Final Report

RP 1284 Research Project
Develop a Standard for Testing and Stating the Efficiency of Industrial Pulse Cleaned Dust Collectors

(ASHRAE 1284-TRP)

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Submitted 21 January, 2010

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Acknowledgement

We would like to express our appreciation for the material contributions to our research effort. These came in the form of donated equipment and test filters and were essential to the charter and expectations of the research. We are deeply appreciative to the following companies for such corporate stewardship:

Camfil Farr Air Pollution Control in Jonesboro Arkansas
Donaldson Company in Minneapolis Minnesota
GE Energy Filtration Technologies in Kansas City Missouri
MAC Equipment Company in Sabetha Kansas

Overview Summation

1. Focus Point

This report is the summary communication of completed ASHRAE sponsored research under the title *"RP-1284 Research Project – Develop a Standard for Testing and Stating the Efficiency of Industrial Pulse Cleaned Dust Collectors"*. The objective of this research was to complete a three-fold set of tasks aimed at facilitating the promulgation of a formal test method to be published by ASHRAE in the near future.

The specific objectives are well detailed in the supporting documentation and appendixes attached to this report but can be summarized as follows:

- **Use a "Black-Box" concept -** where the test system to be evaluated will be operated as per the manufactures instructions without modification and without measuring internal variables. The performance assessment elements of the test system (inlet challenge hardware, outlet emissions quantification instrumentation and means to provide regulated air flow through the system) are to be physically separate elements. These elements should be designed so that they can be arranged and independently fastened to the "Black-Box" to be evaluated.
- **Use real world "pulsed" application of full filter elements** – the primary reason other methods have been shown to be ineffective ways to access performance is that they do not accurately portray the dynamics of pulsed operations of multiple, full filter arrangements. This protocol addresses that pivotal issue by requiring that a sequential pulsing be used (defined as "Collector Cleaning Cycle") with a minimum of 25% pulsing occurring on full filter arrangements.
- **Assess the performance in at least two ways** – Total mass emissions and fractional efficiency by particle count where no more than 25% of the filter elements are pulsed at one time, should be reported. We elected to add a third gravimetric technique as well. Specifically:
    1. Mass emissions – In both total concentration being emitted and mass removal efficiency. Total concentration to be expressed in mg/m^3 of particulate matter exiting in the PM 2.5 or PM 10 ranges. Mass removal to be expressed as a percentage of the emissions to the challenge inlet mass concentration.
    2. Efficiency by particle size – expressed as a percentage of the inlet vs. the outlet aerosol in particle size ranges from 0.3 μm to 10 μm. A minimum of at least six evenly distributed bands across that particle size range is required.
    3. Gravimetric efficiency – We have field-testing experience using EPA method 5 (see reference 12) and recommended adding this technique. Performance is measured by sampling isokinetically onto a downstream membrane. The weight of the membrane would be used to calculate mass removal efficiency as a percentage of the upstream mass concentration.

The tasks and objectives were completed over a thirty-month period using filters and equipment donated by four different organizations. Several developmental trials were conducted to determine the best technique, equipment and instrumentation to achieve the goals. We then ran a series of nine “criteria tests” to demonstrate technique and define sources of error. We then ran a three-test repeatability study using one filter/housing arrangement to identify sources of variability.

All these efforts are intended to provide the necessary technical support that will be needed in publishing a new ASHRAE test standard for testing industrial pulse cleaned filters and equipment systems. Figure 1 below is the initial general layout from the Phase One Report (summarized in the supporting documentation section 2 and attached in it’s entirety as Appendix C). Figures 2 and 3 on the following pages show how this initial concept manifested in complete test system arrangements.

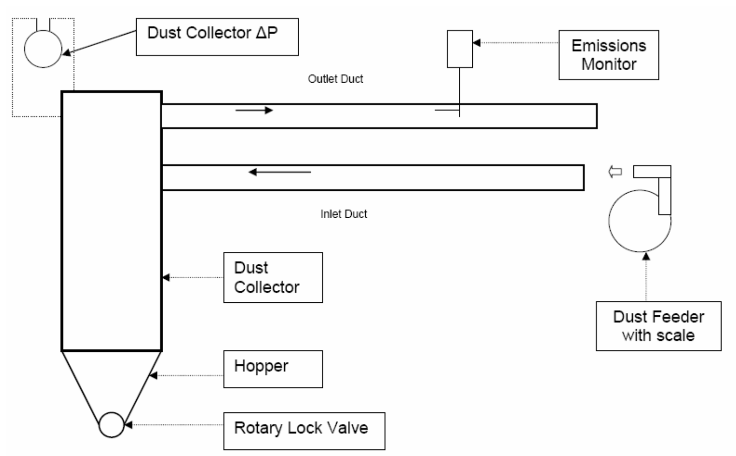


Figure 1 - Initial Concept from Phase One report

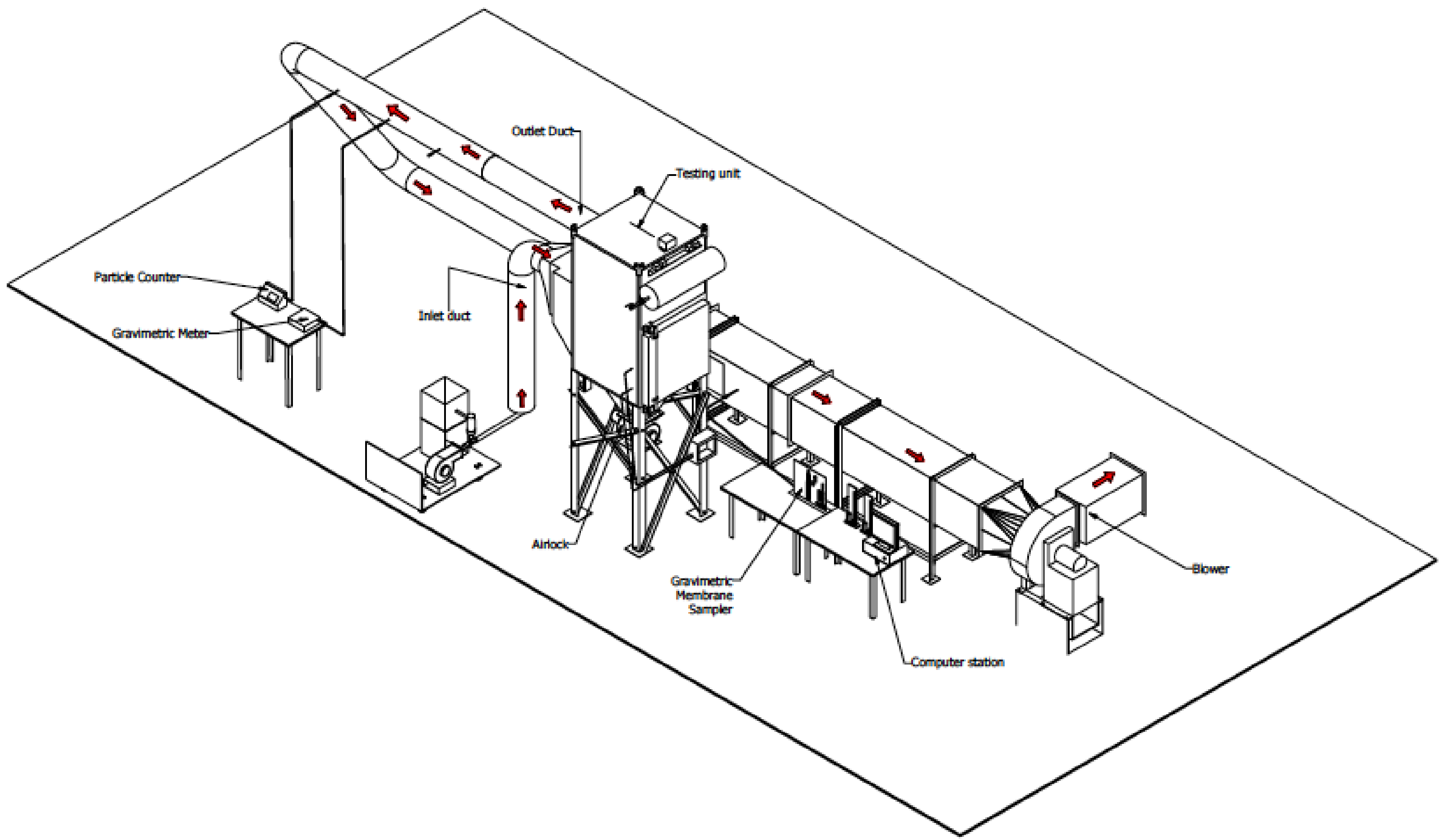


Figure 2 - Finished Arrangement of full test - Vertical Cartridge

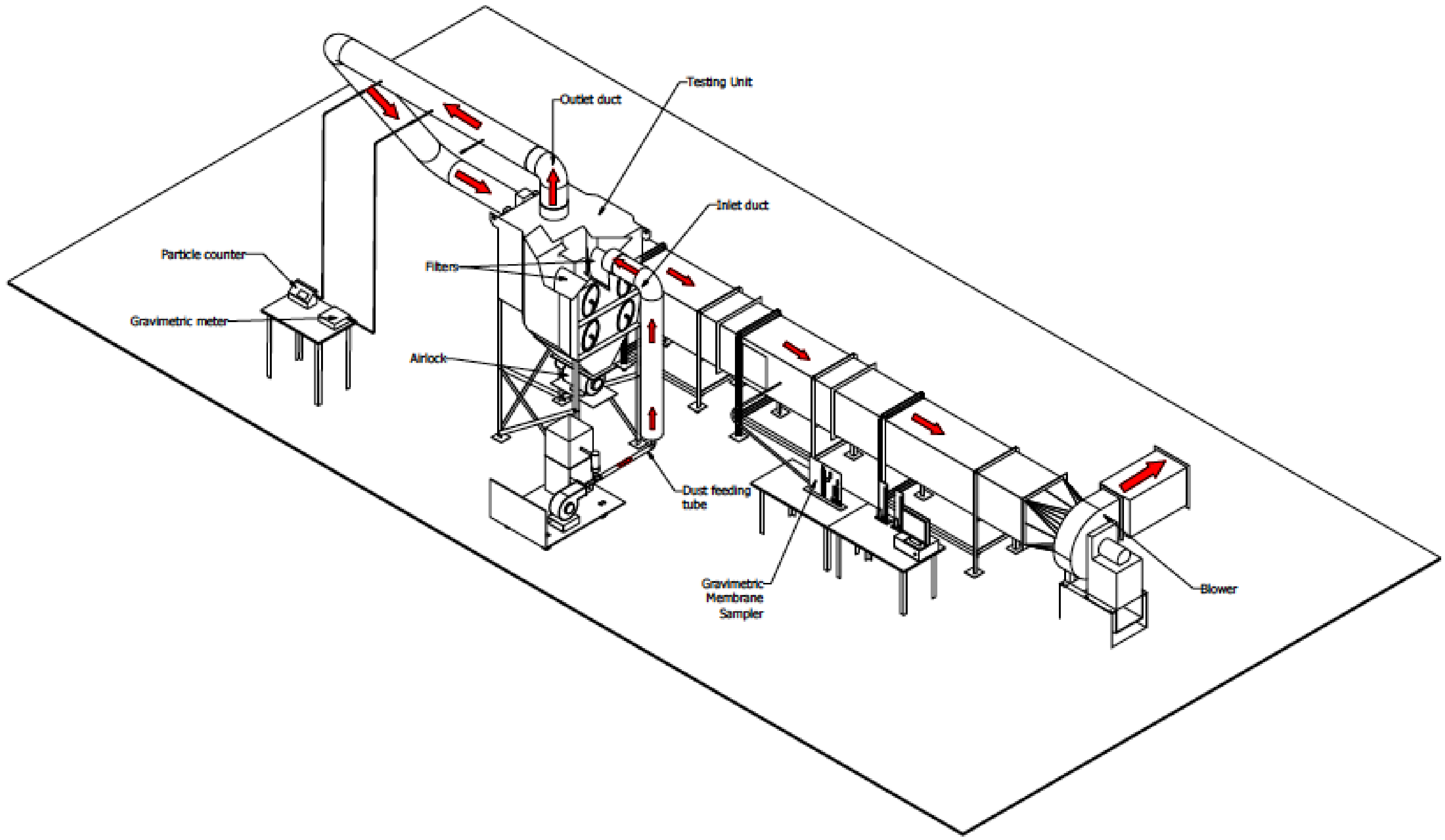


Figure 3 Finished Arrangement of full test - Horizontal Cartridges

Overview Summation

<u>2. Results on Task Assignments</u>

The three specific tasks of the project and our results in achieving them are outlined as follows:

<u>Task One – Literature and technical review</u>
Specific Goal = assemble, review and report on all relevant prior art.
We completed a report entitled "Phase One Report - RP 1284 Research Project - Develop a Standard for Testing and Stating the Efficiency of Industrial Pulse Cleaned Dust Collectors". The report was approved by the PMS on 20 January 2008. A short abstract of the report is in the supporting documentation section 2 and the full report is attached as Appendix C.

<u>Task Two – Experimental Program</u>
Specific Goal = propose and evaluate a series of protocol steps and recommend best options.
Based on the findings of the Phase One report and the guidance of the PMS, we developed and completed a program to determine the proposed protocol. We then initiated action to complete the steps and test out our recommendations. The specific efforts completed and used to set the protocol are detailed here. The protocol is specifically outlined in the "Task Three" section and as a proposed test protocol synopsis in Appendix F.

1. <u>Stages</u> – after some analysis of the prior art and discussions with several experts in the field, we initially looked at a four-stage format to emulate a loading sequence prior to performance testing (reference details in the supporting documentation section 5). The intent was to provide a defendable "conditioning" of the system and filters prior to testing under operating conditions. On further review we elected to add a step that allowed us to initiate normal system cycling (defined as "Normal Cleaning Cycle") both before and after the rapid pulse conditioning. This five-stage sequence was used in all testing and is our recommended methodology.

2. <u>Concentration measurement capability</u> – a significant amount of effort and time was invested in this area. We ran a number of full feed trials solely to determine the capability of feeding the correct challenge concentration and measuring both the upstream and downstream concentrations. We settled on an inlet range of 500 to 10,000 mg/m^3 and were able to measure concentrations as low as the required .01 mg/m^3 downstream. For a more detailed description of how and why these changes were made, see the supporting documentation section 5.

3. <u>Upstream characterization</u> – We made a decision early in the project, with the blessing of the PMS, to not attempt to measure the upstream concentrations in real time. This was a considered a compromise position by some but was judged to be an acceptable alternative to the technically un-defendable options (variability of cascade impactors or dilutors for example). For a detailed defense of this position, please reference appendix D, Section

"Issues related to RP 1284". As the appendix explains, we elected instead to use a total mass measurement and characterization of the distribution based on a lab analysis of a much smaller concentration developed with an identical aspiration technique. We have since learned of a real time instrument capable of both upstream and downstream measurements in the ranges that are desired. As of this writing, we have purchased that instrument and hope to rerun several of the criteria trials that we conducted to improve on our capabilities.

4. Dust feeder – we ran a thorough set of capability trials on products from two different dust feeder manufacturers. We settled on one that has multiple lead screw options and was shown to be capable of feeding as required. We did also choose to load and confirm throughput manually, a decision that could be upgraded easily to automated methods that included a scale and feedback controller provided by the manufacturer.

5. Flow rate – The accurate control of airflow is vital in any test method development. We have experience with several styles of orifice and feedback loops, correcting for ambient conditions. Based on this experience, we elected to use a radiused ASTM nozzle that we crosschecked with a calibrated flow element. Many of the tests were conducted using both devices at the same time. We did find some slight variation in the two methods and recommend that standardized pitot tube traverse testing also be used to confirm accurate flow.

6. Instrumentation – We ran two pairs of instrument trials before we settled on the laser particle counter, mass meter and gravimetric techniques outlined in supporting documentation section 5. The general criteria for these selections were:
    - For the particle counter – Particle size range from 0.3 μm to 10 μm. Flow rate of one ft^3/min. Minimum six bands of delineation over the full range. Cost under $10,000.
    - For the mass meter – Real time feed back and capable of data logging feature. Expressed size ranges as PM 1, PM 2.5 or PM 10. Small portable and easy to use. Cost less than $5,000.

    The general technical specifications of these instruments are detailed in the Task Three section below.

7. Criteria testing – Upon completion of the proposed protocol steps, we ran a series of tests to prove out the method. We labeled these tests "Criteria Tests" and they are the basis of our findings. Please reference the supporting documentation section 4 for these results. The last three tests in this sequence are a small repeatability study using the same part number filters, housing and test parameters on all three tests. This was not part of the original scope of work but was judged to be an important issue by the PMS.

8. 25% cycling – in an effort to approximate real world conditions, the RFQ required that any testing arrangement have the capability of a 25% pulse sequence (defined in this report as “Collector Cleaning Cycle”). Specifically this means that we expect to have 25% of the filters pulsed at any one time. In practical terms, this means that we required that any test system proposed have filters arranged in multiples of four with individual pulsing for each set of filters. (For example – the cartridge filter test rigs we evaluated had four filters and an individual pulse valve for each filter while the bag style unit we evaluated had 16 filters with an individual pulse valve for each set of four filters).

9. 9’s approach – we have tentatively proposed that these filters be evaluated as performing in decade ranges of particle size and mass removal efficiency. In practical terms, the filters perform so well that this terminology makes good use of the performance outcome. Performance would then be expressed as “5 Nines” for a filter with 99.999% plus efficiency or “6 Nines” with a filter performance of 99.9999% plus efficiency. Further delineation is possible and may be required to make the standard evaluation meaningful in some instances.

10. Operating Parameters – we reached a set of minimum input criteria for the operating parameters that should be supplied from the test requesting organization/individual. They are:
    - System test housing layout – each test system will consist of a housing and filter arrangement. The physical details of the system should be well defined in the form of a drawing or schematic. Service requirements should be clearly communicated and the control system operating instructions should be provided.
    - Flow Rate – a computed test flow rate for the arrangement.
    - Pulse details – Frequency, duration, minimum tank pressure and compressed air flow.
    - Test challenge dust – material and concentration expectations as well as PM portion that is desired (PM 2.5 or PM 10).
    - High and low pressure drop pulse settings established.

Task Three – Compilation of Results

Specific Goal = report the details of the proposed protocol.

There are five general protocol areas detailed here as well as a proposed test method synopsis in Appendix F. A presumption is that the test system and particular operating parameters have been agreed to prior to testing and that the unit has been installed with the proper services, airlock system and the filters have been correctly installed.

1. Pretest systems checks and verifications:
    a. Calibrate the mass metering instrumentation for the specified test dust per the manufacturers instructions.

b. Perform an aerosol distribution measurement per Appendix D if direct measurement is not possible..
c. Establish airflow and confirm that the flow is accurately being measured and corrected for ambient conditions (or measured directly if instrumentation is available).
d. Perform a dust feeder throughput check to make sure that the proper amount of dust is being effectively aspirated per time interval (periodically checking the aspiration/dispersion nozzle for flow and wear).
e. Confirm that all three instrumentation packages are installed correctly and that they are sampling properly.
f. Perform pulse trials to confirm that the pulse parameters have been met and that the reservoir pressure recovers between pulses, specifically during rapid pulsing of the stage three conditioning.
g. Make sure there is sufficient dust on hand and that it is properly dried and maintained.
h. Make sure the air lock and bulk dust removal is operating properly and that there are no leaks.
i. Insure that all safety measures have been addressed (unit is securely mounted, electrically grounded and all moving parts are guarded).

2. Procedural steps:
   a. **Stage One** – Static Load Phase = Feed dust without pulsing to the prescribed resistance. Record the amount of time and dust to reach this resistance.
   b. **Stage Two** – Transition Phase = Establish and run the specified upper and lower pressure drop targets for pulsing. Record the resistance data through a minimum of two and one half full cycles of pulsing. A pulse cycle is considered a full sequence through all four quadrants of pulsing.
   c. **Stage Three** – Conditioning Phase = Establish time-initiated pulsing for a rapid sequence of pulses for the specified number of pulses. Record the pressure drop readings throughout the phase.
   d. **Stage Four** – Recovery Phase = Return to the pressure initiated pulsing used in stage two. Run ten full cycles. Record the pressure drop reading through out this sequence.
   e. **Stage Five** – Operation Phase = Maintain the continuous pulsing per the requirements in stage four. Start the sampling sequences for all three instrumentation packages. Record the system pressure drop such that it can be matched up with the emissions from all instrumentation for a minimum of ten full pulse cycles.
3. Data reduction and reporting: (See below for a recommended data summary tool – reference Appendix D for calculation specifics and to Appendix F for the proposed test method synopsis).

Table 1. RP 1284 Test Results (Test 1)

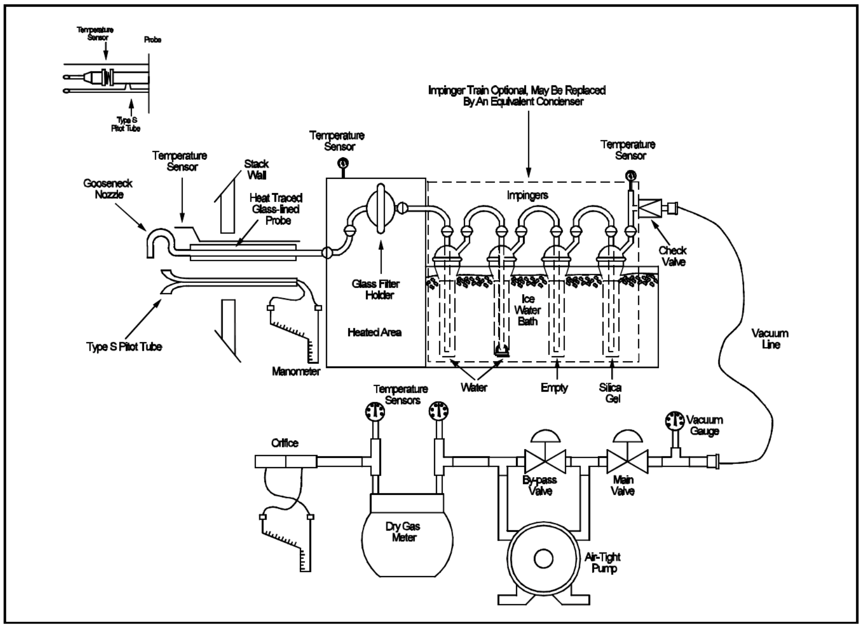
		Stage 1 Static	Stage 2 Transition	Stage 3 Conditioning	Stage 4 Recovery	Stage 5 Operation
Dust Fed vs Time	Graph #					
Start Point (kg, hrs)						
End Point (kg, hrs)						
Pressure Drop vs Dust Fed	Graph #					
Start Point ("wg, kg)						
End Point ("wg, kg)						
Number of Cycles						
Residual Pressure Drop ("wg)	Graph #					
First cycle						
Last Cycle						
Cycle Time (Minutes)	Graph #					
First cycle						
Last Cycle						
PM_{10} emissions vs dust fed	Graph #					
Total mass emissions	(mg/m^3)					
Total mass efficiency	(%)					
PM_{10} Pen vs dust fed	Graph #					
Eff vs Particle Size (0.3 - 10 um)						
End Point Definition						
Procedure Reference		Page B-1 Sect 2	Page B-3 Sect 2	Page B-5 Sect 2	Page B-6 Sect 2	Page B-8 Sect 2

Color codes --- >	don't keep	keep, if available	informative	mandatory

a. Plot the mass emissions vs. dust fed for the gravimetric results. This has been shown to be less than meaningful and may be pulled from our recommendation as we gain more experience.
b. Plot the mass emissions vs. dust fed for the mass meter data.
c. Calculate and plot the mass efficiency using the upstream mass established in the set up vs. the measured mass per the instrument.
d. Calculate and plot the particle size efficiency using the measured upstream distribution or the upstream distribution established in the set up procedure vs. the downstream measurement from the particle counter.
e. Format all graphs onto a single page such that the dust fed x axis for all is lined up (again reference supporting documentation section 4 for examples).

4. <u>Instrument/hardware specs of equipment used during this research project:</u>
    a. **Particle counter** – Laser diode particle counter; 0.3 to 10 µm (micrometer) range; minimum of 6 size ranges; 28.3 L/min (one cfm) flow rate; coincidence loss of maximum 5% at 400,000 particles per ft^3; counting efficiency of 50% on 0.3 µm (micrometer) particles.
    b. **Mass meter** – 90^o light scattering laser photometer; .001 to 100 mg/m^3 range; +/- 0.1 or +/- .001 mg/m3 resolution (whichever is greater); 0.1 to 10 µm (micrometer) size range; output reported in aerosol mass concentrations of PM 1, 2.5 or 10 per EPA specifications.

c. **Gravimetric sampling** – Recommendation is to use a calibrated gas meter and membrane sampling protocol similar to EPA method 5 (see reference 12 and the schematic below).



5. Material specifications:
   a. Challenge Dust – Calcium Carbonate dust in various size ranges. The preferred material size has a mass mean diameter of 3.0 μm (Atomite) but there are several size ranges available.
   b. Membrane sampler material – Teflon with a minimum micron size of 0.3 μm.

Overview Summation

3. Conclusions and Recommendations

Conclusions

In our research and development of this protocol, it became clear that quantifying the performance of pulse cleaned dust removal equipment is exceptionally difficult. Given the wide range of variables and differences in inlet/outlet concentrations of up to six orders of magnitude, we were compelled to add the gravimetric method to the mass concentration and particle counting expectations in the original request for quote on RP-1284. This additional method will be effective in judging performance of lower efficiency products and becomes less useful as the level of product performance increases.

The protocol developed is capable of delineating performance of these products and enhancing decision-making capabilities when designing and specifying the systems. We did find that the early stages of the test can be as informative as conducting the full form of the test. Specifically:

1. Stage one loading can be a quick and accurate way to detect very poor performance with out ever having to pulse and quantify emissions.
2. Stage two and three pulse conditioning can be used as stand alone assessment technique when evaluating dynamic performance of the systems.
3. It is likely that a significant amount of testing cost can be avoided by using these preliminary data products to make early judgment, thereby accelerating the design process.

Recommendations

The techniques developed in this project were subject to instrument availability and prior art at the time the project was initiated. Many aspects of the research were also limited in the project request in an effort to reduce the complexity of the protocol. For these reasons, we have the following recommendations as follow up to our work. It should be noted that we have taken the initiative to act on the first of these recommendations as of this writing.

1. ***The accurate measurement of real time upstream concentrations should be pursued*** – while the body of the report details why we elected to avoid this, new instrumentation has become available that has this capability. We have procured this equipment and begun the assessment of it as a replacement for the instrument recommendations made here.
2. ***Reliability and Repeatability studies should be conducted*** – the results of our three-test repeatability study are explained in the body of the report. Additional works needs to be completed in this regard to derive the meaningful span of application of any standard written around our findings.
3. ***Challenge dust material trials should be initiated*** – We used one specific material composition in varying size ranges and concentrations. Other materials with industry specific physical and composition variables should be experimented with to satisfy the application needs anticipated.
4. ***An ASHRAE standards project committee should be initiated*** – As of this writing, preliminary efforts have been made to do so under the auspices of ASHRAE 199P.

5. ***Comparative Field trials*** – It should be a clear goal to have the lab protocol indicative of meaningful real world results. Additional testing in the field to compare to lab-generated results should be sought to attain the goal.

This is just a sample of the Final Report.

To obtain the report in its entirety, contact ashrae.org.