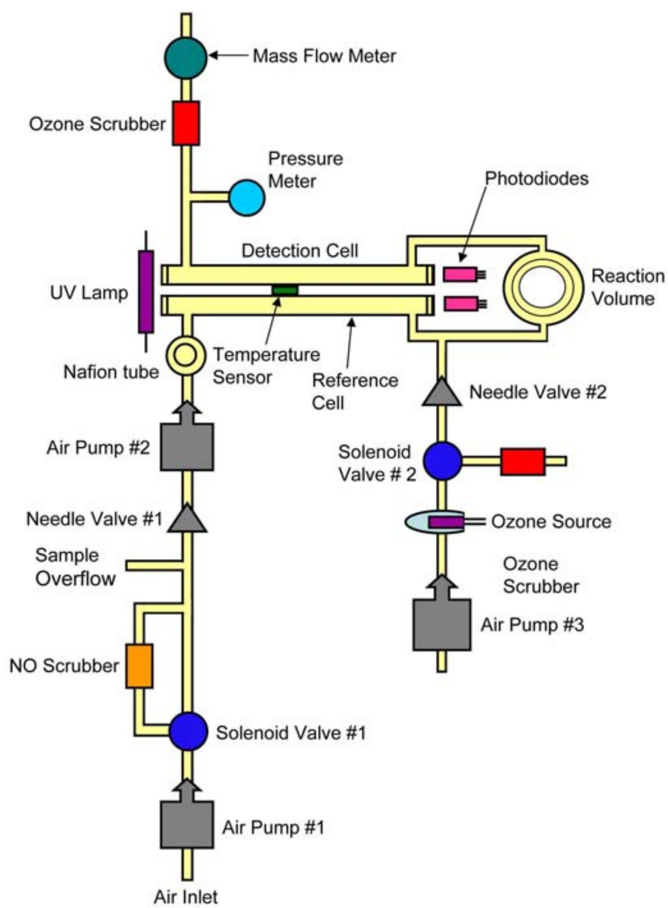

Figure 1. Schematic diagram of the Nitric Oxide Monitor.

A miniature air pump, Air Pump #1, draws sample air into the instrument at a flow rate of 0.8-1.2 L/min. The gas sample then passes through a miniature solenoid valve which alternately directs the flow through a NO scrubber or bypass and then into an overflow tee which vents part of the air sample. A fraction of the sample air is drawn from the overflow tee by Air Pump #2, which pumps the scrubbed or unscrubbed sample air through a Nafion tube and into the reference absorption cell. The Nafion tube equilibrates the humidity of the sample air with that inside the instrument case, assuring that the humidity is the same in scrubbed and unscrubbed air samples. In the Reference Cell, UV light intensity, I_{ref}, is measured at 254 nm using a low pressure mercury lamp and photodiode. The purpose of the reference cell is to correct for ambient ozone and fluctuations in the lamp intensity. Needle Valve #1 is used to adjust the flow through the reference cell in the range 550 to 650 cc/min. Following Air Pump #2, a small flow of ozonized air is added to the sample air stream. The flow rate of ozone/air is regulated by Needle Valve #2, and is set to produce an ozone concentration in the range of 3-5 ppm (3,000-5,000 ppb). This flow constitutes typically 3-5% of the total flow rate.

The sample air containing added ozone next passes through a coiled reactor, which provides adequate reaction time (typically 3.5-4.5 s) for nearly all NO in the sample to react with ozone via reaction 3 above. Correction is made in the software for lack of complete reaction. That correction is typically less than 3%. The sample air, now depleted in ozone by the amount of NO originally present in the air sample, next passes through the Detection Cell where UV light intensity is again measured. From there the air stream passes through an Ozone Scrubber where O_3 is catalytically converted to O_2, through a Mass Flow Meter where the flow rate is measured, and to the instrument case.

Ozone is produced by pumping ambient air through a Pyrex tube containing a low pressure mercury lamp. The lamp has a fused silica window that passes highly energetic atomic emission near 185 nm in addition to the resonant emission at 254-nm. The wavelengths near 185-nm are absorbed by molecular oxygen (O_2) to produce oxygen atoms (O). Those oxygen atoms rapidly attach to O_2 via a termolecular reaction to form O_3:

$$O_2 + h\nu \rightarrow 2\,O \qquad (2)$$

$$O + O_2 + M \rightarrow O_3 + M \qquad (3)$$

Here, $h\nu$ indicates a photon of light having a wavelength near 185 nm, and M is any molecule, principally N_2, O_2, Ar and H_2O in air. The molecule M catalyzes the combination of O and O_2 by removing excess relative translational energy. The flow rate of ozone/air and thus the ozone concentration is controlled by needle valve #2. Flow rates and the actual ozone concentration produced are measured in a cycle at the beginning of an analysis by modulating solenoid valve #2. This valve either allows the ozone/air mixture to enter the stream of gas being analyzed or diverts it to an ozone scrubber.

NO is measured by modulating solenoid valve #1. A low-pressure mercury lamp is located on one side of the absorption cells, and photodiodes are located on the opposite side. The photodiodes have built-in interference filters centered on 254 nm, the principal wavelength of light emitted by the mercury lamp. Shorter wavelengths of light that could produce ozone are absorbed by the low-grade quartz envelope of the lamp itself and by the window of the detection cell, which passes 254-nm but not 185-nm light. The state of Solenoid Valves #1 is switched every 10 seconds in order to measure light intensities for sample air, I_{ref} and I, and scrubbed sample air, $I_{ref,o}$ and I_o. The values of I_{ref}, I, $I_{ref,o}$, and I_o are used to calculate the concentration of NO in the original air sample. In addition to a small correction for incomplete reaction, a correction is made for the small amount of dilution of the NO concentration by the added ozonized air.

Specifications

Measurement Principle	Titration of NO with Ozone with Detection of Ozone Depletion by UV Absorption at 254 nm
Outputs	RS-232, Flash Card Option
Precision and Accuracy	Higher of 2 ppbv or 3% of reading
Data Storage	14,336 lines (10 s avg. = 1.4 days; 5 min avg = 1.4 mo.)
Time/Measurement	10 s (Data averaging options: 10 s, 1 min, 5 min, 1 hr)
Sample Flow Rate	1 L/min
Data Outputs	RS-232, LCD, Flash Card Option
Power Requirements	12 V dc or 120/240 V ac, 11 watt
Size	3.5 x 8.3 x 11.6 in. (9 x 21 x 30 cm)
Weight	6.4 lb. (2.9 kg)