

Standard Operating Procedure for the Continuous Measurement of Particulate Matter

**Thermo Scientific TEOM[®] 1405-DF
Dichotomous Ambient Particulate Monitor with FDMS[®]
Federal Equivalent Method EQPM-0609-182 for PM_{2.5}**

STI-905505.03-3657-SOP

**By:
Alison E. Ray
David L. Vaughn
Sonoma Technology, Inc.**

AUTHOR:

_____ Date

APPROVED:

Manager Date

Quality Assurance Manager Date

ACKNOWLEDGMENTS

We would like to thank the following people for their work contributing to this document: Peter Babich, Connecticut Department of Environmental Protection; Deborah Bowe, Thermo Fisher Scientific, Inc.; Dirk Felton, New York State Department of Environmental Conservation; Michael Flagg, U.S. EPA, Region 9; Stephen Hall, Missouri Department of Natural Resources; Tim Hanley, U.S. EPA, Office of Air Quality Planning and Standards; Matt Harper, Puget Sound Clean Air Agency; Kevin Hart, Utah Department of Environmental Quality, Division of Air Quality; Neal Olson, Utah Department of Environmental Quality, Division of Air Quality; Melinda Ronca-Battista, Northern Arizona University, College of Engineering and Natural Sciences, Institute for Tribal Environmental Professionals; Shawn Sweetapple, Idaho Department of Environmental Quality

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
LIST OF FIGURES	ix
LIST OF TABLES.....	x
1. ABOUT THIS STANDARD OPERATING PROCEDURE	1-1
2. SCOPE AND APPLICABILITY	2-1
3. SUMMARY OF THE METHOD	3-1
4. DEFINITIONS	4-1
5. HEALTH AND SAFETY WARNINGS.....	5-1
6. INTERFERENCES	6-1
7. PERSONNEL QUALIFICATIONS	7-1
8. EQUIPMENT AND SUPPLIES	8-1
9. INSTALLATION PROCEDURES.....	9-1
9.1 Unpacking and Inspection	9-1
9.2 Acceptance Testing.....	9-1
9.3 Site Selection	9-2
9.4 Enclosure Selection	9-4
9.5 1405-DF Installation Steps	9-4
9.5.1 Special Precautions.....	9-5
9.5.2 Tools Needed for Installation	9-7
9.5.3 Determine the Exact Location of the 1405-DF and Make Roof Modifications.....	9-7
9.5.4 Install the Pump.....	9-8
9.5.5 Select a Location for the Supplemental Water Trap and Mount It (If Used)	9-9
9.5.6 Assemble the Flow Splitter	9-9
9.5.7 Assemble the Tripod	9-10
9.5.8 Install the Virtual Impactor and Sample Flow Tubing.....	9-11
9.5.9 Install the PM ₁₀ Inlet	9-11
9.5.10 Install and Connect Remaining Tubing.....	9-11
9.5.11 Install the Temperature/Relative Humidity Sensor	9-12
9.5.12 Check Inlet Tube Grounding.....	9-12
9.5.13 Connect Power	9-12
9.5.14 Connect Data Logger.....	9-13
9.6 Initial Setup and Configuration Check	9-13
9.6.1 Power On and Warm Up	9-14
9.6.2 Review Screen Displays and Touch Screen Functions	9-14

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
9.6.3	Review/Adjust Configuration Parameters 9-15
9.6.4	Perform Initial Verifications and Calibrations 9-17
9.6.5	Load the TEOM [®] (Sample Collection) and FDMS (Purge) Filters 9-22
9.6.6	Select the Data Storage Options Desired 9-26
9.6.7	Set the Password Function, If Desired 9-28
9.6.8	Configure the Required Communications Parameters 9-29
9.7	Communications Setup and Data Download 9-30
9.7.1	Install ePort Software on Site Computer or Network 9-30
9.7.2	Set Up the Analog Outputs, Analog Inputs, and Digital Outputs (Contact Closures) 9-31
9.7.3	Set Up the RS-232 Serial Port for Communication 9-34
9.7.4	Using a USB Flash Drive 9-34
10.	MAINTENANCE AND QUALITY CONTROL PROCEDURES 10-1
10.1	Monthly Maintenance and QC 10-3
10.1.1	Check for Status Codes/Instrument Warnings 10-4
10.1.2	Verify the Total Flow 10-5
10.1.3	Total Flow Tolerances 10-5
10.1.4	Equipment Needed for Total Flow Verification 10-5
10.1.5	Leak Check 10-5
10.1.6	Leak Test Tolerances 10-6
10.1.7	Equipment Needed for Leak Check 10-6
10.1.8	Replace the TEOM [®] Filters Monthly or As Loading Approaches 100% 10-6
10.1.9	Equipment Needed for TEOM [®] Filter Exchange 10-6
10.1.10	Replace the 47-mm FDMS (Purge) Filters 10-6
10.1.11	Equipment Needed to Replace the 47-mm FDMS (Purge) Filters 10-7
10.1.12	Verify the Flow Rates for Each of the Three Flow Fractions 10-7
10.1.13	Tolerances for Flow Rates for Three Flow Fractions 10-7
10.1.14	Equipment Needed to Verify the Flow Rates 10-8
10.1.15	Verify/Calibrate the Ambient Temperature 10-8
10.1.16	Verify/Calibrate the Ambient Pressure 10-8
10.1.17	Adjust the Flow Rates for Each of the Three Flow Fractions 10-9
10.1.18	Clean the Virtual Impactor Monthly 10-9
10.1.19	Materials Required to Clean and Maintain the Virtual Impactor 10-9
10.1.20	Clean the PM ₁₀ Inlet Monthly 10-10
10.1.21	Materials Needed to Clean the Inlet 10-10
10.1.22	Verify the Clock (Time and Date) 10-12
10.1.23	Download the 1405-DF Data Files If Not Automatically Polled 10-12
10.1.24	Compare TEOM [®] 1405-DF Data to External Data Logger Data 10-13
10.2	Six-month Maintenance and QC Procedures: Replace In-line Filters 10-14
10.3	Twelve-month Maintenance and QC Procedures 10-15
10.3.1	Clean the Cooler Assembly 10-15

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
10.3.2 Perform Switching Valve Maintenance	10-16
10.3.3 Clean the Air Inlet System Inside of the Mass Transducer Enclosure ..	10-16
10.3.4 Replace the Dryer(s).....	10-18
10.3.5 Calibrations	10-19
10.3.6 Calibration (K0) Constant Verification.....	10-20
10.4 Eighteen-Month Maintenance and QC Procedures: Rebuild the Sample Pump ..	10-21
11. DATA VALIDATION AND QUALITY ASSURANCE.....	11-1
11.1 Field Quality Control Impacts on Quality Assurance.....	11-1
11.2 Data Validation	11-1
11.2.1 1405-DF Generated Sampling Attribute Data.....	11-2
11.2.2 Field QC-Generated Sampling Attribute Data	11-2
11.2.3 Data Validation Criteria	11-2
11.3 Handling Negative Mass Data Artifacts	11-4
11.4 Data Validation Steps	11-5
12. DIAGNOSTICS AND TROUBLESHOOTING.....	12-1
13. REFERENCES.....	13-1
APPENDIX A: TECHNICAL BULLETIN – 1405 CONNECTIVITY.....	A-1
APPENDIX B: 1405 DF SWITCHING VALVE MAINTENANCE	B-1
APPENDIX C: EXAMPLES OF CALIBRATION FORMS.....	C-1

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
3-1. Schematic representation of the 1405-DF ambient PM _{2.5} monitoring system	3-3
3-2. Schematic representation of the Base MC and Reference MC flow paths for the PM _{2.5} sample air stream	3-4
9-1. Schematic of the isokinetic flow splitter showing the position of the sample tube inside the splitter, which is positioned using a straight edge measure	9-10
9-2. The Data Screen	9-14
9-3. The data entry keypad for user-entered settings	9-15
9-4. Leak check/flow adapter	9-18
9-5. Flow paths of the fine and coarse streams.....	9-20
9-6. Isolate the chiller by “looping the elbows”	9-21
9-7. A close up of the filter element being placed on top of the tapered element and steps in the filter insertion and removal process	9-24
9-8. Stacking order of the 47-mm filter cassette, an open 47-mm purge filter door showing the filter holder, and the filter holder showing the cassette	9-25
10-1. Exploded view of the virtual impactor	10-10
10-2. The PM ₁₀ inlet has two primary components, the Acceleration Assembly and the Collector Assembly	10-11
10-3. The PM _{2.5} and PM-Coarse in-line filters should be changed every six months	10-14
10-4. The bypass flow in-line filter should be changed every six months	10-15
10-5. Air Inlet containing the Mass transducers, thermistors and nozzles	10-17

LIST OF TABLES

<u>Table</u>	<u>Page</u>
8-1. Standard 1405-DF System hardware, diagnostic tools, routine supplies, and spare parts.....	8-2
9-1. EPA PM _{2.5} site selection specifications, applicable to the 1405-DF, include inlet height, inlet radius clearance, proximity to potential particulate matter sources, and distance from roadways	9-3
9-2. Tools and supplies for installation of the TEOM [®] 1405-DF with FDMS [®]	9-7
9-3. List of suggested variables for storage.....	9-27
9-4. List of variables from which up to 20 may be chosen for storage	9-28
9-5. Data logging alternatives with the 1405-DF.....	9-30
10-1. Thermo Scientific-recommended maintenance and QC tasks, frequencies, and SOP and 1405-DF Operating Guide section references.....	10-2
10-2. Default calibration low, high, and set point flow rates for the 1405-DF PM _{2.5} , PM-Coarse, and Bypass flows	10-19
11-1. Critical and operational data validation criteria for PM _{2.5} continuous monitoring with the Thermo Scientific 2405-DF under FEM designation EQPM-0609-182	11-3
11-2. Data validation steps for TEOM 1405-DF FEM PM _{2.5} data	11-6

1. ABOUT THIS STANDARD OPERATING PROCEDURE

On June 17, 2009, the U.S. Environmental Protection Agency (EPA) designated four new equivalent methods for measuring concentrations of PM_{2.5} in ambient air (see 74 FR 28696). The four designations were for instruments manufactured by Thermo Scientific, Inc. Two of the four new PM_{2.5} equivalent methods, referenced here, are automated methods that employ conditioned filter sample collection and direct mass measurements with an inertial micro-balance (Tapered Element Oscillating Microbalance, or TEOM[®]) in near real time. Both of these methods use the Filter Dynamic Measurement System (FDMS[®]) to estimate and adjust for the volatile component of the mass. These two methods (monitors) are very similar, with the main difference being that one analyzer (TEOM[®] 1400a with Series 8500C FDMS[®] [1400a/FDMS]; EQPM-0609-181) achieves particle size separation by a cyclonic method and measures only PM_{2.5}, and the other method (TEOM[®] 1405-DF with FDMS[®] [1405-DF]; EQPM-0609-182) achieves particle separation by a virtual impactor that separates the particles into fine (PM_{2.5}) and coarse (PM_{10-2.5}) fractions. (The equivalency designation for the 1405-DF applies only to the fine fraction.) After particle separation, the processing of the PM_{2.5} sample air stream is identical between the two instruments; thus, even though this standard operating procedure (SOP) focuses on the 1405-DF specifically, the operating procedure principles can be applied to the 1400a/FDMS analyzer as well. The user interface, however, is quite different between the two analyzers, so the step-by-step procedures that utilize the 1405-DF user interface are not directly applicable to the 1400a/FDMS.

This SOP is based upon the Thermo Scientific, Inc. TEOM[®] 1405-DF Operating Guide (42-0100815 Revision A.003, Feb. 15, 2008), the TEOM[®] 1405-DF Quick Start Guide (42-010814 Revision A.002), and SOPs submitted by users of TEOM[®] samplers equipped with an FDMS[®]. It is meant to be used in conjunction with the 1405-DF Operating Guide, which offers additional details not specifically covered in this SOP. Because this is an SOP on operating a Federal Equivalent Method (FEM) PM_{2.5} sampler, the focus of this document will be the operation of the fine particle stream portion of the 1405-DF; however, the operation of the dichotomous sampling of fine and coarse particulate matter is integrated into the discussion.

Users from different regions of the United States, with expertise in one or more areas involving installation, programming, operating, quality checking or maintaining TEOM[®] with FDMS[®] particulate matter monitors and/or quality assuring, validating, or reporting data generated by these instruments, have contributed to the development of this SOP. Some of the diagrams and stepwise procedures from the Operating Guide and submitted SOPs are reproduced in this SOP, and the cooperation of Thermo Scientific and other contributors in development of this model SOP is gratefully acknowledged.

Sections 2 through 8 of this SOP offer synopses of some background topics. Hands-on users will find the most useful portions of the SOP to be **Section 9** “Installation Procedures” and **Section 10** “Maintenance and Quality Control Procedures”. Installation usually occurs once (or perhaps infrequently under re-location) and includes receiving, site and enclosure selection, and the actual putting in place of the system components, followed by system configuration, initial checks, and startup. Maintenance and Quality Control (QC) includes periodic maintenance (e.g.,

filter changes, cleaning) and recurring QC procedures that ensure compliance with Federal Equivalent Method (FEM) criteria and regulatory standards. **Table 10-1** provides a maintenance schedule, lists the QC protocols, and gives cross references to SOP sections containing the procedures.

Factors to consider when using external data loggers are discussed in **Section 9.7.2**, and data validation procedures are covered in **Section 11**.

The SOP attempts to identify common pitfalls and emphasizes details of operating procedures that may help avoid operator missteps and frustration. These discussions are presented so that the rationale underlying the procedures is understood. Agencies may wish to exclude this level of detail from their SOPs. Portions of this SOP may be excerpted, edited, or eliminated as deemed appropriate. For example, since installation is often a one-time-only procedure, it may be judged as unnecessary in the SOP covering routine procedures. Checklists and forms referred to in the text are provided in the Appendices as examples that may be used in whole or in part.

2. SCOPE AND APPLICABILITY

The purpose of this SOP is to provide a set of uniform protocols for installation, operation, maintenance, calibration, and quality control (QC) and quality assurance (QA) of the TEOM[®] 1405-DF Ambient Particulate Monitor with FDMS[®] configured to meet EPA FEM EQPM-0609-182 for PM_{2.5} mass. It is intended to be a "Model SOP" that incorporates best practices on the method, and its use is not required to meet the standards set forth under EQPM-0609-182. These best practices are being made available for incorporation by monitoring agencies, and for Regional offices to consider, when approving an SOP. It is acknowledged that there will always be cases where agencies' needs or guidance on writing SOPs is different from what is in the model.

To meet the federal equivalent method (FEM) requirements for measurement of PM_{2.5} mass as described in the Federal Register (74 FR 28696), the TEOM[®] 1405-DF with FDMS[®] must be

- Configured for dual filter sampling of fine (PM_{2.5}) and coarse (PM_{10-2.5}) particles using the US EPA PM₁₀ inlet and a virtual impactor;
- Operated with a total flow rate of 16.67 lpm, a fine sample flow rate of 3 lpm, and a coarse sample flow rate of 1.67 lpm;
- Equipped with firmware version 1.50 or later. (Firmware version 1.50 has a goal date for release of September 15, 2009.) The firmware update is expected to add a parameter labeled "FEM PM_{2.5} Concentration". This parameter will apply an algorithm to the PM_{2.5} concentration data to generate data that will meet FEM requirements to fit to the FRM PM_{2.5} data.
- Operated with or without external enclosures; and
- Operated in accordance with the Thermo Scientific TEOM[®] 1405-DF Dichotomous Ambient Particulate Monitor Instruction Manual. (An updated manual is scheduled to be released by Thermo Scientific in mid-September 2009.)

3. SUMMARY OF THE METHOD

The TEOM[®] 1405-DF with FDMS[®] is a dichotomous sampler providing near real time measurements of fine (PM_{2.5}) and coarse (PM_{10-2.5}) particulate matter in ambient air. The system draws ambient air first through a PM₁₀ size selective inlet at 16.67 lpm, and then through a virtual impactor that partitions the coarse and fine fractions into separate air streams at 1.67 and 15.0 lpm, respectively. The PM_{2.5} air stream is then split isokinetically into sample (3.0 lpm) and by-pass (12.0 lpm) streams to reduce the sample flow rate and air volume. The fine sample and coarse sample air streams flow in parallel through the FDMS[®] module (described below) and a pair of sample collection filters, one for the coarse particle measurement and one for the fine particle measurement. The 1405-DF maintains each sample air stream at a constant volumetric flow rate, corrected for local temperature and barometric pressure. Each sample collection filter is attached to an inertial mass transducer, or microbalance, TEOM[®] that is weighed continuously. The tapered element oscillates at its natural frequency (like the tines of a tuning fork), determined by the physical characteristics of the tapered tube and the mass on its free end. Any mass added to the filter causes a proportional decrease in oscillation frequency, while loss of mass causes a proportional increase. An electronic control circuit senses the oscillation frequency and, through positive feedback, modifies energy input to the system to modulate any increase or decrease in frequency that is presumed due to changes in mass accumulation on the filter. A precision electronic counter measures the oscillation frequency using a 10-second sampling period. An automatic gain control circuit maintains the oscillation at a constant amplitude.

The FDMS[®] facilitates the measurement of both nonvolatile and volatile PM components. Since the 1405-DF is a dichotomous sampler, the FDMS[®] utilizes parallel and identical components to condition the sample stream of each size fraction concurrently, but independently. **Figure 3-1** is a schematic representation of the 1405-DF system from the air inlet through the tapered element. **Figure 3-2** details the flow path for the PM_{2.5} sample air stream through the 1405 FDMS. (The sample air stream for the coarse fraction follows an identical and parallel path once it leaves the virtual impactor.)

After the 16.7 lpm inlet flow is sequentially split to attain the 1.67 and 3.0 lpm sample flows, the sample stream for each fraction is passed through a diffusion dryer containing Nafion[®] tubing specially designed to minimize particle loss. The dryer lowers the sample stream relative humidity (RH), minimizing positive artifact associated with water sorption onto the collection filter and making possible mass transducer operation at 5 °C above the peak air monitoring station temperature (usually 30°C). An integrated humidity sensor, downstream of the dryer, measures the humidity of each sample stream to determine the drying efficiency. The dryers use re-circulated air that has passed through the sample collection filter so that the dryers do not require any bottled air or a dedicated “zero” air system.

When the sample air exits the dryer it enters a switching valve that, every 6 minutes, alternately directs the air stream either to the sample collection filter (the base cycle) or to an alternate flow path (the reference cycle). The reference flow path includes a standard FRM-style 47-mm filter cassette with a TX-40 filter (Teflon-coated borosilicate) maintained at 4°C. The low

temperature causes volatile PM components to condense on the filter, resulting in an air stream free of both non-volatile and volatile PM components. (The 47-mm filter itself can also be used for time-integrated chemical analysis.) This clean, reference air is routed to the mass collection filter, and the mass measured on the collection filter during this cycle is termed the “Reference mass concentration” (Ref MC). The Ref MC provides an estimate of the volatile PM losses that occur during sampling of ambient particle-laden air, and any loss of mass from the sample collection filter during the Ref MC cycle is quantified and added back to the PM concentration measured during the “Base mass concentration” cycle. The Base MC cycle, operated at 30°C, yields the Base mass concentration of the ambient air sample. Based upon the change in the filters’ sample mass (adjusted for volatile component losses) and the sampled air volume, a one-hour running average of the PM mass concentration is updated every six minutes for each PM size fraction.

In summary, the Base MC is equal to the PM concentration of the conditioned particle-laden sample stream (which is usually a positive number); the Ref MC is equal to the PM concentration of the particle-free sample stream, after passing through a purge filter (which can result in a negative value if mass volatilizes from the filter); and the mass concentration is equal to the Ref MC subtracted from the Base MC. Note that this means that the sampler is measuring particle-laden air for five 6-minute periods per hour (or half of the time) and filtered air for five alternating 6-minute sample periods each hour.

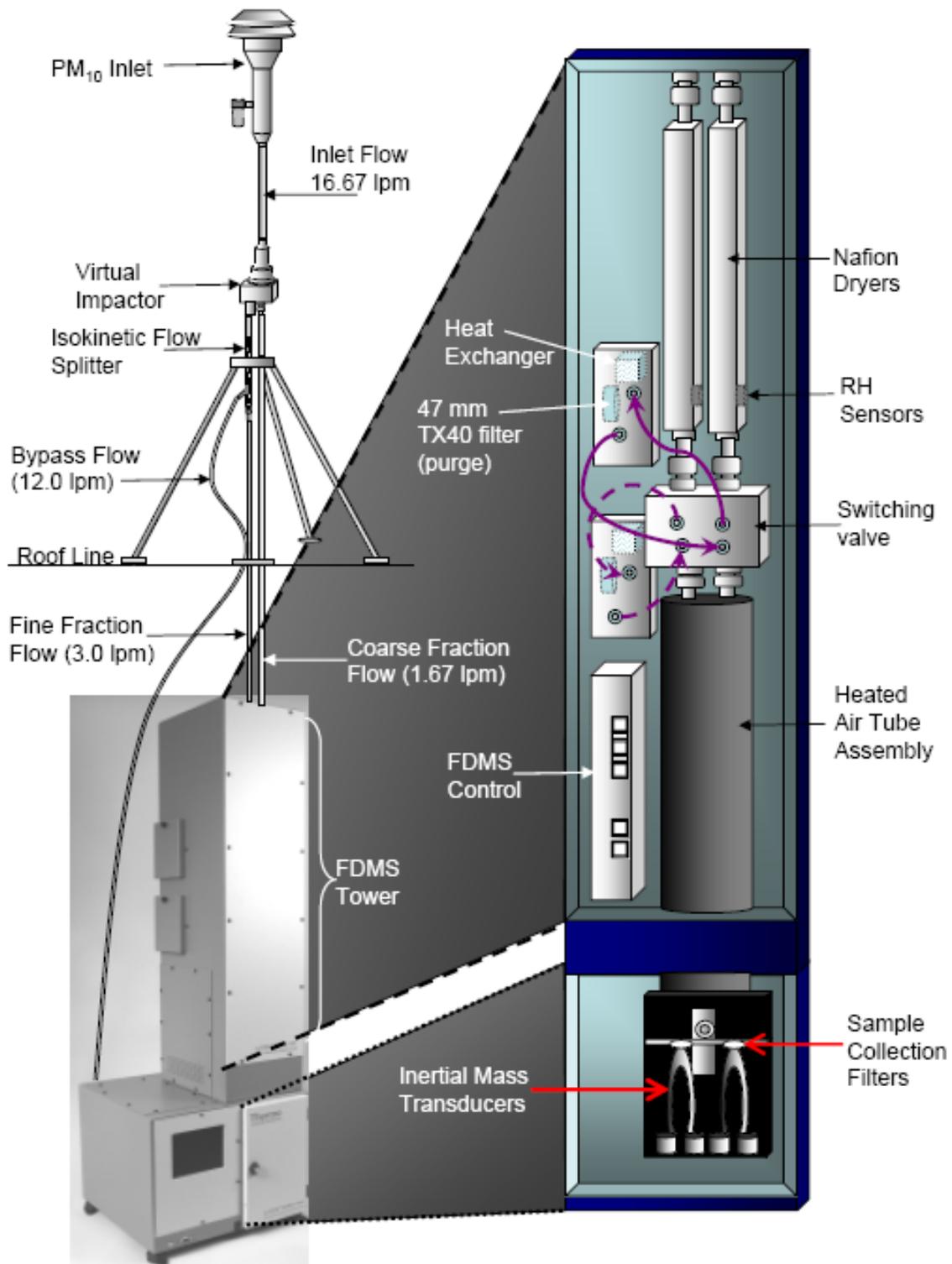


Figure 3-1. Schematic representation of the 1405-DF ambient PM_{2.5} monitoring system.

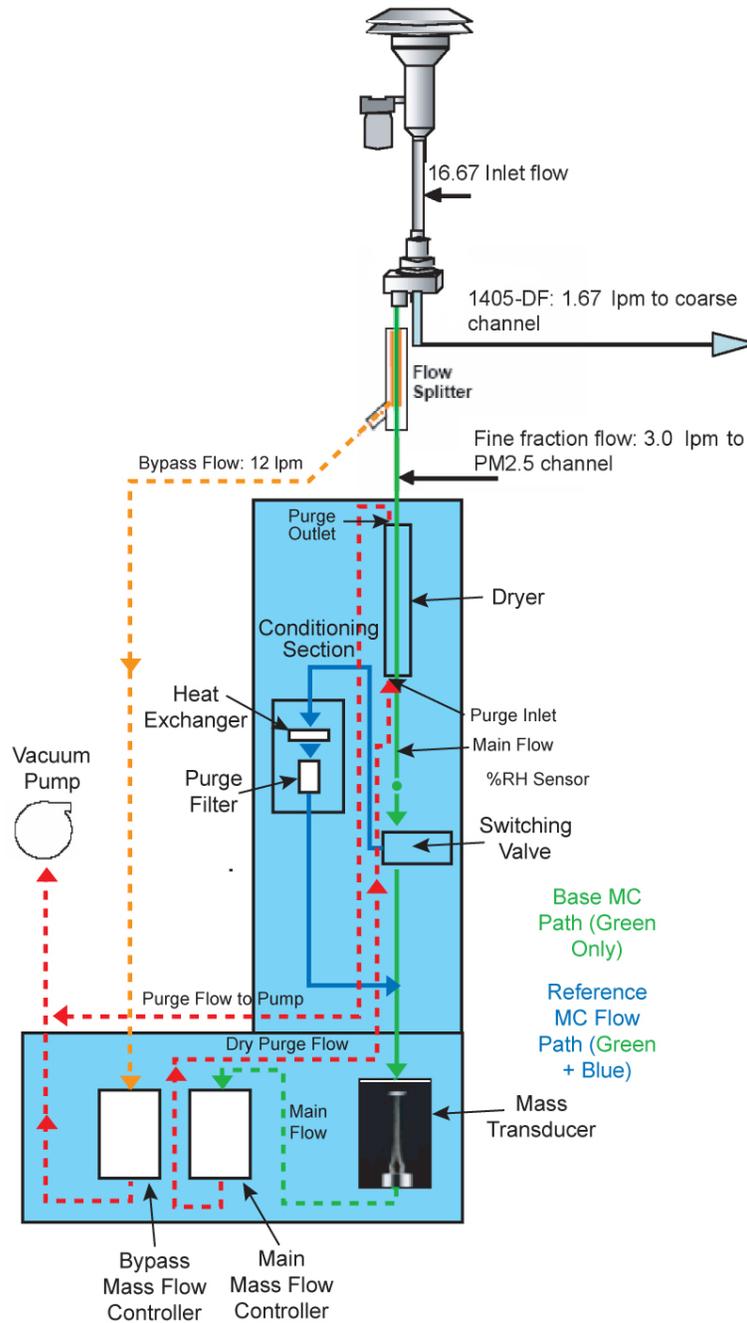


Figure 3-2. Schematic representation of the Base MC and Reference MC flow paths for the PM_{2.5} sample air stream. A parallel system operates simultaneously for the PM-Coarse sample air stream in the 1405-DF. (Original schematic courtesy of Puget Sound Clean Air Agency.)

4. DEFINITIONS

Technical terms in this SOP are defined as they are introduced so that their meaning is made clear in context. This section explains some general terminology.

Two terms used throughout this SOP are “verification” and “validation”. These terms have similar, but distinctly different, meanings. *Verification* refers to the review of interim work steps to ensure they are acceptable and to determine whether the system is consistent, adheres to standards, uses reliable techniques, and performs the selected functions in the correct manner. Verification steps are performed during the process of data collection and include such things as checklists and comparisons to standards. A leak check is an example of a verification procedure used with the 1405-DF. *Validation* involves determining if the system complies with the requirements and performs functions for which it is intended and meets the organization’s goals and user needs. It is a determination of correctness of the data and is usually performed only periodically (e.g., quarterly) or at the end of the project.

Similarly, the terms “quality control” (QC) and “quality assurance” (QA) are often used interchangeably, but in fact have important distinctions. QC refers to the operational techniques and activities used to fulfill the requirements for quality. QC is what the field technician practices when conducting maintenance and verification procedures on the 1405-DF. Routine QC procedures, such as flow checks, are referred to herein as QC checks or QC procedures. QA refers to the planned or systematic activities used to provide confidence that the requirements for quality are fulfilled. An independent audit is an example of a QA activity.

The term “audit” is often used in a generic way to mean check, inspect, examine, or assess, and many SOPs use the term audit to refer to QC procedures, such as flow checks or leak checks, that are carried out by field technicians during the course of normal operations and maintenance. Within the TEOM[®] 1405-DF with FDMS[®] user interface, the term audit is used to indicate a procedure that tests but does not alter a value.

The term “calibration” refers to the act of adjusting an instrument after comparison with a standard. When referring to the instrument software, the term “calibration” is used to indicate a procedure that would alter instrument output. A “calibration check” involves only the checking of an instrument against a standard and involves no adjustment of the instrument.

SOP # xx.x

9/1/09

Page x of x

5. HEALTH AND SAFETY WARNINGS

Safety precautions should be heeded during the setup and operation of the TEOM[®] 1405-DF with FDMS[®]. General safety rules regarding electricity and power tools should be observed. High voltages may be present in all instrument enclosures. Disconnect the power cord from the power source while servicing the instrument. Working at above-ground elevations and on ladders is frequently required, and precautions should be taken to avoid falls and personal injury.

6. INTERFERENCES

The TEOM[®] 1405-DF with FDMS[®] is a robust instrument that has minimal potential interferences. Poor siting, inadequate electrical power or bad grounding, poor control of the sample air RH in humid environments, and significant vibrations are known sources of interference.

Interferences arising from improper siting can be avoided by exercising care during site selection (Section 9.3). Electrical connections should be thoroughly checked during installation and the ground potential should be measured as part of the installation procedure.

Proper control of the *RH* in the sample stream is integral to proper sampler operation. RH issues should be addressed by carefully monitoring and maintaining shelter temperature and instrument sample air dew point(s) to avoid introducing condensation into the sample train (Sections 9.4 and 9.5.1).

Proper *dryer* operation is integral to accurate sampler operation. Dryers should be replaced on a routine basis not to exceed the manufacturers' recommended interval of one year. Areas in which high humidity is common should monitor dryer efficiency; dryers may need to be replaced on a more frequent basis. The dryer efficiency can be estimated by monitoring the dew point of the sample stream which is labeled in the instrument screens and downloads as TEOM A Dryer Dew Point for the fine fraction and TEOM[®] B Dryer Dew Point for the coarse fraction. (Section 10.3.4).

Great care should be taken to maintain a *stable temperature* in the instrument shelter (Section 9.4). Ideally the temperature fluctuation should be less than 2°C over an hour. The temperature should also be maintained as close as possible to 5°C less than the operating temperature of the sample stream (which is generally 30 °C). (Sections 9.4, 9.5.1, 9.5.5, and 10.3.4).

Historical data have shown that it is crucial to avoid a *12-minute cycle on the air conditioning system* of the shelter. Experience has shown that a 12-minute cycle can lead to upwardly biased data, sometimes referred to as "aliasing." The use of a relatively large air conditioning unit in a relatively small enclosure has produced this 12-minute cycle and the "minimum reset time" for the compressor in the heating, ventilation, and air conditioning system may require adjustment to avoid this problem (Section 9.4).

Best practices dictate the use of additional insulation, such as pipe insulation, on all exposed tubing. Air conditioning vents should be directed away from the instrument so that the air flow over the instrument is diffused (Section 9.4).

Vibrations can affect any microbalance; therefore, care should be taken when placing the instrument in the shelter. Placing the instrument on an isolated bench may be beneficial to reduce excessive bench vibrations from other instruments. The TEOM[®] 1405-DF with FDMS[®] pump or any other pumps located in the shelter should be isolated from the instrument as far as is

practicable. Tubing to the TEOM[®] pump may need to be replaced with larger diameter tubing or pipe to avoid an excessive pressure drop due to the longer line length. It may be useful to dampen pump vibrations by placing pumps on foam pads if such placement can be accomplished without creating a fire hazard. Also, consideration should be given to the roof mounting of the sample lines; if the rigid connectors are used and the roof surface flexes during technician service activities then excessive vibrations may be transferred to the transducer resulting in erratic readings. A short flexible section of conductive rubber tubing (Thermo p/n 30-002274) can be used to mitigate the roof movement by allowing a 1-1.5" gap in the rigid tubing. Alternatively, an expanded and reinforced work surface can be added to the roof to minimize roof movement (Sections 9.4, 9.5.1, and 9.5.10).

7. PERSONNEL QUALIFICATIONS

While no special qualifications or training are necessary to operate the TEOM[®] 1405-DF with FDMS[®], a basic understanding of the principles governing ambient air sampling is assumed. The QA procedures detailed herein require an understanding of the TEOM[®] 1405-DF with FDMS[®] flow system and proper operation of calibration reference devices.

EPA Quality Assurance Guidance Document 2.12 (U.S. Environmental Protection Agency, 1998) covers specifics of field personnel qualifications and provides the following general guidelines. All field operations personnel should be familiar with environmental field measurement techniques. Those who service the PM sampler in the field must be very conscientious and attentive to detail in order to report complete and high-quality PM_{2.5} data. Persons qualified to perform PM_{2.5} field operations should be able to

- operate the PM_{2.5} sampler;
- calibrate, audit, and troubleshoot the PM_{2.5} sampler; and
- use common methods to determine temperature, pressure, and flow rate.

8. EQUIPMENT AND SUPPLIES

The equipment and supplies needed vary with the particular tasks associated with installing and operating the TEOM[®] 1405-DF with FDMS[®]. **Table 8-1** lists the 1405-DF standard hardware (supplied by Thermo Scientific), required diagnostic tools, and a suggested inventory of routine parts and supplies. (Additional tools and supplies required for installation are not listed here, but are listed in Table 9-2.) Conductive rubber tube connectors p/n 30-002274, not normally supplied) should be ordered and installed (see Sections 9.5.1 and 9.5.10). Rubber tube connectors allow removal and servicing of FDMS[®] tower components without having to disturb the rooftop inlet hardware.

Table 8-1. Standard 1405-DF System hardware, diagnostic tools, routine supplies, and spare parts.

Page 1 of 2

Category	Components	Part number	Use Schedule
Standard System Hardware	1405-DF TEOM [®] unit	NA	NA
	Temperature/humidity sensor and cable, 10 m	NA	NA
	3/8" green tubing for bypass flow, 10 m	NA	NA
	3/8" green tubing to pump, 5 m (16.5 ft)	NA	NA
	5 Sample tubing extensions, 1.0 m (40")	NA	NA
	1 Sample tubing extension, 0.79 m (31")	NA	NA
	Filter exchange tool	NA	NA
	Flow splitter	NA	NA
	PM-10 inlet	NA	NA
	Sample inlet tube	NA	NA
	Virtual impactor	NA	NA
	Water trap filter assembly	NA	NA
	Flow audit adapter/leak check kit	NA	NA
	Cooler cleaning kit (2 Y-adapters, orifice)	NA	NA
	Vacuum pump	NA	NA
	2 Operating Manuals (one hard copy, one on CD)	NA	NA
Diagnostic Tools	Flow calibrator(s)	NA	NA
	Temperature transfer standard	NA	NA
	Pressure transfer standard	NA	NA
	Digital Multi-meter	NA	NA
	KO calibration verification kit	59-002019	Yearly
	Hand Tools (screwdrivers, wrenches, small sizes, etc.)	NA	NA
Consumables	TEOM [®] Filters	57-007225-0020	Every 30 days or as needed
	FDMS Filters (47-mm TX 40)	10-002387-0025	Every 30 days or as needed
Spare Parts	Pump rebuild kit	32-008672	18 months
	Pump (120VAC)	10-001403	As needed

Table 8-1. Standard 1405-DF System hardware, diagnostic tools, routine supplies, and spare parts.

Category	Components	Part number	Use Schedule
Spare Parts (continued)	In-line Filter Elements	50 cc: 32-010745 172 cc: 32-010755	6 months
	V-seal, TEOM [®] Filter Housing	22-009863	As needed
	O-rings, Inlet Receiver	22-00485-1112	As needed
	O-Rings, Virtual Impactor	22-000485-1152 22-000485-1155 22-000485-1026 22-000485-1020	As needed
	O-Rings, PM ₁₀ Head	Lg: 22-000485-1036 Sm: 22-002853-3026	As needed
	Nafion Dryer	56-009872	Annually
	Valve Seals	22-010280	As needed
	Chiller V-ring	22-002680	As needed
	Chiller Filter Holder O-ring	22-000485-1035	As needed
	Chiller Assembly	56-009871	As needed
	Touch Screen Assembly	56-010414	As needed
	Mass Flow Controller Assembly-DF	55-010022	As needed
	Fuse, Input Module (2 required)		As needed
	Fuse, Power Distribution Board		As needed
Cleaning Supplies	Valve cleaning brush (provided with instrument)	30-009091	As needed
	Ammonia-based cleaner	NA	Monthly
	Silicon grease	NA	Monthly
	Soap, alcohol or Freon solution	NA	Monthly
	Small soft-bristle brush	NA	Monthly
	Cotton swabs	NA	Monthly
	Paper towels, soft cloth	NA	Monthly
	D.I. Water	NA	Monthly
	Hand cleaner	NA	Monthly

9. INSTALLATION PROCEDURES

The installation process for the 1405-DF involves many steps and requires considerable attention to detail. The User's Manual provided by Thermo Scientific offers a comprehensive step-by-step procedure with many supporting pictures. That manual should be the primary reference for installation. This SOP lists the main steps and highlights some tasks that may require extra care when executing.

The major tasks associated with installation include:

- Unpacking and inspecting the TEOM[®] 1405-DF with FDMS[®] components
- Acceptance testing
- Site selection to meet 40 CFR Part 58 siting requirements
- Enclosure selection to provide the TEOM[®] 1405-DF with FDMS[®] with an environment within its operating specifications
- A series of sequential steps to install the TEOM[®] 1405-DF with FDMS[®] main unit and its supporting peripheral hardware
- Configuration of the instrument operating system to ensure that
 - The 1405-DF meets the requirements set forth in the FEM EQPM-0609-182 designation
 - The 1405-DF is set up to be compatible with the local agency data acquisition protocols

9.1 UNPACKING AND INSPECTION

A physical inspection of the TEOM[®] 1405-DF with FDMS[®] system should be made upon receipt of the system from Thermo Scientific, Inc. Visible damage to the shipping container should be reported to the carrier. System components should be verified against the packing list and any missing or damaged components should be reported immediately to the manufacturer.

9.2 ACCEPTANCE TESTING

As with any equipment, basic acceptance tests should be conducted. Some suggested tests include:

- Test pump vacuum
- Leak test of the system
- Test ambient temperature and pressure sensors
- Perform diagnostics test on the cooler to confirm proper operation
- Verify the mass transducer Calibration Constant (K0)

- Verify the F0 value by performing the mass balance test without a filter in place
- Compare operation of new sampler to an existing monitor (when practical)
- Compare operation of sampler in laboratory setting to field setting
- Operate the system for several days with a HEPA filter in place to test instrument stability

Like most air quality instruments, the 1405-DF is factory tested and calibrated prior to shipment to the user. The acceptance testing should verify proper operation of the monitor after shipping and before use in the field. The user must be careful to evaluate any discrepancies found before making adjustments to the system because historically, instruments have been adjusted incorrectly to compensate for a perceived error. Testing procedures will vary by agency, but users have reported that it is generally valuable to set up the instrument in a controlled environment such as a laboratory or workshop to test the instrument before deployment to a field site so that instrument problems can be evaluated separately from problems associated with instrument siting. It may be useful to operate the system with a zero-filter (0.2 micron) in place, to determine the stability of the instrument.

Users may also want to fully verify the operation of the mass transducer by purchasing a mass calibration kit (p/n 59-002107) and performing the mass verification procedure described on page 5-64 in the User's Manual (Rev. A.003). The instrument software provides a "Wizard" to guide the user through the procedure. The calibration constant is based on the mechanical properties of the mass transducer and therefore, should not change materially over the life of the instrument. In addition to verifying the Calibration Constant, labeled "K0" in the instrument software and calibration certificate, the value labeled F0 should be verified. During the K0 constant test the F0 value is displayed; the F0 value showed before a filter is installed should match the F0 value published on the calibration certificate received from the factory with the sampler. The F0 value should remain within ± 0.1 of the published value. If the F0 value changes, it is indicative of a physical problem with the mass transducer, and the manufacturer should be contacted for corrective action options.

9.3 SITE SELECTION

Site selection is important for ensuring the uniform collection of relevant (suitable to its intended purpose) and comparable ambient $PM_{2.5}$ data, and specific site criteria must be satisfied for the 1405-DF to meet the $PM_{2.5}$ FEM regulatory requirements. The design criteria for fine particulate matter ($PM_{2.5}$), including general monitoring requirements, spatial scales, and special site requirements are given in 40 CFR Part 58, App D, Section 4.7 (U.S. Environmental Protection Agency, 2008a).

Extensive details on all aspects of site criteria are given in 40 CFR Part 58, Appendix E (U.S. Environmental Protection Agency, 2006a). When siting an ambient $PM_{2.5}$ monitor such as the 1405-DF, of particular concern is the inlet height, inlet radius clearance, proximity to

potential sources of particulate matter, and spacing from roadways and trees. **Table 9-1** gives the basic requirements applicable to each of these criteria.

Table 9-1. EPA PM_{2.5} site selection specifications, applicable to the 1405-DF, include inlet height, inlet radius clearance, proximity to potential particulate matter sources, and distance from roadways.

Siting Parameter	Situation	Specification	Comments
Inlet height	General	2-15 m AGL ^a	This height interval is considered the “breathing zone”
	On rooftop	2 m above roof surface	Matches inlet specifications for FRM samplers
	Co-located samplers	All inlets optimally at same sample height	Sample heights must meet general height specifications and be at least within 1 vertical meter of each other
	Inlet tube length	Maximum 16 ft (4.9 m)	If inlet is the highest point, then lightning rods are strongly recommended
Inlet radius clearance	General	Minimum 1 m radius clearance	Includes other sampler inlets or objects that may influence airflow
	Adjacent FEM or FRM	Minimum 1 m separation between inlets	
	Co-located	From 1 to 4 m between inlets	
	Near SSI Hi-Vol	Minimum 3 m between TEOM [®] with FDMS and Hi-Vol inlets	
	Near small obstructions	Minimum 2 m	Small obstructions include fences, walls
	Near large obstructions	Distance of 2x height of obstruction	Large obstructions: buildings, sound walls, billboards, etc.
	Overhanging trees	Minimum 20 m from tree drip line	
Arc of unrestricted air flow	Unrestricted 270 degree arc	Prevailing direction of high concentrations must be in the arc	
Nearby particulate sources	General	As far away as possible from blowers or vents	Note: filtered air can contaminate a sample as well as dirty air
Distance from roadways	Less than 3,000 VPD ^b	Minimum 5 m from nearest traffic lane	
	Elevated roadway (>25 m high)	Minimum 25 m away	
	Unpaved roads	As far away as possible	
	Other unpaved areas	As far away as possible	Unpaved sites with vegetative ground cover are acceptable

^a Above ground level

^b Vehicles per day

9.4 ENCLOSURE SELECTION

The 1405-DF may be housed in a walk-in shelter, a mobile trailer, or in specially made environmentally controlled mini-enclosures available from Thermo Scientific (p/n 34-010969-0120.) The enclosure must satisfy the 1405-DF operating temperature range of 8-25°C. (Thermo Scientific is testing the operation of the instrument under a warmer upper limit for the shelter temperature, but the results are not yet available. The results must be reviewed by EPA before a change can be implemented.) To achieve the best results, locate the 1405-DF in an environment with relatively slow temperature fluctuations. Avoid sampling locations with direct exposure to sunlight or that are near a heating or air-conditioning outlet.

As noted in Section 6 (Interferences), care must be exercised to carefully regulate the enclosure temperature to avoid sampler malfunction and/or data bias. Ideally, the enclosure temperature should fluctuate less than 2°C over an hour. The enclosure temperature should also be maintained as close as possible to 5°C less than the operating temperature of the sample stream which is generally 30°C. When possible, the air conditioning system cycle time should be regulated to avoid a 12-minute cycle because this cycle has been observed to cause excessive noise that can overwhelm the sample data.

In addition, the shelter temperature should be regulated based upon the dew point of the ambient air to keep condensation from overwhelming the trap, potentially resulting in improper operation of the sampler or damage to the instrument.

Avoid areas subject to vibration. Since the tapered element microbalance is a harmonic oscillator, external vibrations can perturb the element itself or add uncertainty to the frequency measurements.

9.5 1405-DF INSTALLATION STEPS

The Thermo Scientific TEOM[®] 1405-DF with FDMS[®] Operating Guide (Rev. A.003, Section 2) provides detailed installation procedures. The Operating Guide provides many helpful photos of an actual installation and offers “Installation Considerations” (page 2-2) on key features that must be heeded. A separate outdoor shelter is available from Thermo Scientific, and the Operating Guide provides a separate set of instructions applicable to this deployment option.

This SOP identifies the main installation tasks sequentially and draws attention to those parts of the tasks that are integral to a sound installation. Some special precautions are listed below (Section 9.5.1). Once the installation is complete, the TEOM[®] sample collection filters and the 47-mm purge filters must be installed, and an initial setup and configuration check of the 1405-DF is required (Section 9.6).

The installation procedure involves the following major steps.

1. Determine the exact location for the 1405-DF and make roof modifications
2. Install the pump and cut the tubing to length

3. Install the supplemental water trap, if used
4. Assemble the flow splitter
5. Assemble the tripod
6. Install the virtual impactor and sample flow tubing
7. Install the PM₁₀ inlet
8. Install and connect remaining tubing
9. Install the temperature/relative humidity sensor
10. Check inlet tube grounding
11. Connect power
12. Connect data logger cabling (if used)

The left hand side of Figure 3-1 depicts the 1405-DF system components as they would appear in a typical walk-in installation, with the tripod and inlets located on the roof and the 1405-DF placed on a bench or table. An alternative installation, not shown, places the 1405-DF in the Thermo Scientific environmentally controlled stand-alone outside enclosure. This is described in detail in the manual (Rev. A.003, Section 2, pp 19-26.)

9.5.1 Special Precautions

Some forethought prior to the installation of the system components can prevent subsequent problems; particular consideration should be given to the elements listed below. The 1405-DF is designed to be bench mounted, and it is not practical to install it in a rack because of the height of the FDMS[®] tower.

- Ensure proper inlet alignment and perpendicularity. This is important to avoid transverse stress on the sample tube connectors, which can cause leaks. The sample lines for the PM_{2.5} and PM-Coarse channels should proceed in a straight, vertical line from the PM₁₀ inlet and virtual impactor to the inlet of the unit. *The roof penetration for the sample lines must be drilled 1 3/4" on center directly above the sample lines on the top of the instrument.* The flexible by-pass tubing and the signal cable for the temperature/humidity sensor can be routed thorough an existing side port or a port can be drilled in the roof or wall of the shelter.
- Consider the proper clearance needed on the roof to accommodate the tripod when positioning the instrument on the bench. The legs can be adjusted to different lengths (and angles) to best position the tripod on the roof.
- Make certain the front door to the sampler has adequate room to be fully opened for TEOM[®] filter changes. The operator will generally have the best view to make TEOM[®] filter changes if the instrument is placed at the front lip of the bench.
- Provide adequate access to the back and FDMS[®] side of the instrument for maintenance, repairs, and FDMS[®] filter changes.

- The height of the instrument (50") may require that a drop-down in the bench surface be constructed to accommodate installation.
- Provide clearance for FDMS[®] dryer and valve servicing. A short section of flexible conductive rubber tube, such as that used for Thermo Scientific 8500 FDMS systems, (p/n 30-002274) can be used as a junction in the sample tube between the top of the 1405-DF FDMS[®] tower and the ceiling of the shelter. Removing this short section allows the dryers to be removed without having to remove the rooftop inlet assembly. If this option is used, the gap in the rigid tubing should be about 1 to 1.5"; a longer gap may cause the tubing to collapse during leak checks resulting in a false test failure.
- Provide proper grounding. Poor electrical grounds in any particulate matter sampler can affect concentration values, and proper grounding of the inlet tube is needed to avoid static charge buildup that can lead to errors. The substantial inlet system has a potentially high capacitance, so adequate grounding needs to extend from the size separator inlets, through the sample inlet tubing to the 1405-DF chassis to earth ground. Generally, the design of the instrument and a proper electrical ground will accomplish this but it is best to measure the difference in the potential between the inlet tube and the 1405-DF chassis to confirm the resistance is less than a few ohms.
- Use a tubing cutter to cut the tubing to lengths. Do not allow fragments to fall into the tubes; make sure all cuts are perpendicular to the tube.
- Do not operate the instrument until the ambient temperature/humidity sensor is installed. With no ambient temperature/humidity sensor, the mass flow controllers will attempt to control the sample flow as if the ambient temperature is absolute zero.
- Route the tubing to avoid any HVAC system vents. Reports of condensation problems have been linked to carelessly routed tubing, particularly for the by-pass flow. Inadvertent heating of the sample inlet lines above the FDMS[®] tower could volatilize some PM components before the PM components are measured.
- Provide roof support or harmonic isolation during maintenance. Sampler maintenance will require operators to work on the roof, potentially causing the roof to flex, causing sample tubes to move, and causing disturbance of the mass transducer. Methods to avoid this outcome include installation of a roof platform and/or installation of a section of conductive rubber tubing (p/n 30-002274) in the sample lines to absorb the shock of the roof movement. In addition, areas that receive snow fall may need to plan to avoid extreme temperature gradients or harmonic disturbance. Snow piled along the sample tubes has been reported to cause a steep temperature gradient in the sample flow paths, preventing proper conditioning of the sample stream. It may be necessary to isolate the sample tubes by using a roof flange such as a length of PVC pipe. Also, care should be taken during snow removal from the roof; the tubing may be damaged or the mass transducer disturbed if the inlet is hit by a shovel or other snow removal equipment.

9.5.2 Tools Needed for Installation

Table 9-2 lists the basic tools and supplies that are needed for installing the TEOM[®] 1405-DF with FDMS[®]. Any given installation may require additional tools and supplies as dictated by the situation.

Table 9-2. Tools and supplies for installation of the TEOM[®] 1405-DF with FDMS[®].

Tools and Supplies	Remarks
Drill and drill bits	Half-inch, variable speed drill; 3/8" drill bit for holes to route flexible by-pass tubing and to accommodate cable from relative humidity and temperature sensor; 9/16" bit to accommodate 1/2" sample tubes, and a hole-saw if a PVC pipe is going to be used as a roof flange. Holes for PM _{2.5} and PM-Coarse sample tubes must be drilled 1 3/4" on center directly above sample inlet junction on top of instrument. Depending on roof type, a drill bit extension may be needed.
Hand tools	Screwdriver set, socket set, nut drivers, plumb bob, tape measure, straight edge measure, metal file
All weather caulking	To waterproof the roof flange and feet of the support tripod
Firing strips	To secure sampler position on the bench
Wood screws, lag screws	To secure tripod feet to roof and water trap to the wall
Level	For checking the horizontal level of the TEOM [®] with FDMS [®] and vertical level of the inlet
Tubing cutters	To cut the stainless steel tubes and by-pass tubing
Universal Power Cord	To provide power to the instrument
Bulkhead fittings if PVC pipe used as roof flange	To provide a waterproof seal (1/2" Swagelok male to male bulkhead fitting)
3/8" strain-relief fitting if PVC pipe used as roof flange	To provide a waterproof seal
Analog signal cable	2-conductor cable for analog signals
Ethernet Patch Cable	If data are to be collected through a network connection
Ethernet Cross-over cable	If data are to be collected by a stand-alone computer
25-pin Phoenix Contact male I/O connector if external data logger to be used	The TEOM [®] 1405-DF with FDMS has 8 analog outputs, four analog inputs and two digital contact closures available, or alternatively it can interface to a computer or the data can be downloaded to a USB jump drive
Pipe Insulation	To avoid condensation formation for samplers installed in humid areas

9.5.3 Determine the Exact Location of the 1405-DF and Make Roof Modifications

Refer to the 1405-DF Manual for additional details. Roof modifications for roof tops that are under warranty may need to be performed by a licensed contractor.

- Determine the exact location of the 1405-DF inside the shelter.
 - Ensure adequate access to the instrument, especially the rear and the left side housing the 47-mm purge filters
 - Check that there is adequate room for the tripod legs on the roof
 - Ensure inlet perpendicularity with the 1405-DF inlets at the top of the FDMS[®] tower
- Drill the holes for the sample tubes and roof flange.
 - Once the 1405-DF is in position, a plumb bob may be used to mark the center point of the roof penetration.
 - Once the center point of the roof penetration has been identified on the inside ceiling, use a small diameter drill bit with an extension to drill upwards through the ceiling until it penetrates the exterior roof. That point will mark the center of the roof penetration to be drilled from the rooftop downward.
 - Some users may prefer to install a short section of 4" PVC pipe to use as a roof flange (see 1405-DF Manual (Rev. A.003) for example). This approach allows a little extra leeway, because once the 4" hole is cut in the roof, the 1405-DF may be shifted slightly to accommodate accurate positioning of the stainless steel inlet tubes.
 - *The holes for sample tubes must be drilled 1 3/4" on center directly above the sample tube inlets on top of the FDMS[®] tower.*
- During drilling, protect the 1405-DF from falling debris.
- The flexible by-pass tubing and the signal cable for the temperature humidity sensor can be routed thorough an existing side port, or a port can be drilled in the roof or wall of the shelter. The diameter of the by-pass tubing is 3/8" and the diameter of the cable is approximately the same.

9.5.4 Install the Pump

Refer to the 1405-DF Manual for complete details.

- Determine where the pump will be installed. It is generally installed on the floor below the bench on which the instrument is to be located. It may be placed on a piece of closed-cell foam to dampen vibration, but care must be taken not to create a fire hazard. The pump should be less than 5 meters from the instrument or the provided tubing should be replaced with either rigid pipe or larger diameter tubing to prevent an increased pressure drop.
- Measure and cut the green conductive tubing and install as specified in the manual. All tubing cuts must be perpendicular (square) and smooth to avoid leaks at connections.

9.5.5 Select a Location for the Supplemental Water Trap and Mount It (If Used)

The coalescing filter on the rear of the 1405-DF acts as a water trap. Thermo Scientific has also been supplying an additional water trap with coiled tubing, but this is not required for the 1405. Refer to the 1405-DF Operating Guide for complete details on installing the supplemental water trap.

If the supplemental water trap is used:

- Select a location near the 1405-DF to mount the supplemental water trap assembly. Anticipate the route of the by-pass flow line from the flow splitter on the roof, and
 - Install the trap so there will not be a portion of the by-pass tubing lower than the trap which would result in water in the line instead of the trap.
 - Avoid routing the tubing past HVAC exhausts or vents that would alter the temperature of the air.
- Be aware that the filter element will load from the inside and therefore may appear clean even when heavily loaded. Because this is a redundant filter, depending on local conditions, the element may be removed so that the supplemental system is a simple water trap.

9.5.6 Assemble the Flow Splitter

Refer to the 1405-DF Manual for additional assembly details.

- For the flow splitter to correctly split the entering 15.0 lpm flow into the bypass (12.0 lpm) and fine fraction sample (3.0 lpm) flows, it is essential that the top of the inner sample tube (carrying the fine fraction flow) be positioned 6 inches ($\pm\frac{1}{4}$ inch) from the top of the flow splitter (**Figure 9-1**).

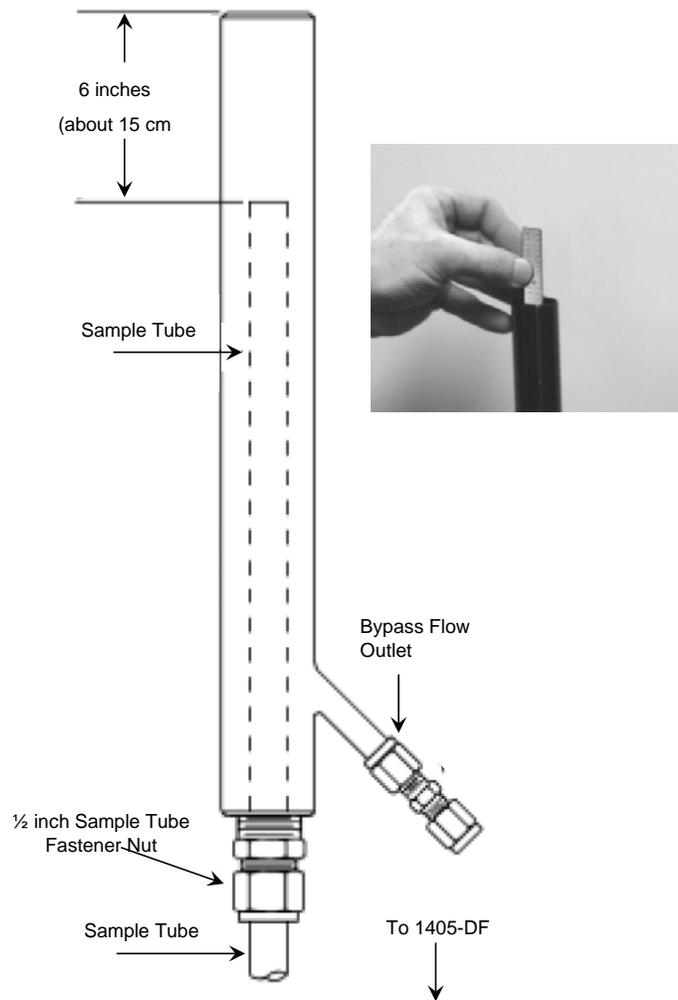


Figure 9-1. Schematic of the isokinetic flow splitter showing the position of the sample tube inside the splitter (left), which is positioned using a straight edge measure (right).

9.5.7 Assemble the Tripod

If the inlet is to be installed on the rooftop of a building, then the optional tripod should be used to support the hardware. Refer to the 1405-DF Manual for complete tripod assembly details.

The assembled flow splitter is inserted into the apex of the tripod, and the tripod is set on the roof above the roof opening leading to the 1405-DF. It is important to adjust the height and position of the tripod legs so that the sample tube extending downward from the flow splitter is vertical (plumb). At this stage only an approximate leveling adjustment is needed.

9.5.8 Install the Virtual Impactor and Sample Flow Tubing

Refer to the 1405-DF Manual for assembly details.

- When making connections, be sure fittings are fully seated to prevent leaks.
 - The flow splitter must be fully inserted into the sleeve of the impactor.
 - The sample tube for the PM-Coarse must be fully inserted into impactor before tightening the Swage nut. Note that the ½" tube for the coarse sample installs *through* the compression fitting on the base of the virtual impactor. This fitting has been drilled out to allow the tube to provide a flush outlet from the virtual impactor without any gap or protrusion that might be possible with a standard compression fitting. A common mistake is to insert the tube as if a stop exists in the fitting.
- The PM_{2.5} and PM-Coarse sample tubes should be parallel, and at equal level at the bottom.

9.5.9 Install the PM₁₀ Inlet

Install the sample inlet tube on top of the virtual impactor and set the PM₁₀ inlet on top of the sample inlet tube.

- The PM₁₀ inlet should ideally be 2 m (but must be between 1.8 and 2.1 m) above the roof.
- Adjust the tripod legs to meet the height requirements and true the sample inlet tubes.

9.5.10 Install and Connect Remaining Tubing

- Measure and cut the stainless steel tubing extensions required to connect the sample inlet ports on the top of the FDMS[®] tower to the fine and coarse sample tubes extending downward from the tripod.
- It is worth the extra effort to install rubber tubing connectors (p/n 30-002274) between the top of the FDMS[®] tower and the ceiling.
 - Install a short section of stainless steel inlet tubing extending up a few inches from the ½" Swagelok fittings on the top of the FDMS[®] tower, and install the rubber tubing connectors between the tubing stub and the rest of the inlet tubing leading to the roof. This enables dryer and valve removal during future servicing of the FDMS[®] unit without having to disturb the inlet hardware infrastructure. The gap in rigid tubing should not exceed 1.5 inches to avoid deforming during leak tests. The tubing must be periodically replaced to avoid leaks due to cracking. The tubing must be conductive; standard elastic tubing can not be substituted due to static build-up.
 - Make final adjustments to the tripod, lowering or raising as needed to complete the tubing connections, and secure the tripod to the roof.
- Connect the by-pass tubing to the by-pass fitting on the flow splitter, and connect the other end of the bypass tubing either to the coalescing filter mounted on the back of the

1405-DF, or, if the supplemental water trap is being used, connect it to the water trap. In the latter case, additional tubing will be needed to connect the water trap to the coalescing filter on the back of the 1405-DF.

- To avoid condensation in the sample tubing, Thermo Scientific strongly recommends that the user insulate the sample tube extension with pipe insulation when operating the instrument in areas of high humidity.

9.5.11 Install the Temperature/Relative Humidity Sensor

Refer to the 1405-DF Operating Guide for complete details.

- Mount the sensor on the flow splitter with the provided U-bolt.
- Identify the best route for the cable from the temperature/RH sensor to the back of the 1405-DF. Additional drilling may be required to provide a port through the roof or PVC fittings.
- Caulk the cable entry port to prevent leaks.

9.5.12 Check Inlet Tube Grounding

A solid station ground (earth ground) must be available for the 1405-DF chassis ground, and the inlet tube must be adequately grounded to the 1405-DF chassis. Any buildup of static charges from an ungrounded inlet tube can cause errors in the 1405-DF measurements, so this ground is important, especially in areas with electromagnetic fields (e.g., near high voltage power lines or radio frequency antennas). Measure the resistance between the bottom of the inlet tubes and the chassis ground terminals on the power plug of the 1405-DF. The resistance should be a few ohms or less.

9.5.13 Connect Power

- The TEOM[®] 1405-DF unit accepts all voltage inputs between 85 and 240 volts AC.
- SAFETY FIRST:
 - Use an appropriate, code-approved, grounded electrical outlet. Contact a qualified electrician if there is doubt as to whether the power service for the instrument is adequate.
 - The connection should be easily accessible.
 - DO NOT attempt to bypass the grounding requirements. It is needed for safety and to prevent buildup of static charges.

Even a momentary power interruption will cause the monitor to perform a stability self-check during which the monitor will not collect data. To avoid this data loss, some users connect the TEOM[®] 1405-DF with FDMS[®] power cord to an uninterruptable power supply

(UPS). If used, both the pump and the control unit should be plugged into the UPS to protect the mass flow controllers in the system. The control unit continuously monitors the flow rates and attempts to maintain the target flow rates by adjusting the valve in the flow controllers. If the control unit is on and the pump is off because only the power to the controller is maintained during the interruption, the controller will repeatedly send control voltage to attempt to fully open the valve, possibly leading to valve failure during an extended power failure. Some users may opt to install a power conditioning system in line, such as a “spike protector.”

9.5.14 Connect Data Logger

If an external data logger is used to capture 1405-DF data (expected), the data logging connections may be made at this time or anytime after the unit is operational. The available connectors on the back of the unit are Ethernet (RJ45), USB, and a 25-pin female I/O supporting analog out, analog in, and digital out (requires 25-pin male connector). A 9-pin RS232 connector and a USB port are available on the front of the instrument. Each user must identify the approach most compatible with their system and configure their data acquisition system and the 1405-DF appropriately. Communications and data downloads are discussed in Section 10 “1405-DF Communications”.

9.6 INITIAL SETUP AND CONFIGURATION CHECK

Once the system hardware components are in place, the following steps will get the TEOM[®] 1405-DF up and running:

- Power on the 1405-DF, the vacuum pump, and allow 1-hr warm-up
- Review touch screen functions and screen displays (new users)
- Review/adjust the configuration parameters
 - Set Flow Control to Actual conditions
 - Review/adjust PM_{2.5}, PM-Coarse, and Bypass flow rates
 - Confirm K0 constant
 - Confirm Temperature settings
 - Confirm Mass Calculation Variables’ settings
 - Set the clock
- Perform verifications/calibrations
 - Leak check
 - Ambient Temperature Calibration
 - Barometric Pressure Calibration
 - Flow calibration

- Load filters (2 TEOM[®] and 2 FDMS[®])
- Select the Data Storage options desired
- Setup the password function, if desired

9.6.1 Power On and Warm Up

Power on the 1405-DF and the vacuum pump and allow the 1405-DF to warm up. A title screen will show briefly, followed by the TEOM[®] Data screen, from which all other touch-screens may be accessed (**Figure 9-2**). In this SOP, unless otherwise explicitly stated, the path to access different screens or parameters is given as “Screen > Button > Button...”.

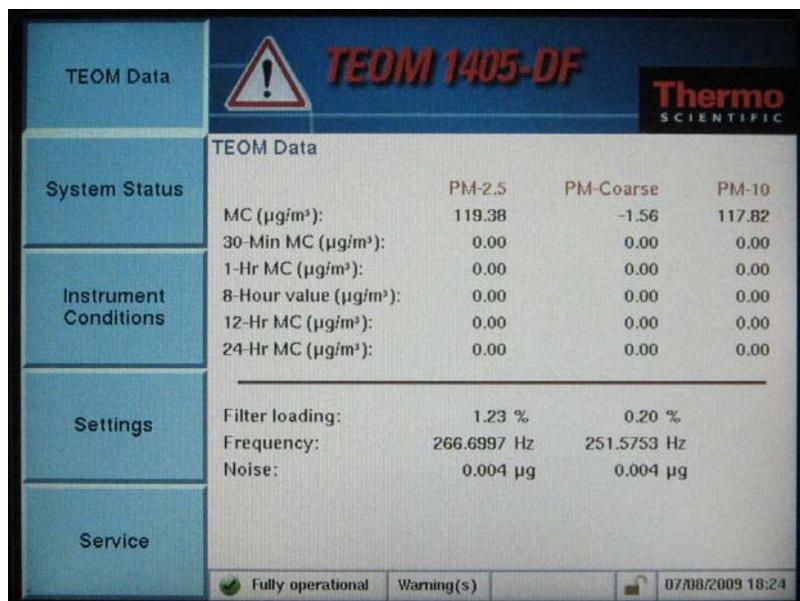


Figure 9-2. The Data Screen. Note the buttons on the left, which provide access to all available 1405-DF operating information.

9.6.2 Review Screen Displays and Touch Screen Functions

The touch screen display interface is used any time a technician interacts with the 1405-DF. Many screens launch Wizards (especially in the Service menu) to guide the operator through the necessary procedures. The instrument warm-up period offers a good opportunity for new users to become familiar with this interactive display. Select each one of the main menu buttons, and, in turn, explore the underlying layers of screens that can be accessed. Most of the screens, and parameters therein, will be intuitively understood by most users, but full explanations are offered in the 1405-DF Operating Guide. The bottom of each screen has a status bar that displays the current operating information about the instrument, including the current time and date, the current status (“Normal”, or “Warning(s)”), and whether the unit is in “lock mode” (requiring a password for access).

User provided set points are entered or changed using a number keypad (**Figure 9-3**), which will automatically appear any time the instrument needs data input from the user.

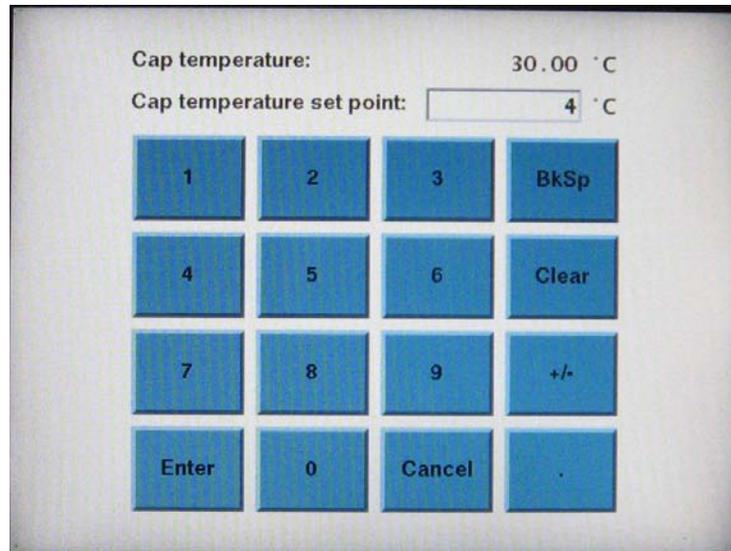


Figure 9-3. The data entry keypad for user-entered settings. The example illustrates adjusting the Cap temperature set point.

Aside from the TEOM Data screen, four other main screens are available:

- System Status Screen. Provides basic operating information and access to the list of the current active status warnings.
- Instrument Conditions Screen. Accesses several temperature and flow settings and the current ambient air conditions for the instrument.
- Settings Screen. Provides access to system, data, and advanced settings for the instrument
- Service Screen. Provides access to maintenance and verification Wizards and procedures, as well as advanced troubleshooting and service tools.

9.6.3 Review/Adjust Configuration Parameters

The setup parameters required to meet FEM EQPM-0609-182 must be checked and adjusted if necessary. Other instrument parameters should be confirmed. The default parameter settings in the instrument as received from Thermo Scientific should be correct, but they must be verified.

Set the Flow Control to Actual Conditions

The instrument must use the ambient temperature and pressure, as measured by the instruments sensors, to control and report the volumetric flow rate.

- Select the Instrument Conditions screen
- Select the Flows button to display the Flows screen
- Select the Flow Control Button to select the Flow Control screen
 - Press the Active button and the Actual button.
 - Press the OK button.

Review/Adjust the Flow Rates

- Select the Instrument Conditions screen
- Select the Flows button to display the Flows screen.
- Select the Flow Rates button to confirm, or adjust if necessary, the desired flow rates:
 - PM_{2.5} (3.0 lpm)
 - PM-Coarse (1.67 lpm)
 - Bypass flow (12.0 lpm)

Confirm K0 Constant for Each Microbalance

- Select the Settings screen
- Select the Advanced button
- Select Mass Transducer K0 Constants button
 - Confirm the current K0 settings of the PM_{2.5} and PM-Coarse TEOMs. The numbers programmed into the unit *must* match the K0 constants on the label near the mass transducer (under the insulation.) One can also locate the original calibration constants (“Average K0”) on the “Instrument Checkout Record” or the “Final Test Record” documents that are shipped from the factory with the instrument.

Confirm Temperature Settings

All parameters which are not listed specifically in FEM EQPM-0609-182 should be left at the default settings listed below.

- Instrument Conditions > Instrument Temperatures:
 - Cap: 30°C
 - Case: 30°C
 - PM_{2.5} Air Tube: 30°C
 - PM-Coarse Air Tube: 30°C

- Instrument Conditions > FDMS Module
 - PM-2.5 Cooler Temp : 4°C*
 - PM-Coarse Cooler Temp : 4°C*

* A second chiller temperature set point, 10°C, is under review, and if approved may prove useful to users in humid locations. A warmer chiller set point, adjusted seasonally, may prevent entrained condensation problems.

Confirm Mass Calculation Variables

- Settings > Advanced > Mass Calculation Variables
 - System wait time: 1800 seconds
 - XX-Hour value: 8 hours
 - Frequency Wait Time: 60 seconds

Set the Clock

The 1405-DF clock should be permanently set for standard time, and should never be reset to daylight savings time. If desired, the date format can be changed.

- Select the Settings screen
- Select the System button
 - Select the Set Time button and set the current date and time
 - Select the Date Format button to select the desired format, “Month/Day/Year” or “Day/Month/Year”. (Note: the 1405-DF must be restarted to have this change take effect.)

9.6.4 Perform Initial Verifications and Calibrations

Before routine sampling is begun, the system must be checked for leaks, the ambient temperature and barometric pressure sensors must be calibrated, and a flow calibration performed. Since the volumetric flow calibration depends upon accurate temperature and pressure inputs, perform the ambient air temperature and pressure calibration before executing the flow calibration procedure.

Conduct a Leak Check

Always use the 1405-DF Leak Check Wizard (Service > Verification > Leak Check) to conduct a leak check. In addition to providing step-by-step instructions, the Leak Check Wizard automatically disables the switching valve during a leak check. *Performing a leak check without the Wizard can damage the switching valve.* The Leak Check Wizard step-by-step instructions are also provided in Section 3 of the 1405-DF Operating Guide. The leak check should be conducted while the sample flows are routed through the two paths—the reference cycle and the

base cycle. Firmware version 1.50 (expected for release in late 2009) is expected to automatically direct the user through the process to leak check both cycles.

The Leak Check Wizard compares the measured difference between the unit's "zero" flow with the vacuum disconnected and flow through the instrument with the inlet blocked (which should match or be near to the "zero" flow value). A leak check/flow adapter is required (**Figure 9-4**).



Figure 9-4. Leak check/flow adapter.

Leak check tolerances may vary by agency. Thermo Scientific recommends a tolerance of ± 0.15 lpm for the PM_{2.5} and PM-Coarse leak checks and ± 0.60 lpm for the Bypass leak check. The Wizards are set to give failure warnings based on those recommendations.

To conduct a leak check

- Select the Service screen;
- Select the Verification button; and
- Select the Leak Check button and follow the instructions on the Leak Check Wizard.
 - Remove TEOM[®] filters from the system
 - NOTE: After the leak check adapter is installed in the inlet and closed, the 1405-DF pauses for 1 minute to allow the flows to stabilize. The next step in the Wizard advises the user to slowly open the leak check valve to restore flows to the system. This should be done right away—if the user waits too long the leak check may fail, even if it was within tolerances. Note, however, the valve should be opened slowly to avoid a sudden change in system pressure.

- NOTE: The only component of the inlet system that is removed for the leak check is the PM₁₀ inlet.

There are numerous places between the top of the inlet and the TEOM® microbalance where leaks could occur. A leak that persists must be located and corrected. The most common cause for a leak is a failure of the press-to-seal connectors. In case of a leak test failure, first check these, and adjust or replace if necessary. If the failure persists, the best method to isolate a leak in any sampler is to cap the flow at about the mid-point and then determine which section of the sampler is leaking. Ideally, the sections would be reduced by half again until the leak is located. The steps below provide guidance to isolate leaks in the 1405-DF. **Figure 9-5** shows the flow paths of the fine (A) and coarse (B) streams and is a visual guide to “section” the system during a leak check. The steps to isolate a leak follow.

1. If, when performing the leak check, the Wizard shows a failure, note which channel fails; follow the isolation process for that channel.
2. Remove the virtual impactor and cap from the separate lines of flow when prompted by the Leak Check Wizard. If only one channel failed the leak check, only the result for that channel need be reviewed. For example, if the Wizard indicated a leak in the Coarse flow channel, cap off only the Coarse flow line and run the check again using the Wizard. The Wizard will indicate an unsuccessful result for each path (because the others are not capped); review only the result for the Coarse flow path and disregard the results for the fine and bypass paths.
3. If the Wizard result still indicates a failure, move to the next connection point—the top of the FDMS® tower or inside the tower below the dryer assembly. **CAUTION!! It is critical not to draw a vacuum in the dryer because the dryer will suffer irreparable damage.** Disconnect the dryer assembly from the top of the switching valve and cap off the flow at the top of the switching valve. Review the result. If the Wizard indicates a pass, the dryer may have a leak and need replacing. If the test fails, continue to the next connection point.
4. Isolate the switching valve from the chiller/conditioner by disconnecting the Teflon lines to the chiller on the associated channel. “Loop” the two elbows on the front of the switching valve by connecting them together using the solid Teflon tube that normally connects the top port on the chiller assembly to the switching valve (**Figure 9-6**). Run the Leak Check Wizard again; if the Wizard indicates a pass, check the seating of the purge filter and seals and return to Step 3. If the test fails, go to the next connection point—the top of the air tube assembly.

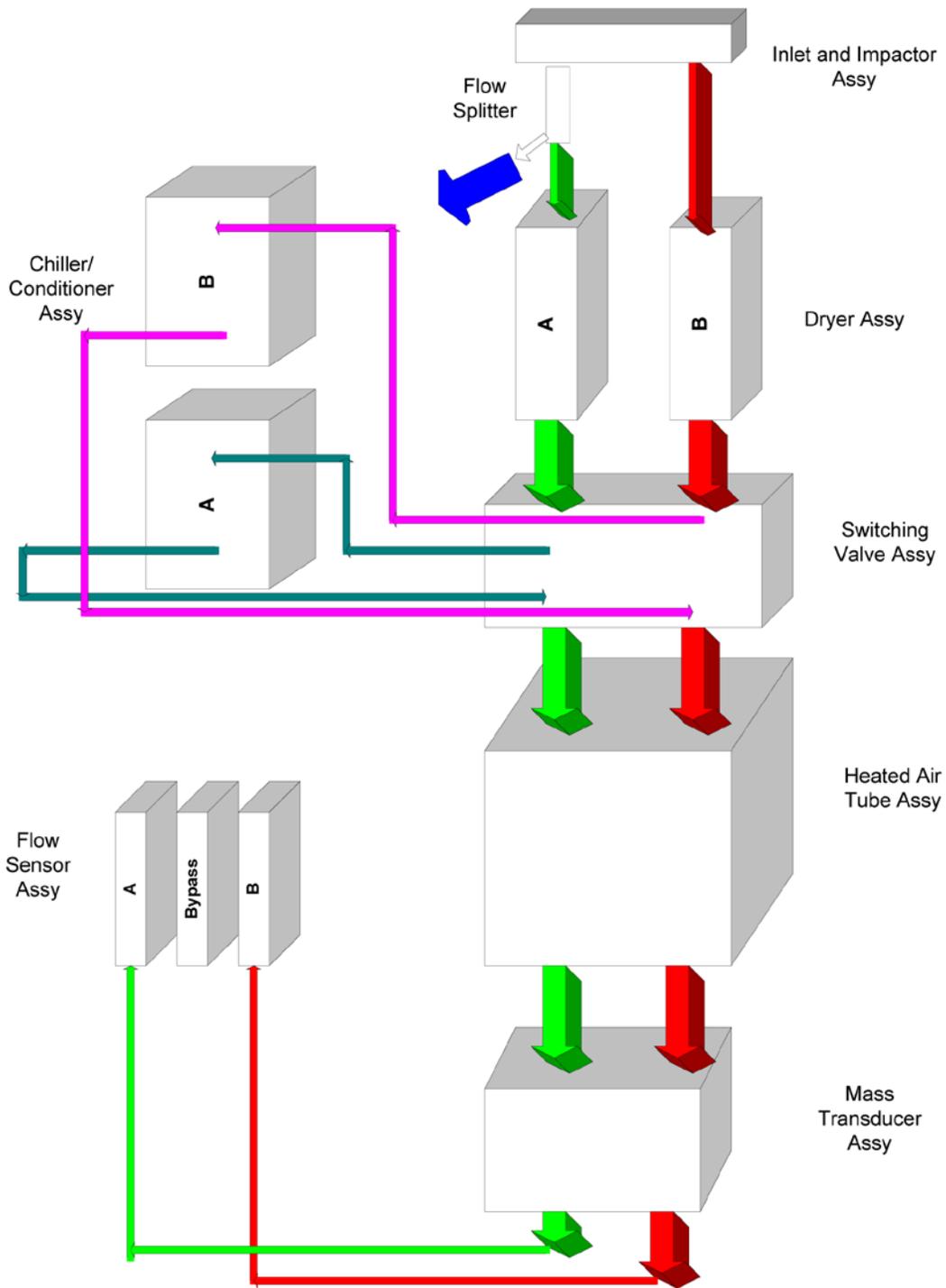


Figure 9-5. Flow paths of the fine (A) and coarse (B) streams.

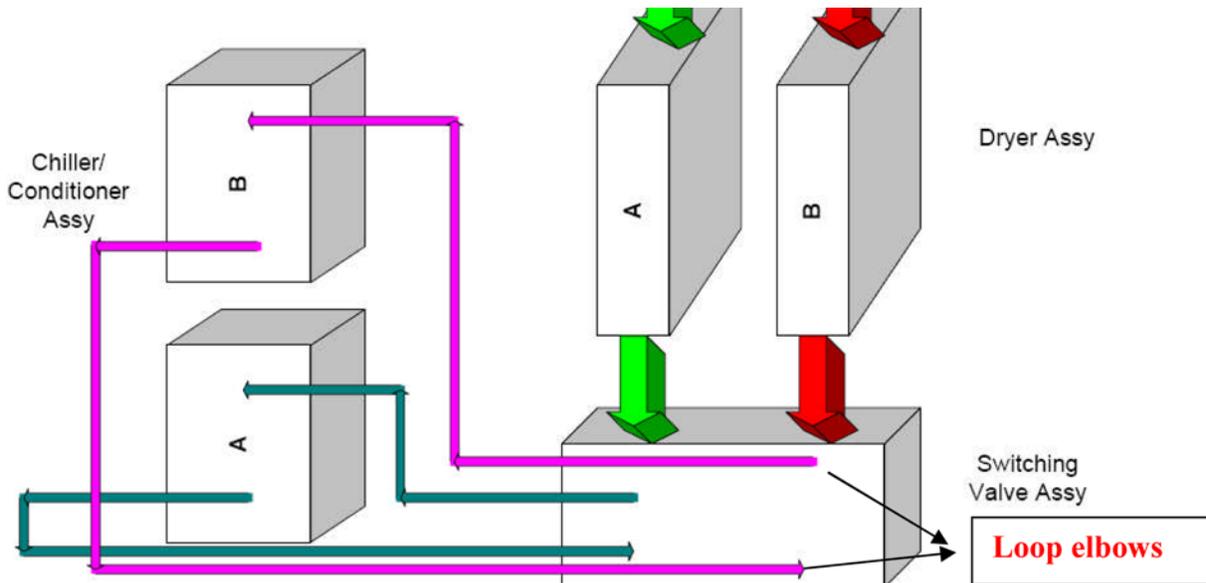


Figure 9-6. Isolate the chiller by “looping the elbows”.

5. Remove the switching valve from the top air tube assembly and run the Leak Check Wizard again. If the result shows that the leak check passes, the leak is in the switching valve. Clean the switching valve, inspect the seals in the block, and replace as needed. If the result shows a test failure, move to the next connection point—the bottom of the mass transducer assembly.
6. Disconnect the rubber tubing from the underside of the mass transducer and cap off end or pinch the tube to form a seal. If the result indicates that the leak check passes, the leak may be in the air tube assembly or in air tube assembly connection to the top of the mass transducer assembly; inspect the tubing. If the result indicates a test failure, move to the next step.
7. Check the in-line filter bowl on the back of the unit for a proper seal; verify that the O-ring is not cracked or missing. If the in-line filter is in good order, replace the flow controller assembly.
8. If the leak can not be isolated after following the steps above, contact Thermo Scientific for technical support.

Calibrate the Ambient Temperature Sensor

A temperature sensor, annually referenced to within $\pm 0.5^\circ \text{C}$ of a National Institute of Standards and Technology (NIST) thermometer, is required to calibrate the 1405-DF ambient temperature sensor. See Section 10.1.15 of this SOP (or Section 5 of the 1405-Df Operating Guide) for calibration instructions.

Calibrate the Barometric Pressure Sensor

A barometric pressure sensor, annually referenced to within ± 5 mm Hg of a NIST pressure sensor, is required to calibrate the 1405-DF barometric pressure sensor. See Section 10.1.16 of this SOP (or Section 5 of the 1405-DF Operating Guide) for calibration instructions.

Perform a Flow Calibration

Because the installation of the 1405-DF is new, all flows should be calibrated. This activity involves a three-point check of the PM_{2.5}, PM-Coarse, and Bypass flows and adjustment of the flow rate for any flow path that deviates from the target rate by more than 2%. The 1405-DF provides a Flow Calibration Wizard to guide the user through the necessary steps. It provides pictures as well as textual descriptions of the steps. The Wizard is entered via the touch screen Service > Calibration > Flow Calibration. See SOP section 10.3.5 and Section 5 of the 1405-DF Operating Guide for a complete listing of the flow calibration instructions as given in the Wizard. A NIST-traceable flow transfer standard capable of measuring flow rates between 1.3 lpm and 16.7 lpm is required.

To conduct a flow calibration,

- select the Service screen;
- select the Calibration button;
- select the Flow Calibration button; and
- follow the instructions in the Flow Calibration Wizard to calibrate the flow rate for each of the three flow fractions independently. This process requires that a 3-point calibration be conducted for each flow fraction.

9.6.5 Load the TEOM[®] (Sample Collection) and FDMS[®] (Purge) Filters

Two TEOM[®] sample filter cartridges and two FDMS[®] purge filters must be loaded into the TEOM[®] 1405-DF with FDMS[®] for sampling. It is important to have equilibrated spare TEOM[®] sample filters available to avoid data interruptions; therefore, spare filters should be installed (and replaced upon use) on the equilibration posts next to the sample filters in the transducer assembly. Thermo Scientific requires that the sample filter only be handled with the special filter loading tool provided with the instrument.

The 1405-DF has a Filter Replacement Wizard, with pictures and instructions. It is strongly recommended that this Wizard be used until the user is fully competent in the technique. Traditionally, filter seating errors have been common problems associated with TEOM[®] use, and using the Filter Replacement Wizard can help detect filter seating problems. An option, “Advanced User Mode”, can be selected in the first screen of the Wizard to allow the user to bypass the Wizard entirely. If this option is chosen, the instrument will be put into Setup mode and will be stopped. When the filters have been replaced, the Wizard will remind the user to check the frequencies and exit the Wizard. (**Important:** If the Advanced Users Mode is

selected, the Wizard DOES NOT automatically verify the frequency. Users MUST ensure that the frequency is stable in order to ensure valid data. Inspect the oscillating frequency change rate on the TEOM[®] Data screen; the last two digits of the reading will fluctuate [due to noise] but the other digits should remain steady. Fluctuation observed in more than the last two digits may indicate that the TEOM[®] filter is loose or defective. Re-seat the filter and check the frequency again. If the frequency continues to show fluctuation in more than the last two digits, replace the filter again. This process may need to be repeated until the frequency stabilizes. Note that if the “Advanced User Mode” is selected, it remains the default setting [highlighted blue]).

The 1405-DF sample collection filters for the PM_{2.5} and PM-Coarse flows need to be changed periodically before filter loading can affect the flow, or at least every 30 days. Always change the PM_{2.5} and PM-Coarse filters at the same time. Also, the 47-mm FDMS[®] purge filters *must* be changed when the TEOM[®] filters are changed. Wipe away any condensation that has accumulated on the FDMS[®] housing before installing the replacement filter.

The filter loading percentage value (TEOM[®] Data screen) indicates the percentage of the TEOM[®] filter’s total capacity that has been used. Because this value is determined by the pressure drop of the main sample flow line, the instrument always shows a non-zero value even if no TEOM[®] filter is mounted in the mass transducer. New TEOM[®] filters generally exhibit filter loading percentages of 15% to 30% at a flow rate of 3 lpm, and less at lower flow rates. Because this value is an indication of a pressure drop, the loading does not progress in a linear fashion. Operators are cautioned to become familiar with the loading pattern based on local conditions, to avoid data loss due to filter overloading. Special diligence is required to monitor the PM-Coarse flow because a small absolute change will result in a large percentage change in the low flow rate. The filter may require changing well below the indicated filter loading of 100% to maintain the proper flow rate.

Some agencies collect the used FDMS[®] filters for post-sampling analysis. If so, special filter handling procedures must be implemented, such as those used for FRM filters. The filters should only be handled with forceps or clean cotton gloves, and may need to be pre-loaded into cassettes and transported with protective covers to ensure that the filters are not contaminated.

Figure 9-7 (left) shows a close-up view of the filter element being placed on the top of the tapered element, and Figure 9-7 (right) schematically illustrates the loading steps, and unloading steps, of the sample filter cartridge in the instrument. Important considerations during the filter handling process include

- Do not touch the filter with anything except the filter tool provided. Keep the tool clean.
- The tapered element is somewhat fragile. The sleeve on the bottom of the filter cartridge needs to be placed straight down on the tapered element; do not try to twist or tilt the filter or the element may break, necessitating a major repair.
- After the filter is placed on the element, use the installation tool to press straight down on the filter to fully seat it.
- The pump should be running when the filter is installed; this will help seat it properly.

- When the filter loading is complete, confirm that the sample frequency remains steady.
- Minimize the amount of time the transducer door is open to avoid large shifts in temperatures in the sample path which will increase re-equilibration times.

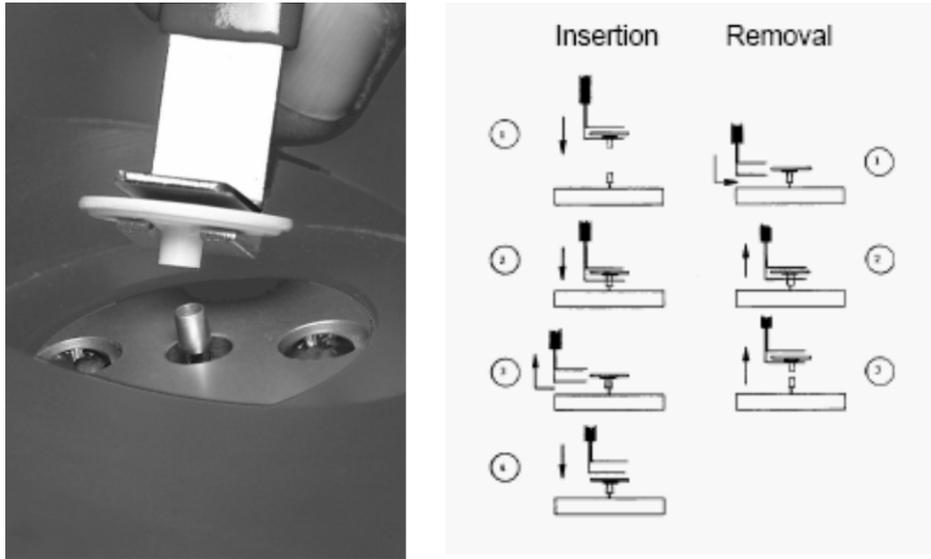


Figure 9-7. A close up of the filter element being placed on top of the tapered element (left) and steps in the filter insertion and removal process (right).

To Install a TEOM[®] Filter

Ensure that the filter exchange tool is clean and free of any contamination that might be transferred to the TEOM[®] filter.

- Select the Service button to display the Service screen
- Select the Maintenance button to display the Maintenance screen
 - Select the Replace TEOM[®] Filters button to start the TEOM[®] Filter Replacement Wizard.
 - Place two TEOM[®] filters on the TEOM[®] filter holders in the mass transducer compartment to condition the filters so that they are already equilibrated when the next filter change occurs.

When the Wizard finishes, the system will automatically test the two newly installed TEOM[®] filters to ensure they are firmly seated. The system will display a screen with the wait time. If the system is unable to obtain a stable frequency for one or both of the filters, it will display a screen telling which filter (or filters) needs to be re-seated. If the filters need to be re-seated, continue to follow the Wizard instructions to re-seat the filter. The system will again display the waiting screen while it is testing for stable frequencies. If it still cannot obtain a

stable frequency for one or both of the filters, it will prompt the user to re-seat the filters a second time. If it still cannot obtain a stable frequency, the Wizard will direct the user to replace the filter again; if that does not rectify the problem, the Wizard will show a failure warning and recommend appropriate service.

The back-supply of TEOM[®] sample filters should be stored inside their original carrier box, in the interior of the unit near the mass transducer to ensure they are at or near the appropriate temperature and humidity level for sampling. They are shipped with a desiccant pack to minimize the equilibration time required for the initial installation. One set of filters should be placed on the equilibration posts in the mass transducer housing to maintain a spare set of fully equilibrated filters for use.

To Install the 47-mm Purge Filters

- Locate the two doors on the left side of the TEOM[®] 1405-DF unit.
- Open one of the small filter doors (**Figure 9-8**).

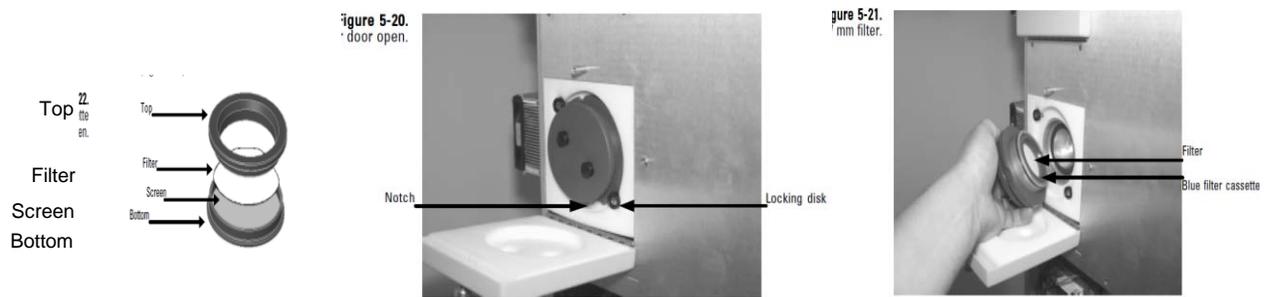


Figure 9-8. Stacking order of the 47-mm filter cassette (left), an open 47-mm purge filter door showing the filter holder (center), and the filter holder showing the cassette (right).

- Turn the filter holder counterclockwise until the notches line up with the locking disk (Figure 9-8), then pull outward to remove the holder from the unit.
- Locate the blue filter cassette and remove the used 47-mm filter.
- Insert a new 47-mm filter into the cassette. Be sure to install the 47-mm filter into the cassette with the textured face of the filter paper facing the “top” of the cassette. The “top” of the cassette fits into the “bottom” of the cassette (Figure 9-8). Note that the filter has a textured face that should be oriented into the air flow or towards the “top”; the smooth side of the filter should be placed towards the screen. Do not touch the filter with your hands if later analysis is desired.
- Close the filter cassette by pressing parts together.
- Install the filter into the filter holder with the “top” of the cassette and filter surface facing out.

- Line up the notches with the locking disks and install the filter holder into unit. Turn the holder clockwise to lock it in place. Do not over-tighten the filter holder. The O-ring creates the seal, not the force of the turn. Over-tightening may damage or distort the O-ring and cause a leak.
- Close the filter door.
- Repeat for the other 47-mm filter.

9.6.6 Select the Data Storage Options Desired

The unit stores only those variables selected by the user. If instrument variables are not set up to be logged, they will not be saved. The system default selections will need to be updated to suit the needs of each individual agency.

To select data storage variables:

- Select the Settings menu button to display the Settings screen.
- Select the Data Storage button to display the Data Storage screen.
- Select the Edit List button to display the Edit Data Storage screen.
 - Press the names of the variables you wish to log, up to a maximum of 20. Use the Next Page > and < Previous Page buttons (10 pages in all) to scroll through the entire list of variables that can be stored. Select the OK button when all the desired variables have been selected. A suggested list of variables is presented in **Table 9-3**; the complete list of variables that can be used is presented in **Table 9-4**.
 - Use the ▲ and ▼ buttons to scroll through the list of variables to save to ensure that all desired variables are selected.
 - Select the Storage Interval button to set the interval for data storage. Enter the desired data storage interval into the keypad and select the Enter button. For example, if the storage interval is 10 seconds, every 10 seconds the instrument will log (save) the data for the selected variables.
 - When all the desired variables are selected and the Storage Interval is set, select the <Back button to return to the Settings screen.
 - Upcoming version of the software (due to be released 9/15/2009) is expected to allow for storage of 30 variables and is expected to allow the user to select the order of the variables so long as ePort version 1.4 or later is used (if an earlier ePort version is used variables will be sorted alphabetically).

The internal 1405-DF data storage capacity is determined by the Storage Interval (how often values are written to memory) and by the number of variables stored. The 1405-DF standard memory allotment is 1.6GB, providing storage for approximately 30 weeks of data when the Storage Interval is set to 1 minute and the maximum of 20 variables is stored.

Table 9-3. List of suggested variables for storage.

PRC Code	Variable	Comment
8	System Status	hexadecimal code
61	Ambient Temperature	°C from outdoor sensor
63	Ambient Humidity	%RH from outdoor sensor
66	Ambient Pressure	ATM from outdoor sensor
90	Bypass Volumetric Flow	to monitor inlet flow
96	Vacuum Pump	should be <0.3 ATM
226	TEOM A Flow Rate	volumetric flow in lpm
242	TEOM A Filter Loading	OK < 80%
243	TEOM A Total Mass	total mass on filter in µg
258	TEOM A Noise	should be <0.1
271	TEOM A Dryer Temperature	should be > shelter temp & <30°C
272	TEOM A Dryer Dew Point	must be >2° below set-pt (4°C)
287	TEOM A Cooler Temperature	°C
310	TEOM B Flow Rate	volumetric flow in lpm
326	TEOM B Filter Loading	OK < 80%
327	TEOM B Total Mass	total mass on filter in µg
342	TEOM B Noise	should be <0.1
361	TEOM B Dryer Temperature	should be > shelter temp & <30°C
362	TEOM B Dryer Dew Point	must be >2° below set-pt (4°C)
373	TEOM B Cooler Temperature	°C

Table 9-4. List of variables from which up to 20 may be chosen for storage.

Operating Mode	System Status	Case heater raw output
Case temperature	Case temperature set point	Cap heater raw output
Cap temperature	Cap temperature set point	Ambient temperature
Ambient relative humidity	Ambient dew point	Ambient pressure
Enclosure temperature	Bypass flow rate	Bypass volumetric flow rate
Bypass flow set point	Vacuum pump pressure	PM-2.5 air tube set point
PM-Coarse air tube set point	Analog output #1 value	Analog output #2 value
Analog output #3 value	Analog output #4 value	Analog output #5 value
Analog output #6 value	Analog output #7 value	Analog output #8 value
Analog input #1 value	Analog input #2 value	Analog input #3 value
Analog input #4 value	PM-2.5 flow rate	PM-2.5 vol. flow rate
PM-2.5 flow set point	PM-2.5 air tube temp	PM-2.5 air tube surface temperature
PM-2.5 TEOM filter pressure	PM-2.5 TEOM filter load	PM-2.5 total mass
PM-2.5 raw MC	PM -2.5 MC	PM-2.5 unclipped MC
PM-2.5 unclipped MR	PM-2.5 30-Min MC	PM-2.5 1-Hr MC
PM-2.5 XX-Hr MC	PM-2.5 12-Hr MC	PM-2.5 24-Hr MC
PM-2.5 mass rate	PM-2.5 frequency count	PM-2.5 frequency cycles
PM-2.5 TEOM starting frequency	PM-2.5 TEOM frequency	PM-2.5 TEOM noise
PM-2.5 TEOM K0	PM-2.5 dryer temperature	PM-2.5 dryer dew point
PM-2.5 dryer RH	Current valve position	Desired valve position
PM-2.5 cooler temp	PM-2.5 cooler set point	PM-2.5 base MC
PM-2.5 reference MC	PM-2.5 30-Min base MC	PM-2.5 30-Min reference MC
PM-2.5 raw base MC	PM-2.5 raw reference MC	PM-2.5 raw base MR
PM-2.5 raw reference MR	PM-2.5 raw base unclipped MC	PM-2.5 raw reference unclipped MC
PM-Coarse flow rate	PM-Coarse vol. flow rate	PM-Coarse vol. flow set point
PM-Coarse air tube raw output	PM-Coarse air tube temp	PM-Coarse air tube surface temp.
PM-Coarse TEOM filter pressure	PM-Coarse TEOM filter load	PM-Coarse total mass
PM-Coarse raw MC	PM-Coarse MC	PM-Coarse unclipped MC
PM-Coarse unclipped MR	PM-Coarse 30-Min MC	PM-Coarse 1-Hr MC
PM-Coarse XX-Hr MC	PM-Coarse 12-Hr MC	PM-Coarse 24-Hr MC
PM-Coarse mass rate	PM-Coarse frequency count	PM-Coarse frequency cycles
PM-Coarse TEOM starting freq.	PM-Coarse TEOM frequency	PM-Coarse TEOM noise
PM-Coarse TEOM K0	PM-10 Total mass	PM-10 MC
PM-10 30-Min MC	PM-10 1-Hr MC	PM-10 XX-Hr MC
PM-10 12-Hr MC	PM-10 24-Hr MC	PM-Coarse dryer temperature
PM-Coarse dryer dew point	PM-Coarse dryer RH	PM-Coarse cooler temp
PM-Coarse cooler set point	PM-Coarse base MC	PM-Coarse reference MC
PM-Coarse 30-Min base MC	PM-Coarse 30-Min reference MC	PM-Coarse raw base MC
PM-Coarse raw reference MC	PM-Coarse raw base MR	PM-Coarse raw reference MR
PM-Coarse raw base unclipped M	PM-Coarse raw ref. unclipped M	

9.6.7 Set the Password Function, If Desired

The 1405-DF has an optional password protection system that can limit access to the operation of the machine.

- Select the Settings screen
- Select the System button

- Select the Password Protection button
 - Set the password (the default password is 100,000)
 - Initiate High Lock or Low Lock mode. (Requires entering the correct password.) In Low Lock mode, the user can view all instrument screens and can change the operating mode to perform filter changes. High Lock mode means the user cannot view any screens other than the TEOM[®] Data screen.

9.6.8 Configure the Required Communications Parameters

The final step in the setup of the 1404-DF is configuring the instrument's communication parameters to be compatible with the protocol(s) in use by the operating agency. The details of specific situations can differ greatly, so making precise recommendations is problematic. An overview of each method is provided below in Section 10, "1405-DF Communications", and additional details are given in the 1405-DF Operating Guide. It is left to the operator to decide the best way to gather the real time data available from the 1405-DF.

1405-DF Communications

There are a number of ways to communicate with the 1405-DF. The most direct, and the one used during the installation process, is the touch-screen interface allowing user access to "TEOM[®] Data", "System Status", "Instrument Conditions", "Settings", and "Service". This direct interface is the way that users interact with the instrument for verifications, calibrations, and maintenance routines. Other methods of communication must be used to download data and upload firmware.

An Ethernet connection utilizing the Thermo Scientific ePort software is the recommended method for routinely downloading data from the instrument and for installing firmware upgrades. The 1405-DF can accommodate automatic or manual data downloads of up to 20 (expected to soon change to 30) user-selected variables via the Ethernet connection through a network, a router, or directly to a PC (a direct 1405-DF/PC Ethernet connection requires a crossover cable). Alternatively, the data can be manually downloaded to a USB jump drive. A third option employs data downloads via a 9-pin RS232 port using RPComm software (provided with the instrument) or HyperTerminal with AK protocol, and a fourth uses the 25-pin I/O port on the back of the instrument, providing 8 analog outputs, 4 analog inputs, and 2 digital outputs (contact closures). **Table 9-5** lists the data logging alternatives with references to relevant sections of the 1405-DF Operating Guide.

Table 9-5. Data logging alternatives with the 1405-DF.

Logging Method	Options	Operating Guide (pages, Revision A.003)	Comments
Thermo Scientific's ePort	ePort Setup	3-10 to 3-15	
	LAN or router	3-16 to 3-19	Standard Ethernet cable
	PC direct	–	Requires crossover cable
	Multiple Instruments	3-20 to 3-21	Each unit needs an IP address
	Manual Downloads	3-22 to 3-23	–
	Automatic downloads	3-24 to 3-27	–
USB Flash drive		3-28 to 3-29	–
Analog/Digital I/O (25-pin connector)	8 analog out	3-31 to 3-33, 4-26 to 4-28	–
	4 analog in		–
	2 digital out		–
RS232 (AK Protocol)	RPCComm	4-29, Appendix B	–
	Hyperterminal		–

9.7 COMMUNICATIONS SETUP AND DATA DOWNLOAD

Depending on the user's needs, setting up communications with the 1405-DF and downloading data will involve one or more of the following tasks:

- Installing ePort software on computer or Network
- Setting up the Analog Inputs, Analog Outputs and Contact Closures
- Setting up the RS-232 serial port parameters
- Using a USB flash drive for data downloads

Note that firmware updates can only be uploaded to the instrument through an Ethernet port. Agencies that cannot use the Ethernet option must contact the manufacturer for special firmware upgrade options.

9.7.1 Install ePort Software on Site Computer or Network

Receiving data files directly from the on-board data logger via ePort is efficient, and provides complete and accurate data sets. Data files are downloaded and saved as .csv files that

can be opened and viewed with Microsoft Excel. This file format also allows for easy import into databases. The file title format is the instrument serial number followed by a date/time stamp.

The 1405-DF Operating Guide, Section 3, and technical bulletins give instructions for installing and using the ePort software (see Appendix A “Technical Bulletin – 1405 Connectivity”). This proprietary software operates on a Windows platform, so keeping current with Microsoft Windows OS upgrades is important. It may also be beneficial to register as a user with the Thermo Scientific “Air Quality Instruments Online Library”, which provides the option of automatic email notification when upgrades to products and services related to the 1405-DF are available. To register as a library user, use the link:

http://www.thermo.com/com/cda/resources/resources_detail/1,2166,200503,00.html

Download Data via the ePort Software

- Launch ePort
- Confirm that the 1405-DF has a valid IP address.
 - In the System Status screen, update, locate and record the IP address. If no IP address is listed, then check Settings > System > Network Configuration
 - Use the ePort PC software to connect to the instrument and display the ePort Main screen (See Section 3 in the Users Guide for complete details).
 - Select Download Data in the Commands window of the ePort Main screen.
 - Select the Begin Download button. The ePort software will download data based on the settings created in the Download Setup Wizard of ePort (See Section 3 in the Users Guide to set up the data downloads). When the download is complete, it will display a “Download Complete” message.

9.7.2 Set Up the Analog Outputs, Analog Inputs, and Digital Outputs (Contact Closures)

These options use I/O protocols to communicate with an external data logger through the 25-pin port on the back of the instrument. Thermo Scientific offers a 25-pin male connector manufactured by Phoenix Contact that can be wired to match to the USER I/O connector on the back of the instrument (p/n 06-004521-0025). The Operating Guide (Rev. A.003) gives the pin assignments for the 1405-DF (page 3-32,) and the user will need to ensure that the connector is properly wired and connected to the appropriate data logger input terminal.

The 1405-DF has 8 user defined analog outputs and 2 contact closures to allow the user to interface the system with an external data logger. Users may want to log analog output data to provide redundancy. The analog outputs allow collection of user-selected variables as a DC voltage. Each one of the 8 analog out channels can be configured for a 0-1 or 0-5 VDC range and assigned to any of the available instrument variables. Two digital outputs (contact closures) are available for alarm notifications.

The analog output boards should be calibrated during instrument installation, and then on an annual basis or if the voltage range is changed. The 1405-DF has an Analog Output Calibration Wizard to guide the user through the calibration process (Service > Calibration > Analog Output Calibration). Section 5 of the Operating Guide (Maintenance and Calibration Procedures) also offers step by step instructions with accompanying photos of the analog output calibration process.

The instrument can also accept and store information from up to four analog inputs. The inputs accept 0-5 VDC and can be converted to a desired scale.

Set Up the Analog Outputs

- Select the Settings screen
- Select the Analog and Digital Outputs button
 - Select the Analog Outputs button to display the Analog Outputs screen. (There are two screens, each with four configurable analog outputs)
 - Use the button associated with each analog output to select a variable
 - Set a minimum and maximum value for the output for the desired output channel
 - Repeat until all desired channels are set up.

Set Up the Analog Inputs

- Select the Instrument Conditions screen
- Select the Analog Inputs button
 - Select the desired analog input (1 to 4)
 - The monitor converts the analog input value to engineering units according to the formula: $\text{Result} = A(X*X) + BX + C$, where X is the analog input percent full scale
 - Select the button for A, B, or C and provide the constant value

The analog inputs are self-calibrating.

Set Up the Digital Outputs (Contact Closures)

- Select the Settings Screen
- Select the Analog & Digital Outputs button
- Select the Contact Closure button
 - Use the buttons to select a variable, operator and compare value for the desired contact closure channel (1-2).

The digital outputs are generally used to record alarm values.

Signal Processing of Analog Data

Signal processing of analog data requires that several issues be considered.

1. The time-stamp applied to the data is made at the bottom of the hour and most data loggers are programmed to receive the time-stamp applied at the top of the hour. Some agencies offset the time between the data logger and the instrument to compensate for this difference; the 1405-DF time is set three minutes ahead of the data logger time. Others agencies transform the time when data are post-processed.
2. If interim values are collected and averaged into hourly values by the data logger program, any time discrepancy, including an offset, may result in the analog data not exactly matching the instrument digital data.
3. The instrument calculates rolling averages; therefore, time issues are difficult to reconcile.
4. In addition, rounding or significant digits processing differences between the data logger and instrument may yield slightly different datum.
5. Only eight variables can be collected creating many challenges for field diagnostics and data validation.
6. Instrument digital and analog data may not match; the digital-to-analog conversion must be verified on a routine basis. An Analog Output Calibration Wizard is available.
7. The sampler generates status codes but they are issued in real time (while the status condition exists, the code is output). However, if the data are polled at a longer interval, such as the top of the hour, a status code may not be captured if the condition only existed for a short time period or was intermittent. These codes are critical for both field operation and data validation.

Because of these issues, collecting data digitally or augmenting analog data with periodic digital downloads from the sampler, especially during periods of sampler malfunctions, is preferable. An inexpensive method, such as using a USB jump drive, may be employed to download the digital data.

The eight most important variables to capture for purposes of data validation and remote confirmation of proper instrument operation are

1. 1-hr $PM_{2.5}$ Mass Concentration
2. 1-hr Reference Concentration (Base Concentration can be back-calculated)
3. 1-hr FEM $PM_{2.5}$ Concentration
4. Status
5. Main Flow
6. Filter Loading

7. Frequency
8. Sample Dew Point

9.7.3 Set Up the RS-232 Serial Port for Communication

The 1405-DF supports AK protocol serial communication, which enables a local or remote computer (or data logger) to exchange information with the monitor. Many users of the earlier models of the TEOM[®] may be familiar with this system. Care must be exercised when using the AK Protocol. For example, **EREG (Enter Register Command)** can assign a new value to any system variable, but the value of variables should only be changed when the monitor is in the appropriate operating mode. A complete explanation of the protocol is available in Appendix B of the Users Manual.

Program Register Codes (PRC) are labels given to the variables in the 1405-DF, and a cross reference of the codes and variable names is needed to be able to communicate with the 1405-DF. Table B-1 of Appendix B of the 1405-DF Operating Guide lists the main PRC codes for the 1405-DF.

To set up the RS232 serial port,

- select the Settings Screen,
- select the Analog & Digital Outputs button, and
- select the RS232 button to set up the unit for serial connections using AK protocol.

9.7.4 Using a USB Flash Drive

Operators may also plug a USB flash drive into USB port on the front of the unit and download the data to the portable drive. The 1405-DF will recognize the flash drive and prompt the user to choose to download all of the stored data, or data since the last download.

10. MAINTENANCE AND QUALITY CONTROL PROCEDURES

Once the 1405-DF is installed and configured, a regularly recurring protocol of maintenance and quality control procedures must be established to ensure that a continuous stream of high quality hourly PM_{2.5} concentration data is obtained.

Table 10-1 lists the Thermo Scientific maintenance and QC procedures, recommended frequencies of recurrence, and the sections of this SOP that describe the sequential steps needed to perform each maintenance procedure. In practice, it may be helpful to provide field technicians responsible for implementing the procedures with an actual calendar, or simple table, with the site-specific target dates for each protocol.

The frequencies at which these procedures are conducted are site- and agency-specific. Some agencies conduct some of these procedures at a higher frequency than listed in the table to minimize the need to invalidate data because of a failure (e.g., filter over-loading leading to a reduced sample flow rate) that may require that data be invalidated back to the last recorded acceptable value. This increased frequency is generally based on experience—if filter loading is exceeding the tolerance before the scheduled monthly visit, the logical solution is to perform the filter exchange more frequently, for example, bi-weekly, or based on real-time monitoring of the filter loading. Since most QC procedures require that the sampling cycle be interrupted, more frequent QC procedures need to be balanced against the one or two hours of lost data.

Tolerance levels for verifications of flow, temperature, pressure, and leak checks must be specified so that field technicians understand when adjustments are needed and when they are not. It is important to consider that *frequent adjustments of instruments may not be necessary* and can lead to *more* data quality uncertainty. It is left to the site supervisor to decide on the recurrence schedule and the tolerance levels that best fit the circumstances.

In general, 40 CFR Part 58 App A (U.S. Environmental Protection Agency, 2008b) and 40 CFR Part 50 App L (U.S. Environmental Protection Agency, 2006b) requirements apply to all Continuous PM_{2.5} methods. The EPA Quality Assurance Handbook Volume II, Appendix D (U.S. Environmental Protection Agency, 2008c) provides some guidance regarding QC checks, in the Continuous PM_{2.5} Local Conditions Validation Template.

Table 10-1. Thermo Scientific-recommended maintenance and QC tasks, frequencies, and SOP and 1405-DF Operating Guide section references. Maintenance items marked with an asterisk (*) have Wizard instructions in instrument firmware version 1.27, upon which this SOP is based.

Maintenance or QC Item	Suggested Frequency	SOP Section	Operating Guide Section (Rev A.003)
Replace the TEOM filters*	Monthly or as filter loading approaches 100%	9.6.5, 10.1.9	5-4
Replace the 47-mm FDMS filters	Monthly or any time the TEOM filters are replaced	9.6.5, 10.1.10	5-16
Leak Check*	Monthly	9.6.4	Wizard: Service > Verification > Leak Check
Temperature verification/calibration*	Monthly	10.1.15	Screen: Service > Calibration > Ambient Calibration
Pressure verification/calibration*	Monthly	10.1.16	Screen: Service > Calibration > Ambient Calibration
Total Flow, One point flow verification*	Monthly	10.1.2	Wizard: Service > Verification > Flow Audit
PM _{2.5} , One point flow verification*	Monthly	10.1.12	Wizard: Service > Verification > Flow Audit
PM-Coarse, One point flow verification*	Monthly	10.1.12	Wizard: Service > Verification > Flow Audit
Bypass One point flow verification*	Monthly	10.1.12	Wizard: Service > Verification > Flow Audit
Clean the PM ₁₀ inlet	Monthly	10.1.20	5-18
Clean the virtual impactor	Monthly	10.1.9	5-22
Replace the in-line filters (PM _{2.5} , PM-Coarse, and bypass)	6 months	10.3	5-24
Clean the coolers*	Annually, or as needed	10.3,1	5-30
Clean the switching valve*	Annually, or as needed	10.3.2 App B	5-36
Replace switching valve seals and O-rings, lubricate			Separate document

Table 10-1. Thermo Scientific recommended maintenance tasks, frequencies, and SOP and 1405-DF Operating Guide section references. Maintenance items with an asterisk (*) have a Wizard in instrument firmware version 1.27, upon which this SOP is based.

Page 2 of 2

Maintenance or QC Item	Suggested Frequency	SOP Section	Operating Guide Section (Rev A.003)
Verify the clock	Monthly	10.1.22	4-24
Verify the calibration constant	Annually	10.3.6	5-64
Clean the air inlet system <i>inside</i> the mass transducer*	Annually	10.3.3	5-28
Rebuild the sample pump	18 months, or as needed	10.4	Separate document
Replace the dryer	Annually, or as needed	10.3.4	Not covered
PM2.5, 3-point flow calibration*	Upon installation then yearly and upon verification failure	10.3.5	Wizard: Service > Calibration > Flow Calibration
PM-Coarse, 3-point flow calibration*	Upon installation then yearly and upon verification failure	10.3.5	Wizard: Service > Calibration > Flow Calibration
Bypass, 3-point flow calibration*	Upon installation then yearly and upon verification failure	10.3.5	Wizard: Service > Calibration > Flow Calibration

10.1 MONTHLY MAINTENANCE AND QC

The monthly site visits and associated tasks are essential for maintaining optimal instrument performance. All data pertinent to the monthly maintenance and QC procedures should be documented, using an appropriate form. Examples of QC forms used by some agencies are provided in Appendix C. Electronic forms (e.g., MS Excel spreadsheets) are preferred by some users.

Recommended order of events for monthly QC:

1. View 1405-DF Data Screen for Warnings (SOP Section 10.1.1).
2. Deploy the temperature reference device to allow it to equilibrate.
3. Conduct “as found” total flow check (16.7 lpm; optional) (SOP Section 10.1.2).

4. Conduct “as found” leak check (SOP Sections 10.1.5 and 9.6.4).
Use the Leak Check Wizard (Service > Verification > Leak Check) or, if Advanced Users Mode is used, leak check in both reference and base cycles.
5. Replace the TEOM[®] and FDMS[®] filters (SOP Sections 10.1.8, 9.6.5 and 10.1.9).
6. Conduct “as found” flow verification on the three flow paths (SOP Section 10.1.12).
Use the Flow Audit Wizard (Service > Verification > Flow Audit).
 - Based on flow tolerances, leave as found, or proceed to temperature and pressure calibrations before making an adjustment.
7. Verify/adjust the ambient temperature sensor (SOP Section 10.1.15)
(Service > Calibration > Ambient Calibration).
8. Verify/adjust the ambient barometric pressure sensor (SOP Section 10.1.16)
(Service > Calibration > Ambient Calibration).
9. Conduct flow calibrations on three flow paths (if warranted) (SOP Section 10.3.5).
Use the Flow Calibration Wizard (Service > Calibration > Flow Calibration).
10. Clean the virtual impactor (SOP Section 10.1.18).
11. Clean the PM₁₀ inlet (SOP Section 10.1.19).
12. Remove the TEOM[®] filters and place on the equilibration posts.
13. Conduct “as left” leak check (SOP Sections 10.1.5 and 9.6.4).
14. Replace the TEOM[®] filters.
15. Install replacement TEOM[®] filters on the equilibration posts.
16. Conduct “as left” flow verification on total flow (optional) (SOP Section 10.1.2).
17. Verify/adjust the 1405-DF clock (SOP Section 10.1.22).
18. Download 1405-DF data (SOP Section 10.1.23).

10.1.1 Check for Status Codes/Instrument Warnings

During each site visit, the instrument should be checked for status condition warnings. When warnings are present, as indicated by the triangle icon and the message in the status bar on the bottom edge of the screen, the user should touch the System Status Button and then press the View Warnings Button, the icon, or the title bar. A list of the current warnings can be scrolled through by using the Next Warning and Previous Warning buttons. In addition, codes for these warnings are contained in the internal instrument data set. The status conditions can be viewed remotely if the digital data are being automatically polled. (Capturing the status codes with an analog connection is problematic because the status codes are output in real time [output while the condition exists] and not held; therefore, if the polling is not performed while the status condition exists it will not be captured.)

Appendix A of the Users Guide (Rev. A.003) explains how to decipher the codes. This process requires converting the value from a decimal number to a hexadecimal number, parsing

the resultant number, and looking up the parsed values in a table. Most agencies develop a program that performs this transformation automatically.

10.1.2 Verify the Total Flow

Users may choose to implement a “total” (the sum of the flow rates for the three paths) flow check immediately before or after the “as found” leak check to gain a general indication if the flow required to achieve the inlet cut-point is being maintained.

The Instrument Audit Screen provides a sum of the three flow fractions, labeled Total Flow (Service > Verification > Instrument Audit). In addition, this screen lists all audit parameters (within the firmware, audit is defined as a test that does not alter a value): the ambient temperature and pressure, the three flow rates, the vacuum pump pressure, and the calibration constants for the PM_{2.5} and PM-Coarse TEOMs. No adjustments, however, can be made from this screen. Firmware version 1.50 is expected to add a Total Flow value to the single point verification screen which then may be used for this comparison, as well.

Place the instrument in SETUP mode to discontinue (valid) data collection. Remove the PM₁₀ inlet and install a flow reference device, using the supplied flow adapter, if necessary. Compare and record the total flow as indicated by the instrument (Service > Verification > Instrument Audit) to the total flow as measured by the reference device.

10.1.3 Total Flow Tolerances

Maintaining the proper total flow through the inlet is necessary to ensure that the desired PM₁₀ cut-point is achieved. Generally, the flow tolerance through the inlet is set at 16.67 lpm \pm 10% but local agencies may wish to take action based on a tighter criterion to prevent data loss due to invalidation. The total flow can not be adjusted directly because it is the sum of the three flow fractions. To correct the total flow rate, the individual fractions must be adjusted or a leak, if present, corrected.

10.1.4 Equipment Needed for Total Flow Verification

- A NIST-traceable flow transfer standard capable of measuring flow rate of 16.7 lpm is required.
- Depending on the flow transfer standard used, a flow inlet adapter may be required

10.1.5 Leak Check

The leak check verification is accessed through the Leak Check Wizard (Service > Verification > Leak Check). See SOP Section 9.6.4 for full details. Note that the first step of the Leak Check Wizard will prompt the user to remove the two TEOM[®] filters from the transducer

to ensure that they are not damaged; if they are damaged, parts of the filter will be pulled into the sample path of the instrument during the leak check procedure.

10.1.6 Leak Test Tolerances

Leak check tolerances may vary by agency. Thermo Scientific recommends a tolerance of ± 0.15 lpm for the PM_{2.5} and PM-Coarse leak checks and ± 0.60 lpm for the Bypass leak check. The Wizards are set to give failure warnings based on those recommendations.

10.1.7 Equipment Needed for Leak Check

A leak check/flow adapter is provided with the instrument (Figure 9-4).

10.1.8 Replace the TEOM[®] Filters Monthly or As Loading Approaches 100%

The rate of filter loading will vary depending on ambient PM_{2.5} and PM-Coarse concentrations. While the suggested frequency for filter replacement is 30 days, this can be greatly shortened depending on local conditions. The best way to avoid data loss due to overloaded filters is to institute a strict regimen of daily (or more frequent) data review. Digital data acquisition using, for example, ePort software, makes this a routine matter, and is highly encouraged.

See Section 9.6.5, for the installation procedure for the TEOM[®] filters. It is recommended that the TEOM[®] Filter Replacement Wizard (Service > Maintenance > Replace TEOM Filters) be used until the user is thoroughly comfortable with the filter replacement process. *Bypassing the Wizard puts the onus of checking the stability of the TEOMs' frequency on the user*, and failure to do so can result in the invalidation of data.

10.1.9 Equipment Needed for TEOM[®] Filter Exchange

- TEOM filters (p/n 57-007225-0020).
- Filter exchange tool (provided with instrument).

10.1.10 Replace the 47-mm FDMS[®] (Purge) Filters

The 47-mm FDMS[®] filters must be replaced any time that the TEOM[®] filters are replaced. There is no Wizard to accompany this process, but the steps are reviewed in Section 9.6.5 (also see 1405-DF Operating Guide, Section 5) If the 47-mm filters are to be used for additional analysis, special filter handling precautions, similar to those employed for FRM filters, must be observed. Condensation should be wiped off the filter housing before the filter is reinstalled.

10.1.11 Equipment Needed to Replace the 47-mm FDMS[®] (Purge) Filters

- Standard FRM-style 47-mm filter cassette with a TX-40 filter (Teflon-coated borosilicate) p/n 10-002387-0025.
- Protective containers if filters are to be used for additional analysis.

10.1.12 Verify the Flow Rates for Each of the Three Flow Fractions

The single-point verification Wizard (Service > Verification > Flow Audit) provides step-by-step instructions on the procedure to verify the flow rate for each sample fraction.

Verify the fine, course, or bypass flow:

- In the TEOM[®] Data screen, select the Service button to display the Service screen.
- Select the Verification button to display the Verification screen.
- Select the Flow Audit button to begin the Flow Audit Wizard.

Follow the Wizard Steps to

- enter the type of flow audit device being used,
 - select which flow rate (fraction) to audit, and
 - connect the flow audit device to the inlet.
- To audit the PM_{2.5} flow channel, remove the inlet, inlet tube and virtual impactor, and attach the 1-1/4" flow adapter/meter to the top of the flow splitter. Disconnect the green bypass line from the side of the flow splitter (do not let it fall to the ground) and cap the bypass fitting with the 3/8" Swagelok cap provided with the system.
 - To audit the PM-Coarse flow channel, remove the inlet, inlet tube and virtual impactor, and connect the 1/2" Swagelok flow audit adapter to the top of the 1/2" Coarse flow inlet. Connect the flow meter/adapter to the flow audit adapter.
 - To audit the bypass flow channel, remove the bypass line from the flow splitter and connect the 3/8" flow adapter to the green tubing of the bypass line. Connect the flow meter/adapter to the flow audit adapter.

The flow rates are mathematically corrected by the instrument temperature and pressure readings and should not be adjusted until after the temperature and pressure sensors have been calibrated.

10.1.13 Tolerances for Flow Rates for Three Flow Fractions

The flow rates must be adjusted (**after the temperature and pressure calibration**) if the flow rate indicated by the instrument differs from the flow rate as measured by the flow reference device by $\pm 4\%$ or the design value (target flow rate) for the specific fraction by more than 5%. Some agencies may wish to take action based on tighter criteria to prevent data loss due to invalidation.

10.1.14 Equipment Needed to Verify the Flow Rates

- A NIST-traceable flow transfer standard capable of measuring flow rates between 1.3 lpm and 14.4 lpm is required.

The reference flow meter should have been recently calibrated to a primary standard, and should have an accuracy of $\pm 1\%$ at the flow rates of interest (3 lpm and 16.67 lpm) and a pressure drop of less than 0.07 bar (1 psi). If the flow meter does not report volumetric flow rates, the readings must be corrected to volumetric lpm at the current ambient temperature and barometric pressure.

- Flow inlet adapters (provided with instrument).

10.1.15 Verify/Calibrate the Ambient Temperature

- Select the Service button to display the Service screen.
- Select the Calibration button to display the Calibration screen.
 - Select the Ambient Calibration button to display the Ambient Calibration screen.
 - Determine the current temperature ($^{\circ}\text{C}$) at the ambient temperature sensor using an external reference thermometer.
 - If the measured value is within $\pm 2^{\circ}\text{C}$ of the temperature displayed in the Ambient Temperature button, no further action is necessary. Select the <Back button to return to the Calibration screen. If the value is not within $\pm 2^{\circ}\text{C}$ of the temperature displayed in the Ambient Temperature button, select the Ambient Temperature button. A keypad will display. Enter the actual temperature as measured by the external thermometer and press the Enter button. The Ambient Temperature Calibration screen will display with the new entered value. Select the <Back button to return to the Calibration screen.

10.1.16 Verify/Calibrate the Ambient Pressure

- Select the Service button to display the Service screen.
- Select the Calibration button to display the Calibration screen.
 - Select the Ambient Calibration button to display the Ambient Calibration screen.
 - Determine the current ambient pressure in atmospheres (absolute pressure, not corrected to sea level).
 - If the measured value is within ± 0.01 atm of the pressure displayed in the Ambient Pressure button, no further action is necessary. Select the <Back button to return to the Calibration screen. If the value is not within ± 0.01 atm of the pressure displayed in the Ambient Pressure button, select the Ambient Pressure button. A keypad will display. Enter the actual pressure as measured by the external device and press the Enter button. The Ambient Pressure Calibration screen will display with the new entered value. Select the <Back button to return to the Calibration screen.

10.1.17 Adjust the Flow Rates for Each of the Three Flow Fractions

If any of the three flow rates did not meet the verification criteria in Section 10.1.12, it (they) should be adjusted. Use the Flow Calibration Wizard (Service > Calibration > Flow Calibration. See Section 10.3.5, Calibrating the Flow Rates, for the necessary procedures.

10.1.18 Clean the Virtual Impactor Monthly

The virtual impactor is an essential component of the 1405-DF inlet system, and it is imperative that it be well-maintained. Monthly inspection and cleaning is necessary to assure efficient particle separation of the sample air stream.

10.1.19 Materials Required to Clean and Maintain the Virtual Impactor

- Ammonia-based, general-purpose cleaner or mild detergent
- Silicone-based O-ring grease
- Phillips screwdriver
- Soft brush or lint free cloth
- Cotton swabs

To clean the virtual impactor,

1. Remove the PM₁₀ inlet, and the 1-1/4" sample tube that connects the inlet to the impactor, from the top of the system.
2. Loosen the 1/2" Swagelok nut that connects the PM-Coarse flow tube inlet to the bottom of the impactor.
3. Lift the virtual impactor off the flow splitter and Coarse sample tube.
4. Place the impactor on a clean work surface and remove the four screws on each corner of the bottom section of the virtual impactor. Separate the body from its base plate (**Figure 10-1**).
5. Remove the three screws that hold the top of the virtual impactor to the body.
6. Use water and a mild detergent to wash the inside surfaces of the body, top and bottom sections of the impactor. A general-purpose cleaner can be used, if necessary. A cotton swab may be useful for cleaning the body.
7. Inspect all O-rings in each section of the virtual impactor for damage and replace them, if necessary. Apply a thin coating of O-ring lubricant onto the O-rings, if necessary.
8. Reassemble the impactor, attach it to the flow splitter and PM-Coarse tube inlet, and reinstall the PM₁₀ inlet.

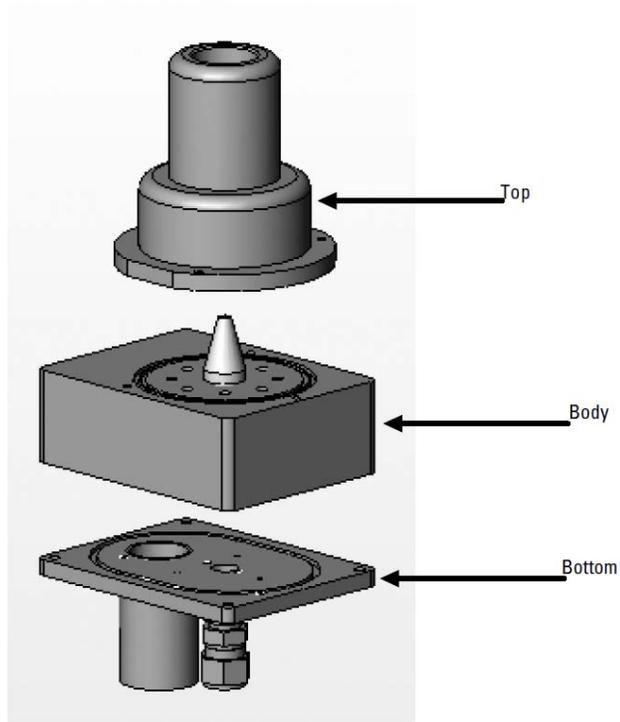


Figure 10-1. Exploded view of the virtual impactor.

10.1.20 Clean the PM₁₀ Inlet Monthly

The PM₁₀ inlet has two primary components, the Acceleration Assembly and the Collector Assembly (**Figure 10-2**). Thermo Scientific recommends cleaning both of these assemblies monthly.

10.1.21 Materials Needed to Clean the Inlet

- Soft bristled paint brush
- Lint free cloths
- Cotton swabs
- Water (or a mild solvent such as an ammonia based cleaner)
- A #2 Phillips screwdriver is needed to remove the top plates from the acceleration assembly of the inlet.

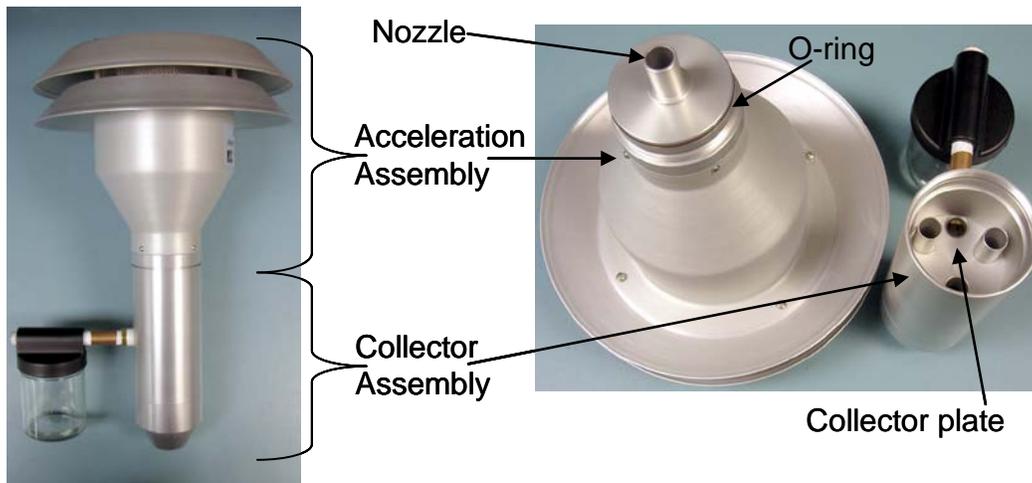


Figure 10-2. The PM₁₀ inlet has two primary components, the Acceleration Assembly and the Collector Assembly.

The 1405-DF Operating Guide has detailed instructions, accompanied by photos, detailing all aspects of the inlet cleaning procedure; they are summarized below.

To clean the inlet,

- Remove the condensation jar and set it aside.
- Unscrew the Collector Assembly (Figure 10-2 bottom portion of inlet) from Acceleration Assembly (Figure 10-2 top portion of inlet) and set it aside.
- Clean the Acceleration Assembly
 - Set the Acceleration Assembly upside down on its top plate and remove the four pan head screws on the bottom side. If the stand-offs turn, hold them in place with pliers.
 - Lift the Acceleration Assembly off the top plate.
 - Lift the lower plate up and carefully remove the insect screen.
 - Clean all the inlet parts of the Acceleration Assembly inside and out (top plates, insect screen, and the Accelerator Assembly body). Depending on local conditions, parts may only need to be wiped with brushes or a lint-free cloth, or blown out with compressed air. Alternatively, the parts may be washed with clean water, which is the best way to remove caked deposits that have accumulated in hard-to-reach places. Parts must be thoroughly dried before re-assembly. Pay special attention to the acceleration nozzle at the base of the cone-shaped body; clean the inside of the nozzle by pushing a moistened piece of cloth through it.
 - Inspect the large diameter O-ring at the base of the Accelerator Assembly. Replace if necessary. Apply a thin film of O-ring grease on the O-ring and a thin film on the aluminum threads of the acceleration assembly.

- Clean the Collector Assembly (lower portion of inlet)
 - Use a brush, lint free cloth and/or cotton swabs to clean the bottom collector plate and the collector assembly walls around the three vent tubes, and the weep hole in the collector plate. Water may be used if needed. Allow to dry.
 - Clean inside the vent tubes by running a moistened cloth through them.
 - Wipe out the area inside the bottom of the Collector Assembly where the two O-rings are located.
 - Inspect the O-rings and replace if needed. Apply a thin film of O-ring grease on the O-rings.
- Wipe out the condensation jar and the jar lid. Apply a thin film of grease to the seal inside the lid.
- Reassemble the PM₁₀ inlet taking care to avoid cross-threading.

10.1.22 Verify the Clock (Time and Date)

The TEOM[®] 1405-DF with FDMS[®] clock may drift as much as a minute per month. The EPA recommends checking the clock monthly to ensure correct sample timing. The 1405-DF clock should be permanently set for standard time and should never be reset to daylight savings time. Hourly data that needs to be expressed on a different time basis can be adjusted by post-processing the time stamp.

In addition, if the data are being collected by an outside device/or database that applies a time stamp, then the time stamps should be examined for accuracy and appropriateness on a monthly basis as well. It may be necessary to offset the times in order to properly process the data from the base and reference periods so that the mass concentration data are correct.

To set the time, use the Service > System > Set Time function and enter the time using the pop-up screen.

10.1.23 Download the 1405-DF Data Files If Not Automatically Polled

The downloading procedure will vary based on the data collection protocol of the individual agency. The 1405-DF can accommodate manual data downloads of up to 20 user-selected variables (expected to change to 30) via an Ethernet connection through a network, a router, or directly to a PC (a direct 1405-DF/PC Ethernet connection requires a crossover cable); to a USB jump drive; or via a 9-pin RS232 port using RPSComm software (provided with the instrument) or HyperTerminal with AK protocol.

10.1.24 Compare TEOM[®] 1405-DF Data to External Data Logger Data

If an external DAS is used to collect the hourly data from the TEOM[®] 1405-DF with FDMS[®], one QC protocol should be a monthly comparison of the internally stored data (assumed to be the “most correct”) with the data stored by the DAS. This is particularly important after a new installation so that any errors associated with the acquisition process can be identified and corrected to avoid continued propagation of the error. Digitally acquired data are less susceptible (although not immune) to acquisition errors than analog, and digital methods are recommended whenever possible.

The comparison of the 1405-DF internal data with DAS data should focus on time stamps and the concentration data:

- Digitally acquired concentration data in the DAS should agree exactly with the concentration data stored internally in the instrument. If it does not, there may be a time stamping problem. Compare a specific record in the data acquisition system (DAS) with the previous and following records (based upon the time stamp) downloaded directly from the 1405-DF. If one of these records matches, then there is a one-hour offset that needs to be corrected in the data acquisition protocol or in post-processing.
- Concentration data collected by the DAS from the *analog* outputs of the TEOM[®] 1405-DF with FDMS[®] should agree with the internal digital data within 1 $\mu\text{g}/\text{m}^3$ (0.001 mg/m^3).
 - Discrepancies of a few $\mu\text{g}/\text{m}^3$ may be attributable to faulty or un-calibrated DAC (digital-to-analog-converter) electronics, or simply a wiring problem between the instrument and the DAS analog inputs. The analog output calibration should be tested on the analyzer using the Wizard available through Service > Calibration > Analog Output. The analog output generally requires calibration about once per year.
 - Discrepancies between analog and digital data of more than a few $\mu\text{g}/\text{m}^3$ that are not consistent can occur if the DAS is using an averaging function and the clocks of the instrument and the DAS are not perfectly synchronized. This can result in hourly concentration values from adjacent hours being averaged together, making the resulting concentration difficult to match with digital data.
 - The above scenarios regarding analog data can be additionally confounded if there is a time stamping problem with the analog data, so be sure to factor that into troubleshooting of discrepancies between downloaded digital data and analog data.

Depending on the DAS used, the time of the instrument may need to be offset from the data logger time. For instance, some agencies using ESC data loggers set the instrument clock 3 to 4.5 minutes ahead of the DAS clock to avoid “overlap” in the base/reference period when the channels are set up as “average math channel.” These offsets will make a comparison of the data sets more difficult and further confound comparison of the data sets, because the concentration data generated by the instrument are rolling averages updated every six minutes based on the result of the base or reference measurement cycle. Verifying that a representative data set is being collected requires diligence and careful attention to detail.

10.2 SIX-MONTH MAINTENANCE AND QC PROCEDURES: REPLACE IN-LINE FILTERS

The filter elements in the small PM_{2.5} and PM-Coarse in-line filters (p/n 32-010745) and the large bypass flow filter (p/n 32-010755) should be changed every six months or as necessary. They are located on the back of the sampler. These filters prevent contamination from reaching the flow controllers. For convenience, replace the in-line filters elements immediately following one of the regularly-scheduled TEOM[®] filter exchanges during the 30-minute flow and temperature stabilization period.

To exchange the in-line filters,

1. Unplug the sample pump.
2. Unscrew and remove the small filter covers for both the PM_{2.5} and PM-Coarse flow channels on the back of the unit (**Figure 10-3**, left).

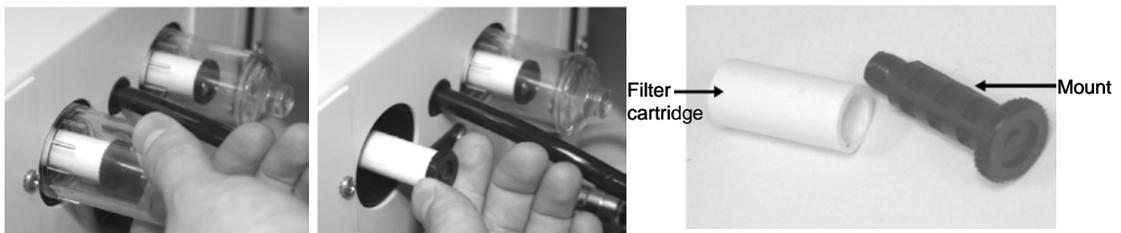


Figure 10-3. The PM_{2.5} and PM-Coarse in-line filters should be changed every six months.

3. Unscrew the filter mounts for both the PM_{2.5} and the PM-Coarse flow channels (**Figure 10-3**, center).
4. Slide the filter cartridges off the mounts and install new cartridges onto the mounts (**Figure 10-3**, right).
5. Install the mounts into the unit and install the covers.
6. Unscrew and remove the large filter cover from the bypass flow channel on the back of the unit (**Figure 10-4**).
7. Unscrew the filter mount for the bypass flow channel.
8. Slide the large filter cartridge off the mount and install a new cartridge onto the mount.
9. Install the mount into the unit and install the cover for the bypass flow.
10. Plug in the sample pump and return to normal operation.

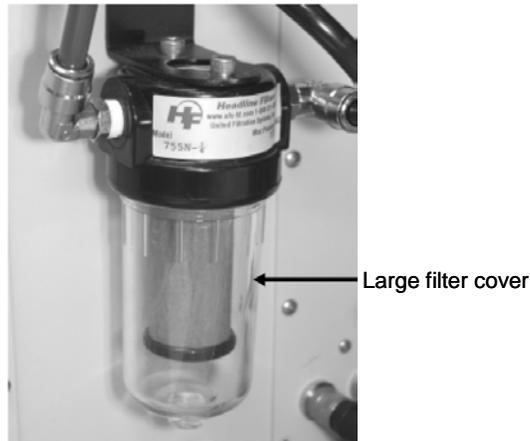


Figure 10-4. The bypass flow in-line filter should be changed every six months. This coalescing filter also serves as the water trap on the 1405-DF.

An independent audit of the system should be conducted semi-annually; it should consist of, at a minimum, a one-point flow audit for the total flow and all three fractions, a one-point audit of the temperature sensor, a one-point audit of the pressure sensor, a leak test, and a time verification.

10.3 TWELVE-MONTH MAINTENANCE AND QC PROCEDURES

A number of maintenance and QC procedures should be performed annually.

10.3.1 Clean the Cooler Assembly

The coolers should be cleaned at least once a year, or as necessary. The Cooler Cleaning Wizard provides pictures and describes all the steps necessary to clean the cooler. The 1405-DF Operating Guide (p. 5-30) mirrors the Cooler Cleaning Wizard instructions and also provides several photos to guide the user.

To clean the coolers,

- Select the Service button to display the Service screen.
- Select the Maintenance button.
 - Select the Clean Coolers button to start the Cooler Cleaning Wizard.
 - Follow the step-by-step instructions in the Wizard. The Wizard itself also has pictures.

10.3.2 Perform Switching Valve Maintenance

There are **two** switching valve maintenance routines. The switching valve should be cleaned at least once a year, or as necessary; the 1405-DF has a Valve Cleaning Wizard to guide the user through the steps. The other routine involves replacement of the seals and O-rings, and lubrication to prevent damage to the seals during the switching process. This procedure is not covered in the Operating Guide, but is available as a separate Thermo Scientific technical bulletin which is included in the SOP as Appendix A. **IMPORTANT NOTE:** At one point, the Valve Cleaning Wizard offers incorrect advice for reassembling the Swagelok connections. When reinstalling the switching valve, the user is advised to tighten the Swagelok fittings to finger tight, and then another 1-1/4 (one and one-quarter) turns with a wrench. *This instruction should be only 1/4 turn past finger tight, not 1-1/4.* When Swagelok fittings of this size are initially seated (during first assembly), they are tightened 1-1/4 turns past finger tight to *initially seat the ferrule*. Subsequent re-tightening of the fitting should only require a 1/4 turn past finger tight. Over-tightening of the fittings can ruin the ferrule and lead to leaks that are very hard to find. If a stainless steel Swagelok fitting can be turned more than 1/2 turn past finger tight, it has already been compromised.

To clean the switching valve

- Select the Service button to display the Service screen.
- Select the Maintenance button.
 - Select the Clean Switching Valve button to start the Valve Cleaning Wizard.
 - Follow the steps through the Wizard. The Operating Guide mirrors the Wizard's steps and provides photos to assist the user.

10.3.3 Clean the Air Inlet System Inside of the Mass Transducer Enclosure

The heated air inlet in the TEOM[®] 1405-DF must be cleaned once a year to remove the buildup of particulate matter on its inner walls. A dampened lint-free cloth should be pulled through the heated air inlet, using a wire or hook, to clean it.

Equipment needed

- A piece of plastic or another protective material to protect the TEOM[®] filters
- Soapy water, alcohol or Freon solution
- A 1/2-inch (or adjustable) wrench
- A soft lint-free cloth
- A length of wire

Follow these steps to clean the air inlet system:

1. Turn off the TEOM[®] 1405-DF unit.
2. Open the door of the unit and pull the black insulating cover down from the top of the mass transducer assembly. Locate the thermistors (**Figure 10-5**, left).
3. Using the 1/2" wrench, remove the thermistors from the top of the mass transducer assembly. (Note. The thermistors have short thread depths. Installation and removal should take 1-1/2 to 2-1/2 turns.)
4. Open the mass transducer compartment.
5. Place a piece of plastic or another protective material over the exposed TEOM[®] filters.
6. Using a soapy water, alcohol or freon solution, clean the entire air inlet (shown at right in Figure 10-5). A lint-free cloth may be used to remove particulate matter from the insides of the walls.
7. Allow the air inlet to dry.
8. Remove the protective material from the exposed TEOM[®] filter.
9. Close the mass transducer and latch the latch
10. Install the air thermistors into the cap of the mass transducer assembly and tighten lightly with the wrench.
11. Close and latch the door to the unit. Keep the door open for as short a time as possible to minimize the temperature change in the system.
12. Turn on the TEOM[®] 1405-DF unit.

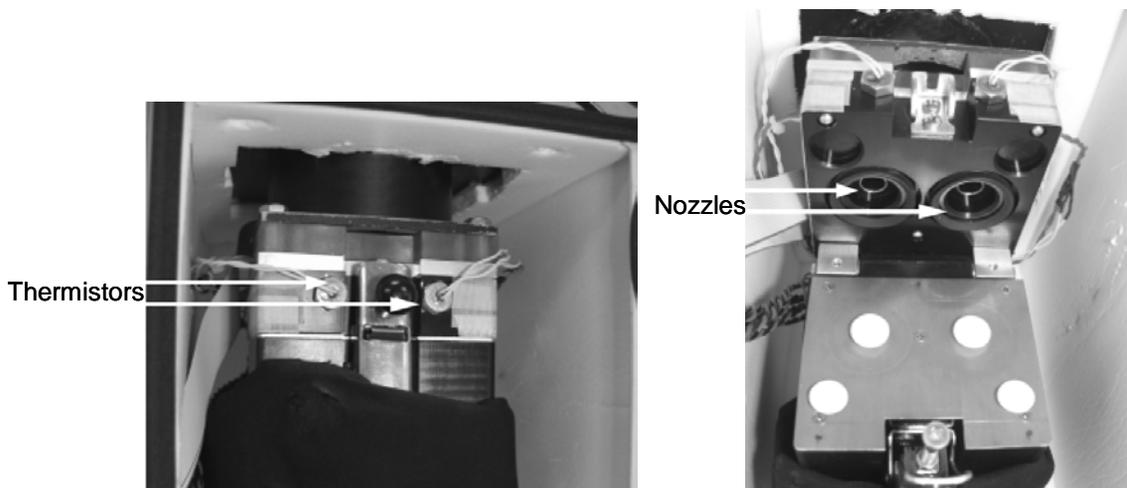


Figure 10-5. Air Inlet containing the Mass transducers, thermistors, and nozzles.

10.3.4 Replace the Dryer(s)

Replace the dryers once every year, or as necessary due to poor performance. Dryer efficiency can be estimated by monitoring the dew point of the sample stream, labeled in the instrument screens and downloads as TEOM[®] A Dryer Dew Point for the fine fraction and TEOM[®] B Dryer Dew Point for the coarse fraction. There are several indications that the dryer operation should be investigated:

- the sample dew point is positive or consistently reads near or within the 2 degrees of the chiller/conditioner set point;
- comparison of the sample dew point to the ambient dew point indicates that the sample dew point is not being controlled;
- the reference mass concentration remains below $-5 \mu\text{g}/\text{m}^3$ over a 24-hr period or the sample dew point shows large fluctuations.
- the data collected from the 1405-DF diverges from the data collected from an FRM sampler.

If the dryer is not working correctly, the 1405-DF may erroneously yield higher FEM $\text{PM}_{2.5}$ concentrations than the $\text{PM}_{2.5}$ data produced from the FRM sampler. The dryer itself may not be the cause of the problem, so a full investigation is warranted. A dryer will not function correctly if the system vacuum is not maintained correctly due to a weak pump or a leak or if the dryer temperature is not maintained appropriately. The system vacuum pressure should be less than approximately 0.4 ATM; typically a new pump would yield a system pressure of slightly greater than 0.2 ATM depending on local atmospheric pressure. The system should be leak free including the dryer purge path. Enclosure temperature and dryer temperature can negatively impact dryer performance. The dryer temperature should be maintained below 30°C , but ideally in the mid- 20° range.

Although no Wizard or instructions are available in the operator's manual, replacing a dryer is a relatively straightforward procedure.

- The sampler should be turned off and disconnected from its power source.
- The front panel of the tower must be removed to access the dryers.
- The dryers are held in place by two Swagelok fittings at the top and the bottom of the dryer; the black vacuum lines on the sides of the dryer; and the control cable which originates on the left side of the dryer. Loosen the Swage-nuts and remove the vacuum tubes from the quick-connect fittings (by pushing in on the retaining ring and then gently pulling on the tubing), and unplug the cable from below to remove the dryer.
- Install the new dryer in its place and tighten the Swage-nuts one quarter turn past hand tight and re-install the vacuum tubes and plug in control cable from the new dryer.
- Re-install the front panel.
- Plug the power cord in and turn the sampler on.

- Perform a leak check.

The sampler will run its stability process and enter into operate mode automatically.

10.3.5 Calibrations

Upon setup and then periodically, the ambient temperature and pressure sensors and flow controllers may require calibration based on the failure of a verification test. The instrument interface provides a Wizard for calibrating the PM_{2.5}, PM-Coarse, and Bypass flows. Although no Wizards are available for ambient temperature and pressure calibrations, they are accommodated via Service > Calibration > Ambient Calibration.

Calibrating the Ambient Temperature

See SOP section 10.1.15 or User's Manual p. 5-44.

Calibrating the Ambient Pressure

See SOP section 10.1.16 or User's Manual p. 5-45.

Calibrating the Flow Rates

Calibration of the PM_{2.5}, PM-Coarse, and Bypass flows is accomplished through the Flow Calibration Wizard (Service > Calibration > Flow Calibration), which leads the user through a 3-point calibration (low, high, set point; see **Table 10-2**) of each of the three system flows.

Table 10-2. Default calibration low, high, and set point flow rates for the 1405-DF PM_{2.5}, PM-Coarse, and Bypass flows.

	Low	High	Set Point
	-----lpm-----		
PM _{2.5}	2.4	3.6	3.0
PM-Coarse	1.3	2.0	1.7
Bypass	9.6	14.4	12.0

The calibration requires a 1-1/4" flow adapter, a 1/2" Swagelok flow adapter, a 3/8" Swagelok flow adapter, and a flow measurement device. The reference flow meter should have been recently calibrated to a primary standard, and should have an accuracy of $\pm 1\%$ at the flow rates of interest (3 lpm and 16.67 lpm) and a pressure drop of less than 0.07 bar (1 psi). If the flow meter does not report volumetric flow rates, the readings must be corrected to volumetric lpm at the current ambient temperature and barometric pressure. To audit the total flow (16.7 lpm), a 1-1/4" flow adapter is required (Figure 9-4). Note that this total flow cannot be calibrated directly, as it is the sum of three distinct flow paths.

To calibrate the fine, coarse, or bypass flow,

- Select the Service button to display the Service screen.
- Select the Calibration button to display the Calibration screen .
- Select the Flow Calibration button to start the Flow Calibration Wizard.
 - Press Next and Select either “Direct Flow Device” or FTS (an orifice-based system that measures flow based on pressure drop).
 - Choose one of the three flow paths to calibrate and complete the Wizard for that flow path. The Wizard will advise at each step.
 - Repeat the calibration steps for the remaining flow paths.

10.3.6 Calibration (K0) Constant Verification

The calibration of the mass transducer in the TEOM[®] 1405-DF Monitor is determined by the mass transducer’s physical mechanical properties. Under normal circumstances, the calibration does not change materially over the life of the instrument. Contact Thermo Scientific if the verification procedure fails. The original calibration constant is located on the “Instrument Checkout Record” or the “Final Test Record” documents that are shipped from the factory with the instrument. Before the TEOM[®] 1405-DF is shipped to the customer, it is calibrated with new, pre-weighed TEOM[®] filters installed in its mass transducer as a calibration weight. Because the mass of the filter cartridge with particulate matter differs from the mass of a new filter cartridge by only a small fraction, calibrating the system with a calibration mass equivalent to the filter mass allows all measurements to be made at essentially the same operating point as the original calibration. To audit/verify the K0 numbers requires a mass calibration verification kit (59-002107), which includes a pre-weighed filter, a filter exchange tool, desiccant and a humidity indicator, and the pre-filter with tubing that was supplied with the unit. Refill kits for the mass calibration verification kit are available from Thermo Scientific (59-002019).

To confirm the system’s K0 calibration,

- Confirm that the PM_{2.5} and PM-Coarse K0 numbers entered into the instrument and the PM_{2.5} and PM-Coarse K0 numbers on the plates on the mass transducer are the same. The K0 numbers entered into the unit can be found in the Audit screen.
- Ensure the instrument is at the normal operating temperature and condition.
- Ensure that the pre-weighed filter in the kit matches the humidity conditions for the test, as shown on the card provided with the kit. If the filter does not match the conditions listed on the humidity indicator, follow the instructions provided with the kit to dry the filter to an acceptable level.
- In the TEOM[®] Data screen, select the Service button to display the Service screen
 - Select the Calibration button to display the Calibration screen
 - Select the Mass Transducer K0 Verification button to start the K0 Verification Wizard.

- Follow the steps in the Wizard.
- The 1405-DF Operating Guide gives details on the K0 calibration process.

10.4 EIGHTEEN-MONTH MAINTENANCE AND QC PROCEDURES: REBUILD THE SAMPLE PUMP

An adequate system vacuum is integral to proper instrument operation; if the pump does not supply adequate vacuum the dryers may not function correctly and the sample filters may over-load prematurely. Rebuild the sample pump once every 18 months, or as necessary (for example, when a poor (high) vacuum pressure reading is indicated on the System Status screen). The pump rebuild kit (p/n 59-008630) contains instructions for rebuilding the pump. Note: A leak, a blocked in-line filter, or exceptionally heavy filter loading could also cause elevated vacuum readings and would not require pump servicing. The pump should be tested with a gauge after rebuilding to determine if it supplies an adequate vacuum; generally the pump pressure should be less than 66% of local pressure.

11. DATA VALIDATION AND QUALITY ASSURANCE

Generally speaking, 40 CFR Part 50 Appendix N (“Interpretation of the National Ambient Air Quality Standards for PM_{2.5}”), 40 CFR Part 50 Appendix L (“Reference Method for the Determination of Fine Particulate Matter as PM_{2.5} in the Atmosphere”), 40 CFR Part 58 Appendix A (“Quality Assurance Requirements for SLAMS, SPMs and PSD Air Monitoring”), and EPA Quality Assurance Guidance Document 2.12 (“Monitoring PM_{2.5} in Ambient Air Using Designated Reference or Class I Equivalent Methods”) are all pertinent to data validation and QA protocols for FEM continuous PM_{2.5} monitoring with the 1405-DF. These documents offer extensive details about procedures intended to assure that PM_{2.5} data meet Data Quality Objectives (DQO). In practice, these procedures are based on some basic principles that, if followed diligently, will foster high rates of data capture and minimize the need to invalidate data. These core principles include the field protocols intended to keep the 1405-DF operating in accordance with FEM designation EQPM-0609-182, and with the 1405-DF User’s Manual. The field protocols aid the post-processing data validation and QA protocols, where collected data are judged under DQO criteria.

11.1 FIELD QUALITY CONTROL IMPACTS ON QUALITY ASSURANCE

The first line of defense against invalid data is the implementation of best practices in day-to-day operations affecting the data collection process:

- Understanding of the principle of operation of the equipment
- Acceptance testing of equipment
- Diligence in site selection followed by rigid installation procedures
- Scheduling and implementation of routine maintenance procedures (e.g., inlet cleaning)
- Scheduling and implementation of QC protocols (e.g., flow checks, instrument settings)
- Documentation/reporting of all field QC results and related field activities
- Daily review of real-time data
- Prompt troubleshooting of any observed operational problems

11.2 DATA VALIDATION

Four primary sources of information are directly related to validation of FEM PM_{2.5} data from the 1405-DF: (1) data generated and stored internally in the 1405-DF (the sampling attribute data); (2) the polled data set; (3) the site log information documenting local conditions and equipment operation; and (4) the standardized forms containing results from the periodic maintenance and QC protocols.

11.2.1 1405-DF Generated Sampling Attribute Data

The FEM 1405-DF internal data files should be the source files used for data validation and ultimate submittal to regulatory agencies when possible. Data acquired through an external DAS is extremely useful for real time data applications such as forecasting or daily review of operational status but are subject to the limitations and potential errors described in Section 9.7.2. Analog data should be, at least, spot checked and preferably reconciled against the internal digital data, so it suggested that the data analyst begin with the original digital data. Externally acquired (data logger) digital data proven to be a true replicate of the internally stored data can be used, with special attention to assure that data logger-applied time stamps are accurate. This scenario is becoming more common as agencies switch to real-time digital data acquisition that flows directly into a permanent database. The storage variables presented in Table 9-3 should be downloaded and utilized. Some Service Data cannot be collected through PRC codes or analog outputs so digital data collection is recommended.

11.2.2 Field QC-Generated Sampling Attribute Data

The purpose of periodic flow checks, leak checks, and other QC protocols is to provide quality assurance for the collected data; thus it is essential that the information, both qualitative and quantitative, be transmitted to the data analyst responsible for the data validation process. This information transfer should be prescribed and not left to chance.

11.2.3 Data Validation Criteria

The EPA reference documents mentioned above were originally developed for 24-hr filter-based federal reference method sampling and have been adapted in **Table 11-1** to provide suggested guidelines for data validation criteria pertinent to continuous (hourly) PM_{2.5} monitoring with the TEOM[®] 1405-DF. The table is modeled on a table in Appendix D, “Measurement Quality Objectives and Validation Templates”, of the QA Handbook, Volume II, Revision 1 (December, 2008).

The top panel of Table 11-1 lists the criteria that *must* be met to ensure the quality of the data. Failure to meet any one of these criteria is cause for invalidation, unless there is compelling justification otherwise. One example of such justification would be known wildfires contributing to excessive filter loading. High filter loading can lead to flow perturbations, but these are nonetheless highly valuable data. These criteria include the 45-minute sampling period for hourly data (and extended to 24-hr data), hourly flow rate, sampler status condition codes indicating the following sampler malfunctions (available under PRC 8) power failure (status code 1), voltage low (status code 16) cooler status (status code 32), valve position (status code 64) and dryer status (status code 128) mass transducer A failure (status code 16,777,216). The criteria for invalidation also includes failing results during a monthly flow check or leak check. Note that the leak check failure is set at 0.30/1.2 lpm here but that some agencies may invalidate at other leak rates. Leak checks are performed under a significantly greater vacuum than operating conditions and the location of the leak also determines its effect on data collected.

The bottom panel in the table has criteria that indicate that there *might* be a problem with the quality of the data and further investigation may be warranted before making a determination about sample validity. Example criteria in this category would be failure to perform manufacturer recommended maintenance. In addition, the sampler operation should be examined for over-all reasonable operation. Data should not be invalidated without a documented reason, but subtle operational problems could result in less robust data. For instance, proper system vacuum and dryer operation are necessary for optimal operation and require detailed review to detect. Developing a full data validation protocol is left to the individual agency.

Table 11-1. Critical and operational data validation criteria for PM_{2.5} continuous monitoring with the Thermo Scientific 2405-DF under FEM designation EQPM-0609-182 (top panel).

Criteria		Frequency	Tolerances	Reference
Critical Criteria: These criteria represent the most important sampling attribute data				
Sampling period	Hourly	Hourly	45 minutes	40 CFR Part 50 App L, Sec 3.3
	24-hr	Daily	1080 minutes	40 CFR Part 50 App L, Sec 3.3
Flow	Average Flow Rate	Hourly	±5% of 16.67 lpm	40 CFR Part 50 App L, Sec 7.4; Method 2.12, Sec 10.2
Verification	Single point flow (Reference Std Reading)	Monthly	±5% of Design Flow	40 CFR Part 50 App L, Sec 7.4; Method 2.12, Sec 10.2; 40 CFR Part 58, App A Table A-2
	Single point flow TEOM A (Instrument Flow Reading)	Monthly	±4% of Reference Std Reading	40 CFR Part 50 App L, Sec 9.2.5; 40 CFR Part 58, App A Table A-2
	Leak Check	Monthly	>0.30 lpm TEOM A/B, >1.2 lpm Bypass	Agency specific
Sampler Status	Significant Malfunction Codes	During occurrence	Codes 1,16,64,128, 16,777,216	Manufacturer
Sampling Mode	Out of service code	During occurrence	Codes S, X	Manufacturer

Table 11-1. Critical and operational data validation criteria for PM_{2.5} continuous monitoring with the Thermo Scientific 2405-DF under FEM designation EQPM-0609-182 (bottom panel).

Criteria		Frequency	Tolerances	Reference
Operational Criteria: These criteria represent tolerances when corrective action may be needed to reestablish optimal sampling attributes				
Verification/ Calibration	Leak Check	Monthly	>0.15 lpm TEOM A/B, >0.60 lpm Bypass	Agency specific
	Temperature Verification	Monthly	±2°C	40 CFR Part 50 App L, Sec 9.3; Method 2.12, Sec 6.4
	Temperature Calibration	Yearly or on failed verification	±0.2°C	TEOM 1405-DF Manual, Rev A.003
	Barometric Pressure Verification	Monthly	±10 mm Hg	40 CFR Part 50 App L, Sec 9.3; Method 2.12, Sec 6.5
	Barometric Pressure Calibration	Yearly or on failed verification	±10 mm Hg	TEOM 1405-DF Manual, Rev A.003
	3-Point Flow Calibration	Yearly or on Failed Flow Check	±2%	TEOM 1405-DF Manual, Rev A.003
	Time Verification	Monthly	1 min/month; ensure appropriate time stamp	40 CFR Part 50 App L, Sec 7.4
Cleaning	PM ₁₀ Inlet and Virtual Impactor	Monthly	Cleaned	TEOM 1405-DF Manual, Rev A.003
	Mass transducer air inlet	Yearly	Verified	TEOM 1405-DF Manual, Rev A.003
	Switching Valve	Yearly	Verified	TEOM 1405-DF Manual, Rev A.003
Other Mfg Recommended Maintenance	Rebuild pump	18 Months	Verified	TEOM 1405-DF Manual, Rev A.003
	Replace Dryer	12 Months	Verified, monitor performance over time	TEOM 1405-DF Technical Note
	In-line Filter Element	6 Months	Verified	TEOM 1405-DF Manual, Rev A.003

11.3 HANDLING NEGATIVE MASS DATA ARTIFACTS

Unlike criteria gaseous pollutants, airborne particulate matter (PM) can be heterogeneous. For example, it can consist of one or more elements (heavy metals such as lead and cadmium, carbon, minerals), inorganic compounds (salts), and semi-volatile components (organic carbon, secondary aerosols such as nitrates and sulfates, water). Particles can also exist in solid form, liquid form, or a mixture of both. PM is often hygroscopic, demonstrating an affinity for water at ambient relative humidity (RH) of 75-80% or higher, but stubbornly retaining that bound water

until experiencing a RH of less than 30-35%. In general, fine particles (such as PM_{2.5}) are more volatile than coarse particles. It is this complex characteristic that can lead to profound difficulty in the consistent quantification of PM air pollution. The challenge is to provide a measure of PM under well-defined thermodynamic conditions (temperature, pressure, filter face velocity, relative humidity).

Whether using a continuous monitor such as the TEOM[®] instrument or a gravimetric sampler, there always are filter dynamics occurring. When particles are collected on a sample filter their mass may be influenced by interaction with airborne gases (such as acid gases or water vapor) or other particles in the sample air stream, or possibly by the filter media. The thermodynamic conditions of the sample air stream and surrounding the sample filter influence the degree to which these ongoing reactions may occur. All of these processes define filter dynamics and may result in a positive or negative sampling artifact component of the PM mass concentration. The higher the time resolution of the PM measurement system the better the PM mass concentration change resulting from filter dynamics can be observed. The Filter Dynamics Measurement System (FDMS[®]) facilitates quantifying these dynamics, however, the precision of hourly TEOM[®] PM data is about $\pm 1.5 \mu\text{g}/\text{m}^3$. So, it is reasonable to expect some small hourly negative values (0 to $-5 \mu\text{g}/\text{m}^3$) when the true mass concentration is very low (0 to $5 \mu\text{g}/\text{m}^3$). This is not uncommon during rain events, for example. Overall, hourly mass concentration values should not routinely be lower than about $-10 \mu\text{g}/\text{m}^3$. As general guidance, small negative hourly values should be considered "clean" conditions and reported. When used to produce daily averages, all hourly values (both positive and negative) should be averaged using equal weighting. This is consistent with the physicochemical understanding of PM provided earlier.

Negative mass concentration numbers indicated by the TEOM[®] monitor can be the result of the nature of particles described above or, possibly, the result of an instrument fault. Thus, it is important to first rule out a malfunction of the monitor or instrumentation setup. Malfunctions may include system interruption due to a temporary power failure, TEOM[®] filter exchange without placing the instrument in "set-up mode", flow control or vacuum pump system fault, or failure of an electronics component (such as frequency counter board). Generally, instrument faults will produce relatively large negative spiking in the mass concentration data. Erratic mass concentration data (many positive and negative spikes) can also be indicative of an instrument problem. It is advisable to also make use of site log notes to investigate further if the suspect data points were a result of a site visit for maintenance, audit, or other reasons.

11.4 DATA VALIDATION STEPS

Table 11-2 lists suggested sequential steps, their components, and specific procedures for validating continuous PM_{2.5} mass data collected with the 1405-DF under FEM designation EQPM-0609-182.

Table 11-2. Data validation steps for TEOM 1405-DF FEM PM_{2.5} data.

Validation Step	Component	Procedure
Verify Data Source	Digital: Direct Download	Download .csv format file
	Digital: Data Logger	Collect Service Data and Data file with Concentrations (PM _{2.5} , PM ₁₀ & PM-Coarse; Ref MC and Base MC), System Status, Ambient Temperature, Ambient Humidity, Ambient Pressure, Bypass Volumetric Flow, Vacuum Pump, TEOM A Flow Rate, TEOM A Filter Loading, TEOM A Total Mass, TEOM A Noise, TEOM A Dryer Temperature, TEOM B Flow Rate, TEOM B Filter Loading, TEOM B Total Mass, TEOM B Noise, TEOM B Dryer Temperature (if 30 storage variables available add TEOM A frequency, TEOM B frequency. If FEM PM _{2.5} concentration is added in new firmware version, collect it.
		Compare time stamp to internal data
		Analog: Data Logger
	Compare concentration to internal data ($\pm 1 \mu\text{g}$)	
Compare time stamp to internal data		
Review TEOM 1405-DF Attribute Data	Convert Status Codes to Hexadecimal Number	Determine each status code present and if significant fault occurred (decimal status codes 1; 16; 32; 64; 128; 16,777,216)
	Check sampling mode	Codes S (setup) and X (stop-all) indicate the sampler is out of service and not in operational mode
	Flow rates	Fine flow within tolerance of 5% of 3.0 lpm; Coarse flow within tolerance of 5% of 1.67 lpm; Total flow within tolerance of 10% of 16.67 lpm
	Elapsed time	1080 minutes
	Average total flow (sum of fractions)	$\pm 5\%$ of 16.67 lpm
	Sample volume	Within tolerance of 23-25 m ³
	Temperature and Pressure readings	Average, Max, Min for reasonableness
Review Field QA	Flow checks	$\pm 4\%$ of transfer standard lpm, compare each of 3 flow fractions to standard
	Leak checks	> 0.6/1.2 lpm, invalidate back to last passing leak check
	Calibration	3-point flow cal every 12-months verified

Table 11-2. Data validation steps for TEOM 1405-DF FEM PM_{2.5} data.

Validation Step	Component	Procedure
Maintenance procedures	Inlet/Virtual Impactor cleaning	Verify
	Annual K0 test	Verify
	Switching Valve cleaning	Verify
	Dryer Replacement*	Verify
	Cooler cleaning	Verify
	Air Inlet (sample train) cleaning	Verify
	Sample pump rebuild	
Periodic component tests	Test: Filter T and RH, Chiller Operation, Dryer Efficiency, Analog DAC	Verify

12. DIAGNOSTICS AND TROUBLESHOOTING

The Thermo Scientific 1405-DF Manual provides a troubleshooting overview (Rev A.003, App A) explaining the error status codes recorded. In addition, Wizards in the user interface (firmware) provide troubleshooting guidance.

13. REFERENCES

- U.S. Environmental Protection Agency (1998) Quality assurance guidance document 2.12: Monitoring PM_{2.5} in ambient air using designated reference or Class I equivalent methods. Prepared by the Human Exposure and Atmospheric Sciences Division, National Exposure Research Laboratory, Research Triangle Park, NC, November.
- U.S. Environmental Protection Agency (2006a) Probe and monitoring path siting criteria for ambient air quality monitoring, 40 CFR Part 58, Appendix E.
- U.S. Environmental Protection Agency (2006b) Reference method for the determination of fine particulate matter as PM_{2.5} in the atmosphere, 40 CFR Part 50, Appendix L.
- U.S. Environmental Protection Agency (2008a) Network design criteria for ambient air quality monitoring, 40 CFR Part 58, Appendix D.
- U.S. Environmental Protection Agency (2008b) Quality assurance requirements for SLAMS, SPMs, and PSD air monitoring, 40 CFR Part 58, Appendix A.
- U.S. Environmental Protection Agency (2008c) Quality assurance handbook for air pollution measurement systems, Volume II: ambient air quality monitoring program. Prepared by the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Air Quality Assessment Division, Research Triangle Park, NC, EPA-454/B-08-003, December.