Analytical Engineering Inc.
BTSA 7.0

Real-time
Diesel Engine
Lubricant Soot
Measurements

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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 1(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.

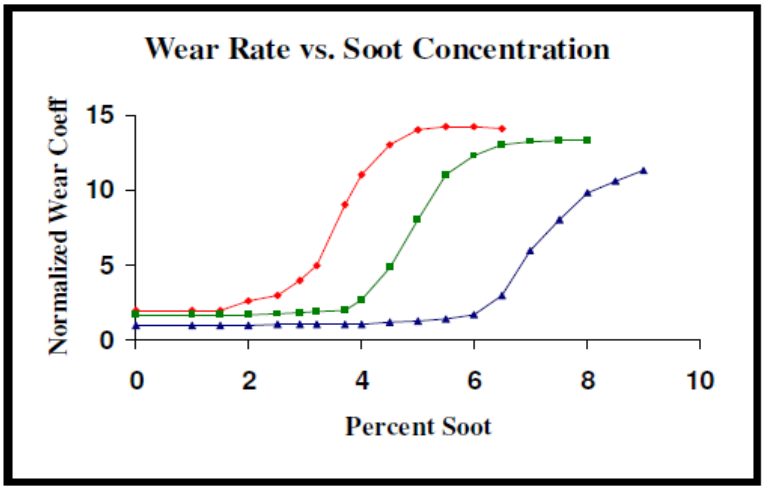
The soot will remain homogeneously suspended in the oil, until the soot concentration reaches a level great enough that it precipitates out of the oil. This may also result in filter plugging. Oil formulations which have high dispersancy levels will keep the soot in suspension to higher concentration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

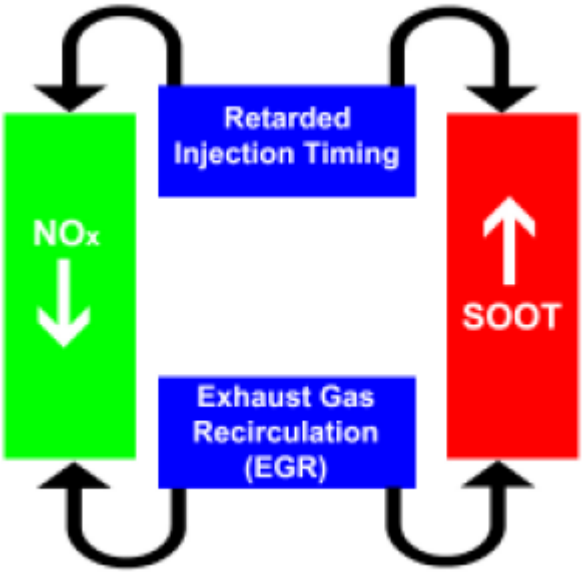
Soot is a non-classical abrasive. It will erode boundary lubricated surfaces at high concentrations. This will cause severe engine wear. Some symptoms of soot induced wear include tappet polishing, cam lobe wear, rocker/crosshead wear and ring wear at top and bottom reversal locations.

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



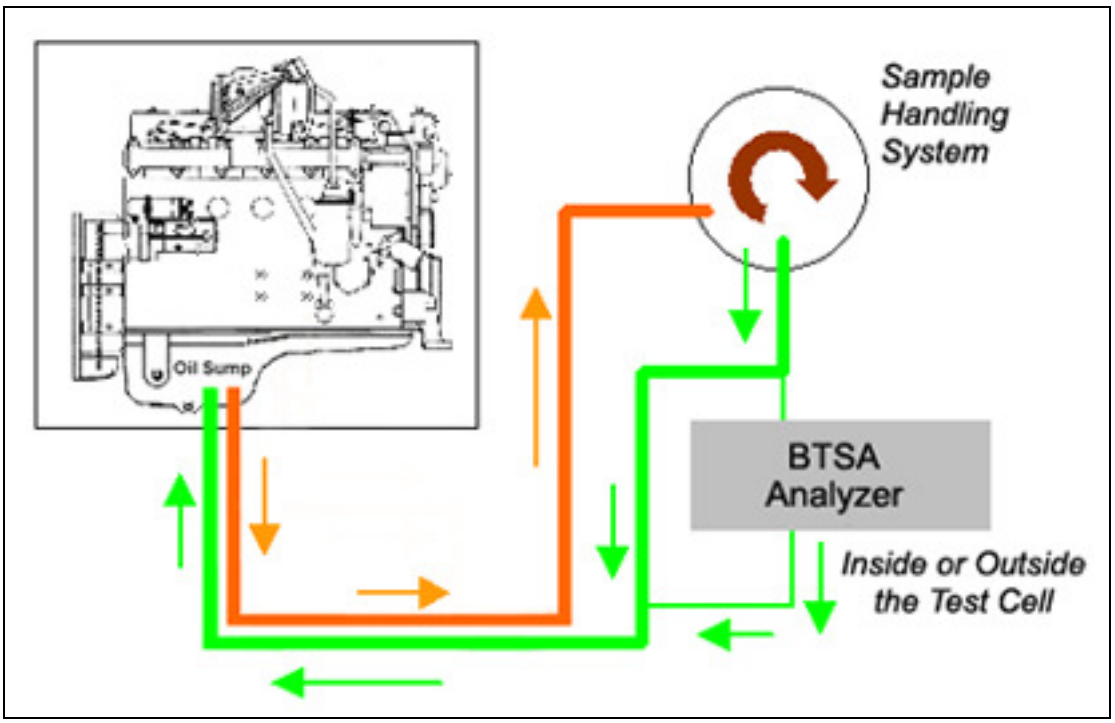


Worldwide regulation of lower exhaust emissions has resulted in retarded fuel injection and the implementation of EGR to control NOx. Both of these NOx control strategies can cause the engine to produce more lubricant oil soot. This has posed a serious challenge to engine developers and oil companies.

Theory of Operation

The system utilizes a light source which emits wavelengths over the far infrared (>20 micron) to visible region (0.5 micron). This beam passes through engine lubricant which is being circulated from the engine. Light and particle interactions occur which preclude the transmission of certain wavelengths through the lubricant. The direct measurement of this light (or absence thereof) can be correlated with the concentration of soot in the oil. By the utilization of a computer, very accurate trends can be established and calculated “real time.”

The system returns the lubricant to the engine without any chemical or physical changes, thus the system is effectively unobtrusive

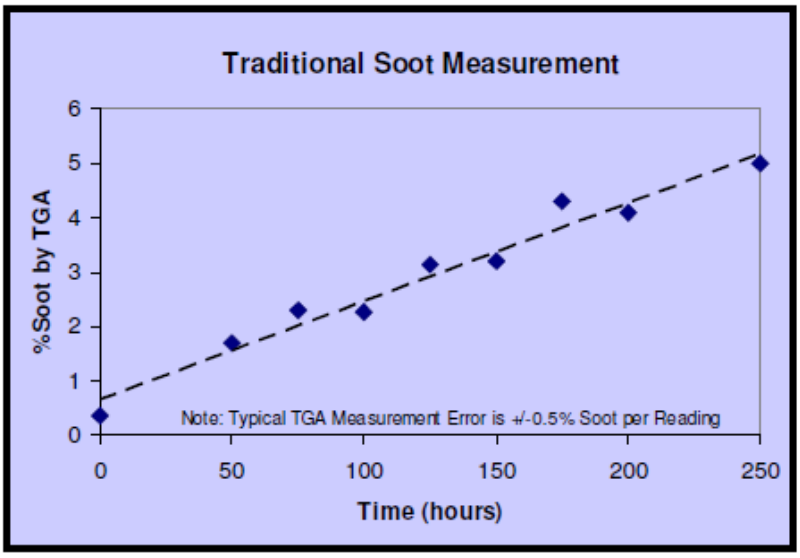


The BTSA measures the engine’s soot concentration during dynomometer testing. As the oil flows through the hydraulic circuit, it is optically scanned to accurately determine the instantaneous soot concentration. The sample is returned to the engine sump, unaffected by the measurement.

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.

Traditional Soot Measurements

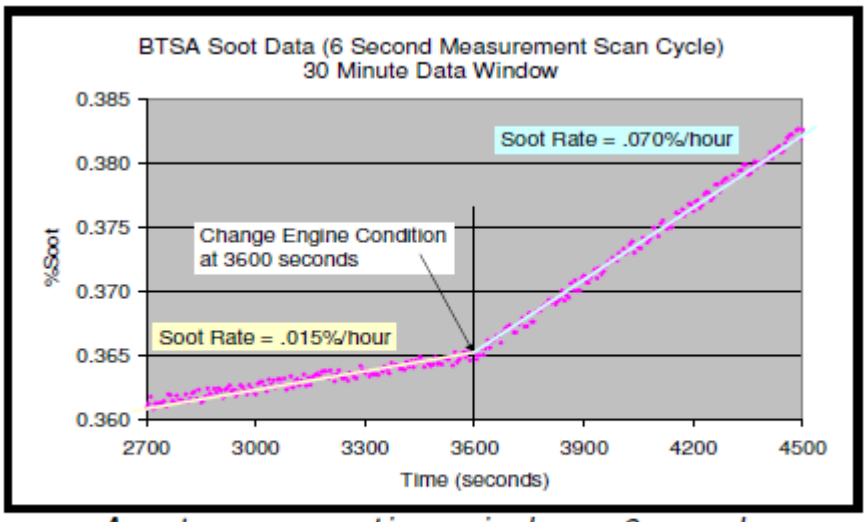
Prior to the availability of the BTSA, several months were required to evaluate an engine's soot production rate and corresponding oil drain intervals. Each operating condition had to be tested for at least 100 hours, with many tests run for 250 hours per condition. Oil samples were taken at 25 hour 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

BTSA: Precision & Speed

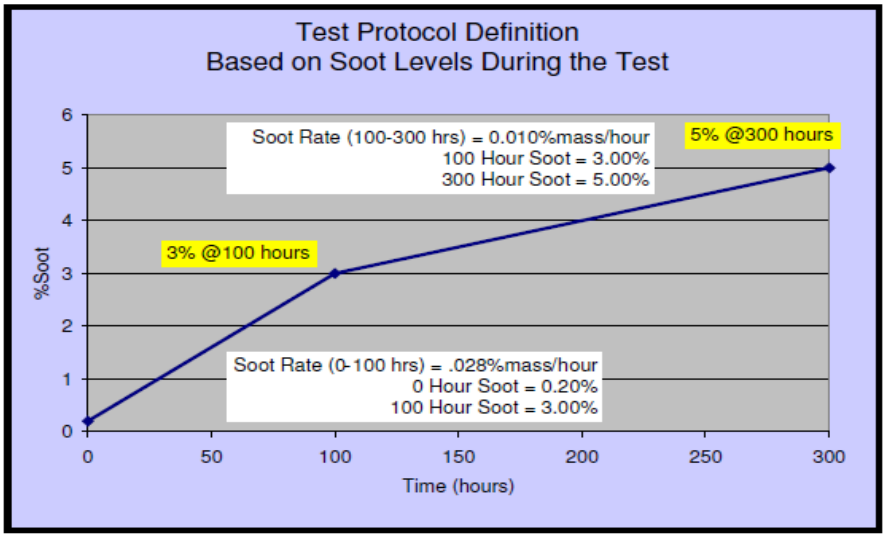
Lube oil soot production on a diesel engine is linear for a given operating condition. The rate of soot production for a given engine can be determined through a linear regression of several soot measurement data points acquired at a known sample time interval. The measurement precision and number of 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.

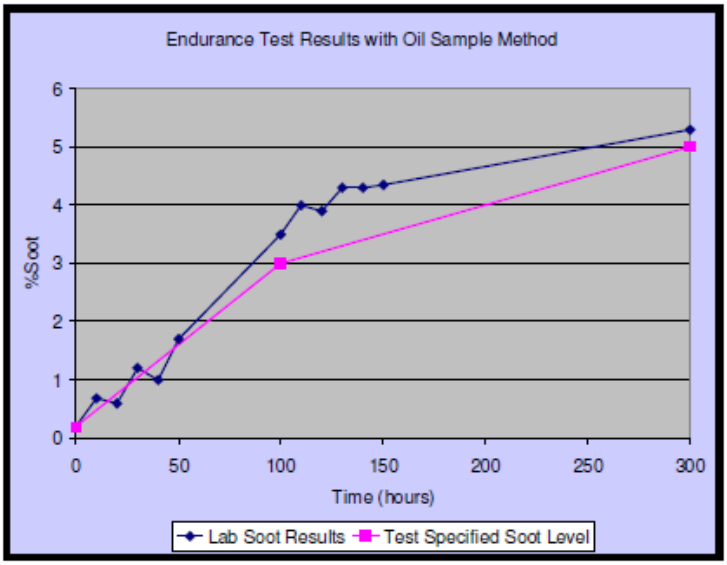


A soot measurement is acquired every 6 seconds. Soot accumulation rate can be determined based upon the trend provided by this 6 second data.

BTSA Applications

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.



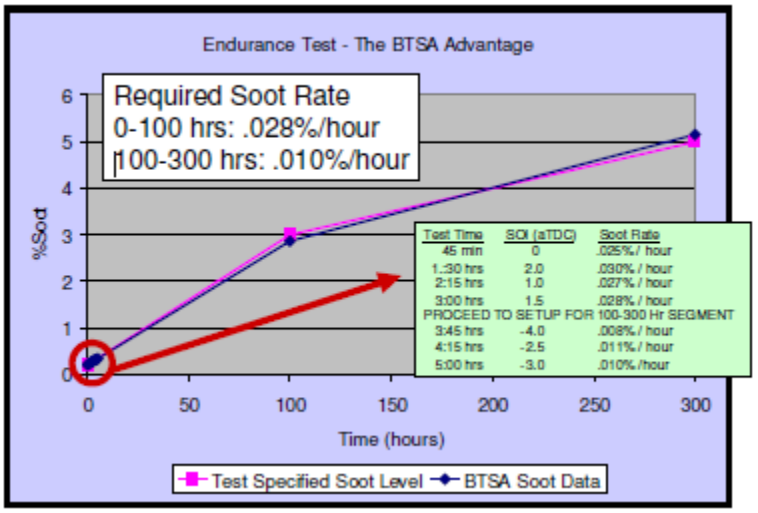


Testing without the BTSA

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 Specification for Version 7.0

Dimensions
Height: 45 inches (114 cm)
Width: 28 inches (71 cm)
Depth: 25 inches (64 cm)
Weight: Approximately 400 lbs. (186 kg)
Footprint: 500 inches$_2$ (3264 cm$_2$)

Computer
Processor: Embedded Intel Atom 1.66 Ghz
Operating System: Windows 7
Monitor: 19 inch, mounted to BTSA.
Unit detachable for remote viewing and includes a 50 ft (16 meter) cable.
Accessories: Keyboard and mouse.

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

Power Requirements
Configured to Customer Requirements

Additional Software
Calibration ModuleSystem
Diagnostic ModuleSystem
Configuration Module

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

I/O Panel
Analog 1: -5 to +5 v / 0-10v
Analog 2: -5 to +5 v / 0-10v (Analog output proportional to soot rate)
RS232: outputs instantaneous %soot concentration and rates
Ethernet: outputs instantaneous %soot concentration and rates
Mouse port • Parallel port
Keyboard port

Operational Parameters
Engine Operation: All speed or load conditions
Engine Displacement: All sizes. During operation, the BTSA will hold approximately 1.5 liters of oil, 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

Recommended Hose Size
Oil Supply from Engine to BTSA: #6 steel-braided hydraulic
Oil Return from BTSA to Engine: #8 steel-braided hydraulic
Minimum Hose Rating: 250°F
The BTSA is delivered with the two recommended hoses in 25 foot (8 meter) length.

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 (not included). 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 (not included), and may be installed at any convenient location, including a return to the sump.