IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 2 Ver. II (Mar. - Apr. 2018), PP 63-71
www.iosrjournals.org

Development of Maintenance Decision Guidelines from Used Oil Data of a Thermal Powerplant.

Kamunge.m.m[1], Prof.P.N.Muchiri[2], Dr.Chris.O. Adika[3], J.M Wakiru[4]
[2&4]Department of mechanical engineering, Dedan Kimathi University of technology-Kenya
[3]Department of mechanical engineering Multi- Media University of kenya-kenya
Corresponding Author: Kamunge.m.m

Abstract: *Engine is the most critical operating mechanism in industrial machines. Its function is to transmit power to the parts of the machine. Diesel power plants utilize two or four stroke engines in their operations and needs to be lubricated with the appropriate lubricant to maintain their performance and reliability. The lubricant creates a thin film between the sliding surfaces thus reducing friction in the machine. Base oil and additives are two ingredients of the lubricant. The base oil gives lubrication to the moving parts to protect them from wear caused by friction while additives prevents deterioration of oil under extreme temperature. Condition monitoring in power plants arises from the fact that in a power plant unexpected fault or shutdown may result to fatal accident or huge loss of output. The recent development in computer and transducer technologies, signal processing and artificial–intelligence (AI) techniques has made it possible to implement condition based maintenance (CBM) more effectively. The objective of this study was to develop a maintenance decision guideline to enhance CBM in a power plant. A detailed analysis of used oil data was done. Viscosity, TBN, pentane insoluble, silicon and vanadium were the parameters analyzed using trend graphs which located their patterns of performance at different points of usage time. Parameter that exceeded threshold limits were marked for RCA analysis. Cause and effect analysis and the five whys were applied in the methodology to further investigate the reasons for oil degradation. Oil degradation as observed in the results occurred at 3000 hrs. Of engine run but control action was taken at 5000 hrs. Which marked the optimum useful life of the lubricant. Lubricant failure triggered mitigating action to be instituted. Combination of theory and experimental results was useful in developing maintenance decision guidelines to enhance CBM in the plant.*

Keywords: *Used oil analysis,useful life of the lubricant, preventive maintenance, root cause analysis(RCA).*

Date of Submission: 15-03-2018 Date of acceptance: 31-03-2018

I. Introduction

The current electricpower supply in Kenya is not sufficient for the fast rising population. This fall below the year 2015/2016 demand of 2500MW thus the need for alternate supply from independent power producers which predominantly is got from thermal power plants[**www.vision2030, 2016**].In thermal power plants it is essential to rotate the rotor of an alternator by means of a prime mover. The prime mover can be driven by different methods. Using diesel engine as prime mover is one of the popular methods of generating power. When prime mover of the alternators is diesel engine, the power station is called diesel power station .Diesel power plant produce power at a range of 2 to 50 Mw.

Most diesel power plants operate with distillate fuel oil (DFO) or heavy fuel oil (HFO).DFO is very common in an output category of 1 to 2 Mw, whereas engines of above 5MW usually operate with HFO. It is rather common that the power plant engines are able to burn fuel with a viscosity of 700cst.To improve the performance and the overall equipment efficiency of a power plant engine, lubrication is a major necessary requirement. Due to the friction of the contact parts of the engine, some means of lubrication must be incorporated to reduce component wear. As such means of monitoring the condition of lubricating oil should be enhanced in the system. In diesel power plant lubricating oil is stored in main lubricating oil tank, which is drawn from the tank by means of oil pump. Then the oil is passed through the oil filter for removing impurities. From the filtering point, this clean lubricating oil is delivered to the different points of the machine where lubrication is required. The oil cooler is provided in the system to keep the temperature of the lubricating oil as low as possible.

Thermal power plants uses CBM maintenance program. CBM program assures a strategy by which maintenance is undertaken only when the component/system reaches a particular state/condition, usually one which is believed to be a precursor to in-service failure. In thermal power plant three critical issues are necessary for CBM to be successful: a) the accuracy of the inspection, b) inspection interval, c) condition limit.

CBM uses primarily non-intrusive testing techniques, visual inspection, and performance data to assess engine condition[**Newell, G.E, 1999**] CBM offers a maintenance perspective utilized by power plant to dynamically supervise the health condition of the engine, to perform maintenance just if it is required and at the appropriate period.

CBM approach specifies a predictive maintenance (Pd.M.) program, based on continuously monitoring the equipment conditions for predicting equipment failure occurrence. The CBM program involves used oil tests done systematically. Thermography testing and vibration monitoring of the machine are also done to give more information about the health of the engine but used oil analysis is a frontline testing technique done without necessarily stopping the equipment and may reveal a lot of information [**Toms. L, 1998].**

1.1 Oil analysis in thermal power plant

In power plants, the lubricant is subjected to extreme temperatures, varying load weights and contamination. Lubricant performance deteriorates under these conditions, and thus oil analysis becomes essential to monitor lubricant condition. Oil analysis is used extensively to help organization maintain their equipment. In order to take full benefit from the test data, it is important to understand the basic properties of a lubricant. Equally important is the understanding of how these properties affect the ability of the lubricant to function.

Two main ingredients of oil are affected i.e. the base oil and additives. During their use, these additives lose their characteristics rendering the lube oil non usable for lubricating purpose. In addition, during their use, the lubricating oils and the metal processing oils pick up fractions of various metals as a result of wearing out of components. The concentration of these impurities depends purely on the application to which the particular oil is put to [**Kumar, M., etal 2013].,**Oil analysis is a necessary predictive maintenance techniques for organizations to reduce costs and to remain competitive .Oil analysis is widely used in industries and maintenance costs can be reduced by 30% by implementing an oil analysis program [**Newell, G.E, 1999**].
Lastly, knowledge of the common test methods and instrumentation used to analyze oil will aid in data interpretation and lead to more productive corrective action. After gaining a fundamental understanding of lubrication, oil analysis technique would be useful to demonstrate the unique challenges inherent in the thermal power plant and how effectively the analysis can be used to enhance CBM. Oil analysis is the most effective way to prolong the useful life of your lubricants while maintaining maximum protection of your equipment. Oil analysis tests in power plant reveal information that can be broken down into two categories namely the lubricant condition and the contaminants.

1.2 Lubricant condition.

Assessment of the lubricant condition reveals whether the system fluid is healthy and fit for further service, or is ready for a change. One of the many by-products of combustion is soot. Soot can be highly abrasive as well as cause filters to become filled and/or plugged in extreme cases. Another contaminant is acidic by-products of combustion, which can produce a highly corrosive mixture and cause corrosion and pitting of internal engine components and additional generation of wear debris. These same acidic solutions can also mix with water inside the engine and form an emulsion that can cause problems with oil filters and passageways **[S.J.Hashemi, S.A.Adnani etal 2013].**A single teaspoon of dirt can sufficiently contaminate 210 liters of oil to the point where it will totally ruin an engine [**Wakiru.J.M, 2014],**Dirt and contamination are by far the number one cause of system failures in engines. Roughly 80% of hydraulic failures are the result of fluid contamination.

1.3 Contaminants

Contaminants can be gaseous, fluid, semi-solid or solid. Modern machinery has evolved in its capabilities, operating at higher temperatures and pressure – for example, it is not uncommon for diesel fuel system that operated at 3,000 psi a few years ago to run at pressures as high as 30,000 psi in today's state-of-the-art fuel system. This means that particles as small as 5 microns can affect a hydraulic system, thus imposing much harsher contamination prevention requirements to keep systems running to acceptable performance [**Fitch J. 2007**].The scenario is similar for lubricants. If they become dirty, heat dissipation decreases. The viscosity thins and the engine cases wear faster or motors may overheat. Again, the result may not be immediate, but the useful life of the component will decrease.

1.4 Critical literature review

In literature review several studies details the application of UOA to maintenance. Different methodologies have been used to analyze the lube oil in systems and conclusions drawn.[**P.K Upadhyay 2013]** proposed that engine oil is an important and the most essential part of machine system. Oil monitoring is a tool to determine lubricant useful life. Lubricating oil analysis can be made for performance testing or engine condition. Knowledge of systems failure modes is helpful for cost effective .researcher used analytical xerography technique to analyze the wear particles present in the used oil. He concluded that used oil analysis is known to be an effective tool for health monitoring and a proactive maintenance technology.**[Amit Kumar Gupta 2012]** used oil analysis reveals the particles in the fluid indicating mechanical wear of the machine. He concluded that when correctly implemented it provides tremendous information of machine under operation. He proposed that performance may be improved by proper filtration of oil.**[M. Lukas and R. J. Yurko 2013,]** proposed that traces of wear in used operating lubricant by principal vary in origin and its concentration value. In this study the researcher concluded that the occurrence of wear by product of these element present in the mechanism can be classified beginning wear and the presence of wear particles should be contained within the acceptable wear severity limitation. A review of the methodology used in all the research discussed above showed that they varied from one research to another, but none of the research addressed the root cause of oil degradation.Also none of the methodology developed a maintenance decision guideline for oil analysis which also would be a useful tool to technicians when conducting maintenance of the engine. This therefore formed the basis of the researcher to determine the root cause of oil degradation and develop a maintenance decision guideline to enhance the CBM in the plant.

II. Materials And Methods

To successfully meet the set objective of this study an elaborate methodology approach was used .The approach involved data collection from a thermal power plant. Each sample result of the oil was separate and therefore had to be consolidated together for easy analysis. At this level parameter verification was done and careful data segmentation was made. The oil analysis data was organized as per the researcher expectations and hence had to be structured as per the objectives of the research. Analysis of the oil data was done, which involved trend graphs and scatter plots where oil parameters were tested over the usage time in hours. Parameters that exceeded the limit levels were further analysed through five why technique so as to establish the root cause of degradation.A cause and effect analysis was used that helped the researcher todevelop a maintenance decision guideline

2.1 Experimental Design

Experimental design involved not only the selection of suitable parameter and outcomes, but planning the delivery of the experiment under statistically optimal conditions given the constraints of available parameter. The main concerns in this experimental design included the establishment of validity, reliability, and replicability. These concerns were addressed by carefully choosing the parameters, reducing the risk of measurement error, and ensuring that the documentation of the method is sufficiently detailed The objectives of this study were to analyze the oil parameters with usage time and their relationships, to establish the RCA of oil parameters and finally develop a maintenance decision guideline to enhance CBM in the plant. A set of experiments were done to meet the objectives. The analysis was categorized into four sets with each parameter analyzed to reveal howit behaved with usage in hours. Table 2.1 below shows the experimentations done and the purpose of doing each experiment.

Table 2.1 Sequence of experiments

OBJECTIVE	OIL CHARACTERISTICS	EXPERIMENT	TOOL	PURPOSE
Analysis of parameter	Oil Properties	1)Viscosity, flashpoint TBN and Soot analysis	Trend analysis with usage time in hours	Identify parameters with abnormal trend and mark them for RCA.
	Additives	2)Calcium, Magnesium and Zinc analysis	Trend analysis with usage in hours	Establish which additives that depleted beyond normal limit and mark it for RCA.
	Wear Metals	3)Iron,Lead,copper Tin, Vanadium and Aluminum analysis	Trend analysis with usage in hours	Establish which metal wear particles are abnormally increasing to give insight of wearing part.
	Contaminants	4)Silicon, sodium and pentane insoluble analysis	Trend analysis with usage in hours	Establish how contaminant behaved with usage time and identify any abnormal increase of contaminant in the oil for RCA.
Analyze the root cause of change of parameters with usage in hours	Parameters with abnormal change beyond the limit	-	Use the five whys.	Establish the root cause of abnormal change
Develop a maintenance decision guideline to enhance CBM	-	All parameters	Review the benchmarks limits of oil ,literature review	Enhance CBM to minimize frequent machine failure.

2.2 Root Cause Analysis

Root Cause Analysis (RCA) in this research was used as a technique to answer the questions of why the problem occurred in the first place. It sought to identify the origin of parameter change as a problem using a specific set of steps, with associated tools, to find the primary cause of the problem. As pointed out by Monroe, 2010 root because analysis is a powerful tool to methodically investigate reliability problems including lubricant degradation. Oil analysis is an excellent tool in the root cause analysis. Measuring chemical changes in the lubricant, along with the creation of insoluble contaminants is the first step in identifying fluid degradation. One of the major pitfalls in lubricant root cause analysis is that assumptions are made by the investigators. As a result, problems are either incorrectly diagnosed or not solved. By approaching lubricant degradation issues with an open mind and by methodically applying oil analysis tools, the root cause of recurring problems can be solved. Five why approach, literature review and expert analysis was used. Five whys approach is an interrogative technique used to explore the cause and effects relationship topick the causes of the lubricant parameter failure. Brainstorming with maintenance engineers linked the causes.RCA in this study helped to establish:-What happened to the oil parameters? Why the oil parameters changed with usage. Find out what to do to reduce the likelihood that the change does not negatively impact on the engines.

2.3 Maintenance decision guideline.

The maintenance decision guideline developed in this research will be useful in the plant to give leading information on maintenance and optimize the lubrication oilto enhance CBM and increase the reliability and out rightly reduce the failures in the plant. All the oil parameters were considered amongst other influencing factors which formed the basis of the conceptual framework developed as shown in Fig 2.1.

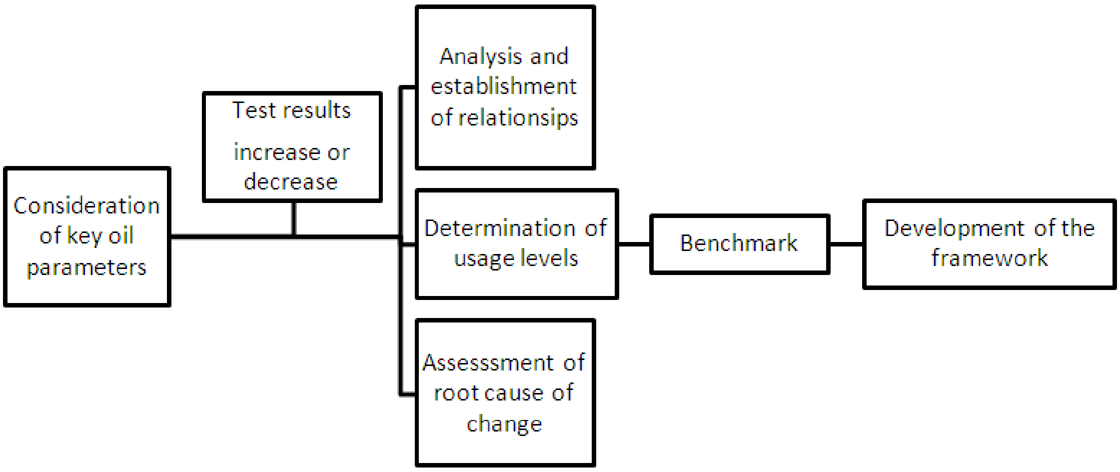

Figure 2.1 Steps of developing a conceptual maintenance framework

III. Results And Discussions

In this chapter the researcher outlines and discusses the findings of the study. The first section elaborates the results of experimentations of oilanalysis through trend graphs. Section two gives a detailed procedure of the RCA and finally section three discusses the decision table which defines the mitigation action to prevent the failure from recurring.

3.1 Results

In this study the analysis of oil parameters was classified in four forms namely the oil properties, additives, the contaminants and the wear metal particles. Each of these groups contains parameters that played important and different roles in oil characteristics. The parameters showed varied results and therefore those parameters that exceeded the limit levels are the ones evaluated in this study. These are viscosity, pentane insoluble, total base number and the silicon.

3.1.1 Viscosity

Viscosity is the main parameter in lubrication oil. Itdetermines the lubrication characteristic of the oil. Thinning or thickening of the oil directly affects friction on moving part and subsequent wear of the parts. Fig 3.1 shows the effect of engine run hours to the viscosity

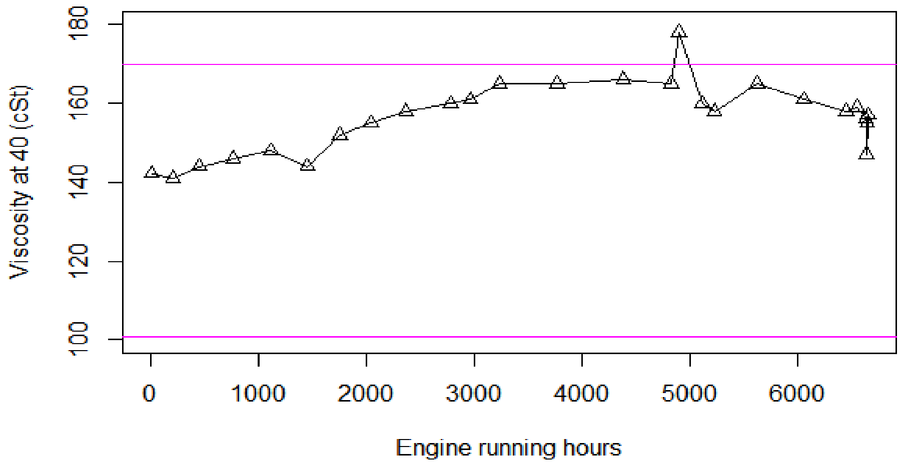

Figure 3.1 Effect of engine run hours to viscosity at 40ºc

Viscosity showed major change at 5000 hours of engine surging above the limit level of 170cst. This was an indication that the lubricity characteristic of the oil depleted with usage time. Mainly the rise of viscosity was due to depletion of additives increased operational temperature of the machine and the ingression of contaminants to the oil which triggered for action. Decreasing trend was noted after 5000 hours of engine run and was contributed by the top up action as a means to reinstate the oil to operable condition.

3.1.2 TBN analysis

This was done to establish acidity and basicity of the lubrication oil which causes corrosion and rapid wear to machine parts. TBN neutralizes any acid formed when lubricant contact with wear metal or water from coolant.

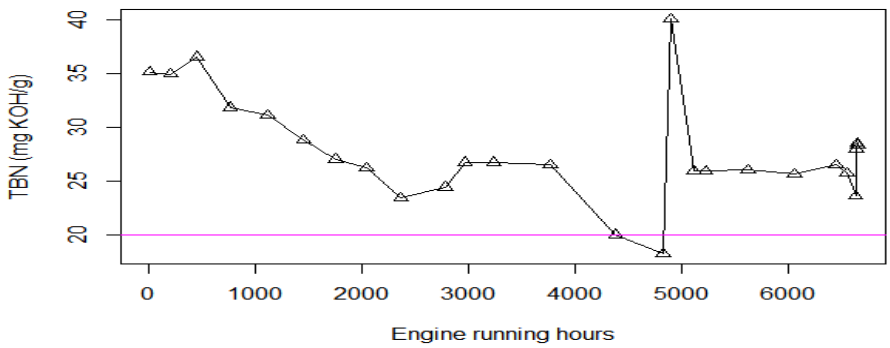

Figure 3.2 Effect of engine run hours to TBN

TBN showed a decreasing trend for the first 5000 hours of engine an indication that more acidic compounds was formed in the oil thus more TBN was required to neutralize it.After 5000hours it rose up a sign that some action was taken to control it after it fell below limit level. Replenishment of the oil was done which boosted the TBN and caused a sudden rise.

3.1.3 Pentane Analysis

Pentane in the oil represents the contaminants formed due ingression of dust in the oil. Pentane insoluble cause the viscosity to increase and there preventing easy flow of lube oil to part of the engine. Fig 3.3 shows the pentane insoluble analysis in oil.

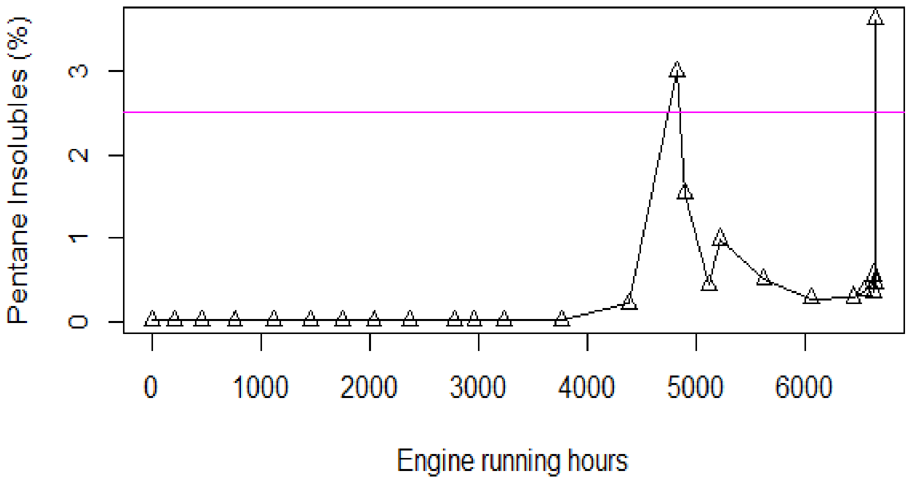

Figure 3.3 Effect of engine run hours to Pentane insolubles

Pentane insolubles were stable up to 5000 hours of engine run an indication that there was nomuch contamination of the oil. The parameter rose beyond the limit level due to more oil contamination. This was characterized by more friction and wear on moving parts of the engine.

3.1.4 Vanadium analysis

Vanadium particles originate from the wear of parts of the engine due to lubrication failure. Parts of the engine that contains vanadium elements are the O-ring,bearings and pistons.Fig 3.4 shows the vanadium trend graph.

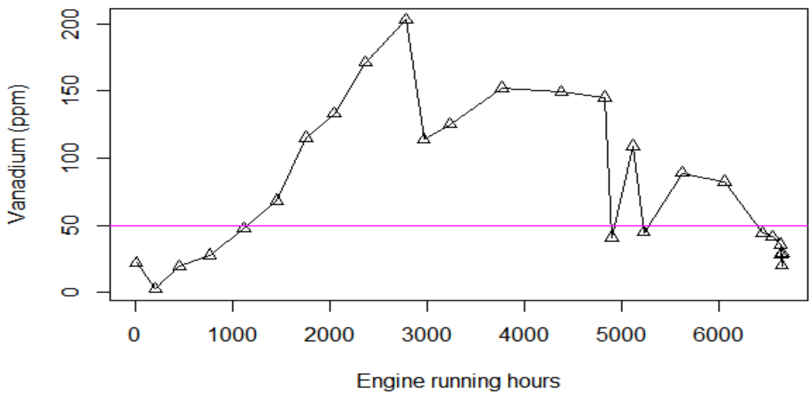

Figure 3.4 Effect of engine run hours to Vanadium

At initial stages an increasing trend was noted this shows that the parts wear was rapid until at 2500 hours of engine run that the vanadium dropped. Some action such as contamination control, temperature drop and viscosity control was implemented that prevented the parts from wearing.

3.1.5 Silicon analysis

Silicon in lube oil is in form of particles of airborne sand and dust that vary in size, shape and abrasive properties. In an engine the ingress of atmospheric dust takes place primarily through the air intake. Efficient air filters remove 99% of the dust that an engine ingests. The remaining 1 % consists of very small dust particles that pass through the air filter. These vary between submicron size particles to particles up to well over 10 microns in size. This dust will pass between piston, rings and cylinder and eventually become suspended in the lubricating oil. Fig 3.5 shows the trend of silicon in the oil under test

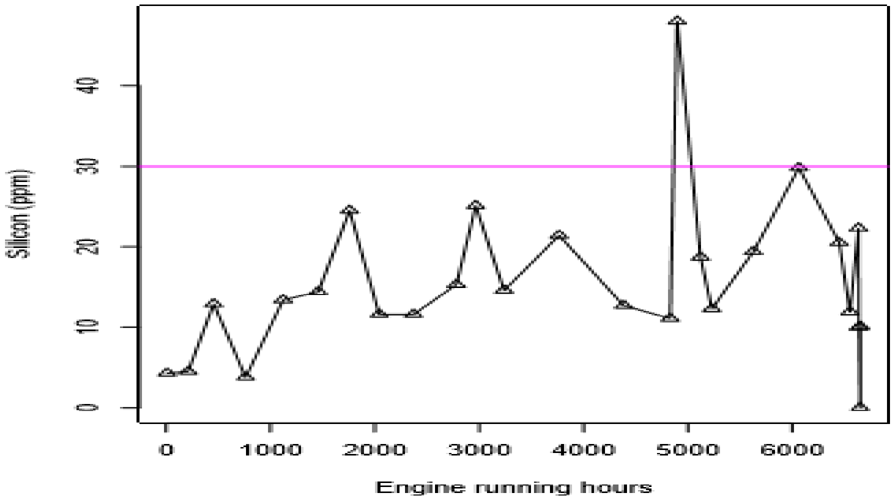

Figure 3.5 Effect of engine run hours to Silicon

Silicon is the contaminant from the environment human error and dirt on the engine parts. Silicon raised with usage time an indication of increased dust contamination of the oil. Consequently it was noted that the oil parameters changed at 5000hours an indication that the useful life of the oil was 5000hours .At this point oil top up was done which reduced the level of silicon that had surged above the limit level. Increased silicon affects the viscosity of the oil and thereafter characterized by increased wear. This can be controlled by constantly examining the filter of the engine.

3.2 Experimental Validation

This section deals with the validation of the results analyzed in this thesis. In oil analysis viscosity is the major parameter because change in any other parameter affects viscosity directly and therefore TBN and viscosity were selected for verification and validation of the results. Fig. 3.6 indicates a graph of correlation between the experimental and the standard American society for testing and materials (ASTM) viscosity data. In this experiment diesel engine with an oil grade 15W60 similar to the one tested in this research investigated.

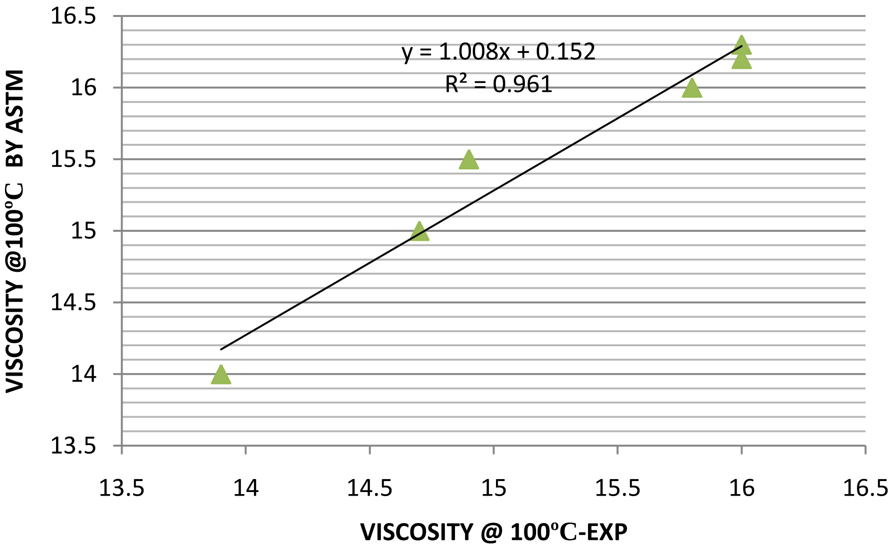

Figure 3.6 Correlation between experimental and standard ASTM viscosity

The test period for ASTM data was 5000 hrs.Unlike the one in this study of 6000hrs .Both results showed a high correlation factor of 0.9618.This was a very high coefficient showing that the data have a high degree of relationship.

Fig 3.7 shows a graph of TBN trend. The graph showed similar results to the ones in the experimental analysis discussed above with a correlation factor of 0.9618 which is also high enough to deduce that there exists a high correlation between the two tests in this study.

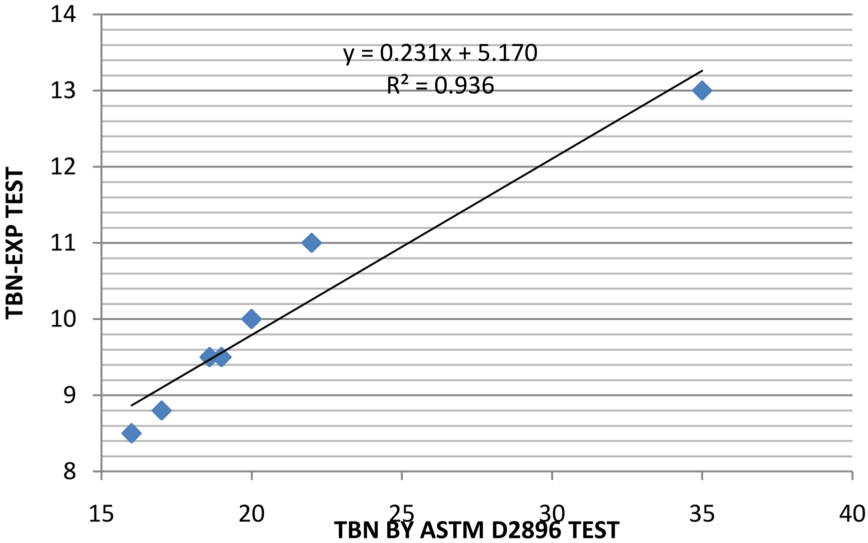

Figure 3.7 Correlation between experimental and ASTM TBN

Fig 3.7 represents the graph of the correlation between the experimental TBN and the standard ASTM data. The graph shows correlation of 0.9368 which is a high correlation. Both graphsi.e. for viscosity and the TBN showed a high relationship factor and therefore verified and validated the data and analysis done in this study.

3.3 Root Cause Analysis

In this study oil parameters namely:-silicon, soot, pentane insoluble, viscosity and TBN were found to be the main source of the oil problem and therefore warranted a further RCA. From the analysis on trend graphs it was noted that these parameters increased beyond the limit levels an indication of oil degradation and loss of lubrication characteristic. From this result therefore the root cause for this problem was necessary to be investigated. In order to perform a thorough RCA five whys were used to investigate the source of oil degradation as demonstrated below in table 3.1.

Table 3.1 Root cause analysis for the oil

PARAMETER	FAILURE MODE	CAUSE	EFFECT
Contamination	Gaseous	Air	Foam Formation
		Combustion Gases	Oil Degradation
		Reaction Product	Oil Degradation
	Liquid	Water	Emulsion Leading To Additive Loss
		Fuel	• Change In Viscosity • Insoluble Formation
		Oil Drain	• Increased Viscosity • Increase In BN
	Particulate	Dust	Increased Insoluble
		Soot	Oil Thickening
Additive Element	oxidation	Increased additive elements	• Oil Thickening • Molecular Structural Changes • Loss Of Anti Oxidation • Colour Change
Oil Properties	Viscosity	INCREASE • Low oil replenishment • Oxidation • Contamination by high viscous fuel • Oil insoluble	• Oil degradation
		DECREASE • Increase in oil temperature • Dilution by light fuels	• Oil degradation

3.4 Decision guidelines and Mitigating Actions

The oil tested showed some abnormalityfor the measured parameter. The depletion levels were acceptable to some parameters and unacceptable to others, however the oil was unfit after 5000hrs. of usage time and therefore required some replenishment for use. The maintenance actions and effect for these and all exceeded parameters are presented in the table 3.2 below.

Table 3.2 Decision Table and mitigating actions

Measured Parameters	Effect For Exceeded Parameter	Maintenance Action
Antioxidant additive	Formation of varnish. Chemical change to the base oil reduces the effectiveness of the oil viscosity of the oil increase clogging of the orifice.	Check for increased wear as the deposit oxidize and cause the anti-oxidant additive to deplete. Check for an increase in operating temperature. Check for leak in the system
TBN	Increase in wear. Increased Viscosity. Metal Corrosion, increased oxidation. Overheating. Oil thickening additive depletion	Check the system for corrosion. Check the system for wear. Check the oil for an increase in viscosity. Check if the correct oil was used
Viscosity	Excess cause formation of sludge excess internal machine wear. Shear down of viscosity index improver	Check the colour of oil, check the presence of sludge, and check the presence of metal particles.
Soot	Cause oil to clump	Keep air filters clean. Blocked air flow will affect the fuel/air ratio. Keep fuel filters clean, clogged filters starve the engine and lower fuel flow Check air induction system for leaks, loose clamps, holes in ductwork
water	Shorter compound life due to corrosion. Wear caused by loss of viscosity. Increased corrosion and this leads to rust particles acting as abrasives. High operating temperature.	Check for sludge. Check bearing seals. Check for leaking oil cooler. Check vapor extractor if working.

From the analysis done above and the development of the maintenance decision guideline for used oil some actions were proposed to the maintenance team to effectively control the oil drain and top up. Maintenance decision guideline is a simple tool that improves availability and reliability of maintenance actions in a plant [**Muchiri, P. et al 2010**].Table 3.2 shows step by step actions that should be followed to diagnose the oil related problems identified in the analysis discussed above.

IV. Conclusion

The experimental results discussed in this report demonstrate the capabilities of analyzing the lubricating oil for condition monitoring of the power plant equipment. Oil parameters were successfully utilized for showing the condition of the oil. A combination of trending analysis and RCA was used for oil sample where the performance parameters such as viscosity, total base number silicon flash point and pentane insolubles were observed. In this experimentation there was varying relationship in oil parameter. For example the trend on the viscosity showed a negative correlation with time. Depletion of all parameters under test took place after 3000 hours of engine run which marked the useful life of the oil beyond which the oil degraded and consequently caused accelerated wear in the engine. This point marked the start of oil degradation and in order to optimize oil usage the action was taken at 5000 hrs. Of engine run.

From the result the TBN also showed a negative correlation with time. This was an indication of high consumption of this property to neutralize the acid in the lubricant. Acidity in lubricating oil is from the combustion processes and the reaction that take place when oil gets into contact with coolant or water. Consideration of all this analysis and evaluation of theoretical information helped the researcher to develop a maintenance decision guideline which would act as a powerful tool to monitor the condition of any industrial machine and give a conclusive report on action best for the machinesand at any particular period of use.

References

[1] Progress (March2016): Energy generation and distribution.http:www.vision 2030, [2016] Retrieved of 3rd march 2017.
[2] Newell, G.E, Oil analysis cost-effective machine condition monitoring technique, industrial lubrication and tribology, 1999, 51(3)
[3] Toms L. (1998) Machinery oil analysis methods, automation &benefits.
[4] Kumar, M., etal. Advancementand current status of wear debris analysis for machine condition monitoring–A review in Industrial Lubrication and Tribology, 2013, 65(1), pp.3-11.
[5] S.J.Hashemi, S.A.Adnani etal (2013) The initial estimate of the useful lifetime of the 0il in diesel engines using oil analysis.
[6] Wakiru.J.M (2014), Development of a maintenance strategy for a thermal power plant-A case study.
[7] Fitch J. (2007), The truths about oil anlysis data trending.
[8] R.K.Upadhay. "Microscopic technique to determine various wear modes of used engine oil. Journal of microscopy and ultrastructure" 1 (2013)111114. [3]
[9] Amit Kumar Gupta, "Wear Debris Analysis of Automotive Engine Lubricating Oil Using By Ferrography." International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 5, November 2012[4]
[10] M. Lukas and R. J. Yurko, "Current technology in oil analysis spectrometers and what we may expect in the future."RFSA 2006[6]
[11] Muchiri, P. et al (2010) Development of maintenance function performance measurement framework and indicator