Spectrometric Oil Analysis – An Untapped Resource for Condition Monitoring

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Abstract

Lubrication monitoring is often underrated among the techniques that constitute condition monitoring. Chemical analysis which is usually based on spectrometric analysis to examine the elemental content of the lubricating oil has often provided good revelations about the health of the machine. In third world economies like Nigeria, where availability of expensive vibration monitoring and performance monitoring equipment constitute great hindrance to good maintenance planning and execution, exploitation of the available spectrometric analysis facilities in the higher institutions of learning, research institutions and industrial laboratories promises a lot of rewards as shown in the various cases reviewed.

***Keywords**: Lubrication monitoring, condition monitoring, health, maintenance, spectrometric analysis.*

Introduction

James (1992) has defined condition monitoring as a maintenance philosophy that involves periodic measurement of the mechanical and process parameters that concerns a machine in order to gain a relative indication of the mechanical state of the machine. The biggest use of condition monitoring is in confirming that the equipment is in good health. A machine in good health refers to a machine with a good level of availability and reliability; this translates to good and continuous financial returns.

Condition monitoring in machineries usually centers on the following fundamental areas:

i. Performance monitoring
ii. Vibration monitoring
iii. Lubrication monitoring
iv. Visual monitoring, and
v. Non – destructive techniques

Lubrication Monitoring

The lubricating oil circulating round within an operating engine or machine is similar to the blood circulating within the living human body. Just as samples of the blood can be extracted and examined in a quest to identify the health state of the blood owner, samples of lubricating oil circulating round within a machine can also be indicative of the health of the machine.

According to Hunt (1997), the advantage of monitoring a fluid (lubricant) is that the fluid is highly likely to carry the evidence of faults from a variety of positions within the machine to some point where a monitor can be fitted.

Lubrication monitoring is a veritable tool for the establishment of the wear rate and level in the machine. The laboratory or chemical analysis of the lubricating oil that has been used in the machine is also useful in establishing the particular member undergoing wear; this is achieved through the monitoring of the concentration of elements in the used oil.

Lubricating Oil Contamination

Lubricating oil usually gets contaminated by carbonaceous particles from incomplete combustion of the fuel, unburned fuel, solid and dust particles, wear debris, free water molecules and other chemical substances that causes or inhibits oxidation.

Oxidation of the lubricating oil may be indicated by an increase in its viscosity, although increase in viscosity is also caused by the presence of suspended oil-insolubles. Decrease in viscosity of the oil may indicate a situation of fuel dilution.

Water within the oil can be responsible for the initiation of failure, and is usually difficult to detect quickly or remove. Once the water content in the oil has exceeded the saturation point of the oil, free water molecules starts to exist, this free water is responsible for most oxidation of components and the formation of emulsion that increase friction while altering the lubrication properties of the oil.

In the course of lubrication monitoring, wear monitoring is also done indirectly. By monitoring the quantity, sizes and shapes of the wear particles or contaminants, it is possible to tell what component is deteriorating as well as, its rate or level of deterioration without dismantling the machine.

The concentration levels of the metallic contaminants may vary widely depending on their origin, that is, whether they are major or minor alloying constituents of the wearing component, the type and operating characteristics of the component and machine, and the nature of present incipient defects.

The limit for the concentration level of a particular contaminant is not a thing that could be easily set based on just simple rational specifications. The decision to take a machine out of service as a consequence of a particular high concentration level must be based on the diagnosis of the source, the concentration trend and the relevance of the deterioration source to the overall reliability of the system.

The following three methods are commonly used for contaminant analysis in the lubricating oil:

i. Magnetic plug inspection
ii. Ferrographic oil analysis system (FOAS or Ferrograghy), and
iii. Spectrometric oil analysis procedure

While magnetic plug inspection and ferrographic oil analysis system are both effective, they are inferior to the spectrometric oil analysis procedure in that they are limited to detecting ferro-based wear elements alone.

Spectrometric Oil Analysis Procedure

Spectrometric analysis methods are based on the principles of atomic physics whereby an atom emits or absorbs light of a certain wavelength within the ultraviolet and visible region of the energy spectrum when there is an upset in the energy balance within its atomic structure.

Spectrometric oil analysis procedure based maintenance is implemented through the following steps:

i. oil sampling
ii. spectrometric analysis
iii. diagnosis – data analysis, and
iv. validation of the diagnosis

Spectrometric analysis method for oil samples is used to determine the quantity and level of the dissolved and atomized wear contaminants (especially metals) in the lubricating oil by these two broad methods:

i. Emission spectrometry
ii. Atomic absorption spectrometry

Figure 1 is a schematic diagram to illustrate emission spectrometry procedure. The system consist of a narrow slit, a grating or a prism (to separate the component wavelength as it passes through the slit), photoelectric system to detect and measure the spectra radiation, data processing electronic components and a print-out system.

The prepared sample will have been “digested” before being subjected to a direct high voltage excitation of about 15kV to cause the metallic impurities in the oil samples to emit their characteristic radiation that can be spectrally analyzed.

The operation of the atomic absorption spectrometry which is shown schematically in Fig. 2 is somewhat similar to that of the emission spectrometry. Their basic difference lies in the fact that instead of subjecting the sample to direct high-voltage as in emission spectrometry, oxy-acetylene flame is used to atomize the metallic elements in the atomic absorption spectrometry method. The wave-length of the light absorbed by the elements

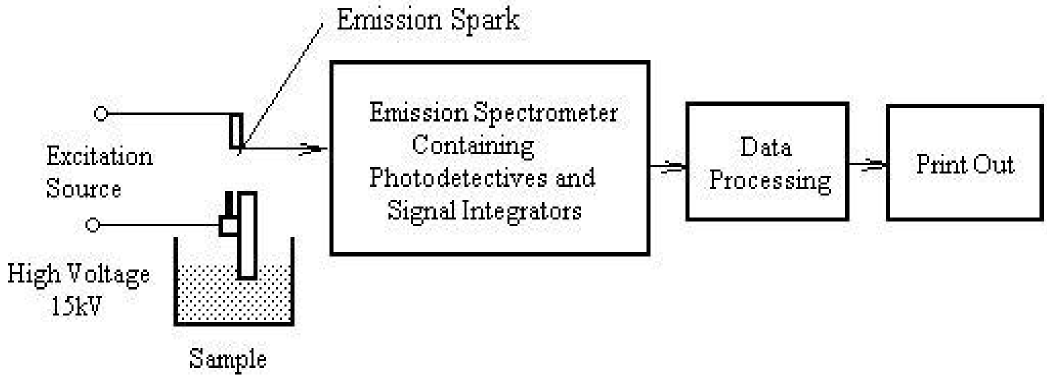

Fig. 1. Schematic illustration of the emission spectrometric analysis.

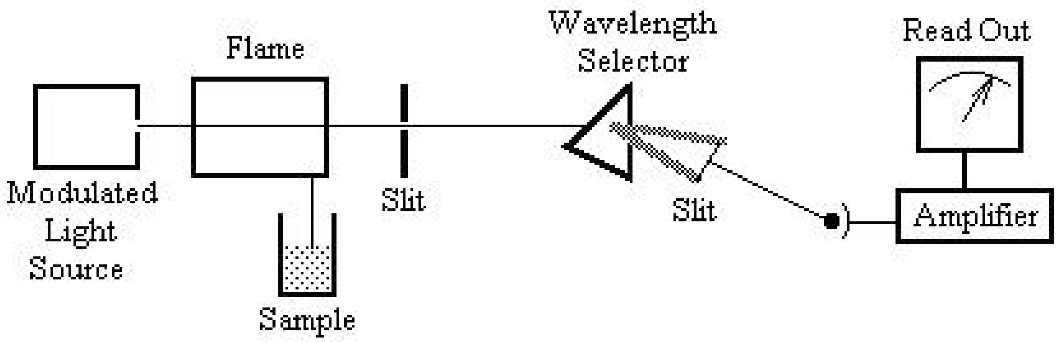

Fig. 2. Schematic illustration of the atomic absorption spectrometric analysis.

in the sample is detected and measured by the spectrometer. Spectrometric analyzers are surprisingly more available in Nigeria than we think, many chemistry and geology departmental laboratories in the Universities and Polytechnics has these machines as well as, various metallurgical, chemical and mineral exploration based research institutes located all around the country. Some private firms like Tractor and Equipment Nigerian limited has established Fluid Analysis Laboratory (Fluids Analysis Technology and Marketing, Port-Harcourt) where they carry out all their lubricating oil analysis for their various commercial maintenance operations and services.

Spectrometric analysis of the oil for elemental content is a way of determining the particular component of the machine that is degrading and at what rate. This is possible when the alloying compositions of the components are known, for example, Czarnecki *et al.* (1991) listed the alloy components of a particular aero-engine component as follows: Mo-5, V-2, Cr-4, Mn-0.01, Fe-83, Ni-0.01, W-6 and others 0.01. Hunt (1997) and Hipkin and Heimann (1978) has suggested the following element and related component sources shown in Tables 1 and 2 for wear debris monitoring.

Materials and Procedure

Materials

The materials, reagents and equipment needed for the spectrometric analysis are as follows: muffle furnace, volumetric flasks, measuring cylinders, burettes, porcelain crucibles, glass rods, filtering papers, conical flasks, p-toluene solution, sulphuric acid solution, nitric acid solution and spectrophotometric analyzer.

Table 1. Wear debris elements and their likely sources and implications (Hunt 1997).

Elements	Implications and Sources
Fe, C, Cr, Mo, Mn, Ni	Ferrous wear and Steel
Cu, Sn, Zn, Al, Pb	Non ferrous wear
C, H, O	Base oil
Zn, Mo, S, CU	Additives

Table 2. Wear debris elements and their likely sources (Hipkin and Heimann 1978).

Elements	Sources
Aluminum	Pistons, Bearings
Boron	In-leak of coolant
Chromium	Rings
Copper	Bearings
Iron	Rolling elements bearings, cylinder, gears
Lead	Bearings, fuel additives
Magnesium	Transmission
Silicon	Airborne dust
Tin	Journal bearings

Sample Preparation and Digestion

Fifteen grams of each of the oil samples were taken into the different porcelain crucibles and heated in a muffle furnace at a temperature between 550^{o}C and 600^{o}C with 1g of P-toluene and sulphuric acid added, until all the carbon became completely oxidized.

When the ashing was completed (in about 30-40 min) the residue was gently warmed with 20ml of 25% nitric acid in each sample in order to facilitate the complete extraction of all the acid soluble elements. The ashes of each sample was then carefully stirred and crushed with glass rod; then the slurries were filtered into 100ml volumetric flask and the residue washed with 20ml of 25% nitric acid, after which each solution was diluted to the 100ml calibrated marks on the flasks.

Spectrometric Analysis

The prepared samples for the atomic absorption spectrometry were aspirated into the oxy-acetylene flame of the spectrophotometer and the displayed absorbance recorded. In the process, the digested solution was converted into vapor containing free atoms. The radiation characteristic of the element being checked is emitted from a light source and directed through the vapor.

Some of the atoms dispersed in the vapor absorbed an appropriate proportion of the radiation resulting in the reduction of the radiation emerging from the vapor. This decrease was measured by a detector as the absorbance. The absorbance values obtained were used to obtain the concentration of the element by extrapolating from the calibration graphs obtained for prepared control solutions.

Case Studies

The following cases which were carried out in August 2002 at a refining and petrochemical plant in Nigeria have been selected from among several other studies carried out on the use of atomic absorption spectrometry to achieve lubrication monitoring. The following four machineries were chosen. A brief discussion about them and their operating conditions are discussed below.

Fifty-cubic-centimeter sample of oil was taken from each machinery while still running and having met their specified times of oil change which was 5,000 hrs running time except in the case of the centrifugal air compressor (90ZA01K01), which had ran for 4,500 hrs. The four samples of used oil obtained were to be compared with another set of four samples that were fresh and unused lubricating oil of the corresponding brand.

Cooling water Circulation Pump (74P01A): This pump is turbine-driven by steam and runs continuously. Its function is to pump condensed water at a relatively high temperature to the cooling tower where it is supplied to other units. Its recommended lubricating oil is Hydrol T-46 manufactured by Unipetrol (now Oando). Mobil's DTE medium oil is a good alternative to Hydrol T-46 (other equivalent alternative lubricating oil brands are listed in Table 1). The oil was replaced after every six months of continuous running of the pump.

The following are the operation specifications of the pump:

Speed	590rev/min
Discharge pressure	5.69 kg/cm^3
Suction pressure	0.69kg/cm^3
Tank capacity	6 Drums (1200 L)

High Pressure Boiler Feed Water Pump (70P01D): This pump is also turbine driven by steam and also run continuously. Its function was to pump feed water to the boiler where it is converted into steam to drive the turbine generators. The recommended lubricating oil for this pump is also Hyrol T-46. The lubricating oil is also replaced after every six months of continuous running. Its operation specifications are as follows:

Turbine speed	7398rev/min
Turbine output	665kW
Delivery pressure	60.5kg/cm^3
Suction pressure	2.5kg/cm^3
Tank capacity	4 Drums (800L)

Centrifugal Air Compressor (90ZA01K01): This centrifugal compressor is used to compress air for the various instruments and equipment of the plant, sand blasting and sand bobbling. It sucks in atmospheric air through a filter and compresses it to a pressure of 9.8kg/cm^3 and temperature 35^oC. Moisture is removed by passing the compressed air through silica gel.

This compressor is driven by an electric motor at 2800rev/min. It has a crankcase lubricating oil capacity of 209litres. The lubricating oil is changed after running for 5,000 hrs. or six mos. Oil sample was taken from this compressor for analysis after it had run for 4,500 hrs. The recommended lubricating oil used on this compressor was DTE medium.

Reciprocating Air Compressor (90K03B): This compressor is driven by an electric motor at a speed of 985rev/min. it has a crankcase lubricating oil capacity of 35litres. Its recommended lubricating oil is Venellus SAE40 which is blended by AP petroleum and is changed after it had been running for 5000hours or 6 months.

Results

The following are the graphs based on the results obtained for the spectrometric oil analysis carried out on the fresh and used lubricating oil in the four machineries studied. Percentage differences of concentration of the various elements checked for were plotted against the elements.

Discussion

Cooling Water Circulation Pump (74P01A)

The quantity of manganese in the used lubricating oil was found to exceed the one in the fresh or unused oil by more than twice the quantity (that is by 227.66%), the quantity of iron, copper and zinc increased by 45.56%, 10% and 20%, respectively. This implied that the machinery components which contained manganese, iron, copper and zinc must be undergoing wear. The used lubricating oil had been depleted of chromium, lead and magnesium to the tune of 20.76%, 22.39% and 8.15%, respectively. This depletion was likely to be because some of the metallic element in the lubricating oil additives chemically reacted with the components of the pump.

High Pressure Boiler Feed Water Pump (70P01D)

The quantity of manganese element in the used oil sample from this pump was also found to have exceeded the one in the fresh oil by as much as 147.27%, while chromium, iron and magnesium all increased by 30, 19.09 and

39.7%, respectively. This again implied that the components that had these elements as alloy members must be undergoing wear thereby losing these elements to the lubricating oil. The lubricating oil also lost copper, zinc, lead and silicon to the tune of 16.67, 4.76, 5 and 2.29%, respectively.

Centrifugal Air Compressor (90ZA01K01)

This machine had the highest concentration of manganese in its used lubricating oil when compared with the unused lubricating oil; this was an increase of 872.39%. It also had an increase of 30% and 0.5% of iron and silicon. The used lubricating oil additives were depleted of the remaining elements to the tune of the values shown in Fig.5.

Reciprocating Air Compressor (90K03B)

The composition of manganese in this compressor only increase by 3.12%, which is quite lower than the concentration in the other machineries considered. It also had the highest concentration of copper which was 55.56% and the concentration of iron and silicon increased by 37.5% and 0.07%, respectively.

Conclusion

In all the cases studied, the concentration of iron and manganese had increased in the used oil beyond the level of concentration in the unused oil, although manganese increased in three cases with an alarming proportion, it is the increases in iron that is worrisome because most of the components in the machines were mainly made of iron, moreover the increase in concentration of manganese can also be indicating wear of ferrous-based components in the machineries. This indicates a necessity to continually monitor the wear rate of the iron and use the wear rate of the other alloying elements to identify the particular component that is degrading. Although a catastrophic failure may still be very far away, lubrication monitoring and indeed wear monitoring by means of spectrometric analysis of the oil keeps the condition monitoring engineer well informed about the trend of wear in his machines.

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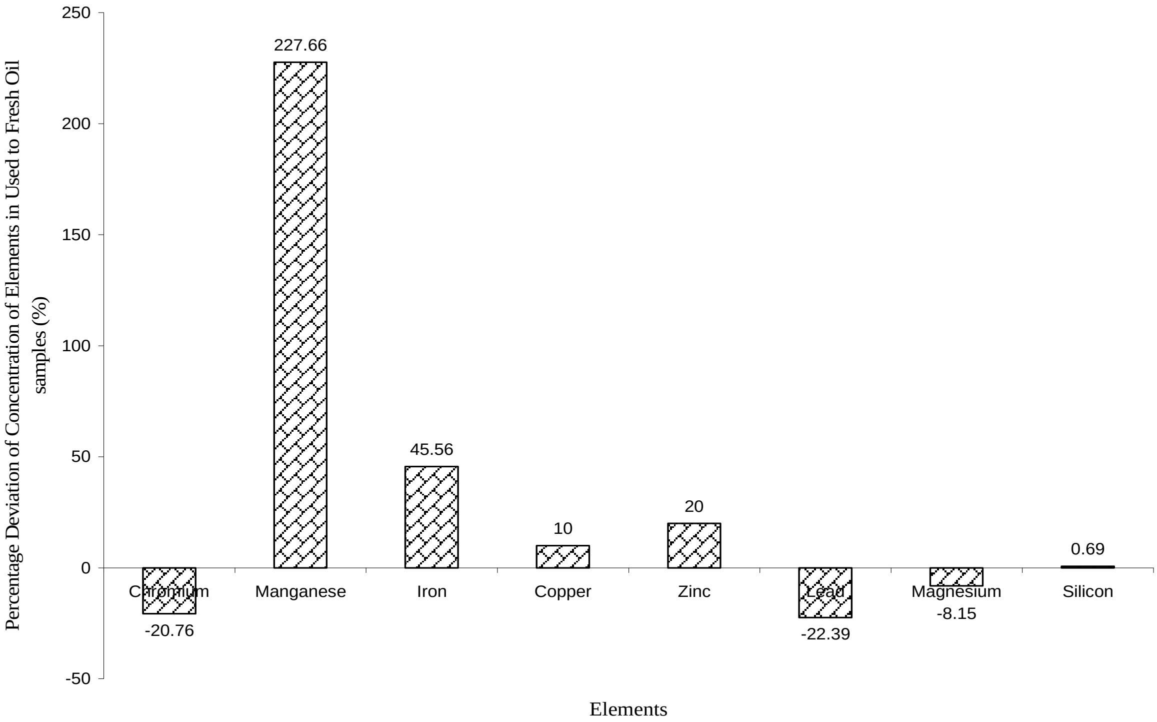

Fig. 3. Percentage deviation of the concentration of elements in the lubricating oil of cooling water circulation pump 74P01A.

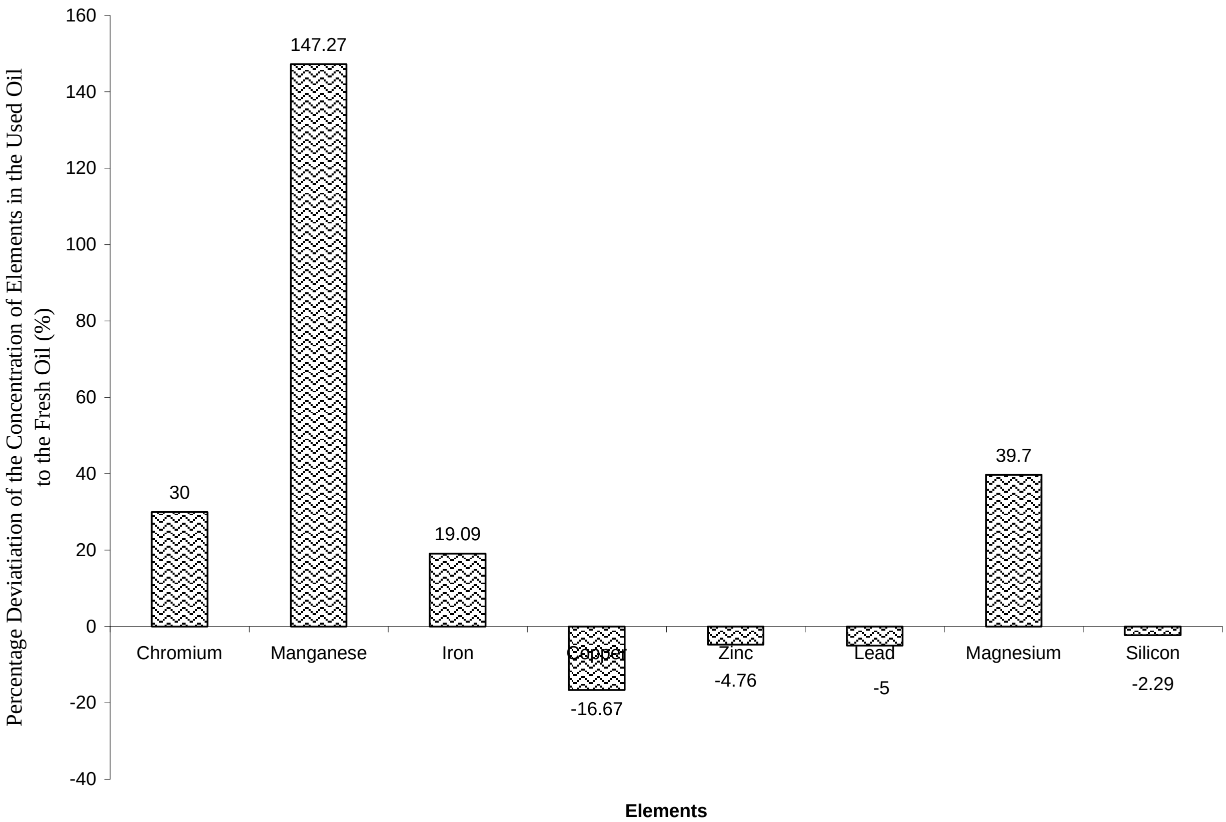

Fig. 4. Percentage deviation of the concentration of elements in the lubricating oil of high pressure boiler feed water pump 70P01D.

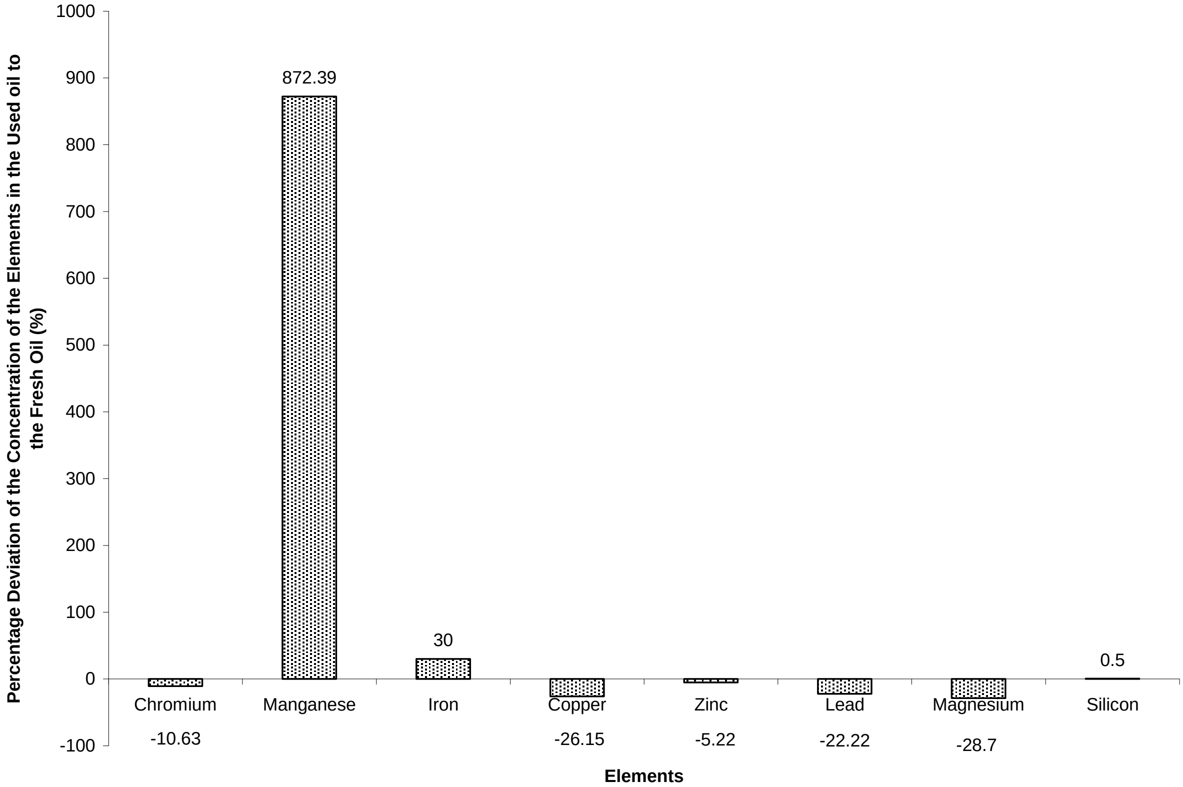

Fig. 5. Percentage deviation of the concentration of elements in the lubrication oil of centrifugal air compressor 90ZA01K01.

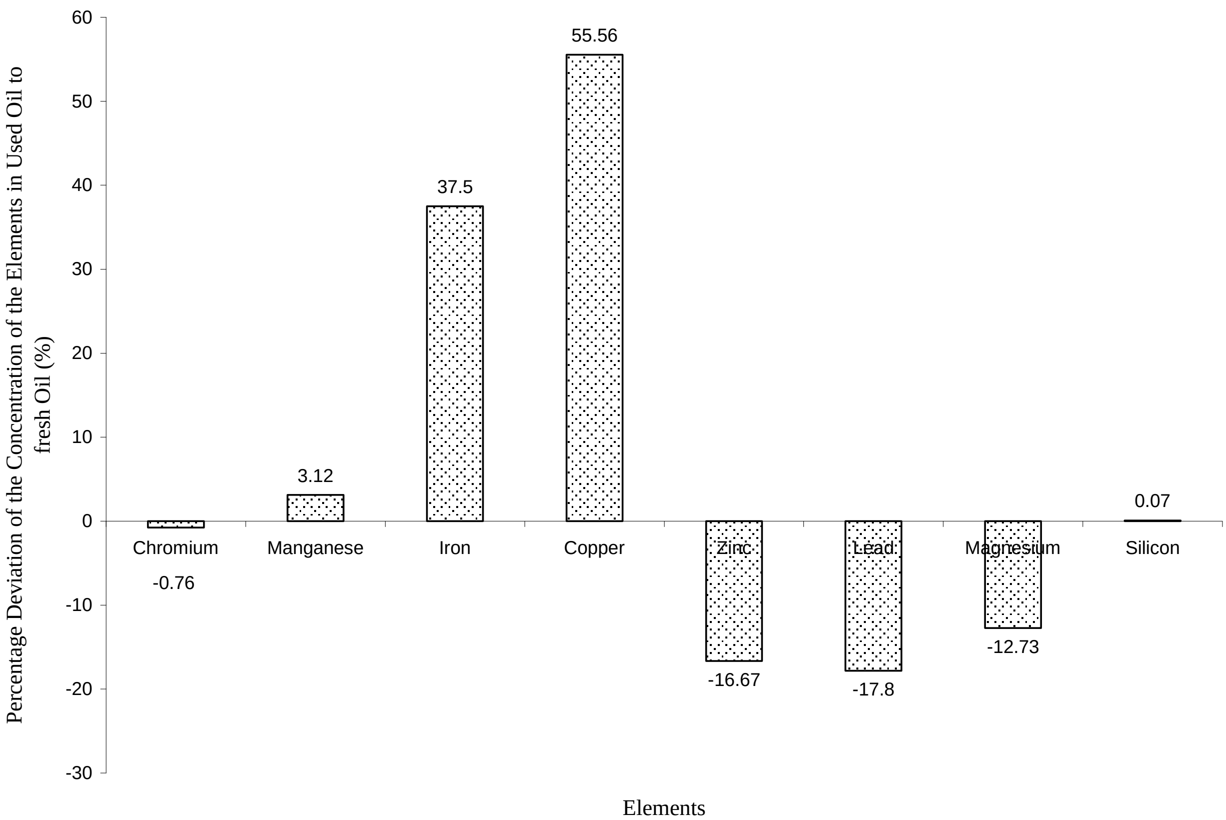

Fig. 6. Percentage deviation of concentration of the elements in the lubricating oil of centrifugal air compressor 90K03B.