TECHNICAL PAPER

FT-IR for Effective, Low-Cost Oil Condition Monitoring

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Background

Periodic sampling and analysis of crankcase, gearbox, turbine, and other lubricant and hydraulic fluids have long been used as a means to determine overall system health and performance. Atomic emission (AE) and atomic absorption (AA) spectroscopy are the most common spectroscopic techniques employed. The AE and AA methods provide information on the level and trend of wear metals, as well as elemental constituents contained in additives and contaminants that may be present in the used oil. A number of physical property tests (PPT) generally compliment the elemental analysis and provide some additional information on the lubricant condition. The PPT usually include kinematic viscosity, total base number, total acid number, flash point, insolubles, etc. However, most PPT were developed for determining the performance and characteristics of new oils and provide only indirect information regarding oil condition and contamination.

The application of infrared (IR) spectroscopy in lubricant analysis developed soon after the introduction of commercial recording spectrophotometers. The output consisted of a graphical presentation of the infrared spectrum, which was interpreted by a trained chemist or spectroscopist—a task that requires many years of training. Moreover, spectral interpretation is labor intensive and unsuitable for routine used-oil analysis. With the introduction of commercial Fourier transform infrared (FT-IR) spectrometers with their attached personal computers (Figure 1), the mathematically-intensive infrared data interpretation techniques became easy. FT-IR applications became commonplace for routine (production) oil analysis laboratories.

The FT-IR provides direct information on molecular species of interest, including additive packages, fluid breakdown products, and external contaminants. Caterpillar Inc. implemented the first wide scale use of FT-IR for used oil analysis in the late 1980's. This method was primarily developed for diesel engine crankcase oil analysis. Synthetic and other petroleum lubricant applications were not included in this development. Modern military and commercial condition monitoring programs must analyze a wide variety of lubricant types, such as polyol and phosphate ester lubricants. Thus, the U.S. Military Joint Oil Analysis Program Technical Support Center (JOAP-TSC) undertook the task of developing a more comprehensive FT-IR analysis method to improve the analytical quality and reliability of JOAP used-oil analysis.

The "Used Oil Analysis" software interprets the IR spectrum of the lubricant and generates numerical values analogous to PPT data, thus eliminating the necessity of spectral interpretation by a chemist. This process is similar to AE spectroscopy, which generates parts per million (ppm) data for elemental analysis and has eliminated the necessity for a chemist for the interpretation of emission spectra.

Figure 1: FT-IR Spectrometer for Oil Analysis

JOAP FT-IR Program

The Army Oil Analysis Program (AOAP) determined the condition of lubricants through qualitative and subjective tests. These tests were not reliable enough to allow on-condition oil changes. The desire to move to on-condition recommendation became the initiative for the JOAP-TSC to evaluate FT-IR spectroscopy as a possible replacement for the old methodology. The JOAP-TSC completed the test and evaluation studies in late 1994 and the Army adopted the FT-IR as the appropriate technology to meet advanced physical property test requirements. Since adoption, the Army has procured and fielded FT-IR systems at all Army laboratories worldwide. Partially because of this technology, the U.S. Army Aviation and Missile Command has enrolled all of the aviation fleet in the program.

In 1998, the U.S. Army avoided 45 million dollars in new oil purchases through their initiative of on-condition oil changes. The switch from scheduled oil change to on-condition oil change was possible due to the reliability of FT-IR analysis in determining actual oil condition. 1999 data shows the cost avoidance was seen across all equipment types in the Army program. Figure 2 shows the overall cost benefit was over 122 million dollars is broken down as follows:

- $45 million was avoided by complying with the Army policy of on-condition oil changes (OCOC). FT-IR analysis is utilized to determine lubricant condition and the need for change.

- $6.8 million was recouped because the Army program was able to calculate the amont of fuel used during off-road exercises. Off-road utilization is exempt from fuel tax.
- $70.4 million was attributed to maintenance savings. The amount is a conservative estimate and reflects a minimum cost to savings ratio of 8:1. Independent studies confirm an estimated annual savings on the order of 8:1 or better with a properly implemented oil analysis program.

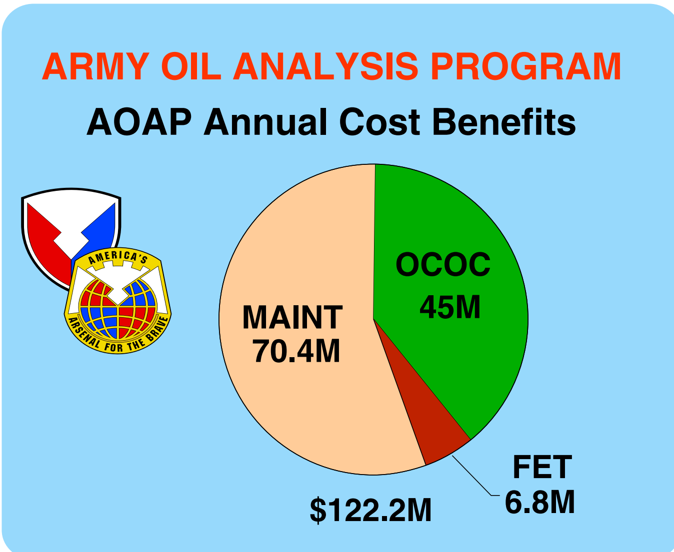

Figure 2: 1999 Benefits for Army Oil Analysis

Figure 3 contains six examples showing the difference between the cost of scheduled oil changes versus on-condition oil changes. The calculation shows the percent reduction in the cost between the former scheduled oil change program and the new condition-based program. For example:

- M1A1 Abrams tank engine (utilizes 2380 gas turbine oil). The cost of scheduled oil change was almost 2 million dollars. The cost of on-condition oil change in 1999 was under 200 thousand dollars – a saving of 1.8 million dollars or a 91% reduction in the cost of oil.
- The M1075 PLS lubrication requirements were reduced from 960 thousand dollars to under 90 thousand. A savings of 91% again.
- The M1037 HMMWV (Hummer) lubrication requirements dropped by 67%.
- The saving for the Army's small fleet of diesel locomotives was 90%, 120 thousand dollars.
- Even the small number of Army power units reflected significant savings.

The downsizing of today's military force with its reduced budget and equipment usage dictates that only state-of-the-art technology may be employed for equipment condition monitoring. Moreover, the technology must have the form, fit and function to be properly and economically applied to each equipment type and operational requirement. FT-IR will continue to be utilized as a bench-top analyzer in laboratories, on the flight line and on the shop floor. However, for high value equipment, a new breed of IR sensors will eliminate the need for sampling while providing real-time data on the various oil failure modes. Foster-Miller, Inc. and the Battelle/Pacific Northwest National Labs have IR sensors under development.

- The Foster-Miller infrared Oil Condition Monitor (OCM) employs a dispersive optical system configured to measure oil acidity (TAN), water content, thermo-oxidative degradation, fuel/coolant dilution, and anti-oxidant depletion for engine oils. The Foster-Miller sensor was developed with Air Force SBIR funds. The OCM was first configured to measure failure symptoms of polyol ester turbine oils but also works well on petroleum oils. The sensor successfully completed on-engine shake down tests, on a T-63 engine, at Wright Patterson Air Force Base during November 1998. The JOAP-TSC provided control testing on a bench-top FT-IR analyzer. The OCM data compares favorably with the results from current FT-IR oil analyzers. The sensor is currently being combined with XRF and metal particle counting sensors for a complete oil condition monitoring capability. US Army and Navy buy-and-try technology demonstration projects are funding this effort.

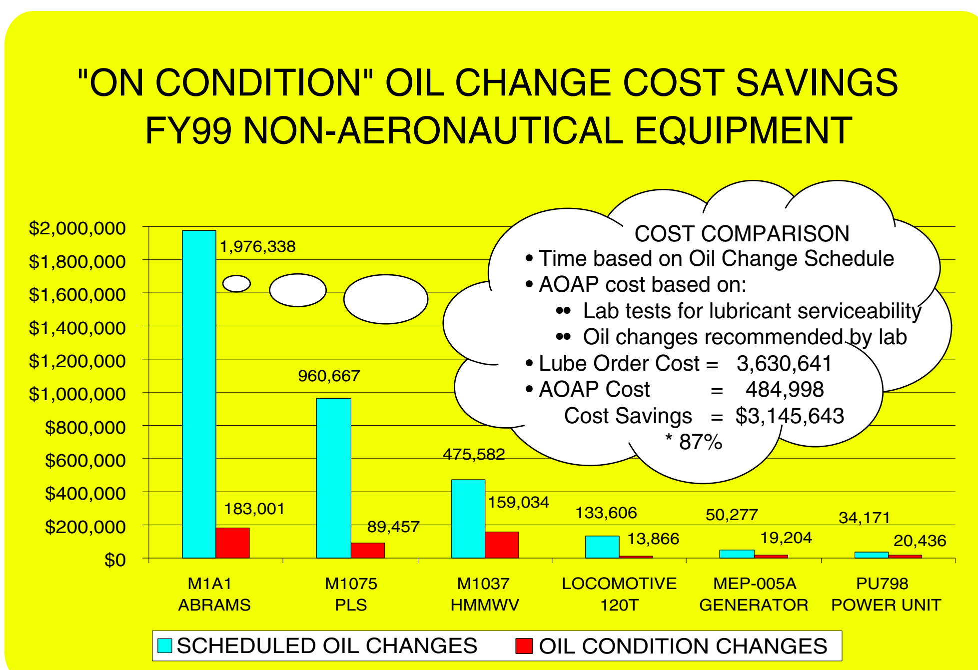

Figure 3: Breakdown of the 1999 Benefits for Army Oil Analysis

- The Pacific Northwest National Labs infrared sensor is also part of a comprehensive package that includes an XRF and a viscosity sensor. The infrared sensor module utilizes a non-dispersive optical system with discrete channels that can be configured to measure oil failure mode symptoms of petroleum and synthetic ester oils. The Battelle sensor package is being developed for railway and military projects and is due to be evaluated by the JOAP-TSC this summer.

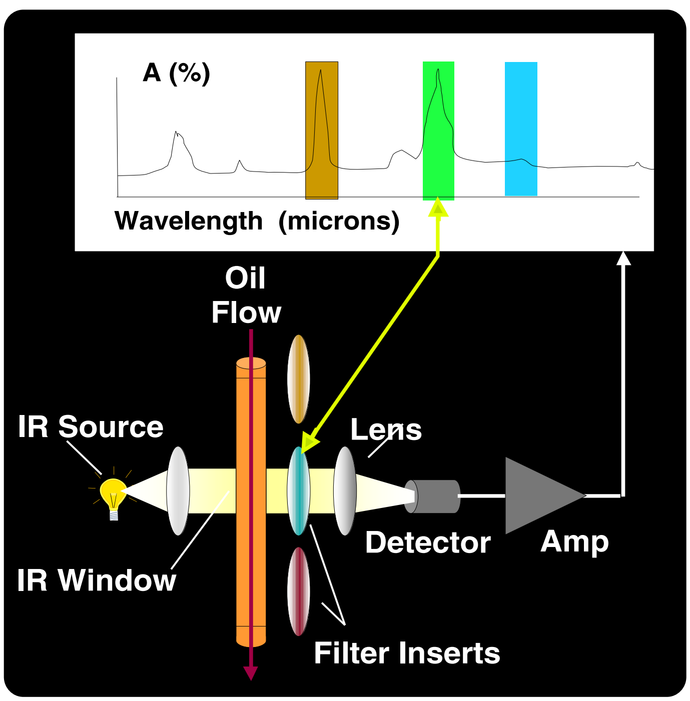

Figure 4: Non-Dispersive IR Sensor Concept

Each of these IR sensors feature a miniaturized infrared spectrometer that measures the absorbance at the specific wavelength region associated with the key oil failure modes. The wavelength bands and calibration criteria where originally developed by the JOAP-TSC for the US Army oil analysis program.

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