Model 3090 Engine Exhaust Particle Sizer™ Spectrometer

Simply the best tool for measuring particle emissions and characterizing exhaust after-treatment devices during transient engine cycles

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TSI®

The Most Reliable Particle Emissions Measurements

New and more-stringent particulate emission regulations require more sensitive measurements to characterize exhaust from vehicles or engines. As mass-based PM measurements have reached their limit of detection, only methods based on particle number can further ensure reliable measurements.

The Engine Exhaust Particle Sizer™ (EEPS™) spectrometer is a fast-response, high-resolution instrument that measures very low particle number concentrations in diluted exhaust. It offers the fastest time resolution available—10 times per second—which makes it well-suited for dynamic and transient tests. It measures the size distribution and number concentration of engine exhaust particle emissions in the range from 5.6 to 560 nanometers, covering the entire range of interest.

The EEPS spectrometer was developed for continuous measurement of entire test cycles. For example, you might use this instrument to observe filter loading or to reduce emissions below certain limits during engine calibration. With real-time data collection and display capabilities, users can visualize and study the dynamic behavior of particle emissions that occur during transient test cycles. This includes particles produced as a result of changes in engine speed, torque, or load, or particle emissions that occur during the first few seconds of a cold start or during regeneration of a diesel particulate filter (DPF).

Every unit is supplied with software that's unmatched in the industry! The software combines data collection and analysis in a single program for ease of use, so there is no need for external processing in spreadsheets.

EEPS Features and Benefits

The Model 3090 EEPS spectrometer offers features that are important to engine development researchers and engineers/technicians who are performing particle emissions tests:

Real-time measurements. A data rate of 10 Hz enables you to identify and correlate particle emissions with specific engine events during the test cycle.

Wide size range and high resolution. It measures particle emissions from 5.6 to 560 nanometers, reporting a total of 32 channels (16 channels of size per decade). Additionally, it operates at ambient pressure to eliminate any concern about evaporating volatile and semivolatile particles.

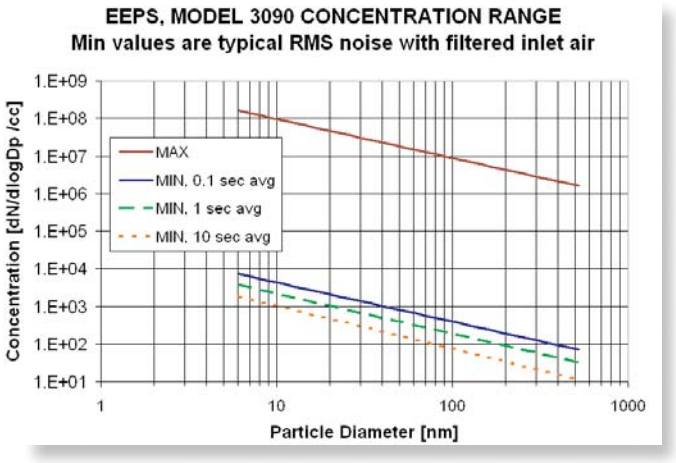

Figure 1. EEPS concentration range

Wide dynamic concentration range. Very sensitive electrometers (patent pending) provide the ability to measure particle concentrations across a very broad range—greater than four orders of magnitude (Figure 1). The EEPS spectrometer is sensitive enough to measure concentration as low as 200 particles/cm^3 (corresponding to <1 µg/m^3), making it well-suited for characterizing exhaust after-treatment devices like particle traps and DPFs.

For high particle concentration applications, TSI offers the Model 379020 Rotating Disk Thermodiluter. It features a probe that's separate from the control unit and the EEPS spectrometer. By diluting the sample at the point of measurement (the tailpipe or CVS tunnel), size distribution and concentration are preserved so that particles can be measured properly by the EEPS. The thermodiluter also features variable dilution over the range from 15:1 to 3000:1 and selectable heated dilution temperatures up to 150°C.

Ease of use. All EEPS components are housed in a single cabinet that weighs just 32 kg, including the vacuum source, making it easy to move the instrument between test rigs. To operate, simply turn on the power and allow the instrument to warm up (approximately 10 minutes). A microprocessor measures temperature and barometric pressure automatically to convert to volumetric flow. This maintains calibration and provides accurate and reproducible measurements. Operation is really that simple—the EEPS does not require a specialist to use it properly!

Ease of maintenance. When it becomes necessary to clean the instrument, a cleaning tool (supplied) allows you to quickly wipe away any layer of soot or other particles that have built up on the electrometers.

Front-panel display. Using the display and built-in control knob, you can view measurements in real time and quickly check operating parameter settings and status. Data can be viewed in a variety of ranges and formats, including auto-range and linear or log scale. Concentration units are normalized (dN/dlogDp) for easy comparison to other instruments. A unique "in range" concentration indicator shows both maximum and minimum concentration ranges to verify that the measurements are within the specified operating range.

Flexible data management. EEPS software combines data collection and analysis for convenience. It offers many advanced features, including:

- Views of the entire engine test cycle with the ability to zoom in on specific events
- 3-D movie view of size distribution and particle concentration versus time
- Handling of effective densities to calculate and output PM

High sample flow rate. The EEPS spectrometer operates at 10 L/min, which greatly reduces particle sampling losses due to diffusion.

Custom inputs. An external "start" input trigger allows for remote operation. Two analog inputs enable you to log and correlate to other engine parameters.

Proven measurement technology. TSI has been designing and manufacturing instrumentation for measuring particles using electrical mobility classification for nearly 40 years. We built on this experience using technology that combines electrical mobility and an array of electrometers, which was developed at the University of Tartu in Estonia more than 20 years ago. The result is a product that's designed specifically for measuring engine emissions.

Characterize Particle Emissions in Real Time

Applications

Real-time measurements and exceptional accuracy make the Model 3090 EEPS spectrometer an effective tool for measuring particle emissions during transient engine cycles and for characterizing exhaust after-treatment devices. Although TSI Scanning Mobility Particle Sizer™ (SMPS™) spectrometers provide a significantly higher size resolution, they are best-suited for measuring steady-state engine operating conditions. The EEPS spectrometer enables you to visualize particle emissions during transient engine test cycles with a 10-Hz time resolution. This makes the EEPS well-suited for:

- Observing DPF loading and particle slippage
- Calibrating engines to reduce particle emissions
- Characterizing DPF efficiency

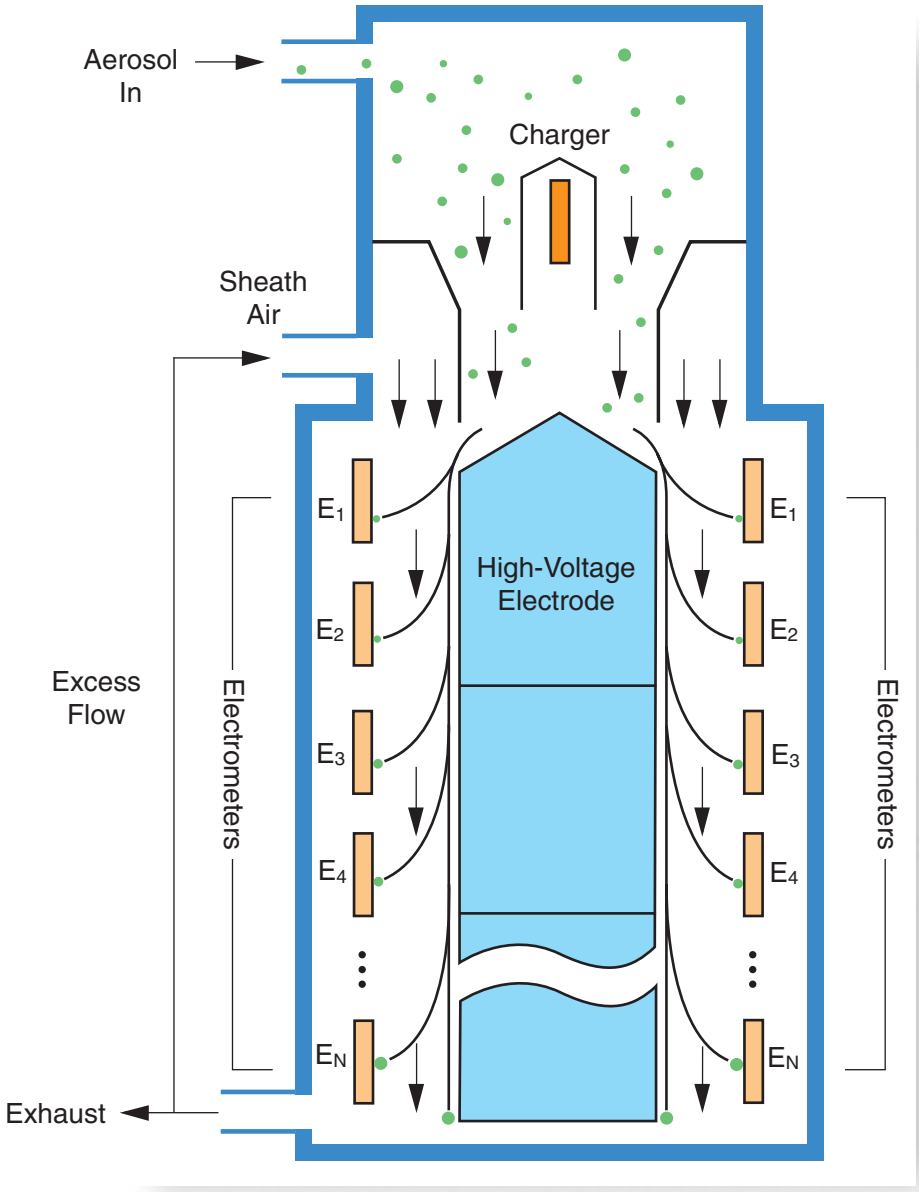

Figure 2. EEPS flow schematic

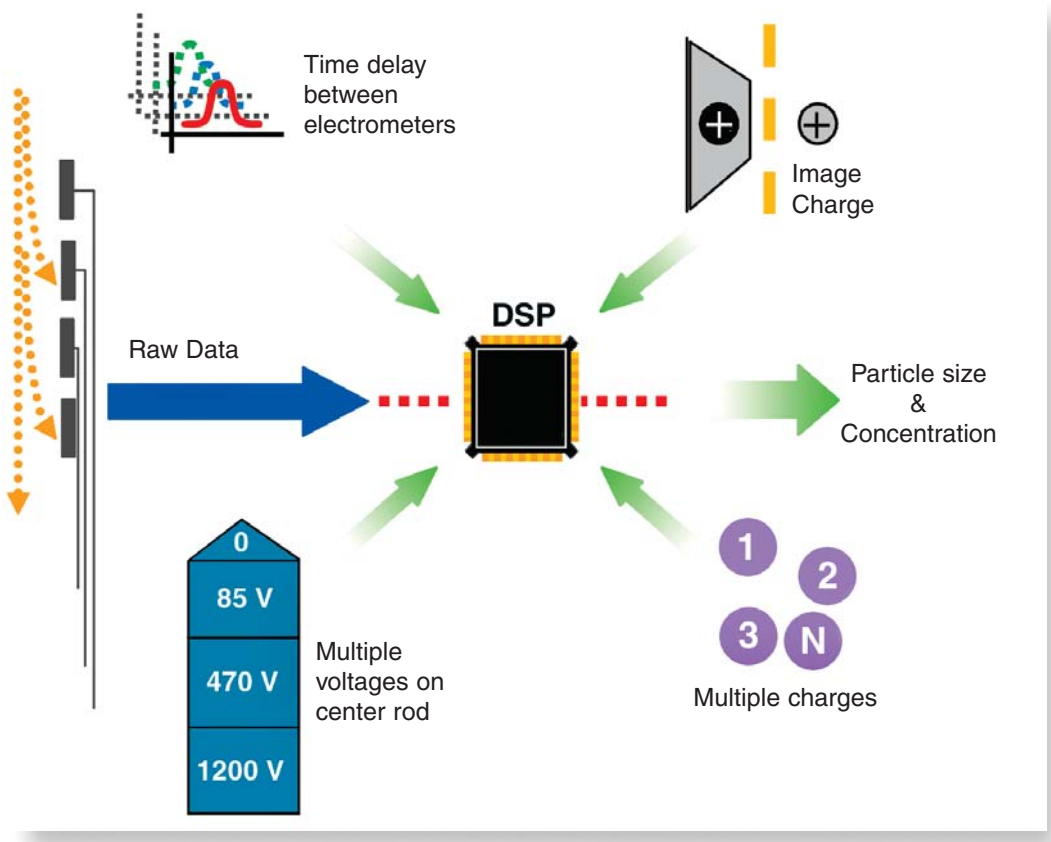

Figure 3. Data inversion schematic

Operation

The instrument draws a sample of the exhaust flow into the inlet continuously (Figure 2). Particles are positively charged to a predictable level using a corona charger. Charged particles are then introduced to the measurement region near the center of a high-voltage electrode column and transported down the column surrounded by HEPA-filtered sheath air. A positive voltage is applied to the electrode and creates an electric field that repels the positively charged particles outward according to their electrical mobility.

Charged particles strike the respective electrometers and transfer their charge. A particle with higher electrical mobility strikes an electrometer near the top; whereas, a particle with lower electrical mobility strikes an electrometer lower in the stack. This multiple-detector arrangement using highly sensitive electrometers allows for simultaneous concentration measurements of multiple particle sizes.

With a built-in, high-performance DSP, the Model 3090 uses a sophisticated, real-time data inversion to deconvolute data. As shown in Figure 3, the inversion accounts for variability in particle charge, image charge, multiple voltages on the center rod, and detection time to present a size distribution that corresponds to a specific time.

The standard method for submicrometer particle sizing is to use a TSI SMPS spectrometer—the instrument that even our competitors use to calibrate their own products. When measuring steady-state engine operating conditions, data from the EEPS spectrometer corresponds well to our Series 3936 SMPS systems (Figure 4). The SMPS is well-suited for measuring steady-state engine operating conditions, but it requires 30 to 60 seconds minimum to obtain a single size distribution. As a result, the SMPS is not suitable for measuring particle emissions during transient test cycles. The EEPS spectrometer provides the ability to measure particle emissions in real time.

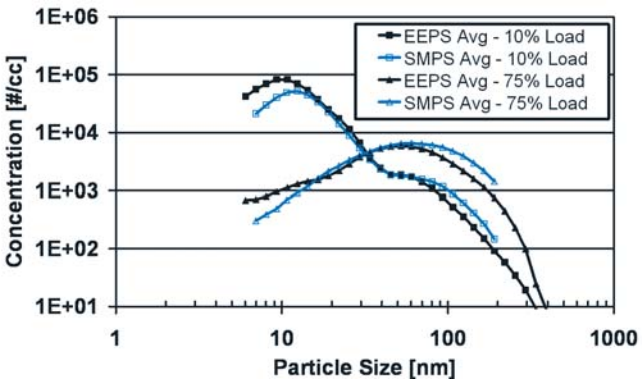

Figure 4. A comparison of SMPS and EEPS particle size data for a heavy-duty diesel engine.

Powerful Software with All the Right Features

The EEPS software is your interface for data collection and analysis. Particle emissions data can be displayed in a variety of formats, during data collection and for post-acquisition analysis. Five predefined main views may be displayed (Figure 5):

- Run View
- Table View
- Histogram
- Total Concentration
- 3-D Plot

The Run View is a 2-D color contour plot that lets users analyze an engine test cycle quickly, then zoom in and analyze interesting events in greater detail using other views. The Table View includes number concentration for each size channel, as well as weightings for surface area, volume, and mass (once you enter an effective density). In addition, the software reports statistics such as median, mean diameter, geometric mean, mode, geometric standard deviation, and total concentration for each of the weightings (Figure 6).

Each of the weightings can be plotted as a Histogram, using either linear or log scaling. View boundaries can be set to limit the range over which the statistics are calculated in the table. "In range" concentration indicators are displayed while collecting and analyzing data. Figure 7 shows both the maximum and minimum concentration ranges, which verify that measurements are valid and within the specified operating range.

A 3-D Plot of size distribution and concentration versus time (Figure 8) makes it easy to identify and correlate particle emissions with specific engine events during the test cycle. Measurements can be replayed for a unique "movie" view of the entire engine cycle, or you can zoom in on a period of interest. Measurements may be started manually, triggered externally, or

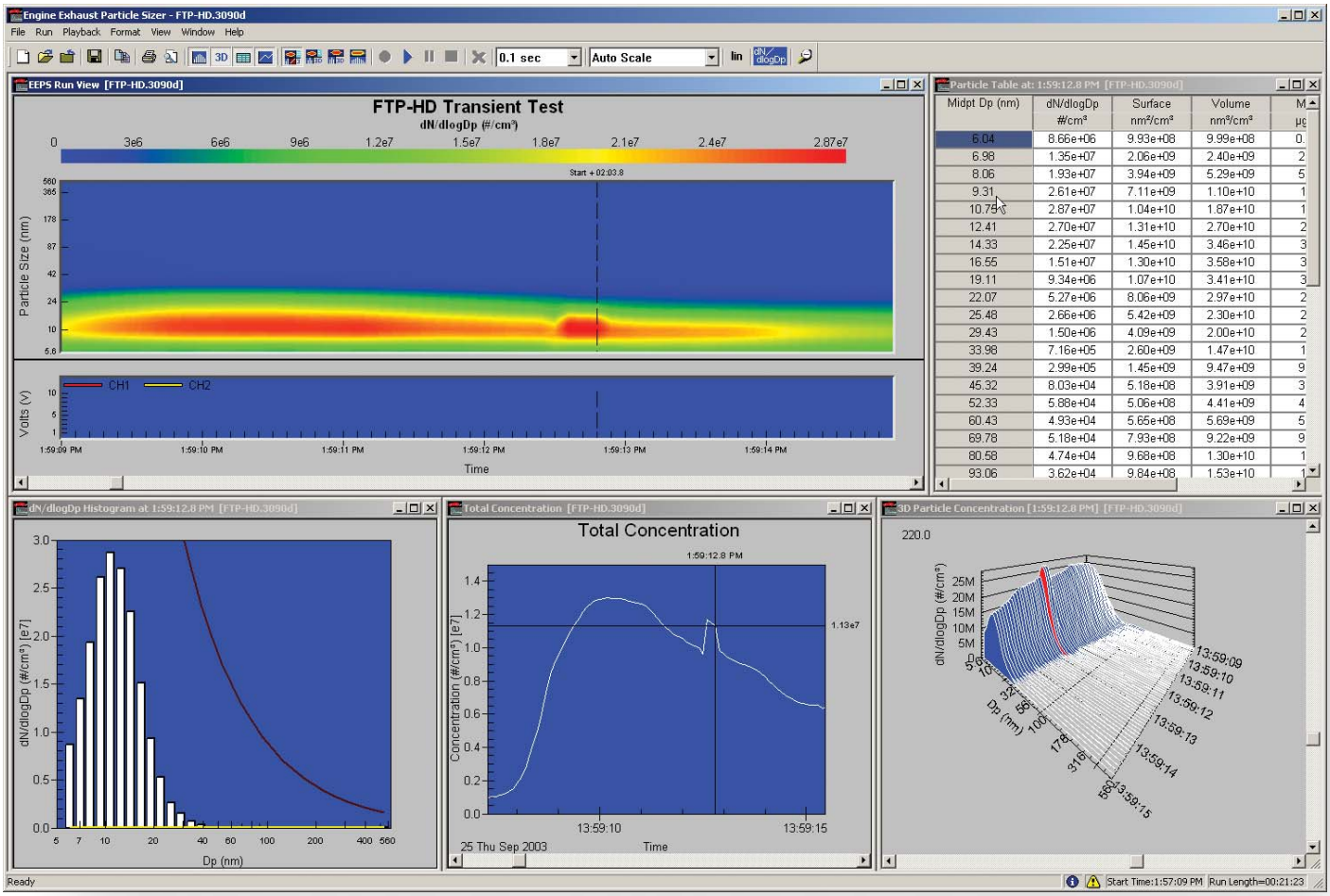

Figure 5. The EEPS software offers five main views of data. This screen depicts a large nucleation mode formed by deceleration during a transient test.

scheduled to begin at a specific time. The software provides user-selectable run lengths of up to 90 minutes.

The EEPS software also provides users with a data export function for customized data-handling requirements. Data can be exported to a text or spreadsheet file, either automatically and continuously as data are collected, or manually after data collection is done. The software offers a wide variety of graphing types and colors, as well as font type and style.

All instrument status indicators and controls can be viewed and managed via the software (Figure 9). This includes operating parameters like instrument flow rates, column voltages, charger currents, sheath air temperature, and inlet pressure. Operation of the flows, chargers, and column voltages can also be turned on and off using the software. In addition, the electrometer readings, size distribution, and total concentration can be measured and monitored before data collection begins.

Particle Table at: 1:59:12.8 PM [FTP-HD.3090d]

Midpt Dp (nm)	dN/dlogDp #/cm³	Surface nm²/cm³	Volume nm³/cm³	Mass µg/m³	Density g/cm³
6.04	8.66e+06	9.93e+08	9.99e+08	1.20	1.20
6.98	1.35e+07	2.06e+09	2.40e+09	2.88	1.20
8.06	1.93e+07	3.94e+09	5.29e+09	6.35	1.20
9.31	2.61e+07	7.11e+09	1.10e+10	13.2	1.20
10.75	2.87e+07	1.04e+10	1.87e+10	22.4	1.20
12.41	2.70e+07	1.31e+10	2.70e+10	32.5	1.20
14.33	2.25e+07	1.45e+10	3.46e+10	41.6	1.20
16.55	1.51e+07	1.30e+10	3.58e+10	42.9	1.20
19.11	9.34e+06	1.07e+10	3.41e+10	40.9	1.20
22.07	5.27e+06	8.06e+09	2.97e+10	35.6	1.20
25.48	2.66e+06	5.42e+09	2.30e+10	27.6	1.20
29.43	1.50e+06	4.09e+09	2.00e+10	24.0	1.20
33.98	7.16e+05	2.60e+09	1.47e+10	17.6	1.20
39.24	2.99e+05	1.45e+09	9.47e+09	11.4	1.20
45.32	8.03e+04	5.18e+08	3.91e+09	4.70	1.20
52.33	5.88e+04	5.06e+08	4.41e+09	5.07	1.15
60.43	4.93e+04	5.65e+08	5.69e+09	6.15	1.08
69.78	5.18e+04	7.93e+08	9.22e+09	9.40	1.02
80.58	4.74e+04	9.68e+08	1.30e+10	12.3	0.950
93.06	3.62e+04	9.84e+08	1.53e+10	13.6	0.890
107.46	2.65e+04	9.61e+08	1.72e+10	14.1	0.820
124.09	1.84e+04	8.88e+08	1.84e+10	13.8	0.750
143.30	1.27e+04	8.22e+08	1.96e+10	13.5	0.690
165.48	9.64e+03	8.29e+08	2.29e+10	14.2	0.620
191.10	7.09e+03	8.13e+08	2.59e+10	14.5	0.560
220.67	5.10e+03	7.80e+08	2.87e+10	14.0	0.490
254.83	3.43e+03	7.00e+08	2.97e+10	12.5	0.420
294.27	2.09e+03	5.69e+08	2.79e+10	10.0	0.360
339.82	1.16e+03	4.20e+08	2.38e+10	6.90	0.290
392.42	628.1	3.04e+08	1.99e+10	4.37	0.220
453.16	315.0	2.03e+08	1.54e+10	2.46	0.160
523.30	218.3	1.88e+08	1.64e+10	1.51	9.20e-02
Median (nm)	**11.3**	**15.9**	**76.9**	**24.7**	---
Mean (nm)	**12.4**	**32.1**	**133.9**	**71.8**	---
Geo. Mean (nm)	**11.5**	**19.2**	**65.3**	**37.0**	---
Mode (nm)	**10.75**	**14.33**	**16.55**	**16.55**	---
Geo.Std.Dev.	**1.44**	**2.22**	**3.67**	**3.01**	---
Total	**1.13e+07**	**6.83e+09**	**3.65e+10**	**30.8**	---

Figure 6. A Table View of particle concentration, with different weightings, densities, and statistics.

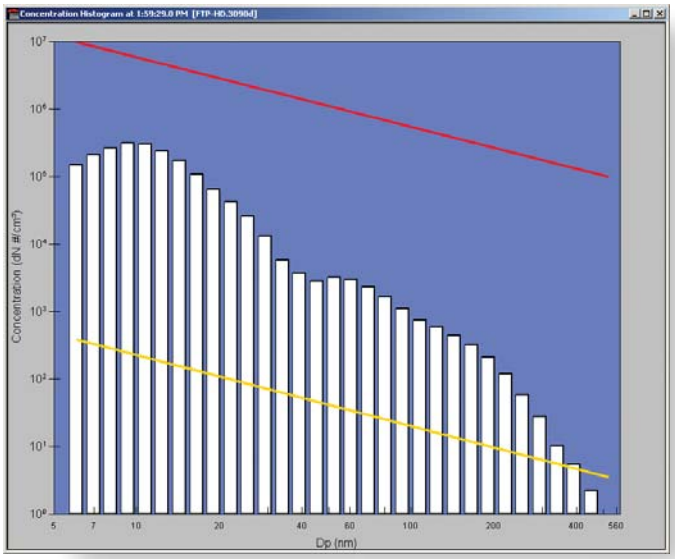

Figure 7. Histogram showing "in-range" concentration indicators (minimum in yellow; maximum in red). Log scale makes it easy to see nucleation and accumulation modes.

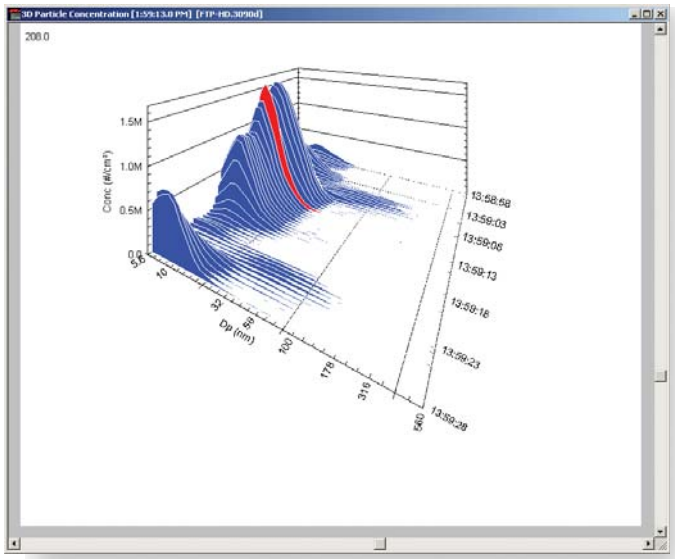

Figure 8. A 3-D Plot showing a gear shift during a FTP-HD transient cycle, with load and speed changes.

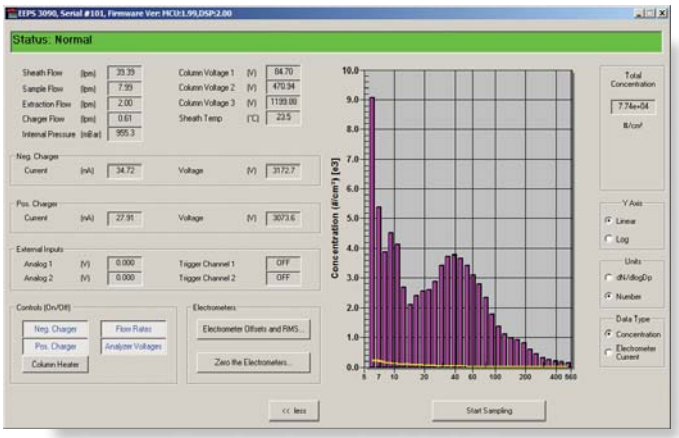

Figure 9. The Instrument Status Window shows data and provides controls.

Specifications

3090 Engine Exhaust Particle Sizer Spectrometer

Particle Size Range	5.6 to 560 nm
Particle Size Resolution	16 channels per decade (32 total)
Electrometer Channels	22
Charger Mode of Operation	Unipolar diffusion charger
Inlet Cyclone 50% Cutpoint	1 µm
Time Resolution	10 size distributions/sec
Flow Rates	
Sample Flow	10 L/min
Sheath Air	40 L/min
Inlet Sample Temperature	10 to 52°C
Operating Temperature	0 to 40°C
Storage Temperature	-20 to 50°C
Atmospheric Pressure Correction Range	70 to 103 kPa (700 to 1034 mbar)
Humidity	0 to 90% RH (noncondensing)
User Interface	Rotary knob and display; EEPS software
Front Panel Display	6.4-inch, color, VGA LCD
Computer Requirements	Pentium® 4 processor, 2 GHz speed or better, at least 512 MB RAM
Operating System Required	Windows® XP or better
Communications	9-pin RS-232
Electrical Inputs	
Analog	Two analog input channels, 0 to 10 V
Trigger	Two trigger input channels, potential-free contact closure or 3.3 V pulled to GND
Electrical Outputs	Trigger output channel, potential-free contact closure
Dimensions (HWD)	70.4 × 34.3 × 43.9 cm (27.7 × 13.5 × 17.3 in.)
Weight	32 kg (70 lb)
Sample Inlet	3/8-in. OD (without inlet cyclone)
Cyclone Inlet	3/8-in. OD
Exhaust/Outlet	3/8-in. OD
Power Requirements	100 to 240 VAC, 50/60 Hz, 250W

To Order

Engine Exhaust Particle Sizer Spectrometer

Specify	*Description*
3090	EEPS spectrometer and software

Optional Dilution Accessories

Specify	*Description*
379020	Rotating Disk Thermodiluter
379030	Thermal Conditioner Air Supply

Computer must be purchased separately.

Acknowledgments

The Model 3090 Engine Exhaust Particle Sizer (EEPS) spectrometer was developed by TSI under license from Airel, Ltd. of Tartu, Estonia. We gratefully acknowledge the contributions from the dedicated scientists at Airel during the development of this instrument.

The Rotating Disk Thermodiluter accessory allows you to dilute the sample at the point of measurement. This preserves the size distribution and concentration so that particles are measured properly by the EEPS spectrometer. Dilution temperatures are selectable, enabling you to study volatile or semivolatile fractions.

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