Portable Lubrication Analytical Instrumentation for Maintenance Application

[1]Adrian Chaplin, Frances Hardiman & Daragh Naughton

***Abstract*—Maintenance practices have a beneficial economic impact in industry. Industrial equipment operators are continuously forced to reduce operating costs while increasing profits to remain competitive. Reaching optimum lubricant capabilities can extend the life cycle of assets, help achieve lower operating costs and maintain the harsh continuous cycling of machinery. Attaining these capabilities without hindering system performance often requires modern portable technologically advanced condition monitoring instruments.**

Increasingly, these portable instruments are replacing the conventional practice of analysing lubricants in commercial laboratories. Delays in laboratorial analysis are eliminated, maintenance response time is increased and production output is increased.

This paper describes the differences of analysing used oils from industry with a bench mounted commercial laboratorial instrument and an on-site portable oil analyser. Furthermore, an evaluation of the modern portable analytical instrumentation that is available for on-site lubrication analysis is conducted.

The research has found that the same maintenance action is prompted by the results of both the commercial instrument and the portable instrument that was used for testing. This paper has also listed other modern, portable, analytical instrumentation for lubrication analysis and described their operating principles, benefits, limitations and applications. The research has shown that a full range of portable instrumentation is available for a complete on-site analysis of lubricating oils.

This research will be of interest to analytical instrumentation manufacturers, maintenance departments and senior managers concerned with manufacturing innovation, manufacturing processes and life cycle engineering.

***Index Terms*— lubricant analytical techniques, maintenance, production optimisation, oil analysis, FTIR oil analyser**

I. Introduction

The drive towards increasing operational capabilities and lowering production costs is forcing organisations to improve maintenance practices. An effective maintenance program will increase production, deliver high quality products and increase profits [1]. Asset life can be increased by monitoring the lubricating substances that provide invaluable protection. Lubrication is essential for equipment efficiency. It provides a barrier for components in motion, shields from thermal effects, protects against oxidation and contamination, limits deterioration and removes unwanted particles from the system [2].

There are many places oil is used as a lubricant and oil will inevitably degrade over time, thereby reducing its effectiveness as it is exposed to internal and external contaminants that reduce the oils life-span [3].

In the manufacturing and production industries, machines are high value assets and routine oil analysis protect their value while avoiding expensive repairs [4]. Oil analysis is used to positively influence a maintenance program, to avoid failures and to increase plant availability [5]. The increasing complexity of fluids requires a large number of analytical procedures for a complete analysis. These techniques may include the analysis of wear particles, chemical degradation, viscosity, contamination and additive depletion [6].

Wear particle testing involves extracting a sample of the lubricant from the machine or engine and studying the particle content of the oil. It provides invaluable information about component particle displacement. The wear detected is caused by the erosion of surfaces in contact and the reason for a failure can be identified [7]. The analysis also involves studying the particles contour, structure, magnitude and quantity. A comprehensive report using spectroscopy, microscopy and ferrography examines the debris and can provide a detailed analysis of the oil sample. Wear debris analysis can be an effective method of identifying component failure at an early stage [8].

Viscosity of a lubricating substance is a measure of the oils ability to resist flow and an effective lubricating substance requires a certain specified viscosity. Additives are incorporated in oil to withstand a wide range of harsh environments and the chosen additives for oil depend on the oils application. Common additives are anti-oxidant, anti-wear, friction modifier, anti-foam and pour point depressant additives [9]. Oil analysis by *Fourier Transform Infrared* (FTIR) spectrometry can identify *Total Base Number* (TBN), *Total Acid Number* (TAN), contamination in the oil, chemical degradation in the oil and additive depletion in the oil [3].

Traditionally, these procedures were carried out by the discerning scientist in commercial laboratories using large bench mounted instruments. These procedures can delay the response time for maintenance personnel. However, the recent developments of portable analytical instrumentation have created the scenario whereby maintenance personnel are conducting on-site analysis. The portable instrumentation is required to be robust and accurate. These

[1] Corresponding Author and Researcher: Adrian Chaplin is with the Department of Mechanical & Automobile Engineering & ACORN Research Centre, Limerick Institute of Technology, Moylish, Limerick, Ireland. Email: Adrian.chaplin@lit.ie, Phone: +353 61 208 208. The author wishes to express gratitude to the Limerick Institute of Technology for funding this research through its Graduate Office Bursary (GRO) bursary.

Frances Hardiman is with the Mechanical Engineering Department & ACORN Research Centre, Limerick Institute of Technology, Moylish, Limerick, Ireland (email: frances.hardiamn@lit.ie).

Daragh Naughton is with the Mechanical Engineering Department & ACORN Research Centre, Limerick Institute of Technology, Moylish, Limerick, Ireland (email: daragh.naughton@lit.ie).

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intelligent tools have provided the means to increase production and reliability, eliminating detrimental plant failures [2].

In this paper we present a brief evaluation of current portable lubricant analytical instruments on the market, while explaining their operating principles, their benefits and limitations and the feasibility of forming a complete on-site oil analysis department within a maintenance department. Secondly, we compare the testing of used lubricants by a laboratorial bench mounted instrument and a portable instrument. This course of research tested 11 oil samples for oxidation, water levels and TAN levels.

Oxidation (abs/mm^2) is measured by the concentration of infrared light absorbed per 0.1mm thickness of the oil (path length). This measurement directly relates to the peak intensities measured from the difference spectrum of the virgin oil to the used oil. This results in the oil thickening and creating a varnish formation on the surfaces of moving components and increases the acidity of the oil which can lead to corrosion. Additives are present in the oil to prevent oxidation occurring. When these additives are fully depleted the oxidation process escalates. The use of FTIR oil analysis can identify when the additive is nearing depletion, hence indicating a need for an oil change before components begin to corrode [10].

TAN (mg KOH/g) is a measurement of the remaining life of the oil. It is determined by the amount of potassium hydroxide (KOH) base required to neutralize the acid in one gram of an oil sample and the standard unit of measure is mg KOH/g. A direct comparison of the acidic level of the used oil to an unused sample will indicate its suitability for additional use and the increasing presence of acids in oil will advance the corrosion rate of metallic parts. Unused oil has suitable levels of antioxidant and a low TAN value. During operation the oil degrades reducing the antioxidant capabilities and increasing the Tan value [11].

Water (ppm) found in oil is identified by parts per million and 1,000 ppm is 0.1% of water in the oil. Water contamination requires urgent attention and signals that a large problem has been identified. Water found in an oil sample can be a result of condensation which can assist machine wear and significantly reduces the life of the oil. Regular monitoring of the oil is required to detect the presence of water in the oil and prolongs the life of the oil [12].

II. Methodology

A. *Oil Analysis by Bench Mounted and Portable FTIR Instruments.*

This section describes the experiments that were conducted using both a commercial bench mounted and portable FluidScan oil analyser. Both instruments use *Fourier Transform Infrared* (FTIR) spectrometry to analyse the used oil. The parameters measured by this method are contamination (soot, water and glycol, fuel content), chemical degradation (nitration, oxidation, sulphur), additive depletion, *Total Acid Number* (TAN) and *Total Base Number* (TBN).

Oil Sampling

Oil samples were provided by local industries from machines and engines. The industrial partners were a Bauxite processing facility in Limerick, Ireland, a maintenance repair facility that overhauls large jet-transport aircrafts in Shannon, Co. Clare, Ireland and a car servicing facility servicing facility based in Limerick, Ireland. The oil samples varied between 50 and 100 milliliters and were extracted onsite using an in-line vacuum pump. This method eliminates any dust particles from the surrounding environment from entering the sampling bottle. A polyurethane tube is placed in a position where there is a turbulent flow of oil. This means the oil sample that is extracted is from a position where the oil is working and not at the bottom of a sump or reservoir where contaminants are prevalent.

Bench Mounted Testing

The bench mounted Varian 640 spectrometer was used for the analysis. This instrument is a typical example of that used in a commercial laboratory for analysing used oil. A graph of wavenumbers and absorption for the oil sample is produced. A transmission cell with *Potassium bromide* (KBr) windows was used to contain the wet sample for analysis. The used oil is injected into the transmission cell and the cell is then mounted in the instrument. A graph of absorbance and wavenumber is produced by the instrument. When interpreting the graph, parameters such as soot, water and glycol and their concentrations can be determined using a simple calibration procedure.

The amount of absorbed light to a known concentration of each contaminant and a calibration curve supplied with the FTIR spectrometer is used. For soot, FTIR data is sometimes also reported as the amount of light transmitted rather than absorbed, typically around 2000 cm-1. A higher degree of soot loading results in a reduction in the amount of light transmitted, which is reflected in the FTIR data reported. A spectrum of a virgin oil sample and a used oil sample were attained during testing. A subtracted spectrum was then achieved by using the pro-resolution software with the instrument.

Traditionally, the subtracted spectrum would then be deciphered and maintenance actions would be selected. The subtracted spectrum is presented as a graph of wavenumbers against absorbance. Absorbance is a measure of the logarithmic ratio of the amount of radiation falling on a material to the amount of radiation transmitted through the material. Contaminants are identified by their specific wavenumbers. A difference spectrum of gear oil and its virgin oil is presented in Figure 1. This difference spectrums peak intensity wavenumbers are compared with the known wavenumbers of contaminants.

Portable Oil Analysis

A FluidScan Q1000 portable oil analyser as described in Table I was used for testing the used oils. The portable instrument analyses the oil in the same way as the bench mounted instrument, but the portable instrument uses mathematical algorithms to process the data from the graph of the analysis to produce quantitative results that be used to

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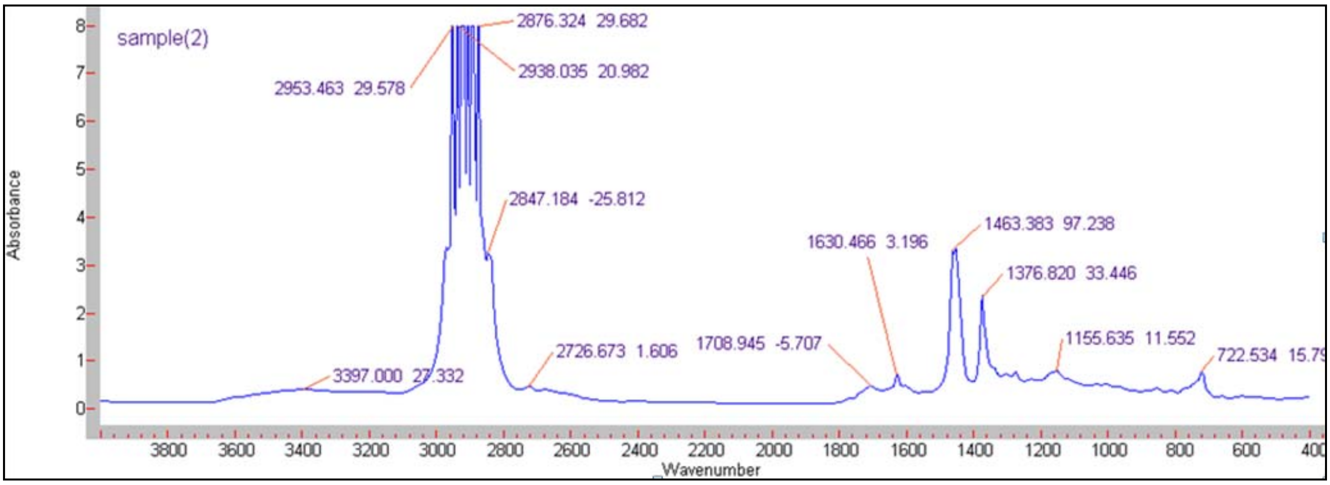

Fig. 1. Difference Spectrum of Used Oil and Virgin Oil from a gearbox.

identify any contaminants in the oil [13] [3]. The portable instrument delivers an instant fluid condition assessment based on ASTM Standard E2412 (Standard Practice for Condition Monitoring of In-Service Lubricants by Trend Analysis Using Fourier Transform Infrared (FTIR) Spectrometry). The results produced are in text format and this removes the skills of deciphering complex graphs of absorbance against wavenumbers that the bench mounted instruments produce.

The results of testing by both the bench mounted and portable instrument are presented in Chapter III.

B. Evaluation of Portable Instruments for Complete Analysis of Oil

While laboratory measurements of oils are mature and robust, there can be several delays involved in getting the oil sample to the laboratory. Often, plant, equipment and machines can be located in remote and harsh environments. Breakdowns and equipment failures can be very costly. Recent technological advancements have developed many portable on-site analytical instruments for monitoring the condition of lubrication substances. A complete analysis of these lubricating substances involves carrying out testing to measure chemical degradation, contamination, additive depletion, viscosity, ferrography and elemental analysis [14]. Table I lists current portable instruments on the market to measure these parameters. Furthermore, Table I describes the operating principles, benefits, limitations and applications of the instruments.

III. Results & Findings

The testing was carried out on gearboxes of numerous types of equipment. Eleven oil samples were tested in total. The type of oil being tested, in this case gear oil, is an input to the instrument.

The instrument only tests the sample for known parameters specific to gear oils such as oxidation, water contamination and TAN levels.

A percentage error of the upper warning limit (which will display a yellow warning light if exceeded) was calculated. All measured parameters for both instruments were below the upper warning limit and prompted a green indication light.

The green light signals the oil has useful remaining life and can be continued to be used. An example calculation for the percentage error of sample number nine is presented below using Equation 1.

$$\% \text{ Error} = \frac{\text{Lab Result} - \text{Portable Result}}{\text{Upper Warning Limit}} \text{ x } 100$$

$$\% \text{ Error} = \frac{5.3 - 4.5}{20} \text{ x } 100 = \mathbf{4\%} \qquad (1)$$

The results of testing the eleven gear oil samples for oxidation, water contamination and TAN levels by using the bench mounted and portable instrument are presented in Tables II, III and IV.

The samples tested for oxidation in Table II display an average percentage error of 4.36% when both instruments are compared and this shows that the portable instrument can achieve very accurate results when testing for oxidation. A result of 20 abs/mm^2 indicates that the oil is nearing the end of its useful life and a result of 30 abs/mm^2 would indicate the oil is no longer suitable for use.

As presented in Table III, an average percentage error of 13.32% is achieved for testing the 11 samples for water levels. This average percentage error is higher than that for testing for oxidation, however this value indicates the portable instrument is capable of producing useful results when testing used oil samples for water levels. All results obtained are below the upper warning limit and shows that the oil has useful remaining life.

A result of 400 ppm yields a warning that the oil is nearing its usefulness and a result of 600 ppm would indicate the oil is no longer fit for use.

The average percentage error is 16.7% when the samples were tested for TAN levels as shown in Table IV. This value is the highest of all 3 parameters tested and indicates the portable instrument isn't as sensitive to detecting TAN levels as the previous parameters. As like the previous parameters tested, this variance still warranted the same maintenance action as all results are below the upper warning limit and this value of 3 mgKOH/g would indicate the oil is nearing its useful life, a result of 4.5 mgKOH/g would signify that the oil has no further use.

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Table I Operating Principles, Benefits, Limitations and Applications of Modern Portable Instrumentation for Oil Analysis.

Analytical Instrument	Operating Principles	Benefits of Instrument	Limitations of Instrument	Application
Portable FluidScan oil analyser (Q1000) by *Spectro Scientific*	The FluidScan analyzes lubricants and fluids using infrared spectroscopy, a technique that measures chemical degradation, contamination and additive depletion.	• Light • Easy to use • Fast results • Accurate results • Has a split cell that only requires 60 microliters of oil for testing.	• The cost of the instrument is €17,000 (at the time of print) and can prove too costly for small to medium enterprises. • 4 hour battery life means a spare battery is required on-site for a full day's work.	• Gear boxes • Compressors • Hydraulic systems • Turbines • Transmissions • Diesel engines
Portable Kinematic Viscometer (Q3050) by *Spectro Scientific*	Measures oil viscosity at a controlled temperature (40C).	• Battery operated • Has a split cell that only requires 60 microliters of oil for testing. • Takes 2-3 minutes for test. • Accurate results • No solvents required for cleaning.	• The cost of the instrument is €10,606 (at the time of print) and can prove too costly for small to medium enterprises. • 6 hour battery life means a spare battery is required on-site for a full day's work.	• Marine vessels • Mining trucks • Pharmaceutical Industry • Manufacturing Industry • Production Industry
Portable fuel dilution meter (Q6000) by *Spectro Scientific*	Measures the concentration of fuel vapour in engine oils.	• Requires only 500 microliters of oil for testing. • Small and light • Portable and battery operated. • Easy to clean (no solvents required). • Fast testing (1-2 minutes) • Accurate results • Easy to use	• The cost of the instrument is €15,218 (at the time of print) and can prove too costly for small to medium enterprises.	• Mining Industry • Railway Industry • Marine Industry
Spectroil (Q100) by *Spectro Scientific*	Method for determination of wear metals in lubricating oils by rotating disc electrode atomic emission spectrometry.	• Detects wear • Conforms to ASTM Standards. • No sample preparation is required. • Analysis takes 30 seconds. • Transportable • Analyzes all elements simultaneously. • Easy to use.	• Requires power • The cost of the instrument is €71,939 (at the time of print) and can prove too costly for small to medium enterprises.	• Marine vessels • Mining trucks • Pharmaceutical Industry • Manufacturing Industry • Production Industry
Portable Laser Net fines (LNF Q210) by *Spectro Scientific*	A non-destructive technique to evaluate the size, shape, composition and concentration of wear metals in oil.	• Fast results • Counts all particles of 4-100 micrometre • Has error correction capabilities for water and air bubble	• Requires power • The cost of the instrument is €30,436 (at the time of print) and can prove too costly for small to medium enterprises.	• Process and manufacturing Industries • Mining Industry • Marine Industry • Aerospace Industry

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Table II Laboratory and Portable Instruments Comparison for Oxidation Levels.

Sample no.	Portable Instrument: Oxidation (abs/mm^2)	Laboratory Result: Oxidation (abs/mm^2)	Upper Warning Alarm Limit Number: Oxidation (abs/mm2)	% Error
1	4.5	4.5	20	0
2	3.7	2.8	20	4.5
3	4.2	2.2	20	10
4	3.6	2.8	20	4
5	7.3	6.6	20	3.5
6	4.2	3.3	20	4.5
7	4.7	3.6	20	5.5
8	8	7.3	20	3.5
9	5.3	4.5	20	4
10	4	3.4	20	3
11	3.6	2.5	20	5.5

Table III Laboratory and Portable Instruments Comparison for Water Levels.

Sample no.	Portable Instrument: Water (ppm)	Laboratory Result: Water (ppm)	Upper Warning Alarm Limit Number: Water (ppm)	% Error
1	151	239.4	400	22
2	113	91.7	400	5.3
3	216	120.8	400	23.8
4	93	118.9	400	6.5
5	79	126.5	400	11.9
6	115	116	400	0.2
7	116	107.9	400	2
8	105	110.8	400	1.4
9	125	46.6	400	19.6
10	150	42.5	400	26.9
11	120	12.1	400	27

Table IV Laboratory and Portable Instruments Comparison for TAN Levels.

Sample no.	Portable Instrument: TAN (mgKOH/g)	Laboratory Result: TAN (mgKOH/g)	Upper Warning Alarm Limit Number: TAN (mgKOH/g)	% Error
1	0.86	1.62	3	25.3
2	0.8	0.14	3	22.0
3	0.96	0.52	3	14.7
4	1.23	0.73	3	16.7
5	2.28	1.55	3	24.3
6	1.17	0.66	3	17.0
7	1.27	0.8	3	15.7
8	2.05	1.73	3	10.7
9	1.03	1.1	3	2.3
10	1.12	0.97	3	5.0
11	1	0.1	3	30.0

IV. Discussion

Traditional practices of sending oil samples to commercial laboratories can be slow and result in delayed maintenance actions. A complete on-site analysis of uses oils is now possible with the development of portable instrumentation for oil analysis as described in Table I. This practice can accelerate decision making within a maintenance department and increase plant availability which critically can yield increased profits. The testing carried out with the bench mounted instrument is slow, laborious and the graphs are difficult to decipher.

The testing of the oil sample with the FTIR portable instrument can take less than 3 minutes after becoming familiar with the instrument. This technique is non-destructive and allows for the storing of tested oils for future reference. Traditionally, used oil sample would be sent to a commercial laboratory for testing. This technique allows for real time analysis, providing fast maintenance decisions. Time and cost are saved as there is no waiting for the results of the testing of the used oils from a laboratory.

The average percentage error varied with every sample tested. The results show that the portable instrument can produce results with great accuracy when testing for oxidation.

The results for testing for water levels indicate the portable instrument can produce accurate results, when testing for TAN levels the highest average percentage error of 16.7% resulted, indicating the portable instrument isn't as sensitive to detecting TAN levels as oxidation and water levels. However, results for all samples tested yield the same maintenance action as all measured parameters were below the upper warning limit. Hence, the oil has useful remaining life and the practice of analysing used oil with a portable FTIR analyser produces accurate and useful results.

The results of the samples tested represent 11 individual gearboxes. Numerous samples from an individual gearbox over time can identify parameters deteriorating. Access to industry was also difficult and only individual samples were available.

V. Conclusion

It is clear from the research that manufactures of analytical instrumentation have provided the markets with a range of portable instruments for a complete on-site oil analysis program to be developed within a maintenance program. There are many benefits of performing this analysis on-site. However, traditionally this analysis is performed by highly skilled and knowledgeable scientists. The portability of these instruments results in maintenance personnel conducting the analysis. Further work is required to investigate if maintenance personnel have the training, skills and knowledge to effectively use such portable instrumentation.

The decreasing cost of such portable equipment means that the analytical technique is now within the grasps of most organisations. Benefits that may accrue include

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quicker decision making and associated economic cost saving benefits.

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