1. Introduction and Scope

The Tapered Element Oscillating Microbalance (TEOM) provides real time mass measurement of selected size particles in ambient air samples. This instrument is used in national and local air monitoring networks to provide continuous data on the mass concentrations of particulate matter (PM) of 10µm aerodynamic diameter and less (PM10) or 2.5µm aerodynamic diameter and less (PM2.5) in ground level ambient air.

The procedure described in this document is for the operation of TEOM samplers reporting data to the NAPS and AENV network.

The operating manual supplied by the instrument manufacturer (R&P part no. 42-003347 & 42-010978) provides detailed installation and operating procedures. Those procedures are part of this operating method.

2. Principle of the Method

This method is a continuous mass measurement of PM present in ambient air. Air is drawn through a size-selective inlet at the rate of 16.67 lpm. The air sample is split with 13.67 lpm discarded and the remaining 3 lpm is directed down a tube onto a sample filter. The sample filter is attached to a hollow tapered glass tube through which the air is drawn. The tapered tube is maintained in a fixed amplitude oscillating motion. When particles are deposited and accumulated on this sample filter, the oscillating frequency of the tapered tube/filter system decreases due to the mass increase of the filter. The oscillating frequency is measured by an electronic counter. A direct analytical relation between the mass of the tube/filter system and its oscillation frequency is calculated by solving the equation of motion for the oscillator system. This calculation is done by the instrument every 2 seconds. Therefore the mass of particles collected on the filter is continuously measured. Typical averaging periods for the instrument are 5 minutes, 10 minutes, half-hour, one hour, and 24-hours.

3. Measurement Range and Sensitivity

The manufacturer states that the minimum detectable limit for the mass transducer is 0.01 µg. Rupprecht & Patashnick, (later Thermo Environmental) the TEOM manufacturer, further states that the microbalance mechanism has an operational range of up to five grams per cubic meter.

4. Equipment and Apparatus

The following models are used in this method.

- Rupprecht & Patashnick (R&P) TEOM Series 1400/1400a including serial number prefixes 1400, 140A, 140AA, 140AB, 140AT, and 140UP.
- R&P TEOM 1400a including serial number prefixes 140AB, 140AT, and 140UP used with Sample Equilibrium Systems (SES).
- R&P TEOM 1400a including serial number prefixes 140AB used with the Filter Dynamics Measurement System (FDMS).
- THERMO TEOM 1405-F with the Filter Dynamics Measurement System(FDMS)

5. Interferences

Volatile Losses

Normal operation of the TEOM requires that the filter be heated (50°C) to maintain operational stability. This heating causes losses of volatile material collected on the filter and introduces a negative interference to the measurement. This may result in the mass of the tube/filter system to decrease, and the instrument to report a negative mass concentration. These situations occur most commonly after the sampled air mass changes from high to low humidity due to the evaporation of particle bound water off the filter. Negative mass readings are also caused by the initial collection, followed by evaporative loss of semi-volatile species such as ammonium nitrate. To minimize this effect the TEOMs in Canada are normally operated at a filter temperature of 40°C. When local conditions causing this problem can not be resolved with this lowered operating temperature, the optional Sample Equilibration System (SES) or Filter Dynamics Measurement System (FDMS) may be used.

The TEOM monitor with the SES dryer uses a Nafion membrane on the sample inlet to reduce the humidity in the sample stream. This TEOM configuration can be operated with sensor temperatures set at 30°C. Even at this temperature, there may be a significant temperature difference between ambient and sensor temperatures. This would still cause significant mass loss if the particles are mainly composed of volatile material. Another option of the TEOM monitor is the Filter Dynamics Measurement System (FDMS). The TEOM monitor with FDMS uses the TEOM in a switched or differential mode, in which the filter is cyclically exposed to sample air with particles followed by particle free or filtered air. The purpose of the differential measurement is to correct for these interferences by directly measuring and accounting for the influence of condensed and evaporated gases and volatile aerosols. In this way, both non-volatile and volatile aerosol components are quantified, as long as the ambient aerosol composition changes slowly compared to the differential switching time.

Temperature Sensitivity

The mass sensor is sensitive to fluctuations in temperature and must be heated and maintained to within 0.1°C. The TEOM monitor uses three separate temperature controlled subsystems for its thermal stabilization. The air sample tube leading to the filter/sensor is temperature controlled to ± 0.5°C designated as Tair (designated as Air Tube Temp in the 1405-F model). The mass transducer assembly is designated as Tcase and the metal block above the sensor connecting the air sample tube to the case is designated Tcap. Tcase and Tcap are controlled to ± 0.1°C (designated as Case Temp and Cap Temp in the 1405- F model).

For the TEOM units in Canada the set points for these temperatures are 40°C ***without*** the SES dryer and 30°C for those ***with*** the SES dryer or FDMS unit (see table 1 in SUI-004b for the TEOM 8500 and SUI 004c for the TEOM 1405).

Inlet and Sample Tube Losses

The particle size-selective inlets have a stable cut-point as long as they are routinely maintained and remain free of significant particle accumulation. Inlets that become dirty may allow particle re-entrainment or bounce, leading to an inaccurate measurement of the actual PM concentration. Many inlets show a shift in cut point when they are dirty, which would lead to incorrect measurement of the actual PM concentration. Due to the high temporal resolution of the TEOM monitor, any unusual loading within the inlet will have a detrimental effect on data quality.

Excessive particle build up on the inner walls of the down tube can affect PM concentration measurements.

System Leaks

Air leaks in the sample system can affect the measured PM concentrations. The TEOM monitor must pass the leak check as described in the manual to produce valid data. The leakage rate for the main flow (3.0 lpm) must be less than 0.15 lpm and 0.65 lpm for the auxiliary flow (13.7 lpm).

6. PRECISION AND ACCURACY

The performance of the TEOM is dependent on particle composition. This is in turn influenced by site location and temporal events that impact on the site.

Accuracy

The performance of the TEOM for PM10 measurement has been approved by the United States Environmental Protection Agency (USEPA) as an equivalent method indicating that the accuracy is within 10% (References 1 and 2).

For PM2.5 measurements the USEPA has tested the system in two field sites and compared the 24 hour average data of the TEOM to the 24 hour data of the US federal reference method (FRM) under the Environmental Technology Verification Program. For TEOM without the SES dryer the comparison showed a slope in the range of 0.459 to 0.964 with intercepts in the range of -1.10 to 2.21µg/m3. For TEOM with the SES dryer the comparison showed a slope in the range of 0.927 to 0.978 and intercept of -18.4 to 4.95µg/m3, (Reference 1 and 2).

Precision

The performance of the TEOM for PM10 measurement has been approved by the USEPA as an equivalent method indicating that the accuracy is within 10%. (Reference 1 and 2)

The precision performance of the TEOM for PM2.5 was investigated by the USEPA under the Environmental Technology Verification Program as above. In this program the inter unit precision of the TEOM and TEOM-SES monitors was tested in two locations where the aerosol composition was different. For the TEOM without SES, the results indicated coefficient of variation (CV) in the range of 12.1% to 22.5% for one hour average data. For 24 hour average data the CV is in the range of 3.2% to 9%. (Reference 1 and 2)

For TEOM with SES dryer, the CV is in the range of 9.3% to 23.2% for one hour average data. For 24 hour average data the CV is in the range of 1.8% to 4.3%, (Reference 1 and 2).

The manufacturer states that in mass determination, at a flow rate of 3 lpm, the instrument has a precision of ±1.5 µg/m^3 (1-hour average) and ±0.5 µg/m^3 (24-hour average). These precision values represent one standard deviation. Therefore the expanded uncertainty values at two standard deviations are ±3.0 µg/m^3 (1-hour average) and ±1.0 µg/m^3 (24-hour average). (Reference 1 and 2)

7. INSTALLATION REQUIREMENTS

The installation procedures of the TEOM are detailed in the R&P Operating Manual. All the steps outlined therein must be followed closely. In particular, attention should be given to locating the system so as to minimize potential rapid fluctuations in room temperature. In addition, the system should be installed so as to minimize physical vibration.

Probe Location Criteria

The location of the TEOM inlet must conform to the probe location criteria below.

Height above ground	2 to 15 metres
Distance from support structure	> 2 meters
Distance from trees	> 20 metres or twice the height of tree above the inlet whichever is greater.
Distance from any air flow obstacle, i.e. buildings	> 2×height of obstacle above the inlet
Airflow Restrictions	unrestricted in at least 3 of the 4 wind quadrants
Local Source Influences	Local source influences must be considered in locating the site for ambient PM10 or PM2.5 monitoring.

Mechanical Vibration

The operating principle of the instrument is based on the changing vibrating frequency of the sensor of the instrument. Extraneous mechanical vibration interferes strongly with the measurement capability of the instrument. Usually this problem manifests itself in the form of high noise level or unusually large fluctuations in mass concentration.

Logger Configurations

The FDMS averaging channel for "Total Mass" is completely different from the 1400A standard averaging channel. Averaging is now a 1 hour rolling average with 6-minute updates. For programming the ESC 8816/8832 data logger, follow the procedure in Technical Memorandum on R&P Series 8500 dated January 8 2004 from Rupprecht and Patashnick Co Inc. *Note: R&P were the initial manufacturers of the TEOM*

Temperature Stability

Temperature fluctuations in the air sample should not influence the performance of the instrument. However if the sensor and control units are placed in close proximity to air conditioning units and/or heating sources, the temperature control of the instrument may not be able to compensate rapidly enough to maintain the temperature stability of the sensor unit. The flow sensor in the control unit may also be affected by rapid fluctuations in temperature. These problems may be manifested as noise or baseline drifts in the data output.

The model 8500 FDMS unit has separate configuration utility software used to monitor and adjust specific configurations. The set point is also set in the TEOM hardware screen. If the ambient temp average is above 20° C and very humid, the Cooler temp must be set to 10° C from its original set point of 4° C. You must use the 8500-configuration utility to adjust the 8500 FDMS unit as well as the "Set Hardware" screen on the Control box to do the adjustment. Do not change the Cooler Temp Set Point unless there is a lot of condensation in the purge filter assembly and Bypass Flow Line. Some condensation in the purge filter assembly is normal. The adjustment for the 1405-F unit does not require a separate utility, the cooler module set point is found in the Instrument Conditions > FDMS module > Cooler Temp screen within the unit itself. The "Cooler Set point" from factory is set to 4° C.

Electric Power Supply

The electrical line voltage to the instrument can influence its performance. Variations in the vacuum pump speed can create feedback problems with the flow controller and hence the stability in the output of the instrument. This problem is often encountered in remote sites where power supply frequency, voltage and spikes may fluctuate significantly.

Exterior Enclosures

Where the site does not allow a straight intake from the sampling inlet to the sensor unit, an exterior installation must be considered. This would involve the installation of a temperature-controlled enclosure with heating and cooling capabilities to house the control and sensor modules and the pump. The outdoor enclosure must maintain the instrument temperature within the range of 2 to 25°C and it should be insulated to reduce the effect of rapid ambient temperature changes. A flat roof or surface would be required to mount such an enclosure.

8. Operational Requirements

All the installation requirements are specified by the manufacturer in the installation procedures of the manual. General requirements listed below must also be followed. Considerations for siting requirements can be found in the reference listed in section 7.0 above.

Refer to setup instructions and set up table for TEOMs for information on selection settings for AENV operations.

In order to properly use the TEOM data generated by an air monitoring network, ***the operating temperature and the scaling factors of the TEOM must be identified when reporting data.***

Instrument Documentation

- All operating parameters must be documented in the station log book or electronic log book and updated as needed. A copy of this documentation should be kept on file.

9. Operational Checks

The following activities must be performed when operating a continuous TEOM monitor in Alberta. The maintenance schedules such as filter change and cyclone inlet cleaning are for a typical site. There are sites with heavy PM concentrations that require more frequent service and an alternate schedule must be used. All operational activities conducted at any ambient monitoring station, must be documented in the station logbook, and/or station checklists. This allows other operators to access a history of the station if the regular technician is not available. The following documentation must be available to the operators on site: operational and maintenance manual(s), and station site documentation.

The analyzer monitors and displays test functions in order for the operator to monitor the performance of specific systems within the analyzer. These test parameters should be monitored on a weekly basis and recorded on the routine checklist.

9.1 System Leak Check

The system leak check should be completed every three months following the manufacturers instructions laid out in the operations manual. This is done to ensure that air is being pulled through the sample inlet only.

Note: Do leak checks after each filter change. When using the flow audit adapter to do leak checks, remove the sample filter (13mm) first. Slowly open the flow audit adapter after doing the leak test to prevent damage to the purge filter.

9.2 Sample Filter Change

The sample filter loading is monitored within the TEOM system. This displays a percent load, 100% being a fully loaded filter. The rate of filter loading depends on the site and the particulate concentrations observed there. For heavy particulate sites the filter will have to be changed more frequently. Typically once the filter load reaches 50% (AENV Network), the filter must be changed. Follow the manufacturer's instructions in the operations manual to complete the filter change.

Note: Sample (13mm) filters, may emit a high noise (Main screen at the bottom) if the filter material pulls away from its plastic backing. This can happen if, during a leak check, the audit adapter valve is opened quickly.

9.3 In Line Filter Change

On both the main flow and bypass flow lines, particulate filters are installed. These are to prevent particulates from reaching the mass flow controllers that measure and control both flows. Preventing particulate from reaching these controllers extends their operating life. These inline filters should be changed at least twice per year, but again, the schedule depends on the amount of particulate observed at the site.

Always exchange the TEOM and Purge filter at the same time. When exchanging the purge filter, wipe down any water build up around and inside the assembly. Before reinstalling the purge filter, use Teflon tape on the holder threads for proper seal. Do not use grease.

9.4 Inlet Head Cleaning

The sample fractioning head must be kept clean on a regular basis to avoid poor cut points as described in section 5. If the system is set up to monitor PM2.5, both heads must be cleaned. Clean the heads as per the instructions found in the operations manual. They must be dismantled and cleaned with water only. To dry, blow compressed air on the wetted surfaces to avoid any contamination.

9.5 Air Inlet Cleaning

Other components of the inlet system, mainly the main sample tubes, need to be cleaned on a periodic basis as well. Fine particulates will build up on the walls of these tubes and potentially cause erroneous readings. This procedure should be completed once per year. Follow the instructions in the manufacturer's operations manual.

The Nafion dryer tube in the FDMS Dryer assembly is typically good for 2-3 yrs.

9.6 Ko Verification

The Ko verification is completed to verify the response of the TEOM monitor. This process determines the TEOMs response with a filter of known weight installed. Similar to a span check on a continuous analyzer, the known value is compared to the observed response. The output can then be adjusted if required. This process should be completed at least once per quarter and according to the manufacturer's instructions in the operations manual.

If the KO factor falls out of the 2.5% acceptable range, a crosscheck can be made by writing down the F0 (no filter installed) reading during the check and comparing this to the factory F0.

9.7 Flow Controller Filter

Follow the manufacturer's instructions on checking and changing the flow controller filters.

9.8 Analog Output Calibration

The analog outputs of the TEOM monitor should be calibrated after installation and following repairs as required. Follow the manufacturer's instructions in the operations manual for this task.

9.9 Pump Overhaul

The vacuum pump needs to be rebuilt on a periodic basis in order to maintain the required vacuum for proper operation of the monitor. This procedure should be completed at least once per year, or more frequently as required.

For dryer efficiency the pump vacuum must maintain 80% of atmospheric pressure. E.g. at 30”Hg of atmospheric pressure the pump vacuum should be 24”Hg. Replace or rebuild pump if it’s 70% or lower.

<u>Note</u>: On pump rebuilding, heat up the Loctite adhesive to help loosen the component using a heat gun.

10. CALIBRATION

To maintain the accuracy of the TEOM within acceptable limits, the following calibration schedule is recommended.

- Flow controllers calibration (software) at **6 month intervals**.
- Ambient and Pressure sensors calibration at **6 month intervals**.
- Mass calibration verification (Ko) at **6 month intervals**.
- Analog calibration at **upon installation and following repair**

This calibration schedule may be accelerated for specific sites depending on the particulate matter concentration characteristics of the site. A flow calibrator with up to date certification by Environment Canada should be used for the calibrating flow controllers.

The main and bypass flow that is indicated in the main screen is what's used to report data in standard EPA format. If after calibrating the main and aux a flow there is a disagreement, data reported always uses the flows indicated on the screen.

In the case where you're flow measurements disagree with the main screen flow; adjustments can be made to A/D #0 for main flow and A/D #7 for the bypass to get agreement between the two. For the 1405-F model, refer to the procedure in the manual for adjustment and calibration.

IMPORTANT: Before making the above adjustment, you must be sure you're measurements are correct and there is no blockages such as the orifice in the MFC starting to plug off which would indicate inaccurate flows or pump problems, etc.

11. APPLICABLE DOCUMENTS

- **EM-004a** Operating Manual, TEOM Series 1400a, Ambient Particulate (PM-10) Monitor, (AB serial numbers), revision B, R&P Part Number 42-003347, March 2002.
- **EM-004b** Service Manual, TEOM Series 1400a, Ambient Particulate (PM-10) Monitor, (AB serial numbers), revision B, R&P Part Number 42-003348, April 2004.
- Technical Memorandum on R&P Series 8500 dated January 8 2004 from Rupprecht and Patashnick Co Inc.

- **EM-004c** Operators Manual, TEOM Series 1405-F, Ambient Particulate Monitor with FDMS® Option, 42-010978 Revision A.000, 15 Feb 2008.

12. Literature References

1.0 Environmental Technology Report, ETV Advanced Monitoring Systems Centre, Rupprecht & Patashnick Co., Series 1400a TEOM Particle Monitor, Kenneth Cowen et al. Batelle, Columbus, August 2001.

2.0 Environmental Technology Report, ETV Advanced Monitoring Systems Centre, Rupprecht & Patashnick Co., Series 1400a TEOM Particle Monitor with Sample Equilibration System, Kenneth Cowen et al. Batelle, Columbus, August 2001.

13. Revision History

Revision 0 (new document)

Revision 1 - Modified: Section 7 – Mechanical Vibration & Temperature Stability

Section 9.1 – System Leak Check

Section 9.2 – Sample Filter Change

Section 9.3 – In Line Filter Change

Section 9.5 – Air Inlet Cleaning

Section 9.6 – Ko Verification

Section 9.9 – Pump Overhaul

Section 10 – Calibration

Revision 2 – Modified Sections 1, 5, 7, 10, and 11 for applicable references to the TEOM model 1405-F FDMS.

Reviewed Dec 29, 2011

14. APPROVAL

Harry Benders

Approved by:	**Harry Benders**	**Date: August 21, 2009**
Title:	**Air Monitoring Team Leader**	