Cost Effective Method to Analyse Lubrication Oil

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Abstract— The lubricating oil analysis is the most common method to identify the condition of any machinery. There are various ways to analyse lubricating oil based on an individual examination of lubricant properties such as Viscosity, Total Base Number (TBN), Total Acidic Number (TAN), Water Content, Impurities (element analysis) etc. However, the equipment required to conduct these analyses are costly, need specific environmental conditions, and generally time consuming. The time consumption of this whole process hampers the maintenance program efficiency. Hence, an onsite, cost-effective, and faster results-giving method to analyse lubricating oil would be a valuable asset. A comprehensive literature survey was carried out to understand the current trends in lubricating oil analysis. Accordingly, the analysis techniques could be categorized as Physical, Chemical, Electro-magnetic, and Optical. The proposed design is based on an optical technique that deals with the Refractive Index (RI) since it is an indicator of the physical as well as the chemical property characteristic of a substance. The critical angle of a material is directly related to RI. Monitoring the critical angle changes leads to an understanding of the quality of the lube-oil. The performance of a proposed lube-oil analyser was assessed using Shell Gardenia 40 (lubricating oil used in high-speed marine engines of Fast Attack Craft) lubricant at different operating hours. The results obtained from the proposed device were compared with the tests carried out according to the American Society for Testing and Materials (ASTM) standards and through a viscometer. Both tests confirm the effectiveness of the proposed device.

Keywords: ***lubricating oil analysis, refractive index, cost-effective lubricating oil analyzer***

I. INTRODUCTION

The relative movement of rubbing parts creates resistance. This resistance is called friction between the rubbing surfaces, and it causes a lot of wear and tear and could also convert a part of the energy of motion into heat. Lubricants are used to reduce this resistance and the other adverse effects caused by it.

At present, Sri Lanka Navy practices Planned Preventive Maintenance (PPM) or scheduled maintenance procedures to maintain machinery condition. The manufacturer of the machine will indicate a schedule (specific time period) to change the lubrication oil without considering the usability of the used oil.

In Condition Based Preventive Maintenance (CBPM) method it is used similar to blood samples are used in diagnostics, lubrication oil analysis of a machine can be used to detect or predict the machine failures.

The contemporary methodology of analysis of the lubrication oil using laboratory-based methods takes considerable time. The current practice is based on specific property analysis of lubricating oil such as viscosity, impurities available (carbon content, dilution, water content, and material particles) etc. These lab-based investigation methods require special conditions such as controlled environments (temperatures, humidity, etc.) and proper sampling methods. Hence, the requirement of a cost-effective lubrication oil analysis method that will not require controlled environmental conditions can enhance the cost-effectiveness of maintenance. This in turn facilitate decision making with lesser delays.

It is essential to replace the lubrication oil with an early notice during industrial applications because an unexpected failure of any machinery will affect the process of the product directly and also the particular machine requires to be stopped to minimize further damages or wear.

The performance parameters are under the variations of optical, electrical, chemical and physical properties which will affect the characteristic changes of a particular lubrication oil towards its degradation. The performance parameters could be identified as viscosity, water content, Total Acid Number (TAN), Total Base Number (TBN), particle counting, flash point, spectrometric oil analysis, etc.

The objective of the study is to identify the functions of lubricants in a lubrication oil system including these main properties of a lubricant. Further to design and fabricate a cost-effective lubrication oil analyzer to check the condition of lubricating oil.

II. UNDERSTANDING THE LUBRICANTS

A. Main Functions of Lubricants

The main functions of lubricants during the rubbing between the surfaces are as follows;

i. It avoids direct metal to metal contact between the surfaces and reduces wear and tear (Lubricants will create an oil film within the surfaces).
ii. Heat is generated due to friction and it destructs the material. Lubrication oil reduces the expansion of metal due to generated heat.
iii. Acts as a coolant since it is a medium to heat transfer.
iv. It avoids rough conditions of the relative movement of surfaces (due to unevenness of the surfaces).
v. Minimizes the cost of maintenance since increases the life expectancy of the equipment.

B. Important Properties of Lubrication Oil

The most important properties that could be used to analyse the condition of the lubrication oil are as follows;

i. Viscosity and Viscosity Index (VI)
ii. Flash point and Fire point
iii. Cloud point and Pour point
iv. Oxidation stability
v. Aniline point
vi. Corrosion stability

III. METHODOLOGY

A. The Constraints of Available Lubrication Oil Analysis Methods

The available lubrication oil analyzing methods are based on the degradation of lubrication oil. These methods are based on identifying the changes in a single property of lubricating oil or calculating the amount of impurities added to lubrication oil. Hence, the lubricating oil analysis reports are providing only the quantitative values of changes related to the aforesaid lubricating oil properties or added impurities. The decision to change the oil or to analyze the condition of the machine is based on these analysis reports. The main disadvantages of this analyzing system are the high cost to analyze a single method of lubrication oil and also the time duration to obtain the reports. Also due to a large number of sampling carried out by the service providers, mishandling of provided sample, adding impurities to the sample, and misplacing of provided samples could result in inaccuracies of the reports.

The available lubricating oil analyzing methods, could be categorized into physical, electrical (magnetic), chemical, and optical techniques. After scrutinizing, it was decided to use an optical method to design a cost-effective lubrication oil analyzing device. The device is to be designed based on the Refractive Index (RI) which is a physical property with the characteristic of a pure compound.

B. The Working Principle of the Designed Lubricating Oil Analyzer

Any visible light changes its direction when it passes through a material with a higher Refractive Index (RI) to that with a lower Refractive Index. As the incident ray angle, Alfa (α) increases, the refractive angle, Beeta (β) will increase in accordance with Snell's Law, and when the refractive angle 'β' (where the incident ray angle 'α') reaches the critical angle (=90°), the total refraction will occur at the boundary between the prism and the lubricating oil sample. However, when the incident ray angle increased beyond 'α_c' (critical angle), the light cannot enter the medium (which is the oil sample) and reflects to the prism. The special feature of this action is the critical angle of the lubrication oil sample will vary with the Refractive Index (RI) of the particular sample. The RI of a lubrication oil sample will be based on the properties of it such as viscosity, suspended particle density, dilutions (liquid impurities), water content and chemical properties.

When we use a divergence beam of light towards the lubrication oil sample through the prism, a fraction of light rays will have an incident angle higher than the critical angle. A schematic diagram of the working principle of the designed lubrication oil analyzer is shown in Figure 1. Because of that, the internally reflected light could be obtained as an image to a separate plane. This image will have a brighter and darker region due to the partial internal reflection of light. When the critical angle changes with a refractive index of the lubrication oil sample, the brighter and darker region of the internally reflected image will change. Further, the appearance of the internally reflected image will vary as per the quality of the lubrication oil sample.

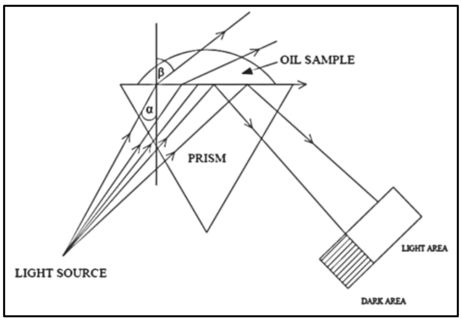

Figure 1. A schematic diagram of the working principle of the designed lubrication oil analyzer

The proposed design of lubrication oil analyzing equipment is based on the reflection theory. It has the capability of comparing the internally reflected image of the original lubrication oil (brand new oil or unused oil) and used lubrication oil. The internally reflected image that is going to be obtained by analyzing unused oil will be examined to understand the main features of the image.

The internally reflected image of the unused oil sample, the area of the brighter region will indicate the quality of the lubrication oil sample where it will depend upon the refractive index. It can be taken as a reference to check the used oil samples which have been taken from the engines. However, the used oil samples are going to be obtained as per pre-defined time frames to identify the variation in the internally reflected image until the Original Equipment Manufacturer (OEM) given lubrication oil changing intervals.

A separate comprehensive computer programme could be used to identify and calculate the variations of the brighter area of the image to analyze the original oil and the used oil. This programme could be used to analyze the condition of any given lubrication oil sample by understanding the internally reflected image comparing with the image of the original oil. However, the reference image is to be obtained by using fresh oil/ new oil samples of any kind of lubrication oil before starting the checking of the used oil samples.

C. Practical Application of the Equipment

During the testing of the designed cost-effective lubrication oil analyzer, the lubrication oil (Shell Gardenia 40) is used in MTU 12 V 396 TE 94 engines because these engines are high speed marine engines. For MTU 12V 396 TE 94 engines, the oil changing interval is 500 operating hours (where centrifugal filters are fitted) as indicated by the OEM. Engine Oil Requirements are selected as per the Original Equipment Manufacturer (OEM). Viscosity class selection is determined in accordance with the engine oil temperature at the time of starting.

IV. FABRICATION OF LUB OIL ANALYZER

A. Components used to Design the Oil Analyzer

i. Prism
ii. Wiring system
iii. Converging lens
iv. Camera
v. Computer
vi. Computer programme

B. Construction Process of the Analyzer

The sample of the used lubrication oil should have the capability to remain within the position even in rough environmental conditions. Therefore, the prism is positioned on the top most part of the equipment (horizontally). Further, there is a circular groove on the upper most plate to pour the lubrication oil samples and the prism is fixed to the cover with a rubber packing to stop leaking of lubrication oil.

A light beam is produced with the help of a Light Emitting Diode (LED) bulb and the direction of the light beam was designed to be adjustable. In addition, a converging lens is fixed to the end of the screw to focus the light beam towards the prism and it will enhance the intensity of the light beam by improving the quality of the internally reflected image.

The electrical circuit is powered by 230 V electric power supply through a power pack and it consists of a variable resister and a switch. Further, the camera is fixed in a side wall of the lubrication oil analyzer, where it can be adjusted to get a clearer image to the computer. The lubrication oil analyzer functions with an optical method and it is mandatory to remove the effect of natural light and other light sources to get an effective outcome of the results. Hence, the equipment is fabricated in a box-shaped arrangement, covering all sides as shown in Figure 2.

Figure 2. Box-shaped arrangement of the designed lubrication oil analyzer

V. DATA PRESENTATION AND ANALYSIS

The fabricated lubrication oil analyzer is tested using the lubrication oil samples obtained through the MTU 12V 396 TE 94 marine engines. Shell Gardenia 40 mono grade lubrication oil is used for these engines. The samples are collected from the relevant engines at an interval of 100 hrs (from 0 hrs- 500 hrs) for 3 different oil samples per each time interval. The internally reflected image obtained without pouring the test samples through the lubrication oil analyzer is a single elliptic shaped image since the camera is not in-line with the image. The obtained image is shown in Figure 3.

Figure 3: Internally reflected image without pouring oil samples to the designed analyzer

The design lubrication oil analyzer is highly depending upon the original oil condition (fresh oil sample of the particular lubrication oil). Hence, 03 new lubrication oil samples of Shell Gardenia 40 were analyzed through the designed analyzer and captured the images of the oil samples (03 Nos samples) are shown in Figure 4.

Figure 4. The captured images of the new lubrication oil samples (Shell Gardenia 40)

The second stage is to obtain the internally reflected image for the first used oil sample, after 100 operating hours. A significant difference can be observed between the images for the new lubrication oil sample and the 100 hours operated lubrication oil sample. The images after 100 operating hours are shown in Figure 5.

Figure 5. The captured images for the 100 hours operated used lubrication oil samples (Shell Gardenia 40)

The comparison of the images obtained through the designed lubrication oil analyzer for the new Shell Gardenia 40 oil sample and 100 operating hours used oil is shown in Figure 6. A considerable deviation in the area of the bright region between the two images can be identified.

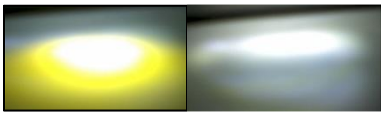

Figure 6. Comparison of the received images of new oil and 100 hours operated used oil sample

The third stage is to check the used oil after 200 operating hours. However, a vast difference between the images of 100 hours operated used oil and the 200 hours operated used oil may not be observed during the comparison. The images of the three samples (200 operating hours) are shown in Figure 7.

Figure 7. The captured images for the 200 hours operated used lubrication oil samples (Shell Gardenia 40)

Similarly, the other samples at 300 hrs, 400 hrs, and 500 hrs were compared with the obtained images using the fabricated lubrication oil analyzer.

A. Comparison of the Results

The results obtained for the 100 hrs used oil to 500 hrs used oil are similar to each other. It indicates the condition of used oil up to 500 hrs operating hours is suitable to operate for a longer period. Thus, even though the OEM recommended Oil Draining Interval (ODI) is after 500 operating hours, depending on the condition of the lubrication oil operating hours can be extended. However, to cross examine whether the obtained readings through the designed lubrication oil analyzer is accurate, the same lubrication oil samples are analyzed with the help of under mentioned lubrication oil analyzing methods.

1) *Viscosities of the samples through Viscosity Comparator*

2) *ASTM Standards*

i. ASTM D 5185 – 05 (Standard test method for Determination of Additive Elements, Wear Metals, and Contaminants)
ii. ASTM D 445 – 06 (Standards test method for Kinematic Viscosity)
iii. ASTM D 4739 – 06a (Standard test method for Base Number)
iv. ASTM D 7899 – 13 (Standard test method for Measuring the Merit of Dispersancy)
v. ASTM D 893 – 05a (Standard test method for Insolubles in Used Lubricating Oils)
vi. ASTM D 92 – 05a (Standard test method for Flash and Fire Points)
vii. ASTM D 95 – 05 (Standard test method for Water in Petroleum Products)

As per the viscosity readings of each used lubrication oil sample, the viscosity is within acceptable limits for the used lubrication oil samples up to 500 operating hours. To finalize the performance evaluation of the lubrication oil analyzer, ASTM standards checking were carried out for the used oil samples of 50 hrs, 250 hrs and 500 hrs.

Table 1. Element Concentration after 50 operating hours

Elements	Method	Maximum Permissible Limit	Fresh Oil Sample	Port Main Engine	Stbd Main Engine
Fe	ASTM 5185	80	< 1.000	19.344	30.921
Cr	ASTM 5185	10	< 1.000	< 1.000	1.107
Si	ASTM 5185	15	< 1.000	1.498	2.955
Al	ASTM 5185	20	< 1.000	< 1.000	< 1.000
Pb	ASTM 5185	20	< 1.000	3.320	4.026
Cu	ASTM 5185	25	< 1.000	13.690	17.313
Sn	ASTM 5185	10	< 1.000	< 1.000	1.196
Ni	ASTM 5185	10	< 1.000	< 1.000	< 1.000

Table 2. Analysis for other ASTM Standards after 50 operating hours

Description	Method	Fresh Oil	Port M/E	Stbd M/E
Viscosity @ 40^0 (cSt)	ASTM D 445	139.00	133.25	132.73
Viscosity @ 100^0 (cSt)		14.40	14.00	14.14
Viscosity Index	ASTM D 2270	103	101.94	103.68
Total Base No. mg KOH/g	ASTM D 4739	10.48*	6.78	6.43
Water Content	ASTM D 95	<0.2	<0.1	<0.1

Table 3. Element Concentration after 250 operating hours

Element	Method	Maximum Permissible Limit	Fresh Oil Sample	Port Main Engine	Stbd Main Engine
Fe	ASTM 5185	80	< 1.000	10.422	9.776
Cr	ASTM 5185	10	< 1.000	< 1.000	< 1.00
Si	ASTM 5185	15	< 1.000	1.738	1.532
Al	ASTM 5185	20	< 1.000	< 1.000	< 1.00
Pb	ASTM 5185	20	< 1.000	< 1.000	< 1.00
Cu	ASTM 5185	25	< 1.000	5.482	5.083
Sn	ASTM 5185	10	< 1.000	< 1.000	< 1.00

Ni	ASTM 5185	10	< 1.000	< 1.000	< 1.00

Table 4. Analysis for other ASTM Standards after 250 operating hours

Description	Method	Fresh Oil	Port M/E	Stbd M/E
Viscosity @ 40⁰ (cSt)	ASTM D 445	139.00	133.25	132.73
Viscosity @ 100⁰ (cSt)		14.40	14.00	14.14
Viscosity Index	ASTM D 2270	103	101.94	103.68
Total Base No.	ASTM D 4739	10.48*	6.78	6.43
Water Content	ASTM D 95	<0.2	<0.1	<0.1

Table 5. Element Concentration after 500 operating hours

Element	Method	Maximum Permissible Limit	Fresh Oil Sample	Port Main Engine	Stbd Main Engine
Fe	ASTM 5185	80	< 1.000	10.422	9.776
Cr	ASTM 5185	10	< 1.000	< 1.000	< 1.00
Si	ASTM 5185	15	< 1.000	1.738	1.532
Al	ASTM 5185	20	< 1.000	< 1.000	< 1.00
Pb	ASTM 5185	20	< 1.000	< 1.000	< 1.00
Cu	ASTM 5185	25	< 1.000	5.482	5.083
Sn	ASTM 5185	10	< 1.000	< 1.000	< 1.00
Ni	ASTM 5185	10	< 1.000	< 1.000	< 1.00

Table 6. Analysis for other ASTM Standards after 500 operating hours

Description	Method	Fresh Oil	Port M/E	Stbd M/E
Viscosity @ 40⁰ (cSt)	ASTM D 445	139.00	126.96	120.96
Viscosity @ 100⁰ (cSt)		14.40	13.36	13.24
Viscosity Index	ASTM D 2270	103	101.94	103.68
Total Base No. mg KOH/g	ASTM D 4739	10.48*	6.78	6.43
Water Content	ASTM D 95	<0.2	<0.1	<0.1

After the comparison of the results obtained through the viscosity comparator and the ASTM standards, it is observed that the condition of lubrication oil samples is good. Moreover, it is observed that the results obtained through the lubrication oil analyzer is also accurate since it shows that the lubrication oil samples are in usable condition.

The results through the designed lubrication oil analyzer could be finalized with a help of a computer programme by considering the features of the obtained internally reflected images for a lubrication oil. A computer programme is written to identify the area of the brighter region of the internally reflected image of each lubrication oil sample. The computer program will identify the number of pixels within the area of the brighter region. The interface of the computer program is shown in Figure 8.

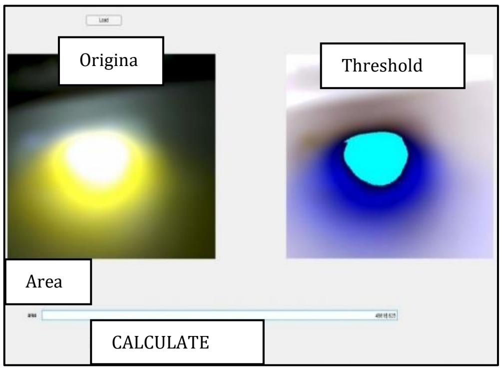

Figure 8. Computer program interface to calculate the area of brighter region for an oil sample.

The variation of the area (brighter area) can be identified for the fresh oil sample and all other used oil samples to visualize the changes of the image area. As per the images obtained for the Shell gardenia 40 lubrication oil samples, the calculated details of areas are indicated in Table 7.

Table 7. Area of the brighter part of the images obtained for Shell gardenia 40 oil samples.

Operated hours	New oil (0 hrs)	100 hrs	200 hrs	300 hrs	400 hrs	500 hrs
Area of brighter region	116337	73369	71310	72258	71062	75374

The used lubrication oil samples which are obtained from the MTU 12V 396 TE 94 marine engines are within the acceptable limits even after 500 operating hours in accordance with the visualized processes mentioned below. The results of the designed lubrication oil analyzer also could be justified with the following reports.

i. Viscosity reading of the viscosity comparator (for sample intervals of 100, 200, 300, 400, and 500 hours).
ii. ASTM standards checking for lubrication oil samples (for sample intervals of 50, 250, and 500 operating hours).

However, the readings obtained through the designed lubrication oil analyzer could be further justified by understanding the correlation between the usable lubrication oil and the diluted oil (mixed with diesel). A usable lubrication oil sample of Shell Gardenia 40 is diluted forcibly with 25%, 50%, and 100% diesel quantities separately. After these lubrication oil samples are analyzed through the designed lubrication oil analyzer.

Table 8. Areas of the brighter part of the images obtained for Shell gardenia 40 diluted lubrication oil samples

Dilution of lubrication oil (%)	Used oil (>1)	25%	50%	100%
Area of brighter region (No of pixels) of the image	23778	28525	34170	39686

It is obvious that the brighter area of the internally reflected image is increasing (compared to good quality used lubrication oil) with the percentage increment of mixed diesel.

VI. CONCLUSION

The results have been obtained through the designed lubrication oil analyzer are cross examined with the results obtained by using viscosity comparator and also with the ASTM standards lubrication oil analyzing methods. During the comparison, it is understood that the readings which are obtained through the designed cost-effective lubrication oil analyzer are accurate.

Further, the results obtained through the lubrication oil analyzer for the correlation between the dilution in a particular lubrication oil (mixing with diesel) samples and usable used oil samples are also confirming the accuracy of the analyzer.

VII. RECOMMENDATION

The requirement of a cost effective lubrication oil analyzing technique is to identify the condition of lubrication oil which will not require any special considerations on the environmental conditions (temperature and other atmospheric conditions) and also to fulfil the feasibility to conduct the lubrication oil analysis at the location where the machinery is installed will enhance the effectiveness and the efficiency of the production process which is the particular machinery is required. The fabricated equipment could be used to fulfil the above requirement since the output results are accurate when compared to prevailing lubrication oil testing methods.

Further, the ODI of a particular machine can be extended beyond the OEM provided oil changing interval after analyzing the results obtained through the designed cost-effective lubrication oil analyzer. However, it is recommended to further improve the system by automating the analysis entirely to assess the condition of lubrication oil where it will not require human involvement and monitor the degradation trend of lubrication oil cost-effectively.

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