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Determination of Wear Metals Debris Concentration in Aircraft Engines

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Abstract: The presence of debris of metals in the lubricating oil provides important information about the conditioning monitoring of machines. Commonly used method involves use of spectroscopic methods. The sample characteristics was analyzed using two samples of lubricating oils that were categorized A1 and A2. The dry ash method was adopted for the preparation of samples of oil and concentrated H2SO4 in a ratio 1: l, followed by dissolution in a 2 Molar HNO3 acid. These samples were separately subjected to absorption spectroscopy based on atomic analysis and infrared spectroscopy based on Fourier analysis. The concentrations of the wear metals debris were determined along with their corresponding wavelengths. The metals determined includes iron (Fe), Lead (Pb), Manganese (Mn), Zinc(Zn), Copper(Cu), Cadmium(Cd), and Chromium(Cr). The information about thesemetal concentration is an important factor for monitoring and maintenance of aircraft engines and can help in quantitatively recovery of these metals, hence solving environmental problems to some extent.

Index Terms: Tribology, Wear, Lubrication, Spectroscopy, Atomic Absorption

I. INTRODUCTION

Analysis of contents of Lubricating oil is an important aspect to monitor the conditions of various locomotives. Works of Denver and Rio Grande Railroads and United States Bureau of Naval Weapons provided important information about failure prediction in aircraft parts. The analysis of a sample of oil taken from a running machine or its component is similar to testing of a blood sample from the human body. The result determines the health status of the unit. Vehicles and machineries need lubricants especially lubricating oils for proper functioning of the engine parts and reduction in its wear [1]. The newly manufactured vehicles and machines of various categories also need lubricating oils.

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A lubricant can be described as a liquid introduced between two surfaces to reduce friction thereby leading to decrease in wear [2]. More than 50 million tons of lubricants are consumed annually and 30 percent of lubricants by volume of hydraulic and transmission fluids are consumed [2]. In lubricants contribute up to about 25% of total pollutants released into the environment [2]. Their constituents include up to 90% of base oil along with 10% additives.

Lubricating oils obtained from petroleum fractions have paraffinic, naphthenic, and small amount of aromatic hydro carbons, while metallo-organic compounds are usually added as additives [1]. Additives help to reduce friction and wear, increasing the viscosity, providing resistance to corrosion and aging of engine parts. Additives also serve as automotive grease to stabilize the grease against high temperatures. Grease is used tom park wheel bearings and disc braking system where much heat is generated. It was noted that the effectiveness of lubricating oil contributes to the life span of an engine [3]. Thus, lubricating oil functions by preventing friction between sliding or rolling engine parts, protection of surfaces from corrosion, transportation of wear metal particles and contaminants as well as transfer of heat through the engine parts. Constituents in the lubricating oils may be classified into three categories, namely wear metals, contaminants and additive elements [4]. The wear metals may be present as metallic particles rather than dissolve metals. The particles usually less than 1nm as well as the dissolved metal concentration of individual wear metals in oil vary from one element to another and are dependent on engine type, age of oil and efficiency of oil filters.

Aucelio studied the analysis of wear metals in engines and turbine components and found that the element the extent of wear is reduce by using lubricating oils [1]. He reported that the wear could be physical generating metallic particles as well as soluble metallic debris passes through the filters and collection into the engine parts and causes more wear.

Hong et. al[5] presented a review of various detection methods principles like spectrograph, ferro graph, optical method, inductive method, resistive-capacitive method, and acoustic method.

Zhu et. al [6] studied a portable wear debris sensor with ferrite cores for online monitoring. Wang et. al [7] presented a model of the cylindrical capacitive sensor to analyze the optimal parameters.

Vahaoja studied the possibility of using the quick kerosene dilution method together with FAAS for a rapid check for certain indicator metals [8].

Since used lubricating oils might contain metallic particle sizes as well as various concentration of dissolved metals, total wear metal concentration of oils could be carried out by various lab tests.
Various components of a mechanical system move against each other. The friction causes wear resulting in tiny metal particles separating from the contact surfaces and remain suspended in the oil. The lubricant used is now collected and taken to the laboratory for test analysis.
Any abnormal higher rate of increase in metal wear can be a symptom of malfunctioning of equipment. Increase in the concentrations of some key elements in the lubricating oil may indicate the extent of the wear. An abrupt increase of Nickel (Ni), Tin(Sn) or Chromium(Cr) indicates corrosion in parts like bearings, valves and pistons. Iron(Fe) concentrations indicates corrosion in various parts, whereas Sodium(Na) contents indicates oil contamination with anti-freeze fluids. Besides bringing economic benefits, such diagnoses save lives [9-12]. Of the many test that an oil sample can be subjected to, perhaps the most known is the spectrometric analysis. There are varieties of instruments that can carry out this test but for the scope of present study, Atomic absorption spectroscopy (AAS) was used [1].
The purpose of the test is to measure the concentration of wear metals. The parameters are determined by the concentration of various elements from the periodic table. The objective of this study is to determine the concentration of wear metals in the aircraft engine oil in order to make necessary adjustments to prolong the life span of the engines by analyzing the engine oil samples from a passenger and a training aircraft. Determining the wear metals in lubricating oil is of vital importance to the operator and owners of aircraft as a component of aircraft maintenance managements aimed at improving engine efficiency, reducing maintenance costs and helping to ensure the safe operation of the aircraft.

II. MATERIALS AND METHODS

2.1 Materials

Samples of lubricating oil were collected from two aircrafts. represented by A1 and A2. One of these aircraft was a passenger aircraft, while the other was a training aircraft.

2.2 Methods

The ash method of metal analysis was adopted for sake of analysis. A known weight of the two lubricating oil sample was separately mixed with concentrated H2SO4 acid in the ratio 1:1 and heated gently on a hot plate to dryness in an evaporating dish. It was carefully transferred into a galen lamp furnace and ash at 550 degrees Celsius for 1 hour. Each of the ash samples was then diluted in a little quantity of 2M HNO3 acid and made up to 50ml mark in a standard volumetric flask. Each of the prepared samples was then subjected to analysis for alkali and alkaline earth metals using atomic spectroscopy and Fourier transform infrared spectroscopy. The designated heavy metals and other critical wear metals was then analyzed using atomic absorption spectroscopy and Fourier transform infrared spectroscopy with the aid of fuel rich air acetylene flame at their individual wavelength.

2.3 Instrumentation.

2.3.1 Atomic Absorption Spectroscopy (AAS)

Atomic absorption spectroscopy (AAS) is a Spectro-analytical procedure used for the quantitative determination of chemical elements using the absorption of optical radiation (light) by free atoms in the gaseous state. This wavelength of energy absorbed is dependent on the concentration of particular element present in the lubrication oil.

2.3.2 Fourier Transform Infrared Spectroscopy

This is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. An FTIR spectrometer simultaneously collects high spectral resolution data over a wide spectral range. An infrared spectrometer works by passing an infrared beam through a fixed thickness of oil, usually 100µm.
Next the beam enters the interferometer where it is encoded using a series of stationary and movable mirrors. The beam then enters the sample and certain frequencies of the energy are absorbed. The residual energy is sent to the detector where it is measured. This measured signal is then sent to a computer where Fourier transformation takes place.

III. RESULTS AND DISCUSSION

3.1 Results

This chapter shows the result of the test ran on the samples.
The table 1 shows the different wear metal concentration of each element tested in each of the test samples.
The calibration curve of each element is given in Figures 1 – Figure7;
Now from the spectrum obtained from FTIR analysis the following observations were deduced:
1. Both test samples have a C-H functional group.
2. No C=O stretch was present. No strong peak around 1700c/m.
3. There are no picks above 3000c/m, the functional group O-H is not present.
4. The clustered peaks in the region of 1000c/m to 1500c/m show the presence of primary and secondary amines which has a functional group of N-H.

4.2 Discussion

The concentration of the 7 wear metals is given in Table 1 and their individual calibration curve is also given. The concentration of Mn in A1 is found to be less than that of A2. The high concentration of Mn in A2 oil sample makes it better than that of A1 because it’s more viscous by virtue of high concentration of Mn and thus prevents wear or corrosion. From Table 1 the presence of wear heavy metals in both oil type, though in varying proportion are observed. A higher value of Pb was obtained from A1 and a higher value of Cr was obtained from A2, this result shows that both engine of the aircraft has experienced critical wear in bearings, piston, and cylinder liners. For this reason the engine of both aircraft needs to be dismantled and the bearings, and liners replaced. The value of the wear metal Fe in A1 is found to be higher than that A2 which indicates that ball bearing, cylinder liners, gears wear a lot more in A1 than A2. Zinc is not a wear a wear metal, it is found in the oil as anti-wear additive used to reduce wear and corrosion

5.1 Conclusions

The presence of the wear metals not used as additives e.g. Fe, Pb, Cr, Cu and Cd indicates wear in the bearing, cylinder liners and gears (Figure 8).

The presence of Zn and Mn shows that they were used as additives in the oil to enhance the oil properties, like its resistance to wear and corrosion. The data obtain from the FTIR shows that there are traces of soot and nitrates in the oil which indicates incomplete combustion of fuel.

5.2 Recommendation

The engine of both aircrafts should be dismantled and the bearings, cylinder liners and gears changed to maintain the efficient functioning of the aircraft. The higher concentrations of lead (Pb) and chromium (Cr) are injurious for health. Higher soot can be avoided by providing correct fuel-air ratio in the combustion chamber of engines.

List of Tables

Table 1: Wear metals concentrations (ppm)

Lubricant oil sample	Wear metals concentration (ppm)						
	Fe	Pb	Mn	Cu	Zn	Cr	Cd
A1	0.1914	0.1032	0.0101	0.0009	0.002	0.117	0.0176
A2	0.1777	0.1011	0.0132	0.0012	0.0086	0.453	0.0008

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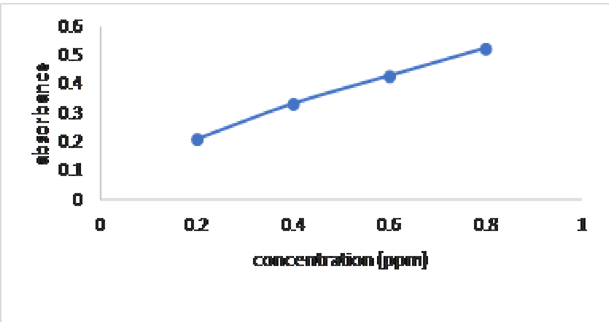

Figure 1: Calibration curve for Manganese (Mn)279.5 nm

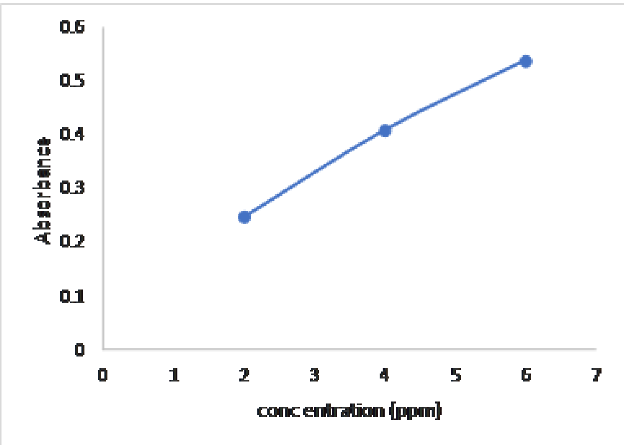

Figure 2: Calibration curve for Lead (Pb) 283.3 nm

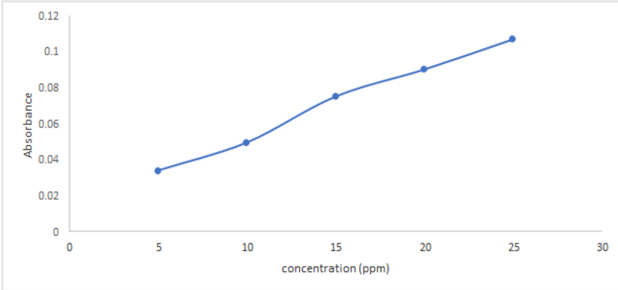

Figure 3: Calibration curve for Iron (Fe) 248.3 nm

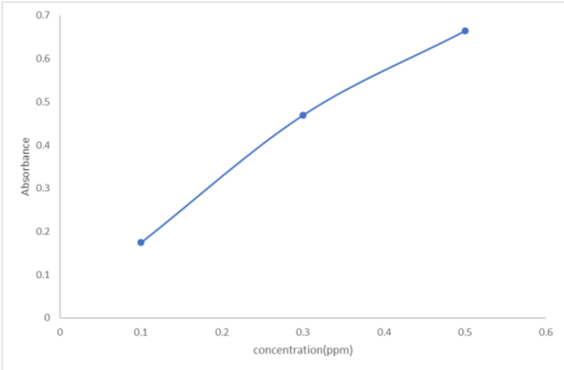

Figure 4: Calibration curve for Zinc (Zn) 213.9 nm

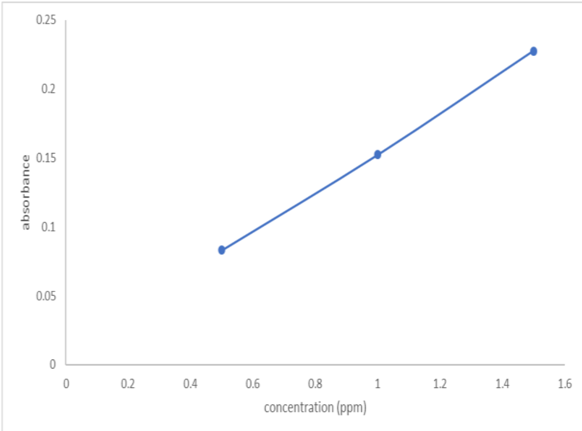

Figure 5 : Calibration curve for chromium (Cr)357.9 nm

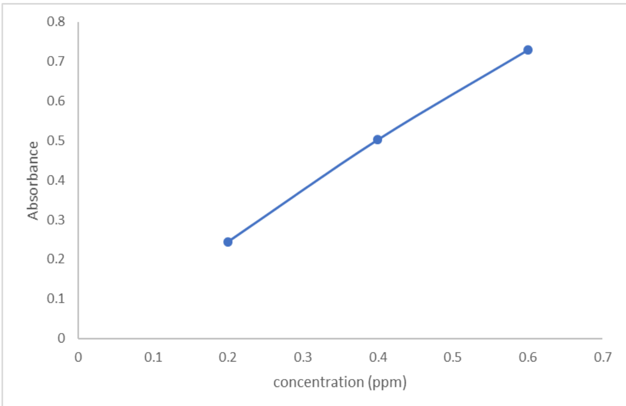

Figure 6: Calibration curve for copper (Cu)324.8 nm

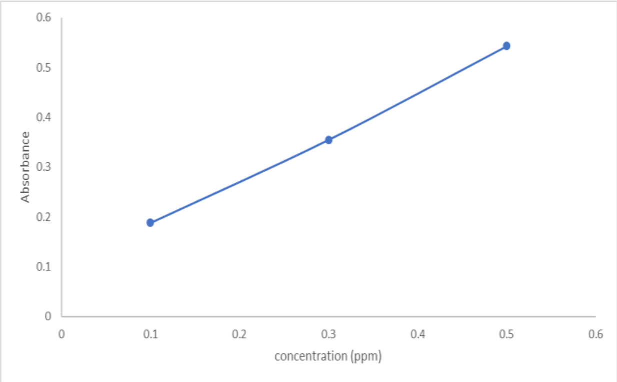

Figure 7: Calibration curve for cadmium (Cd) 228.8nm

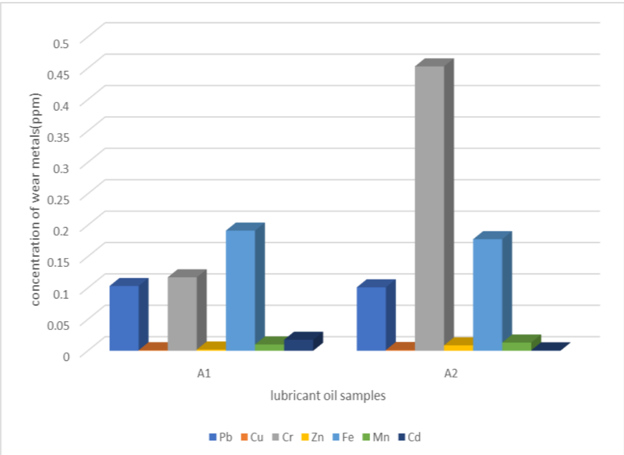

Figure 8: Distributions of the wear metals in both the test samples

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