Air Sample Conditioner Helps the Waste Treatment Plant Meet Emissions Standards – 14646

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ABSTRACT

The air in three of the Hanford Site Waste Treatment and Immobilization Plant (WTP) melter off-gas discharge stacks will be hot and humid after passing through the train of emission abatement equipment. The off-gas temperature and humidity levels will be incompatible with the airborne emissions monitoring equipment required for this type of stack. To facilitate sampling from these facilities, an air sample conditioner system will be installed to introduce cool, dry air into the sample stream to reduce the temperature and dew point. This will avoid thermal damage to the instrumentation and problematic condensation. The complete sample transport system must also deliver at least 50% of the particles in the sample airstream to the sample collection and on-line analysis equipment.

The primary components of the sample conditioning system were tested in a laboratory setting. The sample conditioner itself is based on a commercially-available porous tube filter design. It consists of a porous sintered metal tube inside a coaxial metal jacket. The hot gas sample stream passes axially through the porous tube, and the dry, cool air is injected into the jacket and through the porous wall of the inner tube, creating an effective sample diluter. The dilution and sample air mix along the entire length of the porous tube, thereby simultaneously reducing the dew point and temperature of the mixed sample stream. Furthermore, because the dilution air enters through the porous tube wall, the sample stream does not come in contact with the porous wall and particle deposition is reduced in this part of the sampling system.

Tests were performed with an environmental chamber to supply air with the temperature and humidity needed to simulate the off-gas conditions. Air from the chamber was passed through the conditioning system to test its ability to reduce the temperature and dew point of the sample stream. To measure particle deposition, oil droplets in the range of 9 to 11 micrometer aerodynamic diameter were injected into the environmental chamber and drawn through the conditioning system, which included a filter to capture droplets that passed through the conditioner. The droplets were tagged with a fluorescent dye which allowed quantification of droplet deposition on each component of the system.

The tests demonstrated the required reductions in temperature and moisture, with no condensation forming when heat tracing was added on the upstream end of the sample conditioner. Additionally, tests indicated that the system, operating at several flow rates and in both vertical and horizontal orientations, delivers nearly all of the sampled particles for analysis. Typical aerosol penetration values were between 98 and 99%. Pacific Northwest National Laboratory, Bechtel National Inc., and the instrument vendor are working to implement the sample conditioner into the air monitoring systems used for the melter off-gas exhaust streams. Similar technology may be useful for processes in other facilities with air exhaust streams with elevated temperature and/or humidity.

INTRODUCTION

The Hanford Site Waste Treatment and Immobilization Plant (WTP), currently under construction in southeastern Washington state, will vitrify (immobilize in glass) 56 million gallons (212 million liters) of chemical and radioactive waste currently stored in underground tanks on the Hanford Site. When complete, it will contain four nuclear facilities with 19 separate gaseous emission points. Each of these exhaust stacks must be equipped with stack sampling and monitoring equipment to meet regulatory standards, provide a record of emissions, and provide alarms in case of un-expectedly high emissions. Three of these 19 exhaust stacks are melter off-gas discharge stacks that will be hot (normal temperatures between 117 and 156 degrees Celsius) with sufficient moisture to be incompatible with the necessary airborne emissions monitoring equipment. Therefore, a sample conditioning system has been proposed to reduce the temperature and dew point of the sample stream.

The ANSI/HPS N13.1-1999 standard [1] recommends a graded approach to sampling and monitoring based on the potential impact of emissions from the specific stack in question. In the case of the three WTP melter off-gas systems, the potential impact category (PIC) was designated as the highest impact potential, PIC-1, so both a continuous air monitor (CAM) and a record sampler are required for these stacks. However, the CAM is limited to sample flows that are less than 120 degress F (50 degrees C). Therefore, a sample conditioning system that utilizes instrument service air to dilute the hot, moist sample stream was proposed. The sample conditioning system will be effective if the dry bulb temperature of the conditioned air stream is less than 120°F (the temperature limit of the CAM) and the dew point is several degrees lower than the dry bulb temperature to prevent condensation. In addition, a dew point temperature that is less than the expected room temperature (60 deg F, 15.5 deg C) will ensure condensation does not occur, even without heat trace or insulation on the sample lines.

The ANSI standard [1] requires that at least 50% of the 10 micrometer aerodynamic diameter (AD[1]) particles present in the stack free stream be delivered to the sample collector. Typically, the aerosol penetration through a sample transport line is calculated using software tools such as Deposition [2]. However, the sample conditioner itself is not a component that can be readily modeled using this software. As a result, testing must be performed to quantify the aerosol penetration of the sample conditioner under expected operating conditions.

METHODS

The three melter off-gas systems at the WTP with stack sample conditioning needs are the LV-S3 (in the Low Activity Waste facility), the HV-S3A, and HV-S3B (in the High Level Waste facility) stacks. Since the HV-S3A and HV-S3B systems will have identical conditions, they will be listed as HV-S3 here. The anticipated temperature and moisture conditions for these stacks are listed in Table I. Simply cooling these stack samples alone would, in general, cause condensation to form because the dew point values tend to be higher than or near the target dry bulb temperature of 120 deg F (50 deg C).

[1] The aerodynamic diameter of a particle is the diameter of a unit density sphere with the same settling velocity as the particle.

TABLE I. High temperature stack conditions

Stack	Dry bulb deg F	%RH	Dew point deg F
LV-S3 min	185 (85 C)	16.9	114 (46 C)
LV-S3 normal	243 (117 C)	9.6	135 (57 C)
LV-S3 max	282 (139 C)	5.6	139 (59 C)
HV-S3[a] min	261 (127 C)	2.3	95 (35 C)
HV-S3[a] normal	313 (156 C)	1.7	113 (45 C)
HV-S3[a] max	365 (185 C)	1.5	133 (56 C)

a. These conditions represent both the HV-S3A and HV-S3B stacks.

The sample conditioning system, which in this case is a dilution system, will include a mass flow controller to deliver a specified mass flow rate of dilution air through a customized version of a commercially-available porous tube filter. The expected sample flow rate from the melter off-gas stacks is 1.3 acfm (36.8 LPM), so the dilution flow rate will be set to ensure that the conditioned air stream has a dry bulb temperature less than 120 deg F (50 deg C, the CAM temperature limitation) and a dew point temperature less than 60 deg F (15.5 deg C, the room air temperature, to prevent condensation). The dilution air will be the plant instrument service air (ISA), which will vary somewhat in its temperature and moisture conditions. Table II lists the minimum dilution air flow rates for the normal and maximum ISA conditions along with the conditioned air temperature and dew point for each of the stack conditions listed in Table I. These values are estimates produced using psychrometric software. The sample flow rate from the stack, 1.3 acfm, corresponds to 0.7 to 1.0 scfm (20 to 28 std LPM) for these conditions. In most instances, the dilution flow rate is dictated by the resulting dew point, rather than the dry bulb temperature. The exceptions are the HV-S3 minimum condition, for both ISA conditions, and the HV-S3 normal condition, for the maximum instrument service air condition, which are dictated by the dry bulb temperature.

TABLE II. High temperature stack dilution and conditioned air conditions

Stack	Normal ISA (60 F db / -40 F dp)			Maximum ISA (80 F db / -20 F dp)		
	Dilution Air scfm	Conditioned Air		Dilution Air scfm	Conditioned Air	
		Dry Bulb F	Dew Point F		Dry Bulb F	Dew Point F
LV-S3 min	5.09	85.3	59.9	5.19	98.4	59.9
LV-S3 normal	9.05	78.7	59.9	9.26	96.3	59.8
LV-S3 max	9.76	80.2	59.9	9.97	95.1	59.8
HV-S3[a] min	2.39	118.8	58.6	3.61	118.9	50.7
HV-S3[a] normal	4.07	107.1	59.9	4.63	118.9	57.4
HV-S3[a] max	7.42	92.4	59.9	7.63	109.8	59.9

a. These conditions represent both the HV-S3A and HV-S3B stacks.

Diluter Testing

Physical tests with the proposed sampler conditioner were performed to evaluate its effectiveness and aerosol penetration. Two types of tests were performed: (1) temperature and humidity reduction tests and (2) aerosol penetration tests.

The primary test of the sample conditioning system is to ensure that the sample stream temperature and dew point is reduced so that the sample may be delivered to the necessary monitoring equipment. Aerosol in the sample stream may be “scrubbed” by condensed water, and an excess of water may damage monitoring equipment components, so condensation should be avoided. Tests of temperature and humidity reduction were first performed for each stack temperature and humidity condition. In these tests, a simulated sample stream was diluted with dry ISA at approximately room temperature through a porous tube diluter. This diluter design was selected for the advantage that temperature and humidity reductions occur simultaneously along the length of the diluter without any substantial “cold spots” where condensation might occur. This diluter is a customized version of a commercially available filter design (Mott Corp., Farmington, CT). As a diluter, the hot sample air travels axially through the porous tube, and cool, dry dilution air passes through the porous walls to mix with the sample stream. Figure 1 shows the basic components of the diluter, with the light grey portions representing solid stainless steel components, while orange portions represent the sintered steel inner tube. The diluter used in sample conditioner testing had a 1.5 inch (3.8 cm) outside diameter inlet and outlet tube, and 24 inches (61 cm) of porous tube length within the solid steel housing.

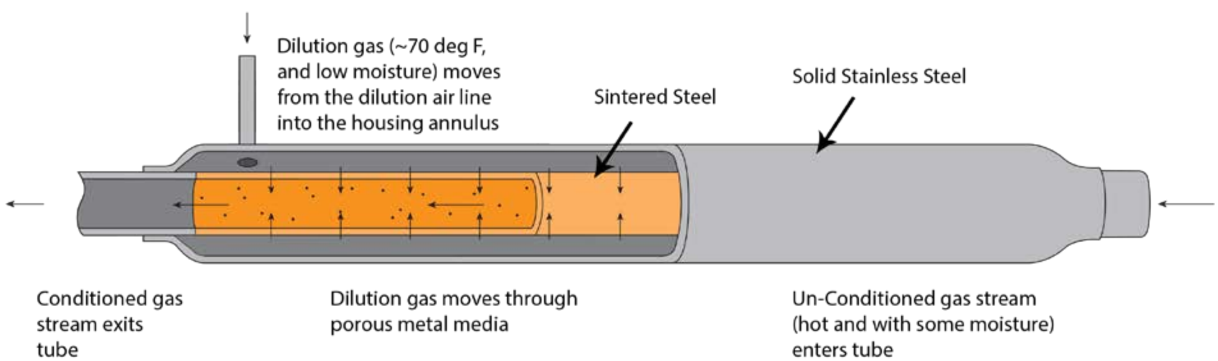

Figure 1. Porous tube diluter design. (Adapted from Mott Corp. inertial gas filter brochure.)

During these tests, the temperature and humidity of the conditioned air was measured and recorded. In addition, a profile of the temperature reduction along the length of the diluter was obtained with the installation of thermocouples within the diluter itself. Each test was approximately 1 hour in duration to allow potential condensation droplets to accumulate so they may be detected.

In the tests of the sample conditioner, the hot, humid air stream was supplied by an environmental chamber to simulate the melter off-gas conditions. A probe was installed within the environmental chamber, and the air was sampled through the probe into the sample conditioning system, which was installed exterior to the chamber. Figure 2 shows a drawing of the environmental chamber used for these tests. The footprint for this chamber is 5 by 8 feet (~1.5 by 2.4 meters), and it is equipped with flanged ports that allow equipment to be mounted through the chamber walls.

The second type of test evaluated the aerosol penetration through the diluter. In these tests, aerosol in the range of 9 to 11 micrometer aerodynamic diameter were generated with a vibrating orifice aerosol generator (VOAG), injected into the environmental chamber, and sampled by a shrouded probe equipped with the sample conditioning system downstream of the sample transport line. The aerosol was nominally monodisperse (single size, rather than a size distribution) oil droplets (oleic acid) tagged with a fluorescent tracer (fluorescein) so the deposition could be quantified. The particle size coming out of the VOAG was measured using either an aerodynamic particle sizer or an optical particle counter during the test to ensure that particles were produced through the duration of the test, and to ensure that particle sizes remained within the expected size range. Figure 3 shows a typical aerosol production/measurement/injection set-up during an aerosol penetration test. The VOAG, with its aerosol drying column (instrument on the right in Figure 3), is connected to the stainless steel injection probe (covered in insulation in Figure 3). A tee on the injection probe allows the aerodynamic particle sizer (instrument on the left in Figure 3) to sample for particle sizing and concentration.

The aerosol penetration through the diluter itself was quantified by comparing the deposition on a 4-inch (10.2 cm) diameter glass fiber filter paper installed downstream of the diluter and the fittings between the diluter and the filter paper against the total aerosol entering the diluter, which is the sum of the filter paper, fittings, and diluter deposition. The method for quantifying aerosol penetration with fluorescent tag is well established. See Kesavan and Doherty [4] for an overview of the use of fluorescein, and Gupta and McFarland [5] as an example of a similar aerosol penetration study.

With the environmental chamber operating at the prescribed temperature and humidity condition, aerosol injection and sampling occurred for about 30 minutes; sufficient time to collect an adequate sample of aerosol on the filter and fittings. After each test, the test components for which the deposition must be quantified (diluter, filter, tubing) were washed with a pH-adjusted solvent (water and isopropyl alcohol) of known mass to remove and retain in solution the deposited aerosol and fluorescent dye. The fluorescence of aliquots (approximately 2ml) was measured with a fluorometer to quantify the deposited aerosol.

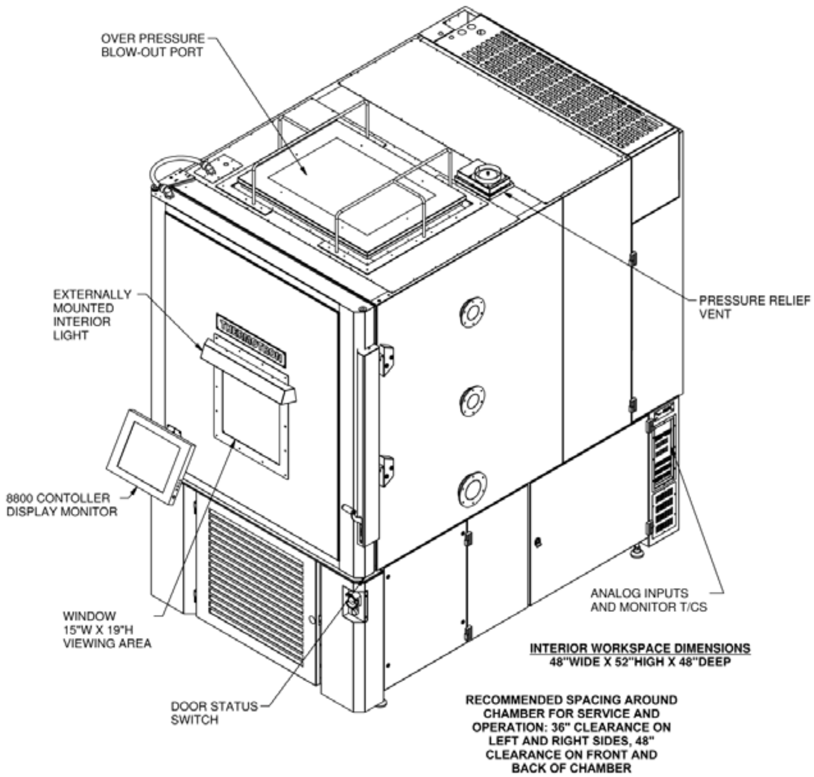

Figure 2. Environmental chamber

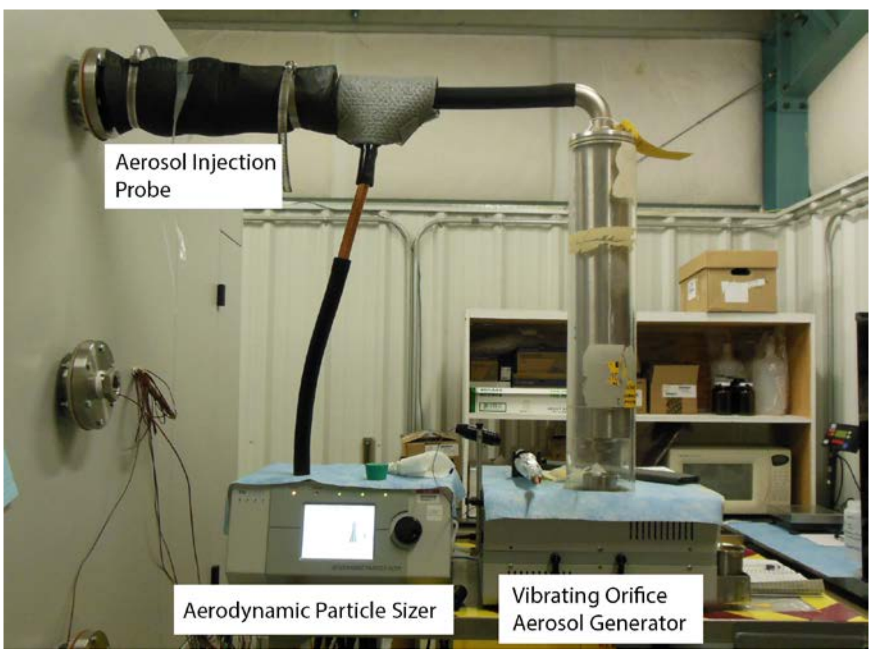

Figure 3. Aerosol production, measurement, and injection equipment.

DISCUSSION

Temperature and humidity reduction tests demonstrated that, with the appropriate implementation, the porous tube diluter is an effective way to condition a hot sample stream. There were several instances during the early tests when condensation occurred, and in each of these instances, the condensation was most likely formed in the first few inches of the upstream end of the diluter. Determining when and where condensation is formed is not a trivial question; however, testing included several items to provide clues about condensation potential. First, a thermocouple was affixed to the wall of the upstream end of the diluter near the interface between the solid and sintered stainless steel. If the temperature at this location was lower than the dew point of the original sample stream, condensation was likely. However, a higher temperature did not eliminate the possibility of condensation, since the wall temperature is very sensitive to position, and the point of condensation may not be captured by a single measurement point. In addition, water indicator dots (3M, St. Paul, MN) were affixed at several locations within the diluter. Typically, a minimum of four dots were placed at the upstream end, again near the interface between the solid and sintered metal, as well as at the downstream end, in case large amounts of condensation are transported through the diluter. These water indicator dots were 5 mm in diameter, and change color irreversibly from white to red when water contacts them. However, these dots were designed for room temperature applications; the red water indicator dye appeared to “set” at the highest test temperatures, preventing color change, even when covered with water. Finally, water soluble markers were used as a way of determining whether condensation was formed. Once again, the upstream end of diluter was the key region for condensation potential, so the solid potion of the tube was covered with a grid of water soluble marker lines. If liquid water contacted the markings, they were erased. Temperature and humidity reduction tests typically included at least the thermocouple on the wall and the water soluble markings. The highest temperature tests did not warrant the use of water indicator dots.

The condensation indicator tools described above pointed to the fact that the cold dilution air, either through heat transfer through the solid metal housing, or from a small amount of upstream transport of the air through the porous tube, was, under certain test conditions, cooling a small portion of the solid stainless steel diluter inlet tube, which allowed condensation to form within the inlet of the diluter. This problem was eliminated by wrapping heat tape around the upstream end of the diluter.

Temperature and humidity reduction tests also demonstrated overall agreement between the measured data and the software tool used to estimate the conditions of the resultant mixture of sample air and dilution air. In general, the tests did not aim to replicate the specific instrument service air conditions; however, dilution rates were sufficient to ensure that the final humidity and dew point were acceptable for the test environment. Table III presents some results from the temperature and humidity reduction tests. The final sample dew point values were, in some cases, greater than 60 deg F, due to the higher ISA dew point. The laboratory space where these tests were conducted often exceeded 80 deg F in ambient temperature, so condensation from the room air temperature was not a concern. Two rows of data in Table III are shaded; these represent test cases when condensation was identified. This illustrates that the sample air dew point value is not sufficient to determine whether condensation was formed. From these data, one sees a significant difference between the dry bulb and dew point temperatures (82 versus 28 deg F, and 89 versus 47 deg F), which might point to a non-condensing case. However, in these cases, the water indicator dots were clearly red (to indicate water contact), and liquid water was visible within the tube. The dew point temperature of air that has condensed some moisture is actually lower due to the removal of liquid water from the air stream.

Table III. Temperature and humidity reduction test results.

Chamber Temp (deg F)	Chamber RH (%)	ISA Flow (scfm)	ISA Temp (deg F)	ISA Dew Point (deg F)	Sample Temp (deg F)	Sample Dew point (deg F)
185	16.9	5.09	77	-26	84	52
243	9.6	9.05	77	-15	82	45
			79	-15	85	28
243	9.6	9.97	80	-14	82	28
			75	-20	82	23
			76	-15	81	27
282	5.6	9.76	85	11	89	47
			76	5	86	43
		9.97	80	-20	85	36
261	2.3	2.39	76	-4	90	71
313	1.7	4.07	79	-17	93	63
		4.17	82	-17	94	60
		7.63	84	-7	92	45
			80	2	88	44
365	1.5	7.42	75	4	86	24
			81	-17	91	50
		7.63	75	4	86	24
		8.50	76	10	84	66
			77	-4	85	53

Aerosol penetration tests showed that this design is ideal for ensuring that particles are delivered to the stack monitoring equipment. The total aerosol penetration in the system must be greater than 50% [1], from the stack to the monitor. It is estimated that the diluter alone should have a better than 80% aerosol penetration to account for the losses expected in other sample transport components (which include horizontal and vertical transport lines, bends, and splitters). The diluter aerosol penetration tests typically resulted in penetration values between 98 and 99%, which is significantly higher than the required minimum penetration. The use of oil droplets results in a conservative test, since they do not bounce and re-entrain within the system. Tests were operated at several flow rates with the diluter in both vertical and horizontal orientations. Figure 4 shows an example of some of the equipment set up for the aerosol penetration test. Although the diluter is expected to be installed in a vertical orientation, tests were performed with the diluter in both a horizontal (as shown in Figure 4) and vertical orientation to determine whether there was an effect based on orientation. Based on the diluter design, which does not allow the sample to contact the porous tube walls, one might expect that the penetration would be insensitive to orientation, and testing revealed that this is, in fact, the case. In addition, several test cases were run at room temperature to ensure that results were comparable with elevated temperature cases.

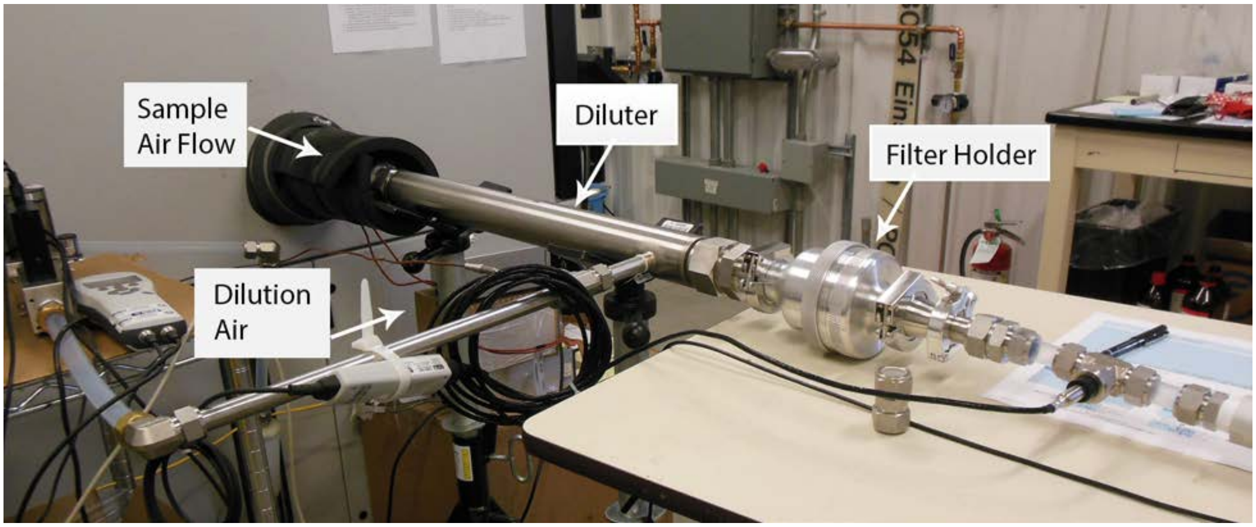

Figure 4. Sample dilution equipment from an aerosol penetration test.

Table IV lists the results of some aerosol penetration tests. In all cases, the aerosol penetration values were 98 to 99%. The first four rows of Table IV show that two tests with the diluter in the horizontal orientation, and two tests in the vertical orientation were performed, at different dilution flow rates, but for nominally room temperature conditions (73.5 to 75 deg F). Subsequent rows of data were for elevated temperatures. For the highest temperature conditions, the diluter used during the test was longer than the space available for a purely vertical orientation. The longer diluter body required these tests to be performed with the diluter angled about 22 degrees from vertical.

Table IV. Aerosol penetration test results.

<table>
<tr><th>Chamber Temp. (°F)</th><th>Chamber RH (%)</th><th>ISA Flow (scfm)</th><th>Diluter Orientation Horiz / Vert</th><th>Aerosol Penetration</th></tr>
<tr><td rowspan="2">73.5</td><td rowspan="2">35</td><td>4.07</td><td>Vert.</td><td>98%</td></tr>
<tr><td>7.42</td><td>Vert.</td><td>98%</td></tr>
<tr><td rowspan="2">75</td><td>22</td><td>9.05</td><td>Horiz.</td><td>99%</td></tr>
<tr><td>40</td><td>9.76</td><td>Horiz.</td><td>98%</td></tr>
<tr><td rowspan="4">243</td><td rowspan="4">9.6</td><td>9.05</td><td>Horiz.</td><td>99%</td></tr>
<tr><td rowspan="3">9.76</td><td>Horiz.</td><td>99%</td></tr>
<tr><td>Vert.</td><td>99%</td></tr>
<tr><td>Vert.</td><td>99%</td></tr>
<tr><td rowspan="5">313</td><td rowspan="5">1.7</td><td rowspan="3">4.07</td><td>Horiz.</td><td>99%</td></tr>
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<tr><td>7.63</td><td>Nearly Vert.</td><td>98%</td></tr>
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CONCLUSIONS

For the three Waste Treatment Plant melter off-gas exhaust stacks that require continuous stack discharge monitoring, the porous tube diluter is an effective design to cool and dry the exhaust air stream to produce a conditioned sample that can be delivered to the monitoring equipment. In practice, the sample transport line at the WTP facilities will need heat tracing from the stack duct to the diluter. This heat tracing should extend through the first 4 inches on the upstream end of the diluter housing to prevent condensation. Dilution air enters through the porous tube wall, so the sample stream does not contact the porous tube wall, and deposition is minimal in this part of the sampling system. The primary assumption in this study was that conditioning would be performed by dilution. Therefore, impacts to the detection of low-level emissions must be managed at the facility. The stack sample will be diluted by up to a factor of 10, which is a fairly significant impact on the ability to detect the lowest activity emissions.

However, alternatives to conditioning by dilution come with a number of other difficulties, which are unlikely to be acceptable at these facilities. These alternatives could include heat sinks or water jackets to cool the sample, or allowing the sample to cool through natural convection. In most instances, the needed cooling would cause condensation, which will remove some particulates from the sample stream. (Removing the sampled particulates would also reduce the ability to detect low activity emissions.) Therefore, the most suitable method to reduce the absolute humidity (without condensation) is to dilute the sample with dry air.

Pacific Northwest National Laboratory, Bechtel National Inc., and the instrument vendor are working to implement the sample conditioner into the air monitoring systems used for the melter off-gas exhaust streams. Similar technology may be useful for processes in other facilities with air exhaust streams with elevated temperature and/or humidity.

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