NYSERDA Standard Operation Procedures for Thermo Scientific 1405-D TEOM™ for use in a dilution tunnel

DRAFT, June 1, 2021

Section 1. Introduction

This document covers operation concepts and procedures for use of the Thermo Scientific model 1405-D TEOM to measure and report continuous particulate matter (PM) concentration measurements in an EPA Method 5G dilution tunnel or equivalent dilution method. The TEOM is designed for ambient real-time PM measurements, and is an inertial microbalance - a true continuous mass measurement method with resolution of 0.01 µg (0.00001 mg). The TEOM operating parameters are highly configurable, allowing the instrument to be set up to best meet the needs of a specific application.

The version of the TEOM used here for measurement of PM in the dilution tunnel is the "Dichotomous" (Dichot) 2-channel configuration (custom configuration, 1405D Base unit without Accessories), without any inlet hardware, virtual impactor, flow splitter, pump, T/RH sensor, or sample conditioning options such as "FDMS". For this application, the TEOM flows, temperatures, and timing settings are changed from the normal ambient settings to allow for fast filter changes with minimal data loss (typically four to five minutes). The second ("PM-coarse") TEOM channel is used as a co-located PM measurement for quality control purposes, similar to the paired filter train in ASTM-2515. Instrument configuration settings are the same for each channel. There are no hardware modifications needed. Instrument manuals, Microsoft Windows instrument software, and related support information are available from the Thermo web site.[1] Technical support is available during eastern time business hours by calling the main Thermo Scientific number: 866 282 0430.

Note: This procedure requires that dilution tunnel flows be at least 600 cfm to avoid condensation of water vapor in the sampling system.

Instrument Software

Thermo provides two Microsoft Windows programs for the TEOM that can be obtained from the 1405 web page. "RPComm" (the serial port interface program) can be used to display the last 15 minutes of data on a graph, download data, and quickly read all key operating parameters during a test run. It is also used to document the instrument settings. "ePort" (the ethernet interface program) is used to control the instrument remotely and to download data. Both programs can be used at the same time. Instrument control and data can be accessed remotely using any program that provides remote PC access.

Instrument Installation.

[1]The TEOM manual, revision of 15Feb2008, is referenced in this SOP, and is available here: https://www.thermofisher.com/order/catalog/product/TEOM1405D

The TEOM must be positioned close to the dilution tunnel sample port location. The length of the sample lines from the tunnel wall to the TEOM inlets must be no more than 18 inches. Consistent with ASTM-2515, samples are taken no more than 1 inch from the tunnel center line, and there must be at least 1 inch distance between the two sample line ends. Sample tubing must be conductive (either metal or conductive flexible tubing) with ¼" ID. A short piece of ¼" OD x 3/16" ID metal tubing must be used for insertion into the tunnel. All of the inlet tubing must be replaced or solvent-cleaned after every series of tests.

The laboratory temperature at the location of the TEOM must be kept sufficiently cool enough to keep the instrument's Case temperature reading from exceeding 0.1 ºC of the setpoint. This requires that the laboratory temperature at the TEOM be at least 1 and ideally 1.5 to 2 ºC lower than the Case temperature setpoint.

The TEOM does NOT have any clear visual warning that the filter needs changing due to loading. The TEOM digital outputs (relay contact closures, page 3-31 of the TEOM manual) must be used to trigger an external audible alarm at 115% filter loading, as shown in the alarm configuration instructions at the end of this SOP.

Supplies and Parts needed for this test method:
1405D Dual TEOM Base unit without Accessories, Thermo p/n 1405D-ANF
1405 Single TEOM Base unit without Accessories, Thermo p/n 1405-ANF
Teom filters, 6 to 8 per test, ordered from Thermo, p/n 57-007225-0020 (box of 20 filters)
Black sample filter change tool, Thermo, p/n 55-002013-0001
Mass transducer calibration kit, Thermo p/n 59-008298 and 1 refill, p/n 59-008299
TEOM sample tube brush, Thermo p/n 30-002227
Particle filter for zero-air tests and transducer calibration
Vacuum pump for 5 lpm at 20" vacuum (connects to TEOMs with 3/8" plastic tubing)
3/8" or 1/4" conductive inlet tubing (metal or conductive plastic[2])
(2) 1/2" to 3/8" swage SS reducing union for inlet tubing
NIST-traceable flowmeter for 0.9 to 3.3 lpm at 20 ºC and 1 Atm, accuracy of 2% or better.
Windows PC for RPComm (with a USB to serial port adaptor) and EPort (ethernet connection)
Filter change alarm parts: a DB25 male breakout connector, alarm, and alarm power supply

Lab air PM is also measured with a TEOM without any particle size cut, with the inlet of the probe located within 10 feet of the bottom of the tunnel's hood and an inlet line using conductive tubing of at least ¼" ID and no longer than 5 feet. This TEOM can be a single channel TEOM (1405). It can use the same pump as the dilution tunnel TEOM, and is configured the same way except for the following settings to increase sensitivity:

Inlet flow = 3.0 lpm
MRMC and MassAVG times set to 120 seconds

The filter for the lab air TEOM must be changed before the start of a series of test runs and whenever filter loading exceeds 80% before the start of a test day. All other operating

[2]Available from Freelin-Wade, Static Dissipative 90A Plastic Tubing - 90A-452, p/n 1J-452-90-01

parameters and procedures are the same as for the dilution tunnel dichot TEOM. Lab air PM concentrations are subtracted from tunnel PM concentrations before any other calculations are performed.

Section 2. Routine Operation Procedures for Thermo 1405-D TEOM

This section is a summary of routine operating procedures.

A. Quality Assurance checks to be completed before and after each set of test runs for tunnel and lab air TEOMs:

1. Modify system settings as detailed in Section 8 (initial installation only).
2. Perform K0 mass transducer verification checks on both channels as detailed in Section 4 of this procedure.
3. Document the system settings listed below using the Thermo RPComm program to display and save the values to a text file. Instrument time (PRC90) is in Unix Epoch format (seconds since 1/1/70, valid through 2037). This example is at May 14, 2021 1:59:05 PM (instrument clock time, not UTC). TEOMA (left sensor) is PM2.5 and TEOMB (right sensor) is PM-coarse. K0 values are calibration constants specific to each of the two TEOM mass transducers.

PRC	Name	Value
1	serial number	1405A247642010
2	instrument firmware version	1.74
3	instrument model	TEOM 1405-D
4	Instrument model variant	Dichot
28	system wait time	0
35	mass average time	30
74	average temperature set point	25.000000
75	standard temperature set point	20.000000
76	average pressure set point	1.000000
77	standard pressure set point	1.000000
78	volumetric flow control	1
79	mass conc reporting	1
91	bypass flow mass set point	0.000000
259	TEOMA K0	15317.000000
343	TEOMB K0	17551.000000
390	instrument time	1621000745
392	MRMC average time	30
407	TEOMA mass constant A	0.000000
408	TEOMA mass constant B	1.000000
409	TEOMB mass constant A	0.000000
410	TEOMB mass constant B	1.000000

Other key instrument operating parameters are always recorded in the data file and thus are not listed here.

B. Routine procedures before every test run to be conducted 1-2 hours prior to testing.

1. Check the TEOM time for both the tunnel and lab air instruments, and set as needed to be within 5 seconds of laboratory time. Changing the time causes an instrument reboot and loss of up to an hour of data. See notes section below. Verify that the 1-minute data records are being recorded with time-stamps within 5 seconds of the top of the minute. If they are not, reboot the instrument and re-check after the top of the next hour.

2. Before installing new tunnel TEOM filters, perform a leak test and flow check on both tunnel TEOM channels using the procedures in section 3 of the SOP. The leak test net results shall be no greater than 0.05 lpm. The flow checks must be performed with a traceable calibration standard. If either measured flow is greater than 2% different than the reported flow, a flow calibration shall be performed using the procedures in section 3.

3. Tunnel TEOM Initial filter change.
Install a clean filter for each channel before each test run and put 2 clean filters on the storage pins inside the sensor. See section 5 for the filter change procedure, including confirmation of proper operation after the filter change.

4. Lab-air TEOM
Verify that the lab-air 1405 TEOM is operating properly and that the filter loading is less than 80%. Change the filter if needed to ensure it does not overload during the test run. Flow and leak check tests are only needed after a filter change and after completion of a set of test runs.

C. Operation During Testing (tunnel TEOM only)

1. Before initiating the test, run the TEOM while sampling dilution tunnel air (with tunnel flow) for at least 10 minutes. The change of pressure in the tunnel can cause a large transient TEOM response which would invalidate the data for several minutes.

2. TEOM filter changes during a test run must be done when any of the following conditions are met, using the "Advanced" filter change mode and the procedure in Section 5. Filters for both channels must always be changed at the same time.

   a. Near the end of burn phases 2 and 3, when 80% of the fuel charge has been burned. This is sufficiently in advance of loading the next fuel charge to allow the TEOM to stabilize after completion of the filter change procedure, and ensures that valid data are available when the next fuel charge is loaded.
   b. Percent loading reaches 115% for <u>either</u> TEOM channel
   c. When the sample flow drops more than 5% of the flow setpoint for either channel.

   (b) will not normally trigger a filter change on a low-emitting device, and (c) should never occur without (b) unless there is a problem with the pump. Note that filter "plugging" does not end the test run – it triggers a filter change and the run continues.

   Proper operation of the TEOM must always be confirmed after a filter change as detailed

in the section 5 filter change procedure.

Note that if the flow starts to drop from the setpoint before 115% is reached, that is an indication of a vacuum pump problem. Vacuum is usually between 0.25 and 0.35 atm as read on the "System Status" TEOM display screen. If it exceeds 0.40 atm, the pump must be serviced.

Detailed information on performing filter changes during testing is provided in Section 5 of this document.

3. At the end of the test, perform external leak and flow checks on both channels as detailed in Section 3 and record the results. For valid results, leak checks shall be no more than 0.05 lpm, and flow checks shall be within 2.0 % of the TEOM flow reading.

4. Download the test data using either the Thermo ePort software (preferred), RPComm, or to a USB thumb drive. Note: the data format may be different depending on how the data are downloaded; the TEOM data template is based on downloading data using the ePort software.

Notes:

- The instrument "Status" code is not normally used for data validation. If the ambient T/RH sensors are not used, a status code of 8 will be present. Other than status codes of 134,217,728 (TeomA) and 524,288 (TeomB) when the % loading is greater than 90%, 8 (for the ambient T/RH sensor) is normally the only allowable "warning" status once the system is operational and running properly. The "8" status will cause the warning triangle on the TEOM display to show all the time.

- When the TEOM is first turned on or rebooted, no data are recorded until the top of the next hour. Other than after a reboot, data will be recorded even when no concentration data is displayed on the screen.

- **After EVERY instrument power on or Reboot:** confirm data are being recorded after the top of the hour. Occasionally the TEOM doesn't store any data after a reboot, even though all operational parameters are normal and concentrations are reported to RPComm and the TEOM display. If this occurs, Stop and Start the instrument to start data storage. A filter change using the Wizard is a Stop and Start cycle.

- When the time is changed, the instrument reboots (after many seconds of being hung, with no information on the screen). When it reboots, no data are recorded until after the top of the next hour (see above).

- TEOM PM concentrations are in micrograms per cubic meter, at EPA STP (20.0 ºC and 1.00 atmosphere) with the instrument configuration used in this procedure. Filter mass loading is reported in micrograms, with a resolution of 0.01 micrograms (10^{-8} grams).

Section 3. Leak and Flow Checks and Flow Calibration for the 1405-D TEOM

A traceable flow standard capable of displaying flow at standard conditions of 20.0 ºC and 1.00 atm shall be used for all flow checks and flow calibrations. Facing the front of the TEOM, the left channel is PM2.5 (TeomA) and the right channel is PM-coarse (TeomB). The lab air TEOM leak and flow checks are done at the start of every set of test runs, whenever the filter is changed, and at the completion of every set of test runs.

Leak Checks

A leak test measures the net flow as reported by the TEOM's flow sensors with no flow. Leak checks shall be done for both channels before the start and after the end of every test run. The TEOM leak test flow readings must be corrected for the TEOM flowmeter's zero offsets. To conduct a flow check, follow the procedures below for each channel:

1. With the TEOM warmed up for at least 30 minutes, read the TEOM reported flow for both channels with the pump turned off or with the TEOM in Stop mode. This is the flowmeter zero reading.
2. Close off the inlets to the TEOM sample train.
3. Turn on the TEOM pump, or set the TEOM to Run mode.
4. Wait one minute and read the flows reported by the TEOM.
5. The leak test values are the difference between the reading without and with flow.
6. The leak tests must be no greater than 0.05 lpm (net value).
7. Open the inlet to the TEOM sample train.

Flow Checks.

The TEOM sample flows for each channel shall be set to 1.00 lpm (at 20.0 C and 1.00 atm). The TEOM must be warmed up for at least 30 minutes before checking or adjusting the sample flows. The sample flows must be measured at the sample train inlet with an external NIST-traceable flow meter that reads in STP (20.0 C and 1.00 atm); measured flows must be within 2.0 % of the flow as indicated on the TEOM display for each of the two channels.

Flow Calibrations.

Flows must be calibrated for each channel with a NIST-traceable flowmeter that reads STP flow at 20.0 C and 1.00 Atm, using the TEOM wizard at Service, Calibration, Flow Calibration (page 5-41 of the Dichot TEOM manual); select "Direct Flow Device" (not FTS). A Flow Check shall be performed immediately after every flow calibration.

Flow Troubleshooting.

When a flow calibration fails, use RPComm to report the "flow offset" and "flow span" parameters [PRC 228, 229 for TeomA, and PRC 312, 313 for TeomB]. If they are not close to 0 and 1 respectively, reset the instrument's flow calibration to 0 and 1 by doing a flow cal routine but just hit "next" without entering any flows. Once that is reset, perform a normal flow calibration and then record the new offset and span parameters.

NOTE: In buildings where heavy electrical equipment is operated, the actual TEOM flows might be unstable even though the reported flow appears to be stable. This can cause erratic and poor

agreement in the PM between the two TEOM channels. For that reason it is recommended to use a constant voltage power supply for this instrument rather than a direct 120VAC wall outlet.

Section 4. TEOM Mass Transducer K0 Check Procedure for the 1405-D TEOM

The mass transducer K0 (calibration factor) checks described here must be done before and after each set of test runs for both TEOM channels and for the lab air TEOM.

K0 Checks

K0 checks confirm the calibration factor for the tapered element mass transducer in use by the TEOM by weighing a clean TEOM calibration filter of known mass (nominally 0.09 grams) as supplied by Thermo. To prevent contamination of calibration filters, the red filter change tool must only be used with calibration filters, and the black filter change tool must never be used with the calibration filters

K0 verifications must be done before and after every set of test runs using the K0 Wizard. See page 5-53 of the Dichot TEOM manual. Verify that the K0 values in use by the instrument are the same as the values on the mass transducer sticker, and document the serial number of the mass transducer. The PM2.5 K0 is on the left, and the PM-coarse K0 is on the right. The transducer serial number is on the far right in the example below; the last four digits are the YYMM of manufacturer. If either of the K0 values in use are different than the original values, the date of calibration and the new values must be recorded.

Record the calibration filter ID, the calibration date, and the average mass value of the calibration filter. Document K0 checks with an ePort screenshot of the result as shown below. If results are greater than 2% different from the values currently being used by the TEOM, or if the difference between the two dichot TEOM channels is greater than 2%, repeat the check. If repeated checks fail either of these criteria, repeat the check with a second calibration filter. If the difference persists, the K0 values in the instrument may need to be changed from the manufacturer's value supplied with the instrument, but this must not be done without clear and robust evidence such as multiple calibrations with multiple filters that the K0 value is out of

tolerance. The new values must be documented and stored with the instrument for future reference.

Section 5. Filter Change Procedure for the 1405-D TEOM

The TEOM measures the pressure drop across the filter as % of maximum (115 %), and is shown on the instrument display screen. A clean filter has a loading of about 5 % at 1.00 lpm. Tunnel TEOM filter lifetime will vary widely depending on the PM concentrations and nature of the smoke being sampled. Under typical sampling conditions, lifetime is an hour or more with concentrations in the 20 to 50 mg/m^3 range, but at very high PM concentrations (several hundred mg/m^3), filter lifetime may be less than 30 minutes. With care, filter changes can be done such that only a few minutes of data are lost. A video showing the TEOM filter change procedure is on the Thermo TEOM web page. This video does not use the "Advanced User Mode" that is required by this SOP, but is useful for training purposes. The Dichot TEOM manual has illustrated procedures for filter changes starting on page 5-6.

Note: Both tunnel TEOM filters must always be changed at the same time, even if only one channel triggers a filter change event.

Filter change procedure.

The following are filter handling procedures that shall be followed:

A. Unused clean filters must be stored in the original box and plastic bag, with the silica gel desiccant in the bag.
B. Two clean filters must be stored in the mass transducer on the posts provided.
C. Filters must only be handled with the black filter change tool.

Minimize the time the mass transducer is open to reduce the time needed to re-stabilize temperatures after the filter change.

1. The filter change menu can be located by choosing Service, Maintenance, Replace Filter. Select the "Advanced" option, and then Next to proceed. This turns off the oscillating element which makes filter seating easier.

2. Open the TEOM cabinet door, open the box of clean filters, and open the mass transducer. Remove the old filters by sliding the filter tool onto the filter and pulling straight out. Do not twist the tool (to prevent damage to the glass tapered element).

3. For each channel, pick up a new filter that has been stored inside the mass transducer with the tool. Position it directly over the tapered element and push the filter on gently. Once the filter is on, remove the tool from the filter and fully seat the filter by pushing firmly straight down on the filter with the bottom of the tool with approximately 1 pound of force for at least two seconds (see the TEOM manual and video for more information). The filter should have a small amount of horizontal play when this is done; if not, the filter may be wedged between the tapered element and the side of the opening for the element. Store two new filters in the mass transducer (this equilibrates them to the sensor temperature).

4. Close the mass transducer, replace the filter box cover, and close the cabinet door. Restart the TEOM by completing the filter change wizard with Next, Finish. The TEOM is not restarted until the Wizard is closed with "Finish", and the Maintenance screen is shown.

5. Proper operation of the TEOM must always be confirmed after a filter change. For the PM2.5 channel, the RPComm PM plot can be used; there must not be excessive noise or large and erratic negative data. The TEOM's PM2.5 and PM-Coarse display (PM-10 is not used) as shown below is used to verify proper operation for both channels as follows.

1-minute after the filter change is completed:
a. Frequencies for both channels must be greater than 200 Hz.

5-minutes after the filter change:
b. Filter mass values for both channels must be similar and not any more negative than -1 µg.
c. Noise values for both channels must be small (< 2 ug) or if larger because of high PM concentrations, similar.

	PM-2.5	PM-Coarse
MC (µg/m³):	0.00	8.66
30-Min MC (µg/m³):	0.00	0.00
1-Hr MC (µg/m³):	0.00	0.00
2-Hour value (µg/m³):	0.00	0.00
12-Hr MC (µg/m³):	0.00	0.00
24-Hr MC (µg/m³):	0.00	0.00
Total mass (µg):	0.07	0.11
Filter loading:	3.68 %	5.51 %
Frequency:	257.9879 Hz	270.8600 Hz
Noise:	0.028 µg	0.129 µg

If the filter change fails, the filter may need to be reseated or is defective, or the sensor latch may not be closed properly. Repeat the filter change "advanced" procedure and take the filter off and re-seat it. Push it on firmly with the back of the filter tool and make sure the sensor is properly closed and latched. If the problem persists after another 5 minutes, restart the procedure with another new filter.

Note: the PM2.5 concentrations on the TEOM display will read 0.0 after a filter change until the top of the next hour. When valid data are being collected, the RPComm graph will indicate PM2.5 concentration, and the "Total Mass" on the TEOM display will read something other than "0.00" for both channels.

Section 6: Data Storage and Download

The TEOM shall be set to store data every 60 seconds. There is storage for more than a year of data at this storage interval. Data can be downloaded while the TEOM is running.

Data are usually downloaded with the ePort software, with the "use old column names" option unchecked. If needed, data can also be downloaded to a USB thumb drive or with the RPComm TEOM software. The data file is in .CSV format for importing into a spreadsheet.

The TEOM shall be configured to record data parameters as follows. There is a limit of 20 parameters (not including the Date and Time, which are always recorded). For the lab air TEOM the list is the same but without the PM-Coarse parameters.

0. Date, Time
1. Operating mode
2. PM-2.5 raw MC
3. PM-Coarse raw MC
4. PM-2.5 total mass
5. PM-Coarse total mass
6. Case temperature

7. Cap temperature
8. PM-2.5 flow rate
9. PM-2.5 air tube temperature
10. PM-2.5 TEOM filter load
11. PM-2.5 TEOM filter pressure
12. PM-2.5 TEOM noise
13. PM-2.5 TEOM frequency
14. PM-Coarse flow rate
15. PM-Coarse air tube temperature
16. PM-Coarse filter load
17. PM-Coarse TEOM noise
18. PM-Coarse TEOM frequency
19. Vacuum pump pressure
20. System status

The key parameters for data validation are:

1. Date and Time – reported as the end of the average interval.
2. Mode – must be 3 or 4 for valid data.
3. PM2.5 raw and PM-Coarse raw Mass Concentration in $\mu g/m^3$. A zero value or a repeating value for Mass Concentration indicates no data. These are always reported even when they are invalid. This minimizes loss of data after a filter change but also requires manual QC of the data file to remove invalid PM concentrations based on review of the data and critical parameters listed below.
4. PM2.5 and PM-Coarse total mass – the mass loading on the TEOM filter in µg since the last instrument reset, filter change, or Stop/Start cycle. A zero value indicates no data.
5. PM2.5 and PM-Coarse flow rate – Flow is lpm at 20.0 C and 1.00 atm.
6. PM2.5 and PM-coarse TEOM filter load – filter loading as % of maximum.
7. Case temperature, in degrees C. Cap and Air Tube temperatures are not normally used for validation.
8. PM2.5 and PM-coarse "Noise" is a mass transducer stability metric and should normally be less than 0.50 µg when PM concentrations are low or zero.
9. Agreement between the PM2.5 and PM-coarse channel PM concentration data in the data processing spreadsheet template meets QC criteria.

Section 7. Data Validation and Calculations

TEOM data are recorded every 60 seconds. Data validation and conversion to PM rate (g/h, using "wet" STP tunnel flow) is performed on the 60 second TEOM data. PM rate data are averaged up to longer intervals for reporting use as required. A valid test run must have at least 95% data capture at the 1-minute level.

One-minute TEOM PM concentration data for each channel (and for the lab air TEOM) are valid only when all of the following parameters are met:

1. Flow reported by the instrument is within 5% of the flow setpoint (between 0.950 and 1.050 lpm)
2. Operating mode (not system status): 3 or 4
3. Noise: 3-minute running average of (100 x noise / concentration) is < 0.10
4. Case temperature: +/- 0.10 C of setpoint (32.90 to 33.10 C)
5. Concentration is not 0.00
6. Total Mass for is not 0.00
7. Concentration is different from the preceding interval.
8. Lab air PM data are available and valid.

Items 5, 6, and 7 are usually covered by item 2 (Mode) but there can be cases such as a failed filter change where mode indicates valid data but some of these parameters indicate invalid data.

When a filter change is done during a test run, the TEOM data may skip a time interval. The time sequence during a filter change must be examined using the data processing spreadsheet and corrected if needed.

Since the "wait time" is set to 0 to minimize data loss during a filter change, the TEOM never invalidates any data. Thus the data must always be reviewed and validated manually using the criteria above and the data processing spreadsheet. 1-minute intervals during the test run that do not have valid data are represented using empty spreadsheet cells for those intervals. Any longer interval calculated from the 1-minute data (such as a burn-phase) must have 75% of the possible 1-minute values. Example: a 20-minute interval must have at least 15 minutes of valid data to be valid.

Note that negative TEOM PM concentration data are considered valid data. This can occur when there is substantial mass on the TEOM filter and the burn cleans up. The filter can lose mass when this occurs, and that results in negative PM being reported.

The output of the TEOM is PM concentration in $\mu g/m^3$ at 20.0 ºC and 1.00 Atmosphere (29.92 inches Hg) pressure. The TEOM flow is "wet" e.g., not dried. The tunnel flow used to convert PM concentration into PM emission rate must also be "wet", without any water vapor correction.

Run validation parameters.

The Excel dichot TEOM data template calculates the following parameters for the entire run from the PM concentration data for the two channels. These values must meet these criteria for TEOM data from a run to be valid, and assume the dilution tunnel is well-mixed.

%D of run-average PM: no more than 7.5%

Calculations.

The final product of this SOP is valid 1-minute TEOM PM concentrations using the average of both channels and with lab air PM subtracted. An Excel spreadsheet data template is provided to facilitate TEOM PM concentration calculations and TEOM data validation steps described in this section.

The 1405-D TEOM does not report the actual PM-coarse channel (TeomB) concentration because it is designed for use with a dichotomous sampler virtual impactor inlet system. The PM concentrations for the PM-Coarse channel must be calculated as follows:

PM-Coarse raw MC * (16.67/PM-Coarse flow).

For 1.00 lpm flow, the calculation is:

PM-Coarse channel ($\mu g/m^3$) = 16.67 * PM-Coarse raw MC.

The PM2.5 TEOM channel does not need any additional calculations.

Conversion to PM emission rates and other reporting metrics require data generated from other sources (wet STP tunnel flows, stove scale weights, and heat output data).

The final 1-minute TEOM PM concentrations are converted into grams/hour using the wet STP tunnel flow as follows:

g/h = 0.000001699 * (tunnel flow in wet CFM) * (net PM concentration in $\mu g/m^3$)

The values used for tunnel flow must be the actual (wet) measured values corrected to STP, at intervals of no greater than 10 minutes, except as follows. If the range of 10 minute tunnel flow measurements (100*(Max - Min) / average) is no greater than 5.0% of the run-average tunnel flow, the run average tunnel flow can be used for these calculations. Note that proportionality of TEOM flow to tunnel flows does not need to be maintained since emission rate data are calculated on a 1-minute basis rather than on a run-average basis, and then averaged up to the time period of interest.

For calculation of lbs/MMBtu or grams/kg, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the duration (in hours) of that test period. Grams are converted to lbs by dividing grams by 453.6. Heat output calculations are in the main IDC protocol.

Section 8: TEOM Configuration Changes for Fast Response and High PM Concentrations, and List of TEOM Parameter Configuration Values.

These settings are for the 1405-D TEOM as used in this application that are different from instrument default settings. See the 1405-D manual for detailed information on how to change these values. Settings that are different for the lab air TEOM are noted in steps 2 and 3.

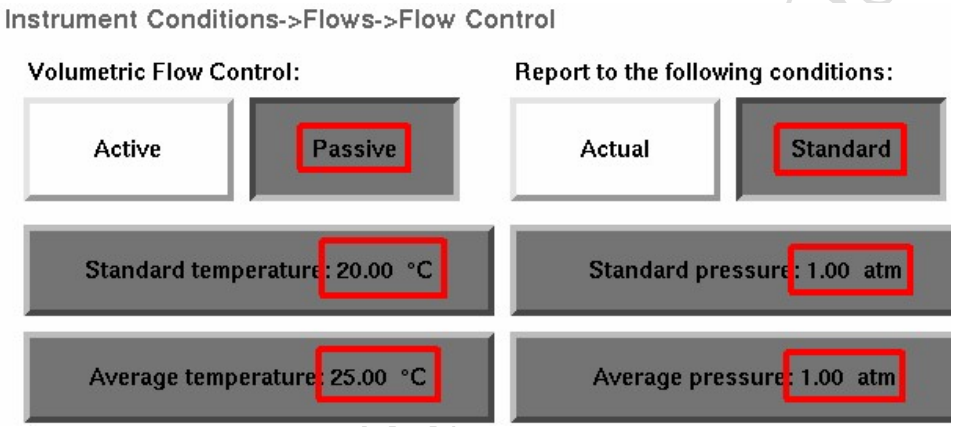
1. For both channels (TEOMA and TEOMB), confirm that all of the "Mass Constants" A and B factors are set as follows: The 3 "Mass Constant A" values are set to 0.0, and the 3 "Mass Constant B" values are set to 1.00.

2. Change system signal filtering and wait time settings:
Mass Avg time from 750 to 30 seconds (120 for lab air TEOM)
MR-MC (Mass Rate/Mass Conc) Avg time from 750 to 30 seconds (120 for lab air TEOM)
System Wait Time from 1800 to 0 seconds (disabled)

3. Change the sample flow from 3.00 to 1.00 lpm for the PM2.5 channel (3.00 lpm for lab air TEOM), and from 1.67 to 1.00 lpm for the PM-Coarse channel. Change the bypass flow to 0.00.

4. Change all four temperature zones [Case, Cap, PM2.5 Air, and PM-Coarse Air] to 33 C.

5. Set the Flow Control to Passive, and Reporting conditions to Standard. Change T/P values to 20.0 (Std) and 25 (Avg) C and 1 atm as shown below.



6. Change the Data Storage interval to 60 seconds.

A complete list of 1405-D TEOM Settings that are modified from instrument defaults are shown below. TEOMA is the PM2.5 (left) channel, and TEOMB is the "Coarse PM" (right) channel.

PRC*	Description	Value	Unit	Notes
12	storage interval	60	Sec	
28	system wait time	0	Sec	Always reports data
35	mass average time**	30	Sec	See also PRC392 (MRMC Avg)
48	case T	33.00	ºC	
59	cap T	33.00	ºC	

74	average T	25.0[3]	ºC	For reporting PM at 20 ºC
75	standard T	20.0	ºC	For reporting PM at 20 ºC
76	average P	1.00	ATM	For reporting PM at 29.92 "Hg
77	standard P	1.00	ATM	For reporting PM at 29.92 "Hg
115	TEOMA air tube T	33.00	ºC	
225	TEOMA flow rate**	1.00	lpm	
309	TEOMB flow rate	1.00	lpm	
321	TEOMB air tube T	33.00	ºC	
392	MRMC average time**	30	Sec	See also PRC35 (Mass Avg)
407	TEOMA mass constant A	0.0	µg	Intercept
408	TEOMA mass constant B	1.00		Slope
409	TEOMB mass constant A	0.0	µg	Intercept
410	TEOMB mass constant B	1.00		Slope

* TEOM Program Register Code

** Different for lab air TEOM (3.0 lpm and 120 seconds)

[3] 25C is correct here for data at 20 ºC

1405-dichot TEOM filter change alarm setup.

This configuration uses the TEOM contact closure ("digital") outputs, and triggers alarms when either Teom channel exceeds the filter loading threshold. The male DB25 connector goes on the TEOM USER I/O connector. See pages 3-31 to 3-33 of the dichot TEOM manual.

Any kind of low voltage alarm can be used, typically a 6 to 12 volt DC alarm. The TEOM interface is only a contact closure - it does not supply any alarm power, so an external alarm power supply must be used.

Parts needed.

1. DB25-male breakout connector, such as Mouser p/n 651-2761622, Phoenix Contact p/n 2761622 https://www.mouser.com/ProductDetail/Phoenix-Contact/2761622/?qs=p6trItWzfMXZ%2FKY9Mkeclg%3D%3D or equivalent. Thermo p/n 102562-00 is a DB25 male connector cable that goes to a DB25 breakout board where you can connect alarm and power wires.

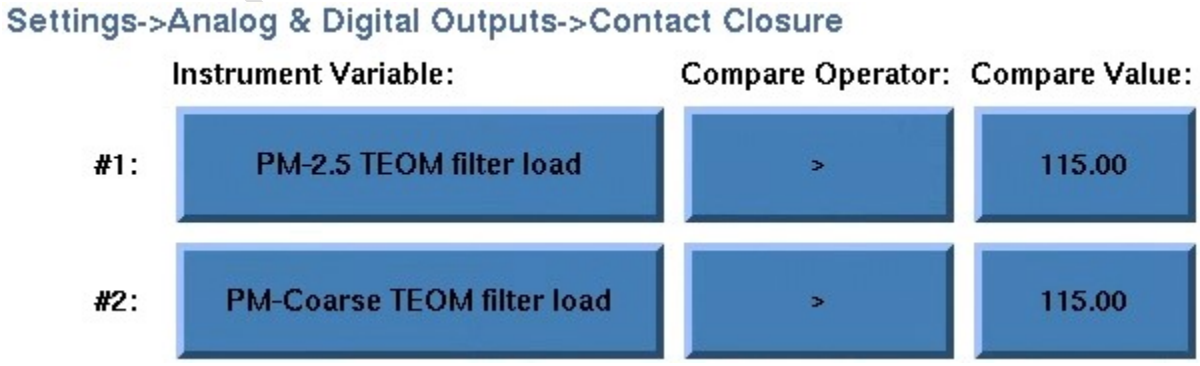
2. A low DC voltage alarm (6 to 24 volts).

3. DC power supply for alarm

Alarm wiring.

DB25 pins 12 and 13 both go to DC power positive
DB25 pin 24 and 25 both go to alarm positive power connection
DC power negative to alarm negative power connection

1405-dichot Teom contact closure alarm config:



Data processing and validation review Excel Template for 1405-D dichot TEOM

The TEOM data file includes PM concentrations and related operational parameters as specified in the TEOM 1405-D SOP. The SOP contains a list of parameter limits used to determine if a 1-minute data record is valid or not. An Excel spreadsheet template is used to format the raw data output from the instrument, to remove invalid data during filter change periods, calculate PM-coarse channel PM concentrations, and to check for missing data records. The resulting 1-minute data are then manually screened to identify any additional problems. The template also generates an assessment of how well the two dichot TEOM channels agree based on 10-minute block average data. This assessment is used to determine if the run data meet specified data quality objectives.

The operator must manually review the spreadsheet data to verify that limits for flow, temperature, and instrument "noise" are met; charts are generated in the template to facilitate this review. The template also generates a "reconstructed" column of time records to facilitate the check for missing data records. The following steps are to be followed for this data review process.

1. Open the dichot tunnel TEOM data file that was downloaded from the instrument in Excel and trim the data rows to remove data before and after the actual test times. Note that the time shown for the Teom time stamp is the END of the 1-minute interval, not the start.

2. Paste the trimmed dichot tunnel TEOM data from Step 1 into the first template spreadsheet tab "Paste raw tunnel data here", including column headers. The TEOM must be configured to save data as specified in the SOP.

3. In the "1405" spreadsheet tab, if the TEOM flows are not 1.0 lpm, enter the flow setpoint flow value in cell C2, the yellow highlighted cell.

4. Verify there are no missing data records by comparing the reconstructed time with the last time reported by the TEOM in column B of the "1405 spreadsheet" tab. Missing data records can occur when the filters are changed, since no data are recorded during a filter change. If there are missing records, note the time, exit the template without saving, and insert a blank line in the original TEOM raw data file as a placeholder for the missing data record. Then copy and paste the TEOM data into the template and repeat the review of time records.

5. Review the three time-series plots in the "T, F, & Noise review" tab to verify that these parameters are within the SOP limits.

6. Open the lab-air TEOM data file, remove data rows before and after the actual test run times (time stamp is the END of the minute interval), and copy the data into the lab air TEOM template. Review the data for proper operation (flow and temperatures), removing any invalid PM concentration data such as large negative values. Lab air TEOM data are simpler to validate since there are no filter changes or other interruptions to the instrument operation during the test period, and thus all the data are usually valid.

7. Paste the validated lab-air TEOM 1-minute PM data from column D into column D of the dichot TEOM template "1-min data and collo analysis" tab.

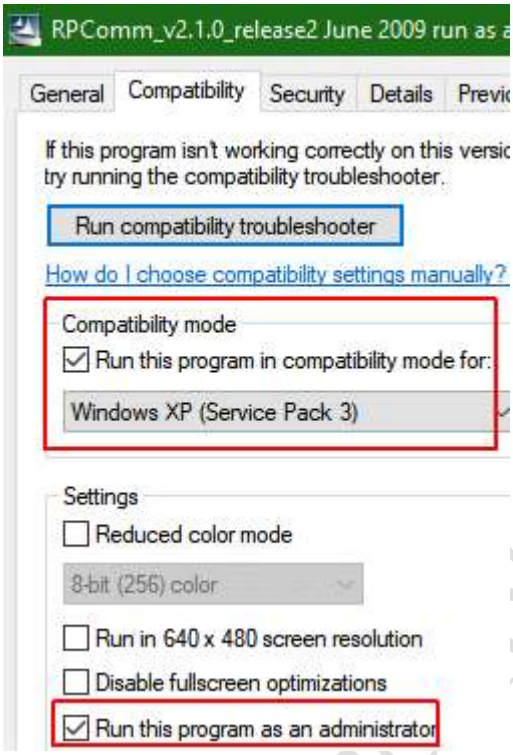
The final 1-minute data product is in column E (1-min avg PM) of the "1-min data and collo analysis" tab. This is the average of both dichot TEOM channels with lab air PM subtracted. Results are not shown in column E unless there are valid data for both dichot TEOM channels and for the lab air PM TEOM data.

The dichot TEOM performance for the entire test run is assessed with 10-minute block average data (without lab air PM subtracted). For the test run to be valid, the performance metrics in column V of the "1-min data and collo analysis" tab must meet the criteria specified in the TEOM SOP.

Installation of RPComm on Windows 10

1. The account you install it from must have administrator rights.

2. Right-click on the executable file for the RPComm install program, and on the compatibility tab enable settings for "Compatibility mode" and "Run as administrator". If these 2 compatibility settings are not available as shown in the screenshot below, you may not have administrator rights. RPComm may install and start, but it will crash when you try to use it.



It is recommended to create a Windows restore point or system backup before attempting to install RPComm. Things may go wrong that are not readily recovered from.

After installing but before running RPComm:
RPComm needs a parameter file that matches the firmware version installed on the TEOM. This file is included in the firmware update zip file on the 1405 web page – it is not included in the RPComm install package. Download the firmware file, open it, and copy the "RP14051.74.txt" file (or other RP14051.nn.txt file that matches the firmware version in use) to the location where RPComm is installed, usually "C:\Program Files (x86)\RPCO\RPComm\" (for 64-bit Windows). Then rename that file to remove the ".txt" filename extension to make the filename "RP14051.74".

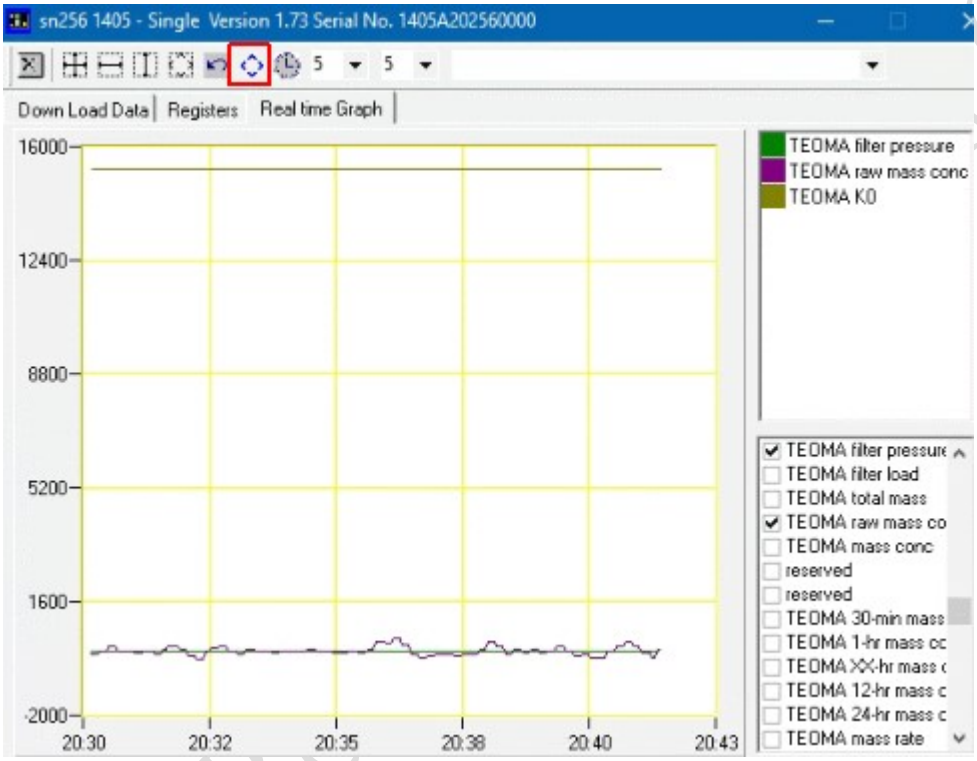
Note: you must enable the Windows File Explorer to show file extensions. By default they are hidden for known extensions like ".txt".

Using RPComm.

Multiple TEOMs can be accessed from a single instance of RPComm. To rename a connection in the main RPComm window, single-click it.

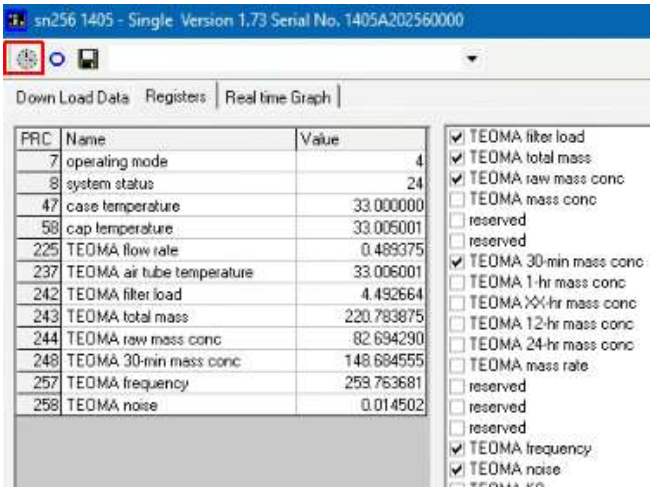
Below are screenshots showing how to use RPComm. These examples are from a single channel Teom.

For the plots, put a 0 [filter P] and a 15k value [K0] to anchor the scale, and the raw mass conc:



The icon circled in red auto-scales it as needed beyond these 2 values. You can also put TEOMB raw mass conc on the plot, but it's 16.7 times too low (at 1 lpm flow).

For the Register tab, set it to list key parameters - this is the only way to get a quick look at everything that matters for proper operation:



The icon circled in red refreshes the values. There is no auto-refresh in this screen. This is from a single channel TEOM.