UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Office of Research and Development
Reference and Equivalent Methods Designation Program
109 T.W. Alexander Dr., Research Triangle Park, NC 27711

To: Regions, State and Local Agencies

From: Robert Vanderpool, EPA – ORD Reference and Equivalent Methods Designation Program
Joann Rice, EPA - OAQPS Ambient Air Monitoring Group
Mike Papp, EPA - OAQPS Ambient Air Monitoring Group

Subject: Clarification Regarding Flow Rate Measurement in the Teledyne T400 Ozone Analyzer

Background

On Sept. 12, 2002, EPA formally approved the Teledyne T400 analyzer as a Federal Equivalent Method (67 FR 57811) for ozone NAAQS determinations. As part of the analyzer's original designation description, the instrument's sample flow rate was specified as "800 +/-80 cm^3/min (sea level)". The common interpretation of this operational description is that externally audited flow rates of the T400 must be converted to standard temperature and pressure conditions (i.e., mass flow rate) rather than reported at actual temperature and pressure conditions (i.e., volumetric flow rate).

While the T400 routinely maintains mass flow rate of 800 cm^3/min within the stated +/-10% flow rate tolerances at low altitudes, users operating the T400 under high altitude conditions have occasionally reported that the audited flow rates of the instrument sometimes drop below the specified minimum 720 cm^3/min when the flow rate is reported at standard conditions (i.e., sea level). Under these conditions, users also note that the flow rate displayed by the T400 similarly drops below the minimum 720 cm^3/min value. Therefore, EPA has received inquiries from these instrument users questioning the validity of ozone compliance data collected with the T400 analyzer when the instrument operates under these conditions. In particular, these questions included:

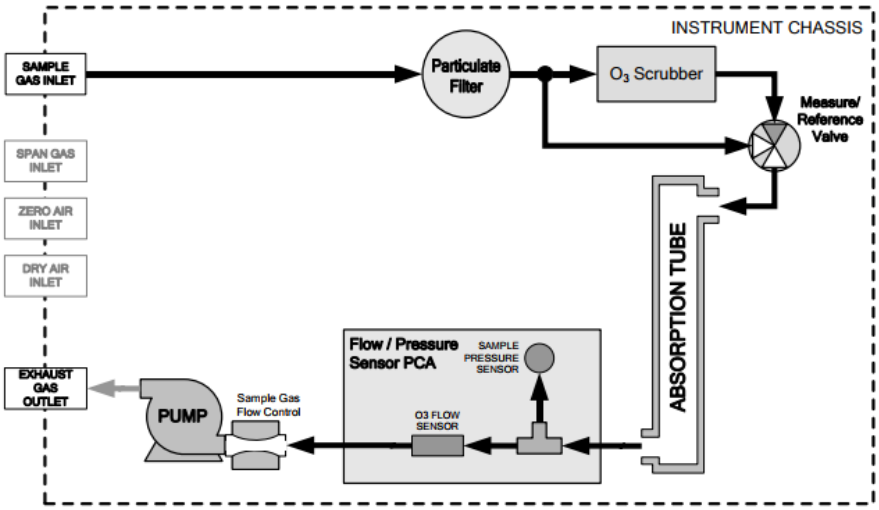
1) How should the T400's original designation description's "800 +/- 80 cm^3/min (sea level)" flow rate be interpreted? Is this flow rate specification technically accurate or should it be corrected?
2) Does the T400 maintain a near constant volumetric flow rate with altitude?
3) If the audited flow rate (corrected to sea level conditions) is observed to be less than the specified minimum of 720 cm^3/min, should data in a NAAQS network be flagged or invalidated due to uncertainties in the T400's ozone measurement accuracy?

The purpose of this document is to clarify the mechanics of flow control in the Teledyne T400 ozone analyzer and to provide clarification regarding proper interpretation of the "sea level" specification in the analyzer's original designation description. This Technical Note will also summarize the results of recent laboratory tests conducted by Teledyne to determine if the T400 properly maintains its design flow rate under high altitude conditions and whether measured ozone concentrations are valid during the instrument's high-altitude operation. This Technical Note will also

describe a recent change to the T400's designation description to clarify the instrument's flow rate specification and how externally audited flow rates should be referenced.

Flow Control in the T400 Ozone Analyzer

Below is a pneumatic diagram which illustrates the T400's primary flow components. In the T400, flow rate is controlled through use of a critical flow orifice, labeled "Sample Gas Flow Control" in the diagram. Sonic conditions in the critical orifice is established by maintaining a pressure downstream of the orifice less than 53% of the upstream pressure. Because sonic velocity through a critical orifice is virtually independent of air pressure, the critical orifice maintains a near constant volumetric flow rate through the instrument. However, because the density of the sampled air decreases with increasing altitude, this constant volumetric flow rate results in a corresponding decrease in the air's mass flow rate. This behavior thus directly accounts for the user's high-altitude observations with the T400 when converting audited measured flow rates to sea level conditions.



The diagram also depicts an "O3 flow sensor" which is located immediately upstream of the T400's critical orifice. It is important to note that this component is a mass flow *sensor* rather than a mass flow *controller*, and thus in no way controls or influences the flow rate through the system. As previously mentioned, flow rate through the T400 is controlled solely by the system's critical orifice. The only purpose of the mass flow sensor is to monitor system flow rate to ensure that the unit's absorption tube is thoroughly purged of ozone during the continuous zero and measurement gas cycles.

Based on the T400's design, Teledyne has contended that the instrument maintains near constant volumetric flow rate through the system, as is intended. Further, Teledyne has also stated that the T400 should provide accurate ozone measurements if the volumetric flow rate is maintained within 800 +/- 80 cm^3/min.

To help clarify these issues, Teledyne recently conducted a series of tests with the T400 under laboratory conditions designed to simulate operation at different altitudes above sea level. Using a needle valve upstream of a calibrated T400 to vary inlet pressure, flow rate tests of the T400 were conducted at pressures of 691, 638, and 584 mm Hg, corresponding to simulated use of the instrument at elevations of approximately 800, 1446, and 2150 feet above sea level, respectively. As presented in Table 1 below, the volumetric flow rate immediately upstream of the instrument was observed to

decrease only slightly with increasing simulated altitude. All three volumetric flow rate measurements were well within the 800 +/- 80 cm^3/min flow rate specification.

Table 1. T400 Simulated Altitude Flow Rate Tests			
T400 Sample Pressure (mm Hg)	Approx. Altitude (feet)	T400 Displayed Mass Flow Rate (std cc/min)	BIOS Volumetric Flow Rate (cc/min)
691	800	813	806.3
638	1450	735	804.4
584	2200	682	794.7

Using a Teledyne T700 dynamic dilution calibrator to provide known concentrations of ozone, Teledyne then conducted laboratory tests of the T400 at the three simulated altitudes. As shown in the below Table 2, the measurement accuracy of the T400 at span concentrations of 100, 400, and 700 ppb was unaffected by decreasing air pressure.

Table 2. T400 Simulated Altitude Ozone Span Test				
T400 Sample Pressure (mm Hg)	Approx. Altitude (feet)	T400 O_3 @100 ppb Span	T400 O_3 @200 ppb Span	T400 O_3 @700 ppb Span
696	800	99.5	200.1	700.9
635	1450	97.6	197.6	699.8
584	2200	99.2	200.0	700.7

As a result of the design considerations of the T400 and the laboratory test results provided by Teledyne, it is EPA's determination that the "800 +/- 80 cm^3/min (sea level)" specification in the original designation description is technically inaccurate. Instead, the flow rate specification should be clarified to indicate that external audit flows should be measured volumetrically, rather than at "sea level" conditions. As a result, EPA recently modified the T400's designation description to read "800 +/- 80 cm^3/min (measured volumetrically at actual T & P conditions)". This update was posted on AMTIC's website on December 15, 2017: https://www.epa.gov/amtic/air-monitoring-methods-criteria-pollutants

Based on these test results, modified the T400's firmware to display the ozone sensor's measured flow rate on a volumetric basis, rather than on a mass flow basis as is currently the case. Although external flow rate auditing of the T400 will still be periodically required, this displayed volumetric flow rate measurement should provide the user some assurance that the unit is operating within its design volumetric flow rate of 800 +/- 80 cm^3/min, as measured volumetrically at actual temperature and pressure conditions.

Summary

1. Based on a review of the T400's technical design and the results of recent tests conducted by Teledyne, the instrument's flow rate specification of "800 +/- 80 cm^3/min (sea level)" in the original designation description is technically incorrect. The AMTIC "List of Designated Reference and Equivalent Methods" was updated in December 2017 to specify the flow rate as "800 +/- 80 cm^3/min (measured volumetrically at actual T & P conditions)".

2. Teledyne's laboratory tests show that the T400 should be capable of maintaining volumetric flow rate within the required specifications when tested at elevations above sea level. If the minimum flow rate of 720 cm^3/min cannot be achieved, users are encouraged to conduct troubleshooting of the instrument to identify possible sources of the low volumetric flow rate. These sources could include insufficient pump vacuum, a plugged critical orifice, and/or system flow leaks. If the insufficient flow rate problem is unresolved using methods detailed in the instrument's Operating Manual, the user should contact Teledyne-API Technical Support for assistance. In instances where the T400 is operated at extreme altitudes and the troubleshooting procedures are not fully effective, Teledyne may provide users with a slightly larger critical orifice than currently exists in the instrument.

3. In April 2018, Teledyne revised the T400's firmware so that flow rate displayed by the instrument is reported volumetrically at actual temperature and pressure, rather than at standard temperature and pressure, as was previously the case. Users interested in obtaining the updated firmware after this date should contact Teledyne-API Technical Support for assistance.

4. Laboratory tests conducted by Teledyne at ozone concentrations of 100, 400, and 700 ppb indicated that the T400's ozone measurement accuracy is not adversely affected during operation of the instrument above sea level at simulated elevations up to 2200 feet. As long as the instrument is capable of maintaining the specified volumetric flow rate at higher elevations, the accuracy of the T400's ozone measurement should not be adversely affected.