International Journal of Bridge Engineering (IJBE), Vol. 11, No. 1, (2023), pp. 43-71

LUBRICATION OIL CONDITION MONITORING IN INTERNAL COMBUSTION DECKS ENGINES

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ABSTRACT: Engines are the main part of power plants and decks sea transport facilities. The performance of the engine depends upon the good condition of the components. The failure of engine components could be reduced by using condition-monitoring techniques. These are including vibration analysis, infrared thermography, and engine used oil analysis.

The aim of this research is to reduce the failures of engine components by analyzing the used oil. Oil is the life-blood of engines. Much as if doctors assess human health through blood analysis, engine components can be monitored in much the same manner. Analysis is done for various properties like Viscosity, Total Base Number (TBN), Total Acid Number (TAN), Ash Content, Flash Point, Water Content, Contamination, and Wear Metal particles, which used to monitor the wear rate of engine components.

The results of the study showed that the intervals of oil replacement based on the oil quality instead of the fixed running hours extend the intervals of oil replacement and achieve the targeted five thousand hours, resulting in reducing maintenance total cost. In condition monitoring, the study figured out the healthiness of engine internal components and no any potential failures are detected.

KEYWORDS: Used oil analysis, Basics of oil analysis, Procedure for used oil analysis, The engine and its lubrication system, Condition monitoring.

1 INTRODUCTION

The definition of analysis can be expressed in many ways, it can be defined as a close examination of something in order to understand it better or draw conclusion from it. Another definition, it is the separation of something into its constituents in order to find out what it contains. It can be defined as to examine individual parts or to study the structure of the whole. Analysis can be an assessment, description or explanation of something usually based on careful consideration or investigation.

Used oil analysis is an important part of engine maintenance. It provides information about the condition of the oil, its suitability for further use, and to certain extent information about condition of the machinery lubricated by the oil. Precondition of a valuable oil analysis and its interpretation is a sample being taken according to a reliable procedure.

Two methods are used for oil analysis, routine and advanced methods. Routine methods are used in all engines oil analysis. The advanced methods are several and provide additional information.

The laboratory oil analysis is a snap-shot of oil condition at the time the oil sample was taken. Filling the gap between oil sampling can be done with on-line monitoring or with on-site analysis using portable test kits.

Oil analysis techniques fall into the following three types. The first is concentration analysis of wear particles in lubricant. This can be conducted in the field or the laboratory. The second is wear debris analysis. This deals with examination of the shape, size, number, composition, and other characteristics of the wear particles to identify the wear state. This is usually conducted in the laboratory. The third is lubricant degradation analysis. This is used to analyze physical and chemical characteristics of lubricant and determine the state of lubricant. This can be conducted in the field or the laboratory [1].

2 LITERATURE REVIEW

2.1 Used oil analysis

For many years, lubricant inspection and testing has been used to help diagnose the internal condition of oil-wetted components and provide valuable information about lubricant serviceability.

The first test method used for this purpose included such simple procedures as smelling used oil for the sour odor of excess acid, checking visually for obvious signs of contamination, or placing a drop of sample on absorbent paper to detect contaminants and monitor additive effectiveness.

As basic research and technology expanded, progress in lubricant testing kept moving. An increasingly large numbers of test were developed to assess lubricant physical properties and detect contaminants.

In 1946, the Denver and Rio Grande Railroad research laboratory successfully detected diesel engine problems through wear metal analysis of used oil. A key factor in this success was the development of the spectrograph, a single instrument that replaced several wet chemical methods for detecting and measuring individual chemical elements such as iron and copper [2].

A research study was conducted for two used engine oil sample collected by two different automobile vehicles, one is petrol engine run for 2400 km, and the is diesel engine run for 8860 km. The analysis carried out for viscosities at 40 and 1000 C, total base number, total acid number, water content, total insoluble, and wear metals. The study concluded that petrol engine is health and condition is good, it has no change of catastrophic failure as compare to diesel engine. Diesel engine health and condition is not good [3].

Another study for used engine oil is carried out on a vehicle engine for a three totally different kilometers (3450, 6090, and 8487). The analysis test is carried out without any oil purification to keep oil properties unmodified. The study concluded that the work done by the engine is inversely proportional to the engine oil properties. If the viscosity of the oil increases means overheated engine, restricted oil flow, accelerated wear will occur. The total base number value increased, and it leads to corrosion of metal parts. If total acid number value increased, it leads to oil degradation and corrosion of components. Presence of wear elements in the engine oil has an adverse effect on the engine components. As the concentration of wear elements on engine leads to the complete failure of the components. Iron and chromium content increased means it is the chance to failure of piston rings and cylinder walls, Aluminum content in the oil means its lead to failure of Pistons, Copper content in oil means its lead to failure of Bearings [4].

The various techniques for wear characterization of internal combustion engines are Atomic absorption spectrometry (AAS) of lubricating oil samples from engine and Ferrography Technology of used lubricating oil drawn from lubricating oil sump. These methods of oil analysis provide advanced warning of abnormal wear in high value critical assets can provide important options otherwise unavailable to decision-makers. Secondary damage may be avoidable by identifying and removing the worn parts, and therefore reducing subsequent maintenance costs that would result if a catastrophic failure were to occur. In addition, a better understanding of the nature of the problem can be obtained, reducing uncertainty about maintenance procedures. All these are determined by a study carried out on analysis of wear rate of internal combustion engine using Ferrography Technique.

The study concluded that the normal rubbing wear particles, severe sliding wear particles, bearing particles, gear wear particles, found in marginal quantity during initial run of vehicles, and it is clear from this the initial wear rate of engine components like piston, piston ring, crankshaft, bearings etc. found was more and their sizes are more than 100 microns which is adverse failure. Large quantities of rubbing wear particles can create excess rubbing of internals and can lead to the generation of secondary wear in the equipment. During initial run of engine or say up to certain distance of engine run cleaning the lubricant (centrifuge to remove the existing wear particles and contaminants) or changing the lubricant is necessary to avoid the generation of secondary wear i.e. abrasive wear.

Presence of white nonferrous sliding wear particles could be due to severe sliding stress due to excessive load/speed conditions on the piston and related components, which may lead to failure. Excessive sliding stress on the ferrous components (gears, cams, cam rollers, etc.) is also indicated by the presence of marginal quantities of low alloy steel sliding wear particles. From this study, inspection of internals can be planned at the earliest possible maintenance schedule for severe wear out of piston and related components [5].

The importance of using a combination of physical and spectrochemical tests to monitor lubricant and component condition is now universally accepted.

Oil analysis test procedures are established and reviewed by such agencies as the International Organization for Standardization (ISO), the American Society for Testing and Materials (ASTM), and the Society of Automotive Engineers (SAE), and a wide variety of laboratory and personnel certifications has emerged. The basics of modern oil analysis is the use of Optical Emission Spectroscopy (OES) to measure the ppm (part per million) levels of wear metals, contaminants, and additives in oil sample. Whatever else an oil-testing laboratory may measure; a multi-elemental analysis is the core of current in-service oil analysis. The latest trend in dedicated oil analysis equipment is steady progression of smaller, lighter, more versatile instrument. Such new instruments are result of great advancement in electronics, computers and sensors technology, and are usually less expensive, requires less operator interference or sample preparation [2].

The procedure for used oil analysis is as follows:

Analysis (routine and non-routine); key actions required for a correct analysis; oil sample procedure; sample turnaround time; oil sampling intervals; interpretation of oil diagnosis and test results [6] and [7].

2.2 The engine and its lubrication system

The Lubrication of Vital Engine Components include: Bearing Lubrication; Piston Cooling; Cylinder Lubrication; Other Aspects of Lubrication which includes the camshaft and gear train, the fuel injection system to serve as a fuel/lubricant barrier, the rocker arm-assembly and valve guides in the valve train [7].

2.3 Condition monitoring

The crudest method for operating machines is to run them until they fail, and then to try and repair them in order to make them fit for further service. This method of operation can be very expensive in terms of lost output and machine destruction, and in addition can involve hazards to personnel. It is now well recognized that particularly in the case of large engines and expensive plant; it is more economical and operationally satisfactory to carry out regular maintenance. This maintenance is carried out at regular intervals to reduce the likelihood of failure during a time when the machine is required to be available for use.

A more satisfactory compromise in terms of maintenance strategy is to carry out preventive maintenance at what may be irregular intervals, but to determine these intervals by the actual condition of the machine at that time. For such condition-based maintenance to be possible, it is essential to have knowledge of the machine condition, and its rate of change with time. The main function of condition monitoring is to provide this knowledge.

2.3.1 Methods of condition monitoring

There two methods of condition monitoring: Trend monitoring and condition check [8].

2.3.1.1 Trend monitoring

Trend monitoring is the continuous or regular measurement and interpretation of data, collected during machine operation, to indicate variations in the condition of the machine or its components, in the interests of safe and economical operation. This involves the selection of some suitable and measurable indication of machine or component deterioration and the study of the trend in this measurement with running time to indicate when deterioration is exceeding a critical rate [7].

2.3.1.2 Condition check

Condition checking is where a check measurement is taken with the machine running, using some suitable indicator such as, again, one of those are listed in Figure 1, and this is then used as a measure o the machine condition at that time.

To be effective the measurement must be accurate and quantifiable, and there must be known limiting values which must not be exceeded for more than a certain number of permitted further running hours.

To fix these values requires a large amount of recorded past experience for the particular type of machine, and this makes the method less flexible than the trend monitoring, particularly if it is required to give lead time as well as machine knowledge. It can be particularly useful, however, in a situation where there are several similar machines operating together as in this case comparative checking can be done between the machine which is monitored, and other machines which are known to be in new or good condition [8].

Figure 1 below shows the regular monitoring of deterioration to give advance warning of failure.

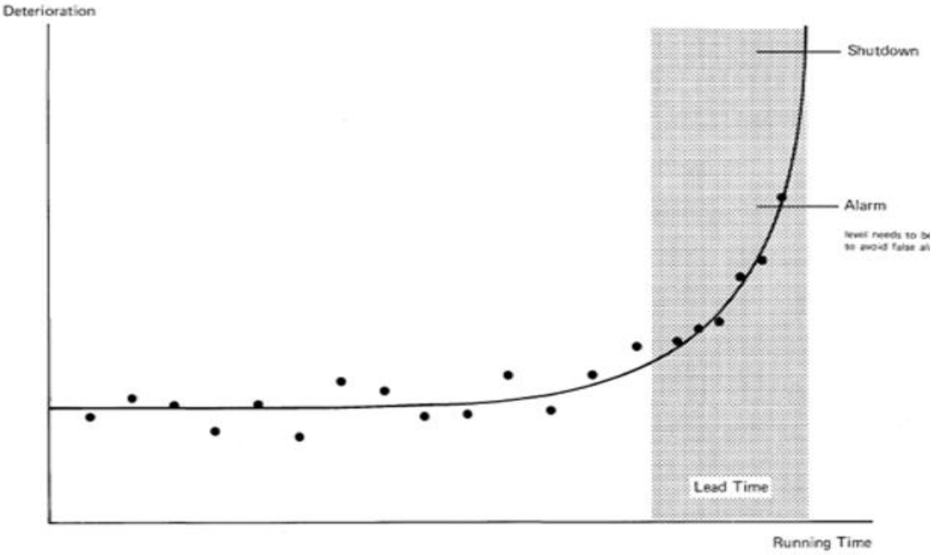


Figure 1. The regular monitoring of deterioration to give advance warning of failure

2.3.2 The economics of condition monitoring

The main savings, which can be made by application of condition monitoring in industrial machinery, arise by avoiding losses of output due to breakdown of machines, and by reducing the costs of maintenance. Output related losses can be estimated from the number of days output lost multiplied by the added value output per day. The maintenance costs, which can be saved, are rather more difficult to quantify, but are likely to relate mainly to the labor costs of breakdown maintenance.

One method of obtaining a more realistic figure for the likely savings is to identify the industrial sectors, which operate suitable plant machinery, and then to take the savings from these sectors only, in order to reach a more realistic total.

Industrial sectors, which rely on machinery rather than on manual work to produce their output, will be particularly appropriate for condition monitoring, and sectors of this type will have a high value of annual capital invested in plant and machinery per employee. In addition, if the plant is concentrated in one place and operated intensively, condition monitoring will again be particularly applicable, and industrial sectors using plant in this way will have a high value of annual benefit output per establishment [8].

2.3.3 Evaluating new condition monitoring technique

The new technique can be evaluated through the following facilities:

Applicability; consistency/repeatability of measurement; statutory regulations and cost effectiveness [9].

3 METHODOLOGY

3.1 Test methods

The following methods are used for oil analysis;

1. ASTM D 445, test method for Kinematic Viscosity at 40ºC and 100ºC.
2. ASTM D 2270, test method for Viscosity Index for Kinematic Viscosity at 40ºC and 100ºC.
3. ASTM D2896, test method for Total Base Number TBN.
4. ASTM E2412, test method for Condition Monitoring by Trend Analysis Using Fourier Transform Infrared (FT-IR) Spectrometery.
5. ASTM D4951, test method for Metallic Particles.
6. Crackle Test for Water Content.

3.2.1 D 445 standard test method for kinematic viscosity

This test method specifies a procedure for the determination of the kinematic viscosity of liquid petroleum product, by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer.

The range of kinematic viscosities covered this test method is from 0.2 to 300000 mm^2/s at all temperatures [10].

3.2.1.1 Significance and use

Many petroleum products and some non-petroleum materials are used as lubricants and the correct operation of the equipment depends upon the appropriate viscosity of the being used. In addition, the viscosity of many petroleum fuels is important for the estimation of optimum storage, handling, and operational conditions. Thus, the accurate determination of viscosity is essential to many product specifications.

3.2.1.2 Summary of test method

The time measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer under a reproducible driving head and at a close controlled and known temperature. The kinematic viscosity (determined value) is the product of the measured flow time and the calibration constant of the viscometer. Two such determinations are needed from which to calculate a kinematic viscosity determined values.

3.2.1.3 Test apparatus

The apparatus used in the test includes the following components: Viscometers; Viscometer Holders; Temperature-Controlled Bath; Temperature Time Control; Temperature Measuring Device; Timing Device.

3.2.1.4 Reagent materials

These include the following materials: Chromic Acid Cleaning Solution; Sample Solvent; Drying Solvent; Water.

3.2.1.5 General procedure for kinematic viscosity test

1. Adjust and maintain the viscometer bath at the required test temperature. Thermometers shall be held in an upright position under the same conditions of immersion as when calibrated. In order to obtain the most reliable temperature measurements, it is recommended that two thermometers with valid calibration certificates be used. They should be viewed with a lens assembly giving approximately five times magnification and be arranged to eliminate parallax errors.
2. Select a clean, dry calibrated viscometer having a range covering the estimated kinematic viscosity. A wide capillary for a very viscous liquid and a narrow capillary for a more fluid liquid. The flow time for manual viscometer shall not be less than 200s, and flow times of less than 200s are permitted for automated viscometers.
3. Charge the viscometer in the manner dictated by the design of the instrument. This operation being conformity with that employed when the instrument was calibrated.

   If the sample is thought, or known to contain fibers or solid particles, filter through a 75µm screen, either prior of during charging.

   Allow the viscometer to remain in the bath long time to reach the test temperature. Where one bath is used to accommodate several viscometers, never add, withdraw, or clean a viscometer while any other viscometer in the use for measuring a flow time. Thirty minutes should be sufficient except for the highest kinematic viscosities. Because this time will vary for different instruments, for different temperatures, and for different kinematic viscosities, establish a safe equilibrium time by trial. When the design of the viscometer requires it, adjust the volume of the sample to the mark after the sample has reached temperature of equilibrium.
4. Use suction (if the sample contains no volatile constituents), or pressure to adjust the head level of the test sample to a position on the capillary arm of the instrument about 7mm above the first timing mark, unless any other value is stated in the operating instructions for the viscometer. With the sample flowing freely, measure, in seconds to 0.1s, the time required the meniscus to pass from the first to the second timing mark. If this flow time is less than the specified minimum, select a viscometer with a capillary of smaller diameter and repeat the operation.

   Repeat the described procedure to make a second measurement of flow time. Record both measurements.

   From the measurements of flow time, calculate two determined values of kinematic viscosity. If the two determined values of kinematic viscosity calculated from the flow time measurements agree with the stated determinability figure for the product, use the average of these determined values to calculate the kinematic viscosity result to be reported. Record the result. If not, repeat the measurements of flow time after a thorough cleaning and drying of the viscometer and filtering of the sample where required, until the calculated kinematic viscosity determinations agree with the stated determinability.

5. Cleaning of Viscometer. Between successive determinations of kinematic viscosity, clean the viscometer thoroughly by several rinsing with sample solvent, followed by the drying solvent. Dry the tube by passing a slow stream of filter dry air through the viscometer for 2 min or until the last trace of solvent is removed. Periodically, clean the viscometer with the cleaning solution, for several hours to remove residual traces of organic, deposits, rinse thoroughly with water or a vacuum line.

   Remove any inorganic deposits by hydro-chloric acid treatment between the uses of cleaning acid.
6. Calculation. Calculate each of the determined kinematic viscosity values ν1 and ν2 from the measured flow times, $\tau_1$and τ_2 and the viscometer constant C, by means of the following equation,

   $$\nu_1 \; \nu_2 = C. \; \tau_1 \; \tau_2$$

   Where:

   $\nu_1 \; \nu_2$ = determined kinematic viscosity values respectively, mm^2/ s.
   C = calibration constant of viscometer, mm^2/ s^2.
   $\tau_1 \; \tau_2$ = measured flow times respectively, s.
   Calculate the kinematic viscosity result ν as an average of ν1 and ν_2.
7. Expression of Results. Report the test result for the viscosity to four significant figures, together with test temperature.
8. Report the following information. Type and identification of the product tested. Reference of test method, or International Standard. Result of the test. Any deviation, by agreement or otherwise, from the product specified. Date of the test. Name and address of the test laboratory.

3.2.2 D 2270 Standard practice for calculating viscosity index from kinematic viscosity at 40 and 100 ^{0} C

This practice covers the procedure for calculating the viscosity index of petroleum products, such as lubricating oils, and related materials from the kinematic viscosities at 40^0C and 100^0C [11].

3.2.2.1 Significance and use

The viscosity index is a widely used and accepted measure of the variation in the kinematic viscosity due to change in in the temperature of a petroleum product between 40^0C and 100^0C. A high viscosity index indicates a smaller decrease in kinematic viscosity with increasing temperatures of the lubricant. The viscosity index is used in practice as a single number indicating temperature dependence of kinematic viscosity.

3.2.2.2 Test procedures

There are two test procedures:

I. Procedure A, oils of viscosity index up and including 100:

1. Determine the kinematic viscosity of the sample at 40^0C and 100^0C.
2. If the kinematic viscosity of the oil at 100^0C is less or equal to $70mm^2/s$ (cSt), extract from the table of basic Values for L and H for Kinematic Viscosity in 40 to 100°C System, the corresponding values of L and H, measured values that are not listed, but are within the range of basic values table, may obtained by linear interpolation.

   If the kinematic viscosity at 100^0C above $70mm^2/s$ (cSt), calculate the values of L and H as follows;

   $$L = 0.8353\ Y^2 + 14.67\ Y - 216$$

   $$H = 0.1684\ Y^2 + 11.85\ Y - 97$$

   Where: L = kinematic viscosity at 40^0C of an oil of viscosity index having the kinematic viscosity at 100^0C as the oil whose viscosity index to be calculated, mm^2/s (cSt); Y= kinematic viscosity at 100^0C of the oil whose viscosity index to be calculated, mm^2/s (cSt);

   H = kinematic viscosity at 40^0C of an oil of 100 viscosity index having the same kinematic viscosity at 100^0C as the oil whose viscosity index is to be calculated, mm^2/s (cSt).
3. Calculate the viscosity index, VI, of the oil as follows;

   $$VI = [(L - U) / (L - H)] \times 100$$

   Where:

   U = kinematic viscosity at 40^0C of the oil whose viscosity index is to be calculated, mm^2/s (cSt).

II. Procedure B, oils of viscosity index of 100 and greater:

1. Determine the kinematic viscosity of the sample at 40^0C and 100^0C.
2. If the kinematic viscosity of the oil at 100^0C is in the range of 2 to $70mm^2/s$ (cSt), extract the corresponding value for H from the table of basic Values for L and H for Kinematic Viscosity in 40 to 100°C System, measured values that are not listed, but are within the range of the table, may obtained by linear interpolation.
3. If the measured kinematic viscosity at $100\ ^0C$ is greater than $70\ mm^2/s$ (CST), calculate the value of H as follows;

   $$H = 0.1684\ Y^2 + 11.85\ Y - 97$$

Where:
Y = kinematic viscosity at 100^0C of the oil whose kinematic viscosity is to be calculated, mm^2/s (cSt); H = kinematic viscosity at 40^0C of an oil of 100 viscosity index having the same kinematic viscosity at 100^0C as the oil whose viscosity index to be calculated, mm^2/s (cSt).
Calculate the viscosity index, VI, of the oil as follows:

$$VI = [((\text{antilog } N) - 1) / 0.00715] + 100$$

Where: $N = (\log H - \log U) / \log Y$ and $Y^N = H/U$ and U = kinematic viscosity at 40^0C of the oil whose viscosity index is to be calculated, mm^2/s (CST).

3.2.2.3 Test report

1. Report the viscosity index to the nearest whole number.
2. When the number is exactly halfway between the nearest two whole numbers, round to the nearest even number, for example, 15.5 should be 16.
3. The test report shall contains at least the following information: A reference to the standard; the type and complete identification of the product tested; the result of the test; whether procedure A or procedure B was used; any deviation, by agreement or otherwise from the procedure specified. The date of the test.

3.2.3 D 2896 standard test method for base number of petroleum product

This test method covers the determination of basic constituent in petroleum products by titration with perchloric acid in glacial acetic acid [12].

3.2.3.1 Significance and use

New and used petroleum products can contain basic constituents that are present as additives. The relative amounts of these materials can be determined by titration with acids. The base number is a measure of the amount of the basic substance in the oil, always under the conditions of the test it is sometimes used as a measure of lubricant degradation in service; however, any condemning limits must be empirically established.

3.2.3.2 Summary of the test

The sample is dissolved in an essentially anhydrous mixture of chlorobenzene glacial acetic acid and titrated with a solution of perchloric acid in glacial acetic acid using potentiometer Titrimeter. A glass indicating electrode and a reference electrode are used, the latter being connected with the sample solution by means of a salt bridge. The meter readings are plotted against the respective volumes of titrating solution, and the end is taken at the inflection in resulting curve.

3.2.3.3 Test apparatus

These include the following apparatus that are used to carry out the test:

1. Potentiometric Titrimeter: Either automatic recording or manual.
2. Glass Electrode: General-purpose type with pH 0 to 11.
3. Reference Electrode: Silver/silver chloride (Ag/AgCl) reference electrode with a nonaqueous bridge.
4. Stirrer: Either mechanical or electrical, with variable speeds and with propeller or paddle of chemically inert material. When an electrical stirrer is used, it must be grounded so that disconnecting or connecting the power to motor will not produce a permanent change in meter reading during the course of titration. A magnetic stirrer with stirring bar can be used provided it meets these conditions.
5. Buret: 10mL or 20mL graduated in 0.05mL divisions and calibrated with accuracy of ±0.02mL, or an automatic buret of similar accuracy.
6. Titration Beaker: Made of borosilicate glass or other suitable titration beaker, tall form recommended. For procedure A, use a beaker of 250mL or 300mL capacity. For procedure B, use a beaker of about 150mL capacity such that 60mL of titration solvent will cover the electrodes.
7. Titration Stand: Suitable to support the beaker electrodes, stirrers, and buret. An arrangement that allows for the removal of the beaker without disturbing the electrodes, buret, and stirrers is desirable.

3.2.3.4 Reagent and materials

The following reagents and materials are used during the test method, associated with required handling precaution;

1. Purity of Reagent: Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specification are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficient high purity to permit its use without lessening the accuracy of the determination.
2. Purity of Water: Unless otherwise indicated, references to water shall be understood to mean reagent water that meets the requirement of either type I, II, or III of specification D 1193.
3. Acetic Acid: Glacial, toxic and irritant, caution must be taken.
4. Acetic Anhydride: Toxic and irritant, caution must be taken.
5. Chlorobenzene: Toxic and irritant, caution must be taken.
6. Perchloric Acid: Stand solution in Acetic Acid ($0.1N$) [4]. Powerful oxidant when dry or heated. Great care should be taken to avoid contact with organic matter under condition that may result in subsequent drying or heating, and spills should be washed immediately and thoroughly with water.
7. Potassium Hydrogen Phthalate $KHC_8H_4O_4$.

8. Sodium Perchlorate Electrolyte Na ClO_4: Toxic and irritant, also it is a powerful oxidizing agent when dry or heated. Great care should be taken to avoid contact with organic matter under condition that may result in subsequent drying or heating, and spills should be washed immediately and thoroughly with water.
9. Titration Solvent: Add one volume of glacial acetic acid to two volumes of chlorobenzene.
10. Sodium Carbonate, anhydrous Na CO_3.
11. Sodium Acetate Solution, 0.1*N* in acetic acid.

3.2.3.5 Preparation of sample

The following steps prepare sample:

1. It is essential to ensure that the sample is representative since any sediment can be acidic or basic or have adsorbed acidic or basic materials from the sample.
2. When necessary, samples are warmed to aid mixing.
3. Used oils should be vigorously shaken to ensure homogeneity before sampling.

3.2.3.6 Preparation of electrode system

The following steps are used to prepare the electrode system: Preparation of Electrodes; Testing of Electrodes; Cleaning of Electrodes.

3.2.3.7 Test procedure

Two test procedures are used, procedure A by using a 120mL, and procedure B by using a 60mL of titration solvent.

1. Procedure A, 120mL of titration solution:

Calculate the quantity of sample required for its expected base number BN as follows;

1. Approximate weight of sample, g = 28/ expected BN.
2. Weight the sample into the titration beaker, applying the limits given for the test procedure, a maximum of 20g should be taken for analysis.
3. Add 120 mL of titration solvent to the sample.
4. Place the beaker on the titration stand and stir the solution until the sample is dissolved.
5. Position the prepared electrodes in the solution so that they are immersed as far as possible.
6. Continue stirring throughout the determination at a rate of sufficient to produce vigorous agitation without spattering and without stirring air into the solution.
7. Adjust the meter so that it reads in the upper part of the millivolt scale, for example 700mV.

8. Fill the beaker with 0.1 *N* $HClO_4$ solution and place the buret in position in the titration assembly, taking care that the tip is immersed below the level of the surface of the liquid in the beaker.
9. Record the initial buret and meter (cell potential) readings.
10. In Manual Titration, add suitable small portion of titrant and, after waiting until a constant potential has been established, record the buret and meter readings.
11. At the start of the titration, and in any subsequent regions (inflations) where 0.1mL of titrant consistently produces a total change of more than 0.03V (corresponding to 0.5 pH scale unit) in the cell potential, add 0.05 portions.
12. In the intermediate regions (plateaus) where 0.1mL increments change the potential by less than 0.03V, add large portions sufficient to produce a total potential change approximately equal to, but not greater than 0.03V.
13. Titrate in this manner until the potential change less than 0.005V (corresponding to 0.1pH scale unit) per 0.1mL.
14. In automatic recording titration, adjust the instrument in accordance with manufacturer instructions and set the titration speed at 0.1mL/min maximum.
15. On completion of the titration, remove the beaker and rinse the electrodes and buret tip with titration solvent, then with water, then again with the titration solvent and store in water when not in use.
16. For each set of samples, make a blank titration using 120mL of titration solvent.
17. For a manual titration add 0.1 *N* $HClO_4$ solution in 0.05mL increments, waiting between each addition until a constant cell potential is established.
18. Record meter and buret readings after each increment.
19. In automatic recording titration, adjust the instrument in accordance with manufacturer instructions and set the titration speed at 0.1mL/min maximum.

2. Procedure B, 60mL of titration solution:

Calculate the quantity of sample required for its expected base number BN as follows;

1. Approximate weight of sample, g = 10/ expected BN.
2. Weight the sample into the titration beaker, applying the limits given for the test procedure, a maximum of 10g should be taken for analysis.
3. Add 60mL of titration solvent to the sample.
4. Place the sample on the titration stand and stir the solution until the sample is dissolved.
5. Position the prepared electrodes in the solution so that they are immersed as far as possible.
6. Continue stirring throughout the determination at a rate of sufficient to produce vigorous agitation without spattering and without stirring air into the

solution.

7. Adjust the meter so that it reads in the upper part of the millivolt scale, for example 700mV.
8. Fill the buret with 0.1 *N* $HClO_4$ solution and place the buret in position in the titration assembly, taking care that the tip is immersed below the level of the surface of the liquid in the beaker.
9. Record the initial buret and meter (cell potential) readings.
10. In Manual Titration, add suitable small portions of titrant and after, waiting until a constant potential has been established, record the buret and meter readings.
11. At the start of the titration, and in any subsequent regions (inflations) where 0.1mL of titrant consistently produces a total change of more than 0.03V (corresponding to 0.5 pH scale unit) in the cell potential, add 0.05 portions.
12. In the intermediate regions (plateaus) where 0.1mL increments change the potential by less than 0.03V, add large portions sufficient to produce a total potential change approximately equal to, but not greater than 0.03V.
13. Titrate in this manner until the potential change less than 0.005V (corresponding to 0.1pH scale unit) per 0.1mL.
14. In automatic recording titration, adjust the instrument in accordance with manufacturer instructions and set the titration speed at 0.1mL/min maximum.
15. On completion of the titration, remove the beaker and proceed with electrodes cleaning. Store electrodes in water when not in use.
16. For each set of samples, make a blank on 60mL of titration solvent.
17. for a manual titration add 0.1 N $HClO_4$ solution in 0.05mL increments, waiting between each addition until a constant cell potential is established.
18. Record meter and buret readings after each increment.
19. In automatic recording titration, adjust the instrument in accordance with manufacturer instructions and set the titration speed at 0.1mL/min maximum.

3.2.3.8 Calculation

1. For manual titration, plot the volumes of the acid added against the corresponding meter readings.
2. Interpret the end from the graph obtained from the manual or automatic titration. The end is the midpoint of the inflection, that point at which the curve changes from concave to convex.
3. A useful but not mandatory guide is that the end is preceded and followed by a defection of a least 50mV/0.1mL of titration.
4. Calculate the base number *BN* as follows;

$$\text{BN, mgKOH/g} = [(E-F).N_A - 56.1]/S$$

Where:

E = $HClO_4$ solution used to titrate the sample to the inflection point on the titration curve, Ml; F = volume corresponding to E for blank titration at same potential as sample, Ml; N_A = normality of $HClO_4$ solution; S = sample, g.

3.2.3.9 Report

Report the result as follows:

1. Base Number (D2896 procedure A or B) = Result.
2. Report the base number values less than 100mg to 0.1mgKOH/g and values 100 or greater to 1mgKOH/g.

3.2.4 E 2412 standard test for condition monitoring of in-service lubricants

This practice covers the use of FT-IR in monitoring additive depletion, contaminant build up and base stock degradation in machinery lubricants, hydraulic fluids, and other fluids used in normal machinery operation. Contaminants monitored include water, soot, ethylene glycol, fuels, and incorrect oil. Oxidization, nitration, and sulfonating of base stocks are monitored as evidence of degradation. The objective of this monitoring activity is to diagnose the operational condition of the machines based on fault conditions observed in the oil. Measurement and data interpretation parameters are presented to allow operators of different FT-IR spectrometers to compare results by employing the same techniques [12].

3.2.4.1 Significance and use

Periodic sampling and analysis of lubricants have long been used as a means to determine overall machinery health. Atomic Emission (AE) and Atomic Absorption (AA) spectroscopy are often employed for wear metal analysis. A number of physical property tests complement wear metal analysis and are used to provide information on lubricant condition. Molecular analysis of lubricants and hydraulic fluids by FT-IR spectroscopy produces direct information on molecular species of interest, including additives, fluid breakdown products and external contaminants, and thus complements wear metal and other analysis used in a condition-monitoring program.

3.2.4.2 Summary of the practice

Periodic samples are acquired from the engine of machine being monitored. An infrared absorbance spectrum of the sample is acquired, typically covering the range of 4000 to 550 cm^{-1}, with sufficient signals-to-noise (S/N) ratio to measure absorbance areas of interest. Exact data acquisition parameters will vary depending on instrument manufacturer but most systems should be able to collect an absorbance adequate to for most measurement in less than one minute. Features in the infrared spectrum indicative of the molecular level component of interest (that is water, fuel, antifreeze, additive, degradation and so forth) are measured and reported. Condition alerts and alarms can be then triggered according to both the level and the trends from the monitored system.

3.2.4.3 Test apparatus

The apparatus used in this method requires the following components: Fourier Transform Infrared Spectrometer FT-IR; Infrared Liquid Transmission Sampling Cell; Cell Flushing/Cleaning Solvent.

The optional components consist of the following: Sample Pumping System; Filter; Seal Sample Compartment; Hydrocarbon Leak Alarm; Check Fluids.

3.2.4.4 Sampling and sample handling

The following steps are used for sampling and sample handling;

1. Sample Acquisition: The objective of sampling is to obtain a test specimen that is representative of the entire quality.
2. Sample Preparation: No sample preparation is required. Laboratory samples should be shaken or agitated to ensure a representative sample is taken for the bottle.

3.2.4.5 Instrument preparation

Instrument is prepared as follows;

1. Spectral Acquisition Parameters: Spectral Resolution, 8cm^{-1}, or better (low numeric value). Data Point Spacing Resolution, 4 cm^{-1}, or better (low numeric value). Typical Range 4000 to 550cm^{-1}. Spectral Format, absorbance is a function of wave number. Other Optical, Electronic Filtering and Interferogram Computational Parameters, these parameters should be as recommended by the manufacturer or as determined necessary for adequate measurement quality.
2. Background Collection: The single-beam background collection should be performed frequently enough such that ambient changes in atmospheric water vapor levels and other changing ambient conditions do not significantly affect the sample result. The frequency of background checks should be determined by the individual laboratory conditions and sampling techniques. Note that changing water vapor levels will have the strongest effect, as water vapor is strong infrared absorber. A water vapor check may be included in the software to monitor the intensity of the water vapor in the single-beam background spectrum.
3. Cell Path length Check: A cell path length check is needed to verify the path length consistency of the cell. Results are referenced to 0.100. This check is particularly important for water-soluble salt cell windows. For systems using a fixed flow cell, the check can be performed at the same time as the background collection. Different instrument manufacturer may use different

techniques for cell path length checks that may require the use of a reference or calibrated fluid(s).

3.2.4.6 Procedures, calculation and reporting

These include the following steps:

1. Sample Introduction: A representative sample is introduced into the infrared transmission cell, either manually or by an automatic pumping system.
2. Sample Integrity Check: To ensure accurate and consistent results, the infrared spectrum of the sample should be checked to verify that the cell is completely filled and that air bubbles passing through the cell during data collection are not affecting the results. A sample integrity check is based on measurement of the absorbance intensity over the wavenumber range from 3000 to 1090 cm^{-1} is suitable for multiple lubricant types. The exact absorbance intensity will depend on the spectral resolution and the path length of the cell being used.
3. Sample System Cleaning and Check: To ensure that either the minimum amount of sample cross-contamination or sample carryover, a minimum volume of the next sample can be flushed, or a volatile solvent can be flushed through the cell and the cell dried. The amount of absorbance from either the previous sample or residual wash solvent in the sample cell can be checked. This check is performed by the same spectral analysis operation as described above. The maximum absorbance intensity should be below a preset threshold in the monitoring region. For most petroleum and synthetic lubricants and wash solvent this intensity will be less than 0.2 absorbance units. The optimal threshold will depend upon the specific system configuration, in some systems are designed to “push-out” the residual oil sample and wash solvent with the next sample.
4. Data Processing: Data is processing as follows:

4.1 All spectral will be processed in units of absorbance as a function of wavenumber. Calculated data must be corrected to reference path length of 0.100mm prior to reporting to account for cell path length variation that will be seen in commercially available cells. Any other spectral data treatment should occur prior to calculating results from the spectrum.

4.2 Spectral data processing results can be trended directly from the in-service oil spectrum. The only spectral data treatment is the correction of the spectrum results to the 0.100mm reference path length and the application of fringe reduction algorithms to the spectrum, if required.

4.3 Spectral data processing can also be obtained by spectral subtraction processing, which requires a reference spectrum (spectral subtraction). Where spectral is used, processing of results is done from the difference spectrum that is generated by subtracting the appropriate new oil reference spectrum from the spectrum of the in-service oil sample. The in-service oil spectrum and new oil reference spectrum must both be corrected to the reference path length of 0.100mm prior to subtraction and 1:1 subtraction factor used. The subtracted spectral results can be trended over time and treated in a manner similar to those collected using the direct infrared trending method.

4.4 The most commonly used reference is a sample of new oil if possible, the new oil should be from the same lot and drum as the in-service oil. An alternate approach that might yield a more representative reference would be to take a sample of oil one hour after the oil has reached operating temperatures.

4.5 Post-analysis data treatment can use simple multipliers and other scaling techniques, for example “volume x 100” at the result of maintenance personnel for ease in evaluation and presentation.

5. Spectral Analysis of Sample Data:

Selected spectral regions containing information relevant to condition monitoring are measured and reported. The regions analyzed are specific to different lubricating fluid types. New oil sample parameters can be used as the point from which to trend when initially implementing an analysis process for a lubricant type.

3.2.5 D4951 standard test method for determination of additive elements in lubricating oils

This method covers the quantitative determination of barium, boron, calcium, copper, magnesium, molybdenum, phosphorous, sulfur, and Zink in unused and used lubricating oils and additive package [13].

3.2.5.1 Significance and use

This test method usually requires several minutes per sample. This test covers more than eight elements and thus provides more elemental composition data.

Additive packages are blends of individual additives, which can act as detergents, anti-oxidant, anti-wear agents, and so forth. Many additives contain one or more elements covered by this test method. Additive packages specifications are based, in part, on elemental composition. Lubricating oils are typical blends of additives packages, and their specifications are determined, in part, by elements composition. This test method can be used to determine if additive packages and unused lubricating oils meet specification with respect to elemental composition.

3.2.5.2 Summary of test method

A sample portion is weighted and diluted by mass with mixed xylene or other solvent. An internal standard, which is required, either weighted separately into the test solution or is previously combined with the dilution solvent. Calibration standards are prepared similarly. The solutions are introduced to the Inductively Coupled Plasma, ICP instrument by free aspiration or an optional peristaltic pump. By comparing emission intensities of elements in the test specimen with emission intensities measured with the calibration standards and by applying the appropriate internal standard correction, the concentrations of elements in the sample are calculated.

3.2.5.3 Test apparatus

The required apparatuses for this method are:

1. Inductively - Coupled Plasma Atomic Emission Spectrometer: Either sequential or simultaneous spectrometer is suitable, if equipped with a quartz ICP torch and RF generator to form and sustain the plasma.
2. Analytical Balance: Capable of weighing to 0.001g or 0.0001g, with sufficient capacity to weigh prepared solutions.
3. Peristaltic Pump: A peristaltic pump is strongly recommended to provide a constant flow of solution. The pumping speed must be in the range 0.5 to 3ml/min. the pump tubing must be able to withstand at least 6 hours exposure to the dilution solvent. Fluoroelastomer copolymer is recommended.
4. Solvent Dispenser (optional): A solvent dispenser calibrated to deliver the required weight of diluent can be advantageous. Ensure that solvent drip does not affect accuracy.
5. Specimen Solution Container: Of appropriate size, glass or poly olefin vials or bottles, with screw caps.
6. Vortex (optional): Vortex the sample plus diluent mixture, until the sample is completely dissolved.
7. Ultrasonic Homogenizer (optional): A bath-type or probe-type ultrasonic homogenizer can be used to homogenize the test specimen.

3.2.5.4 Reagents and materials

This includes:

1. Purity of Reagents: Reagent grade chemicals shall be used in all tests.
2. Base Oil: U.S.P white oil or lubricating base oil that is free of analyzes, having a viscosity at room temperature as close as possible to that of the samples to be analyzed.
3. Internal Standard: An oil-soluble internal standard element is required. The following internal standards were success in the inter laboratory study on precision; Ag, Be, Cd, Co (most common), La, Mn, Pb, Y.
4. Organometallic Standards: Multi-element standards, containing known concentrations (approximately 0.1 mass %) of each element, can be prepared from the individual metal concentrates. When preparing multi-element standards, be certain that proper mixing is achieved.

   More than one multi-element standard can be necessary to cover all elements, and the user of this test method can select the combinations of elements and their concentrations in the multi-element standards. It can be advantageous to select concentrations that are typically of unused oils. However, it is imperative that concentrations are selected such that the emission intensities measured with the working standards can be measured precisely (that is, the emission intensities are significantly greater than background and that these standards represent the linear region of the calibration curve. Frequently, the instrument manufacturer publishes guidelines for determining linear range).

5. Dilution Solvent: Mixed xylene, o. xylene, and kerosene were successfully used in the inter laboratory study on precision.

3.2.5.5 Internal standardization

The internal standard procedure requires that every test solution (sample and standard) have the same concentration (or a known concentration) of an internal standard element that is not present in the original sample. The internal standard is usually combined with the dilution solvent. Internal standard compensation is typically handled in one of two different ways, which can be summarized as follows:

1. Calibration curves are based on the measured intensities of each analytic divided (that is, scaled) by the measured intensity of the internal standard per unit internal standard element concentration. Concentrations for each analysis in the test specimen solution rations for each analytic in the test solution are read directly from these calibration curves. For each analytic and the internal standard element, calibration curves are based on measured (un-scaled) intensities. Uncorrected concentrations for each analytic in the test specimen solution are read from these calibration curves. Corrected analytic concentrations are calculated by multiplying the uncorrected concentrations by a factor equal to the actual internal standard concentration divided by the uncorrected internal standard concentration determined by analysis.
2. Dissolve the organometallic compound representing the internal standard in dilution solvent and transfer to a dispensing vessel. The stability of this solution must be monitored and prepared fresh (typically weekly) when the concentration of the internal standard element changes significantly. The concentration of the internal standard element shall be at least 100 times its detection limit. A concentration in the range of 10 to 20 mg/kg is typical.

3.2.5.6 Sampling

The objective of sampling is to obtain a test specimen that is representative of the entire quantity. Thus, take lab samples in accordance with the instructions in practice of sampling. The specific sampling technique can affect the accuracy of this test method.

3.2.5.7 Preparation of apparatus

The apparatus is prepared as follows:

1. Instrument: Design differences between instruments, ICP excitation sources, and different selected analytical wavelengths for individual spectrometers make it impractical to detail the operating conditions. Manufacturer's instructions for operating the instrument with organic solvents should be consulted. Setup the instrument for use with the particular dilution solvent chosen.
2. Peristaltic Pump: If a peristaltic pump is used, inspect the pump tubing and replace if necessary, before starting each day. Verify the solution uptake rate and adjust it to the desired rate.
3. ICP Excitation: Initiate the plasma source at least 30 minutes before performing an analysis. During this warm up period, nebulize dilution solvent. Inspect the torch for carbon buildup during the warm up period. If carbon buildup occurs, replace the torch immediately and consult the manufacturer's operating guide to take proper steps to remedy the situation.
4. Wavelength Profiling: Perform any wavelength profiling that is specified in the normal operation of the instrument.
5. Operating Parameters: Assign the appropriate operating parameters to the instrument task file so that the desired elements can be determined. Parameters to be included are element, wavelength, background correction points, interelement correction factors, integration time, and internal standard compensation. Multiple integrations (typically three) are required for each measurement. A typical integration time is 10 seconds.

3.2.5.8 Preparation of test specimens

Test specimens are prepared as follows:

1. Diluent: Diluent refers to the dilution solvent containing the internal standard.
2. Test Specimen Solutions: Solutions are prepared in the same way that calibration standards are prepared. The mass percentage oil in diluent must be the same for calibration standards and test specimen solutions.
3. Lubricating Oil Specimen: Weigh appropriate amount of the test specimen to nearest 0.001g. The weight of the test specimen taken will vary depending upon the metal concentration of the specimen. Dilute by mass with the diluent and mix well.
4. Additive Packages: The concentrations of additive elements in additive packages are typically ten times the concentration in lubricating oils. Therefore, additive packages are first blended with base oil before adding diluent.

3.2.5.9 Preparation of calibration standard and check standard

Preparation of calibration standards and check standards carried out as follows:

1. Diluent: The diluent refers to the dilution solvent containing the internal standard. The user of this test method has the option of selecting the diluent factor, that is, the relative amounts of sample and diluent. However, mass % sample in diluent (for calibration standard and test specimens) must be constant throughout this test method, and mass % sample in diluent must be in the range of 1 to 5 mass %. All references to dilute and diluting in this test method refer to user-selected dilution.
2. Blank: Prepare a blank by diluting the base oil or white oil with the diluent.
3. Working Standard: Weigh to the nearest 0.001g approximately 1 to 3 g of each multi-elements standard into separate bottles. Dilute by mass with diluent.
4. Check Standard: Prepared instrument check standards in the same manner as the working standards such that the concentrations of elements in the check standards are similar to the concentrations of the elements in the test specimen solutions. It is advisable to prepare the check standard from alternative sources of certified organometallic standards.

3.2.5.10 Calibration

Calibration is carried out as follows:

1. The linear range of all calibration curves must be determined for instrument being used. This accomplished by running intermediate standards between the blank and the working standards, and by running standards containing higher concentration than the working standards. Analysis of the test specimen solution must be performed with the linear range of the calibration curves.
2. At the beginning, of the analysis of each set of test specimen solution, perform a two-point calibration using the blank and working standards.
3. Use the check standards to determine if each element is in calibration. When the results obtained with the check standard are within 5% (relative) of the expected concentrations for all elements, proceed with the analysis, otherwise, adjust the instrument that are necessary and repeat the calibration.
4. Calibration curves can be constructed differently, depending on the implementation of internal standards composition;

4.1 When analytic intensities are rationed to internal standard intensities, the calibration curve is in effect, a plot of I (Re) versus analytic concentration and

$$\mathrm{I}(Re) \;=\; \{I(e) - I(Be)\} \,/\, I(is) \qquad (1)$$

Where:
I (Re) = Intensity ratio for analytic e.
I (e) = Intensity for analytic e.
I (Be) = Intensity of the blank for analytic e.
I (is) = Intensity of internal standard element.

4.2 When internal standard compensation is handed by multiplying all results for a certain test specimen by the ratio of the actual internal standard concentration to the determined internal standard concentration, the calibration curve is, in effect, a plot of $\{I(e) - I(Be)\}$ versus analyte concentration.

3.2.5.11 Analysis

Analysis is carried out as follows:

1. Analyze the test specimen solutions in the same manner as the calibration standard (that is, same integration time, background correction points, plasma conditions, and so forth). Between test specimens, nebulize dilution solvent for a minimum of 60 seconds.
2. When the concentration of any analytic exceeds the linear range of the calibration, prepare another test specimen by mixing the sample with base oil before adding diluent. Then reanalyze.
3. Analyze the check standard after every fifth test specimen solution. If any result is not within 5% of the expected concentration, recalibrate the instrument and reanalyze the test specimen solutions back to the previous acceptable check standard analysis.

3.2.5.12 Calculation and report

Calculate concentrations, based on sample using (Equation (1));

$$C = S\,X(W1 + W2 + W3)/W1 \tag{2}$$

Where:

C = Analyte concentration in the sample, mass percentage.
S = Analyte concentration in the test specimen, mass percentage.
$W1$ = Sample mass, g.
$W2$ = Diluent mass, g.
W3 = Base oil mass (if any), g.

Generally, the ICP software performs this calculation automatically.

3.2.6 Crackle test for water content

This test is intended to determine whether there is water in lubrication oil [14] and [15].

3.2.6.1 Background

Water contamination in industrial oils cause some issues with machinery components. The presence of water can alter the viscosity of lubricant as well as cause chemical changes resulting in additive depletion and formation of acids, sludge, and varnish. Water testing is always a part of any lubricant condition-monitoring program.

Water contamination in industrial oils with strong water separation properties has been historically difficult to measure with any technique. Water can coexist as three phases in an oil sample, dissolved, emulsion mix, and free globules, which can make it challenging to obtain a representative sample. The additive formulations in this type of oils are designed to separate water efficiently above saturation limits of 50-25 ppm water. Above saturation, the water will form discrete water droplets and eventually separate from the oil if left to sit.

Dissolved water is typically not too much of a concern for industrial application, but free water or emulsified water must be stringently controlled.

3.2.6.2 Crackle test

The crackle test is a simple test to determine whether there is water in lubrication oil. The crackle test can be performed in the field using a hot plate. The test is mostly qualitative. It tells you whether there is water present. Careful observation of the oil on the hot plate can gives some semi qualitative information about the amount of water present, but it is very dependent on the skill of the operator.

The crackle test requires a temperature controlled hot plate. Typically, the hot plate temperature is set to approximately 160^0 C. ideally; vigorous shaking mixes the sample. This creates a more homogenous suspension of water in oil. Once the sample is prepared, a drop of oil is placed onto the hot plate and observed.

If there is no water in the oil, no crackling will be observed. Conversely, if the oil does contain liquid water, the heat will cause it to change to vapor stage creating observable bubbles in the oil droplet. The size of the bubbles roughly correspond to the amount of water present in the oil, the large the bubble, the more water there is dissolved in the oil. By observing the size of the bubble created in the hot plate, some quantitative judgments can be made about the concentration of water present in the oil sample.

4 ANALYSIS AND RESULTS

4.1 Samples collection duration

Samples of used oil analysis for this study were collected in the period from November 2018 to December 2019 based on engines operation schedule and overhaul plans. The intervals of samples collection were about four weeks or 500 running hours.

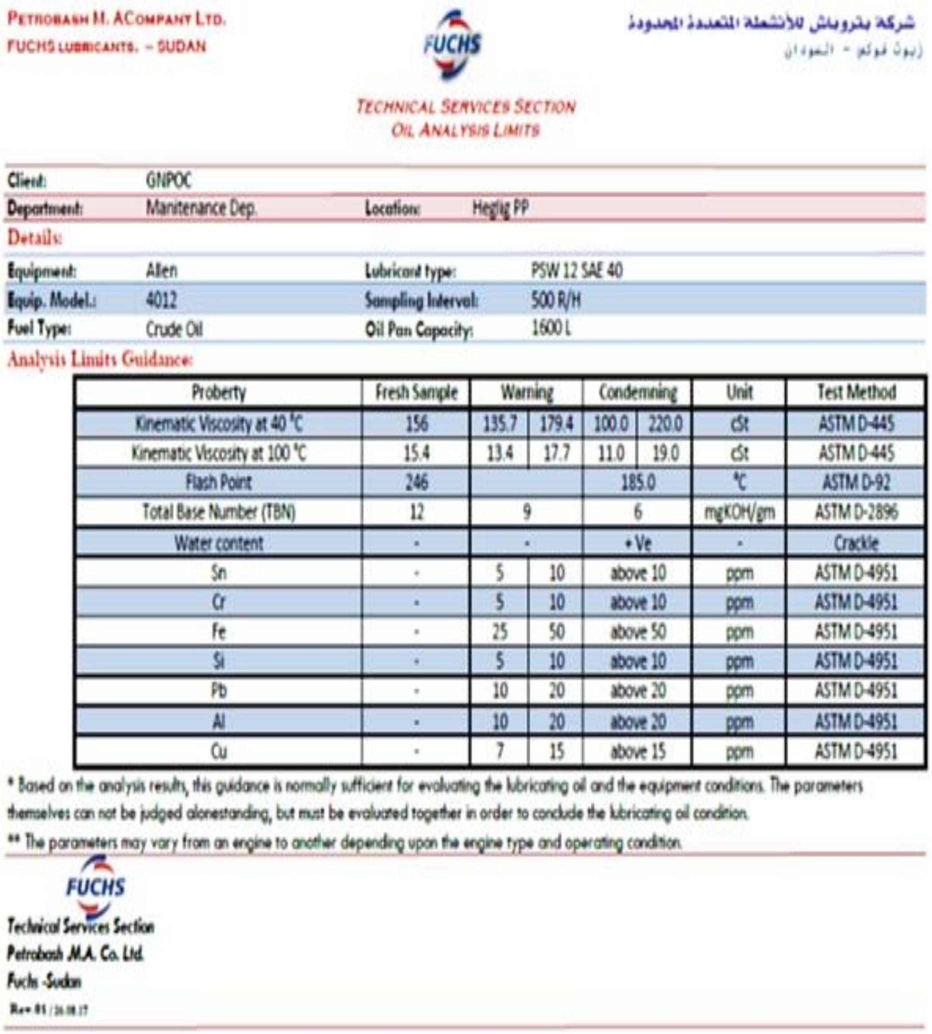
4.2 Samples analysis

Used oil samples are subjected to many tests, which considered in the previous chapters to assess used oil quality for more usage, and to monitor the condition of engine internal parts for any kinds of wear, based on the limits given by lube oil manufacturer for each parameter as per Table 1.

4.3 Test analysis reports

The results of used oil analysis test are given in test reports with interpretation and recommendation, and a trend analysis reports for oil viscosities at 40^0 C and 100^0 C and Base Number. Table 2 summarized engines used oil analysis results and its interpretations and recommendations.

Table 1. Lube oil analysis limits guide lines



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زيوت فوكس - السودان

FUCHS

TECHNICAL SERVICES SECTION
OIL ANALYSIS LIMITS

Client:	GNPOC		
Department:	Manitenance Dep.	**Location:**	Heglig PP

Details:

Equipment:	Allen	**Lubricant type:**	PSW 12 SAE 40
Equip. Model.:	4012	**Sampling Interval:**	500 R/H
Fuel Type:	Crude Oil	**Oil Pan Capacity:**	1600 L

Analysis Limits Guidance:

Proberty	Fresh Sample	Warning		Condemning		Unit	Test Method
Kinematic Viscosity at 40 °C	156	135.7	179.4	100.0	220.0	cSt	ASTM D-445
Kinematic Viscosity at 100 °C	15.4	13.4	17.7	11.0	19.0	cSt	ASTM D-445
Flash Point	246			185.0		°C	ASTM D-92
Total Base Number (TBN)	12	9		6		mgKOH/gm	ASTM D-2896
Water content	-	-		+Ve		-	Crackle
Sn	-	5	10	above 10		ppm	ASTM D-4951
Cr	-	5	10	above 10		ppm	ASTM D-4951
Fe	-	25	50	above 50		ppm	ASTM D-4951
Si	-	5	10	above 10		ppm	ASTM D-4951
Pb	-	10	20	above 20		ppm	ASTM D-4951
Al	-	10	20	above 20		ppm	ASTM D-4951
Cu	-	7	15	above 15		ppm	ASTM D-4951

* Based on the analysis results, this guidance is normally sufficient for evaluating the lubricating oil and the equipment conditions. The parameters themselves can not be judged alonestanding, but must be evaluated together in order to conclude the lubricating oil condition.

** The parameters may vary from an engine to another depending upon the engine type and operating condition.

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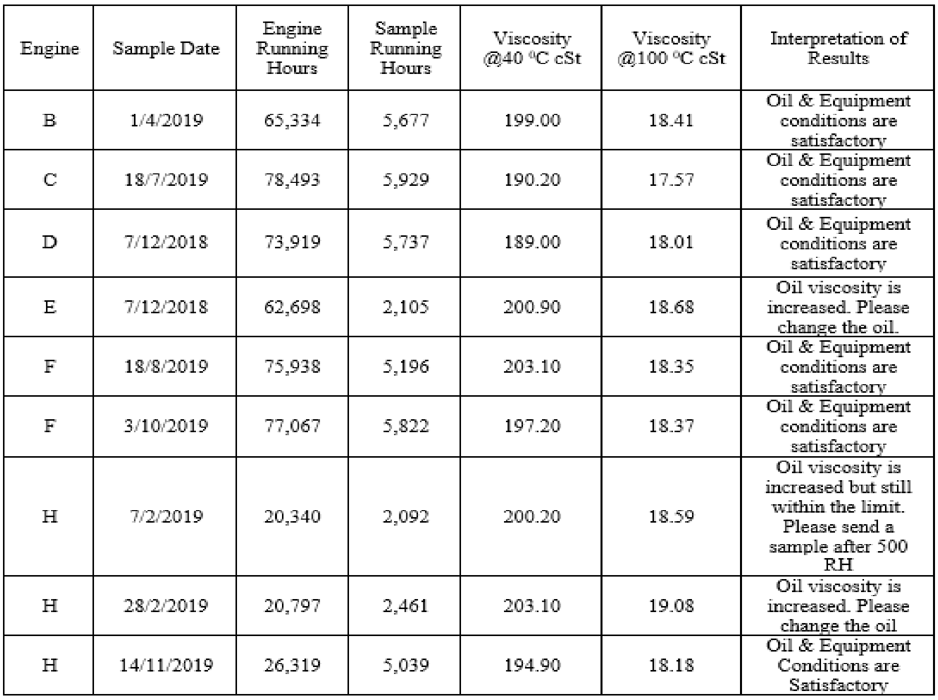
Table 2. Summary of oil analysis reports and its recommendations



Engine	Sample Date	Engine Running Hours	Sample Running Hours	Viscosity @40 ^{o}C cSt	Viscosity @100 ^{o}C cSt	Interpretation of Results
B	1/4/2019	65,334	5,677	199.00	18.41	Oil & Equipment conditions are satisfactory
C	18/7/2019	78,493	5,929	190.20	17.57	Oil & Equipment conditions are satisfactory
D	7/12/2018	73,919	5,737	189.00	18.01	Oil & Equipment conditions are satisfactory
E	7/12/2018	62,698	2,105	200.90	18.68	Oil viscosity is increased. Please change the oil.
F	18/8/2019	75,938	5,196	203.10	18.35	Oil & Equipment conditions are satisfactory
F	3/10/2019	77,067	5,822	197.20	18.37	Oil & Equipment conditions are satisfactory
H	7/2/2019	20,340	2,092	200.20	18.59	Oil viscosity is increased but still within the limit. Please send a sample after 500 RH
H	28/2/2019	20,797	2,461	203.10	19.08	Oil viscosity is increased. Please change the oil
H	14/11/2019	26,319	5,039	194.90	18.18	Oil & Equipment Conditions are Satisfactory

4.4 Results of oil analysis

During the period of this study, the numbers of sent used oil samples for each engine was varying between 7 to 11 samples based on engines operation schedule and engines overhaul plans. The following results are found during the study, and showed some benefits of carrying out these activities:

1. Five engines (out of eight) were successfully exceeded the targeted 5000 running hours with the normal oil topping up.
2. Two engines were subjected to oil replacement as per analysis result recommendation due to increased viscosity.
3. Two engines were subjected to lube oil replacement to some engine parts failure, which led to lube oil contamination and thus oil viscosity increased.
4. One engine is subjected to lube oil replacement before reaching the targeted running hours due to overhaul plan.
5. Three engines were subjected to lube oil replacement according to increased viscosity as per analysis result, but no reason found for this increment.
6. No any potential failure detected by using used oil analysis for condition monitoring and the metallic particles are within the lube oil manufacturer limits, which indicate to the healthiness of engine internal parts.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Used oil main parameters (viscosity, viscosity index, base number, water content and metallic particles) are being analyzed to assess the oil quality to provide recommendation on its suitability for further use in power plants and sea water decks facilities, and to assess the condition of the engine to enable detection and prevention of any potential issues that may impact the reliable operation of the engine. The interpretation of the study results of used lube oil conclude that the good management of lubricant is extending the intervals of oil replacement to more than the targeted five thousand running hours with the normal lube oil topping up, by a close monitoring for lubricant quality.

The study shows lubricating oil has less contamination and has a low concentration of metallic particle, which indicates a good oil quality. This shows the good health condition of engines and less potential failure of components. The study shows that reliability of engines is increased, because the potential failures are detectable and could be avoidable.

The contribution of used oil analysis technique is well determined by the study through cost cutting by extending oil replacement interval and reducing the number of services and its consequence costs.

5.2 Recommendations

The study implicates the need to:

1. Avail On-Site analysis kits for a quick test for immediate recommendation.
2. Install on line test devices for a continuous testing and condition monitoring to fill the gap between oil sampling.
3. Build Structured Query Language (SQL) database to capture all engines lube oil test results for predictive maintenance utilization.
4. To carry out a regular test analysis for engine cooling water to assess its suitability for corrosion inhibiting to eliminate water passages failure, which may lead to lube oil contamination.

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