

# **GAS TURBINE FILTER EFFICIENCY TEST PROCEDURE: LIQUID AND SOLUBLE PARTICLES**

Prepared by

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**SwRI® Project No. 15481.01.401**

Prepared for

**Gas Machinery Research Council  
3030 LBJ Freeway, Suite 1300  
Dallas, Texas 75234**

**March 9, 2011**

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## 1. INTRODUCTION

Current filter testing standards exist (primary standards for fiber type filters are ASHRAE 52.2 and EN 779) that specify how to test filters for mass efficiency and particle size efficiency of dry particles in low humidity environments. However, in many real-world environments, either the humidity is high or there are wet particles that filters must deal with. In addition, there may be particles that are soluble in water that can leach through a fiber filter because of the presence of liquid. To provide a more accurate measure of how various types of filters and filter systems will perform in these environments, this test procedure describes a method to achieve a standard measure of filter and filter system performance in wet and humid environments.

## 2. TEST SETUP

### 2.1 GENERAL SETUP DESCRIPTION

The test setup for measuring filter and filter system efficiency is based upon what is described in the existing specifications of ASHRAE 52.2-2007 and EN 779-2002, which will be referred to as the “existing standards” from this point on. The recommended setup for this testing is shown in Figure 1. The largest modifications from the existing standards are the inclusion of a nozzle array for entraining liquid into the air stream, and the addition of a set of drains to measure liquid that falls out of the airflow. Also, for tests of filter systems, the single filter element will be replaced by the components of the filter system.

If no specific mention of a component’s design or location is made in this procedure, the existing standard employed by the facility should be referenced to obtain further details.

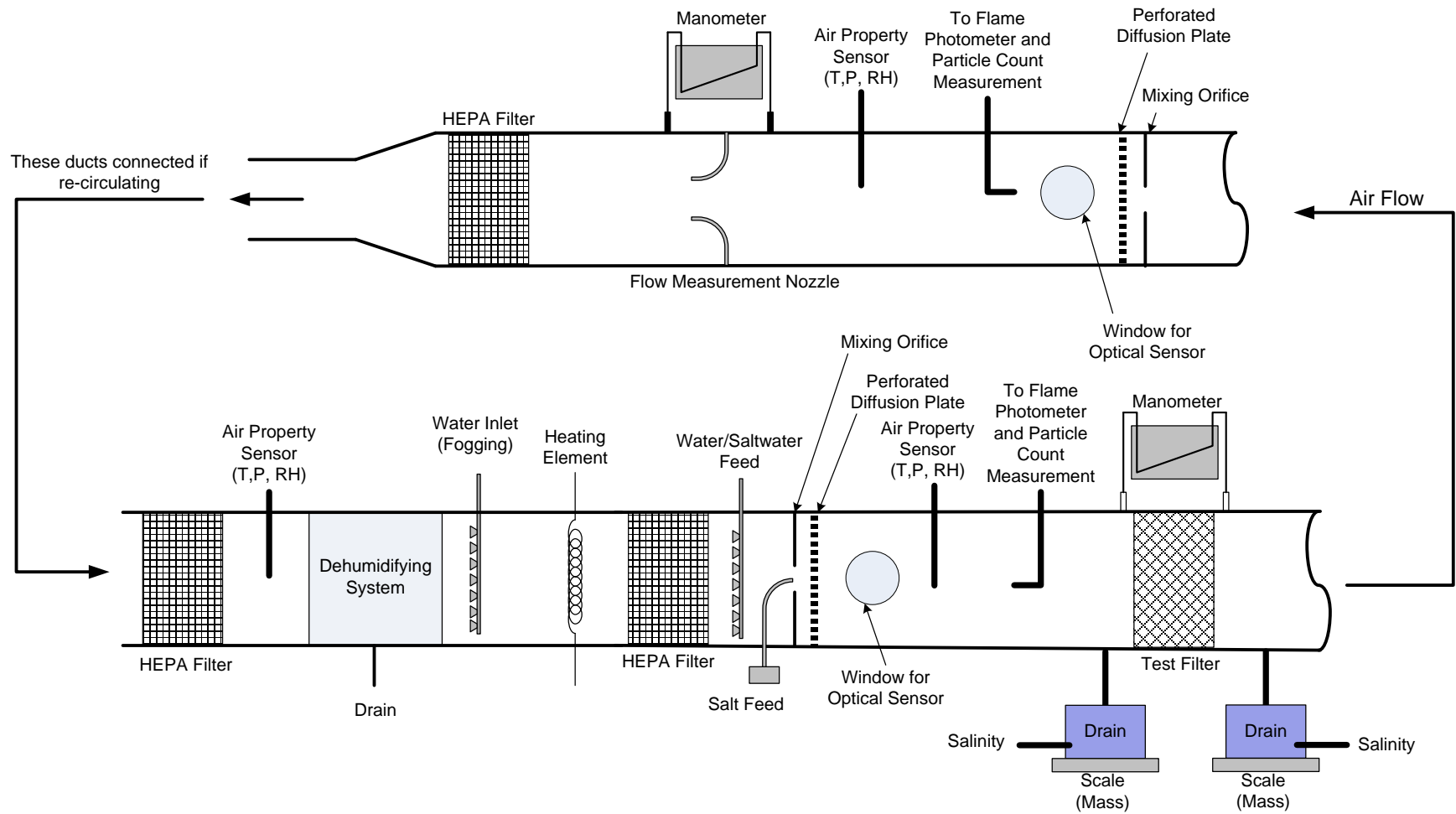
Other modifications include the addition of either windows, or clear test sections to allow optical sensors to be placed outside of the test duct for measuring particle size and counts if they are used. An additional sampling tube is needed upstream and downstream of the test section to take samples for a compositional analysis with a sodium flame photometer or another similar technology.

The dust feeder described in the existing standards could remain in this setup, but for the purposes of this testing, it would be used to inject a mixture of test dust and dry salt particles. Regarding this topic, more details are provided in section 4 of this procedure.

### 2.2 TEST DUCT

The test duct shall be similar in design to what is defined in the existing standards with the modifications described in this document. The inclusion of the two sets of mixing plates should be dictated by the existing standard that is currently referenced for the test facility. When the plates are used, each set will include a mixing orifice plate, and a perforated diffusion plate. The existing standards provide dimensions to use for each plate. These plates must be located immediately upstream of the location where particle size-measurement and count will be taken.

If a filter system (multiple filter elements) is being tested, then modifications will be made to the existing duct to allow for an elongated test section to fit all the filter elements.



**Figure 1. Test Setup Equipment**

## 2.3 WATER AND SALTWATER SPRAYS

To test over the range of droplet sizes and liquid concentration levels for the various filter components that could be tested may require an array of nozzles connected to a manifold system. The range of droplet sizes for these nozzles needs to be from 1 to 100  $\mu\text{m}$  in diameter. These sizes are representative of the water droplets, which would be removed in a GT filtration system. The flow rate for the entire nozzle array needs to be capable of producing a concentration of 1000 particles/ $\text{cm}^3$  or greater, with at least 50% by weight of the particles under 30  $\mu\text{m}$ , and at least 95% by weight of the particles under 100  $\mu\text{m}$ .<sup>1</sup>

When liquid is being sprayed, the mixing orifice and diffusion plate should be removed upstream of the test filter. The downstream mixing orifice and plate can be left in place if low amounts of liquid are expected downstream. The nozzle should be set a distance upstream from the nearest obstruction (such as the mixing plates) by at least two, but preferably three, effective duct diameters and downstream from the previous obstruction by at least one effective duct diameter.

## 2.4 SALT FEED

Dry salt will be injected into the test duct in a mixture with ISO fine test dust. The mixture should be 50% ISO fine test dust and 50% salt dust by weight. The salt dust should be prepared before mixing with the ISO fine dust. The salt dust should be comprised of particles less than 30  $\mu\text{m}$  with 50% by count under 1  $\mu\text{m}$  and 95% under 10  $\mu\text{m}$ . The dust should be fed at a rate from 12.5 to 72  $\text{mg}/\text{cm}^3$ .

The salt dust mixture should be fed into the test duct with a dust feeder that allows for continuous and consistent feeding. Some dust feeders do not allow for consistent feeding. Also, care should be taken to ensure that the salt mixture remains dry before feeding. Any moisture can cause the salt to clump together and not feed well.

An aerosol generator may also be used to load the filter with salt (in place of the salt dust). If this is used, then loading with salt and ISO fine test dust should be alternated in order to ensure the filter is loaded with 50% salt and 50% ISO fine test dust by weight.<sup>2</sup>

## 2.5 DRAINS

The drains are meant to capture any of the liquid that falls out of the air stream. To aid in this collection, the bottom of the test duct will need to be slightly sloped to the drain connections. To account for the liquid that is collected, the drains will empty into a vessel that can allow for mass and salinity measurements in between tests. This vessel also needs to have its own drain to allow emptying between tests.

## 2.6 WINDOWS AND OPTICAL PARTICLE COUNTERS

Because this testing will include salt and water, the use of any insertion probes could provide a location for salt buildup, or allow slugs of water to build up before passing to the measurement

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<sup>1</sup> One possibility uses a 0.2mm nozzle from AmFog Nozzle Technologies, Inc. with a 500 psi liquid feed; this would roughly be a liquid flow rate of approximately 52 mL/min for the highest test duct air flow.

<sup>2</sup> Model 8108 from TSI is one possible aerosol generator that meets these criteria.

instrument. Either way, the probe needs to be monitored to ensure there is no interference with the measurement. Therefore, this procedure allows for particle counters that measure the particles in flow instead of a sample (if optical particle measurement is used, then continuous particle counting is not necessary as described in Section 2.7). To accommodate this, the portion of the test duct where measurements will be made must be transparent.

The minimum modification can be a window made of clear plexi-glass large enough for the optics of the optical particle system to use. Ideally, though, the entire section of ducting would be replaced with a transparent section. This will aid in other ways by allowing visual inspection of the duct interior, and particle measurements in multiple locations of the cross section. It should be noted that there may be issues with optical measurements when the air in the duct has high humidity (> 95%). The windows may fog which prevents the optical sensors from working correctly.

The particle counting system must have the capability to measure over at least the range of 1-30  $\mu\text{m}$ , and the concentration limit of the system will be critical to the injection rate of the salt and liquid particles.

## **2.7 SAMPLING SYSTEM**

Sampling is necessary to measure the particle counts and sizes in the air flow and the composition of the matter in the airflow, specifically the salt content in the high-humidity or liquid particle tests. If the optical particle counter with the window is used, then sampling is not needed for particle counts during test intervals.

The sampling probe needs to fulfill the guidelines for the aerosol collectors in the existing standards. Two sampling probes are needed at both the upstream and downstream locations. One set of probes (one upstream and one downstream) are needed to acquire particle samples and the other set is necessary to take the compositional measurements. These probes should either be in-line with one another or the particle sampling probes should be placed upstream of the compositional sample probes.

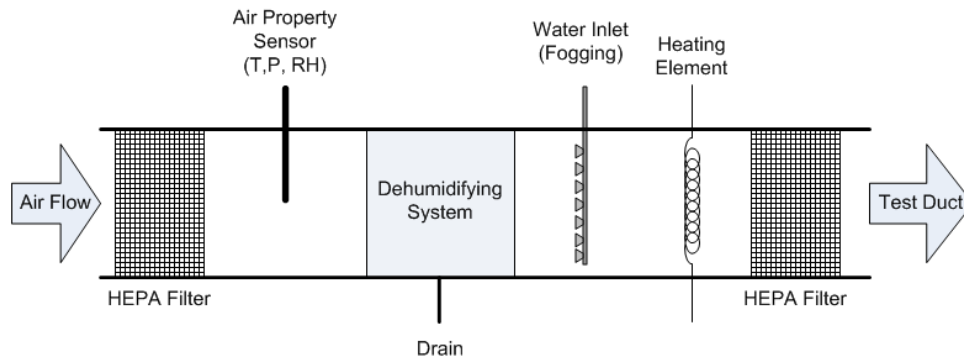
The system to measure the sample must be able to calculate chemical composition; specifically in this case, the concentration of sodium in the sample. A flame photometer is one option. It is preferred that the system be capable of recording continuous electronic measurements.

## **2.8 RELATIVE HUMIDITY CONTROL**

In order to control the humidity in the test section, additional equipment upstream of the first HEPA filter in Figure 1 is required. Since this testing involves air with higher humidity and requires stricter control of the humidity than the existing standards, some additional equipment may be necessary over what is currently specified. Specifically, to increase humidity, a system to inject additional water into the air stream will be required. Designs for this type of system already exist; inlet foggers or steam injection are two possible systems. Equipment to reduce the relative humidity would also be needed at testing locations with naturally high humidity. An option is to use an independent source of air instead of circulated air. This air would be below the humidity level of interest so that humidity could be adjusted by controlling the amount of vapor added to the system.

Additionally, to maintain inlet air temperatures, it may be necessary to add a heating or cooling system to the test duct. The heating element could also be used to further control the relative

humidity in certain situations. The settings of these three components (dehumidifier, water foggers, and heating element) can be adjusted manually during the test setup. Alternatively, an additional air property sensor could be inserted just upstream at the air inlet and the resulting measurements fed into a control system that would adjust settings to match the output air to a desired humidity. The humidity control system could be set up similar to what is illustrated in Figure 2, with sufficient distance between the different components for thermal equilibrium to be achieved.



**Figure 2. Humidity Control Schematic**

The purpose of the first HEPA filter is to condition the inlet air by removing any particulate. The second HEPA filter, which is the first HEPA filter in Figure 1, is to remove any liquid droplets that do not evaporate after injection from the foggers.

## 2.9 BLOWER

Airflow in the test duct will be controlled by a blower. The blower can be placed either upstream, before the very first HEPA filter, or downstream, at the air outlet after the very last HEPA filter. In either scenario, the fan needs to be capable of creating an airflow rate in the test duct over the range of filter airflow ratings to be tested (which is expected to be in the range of 450 – 4000 cfm). It is recommended if possible that the blower be placed upstream of the test section.

## 3. MEASUREMENTS

The performance of the filter with water, salt, and dust is quantified in several ways in this procedure. Each calculated efficiency represents a different aspect of the filters performance and is necessary in order to understand how the filter’s performance is affected by the presence of liquid and soluble particles.

First, the efficiency of the filter is measured using the procedure outlined in ASHRAE 52.2. This involves the use of a KCl particle generator and particle count measurement upstream and downstream. This efficiency measurement is taken with the filter in a new condition, in between each loading interval during a test, and after completion of a test. This measurement shows how the filters dry particle performance is influenced by the tested parameter (water performance, salt performance, etc.).

The second efficiency measurement is calculated using the upstream and downstream compositional analyses. Samples of the air flow at both the upstream and downstream

locations are taken when salt is either being loaded as a dry mixture or a salt water spray. The comparison of the upstream and downstream measurements provides salt removal efficiency. The compositional samples should be taken at each test interval to quantify how the salt removal efficiency changes during the test.

The last efficiency measurement is taken when the filter is being loaded with salt dust mixture, water, and salt water. A particle count measurement (with typical particle size ranges measured) should be taken continuously upstream and downstream of the test filter during the loading intervals. The particle count measurements allows for a particle count efficiency to be calculated. The calculated efficiency provides information on how the filter performs with the substance it is being loaded with. These efficiencies will be different than the efficiencies measured with the KCl aerosol in the ASHRAE 52.2 efficiency test.

Each measurement required to calculate the three efficiencies discussed above are detailed below. It should be noted that electronically recorded measurements (not hand written) are preferred for the testing.

### **3.1 DRY EFFICIENCY MEASUREMENT**

The measurement of the dry dust efficiency should be conducted in accordance with ASHRAE 52.2 procedures. KCl aerosol should be used and the particle counts should be measured upstream and downstream. This procedure does not require all 10 particle count measurements required in ASHRAE 52.2 to be completed. Five upstream and five downstream particle count measurements are sufficient for the efficiency calculations.

### **3.2 COMPOSITIONAL MEASUREMENT**

A compositional measurement must be taken upstream and downstream of the test filter to determine the salt removal efficiency of the filter. This measurement can be taken with sample probes. The measurement should be taken a minimum of three times during any salt loading interval (dry or wet). The procedure recommends the use of a sodium flame photometer for this measurement.

### **3.3 AIR FLOW PARTICLE MEASUREMENTS**

During all loading intervals (dry salt, water, salt water) the particle count and size in the air flow stream is to be measured. There are several ways the measurement can be done. First an optical particle system (with windows on the test duct) can be used to capture the particle distribution in the flow stream. This method avoids the uncertainty of particle sampling, which can come about due to liquid particles conglomerating in the sample tube and salt depositing on the sample tube.

A second method for the measurement is with a sampling device. The device must be capable of counting particles and measuring particle sizes (in the range of 0.1 to 30  $\mu\text{m}$ ). In addition, it should be able to handle liquid particles and the concentration of particles required for this testing (greater than 1000 particles/ $\text{cm}^3$ ). Care should be taken when sampling during the water spray tests to avoid flooding the sensor. If this occurs, the flow rate of water in the test duct may need to be reduced.

### **3.4 RELATIVE HUMIDITY**

The relative humidity of the air is a necessary measurement required to fully characterize the air stream, especially with regard to the liquid particles. Therefore, a measurement in close proximity to the optical measurement systems is necessary. The actual measurement device can be obtained from multiple test-equipment manufacturers, but should have an accuracy of at least 2%.

### **3.5 PRESSURES**

#### **3.5.1 FILTER PRESSURE DIFFERENCE**

As with existing standards, one of the filter performance characteristics is the pressure drop across each test filter. The existing instrumentation in place to measure the pressure drop across each test filter element for the existing standards is sufficient for this testing as well.

#### **3.5.2 STATIC PRESSURES**

A static pressure measurement is also required to fully characterize the air stream. This measurement is especially critical near the locations where the air properties are an essential factor, such as near the flow or relative humidity measurement devices.

### **3.6 TEMPERATURE**

Although not specifically described in the existing test standards, temperature was a recordable measurement. In this testing, however, it is of additional interest as the relative humidity is greatly affected by the air temperature, and whereas the existing standards only limit the relative humidity, it is the goal of this testing to control the relative humidity. Test points specifically near the test filter, and in close proximity to the other measurement locations are required. A thermocouple or RTD is appropriate for this measurement.

### **3.7 AIR FLOW RATE**

The performance of the filter will be measured over the rated operating conditions of the filter, so a measure of the flow is required as it is in the existing standards. Since this is a carryover from the existing test standards, this measurement can be made as described in the existing standards.

## **4. GENERATION OF DRY SALT AND LIQUID AEROSOLS & HUMIDITY CONTROL**

### **4.1 DRY SALT**

Generally, marine, offshore, or coastal facilities are prone to a variety of soluble contaminants. The primary component, however, is sodium-chloride salt (NaCl). Therefore, in this testing, NaCl will be the primary solid particle of interest. The concentration of dry salt particles is described earlier in section 2.4. Also as mentioned there, two methods are possible for the generation and injection of the dry salt into the air stream: through the aerosol generator or the dust feeder system.

It should be noted that use of aerosol generators is preferred over the dry salt feeder because any moisture in the air can affect the size distribution of the dry salt before injection, which can affect the results of the performance test. Also, the aerosol can provide a more consistent feed of the salt than the dust feeder can.

#### **4.1.1 AEROSOL GENERATORS**

Because of the similar size interest to the existing standards' specifications for aerosol particles, it is possible that the aerosol generators already in place could be used to generate and inject the NaCl salt particles but they must be able to generate particles at the high concentration required for loading. The solution used for the aerosol generation will be made using salt that is at least 95% NaCl by mass, and shall be prepared according to the aerosol generator guidelines.

The aerosol generator manufacturer needs to be consulted to ensure proper operation is possible with NaCl.

#### **4.1.2 DUST FEEDER SYSTEM**

The second alternative is to treat the mixture of dry salt particles and ISO fine test dust as the dust in the existing standards; generating the salt particles externally and injecting into the air stream using the existing dust feeder system.

##### *Preparation of Salt Dust Mixture*

Preparation must start with salt that is 95% or greater by mass NaCl<sup>1</sup>. Then using a pulverizer or grinder, the salt crystals should be reduced in size until the desired particle size distribution is achieved. It may be necessary to create smaller volumes of salt over a narrower range and then mix together the volumes to create the final salt dust. Once the salt dust is prepared, it should be mixed with ISO fine test dust to create the salt dust mixture for feeding.

#### **4.2 SALTWATER AND WATER**

Both the saltwater and water will be injected through a nozzle, or set of nozzles, upstream of the test filter. The injected droplets should be in the size range from 1-30  $\mu\text{m}$  with the distribution described earlier, and should be injected at rates sufficient to create a concentration in the test duct of 1000 particles/ $\text{cm}^3$  or more. The specific conditions are described later in section 7.

The saltwater is to be generated by mixing distilled water with salt that is at least 95% by mass NaCl to form a solution that has a salinity in the range of 35 ppt (parts per thousand); this is roughly a ratio of 35 grams of salt dissolved in 1 liter (or 1 Kg) of water. The salinity of the solution must not vary by more than 1.75 ppt. The salinity should be verified before testing begins.

#### **4.3 HUMIDITY CONTROL**

There are three stages of humidity control. The first two stages are set at maintaining a set relative humidity point; one below 70% relative humidity to test at conditions similar to the existing standards, and the other at a high relative humidity (near 100%, but with room to

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<sup>1</sup> The initial size of the salt particles is only relevant in the amount of time spent pulverizing or grinding. Morton International makes a variety of salt products that could be used. Among them are two grind sizes of pulverized salt: "Extra Fine 200" (ground to less than 75  $\mu\text{m}$ ), and "Extra Fine 325" (ground to less than 45  $\mu\text{m}$ ).

provide control to the humidity control system). The final stage will ramp the relative humidity over time to simulate the conditions that might be experienced in a real world scenario.

## **5. QUALIFY TEST SETUP AND INSTRUMENTATION**

### **5.1 AIR VELOCITY UNIFORMITY**

Qualification of this property can be performed as indicated in the existing standards.

Alternatively, if the optical particle counters are equipped with the capability of measuring velocity, this qualification test could be performed in conjunction with sub-section 5.2.

### **5.2 AEROSOL UNIFORMITY**

This qualification test can be performed as described in the existing standards, with a few modifications. First, instead of an insertion probe, the optical particle sensors can be used (if this device will be used during testing).

As mentioned in the air velocity uniformity test, these two qualification tests can be combined if the optical particle equipment is capable of making both the concentration and velocity measurements.

### **5.3 UPSTREAM COMPOSITIONAL UNIFORMITY**

While liquid saltwater is injected into the duct, a compositional sample will be taken just upstream of the test filter location. The measured salinity should be within  $\pm 1.75$  ppt of the desired 35 ppt in order to make the assumption that the particles reaching the filter are of the same composition as what is injected.

### **5.4 DOWNSTREAM MIXING OF AEROSOL**

Refer to the existing standards for this qualification with the exception that the measured concentration of the challenge aerosol will be in terms of total volume.

### **5.5 100% EFFICIENCY TEST**

Perform as described in existing standard.

### **5.6 OVERLOAD TEST OF PARTICLE COUNTER**

Perform as described in existing standard.

### **5.7 CORRELATION RATIO TEST**

Perform as described in existing standard.

### **5.8 DRY SALT GENERATION/INJECTION**

Depending on the method that is used to generate and inject the dry salt particles into the test duct, one of the two following qualification tests must be performed.

### **5.8.1 AEROSOL GENERATOR RESPONSE TIME**

If the aerosol generator system is used to create the dry salt particles, this qualification test will be performed as described in the existing standard.

### **5.8.2 DUST FEEDER AIR FLOW RATE**

Alternatively, if the dust feeder system is used to inject the salt dust mixture, this test will be performed and must also conform to the existing standard description.

### **5.9 DUCT LEAKAGE TEST**

Perform as described in existing standard.

### **5.10 PARTICLE COUNTER ZERO**

Perform as described in existing standard.

### **5.11 PARTICLE COUNTING SIZING ACCURACY**

Perform as described in existing standard.

### **5.12 RADIOACTIVITY**

Perform as described in existing standard.

### **5.13 HUMIDITY CONTROL RESPONSE TIME**

The time it takes the humidity control system to adapt the incoming, or re-circulating air, to a set value needs to be measured. At an air duct velocity of 500 ft/min (flow rate of 2000 cfm in ASHRAE 52.2 duct), and without any test filters in place, the system shall be brought to a steady state condition with a relative humidity within a range of 68-72% and a temperature within the range of 80 F to 100 F. The set point for relative humidity should then be changed to a value of 98%. The elapsed time should then be measured for the system to reach relative humidity levels of 80%, 90%, and 98% while maintaining a temperature within  $\pm 5$  F of the original temperature.

The average of the time intervals for each relative humidity step must be no more than 5 minute.

### **5.14 LIQUID SPRAY UNIFORMITY**

This test is to be performed identically to the aerosol uniformity test described in part 5.2 with the exception that instead of the salt being injected into the air stream, liquid water should be the injected particle.

### **5.15 CALIBRATION OF SENSORS**

Calibration of all testing sensors (temperature, pressure, etc.) must be performed on a regular maintenance schedule at least as frequently as dictated by the sensor's manufacturer guidelines.

## 6. PREPARATION OF THE TEST FILTER SYSTEM

Multiple test filters will be required for the completion of all testing to be done under this procedure. There are some tests that can make use of the same filter; however, using a new filter for each test is acceptable. Test filters are to be prepared as dictated by the existing standards, and by the filter manufacturer guidelines when possible. If a filter is to be used in multiple subsequent test phases, listed in the next section, it must be dry prior to beginning of the test.

## 7. TEST PROCEDURE

A set of six tests will be run in order to capture the full performance of the test filter system in question. These tests are summarized in Table 1 below. This table indicates which particles will be present in the test, and under what humidity range the test will be performed. The order in which these tests are performed is not critical.

**Table 1. General Testing Conditions**

Test No.	Dry Salt	Water	Salt Water	< 70% Humidity	90 - 100% Humidity
1		X		X	
2			X	X	
3	X	X		X	
4	X				X
5			X		X
6	X				Ramp

### 7.1 AIR FLOW RATE

The test duct airflow rate will be set according to existing standards.

### 7.2 AIR PROPERTIES

Unless otherwise stated in the specific test procedures, the air temperature must remain in the 60 to 100 deg F range. The temperature will be tracked and recorded, along with the air pressure and relative humidity over the testing periods.

### 7.3 PARTICLE COMPOSITION SAMPLING

Reference the existing standards for the insertion probe requirements for sampling. When using a flame photometer, the mass of salt in the sample can be obtained. This mass can be converted to a volume by using the density of dry salt. The remaining total volume of the particles (as measured by the particle counters) can be assumed to be water. The total mass can then be calculated.

### 7.4 TEST TIMES

With the exception of test #6, each of the test intervals must be run for a minimum of 15 minutes once stable injection rates are achieved.

## 7.5 TEST TOLERANCES

A tolerance of  $\pm 5\%$  should be maintained for all test values except where specifically stated, or where a range of possible values is provided.

## 7.6 TEST DUCT INSPECTION

Inspection of the inside of the test is needed after each test interval to determine the amount of salt dust mixture or water that either sticks to the duct wall or rests at the bottom of the duct. The dust or water should be removed from the duct after each test interval before the next test begins.

## 7.7 SPECIFIC TEST PROCEDURES

### *Test 1: Water Spray in Low Humidity*

This test will provide information on the test filter system's ability to remove liquid droplets from the air stream. Similar to what is expected for units that are close to locations of high wave or surf activity that could create sprays of water in low humidity. The liquid water should be injected at a flow rate to create a concentration of 1000 particles/cm<sup>3</sup> or more, and the relative humidity of the inlet air should be maintained between 0% and 40% before the water injection location.

The performance of the filter for this test is determined with the ASHRAE 52.2 efficiency measurement and from particle count and size measurements when the water is being sprayed onto the filter.

During this test, water should be sprayed at a constant flow rates and several time intervals with ASHRAE 52.2 efficiency measurements in between each interval. The pressure drop across the filter should be monitored to determine how much it increases with time.

Water should be collected from the drains in between test intervals. The volume of this water should be measured and a flow rate into the bucket should be estimated for each interval. This is done to check that water is reaching the filter. Therefore, the water flow into the bucket should be less than the water flow into the test duct.

### *Test 2: Saltwater Spray in Low Humidity*

Similar to the previous test, this test considers units that are close to high wave or surf activity that has the potential to create spray, but this test will determine how the filter performs with liquid containing a soluble component. The saltwater needs to be injected at a flow rate to create a concentration of 1000 particles/cm<sup>3</sup> or greater, with inlet air that has a relative humidity between 0% and 40%. Salinity of the saltwater shall be maintained as previously described.

In this test, the filter performance should be determined as described in test 1 with an additional measurement of the salt removal performance. A photometer or similar device will be used to measure the salt concentration upstream and downstream of the filter to determine the salt removal efficiency. This test should also be performed at several intervals as described in test 1.

### *Test 3: Water Spray with a Loaded Test Filter in Low Humidity*

This test is meant to determine the performance of the filter, when due to some environmental factor a large quantity of water particles encounter a filter with a high amount of soluble particles

already collected within the filter; such as a heavy rain storm in areas where salt can collect in the filter during normal conditions.

The first step of this test will be to load the test filter with the salt dust mixture. The salt dust mixture can be injected at the highest rate possible, but not above a duct concentration of 72 mg/m<sup>3</sup>. The relative humidity during the loading needs to be maintained within a range of 0% to 40%. The filter will be loaded until the test filter pressure differential increases by 1.8 inH<sub>2</sub>O.

After the filter is fully loaded, water will be sprayed onto the filter at a flow rate to create a concentration of 1000 particles/cm<sup>3</sup> or greater, with inlet air that has a relative humidity between 0% and 40%. The water spray should continue for at least 15 minutes. It may be beneficial to spray water at several intervals and measure the filter efficiency to observe the change in filter performance over time.

The filter performance will be determined with the ASHRAE 52.2 efficiency measurement, particle count measurement during dry and wet loading intervals, and with a salt removal efficiency measurement. The ASHRAE 52.2 efficiency measurements should be made at the beginning of the test, after each dust and water loading interval, and at the end of the test.

When the filter is being loaded with the salt dust mixture, a salt concentration measurement should be made upstream and downstream of the test filter to determine the dry salt removal efficiency. When water is being injected into the test section (after dust loading), a salt concentration measurement only needs to be made downstream of the test filter since no salt is being injected into the test duct. This measurement is important to determine if the filter releases salt due to salt leaching through the filter.

Lastly, during both dry and loading intervals, particle count and size measurements should be made upstream and downstream of the test filter. During the dry loading, the particle count efficiencies should be positive. However, when the filter is loaded with water, if salt is being released downstream of the test filter due to leaching, the particle count efficiencies could be negative (higher number of particles downstream versus upstream of the test filter). This can also occur due to water particles conglomerating and larger particles being released downstream of the test filter.

#### ***Test 4: Loaded Test Filter in High Humidity***

Similar to the previous test, this test is looking at a filter loaded with salt particles, and then determining the filter performance when the humidity is increased to an extreme level. This test simulates scenarios where instead of a heavy rain; there may be high humidity and salt present.

The loading process and efficiency measurements of the dry salt dust loading will be identical to test 3. After loading with the salt mixture, the relative humidity will be increased and maintained at near 100%; actual humidity level should be maintained between 95% and 98%. Also, the temperature of the test duct should be held from 80 to 90 deg F.

When the filter is being exposed to high humidity, the salt concentration is to be measured downstream of the filter. Salt release from the filter is heavily dependent on how long it takes for the filter to become fully saturated. Once the filter is saturated, salt may begin leaching through the filter at which point it will become able to be detected downstream. It is beneficial to periodically check the filters to see if it is fully saturated.

The particle counts will be measured upstream and downstream during the humidity exposure. Theoretically, no particles should be present upstream, but there may be some particles present due to water which did not evaporate or condenses in the test duct. Water can condense in test ducts which are in cold environments. If the test duct is in a cold room, the room temperature should be increased, or the test duct insulated in order to minimize the amount of water which condenses in the test duct. The particle count measurements can be used to calculate filter efficiency. The calculated efficiency will most likely be a negative efficiency (particles present downstream, but not upstream).

**Test 5: Saltwater Spray in High Humidity**

This test will determine filter efficiencies for when the filter could experience very high amounts of saltwater spray during periods of high humidity. This test will be nearly identical to test 2 with the exception that the humidity should be set and maintained between 95% and 98%.

**Test 6: Cyclic Testing Simulation**

The final test is to more closely simulate the normal operating conditions for a test filter. This procedure will incorporate both salt injection and humidity control. Keeping a constant airflow through the test duct of the maximum rated airflow for the filter, the temperature, relative humidity, and salt injection rate will be cycled over a 4-hour period to simulate the values that might be seen in a 2-day period. To simplify, the cycles of each variable will be assumed to be sinusoidal, with values similar to what is shown in Figure 3.

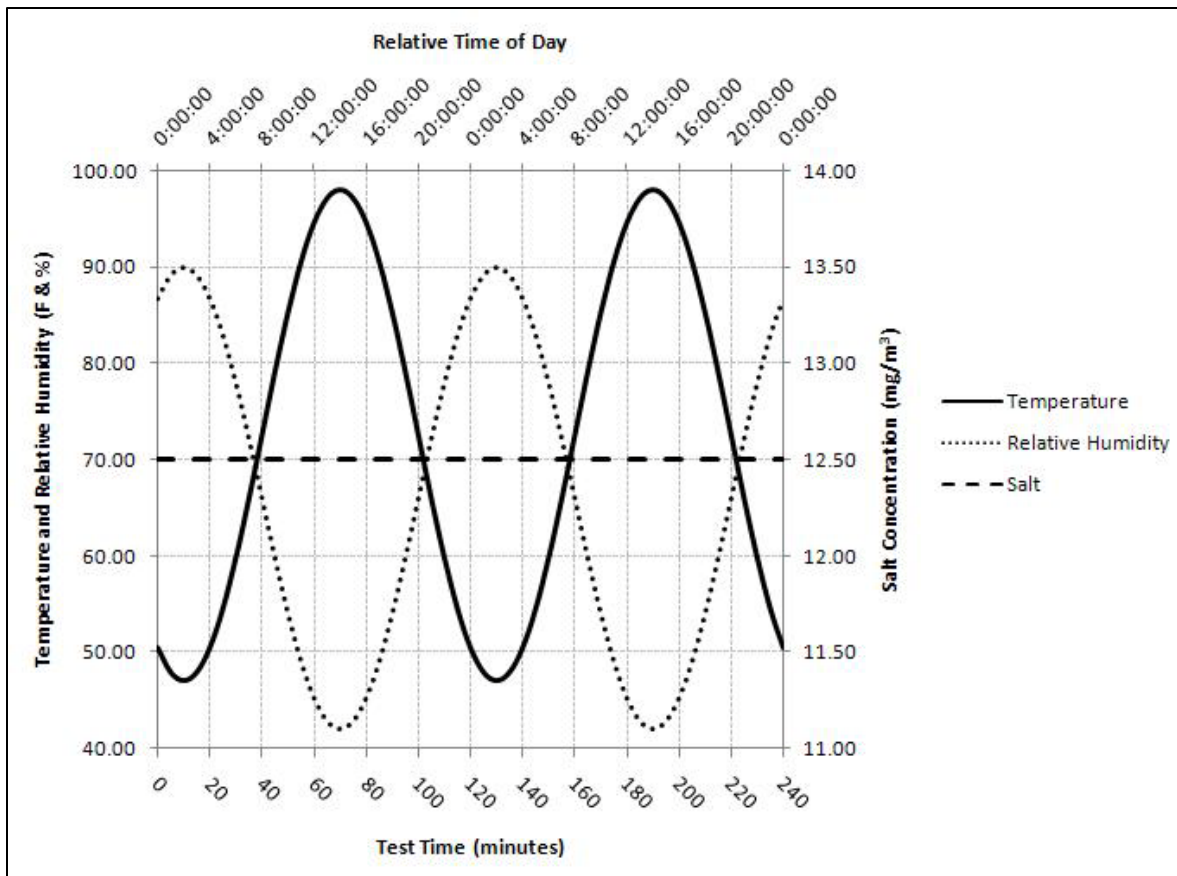


Figure 3. Typical Values for Control Variables to Simulate a 2-day Period

The sinusoidal curves in this graph cycle the temperature between a range of 47 and 98 deg F, the relative humidity between 42% and 90%, and the salt concentration at an average of 12.5 mg/m<sup>3</sup>. The curves are also adjusted to have the temperature maximum at 14:00:00, and the relative humidity and salt maximum at 2:00:00 (where the temperature is the lowest). The period of each cycle is 24 hrs, which is 120 minutes in test time.

During this cycling, two measurements will be made. The salt concentration and particle counts upstream and downstream of the filter should be monitored throughout the test. The results from these measurements can be averaged over 10 minute intervals to determine how the filter efficiency changes.

## 8. REPORTING RESULTS

### 8.1 SUMMARY PAGE

The summary page needs to include, at the minimum, the following items:

1. Name and location of the test laboratory
2. Date of the test
3. Test operator's name(s)
4. Brand and model number of test equipment (particle counters, sampling system, etc.)
5. Client's name
6. Description of the test filter
  - a. Brand (Manufacturer) and model number
  - b. Physical description of construction
  - c. Face dimensions and depth
  - d. For fiber media air cleaners:
    - i. Type and color of media
    - ii. Effective media are
    - iii. Type and amount of dust adhesive, if known
    - iv. Electrostatic charge, if known
  - e. Manufacturer's recommended operating data
    - i. Air flow rating
    - ii. Final resistance

7. Standard dry filter efficiency rating

## 8.2 TEST DATA

For each test, the following data must be recorded in the test data section for each test interval<sup>1</sup>:

1. Test air flow rate
2. Average air properties for upstream and downstream test points
  - a. Temperature
  - b. Pressure
  - c. Relative humidity
3. Injection rate of test particles
4. ASHRAE efficiencies at each test interval
5. Salt removal efficiency (where applicable)
6. Particle count efficiencies at each test interval

When possible, a chart showing the measured test parameters over time for each test should also be included.

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<sup>1</sup> Exception to this is Test #7, which should have data recorded every 5 test minutes.

## 9. FUTURE PROCEDURE DEVELOPMENT

Parts of this procedure were validated with testing. During this testing, it was found that there are still several parts of the test procedure that need to be validated before the procedure can be published as a standard. The remaining items to be addressed in this procedure are listed below.

- Overview
  - During the initial validation testing tests 3 and 5 were completed. Test 1 does not need to be tested, since it is representative of a typical ASHRAE 52.2 efficiency test. Tests 2, 4, 6, and 7 should be completed to validate the recommended procedures.
  - Multiple tests need to be conducted in order to validate the repeatability of the proposed tests.
  - In this procedure, it is recommended that the diffusion plate and mixing orifice be removed when water is sprayed. The necessity of this was not verified with testing.
  - The minimum number of intervals for each test needs to be defined.
  - The specifics on how to calculate each efficiency and the uncertainty of the results needs to be outlined.
  - A method to classify the filter based on the three efficiencies calculated in the procedure needs to be defined.
- Test 5
  - During test 5 in the initial validate testing, it was found that no salt was detected downstream of the filter when there was high humidity. High humidity air was flowed through the filter for approximately 45 minutes. The test filter was found to moist on the upstream side of the filter, but the fiber material was not fully saturated. It is thought that since the fiber material was not fully saturated, the salt could not leach through and be released downstream. This needs to be verified with further testing. Essentially the test needs to be conducted until the filter is fully saturated.
- Measurements
  - During testing, the upstream relative humidity (RH) sensor failed when it was exposed to high humidity. The majority if not all RH sensors will fail when exposed to 100% humidity. Since the filter is being tested in near 100% relative humidity conditions in several tests, a RH sensor which can tolerate 100% RH should be identified or a method to protect the RH sensor needs to be outlined for the test.

- It is best to have electronic logging of all test data during the test. This is recommended for any additional validation testing.
  - If possible, it is best to have simultaneous upstream and downstream measurements of particle counts during loading intervals. Any changes in the loading will have a significant effect on the results if simultaneous measurements are not used. If simultaneous measurements are not used, then the results should be average over specified intervals. These intervals need to be determined.
  - The use of an external optical particle counter in the proposed procedures needs to be tested.
  - During the testing with the humidity, the windows on the test duct fogged over. This will cause error if the optical particle counter is used. Is there a way (a coating or surface treatment) that can be used to prevent the window from fogging over?
- Salt dust feed
    - During the initial validation testing it was found that loading the test filter with only salt was very difficult. Therefore, the current procedure proposes the use of a test dust which is a mixture of dry salt and ISO fine test dust. The inclusion of salt will still allow for the test objectives to be met and the inclusion of ISO fine test dust allows for the filter to be loaded at a faster rate. In addition, it is thought that the ISO fine test dust will help the salt adhere to the test filter. However, this has not been verified.
    - When using a dust feeder, it was found that the ground salt clumped together which made it difficult to feed into the test duct. Some of the salts considered for testing (but not used during initial validation testing) had an additive that made the salt more free flowing (or in other words, not clump). It is recommended that the use of additives to minimize salt dust clumping be investigated in the future. It is important to ensure that any additives used with salt do not change the hygroscopic behavior of the salt.
    - For salt loading, the use of the dust feeder is not the preferred method, but it is the most convenient method for loading large amounts of salt quickly into the filter. A tray/wheel type feeder was used in the initial validation tests. This type of feeder was found to feed the dust sporadically (not constant over time). While this is not an issue for a typically ASHRAE 52.2 test, it does present problems when using the sodium flame photometer. The photometer (since it is currently a manual/analog device) does not work well with non-continuous salt events. This device requires a continuous stream of particles in the air flow in order to obtain a steady measurement. The issue with the photometer can be solved in two ways: 1) use a digital photometer which can record time varying feed events (this is not currently available and is dependent on the photometer suppliers) or 2) have a consistent (over time) dust feed. It is recommended in further development of this procedure that a dust feeder which produces a more consistent dust feed be used.

- During the initial validation testing a dust feeder was used to load the filter with salt. This was done because an aerosol generator was not available with the capacity required for the dust feed. The use of an aerosol generator for the salt loading needs to be validated with testing.
- In preparations for testing, it was found that salt dust (for dry salt feeding) with the particle distribution desired was not available for purchase. The salt was ground in-house for the testing with a coffee grinder. Either a vendor which can supply the ground salt to the specification should be identified or a procedure for grinding the salt to get consistent particle size distribution needs to be developed. It should be noted that a large amount of salt will be required for loading the test filter (1000g or more).