A Framework for Identifying Maintenance Actions for Lubrication Analysis

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ABSTRACT

Increasing industrial competitiveness creates a necessity for new practices to elevate a company's position. Many changes in industrial and manufacturing systems are taking place due to the rapid evolution of technology, such as, flexible manufacturing systems and robotics. Industry is concerned with establishing new practices for competiveness in terms of service, cost, quality and on-time delivery. There are increasing pressures on industry to protect such asset. Proactive maintenance techniques can provide a metric for protecting such assets while sustaining competiveness.

Recent technological advancements have produced cutting-edge analytical instrumentation to monitor such complex systems in industry. These analytical instruments have become robust and portable allowing real-time on-site condition monitoring. Quick maintenance decisions from such instrumentation can help avoid premature replacement costs, maintain production time while increasing plant availability and reliability.

This study is concerned with one such portable analytical instrument, namely a Fourier Transform Infrared (FTIR) oil analyzer and its use for maintenance application. This maintenance technique analyses used oil from machines and equipment. Oil analysis by 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.

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However, experiments performed during this research indicate that the testing of used oils by FTIR portable instrumentation produces complex results in very scientific terms that prove difficult for maintenance personnel to use effectively. The purpose of this study was to develop a means for overcoming this difficulty.

Various oils were analysed and a framework was developed to help maintenance technicians identify maintenance actions when an abnormality is detected. The framework was formulated through extensive primary and secondary research methods. The framework also details the effects of continuous use for contaminated oil. This information can be a major advantage for maintenance decision making of high demand assets.

1 INTRODUCTION

World-wide competition has compelled companies to continuously improve their operations in an ever increasing manner. Therefore, it is imperative that such companies implement the necessary structures to complement their continuous improvement cycles. Maintenance management offers a rich avenue for product quality and service improvement if correctly optimized [1]. Maintenance activities directly affect a company's output and profit margins and must be considered at all times when seeking process improvement [2].

Maintenance can be defined as the process of preserving the condition of assets to a minimum operating benchmark [3]. An effective maintenance program can increase production and deliver high quality products. *Al-Najjar* has postulated that such efficiencies may result in increased profits for the enterprises involved [4]. Organisations accrue many benefits by adapting a type of maintenance, namely, predictive maintenance. There are many methods deployed within a predictive maintenance program, such as; vibration monitoring, oil analysis, thermography, ultrasonic testing and visual inspections [5]. Oil analysis is an essential part of a predictive maintenance program. Oil analysis can reduce maintenance costs by monitoring the condition of systems to avoid catastrophic failures [6]. Therefore, oil analysis is a necessary predictive maintenance technique for organisations to reduce costs and to remain competitive [7]. *Newell* describes that oil analysis is widely used in industry and maintenance costs can be reduced by up to 30% by implementing an oil analysis program [8].

Technological advancement in maintenance analytical instruments has developed exponentially in recent times. The deployment of *intelligent electronic instrumentation devices* has provided a tool to both observe and manage any maintenance operation [7]. The aim of this research is to establish a framework for maintenance technicians to aid in identifying maintenance actions of oil analysis results from a *Fourier Transform Infrared* (FTIR) oil analser.

The use of FTIR Spectroscopy in itself is not new, but the miniaturization of the equipment has led to a portable handheld device, which has found its way from traditional oil-analysis laboratories into the hands of maintenance fitters/engineers. There is very little published literature in a maintenance context regarding how portable FTIR oil analysis can benefit a maintenance program. This research is concerned with analyzing used oils from industry using FTIR spectroscopy to identify maintenance actions within a maintenance program.

There are many oils used in industry and for this research, a case study has been carried on three types of oils, namely, hydraulic, gear, and turbine oil. These oils were chosen as they are commonly used in machines and equipment. The analysis of these oils can help illustrate some limitations that exist within maintenance programs. There are different parameters measured in different oils. This is due to the fact that the make-up of the oils differs and the instrument only measures for the parameters that exist in the oil. The parameters that were measured for the three oils examined during this research are:

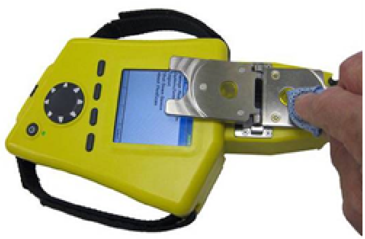
- *Oxidation* (abs/mm^2) occurs when the oil is exposed to oxygen at high temperatures [9].
- *Antioxidant depletion* (%) is measured by the percentage of additive remaining in the oil compared to the full amount that was measured in the virgin oil [10].
- *Water* (ppm) found in oil is identified by parts per million [11].
- *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 [12] [13].

Oil samples were provided from a Bauxite processing facility in Limerick, Ireland and a maintenance repair facility that overhauls large jet-transport aircrafts in Shannon, Co. Clare. These industries provide a broad range of maintenance activities in the industrial sector; they are continuously growing and are an integral part of the world’s economy. The world economic outlook published by the International Monetary Fund in 2015 projects a growth of 3.5% for the manufacturing industry, 3.3% in the automotive industry and 4.8% in the aviation industry for 2016 [14]. Ireland provides an interesting *locus* for the research because of its diverse manufacturing activities and its exposure to new technologies from foreign direct-investment organisations.

2 METHODOLOGY

Oil samples collected from industry were tested in a controlled environment using a portable FTIR oil analyser.

There are many different types of FTIR oil analysers available for maintenance application. The portable oil analysis instrument used in this study was a “Spectro FluidScan Q1000” analyser and conforms to industrial standards for correct use and is based on the ASTM standard “E 2412”, titled “Standard Practice for Condition Monitoring of Used Lubricants by Trend Analysis Using Fourier Transform Infrared (FTIR) Spectrometry”. This instrument as presented in Figure 1 was selected for use as it was the only one available to the researcher.



Specifications

Power: 4 hours rechargeable Li-Ion battery
Size: 17 x 14 x 9 cm
Weight: 1.6 Kg
Connectivity: Has USB port to connect to a PC
Storage: Comes with a protective carry case
Recording: 5,000 measurements of oil samples can be stored
Features: 4 soft buttons and a directional pad are featured on the instrument to navigate through performing analysis

Fig. 1 Spectro FluidScan Q1000 Oil Analyser

Each Lubricant tested has pre-defined alarm limits set in the portable instrument that were attained from the lubricants technical specifications and are tested in accordance to ASTM test methods. These pre-defined alarm limits consist of a warning alarm limit and a maximum limit. The parameter is highlighted in yellow if it has exceeded the warning alarm limit and indicates the oil is nearing the end of its useful life. The parameter is highlighted in red and indicates the oil has exceeded its useful life when a particular parameter exceeds the maximum limit. When the parameter is highlighted in red from the results of the analysis, the oil must be replaced. Equipment will eventually fail if it is continued to be used without the oil being replaced. This practice can lead to expensive maintenance correction and long periods of downtime. A Standard Operating Procedure (SOP) was followed for the testing of the oils.

The instrument uses an infrared spectrometer that mathematically converts raw data obtained during testing into meaningful terms [15]. An infrared spectrum is obtained when an infrared light is passed through a sample of oil and a measure of the transmission of the light is obtained. Different molecules of different substances in the oil absorb the infrared light at distinct frequencies [10]. The results from the testing are conveyed in complex and very scientific terms that are difficult for maintenance technicians to effectively use. These results were recorded and a framework was then created to aid maintenance technicians in identifying maintenance actions.

The potential causes and effects of exceeded parameters were gathered form both primary and secondary research methods. Expert, machinery lubricant analysts in commercial laboratories were consulted during the research and information was provided on how to use the results obtained from FTIR analysis for a maintenance program. The researcher also obtained knowledge for the development of the framework during the training attended to become a certified machinery lubricant analyst. Furthermore, the research conducted during the literature review helped towards the development of the framework.

3 TESTING & RESULTS

Gear oils, hydraulic oils and turbine oils from industry were tested using the portable instrument. The pre-defined alarm limits and an oil analysis result for one such gear oil, hydraulic oil and turbine oil are presented in Tables 1, 2 and 3.

Table 1 Pre-defined alarm limits and the oil analysis result for Gear oil

	Parameters		
	Water (ppm)	Antioxidant Depletion (% remaining)	TAN (mgKOH/g)
Lower limit	45	0	0
Lower warn limit	55	0	0
Upper warn limit	0	1.5	1000
Upper limit	0	2	1500
Actual result	**1222**	**80**	**0**

Table 2 Pre-defined alarm limits and the oil analysis result for Hydraulic oil

	Parameters		
	Oxidation (abs/mm^2)	TAN (mgKOH/g)	Water (ppm)
Lower limit	0	0	0
Lower warn limit	0	0	0
Upper warn limit	20	3	400
Upper limit	30	4.5	600
Actual result	**3.6**	**4.7**	**120**

Table 3 Pre-defined alarm limits and the oil analysis result for Turbine oil

	Parameters		
	Water (ppm)	Antioxidant Depletion (% remaining)	TAN (mgKOH/g)
Lower limit	0	45	0
Lower warn limit	0	55	0
Upper warn limit	1000	0	1.5
Upper limit	1500	0	2
Actual result	**983**	**76**	**2.2**

Each parameter that was measured during the testing and the oil type was considered for the development of the framework to aid maintenance technicians to identify definite maintenance actions. The framework also details the effects of not changing the oil after a parameter has exceeded its upper limit and hence will display a red light. A yellow warning light indicates the oil is nearing the end of its useful life and should be considered for replacement. A red light indicates the lubricating oil is no longer fit for purpose and requires immediate replacement. The gear oil tested has an abnormality detected for the measured parameter of water. Both the measured parameters antioxidant depletion and TAN were satisfactory. The hydraulic oil tested showed that both the water and antioxidant depletion levels are acceptable; however the oil is unfit for use as the TAN levels have exceeded the predefined upper limit. This oil requires replacement. The turbine oil displays acceptable results for both water and antioxidant depletion but has exceeded the predefined upper limit for TAN levels and therefore, continuous of this oil will cause failures.

The maintenance actions and effects for these and all exceeded parameters in gear, hydraulic and turbine oil are presented in Tables 4, 5 and 6.

Table 4 Maintenance Actions and Effects for Exceeded Parameters in Gear Oils

Measured Parameter	Maintenance Actions for Exceeded Parameters	Effects for Exceeded Parameters
Oxidation (abs/mm^2)	Check for an increase in temperature in the system. Check for an increase in pressure in the system. Check for increase in contaminants in the oil that leads to agitation. Check for dirt in the system. Check for pipe coatings such as paint in the system.	Formation of varnish. Chemical change to the base oil reduces the effectiveness of the oil. Increased corrosion. Viscosity of the oil increases from the varnish and this increases the pressure in the pumps in the system.
Water (ppm)	Check all seals and gaskets for leaks. Check all plugs at oil drain port and oil fill port. Check for blockages around the gearbox that may hold water and lead to an increase in condensation.	Shorter component life due to corrosion. Etching on components from cavitation. Wear caused by loss of viscosity. Increased corrosion and this leads to rust particles acting as abrasives. High operating temperature. High levels of wear metals.
Total Acid Number (TAN) (mg KOH/g)	Check the system for corrosion. Check the system for wear. Check the gear oil for an increase in viscosity. Check the system for overheating.	Increased wear. Increased viscosity. Metal corrosion. Increased oxidation. Overheating.

Table 5 Maintenance Actions and Effects for Exceeded Parameters in Hydraulic Oils

Measured Parameter	Maintenance Actions for Exceeded Parameters	Effects for Exceeded Parameters
Oxidation (abs/mm²)	Check for an increase in temperature in the system. Check for an increase in pressure in the system. Check for increase in contaminants in the oil that leads to agitation. Check for dirt in the system. Check for pipe coatings such as paint in the system.	Formation of varnish. Chemical change to the base oil reduces the effectiveness of the oil. Increased corrosion. Viscosity of the oil increases from the varnish and this increases the pressure in the pumps in the system. Clogging of orifices and valves.
Water (ppm)	Check for rain leakages in external reservoirs. Check reservoir covers for seepage. Check access panels. Check for condensation from the air in the reservoir and in other system areas. Check for leaks in heat exchangers and coolers.	Shorter component life due to corrosion. Etching on components from cavitation. Wear caused by loss of viscosity. Increased corrosion and this leads to rust particles acting as abrasives. High operating temperature. High levels of wear metals. Power loss. Bearing corrosion.
Total Acid Number (TAN) (mg KOH/g)	Check the system for corrosion. Check the system for wear. Check the hydraulic fluid for an increase in viscosity.	Increased wear. Increased viscosity. Metal corrosion. Increased oxidation. Overheating. Oil thickening. Additive depletion.

Table 6 Maintenance Actions and Effects for Exceeded Parameters in Turbine Oils

Measured Parameter	Maintenance Actions for Exceeded Parameters	Effects for Exceeded Parameters
Antioxidant additive (%)	Check for increased wear as the deposit oxidise and cause the antioxidant additive to deplete. Check for an increase in operating temperature. Check for leaks in the system.	Formation of varnish. Chemical change to the base oil reduces the effectiveness of the oil. Increased corrosion. Viscosity of the oil increases from the varnish and this increases the pressure in the pumps in the system. Clogging of orifices and valves.
Water (ppm)	Check the turbine for sludge and varnish build up. Check all bearing seals for damage. Check the turbine wear that may permit water into the system. Check for atmospheric condensation. Check for leaking oil coolers. Check vapour extractor is working.	Shorter component life due to corrosion. Etching on components from cavitation. Wear caused by loss of viscosity. Increased corrosion and this leads to rust particles acting as abrasives. High operating temperature. High levels of wear metals. Bearing corrosion.
Total Acid Number (TAN) (mg KOH/g)	Check the system for corrosion. Check the system for wear. Check the oil for an increase in viscosity. Check the correct oil was used.	Increased wear. Increased viscosity. Metal corrosion. Increased oxidation. Overheating. Oil thickening. Additive depletion.

4 DISCUSSION & CONCLUSION

The results of testing the oils as set out in section 3 show that there are abnormalities present in each oil sample. The traffic light coding system can easily depict if the oil is nearing the end of its useful life or if it is no longer fit for use. However, these results do not provide any meaningful information with regards to the causes of these abnormalities, what maintenance actions can be carried out to rectify these abnormalities or what are the effects of using the degraded oil.

The abnormality identified in Table 1 shows that there are exceeded levels of water in the oil. The framework outlines in Table 4 that there may be a gasket leaking, there could be a blockage in the gearbox or an issue with oil fill ports. The oil is nearing the end of its useful life and continuous use after this may cause wear and corrosion as detailed in Table 4. The red light signal in the hydraulic oil presented in Table 2 displays that the TAN parameter has exceeded its upper limit. Table 5 describes the maintenance checks that can be carried out to establish the cause for this abnormality, such as to check the system for wear or corrosion. Continued use of this oil can lead to increased oxidation and overheating as set out in Table 5. The TAN levels are also exceeded in the turbine oil tested as set out in Table 3, a maintenance action that can be performed to find out how this parameter has been exceeded is to check the correct grade of oil was used in the system, these maintenance actions are described in Table 6. Continuous use of this oil can lead to the oil thickening and increased wear and this information can be obtained from Table 6.

The portability of analytical instrumentation for oil application provides an opportunity for real time analysis to provide quick maintenance decisions. The instrument used for this study produces complex results that are difficult for maintenance technicians to use effectively. The framework developed in section 3 can help maintenance technicians overcome these difficulties. The framework can also enhance a maintenance program by providing maintenance actions for the abnormalities detected. The framework can also help protect high value assets and high demand assets by providing information of the effects of continuous use of degraded oil.

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