Radial Flow HEPA Filter Test Stand Aerosol Instrumentation Sampling Configuration

Robert Jacks and Charles A. Waggoner
Institute for Clean Energy Technology, Mississippi State University
205 Research Blvd, Starkville, MS 39759

ABSTRACT

The Institute for Clean Energy Technology (ICET), under contract with Bechtel National, Inc., is a state of the art facility utilizing the most up to date aerosol testing technology to test nuclear grade radial flow HEPA filters. ICET has developed a testing program centered on meeting the criteria of and testing prototype Section FK HEPA filters in accordance with standards such as IEST-RP-CC007.2 [1] and ASME AG-1 2012 [2]. Aerosol sampling is one of the most important factors to consider when testing such vital components to be used in the nuclear industry. An aerosol sampling configuration has been developed by ICET personnel to meet the requirements of qualification testing performed by ICET.

INSTRUMENTATION

Table I, at the end of this section, lists available aerosol instrumentation at the ICET facility along with specifications of each one.

Laser Aerosol Spectrometer 3340

The Laser Aerosol Spectrometer (LAS), produced by TSI Inc., is one of ICET's main aerosol sampling instruments. One unit is used for both upstream and downstream sampling (See section III). It has a highly sensitive particle detection system and boasts a high resolution while sizing particles in real time. The LAS also meets the requirements of IEST-RP-CC007.2 and ASME AG-1 2012 for laser particle counting. The LAS 3340 can be seen in Fig. 1 [3].

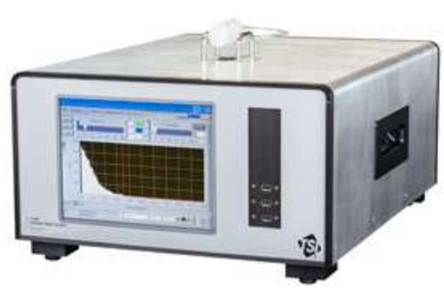

Fig. 1. TSI Laser Aerosol Spectrometer 3340.

The LAS operates by using sheath air to focus the sample of particles to an intense laser beam. The amount of light scattered counts and sizes the particle using various electronics. The LAS 3340 has an adjustable sampling time and size range with a minimum and maximum of 90 nm and 7500 nm respectively. No full scale filter tests are performed with the LAS unless the calibration has been verified using ICET's Particle Sizing Verification procedure that utilizes NIST traceable polystyrene latex (PSL) spheres with a diameter of 300 nm [3].

Scanning Mobility Particle Sizer

ICET's Scanning Mobility Particle Sizer (SMPS) is a combination of two of TSI's latest particle sampling instruments, the Electrostatic Classifier (EC) 3082 with a custom 95 cm long column differential mobility analyzer (DMA) and the Condensation Particle Counter (CPC) 3775. The SMPS is used alongside the LAS with twice the sampling time both upstream and downstream. The SMPS, however, only samples a particle size range of 24.6 nm to 1000 nm for the same duration as two of the LAS samples, approximately 1.5 minutes. Table 1 lists brief specifications for each component of the SMPS and Fig. 2 shows the ICET's SMPS on the sampling table [4].

Fig. 2. ICET's SMPS Set-up on Sampling Table.

The EC 3082 seen on the left of Fig. 2 is the latest model from TSI and is viewed as a highly reliable device. It is capable of neutralizing an aerosol concentration and producing a monodisperse output of aerosol with the electrostatically charged, custom 95 cm long column DMA to then be counted by the CPC. It boasts a size range of 24.6 nm up to 1,000 nm with the custom DMA. ICET uses an X-ray neutralizing source to establish a bipolar-equilibrium charge on the particles [4].

The CPC 3775 is the other half of the SMPS system used by ICET. The CPC allows for the monodisperse aerosol from the EC to be condensed by supersaturated butanol and counted by optical scattering. When the CPC is used in the SMPS system, it is set to a low flow mode with a sample flow of 0.3 L/min [5].

Aerodynamic Particle Sizer 3321

Unlike the LAS and SMPS, the Aerodynamic Particle Sizer (APS) is only used upstream for collecting data that will characterize the larger particles found in dusty aerosols used to load HEPA filters at ICET. The APS measures the aerodynamic diameter of particle via time of flight measurements between two laser beams. The APS can measure particle diameters from 0.5 µm up to 15 µm, a range that neither the LAS nor the SMPS can reach. The APS is also capable of measuring the mass size distribution of an aerosol concentration if the density of the aerosol substance is known. The APS specifications can be seen in Table 1, and Fig. 3 shows the APS used by ICET [6].

Fig. 3. TSI APS 3321.

Overview of Available Instrumentation

Table I provides an overview of available aerosol instrumentation at the ICET facility with specifications.

Table I. Available Aerosol Instrumentation and Specifications [3] [4] [5] [6]

Instrument	Particles/cc (min)	Particles/cc (max)	Particle Size Distribution (µm)
TSI Model 3010 CPC	1	$1x10^7$	0.001 – 1
TSI Model 3022A CPC	2	$1x10^8$	0.008 – 1
TSI Model 3775 CPC	1	$1x10^7$	0.004 – 3
TSI Model 3936L10 SMPS	1	$1x10^7$	0.001 – 1
TSI Model 3936L22 SMPS	2	$1x10^8$	0.008 – 1
TSI Model 3321 APS	1	$1x10^3$	0.3 – 20
TSI Model 3340 LAS	<0.02	$1.8x10^4$	0.90 – 7.5
Dekati ELPI Model 3935-30	80	$1x10^7$	0.03 – 20
ATI Photometer Model 2i			
TSI Diluters for SMPS, LAS, and APS	n/a	n/a	n/a
Pilat Cascade Impactors	Variable	Variable	Variable

Fig. 4 shows the size ranges of the three TSI instruments listed above relative to each other and various aerosols and organisms.

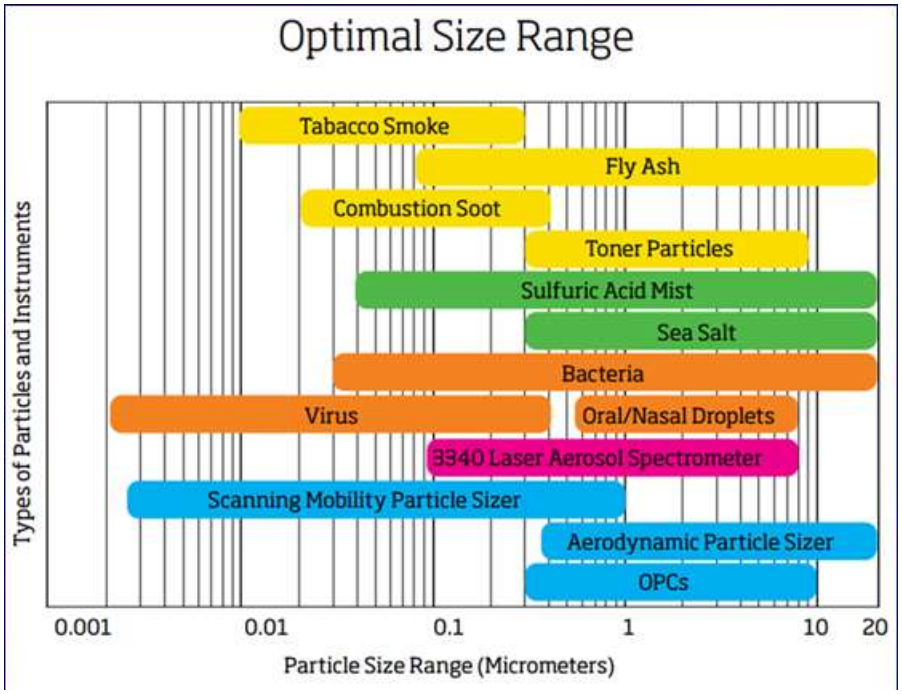

Fig. 4. ICET's Three Main Aerosol Instruments Compared to Each Other.

RADIAL FLOW LARGE SCALE TEST STAND

It is important to discuss the test stand that this aerosol instrumentation sampling configuration is attached to and used on. ICET is currently working with Bechtel National, Inc. (BNI) to develop qualification testing of prototype, radial flow nuclear grade HEPA filters to be used at the Hanford Tank Waste Treatment and Immobilization Plant (WTP). One of the test stands built to test these prototype filters is the Radial Flow Large Scale Test Stand (RLSTS). A drawing of the entire RLSTS can be seen in Fig. 5. The upstream portion of the test stand is the elevated ducting and the downstream is connected to a large blower capable of reaching flow rates up to 5,000 scfm.

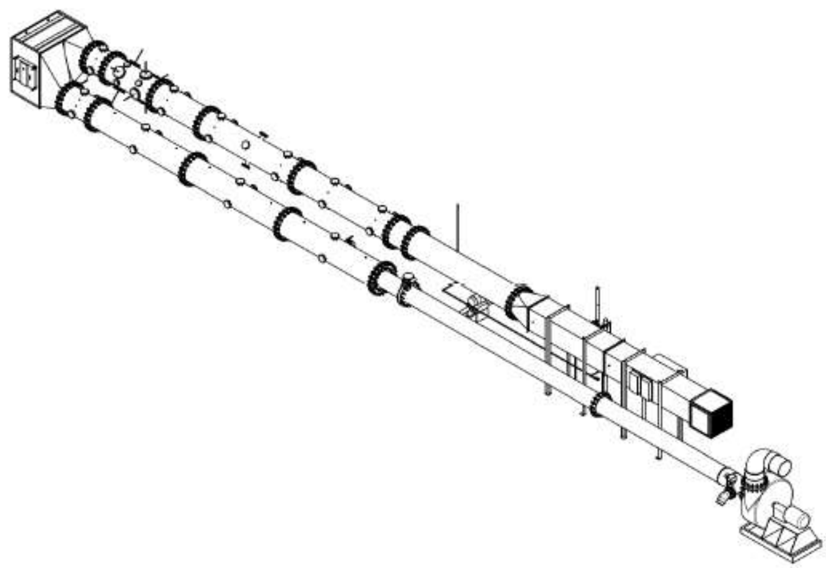

Fig. 5. Drawing of the RLSTS.

Fig. 6 and Fig. 7 show actual pictures of the inside portion of the RLSTS and the location of the aerosol instrumentation set up. The APS is not seen due to being on the upstream side of the ducting.

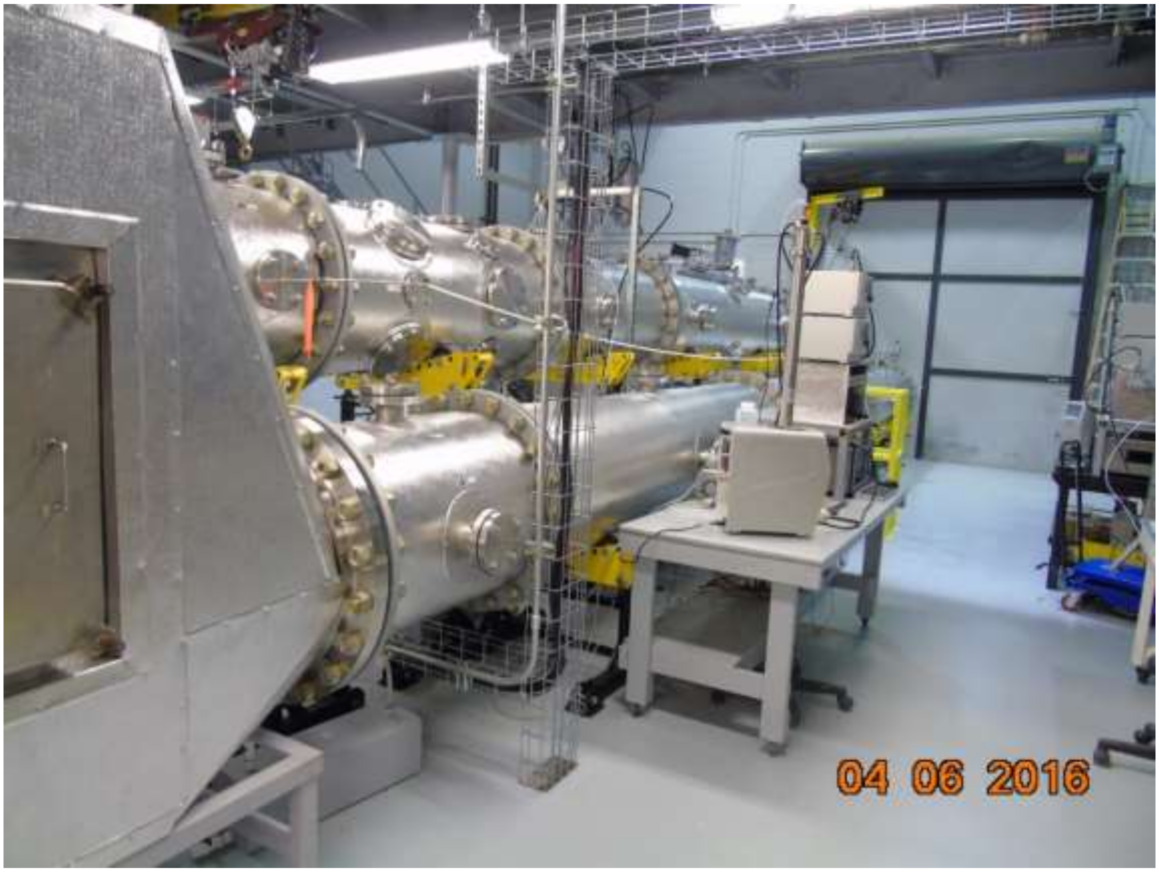

Fig. 6. First Half of Interior RLSTS with Aerosol Instrumentation shown.

Fig. 7. Second Half of Interior RLSTS with Downstream Sampling Port Shown.

Also in Fig. 6 and Fig. 7 the upstream and downstream sampling ports can be seen. Sampling ports on the RLSTS are marked by neon orange caution tape. The downstream port also has a yellow barricade around it to protect the sampling nozzle. The APS's sampling port is on the exact opposite side of the SMPS and LAS upstream sampling port showing in Fig. 6. The sampling ports have curved sampling tubes to decrease particle losses in the sampling line. A close up of the LAS and SMPS sampling port is seen in Fig. 8.

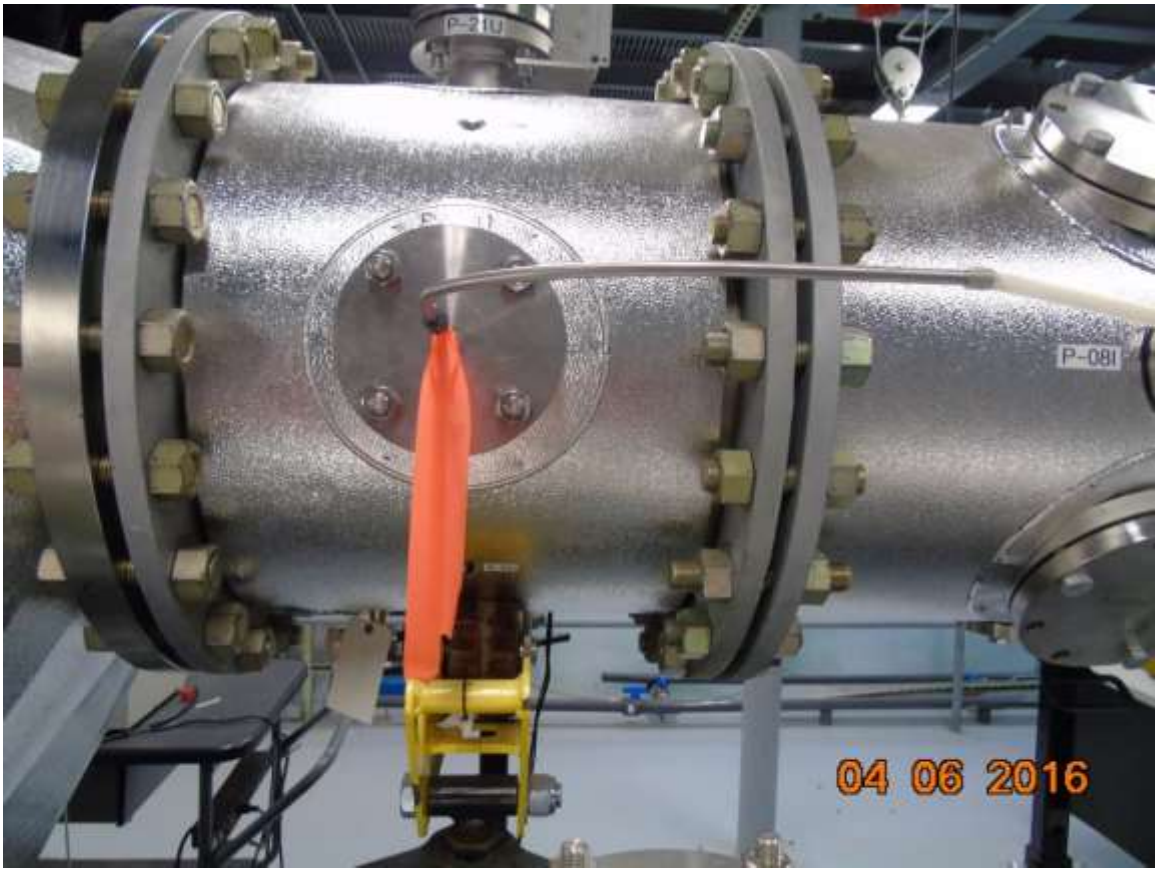

Fig. 8. Close up of Upstream Sampling port.

The sampling nozzles used are type SS from Apex Instruments. The nozzles are facing upstream and parallel with the flow of air. The interior of the upstream ducting with the nozzles installed can be seen in Fig. 9.

Fig. 9. APS Sampling Nozzle Left, LAS and SMPS Sampling Nozzle Right.

SAMPLING CONFIGURATION

ICET has constructed a custom aerosol instrumentation sampling system for ease of use and testing efficiency. ICET's aerosol sampling setup can be seen in Fig. 10.

Fig. 10. Aerosol Sampling Setup Used on the RLSTS at ICET.

As seen in Fig. 10, the sampling setup is comprised of three 3-way ball valves together called a valve train, two easily removable and interchangeable diluters, an LAS, and an SMPS. The LAS and SMPS are connected to the bottom of the valve train via a splitter. The upstream sampling line connects to the valve on the right of the diluters. This valve is connected to a HEPA capsule and the top of the diluters. Below the diluters is a second valve that is used to switch between upstream, via diluters, and the downstream. The downstream sampling line is seen in the foreground on the right of Fig. 10. It connects to a valve similarly to the upstream valve but either goes straight to the aerosol instruments or to a HEPA capsule. The HEPA capsules are used for zeroing instruments and confirming that the valve train and sampling setup is not leaking. The sampling lines are clear Tygon tubing that can be visually inspected for clogging or need of cleaning. Each sample line is exactly the same length to account for any particle losses [1]. A diagram of the sampling setup is shown in Fig. 11.

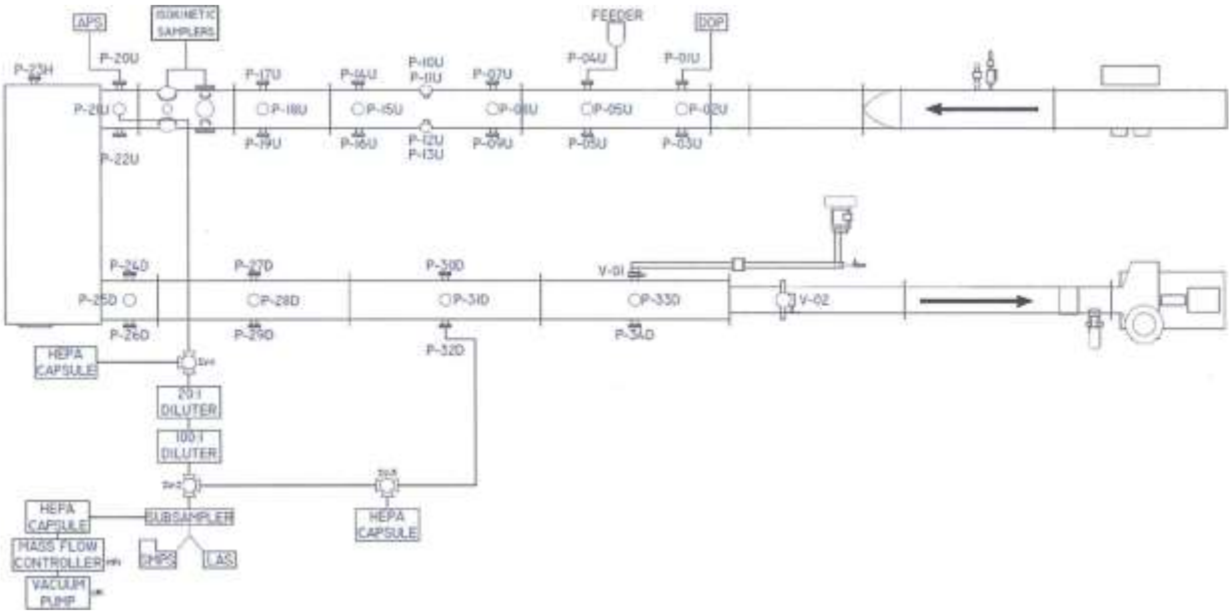

Fig. 11. Diagram of Sampling Configuration.

The diluters used in this setup are TSI 3302A model diluters. The top diluter has a 20:1 capillary and the bottom has a 100:1. The diluters require a 5 L/min flowrate through them to meet TSI calibration conditions. Since the SMPS only samples at 0.3 L/min and the LAS at 50 sccm, a vacuum pump is attached to a primary splitter, provided by TSI for such applications, via an Alicat flowmeter. The flow meter is set to a flow rate that will equate to 5 L/min when taking the sample flow rates of the instruments into account. A close up picture of the diluters and valve train can be seen in Fig. 12.

Fig. 12. Diluters and Valve Train Setup.

AEROSOL PARTICLE GENERATION

A robust set of particle generators has been assembled in order to have the ability to vary particle size distribution, the chemical matrix of the particles generated, and number density concentrations of particulate matter (PM) used as challenge agents in the radial flow large scale test stand. ICET has the following means for introducing PM into the test stand.

1. *TSI* 9306A polydisperse PM generator
2. *TSI* 3475 monodisperse PM generator
3. *ATI* PSL (polystyrene latex) generator
4. *ATI* DOP (dioctyl phthalate) generator
5. ICET large-scale PM generator
6. *Laskin* nozzles
7. KTRON powder feeders

The main generators used on the RLSTS are the ATI DOP generator and the KTRON powder feeder. Images of these two aerosol generators can be seen in Fig. 13 and Fig. 14.

Fig. 13. ATI DOP Generator.

Fig. 14. KTRON Powder Feeder.

The KTRON powder feeder is used for dusty aerosols such as Aluminum Trihydrate ($Al(OH)_3$) and ISO 12103-1 A1 Ultra-Fine Arizona Test Dust. These aerosols are useful representatives of typical dust at treatment facilities and give larger mass median diameters near 1.05 µm and 5 µm respectively. Another aerosol used in testing is Acetylene soot generated from torches installed on the upstream section of the test stand. The torches produce a smaller particle size distribution typically seen in accidental fires. An image of these torches being used to produce soot is seen in Fig. 15.

Fig. 15. Acetylene Torches Used to Produce Soot for Filter Testing.

REFERENCES

[1] *IEST-RP-CC007.2 Testing ULPA Filters*, Institute of Environmental Sciences and Technology, Contamination Control Division Recommended Practice 007.2, 2007

[2] *ASME AG-1-2012 Code on Nuclear Air and Gas Treatment*, The American Society of Mechanical Engineers, 2013

[3] *Model 3340 Laser Aerosol Spectrometer Operation and Service Manual*, TSI Inc., 2010

[4] *Electrostatic Classifier Model 3082 Operation and Service Manual*, TSI Inc., 2014

[5] *Condensation Particle Counter Model 3775 Operation and Service Manual*, TSI Inc., 2014

[6] *Model 3321 Aerodynamic Particle Sizer Spectrometer Operation and Service Manual*, TSI Inc., 2006

ACKNOWLEDGEMENTS

Bechtel National, Inc.