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Condition Based Maintenance System for Heavy Equipments Case study: Using Trend Analysis in Oil Monitoring

Ali Sayyah[1], Baharudin BTHT[2], N.Ismail[3]
[1, 2, 3] Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia
43400 UPM, Serdang MALAYSIA

Abstract

Contaminant materials in lubricants are signs for prediction and measurement of wear in engines. Therefore oil monitoring is considered as one of the most effective techniques for maintaining the heavy equipments. However based on oil analysis data, the identification of engine problem is very hard due to different contribution factors. Hence, this paper is purposed to analyze the wear behavior of some sets of selected heavy equipment engine based on documented oil analysis data during two years in different conditions to track engine failures using trend analysis. Furthermore the selected equipments are divided into two major groups (plantation and forestry, and general construction) based on their environment, to show the effects of conditions on the engine wear behavior.

Keywords
Oil monitoring, Trend Analysis, Condition Based Maintenance, Reliability

1. Introduction
Condition Based Maintenance (CBM) is a maintenance technique that offers some activities based on information which is gained from condition monitoring of selected equipment [1]. A CBM program, if properly established and effectively implemented, can significantly reduce maintenance cost by reducing the number of unnecessary scheduled preventive maintenance operations. Oil analysis is one of the most popular methods of CBM that companies have recently been drawn to use [2]. Although nowadays machinery oil analysis Condition Monitoring (CM) techniques are known as effective methods for monitoring abnormal wear in equipment and mechanical systems, factors such as issues like wear behavior, technical features, and previous records and event data of oil analysis results are also essential for interpreting the results of oil analysis [3]. This paper is purposed to show how it is possible to determine the faulty parts in a diesel engine based on historical data and technical features and wear behavior of selected equipments without any inspection and over hall using trend analysis. One of the reasons that some companies are not motivated for using oil analysis for maintenance schedule is that the standards which are offered by manufacturer or unions are not based on the condition of their machines. Mostly these standards are established for wide group of machines not especially for a specific machine [4]. Therefore companies mostly don't use those standards and they let their experts to judge whether the machine have problem or not without considering standards. Hence this article is going to present the correct way of using standards and guidelines based on the condition of equipment to have precise interpretation of historical data.

2. Methodology

To achieve above mentioned goals five sets of heavy equipment from Caterpillar Company have been monitored for two years from 2006 to 2008. The oil samples for all cases have tested for 8 contaminant materials namely: (Cu, Fe, Cr, Al, Pb, Si, Na).
To achieve above mentioned goals trend analysis, which is the key method in CBM has done for 5 cases based on the results of oil analysis which is recorded for more than 2 years. In this part the trend of each wear element have analyzed based on four sources:

1. General standards of diesel engines
2. Metallurgy information of selected diesel engine which is provided by manufacturer (CAT Company)

3. CBM principles
4. Experts' experiments

Based on these four sources, the status of each engine is analyzed and some practical solutions are suggested in order to eliminate the problems in diesel engines and also to improve condition monitoring method.
As it is mentioned, one of the effective conditional criteria is environmental circumstances. So the cases of this research are chosen from two different conditions "*plantation and forestry*" environment and "*General construction*" purposes to show the effect of condition on engine status.

3. Analysis of Cases

3.1. Case 1

The first equipment selected for trend analyzing is a 416E Backhoe Loader which is used in a plantation area. In this case there are 13 records in its historical data which are enough for a trend analysis. The oil sample was tested for all eight contaminant materials (Cu, Fe, Cr, Al, Pb, Si, Na). However here we only focus on those contaminants which may cause problems and, according to general criteria of oil analysis, will give suggestions for owners to check their equipment to avoid failure. Ingeneral the main sorces of copper in oil samples are brass and bronze. These metals are mostly used in bushings in rocker arms, wrist pins and the turbo bearings. A layer of bronze may be used in crankshaft and camshaft bearing below a lead bearing. Apart from that, governor, the oil pump and the service meter drive gear are also other sources of copper in diesel engine. To identify that which of these sources is the main cause of contamination in oil samples, companion elements such as tin and zinc which are used in deferent compartments may help likewise for metals generated from mating surfaces (typically iron)._It is expected that the amount of companion elements is much lower than copper because they used in lower percentile as metallurgical component of diesel engine compartments [5].
Based on Fgure 3 it can be seen that although only Cu exceeded the limits and increased to critical status, in three other metals, there is an increasing trend to reportable level.
Engine oil may become contaminated with coolant due to leaks from oil cooler cores, internal coolant passages, and cylinder head gaskets. Since both Na and Cu exist in coolant and also there is increasing trend in pb which is one of the components of a head cylinder. Hence there might be high pressure on the coolant to circulate fast within engine body in order to make engine cold. However, after almost one and half years, as it can be seen in Figure1, pressure

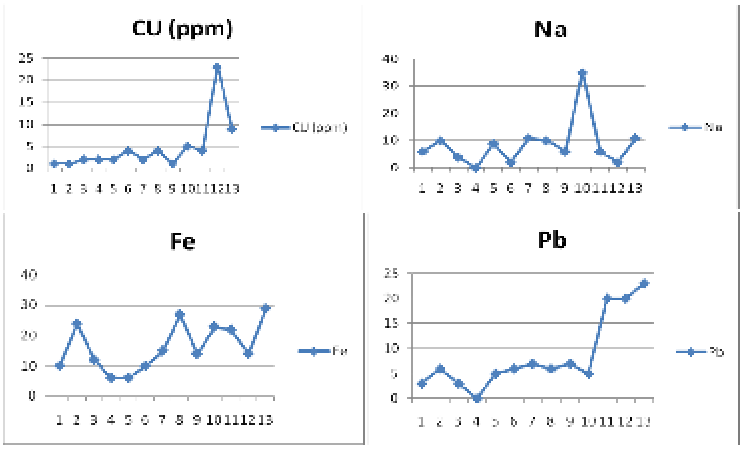

Figure 1: Trend of changing Cu, Na, Fe and Pb in oil samples of 416E CAT diesel engine The X axis refers to Number of samples and Y axis refers to Number PPM (part per million)

caused the coolant to break in to the engine environment. This event may have happened due to burning cylinder head which can cause coolant leak in to the engine. In addition, it can be seen that both Cu and Fe increased together. This event shows that the high amount of Cu might be due to residues entering from the coolant system. Therefore, according to oil analysis, the coolant system and head cylinder should be checked. If this trend continues in the next samples, a separate test for glycol would be suggested to further identify coolant entry. It should be noted that this analysis is not absolute, and especially for Na and Si, an external third party may affect oil samples. However, it is clear that by tracing the oil sample results, there is no longer any need to check different parts for the next two years and that using the CBM method will avoid a lot of time and money which would have been spent using the PM checking system.

3.2. Case 2

The second case is another loader 416E loader which is used in a plantation area. There are 9 oil samples in its historical data. These oil samples were tested for all eight materials a mentioned before. Cr, Al, Mo show an almost constant trend but the others metal listed in Figure 2 shows an almost smooth trend. Only Na has erratic fluctuations. Sodium is usually added to a coolant as anticorrosion. Hence, when it appears as a contaminant material in oil analysis, it shows that there is a leak in the cooling system matrix [6].

Another probable reason for existence of Na is the presence of an external effector especially water. In this case it causes the lab experts to analyze another factor that exists in coolant in order to evaluate the dramatic change, in Na. Here, Cu has a decreasing trend, especially after the increasing in Na. This shows that the increase in Na is not due to corrosion in the engine's devices since in that case, Cu should at least be constant or increased while Na itself should decrease after that significant rise. Hence, this jump in the Na curve is not important and it may have been caused by a small leakage from the coolant or external causes.

Apart from Na, the other wear materials (Cu, Fe, Si, and Pb) decreased from the first oil sample to the second which shows that the oil has been changed. Since Si contamination mostly refers to soil contamination in engines [7], it might be a sign of breathing system or air filter failure which could not avoid soil or dust particles entering into the engine. When these soil and dust particle cross from the air filter and enter in to the piston environment through air valve they stick to the cylinder walls. Therefore moving pistons will cause cylinders to be worn [6]. Although oil was changed at the beginning of this series of oil analysis, Pb still increased during the duration of the tests. Therefore, there might have been problems with engine components which are made with Pb. The main bearings are the most probable places that should be inspected [8].

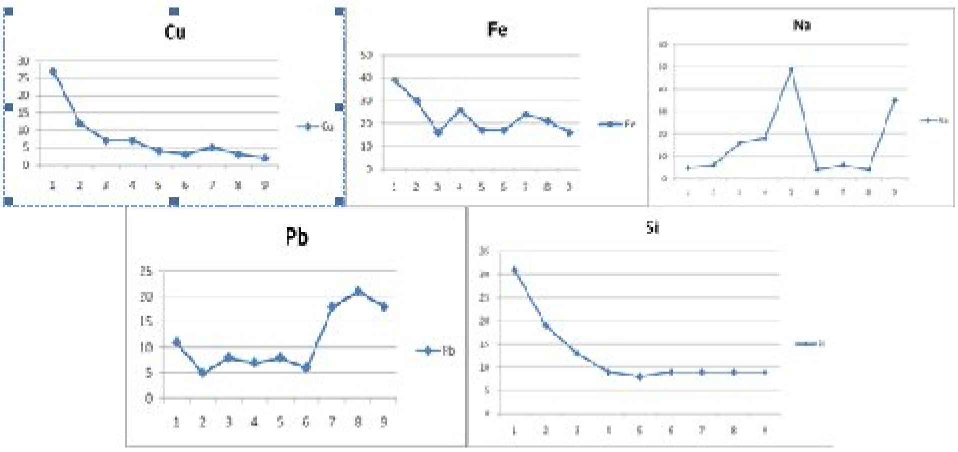

Figure 2. Trends of changing Cu, Fe, Na, Pb, Si in oil samples of 416E CAT diesel engine. The X axis refers to Number of samples and Y axis refers to Number PPM (part per million)

3.3. Case 3

The third case is a 416D CAT loader which is used in a forestry environment for the purpose of cutting trees. Based on Figure 3 almost 20 samples were taken during the years 2007 to 2009. With this amount of data, the condition of this loader can be precisely traced step by step.

As shown in Figure 3, there are three points that show all wear materials as decreasing. These points refer to oil changing points which approximate the 6th, 11th, 16th sample times. This case is an ideal case to show that a contaminant material can affect other materials. For example in some cases, even though the density of one material is acceptable, according to its effect on another element it may cause an increasing trend for other wear debris inside the oil [9]. According to Figure3, although Si contamination is acceptable this figure clearly shows that Si is increasing smoothly. Although the oil has been changed three times, Si continued to increase. Simultaneously both Pb and Fe have increasing trends. Pb and Fe are the main components of cylinders, pistons and bearings of diesel engines. Hence, it can be concluded that the continued increase in silicon is a sign of problems in the breathing system and air filter [6]. Thus, dust and soil particles can enter in to the engine environment through air valves, stick to the cylinder walls, and cause wearing. Fe and Pb contamination shows that there is a problem in cylinder liners, piston rings, lower rod and crankshaft [10]. However, since the presence of soil and dust particles in the engine is the reason of increasing trend for Fe and Pb, the first suggested activity is to inspect the air filter and breathing system to avoid soil and dust entering.

Two points about this case show the efficacy of Trend analysis in CBM:

Firstly, based on this case, another advantage of trend can be explained. As shown in this case, a very simple problem in air filter can cause major problems in the main parts of an engine such as in the pistons, cylinders, and crankshaft. However if oil analysis had been done but the trend of contamination from other materials was not considered, have been possible for us to find the main cause of the fault and the owner of the engine may change may change the pistons or crankshaft, which are so expensive replacements, but after a short time, the problem would occur again. This is because although the pistons or crankshaft have been changed, the soil particles can still enter the engine.

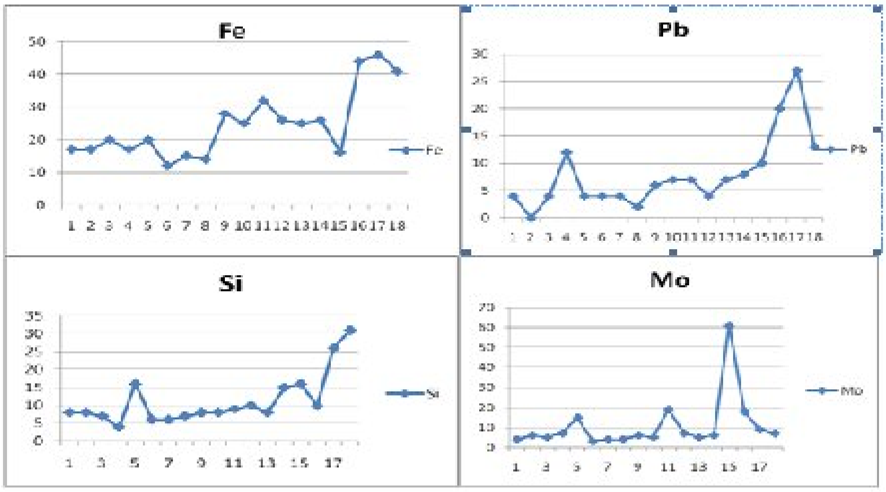

Figure 3 .Trends of changing Fe, Pb, Si, Mo in oil samples of 416D CAT The X axis refers to Number of samples and Y axis refers to Number PPM (part per million)

The second observation about this case is that although the level of Si contamination in oil is under generally accepted standard limitations, it causes an increase other contaminants. Therefore, according relationship between material trends a new baseline will be determined to avoid wear on other parts. Hence, although general standards accept that Si should be less than 40 ppm, in this specific case, it should not be more than 15 ppm, otherwise trend analysis should be done to determine whether Si is responsible for any other increasing trends in other parts of the engine.

Based on the results of above investigated cases it can be concluded that general standards are not enough for interpreting the results of oil analysis. To cover this problem trend analysis is used. However, trend analysis is a time consuming method and experts should consider previous data for all investigated elements which is a hard work and increase the probability of errors occurrence. Hence In order to facilitating the determination of engines status under specific condition, baselines should be made according to each specific condition.

3.4. Case 4

The forth case is a 416 E CAT loader which is used in forestry environment 15 oil samples are tested for this heavy equipment during two years from 2007 to 2009. According to **Error! Reference source not found.** the level of all wear materials are acceptable until almost the 7th sample. The striking point in this part of figure is that converse to the previous case, although level of Silicon contamination is similar to previous case, the trend of Si constant. Therefore it shouldn't be considered as problem sign in air filter. On the other hand Fe also has not increased which shows that silicon doesn't enter to the cylinder.

For the second part of **Error! Reference source not found.** which is starting almost from 6th sample, in all materials increasing trends can be seen. Firstly Mo has increased significantly. There are three major origins for Mo

in engine: 1- Additives 2- Bearings ,3- Crankshaft [7]. As in parallel with Mo, Pb starts to increase and both of these materials are main ingredients in bearings main is probably wearing in during the time between 6th and 10th sample time. Unfortunately the customer didn't pay attention to this trend consequently in sample 10th there is a significant increase in Fe which shows that wearing in bearings caused looseness inside bearings which are connected to main parts of engine like crankshaft and connecting rod which are made of Fe. As the amount of Pb contamination in oil also increased and this material is also used for making crankshaft it shows that the crankshaft and connecting rod and consequently piston are wearing. In such a this situation the equipment should stop working immediately because apart from high expense of crankshaft and piston to be replaced or repaired, the majority parts of engine which are connected to crankshaft are affected by it.
In addition to that Cu and Na both of them have increased significantly after 10th sample. As it is mentioned before

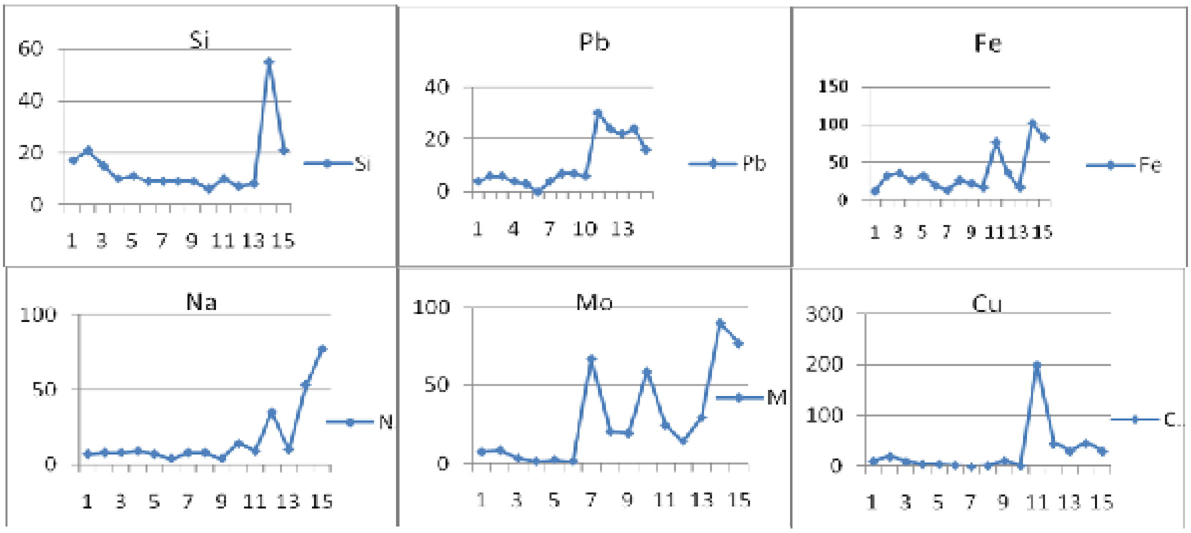

Figure **Error! No text of specified style in document.**. Trends of changing Cu, Fe, Pb, Si, Na, Mo in oil samples of 416E CAT diesel engine. The X axis refers to Number of samples and Y axis refers to Number PPM (part per million)

Na is one of the ingredients of coolant liquid and on the other hand the oil cooler cores are also made of cupper. Hence increasing the intensity of these two materials might be the singe of leaking cooling liquid to engine environment. In this case this increasing have happened just at the same time that Fe, Pb, Mo have increased with each other. Therefore there is reason to believe that problems in crankshaft and piston after 4 samples until 10th caused looseness in joints especially in cylinder head and consequently coolant can leak to cylinder environment.

3.5. Case5

The fifth case is a CAT 330 L excavator which is used for general construction. The historical data for this equipment consists of 26 oil sample results which show the trend of corrosion of this engine for 2007 to 2009. In this case it is stated in documents that in sample 4 the oil is changed. And also in after sample12 there was an inspection on this equipment. As it is shown in Figure in the first sample copper contamination is unacceptable while other wear materials are acceptable. But with one record it cannot be concluded that there are major problem and the equipment should be stopped. Always there are some factors that cause making mistake in process of oil analysis some of them as bellow:

1- Oil sample is not taken in right time and condition.

2- The oil sample may contaminant by wear parts from external environment.

3- The lab expert may mistake in transferring data from one data base to another.

But here a dramatic increase can be seen in Sample 3 in all Cu, Fe, and Pb. According to documents after sample 4 the oil is changed and obviously the contamination level decreased in all of the three wear debris. But a little after that again Pb, Fe and Cu increased again. In this situation undoubtedly these is a major problem in mechanical parts.

The origin of Cupper mainly is coolant system and bearings, as Na is one of the major materials of coolant and here it has not increased specially in this period. Therefore the contamination of Cu is not due to leakage from coolant system. In addition in parallel with that Fe and Pb also increased which shows major wearing problem. Generally Pb is considered as singe of wear problem in diesel motor [11]. The major parts of engine which is made from all of these three materials is bearing [7] specially turbo bearing which in General construction high pressure is on it. Hence here an inspection is vital to change bearing or other parts. Just after repairing, Mo rises dramatically. The main origin of Mo is additives to piston or bearings. [11]. Additives are chemical materials which impart new properties lubricants. Additives enhance the existing properties of the lubricant into which they are incorporated. The amount and type of additives that are blended with the lubricant depend on the performance features desired from the lubricant [12].
Here in this case because this increasing was just after repairing activity and in repairing activity usually they add this kind of additives to increase the quality of lubrication and facilitating motor movements undoubtedly the origin of this contamination is additive material. So no action is required in such this situation.

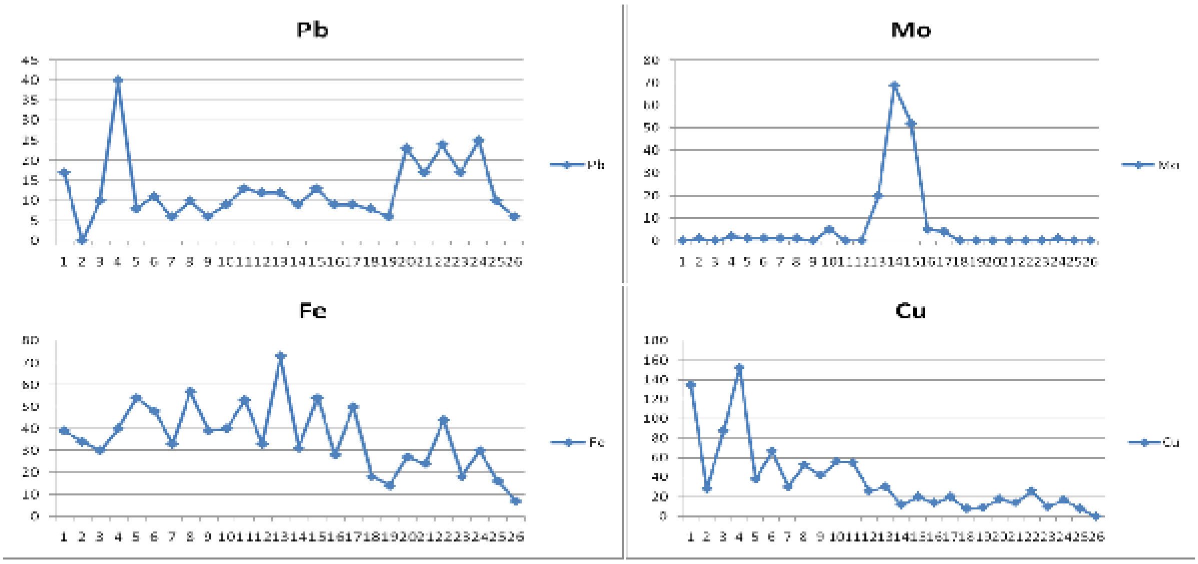

Figure 5. Trends of changing Cu, Fe, Pb, Si, Mo in oil samples of the 330 CAT diesel engine. The X axis refers to Number of samples and Y axis refers to Number PPM (part per million)

4. Conclusion

Apart from the analysis and solutions which this research has provided for each case, we can conclude that adhering to general standards for maintenance activities especially for oil analysis, is not very practical, given the different conditions. This fact can be seen during the trend analysis of the many cases tested. Although the level of contamination material is below the standard limitations, increasing the trend of an element in parallel with the increasing trend in another wear material indicates that a problem has occurred. Conversely, in some cases, some elements contamination was above the normal standard, but based on the information on the condition of the equipment, it is considered normal. Hence, unnecessary inspection and interruptions in operations can be avoided.

5. Acknowledgment

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