BTSA

Bench Top Oil Soot Analyzer

Rev. 5.1

Real-time Diesel Engine Lubricant Soot Measurements

analytical engineering, inc.

BTSA Overview

In the world of lubrication oil soot measurements on diesel engines, the BTSA saves time and money by compressing 100 to 500-hour tests into a few minutes. The methodology through which this is accomplished requires extreme measurement precision and a very robust continuous oil sampling system. This combination allows engine oil to be continuously circulated from the engine to the instrument and back during measurements. The oil soot is measured with an extremely sensitive optical subsystem that provides fast and precise soot concentration measurements in **real time**.

A rate is calculated by analyzing the trends associated with the soot accumulation in time. This process is normally accomplished in under 15 minutes. The rate is then translated into a predicted concentration at a specified number of hours, i.e., 100 or 250 hours. Therefore, engine testing for lubricant oil soot can be accomplished in a few minutes instead of weeks or months, saving time and significantly lowering cost.

Moreover, by allowing an engineer to acquire a soot rate in minutes, routine acquisition of entire soot maps can be achieved in a few hours. Today's engines are equipped with many variable controls, such as VG turbochargers, variable rate EGR, pilot injection, injection rate shaping, expansion cooling, etc., and it is critical to have fast analysis equipment in order to characterize all of the resultant effects in a reasonable amount of time.

Simple to install and use,
Robust, Reliable, Fast and Accurate

The BTSA utilizes an integral pump that circulates the oil from and back to the engine during engine operation. A small amount of that oil is routed through a sample conditioning system and then into an optical module where it is analyzed for the soot concentration. This concentration is accurately measured with precision approaching 0.0001% by weight, and this process is repeated each 6 seconds. As soot accumulates in the oil during engine operation, the measurement precision is sufficient to generate smooth and reproducible accumulation trends that allow accurate predictions over hundreds of hours to be calculated.

This capability enables an engineer to acquire soot rates in about the same amount of time that is normally taken for steady state emissions, performance and fuel measurements. The BTSA has proven to be an essential tool for comprehensive product development.

Please contact us at AEI at 812-376-6472 for additional information.

What is Lubricant Oil Soot?

Lubricant soot is a by-product of diesel combustion. Soot is formed in fuel-rich, cool regions of the combustion chamber and impinges on the cylinder wall, where it is scraped into the engine oil sump by the piston rings. Soot is partially burnt fuel which results in a heterocyclic hydrocarbon particle.

Upon entering the engine oil sump, the soot is rapidly mixed in with the bulk oil and circulates throughout the engine. As oil passes through the engine gears, the soot particles are ground into extremely fine particles, nominally 1000 Angstroms, and are maintained in suspension by the lubricant dispersants.

Lubricant soot particles cannot be effectively filtered by barrier filter media. Therefore, oil drain intervals are largely driven by soot concentration in the oil pan.

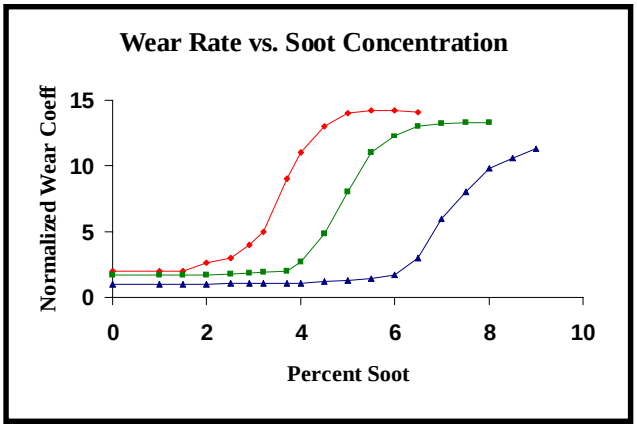
The soot will remain homogeneously suspended in the oil, until the soot concentration reaches a level great enough that it precipitates out of the oil. This may also result in filter plugging. Oil formulations which have high dispersancy levels will keep the soot in suspension to higher concentration levels.

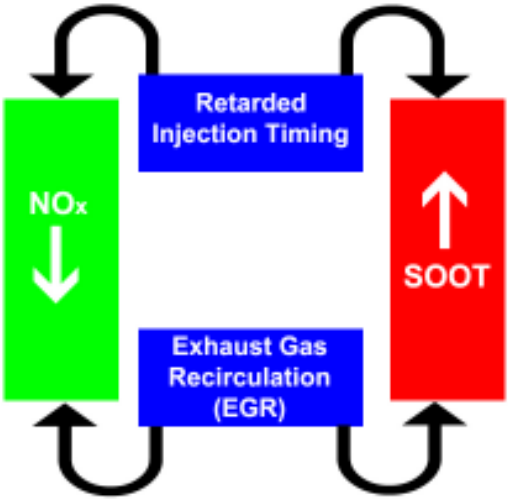
Soot is a non-classical abrasive. It will erode boundary lubricated surfaces at high concentrations. This will cause severe engine wear. Some symptoms of soot induced wear include tappet polishing, cam lobe wear, rocker/crosshead wear and ring wear at top and bottom reversal locations.

Soot = Engine Wear

Controlling the concentration of soot in the oil is critical to diesel engine durability. Soot can cause severe engine wear on boundary lubricated surfaces including:

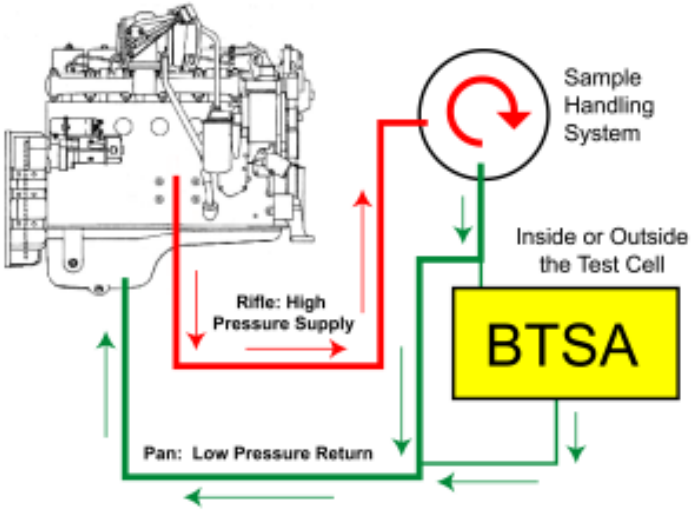
top ring reversal • rocker levers • crossheads
camshaft • tappets





Worldwide regulation of lower exhaust emissions has resulted in retarded fuel injection and the implementation of EGR to control NOx. Both of these NOx control strategies can cause the engine to produce more lubricant oil soot. This has posed a serious challenge to engine developers and oil companies.

Theory of Operation



The BTSA measures the engine's soot concentration during dynomometer testing. As the oil flows through the hydraulic circuit, it is optically scanned to accurately determine the instantaneous soot concentration. The sample is returned to the engine sump, unaffected by the measurement.

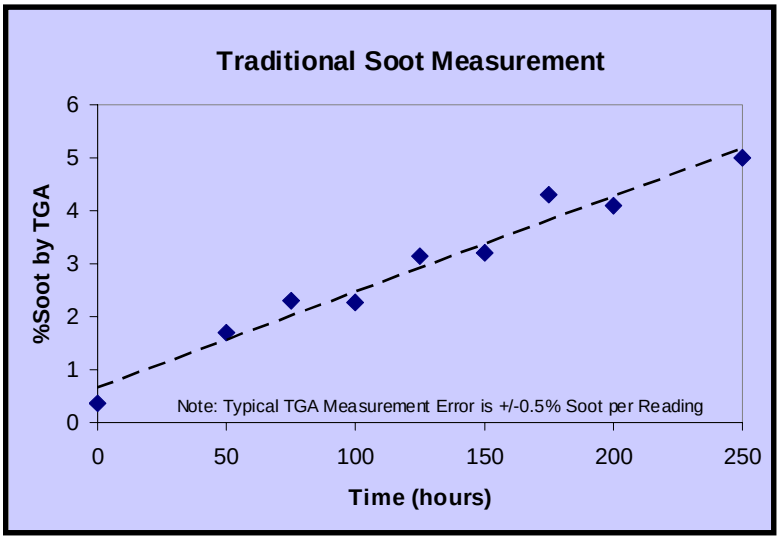
The internal temperature of the BTSA is automatically controlled, making the unit suitable for installation either inside or outside of the test cell while maintaining thermally stable conditions for the high precision optics.

Outside the Test Cell

Inside the Test Cell

Traditional Soot Measurements

Prior to the availability of the BTSA, several months were required to evaluate an engine's soot production rate and corresponding oil drain intervals. Each operating condition had to be tested for at least 100 hours, with many tests run for 250 hours per condition. Oil samples were taken at 25 hour intervals and sent to a laboratory for Thermogravimetric Analysis (TGA) of the oil's soot content, with nominal measurement accuracy of +/-0.5% by weight. At the end of test, soot data were plotted vs. test time, and a linear regression of the data provided soot concentration at any given test time. This test had to be performed for several operating conditions, and test repeatability was an issue due to changes that may have occurred during testing, such as oil consumption, a soot rate change mid-test due to worn engine parts, and control of the ambient testing factors.



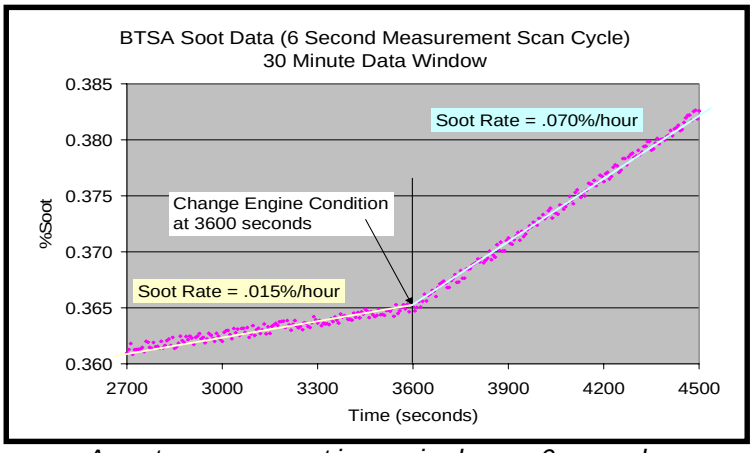
Soot Measurements Using Laboratory TGA Methods

Test time is a precious commodity as engineers strive to develop engines that meet stringent emissions standards, while providing customers with power, fuel economy, driveability, durability, and reliability.

BTSA: Precision & Speed

Lube oil soot production on a diesel engine is linear for a given operating condition. The rate of soot production for a given engine can be determined through a linear regression of several soot measurement data points acquired at a known sample time interval. The measurement precision and number of samples will determine the accuracy of the soot rate. The AEI BTSA has a measurement precision approaching .0001% soot concentration and acquires a data point every six seconds providing the user with rapid and repeatable soot rate measurements.

The soot rate accuracy will increase with the number of data points used in the calculation. This example illustrates BTSA typical measurement accuracy as a function of the user-defined sample period of time. The soot rate has been extrapolated to an equivalent oil soot concentration in the sump at 250 hours.



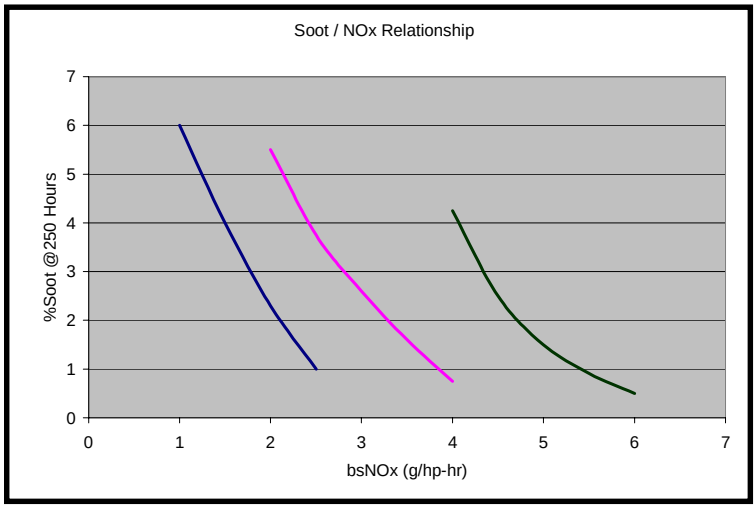
A soot measurement is acquired every 6 seconds. Soot accumulation rate can be determined based upon the trend provided by this 6 second data.

BTSA Applications

• Engine Perfomance Optimization

Modern diesel engines have become extremely complex. This complexity has created very large test matrices to evaluate the numerous combinations of variables. Historically, soot data has been taken during long-term durability testing. The time and cost associated with running long term tests to acquire soot data has escalated with the increased engine complexity.

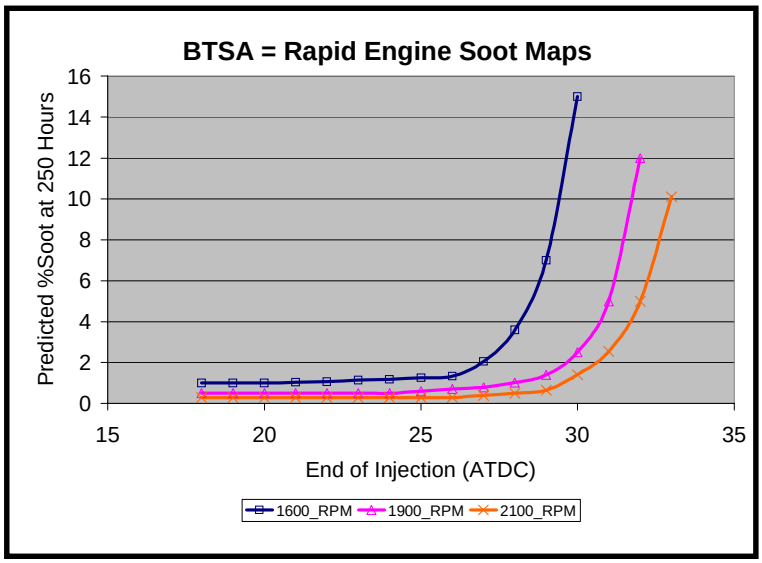
Early 1980's	Fixed Mechanical Injection Timing
Mid 1980's	Mechanical Variable Injection Timing
Late 1980's	Electronically Controlled Injection Timing
Mid 1990's	Electronically Controlled Injection Timing and On/Off EGR
2000+	Variable EGR Rate, Cooled EGR, Flexible Fuel System, Injection Rate Shaping, Multiple Injections, Variable Injection Pressure, Late Injection for Exhaust Aftertreatment, VG Turbocharging



Understand the Soot/NOx Trade-off for Different Configurations

The BTSA enables the acquisition of soot data, simultaneous with other performance development parameters. This simultaneous approach prevents an engine performance recipe from being developed, to be rejected afterward based upon unacceptable oil soot levels.

Development engineers must be able to quantify the relationship between many engine performance and emissions characteristics in order to effectively optimize the engine. AEI's BTSA enables the user to quickly evaluate trade-offs, such as NOx vs. Soot, for many different engine configurations.



Determine soot rate as a function of fuel injection parameters

The correlation between soot and different fuel injection parameters can be quickly mapped with the BTSA. This mapping capability enables the engineer to configure the engine such that it produces the least amount of soot, while still meeting other technical profile requirements.

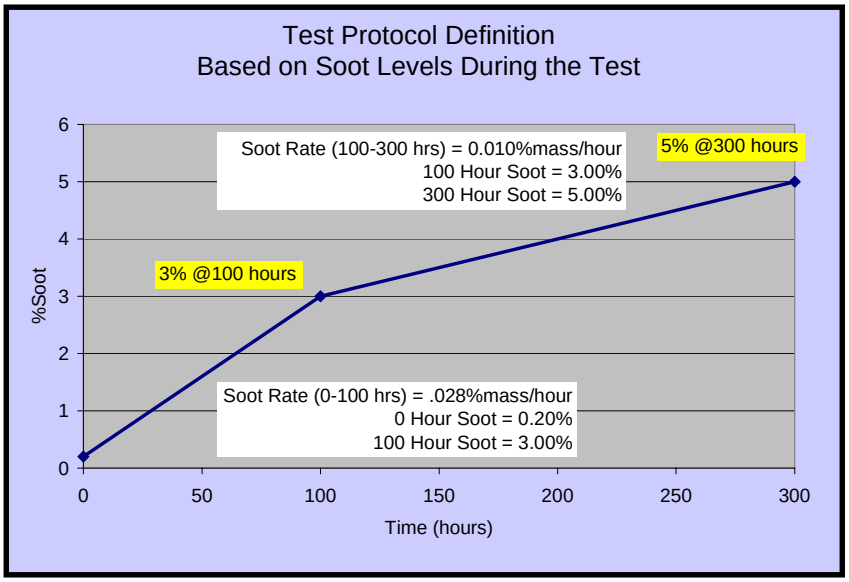
• Oil Drain Service Interval

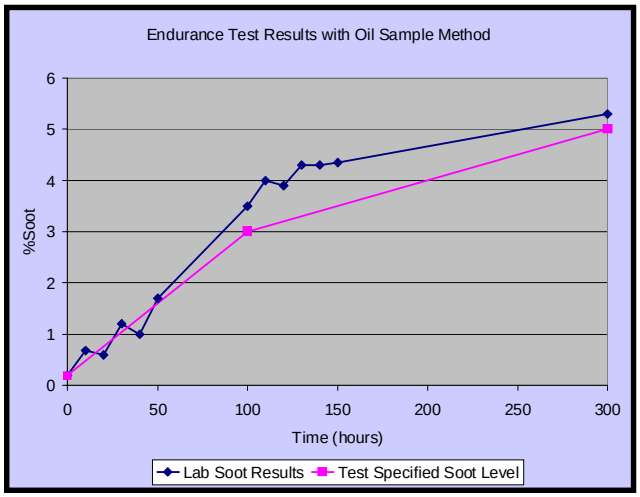
Soot loading is a key factor in manufacturer specified oil change intervals. Soot rate data from the BTSA can be extrapolated to run-time hours or miles. The corresponding oil change interval is then specified to maintain the engine oil sump at acceptable soot concentration levels.

BTSA Applications

• Durability & Oil Qualification Test Setup

Durability and oil qualification tests have defined lubricant soot concentration targets. Certified and pre-measured engine components make these tests expensive, and if the soot levels are incorrect, the entire tests may be invalid. The BTSA enables the user to quickly configure the engine to produce the desired amount of soot for a given test, saving the user both time and money.



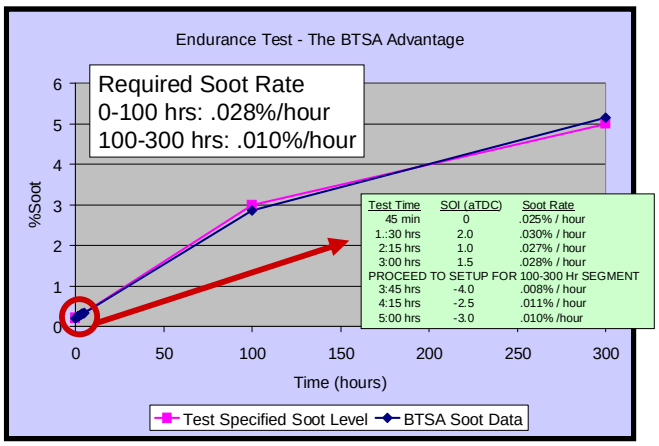


Testing without the BTSA

Oil test samples are taken approximately every 10 hours and sent to the lab for TGA analysis. The procedure is cumbersome and may require several days as engine operating parameters are adjusted in an attempt to reach the correct soot targets. Given the small number of oil samples, variability in the soot measurement could lead to an unacceptable soot level at end of test, thus invalidating the entire test.

Improved Tests with the AEI BTSA

The BTSA is connected to the engine oil supply for real-time measurements. The required soot rate for the first part of the test is .028%/hour and for the second part of the test is .010%/hour. In approximately one-half day, the relationship between fuel injection timing and soot is obtained for each operating condition in the test plan. The engine is set to the correct injection timing for the desired soot level and the test is run.



BTSA Features

Robustness

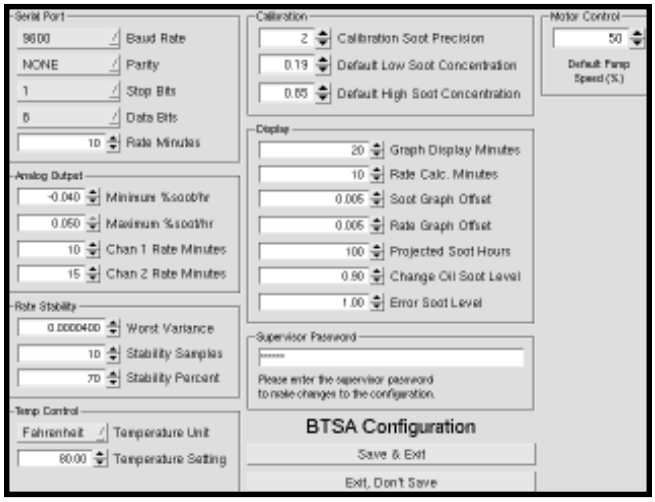
- Sheathed, braided, stainless steel transfer lines to prevent accidental damage and breakage
- Durable calibration hardware for ease of use
- Temperature controlled enclosure

Versatility

Each unit features an auxiliary oil pump providing more consistent oil pressure and flow to the sensors enabling the unit to be used with smaller displacement engines and engines that cannot tolerate the parasitic load on the oil pump. Plumbing can be connected to either engine oil sump or engine oil gallery (rifle).

Ease of Operation

- Built in stand for clamping the flat screen monitor to the top of the cart, as well as a compartment below the unit for storage and transport
- Oil connection junctions featuring dripless hydraulic quick-disconnects
- Software that performs real-time monitoring of on-board subsystems
- Configuration files that are flexible and easy to use



BTSA Configuration Screen

Performance

- Each unit has an integrated spectrometer amplifier board, which provides a 2X improvement in signal to noise ratio over the previous revision. This board also incorporates features that provide more mechanical vibration tolerance.
- Each unit includes Enclosure Temperature Management. The externally accessed temperature controller has been replaced by an on-board temperature control that is managed by the computer. This provides superior temperature maintenance and eliminates a potential failure mode. Additionally, the temperature set point is easily entered via the computer configuration file.
- The spectrometer performance is monitored and controlled via the on-board computer.

Remote Diagnosis and Repair

- Power Conditioning/Servo Hybrid Board—A newly designed board combines the function of power conditioning, power distribution, servo motor control, spectrometer control, computer interface and over-temperature control. The board can be easily removed and thus replaced, aiding during field service. All electronic connections to the board are keyed and quickly installed or removed.
- The power supply offers a robust service factor and reduces the number of potential failures. Combined with the power distribution board, the BTSA computer monitors power supply performance throughout operation and troubleshooting.
- Integrated troubleshooting subroutines keep the BTSA in optimum operational mode.
- Self diagnostic software for onsite troubleshooting.
- Improved modular design allowing the replacement of several key components with minimal work and no rewiring.

BTSA Specifications

Dimensions
Height: 45 inches (114 cm)
Width: 28 inches (71 cm)
Depth: 25 inches (64 cm)
Weight: Approximately 300 lbs. (186 kg)
Footprint: 500 inches^2 (3264 cm^2)

Computer
Processor: Embedded Pentium
Operating System: Windows
Monitor: 15 inch, mounted to BTSA. Unit detachable for remote viewing and includes a 50 ft (16 m) cable.
Accessories: Keyboard and mouse with 50 ft (16 m) extension cables.

Performance
Sampling Interval: 6 seconds
Scan to Scan precision:
Nominally $\pm$ 0.0002% soot
Prediction Accuracy:
Nominally $\pm$ 0.002%/hour on average reading cycle

Power Requirements
Configured to Customer Requirements
110-125 VAC at 50/60 Hz (U.S.)
215-240 VAC at 50/60 Hz
100-115 VAC at 50/60 Hz

Additional Software
Calibration Module
System Diagnostic Module
System Configuration Module
Pump Prime Module

Operational Parameters
Engine Operation: All speed or load conditions

Engine Type: Diesel, DI, IDI, lean burn gasoline or other lube oil soot forming IC engines

Engine Displacement: All sizes, verified on 0.5 liter through 90 liter

During operation, the BTSA will hold approximately 1.5 liters of oil with the 25 ft hose set measured from supply connection at the engine to the return connection at the engine. The engine must be capable of operation with this quantity of oil dedicated to the BTSA.

Ambient Temperature Range: 45°F to 115°F (7°C to 46°C)

Sump lube oil soot concentration limit: Oil change required at approximately 0.8% soot.

Oil Flow Rate: Approximately 1 pint (.5 liter) per minute

AEI Supplied Hose Size
Oil Supply from Engine to BTSA:
#6 steel-braided hydraulic 3/8" ID

Oil Return from BTSA to Engine:
#8 steel-braided hydraulic 1/2" ID

Minimum Hose Rating: 250°F

The BTSA is delivered with the two recommended hoses in 25 foot (8 meter) length.

I/O Panel
Analog 1: -5 to +5 v
Analog 2: -5 to +5 v
(Analog output proportional to soot rate)

RS232: outputs instantaneous %soot concentration and soot rate

Mouse port • Video port
Keyboard port

Engine Connections
The engine requires connecting a line to supply the BTSA. It is recommended that this connection be from the engine sump, and requires a 3/8" female NPT fitting. The connection is recommended to be installed from the side near the bottom of the oil pan, which minimizes debris entering the supply line. The return from BTSA to engine also requires a 3/8" female NPT and may be installed at any convenient location, including a return to the sump.

Warranty
One year full limited factory warranty
Extended service plans available.

---

analytical engineering, inc.
2555 Technology Blvd. • P.O. Box 2603
Columbus, Indiana 47202-2603 USA

www.aei-tech.com
Phone: (812) 376-6472
Fax: (812) 376-7675