Advances in Comprehensive Fluid Analysis

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Abstract

We describe advanced forward deployed comprehensive fluid analysis for wear debris and fluid condition of lubricating oil, hydraulic oil and fuel. Examples from mechanical systems are given for detection of wear-related and fluid condition-related faults.

Introduction

We describe advances in comprehensive forward deployed fluid analysis based on fluid condition assessment with a FluidScan® analyzer and a viscometer and contaminant and wear debris analysis with the LaserNet Fines® (LNF) optical particle analyzer. The combined technologies provide comprehensive analysis of fluid condition and machinery health, and are implementable either as a forward-deployed portable instrument or a continuous, autonomous online monitor. The combined technologies provide comprehensive immediate on-the spot actionable information at the operational level about the current condition of platforms and machinery, readiness for deployment or usage, and advanced warning about impending failures or need for specific maintenance. A forward deployed portable instrument, which can analyze lubricating oils, hydraulic fluids and fuels is of value for monitoring fleets of vehicles or platforms with a single instrument using bottle sampling. An online monitor [1] is of value in providing continual assessment of the condition of critical, high-value equipment where serious faults can develop between bottle sample intervals, and can help support reduced manpower or workload environments.

The first generation Portable Fluid Analyzer (PFA) [2] is shown in Fig. 1.

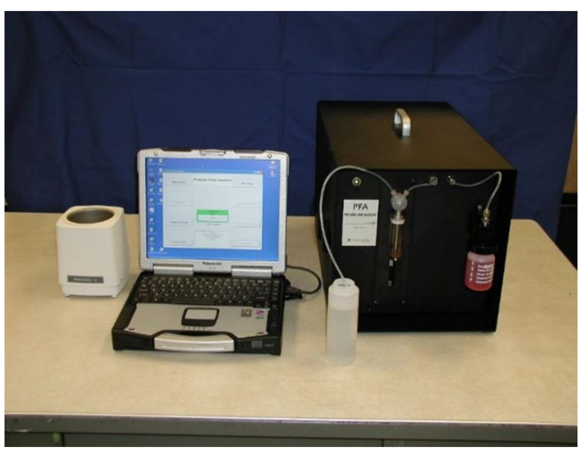


Fig. 1. First generation PFA with laptop computer

Analysis of a fluid sample is accomplished by drawing fluid from a sample bottle into the PFA, which contains LNF, FluidScan and viscometer analyzers arranged in series along the fluid path. Raw data from each device is transmitted to a laptop computer. Software on the laptop computer controls the PFA instrument, analyzes the results of measurements, and displays results to the user. The instrument also automatically flushes the internal lines between samples with solvent. Spent fluid is collected in a separate bottle for disposal

Case Studies

Here we will illustrate the capabilities of the PFA instrument in detecting mechanical and fluid faults with two case studies as examples. Our examples will show the benefits of immediate on-site fluid analysis, as well as combined analysis of fluid condition and wear debris, allowing immediate assessment of equipment readiness and improved ability for remedial action.

The PFA wear debris measurements from transmissions in a fleet of six vehicles over a period of nine months are shown in Fig. 2. For this study, samples were taken on an "as available" basis as opposed to prescribed intervals driven by calendar time or operating hours.

A baseline of "normal" operation is established by assuming that the vehicles have all been subjected to the same operational conditions historically, and are all operating normally at the start of the monitoring period. Over the period of study, the particulate concentration in one of the PFA particle categories (fatigue particles between 25 and 50 microns in size) varies randomly over a small range at a relatively low level for five of the six vehicles. This range can be taken to be indicative of the concentration of fatigue particles for normal operation.

Near the start of the study the concentration of particles in vehicle 4 (V4 TR) starts to increase and continues to grow, slowly at first and then more quickly. At the maximum level detected in the study (Point "A") a catastrophic failure occurred for vehicle 4 with the particle filter plugged and the transmission inoperable. At this point, not only was the fatigue particle concentration significantly elevated in the 25-50 micron size range (Fig 2b), but the size distribution shows an peak in that size interval, as shown in the histogram in Fig 2c. Following the failure event, the transmission was replaced. Analysis of samples taken immediately after replacement (V4 TR2) continued to show high levels of fatigue wear debris because of incomplete flushing of the transmission sump. Subsequent measurements made after a complete flush of the transmission (Point "B") show that the wear particle concentration returned to the "normal" range (Fig 2d) and, more importantly, the size distribution changed to one that falls rapidly with increasing particle size (Fig 2e).

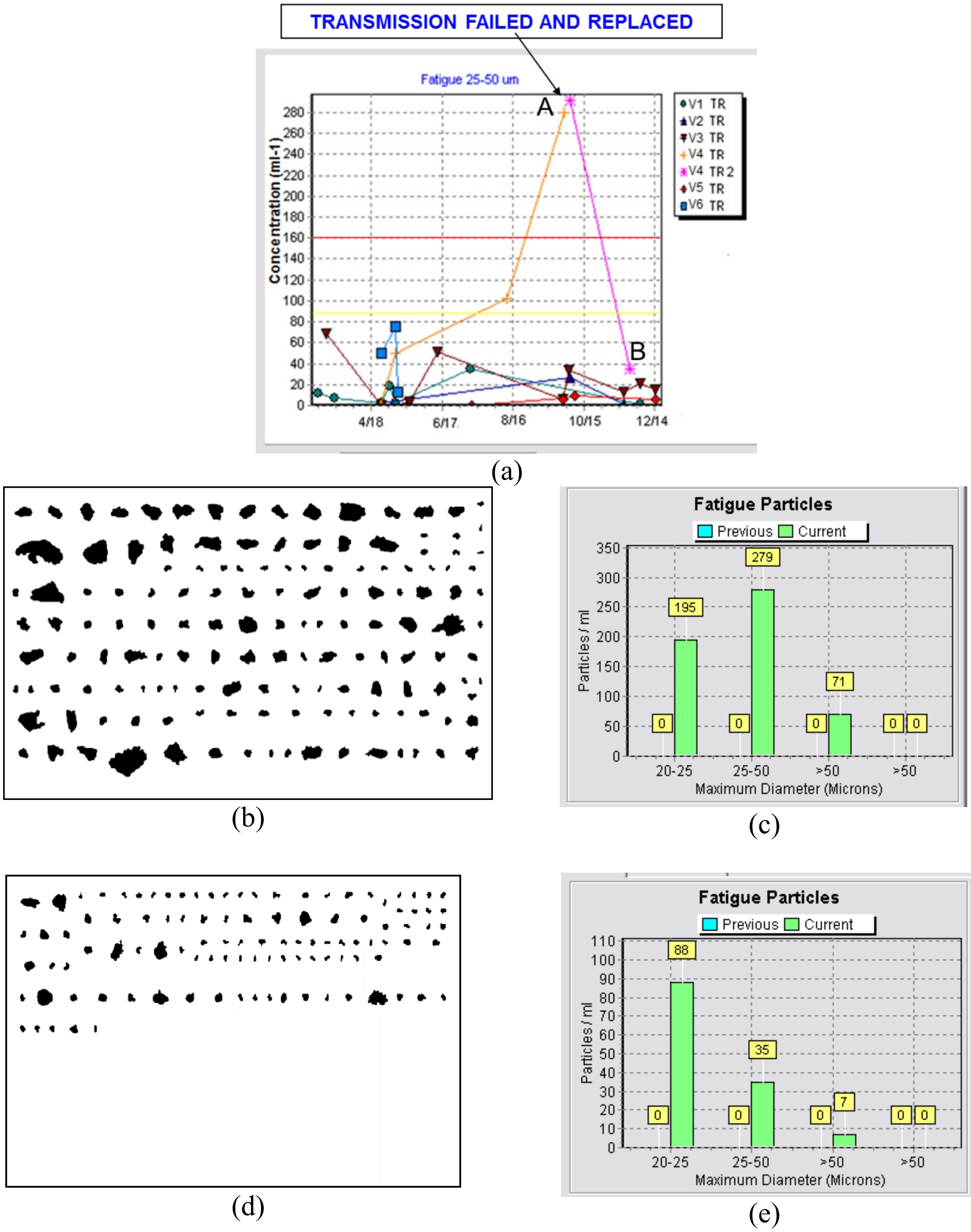


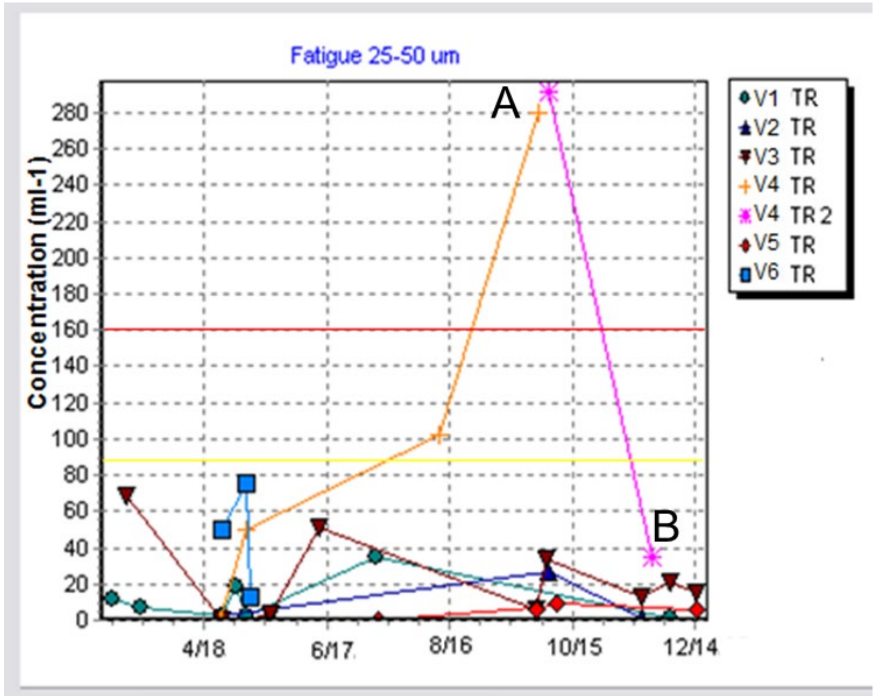
Fig. 2. Wear particle analysis by PFA on the transmissions (TR) a fleet of six vehicles. At point "A", the transmission of vehicle 4 failed and was replaced. After replacement, normal operation resumed at point "B". (a) fatigue particle concentrations in the 25-50 μm size range. (b) Particle image map of vehicle 4 at point A (1 of 6 pages of fatigue particles). (c) Fatigue particle size distribution for vehicle 4 transmission at point A. (d) Complete fatigue particle image map of vehicle 4 at point B. (e) Fatigue particle distribution for vehicle 4 at point B.

These results indicate the benefits and power of debris analysis that combine morphological analysis with quantitative measures. Morphological analysis allows us to separately identify those particle associated with specific types of faults. Typically, these are a small fraction of the total population of particles contained in the lube oil. By singling them out for individual analysis, it is possible to detect faults at their earliest stages. Simultaneous quantitative analysis allows us to identify the transition from normal or early wear to the onset of fault-related excess wear more reliably. This transition can be judged not only by an increase in particle concentration, which can happen for a number of reasons, but by changes in the size distributions within a class, which is generally associated with the progression of fault conditions.

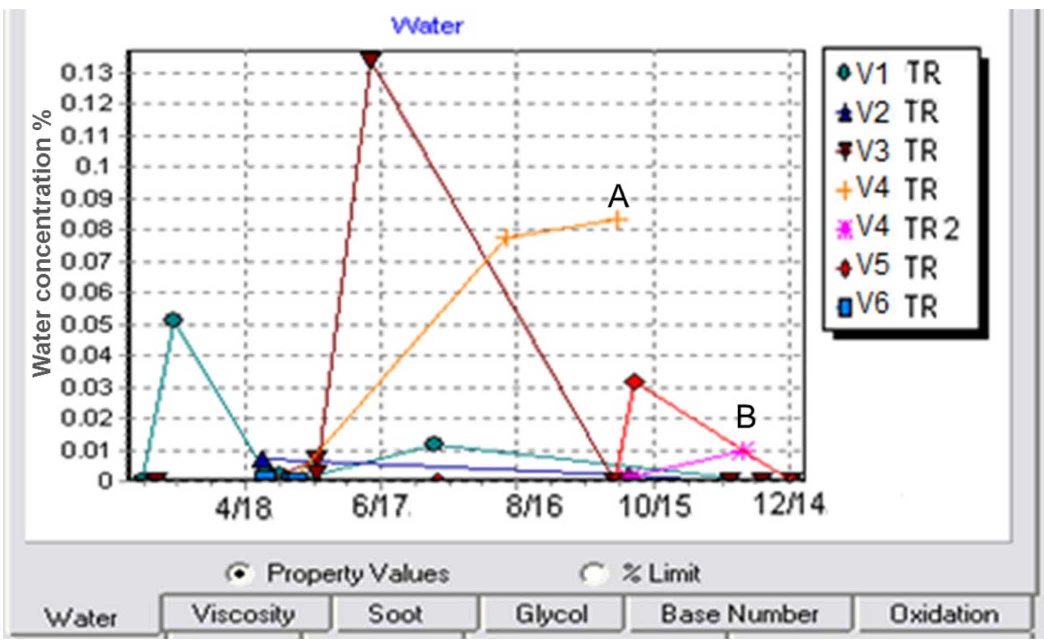
Additional information can be obtained by combining the wear debris results with fluid condition analysis. The same particle data in Fig 2a is shown in Fig. 3a, along with water concentration measurement over the same period in Fig 3b.

Here it can be seen that for several months prior to the catastrophic transmission failure (Point A) the water level in vehicle 4 was elevated at a value of the order of 0.08%. This level is well below the maximum allowed level of 0.2% for this vehicle. However, it is known from controlled studies [3] that water levels in the range of 0.08% for extended periods can shorten bearing life significantly, as shown in Fig. 4.

The results shown in Figs 2 and 3 illustrate the value of on-site comprehensive monitoring. The particulate data shows that five of the six vehicles in the fleet remained fit for service, but vehicle 4 became unfit near the end of the sixth month in the study. Such information is vital for field commanders, both military and civilian, to obtain optimal effective service from their fleets. An addition, the fluid condition results strongly indicates that the failure near the end of month 8 of the study could be traced to the elevated water levels occurring earlier. Suitable remedial action based on these results could well have averted the subsequent catastrophic failure.



(a)



(b)

Fig. 3. PFA (a) fatigue particle and (b) water concentration measurements for a fleet of six vehicles. Point A corresponds to the point where vehicle 4 transmission failed. Point B corresponds to the point where the transmission was replaced and the system flushed.

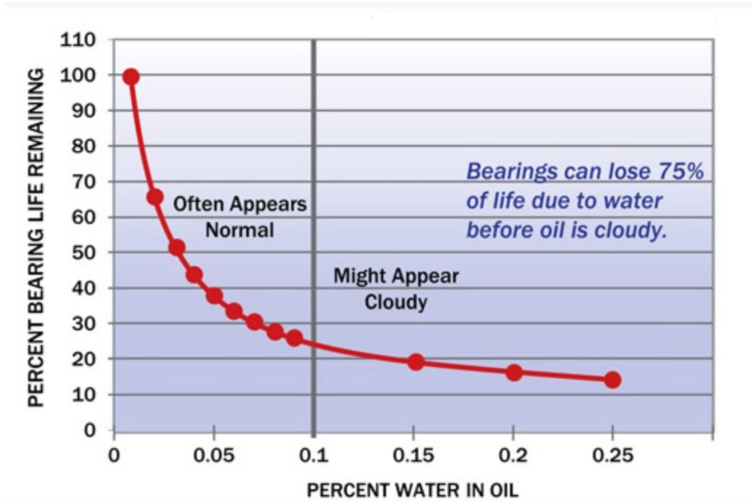


Fig. 4. Dependence of bearing life on concentration of water in lubricating oil as described in Ref 3. Reprinted with permission.

An additional example of the value of immediate on-site information is illustrated in Fig. 5.

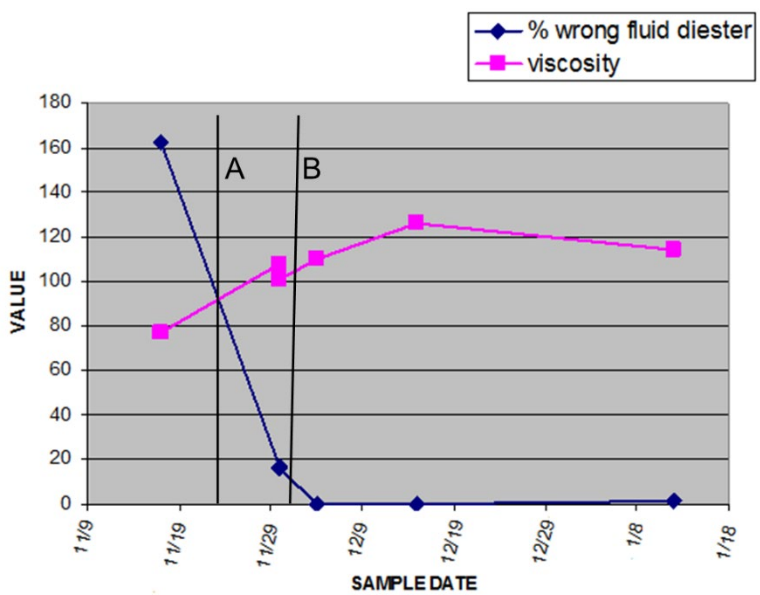


Fig. 5. Measures of viscosity and wrong fluid in a diesel engine. At Point "A", the engine was replaced based on PFA analysis. At that time, the system oil was replaced. At Point "B", the engine oil was replaced a second time.

Here we show results of measures of viscosity and wrong fluid (synthetic diester in mineral lube oil) in a diesel engine. During routine analysis, one of the samples showed a significant concentration of synthetic diester (wrong fluid) in the mineral lubricating oil, along with a reduction in viscosity from a normal value of 120 cSt down to 78 cSt. The elevated diester level was subsequently traced to a broken seal in the engine between the high-pressure hydraulic system and the lower pressure lube oil system. Corroborating this finding is a drop in viscosity, although the viscosity remained at an acceptable value and would not have, in itself, indicated a problem. In this situation, the broken seal was replaced before the engine failed.

Fuel Analysis

We have also developed algorithms for fuel analysis using mid infrared spectroscopy with an FTIR spectrometer. The purpose of the algorithms is to determine if an unknown fluid is a fuel, if so, its type and multiple physical properties relevant to the fuel type. The approach is based on Soft Independent Modeling by Class Analogy (SIMCA). We have developed the ability to distinguish the broad classes of gasoline, diesel and aviation fuels, and also several subtypes within each class. The truth table showing the SIMCA classification of over 1400 samples of various fuel types compared to ground truth in Fig. 6.

CLASSIFIER

GROUND TRUTH

	Unknown	JP-8	JP-5	Diesel	Gasoline	fraction correct
Unknown	1	0	0	0	0	1
JP-8	1	161	0	1	0	0.99
JP-5	2	0	18	0	0	0.90
Diesel	18	0	0	779	0	0.98
Gasoline	17	0	0	0	631	0.97

CONSOLIDATED FUEL CLASSES

Fig. 6. Summary truth table showing the number of fuel samples classified in each category by SIMCA compared to ground truth.

Once a fuel type has been identified, chemometric analysis of the spectra is used to identify multiple appropriate physical properties as indicated in Fig. 7.

Property	gasoline	biodiesel	JP-8	diesel
Density	X	X	X	X
Distillation – Initial Boiling Point	X	X	X	X
Distillation - 10%		X	X	X
Distillation - 50%		X	X	X
Distillation -90%		X	X	X
Distillation – Final Boiling Point	X	X	X	X
FAME (%)		X		X
Flash Point	X	X	X	X
Cetane Index		X		X
Cloud Point		X		X
Octane Number	X			
Freezing Point			X	
FSII			X	
Water	X	X	X	X
Sediment	X	X	X	X

Fig. 7. Physical properties calculated for different fuel types

The physical properties determined as shown in Fig 7, combined with specified limits and fuel type identity, allows the use of these results to determine in the field if an unknown fluid is a fuel and, if it is a fuel, what type it is and whether it is usable. The fuel analysis capability will be incorporated in a future version of the PFA.

Summary

We have described an approach to the development of forward deployed comprehensive fluid analysis for analysis of lube oil, hydraulics and fuel. The instrument can be used by non-trained personnel in the field to obtain immediate actionable information about the usability of the equipment and the presence of specific faults, allowing remedial action or planned maintenance.

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