FluidScan Handheld Lubricant Condition Monitor

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Introduction

The FluidScan, Figure 1, is a handheld condition monitor that delivers fluid condition assessment based on ASTM International and JOAP (Joint Oil Analysis Program) standard practices. It protects machinery by determining when a lubricant needs to be changed due to excessive contamination, degradation or fluid mix-up. FluidScan detects lubricant degradation and contamination by other fluids (water, glycol, incorrect lubricant) at the point of use by measuring key oil condition parameters in both synthetic and petroleum based lubricants and fluids.

Figure 1 - FluidScan Handheld Lubricant Condition Monitor

The FluidScan analyzes lubricants and fluids using infrared spectroscopy, a technique that has found wide acceptance as a primary test for contamination and degradation. It performs, displays and stores the analyses with the same accuracy as laboratory instruments, but does so on-site in a handheld version. The analysis information stored on the device's database can be synchronized with the FluidScan Manager software, a powerful database analysis package which runs on a personal computer that can archive and trend data and generate machine condition reports.

The FluidScan Lubricant Condition Monitor is applicable to any mechanical system where unexpected downtime is unacceptable. It enables operators of power generation equipment, marine vessels, trucks, wind turbines, mining, military vehicles and aircraft, and heavy construction equipment, or any large industrial system, to establish predictive maintenance programs based on oil condition rather than on a pre-set schedule based on time or distance.

The FluidScan provides immediate on-site analysis of lubricant properties, and accurately warns the user when it is time to change the lubricant due to contamination or degradation. The primary benefits of real-time, on-site analysis include:

- *Extended oil change intervals*
- *No delay in waiting for laboratory analysis*
- *Reduced operational and maintenance costs*
- *Reduction of unscheduled maintenance outages*
- *Prevention of catastrophic failures*

Main Features

- *Small, handheld rugged mid-infrared spectrometer (weight ~ 1.8 kg, 4 lbs)*
- *Sensitive, comparable to laboratory FTIR spectrometers*
- *Provides on-site analysis*
- *Patented optical waveguide technology*
- *Reliable performance – self-calibrating reference*
- *Requires no solvents or consumables*
- *Under 1 minute analysis time*
- *A patent pending flip-top cell provides:*
  - *Small sample volume, < 1 ml*
  - *Quick loading from a pipette or dipstick*
  - *Transmission cell with 100 µm path length*
  - *Nonparallel cell walls to eliminate cell fringing*
- *Measures key oil condition parameters including:*
  - *Total Acid Number (TAN)*
  - *Total Base Number (TBN)*
  - *Oxidation*
  - *Nitration*
  - *Sulfation*

- *Incorrect lubricant*
- *Additive depletion*
- *Soot*
- *Glycol/Antifreeze*
- *Water*

• *For biodiesel fuels:*

- *Glycerin*
- *TAN*
- *FAME (Fatty Acid Methyl Esters) a measure of biodiesel content in blended fuels*
- *Water*

• *Ability to measure TAN and TBN with superb correlation compared to complex and time consuming laboratory titration methods*

Theory of Operation

The FluidScan lubricant condition monitor is a self-contained handheld analyzer that delivers instant fluid condition assessment to the user based on ASTM Standard Practice E 2412. It eliminates the need for sample preparation and time-consuming cleanup by using a flip-top sampling cell for easy and rapid on-site analysis as shown in Figure 2. At the core of the FluidScan is a patented, mid-infrared spectrometer with no moving parts. The spectrometer collects the infrared light transmitted through the fluid in the flip-top cell into a waveguide as illustrated in Figure 3. The waveguide then carries the light to a prism-like diffraction grating that reflects the light into a high-performance array detector which registers the infrared spectrum of the fluid. The waveguide completely contains the infrared signal, minimizing any atmospheric interference and maximizing the amount of light within the spectrometer. In this way, the FluidScan maximizes optical throughput and spectral resolution in a palm-sized device. Consequently, it provides more than adequate spectral range, resolution and signal-to-noise ratio for the rapid analysis of in-service lubricants. This unique technology has been optimized for low power consumption that enables the production of a rugged, highly accurate miniature device that operates on 3 AA Li-Ion batteries for up to 8 hours.

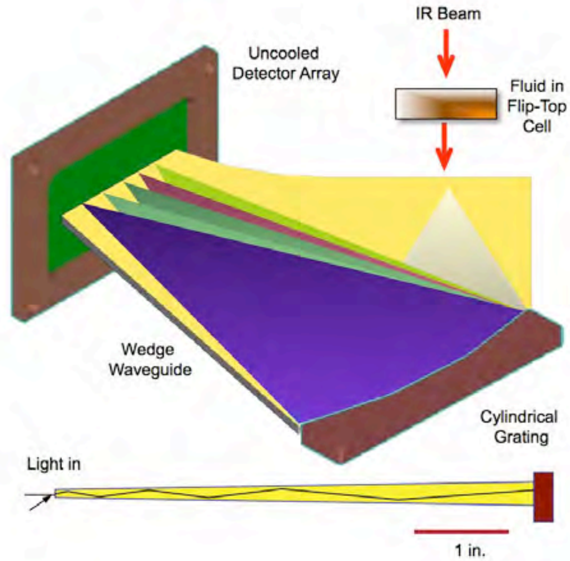

Figure 2, FluidScan Flip-Top Cell

Figure 3, Design Features of the FluidScan

Key infrared signatures of fluid condition, established by the Joint Oil Analysis Program Technical Support Center (JOAP-TSC), are used to obtain fluid status in real-time. The user loads a sample into the flip-top cell, enters sample information, and initiates an analysis using the FluidScan's intuitive user interface and navigation pad. Status and supporting fluid condition parameters are then determined and displayed to the user, and can be stored for trending and exporting to a central database. The information stored on the FluidScan device can be synchronized and downloaded to a PC using the FluidScan Manager database software. This software provides data logging, trending, warning and alarm condition alerts. The FluidScan can operate without ever needing a PC, but the FluidScan Manager desktop application makes data entry and reporting easier.

Software

FluidScan provides both a handheld and a desktop application. Apart from running the handheld instrument, the software is also an asset management system. Asset information may be managed either from the handheld device or by the desktop application.

The software is organized so that 'assets", which may be considered to be specific sampling points on machines that are to be included in an in-service lubricant monitoring program, are described by user *defined "descriptors". Multiple levels of these customized descriptors may be used to identify sampling points within the software of the FluidScan. A flexible database structure allows operators to customize it based on types of equipment, location, equipment type, etc. An example might be a coal mine that operates two pits. The user might assign the following nine levels for setting up the FluidScan monitoring program:*

*Level 1 - **Location** – Since the mine has two operating locations, this might be chosen as the first level of asset identification.*

*Level 2 - **Equipment** – This level identifies which type of equipment the sample comes from such as dozers, excavators, haul trucks, etc.*

*Level 3 - **Equipment Manufacturer** – This identifies the vendor from whom the equipment was purchased, such as Caterpillar, Komatzu, etc.*

*Level 4 - **Equipment Number** – Similar types of equipment within one company usually have an assigned number.*

*Level 5 - **Component** – This level identifies the component such as engine, transmission, wheel motor, etc.*

*Level 6 - **Component Manufacturer** – This level identifies the manufacturer of the component. This may be the same as the equipment manufacturer or it may be a supplier of components to the equipment manufacturer.*

*Level 7 - **Component Model** – The specific component model.*

*Level 8 - **Serial Number of Component** – This provides for specific component information if available.*

*Level 9 - **Sampling Port** – Some components may have multiple sampling ports although in most cases samples from a unique component are taken only one way, such as from the middle of a tank or from a sampling valve. Therefore, "Sampling Port 1" may be assigned as the only sampling port.*

As an example, one asset may look like the following:

Level 1 - North Coal Pit
Level 2 - Haul Truck
Level 3 - Euclid-Hitachi

Level 4 - HT-8

Level 5 - Engine

Level 6 - MTU/Detroit Diesel

Level 7 - Series 4000

Level 8 – C816539

Level 9 – 1

Descriptors have a multi-level structure so that data may be subsequently sorted at different levels for the purpose of statistical analysis, trending and alarm setting. For example, after some months of data have been collected, it may be desirable to sort out all data for MTU/Detroit Diesel Series 4000 engines. Then it might be interesting to group the engines used at the North Coal Pit from those used at the other pit, the South Coal Pit.

After a sample from a particular asset is run, results are displayed on the FluidScan screen and out of limit results are highlighted in red.

Data Correlation

Total Acid Number and lubricant oxidation are analytical tests used by oil analysis laboratories to determine the deterioration of in-service lubricants. The more acidic a lubricant is, the more it has degraded. Oxidation is a form of lubricant degradation that occurs as lubricant molecules are exposed to oxygen over long time periods and is accelerated by high operating temperatures. As oils or hydraulic fluids break down, they form acidic by-products that can corrode metal components, decrease lubricity, accelerate wear, form deposits and increase viscosity. Thus as fluids degrade, the levels of corrosive acids increase along with the danger of component failure.

Some fluids are acidic in their formulation. Therefore, effective monitoring requires comparison to new oil or to previous samples. Wet chemical titration techniques can be used to accurately determine lubricant degradation. However, most modern laboratories apply simpler and less expensive tests such as FT-IR to measure degradation because these techniques eliminate the need for a complex and time-consuming wet chemical analysis.

In order to demonstrate FluidScan's ability to determine lubricant degradation, synthetic and petroleum based in-service oils were collected from various in-service platforms. The samples came from two *families of lubricants, MIL-PRF-23699, a synthetic polyol ester oil and MIL-PRF-2104, a petroleum based oil. The oil samples were then analyzed by the FluidScan and the results were compared to acid number and oxidation measurements for the same samples.*

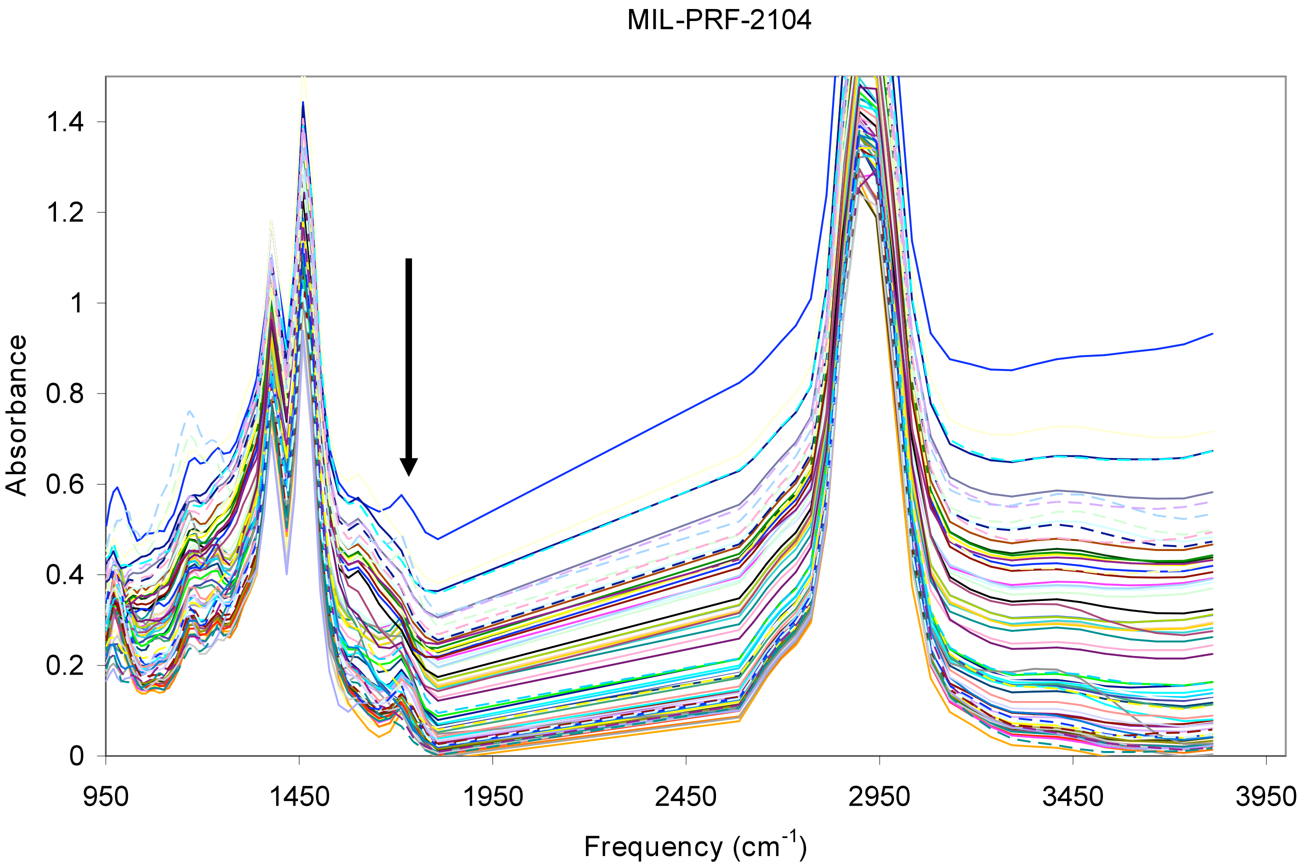

Figure 4, FluidScan Spectra of In-Service Oil Samples Showing Response to Varying Levels of Degradation

Lubricant degradation of petroleum lubricants is measured by IR spectrometers in the region between 1800 cm^{-1} and 1670 cm^{-1}. Figure 4 shows the IR spectral response of FluidScan on lubricants with varying degrees of degradation ranging from 7 to 25 Abs/mm^2. As can be seen from Figure 4, FluidScan can easily differentiate among the degrees of degradation.

Scans as shown in Figure 4 are of interest to experimenters and scientists, but not necessarily to the maintenance professional. For that reason, the FluidScan is calibrated to provide readings in units that are standard in the industry and easy to store and use as the basis of trends in predictive maintenance programs. To accomplish this, chemometric calibrations are stored in FluidScan to provide excellent correlation to acid number and oxidation. For this comparison, the acid number analyses on the MIL-PRF-23699 in-service oil samples were performed by a laboratory using wet-chemistry titrations. The results in mgKOH/g are compared to FluidScan analyses as shown in Figure 5.*

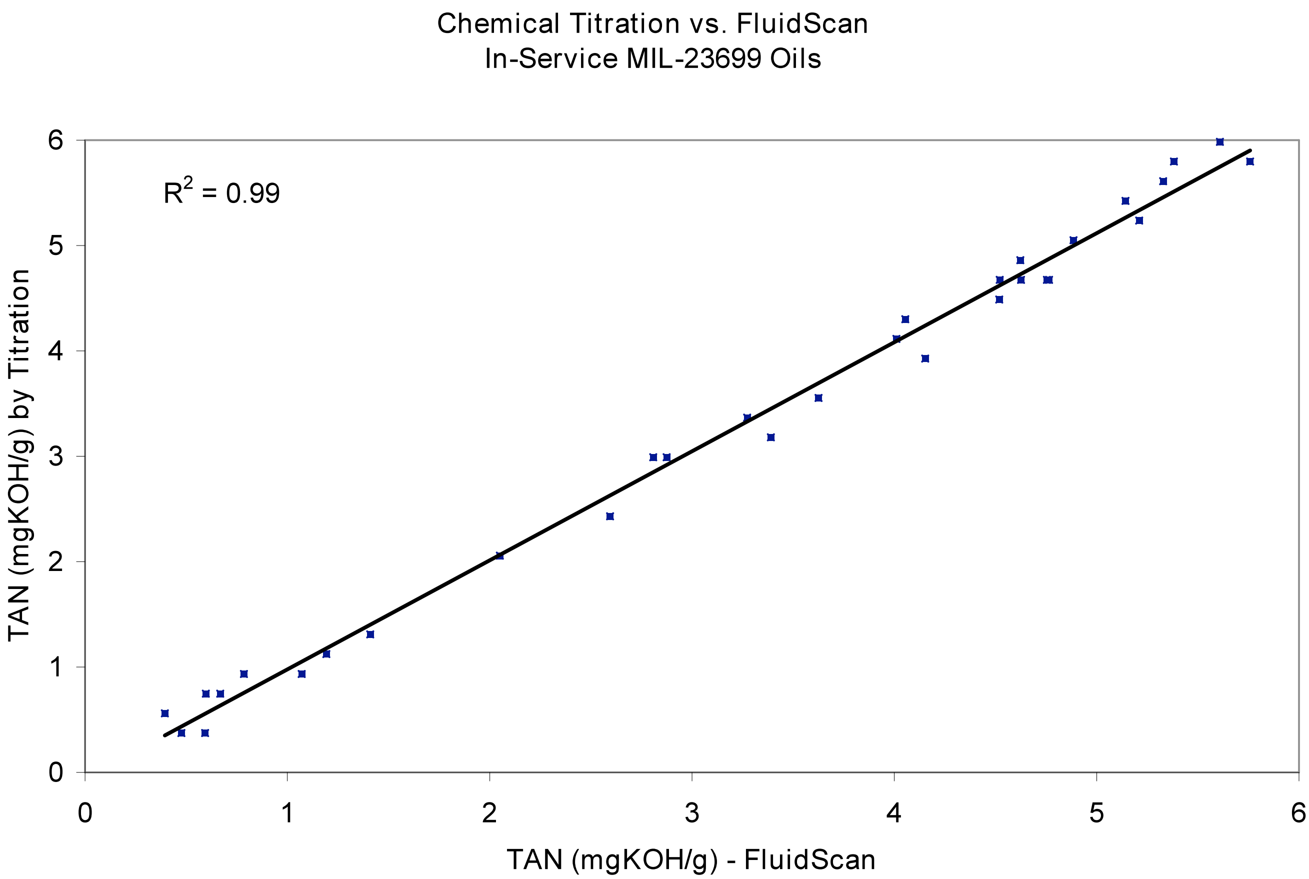

Figure 5 – Comparison of TAN by FluidScan with TAN by laboratory titration.

The correlation between the tests performed on the FluidScan and by the laboratory for acid number is excellent with a correlation factor over 99%.

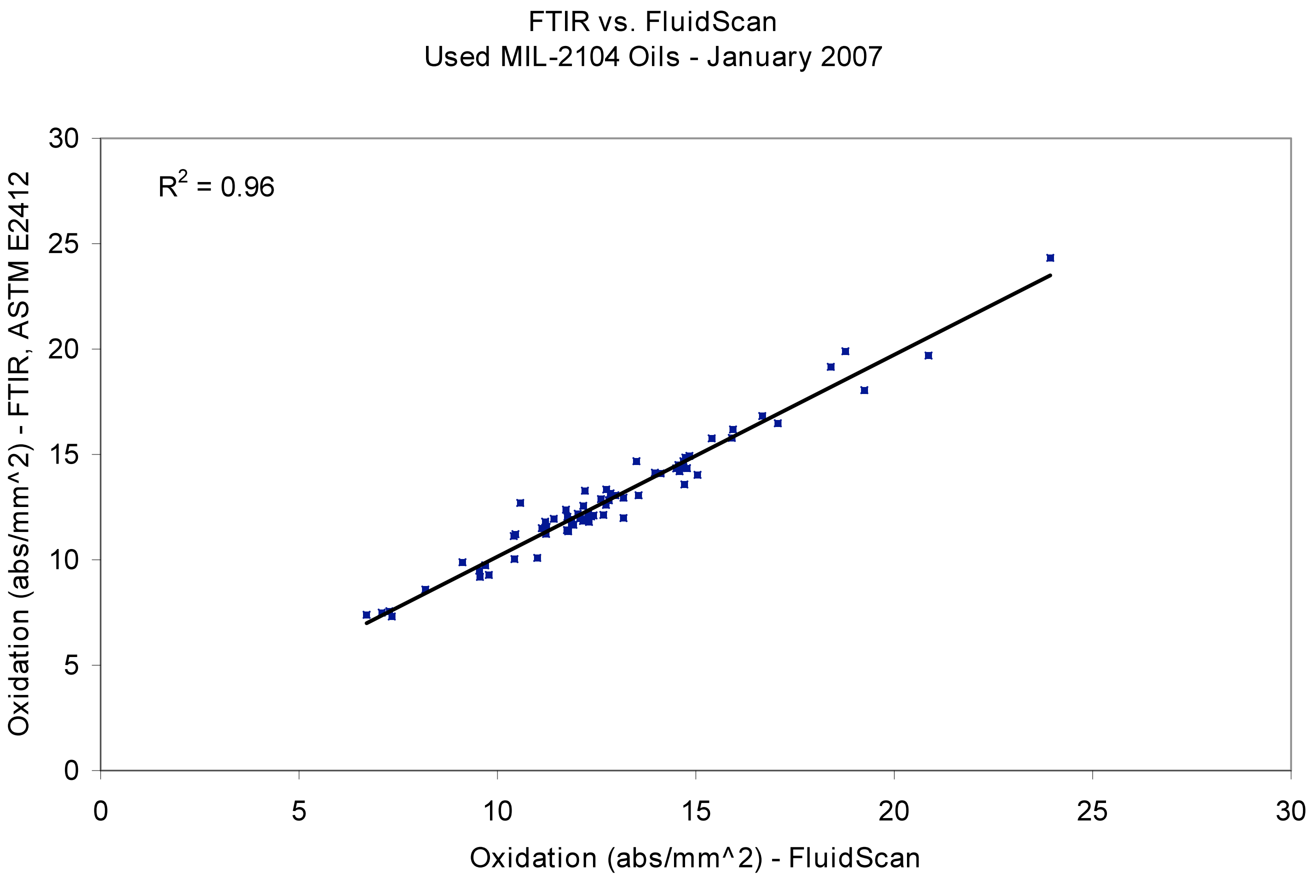

Figure 6, FT-IR and FluidScan readings of Oxidation (abs/mm^{-2}) in used MIL-PRF-2104 samples.

The MIL-PRF-2104 samples were analyzed to ASTM Standard Practice E-2412 using a Fourier Transform Infrared spectrometer (FT-IR). The same samples were analyzed with FluidScan and the results were compared as shown in Figure 6.

The correlation between the lubricant degradation data based on oxidation analysis with the FT-IR spectrometer and FluidScan is excellent with a correlation factor over 96%.

Quantitative Measurements Using Commonly Understood Units

The FluidScan is delivered with algorithms for most common oil types for the device to report quantitative properties. These are being continuously upgraded. Extensive applications work has been *done with the FluidScan to provide accurate, absolute quantitative measurement of the following key properties:*

TAN (mg of KOH per g)
TBN (mg of HCL per g)
Water (ppm)
Glycol (ppm)
Soot (per cent by weight)
Incorrect Fluid (per cent by volume)

Quantitative measurement of these parameters is specific to fluid type. Therefore, an extensive library containing hundreds of fluid spectra have been collected and stored in the memory of the FluidScan so that an appropriate new lubricant reference may be applied to give accurate quantitative data. The FluidScan is calibrated to TAN, TBN and Karl Fischer values determined by ASTM laboratory titration methods. Soot is calibrated to soot percentages determined by thermo-gravimetric analysis. Glycol and incorrect fluid percentages are calibrated to samples prepared with known concentrations of glycol and incompatible fluids.

It is only possible to give good absolute quantitative results by infrared spectroscopy for the above fluid properties by reference to the correct fluid type and with a calibration curve for that type of fluid as is provided with the FluidScan.

FluidScan is meant primarily to be used at the sampling point to screen for lubricant deficiencies, but it may also be used in the laboratory as a quick and economical substitute for laboratory titrations for TAN, TBN and water. Furthermore, glycol, soot, oxidation, nitration, sulfation, anti-wear additive depletion and incorrect fluid are simultaneously measured and reported.

Conclusion

A new quantitative tool now exists for the convenient on-site analysis of in-service lubricants for degradation and contamination to determine if a lubricant is fit for further service or if an oil change or other maintenance action is required.

About the Authors

Dr. Pat Henning is currently a Technology Manager in the Technology Solutions Group of QinetiQ North America. Since 2001, he has led efforts in the development and integration of miniature infrared spectrometers into fluid process monitoring and chemical/biological detection systems. He has also developed calculational techniques to predict the performance of complex structures in the infrared including nanotube grids, photonic bandgap antenna structures, and multilayer EMI surfaces. He earned a Ph.D. in physics from Florida State University/National High Magnetic Field Laboratory in 1996. Dr. Henning was Postgraduate Research Physicist at the University of California, San Diego from 1997 to 1999, where he specialized in the infrared spectroscopy of materials, particularly at frequencies in the terahertz regime, as well as the development of novel instrumentation and analysis approaches for this purpose. He was part of the scientific team that developed and built the U12 IR beamline of the National Synchrotron Light Source at Brookhaven National Laboratory. He has served as an editorial referee for Physical Review B, Physical Review Letters, and the Journal of Air and Waste Management.

Daniel P. Anderson graduated from M.I.T. in 1970 majoring in Materials Science & Metallurgy. He worked for seven years as an aerosol scientist and instrumentation engineer before beginning his career in tribology with The Foxboro Company in 1977 to work as lab manager in the ferrography product group. He prepared the Wear Particle Atlas (Revised) in 1982, still the primary reference on ferrography. He moved to Cleveland in 1984 to become lab manager when Predict Technologies was first started by Standard Oil of Ohio. He joined Spectro Inc., manufacturer of oil analysis spectrometers, in 1986, and has traveled extensively promoting and installing instruments and turnkey laboratories for predictive maintenance by oil analysis. He is the inventor of rotrode filter spectroscopy. In 1991, he was one of the founders of National Tribology Services, a commercial oil analysis laboratory, recently sold to the Bently Nevada Company. He was for many years VP of Sales for Spectro Inc. and is now VP of Product Management. Spectro Inc. is part of the Technology Solutions Group of QinetiQ North America.