23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

PREDICTIVE MAINTENANCE TECHNIQUES APPLIED IN FLEET OIL MANAGEMENT

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Abstract. *The benefits generated by an efficient planning and control of maintenance are evident when dealing with fleets. Predictive maintenance through analysis of lubricating oil, which estimates the life cycle of components and increase machine availability, will be detailed in this work. The vehicles are more powerful and more sensitive to contaminants nowadays, so it is necessary to use modern techniques for monitoring machine components and vehicles. Reports about the used lubricating oil are an important tool to prevent failures, avoiding disassembling parts for inspection at the first time by monitoring oil working condition. Technical analyses performed by experts on the subject make it possible to identify the presence of dust which indicates leakages. Further methods for oil removal from equipment are studied and applied to avoid contamination of the lubricating oil. It is considerably important to companies, repair shops and vehicle owners to perform this procedure properly for better fleet availability.*
Keywords: *predictive maintenance, oil analysis, fleet*

1. INTRODUCTION

Market needs in terrestrial fleet business, regarding transportation, logistics and heavy-duty construction, are continuously demanding high performance levels from production and equipment maintenance. Trucks, buses and large-sized machinery have grown in power specifications, higher pressure and lower tolerance conditions, requiring all parts to work in nearly perfect synchrony. However, the continuous wear of moving components can lead to drastic failures and loss of parts, engendering not only productivity loss, but also accidents.

The justification for this study remains in the fact that corrective maintenance in most cases is responsible for considerable financial and human resources allocation loss for companies. This can be avoided with a periodic and systematic maintenance promoted by the operator and certified professionals.

One specific predictive maintenance technique will be further discussed, the oil analysis, confirming its benefits and exploring its practical effects with the study case of OPT Soluções, a management and optimization fleet company, established in the Regional Innovation and Technology Transfer Centre (CRITT/UFJF) and cofounded by Felipe Lima Bronté. The topic theoretical discussion will be followed by a case study from a project developed by the company analyzing a fleet composed by a Dump Trucks (A), shown in Fig. 1, detailing their hydraulic, powertrain and differential systems. Although not all of these equipment were the focus of this study, the analysis can be extended for any terrestrial system with similar operation conditions, in order to provide important orientation for the operator and the maintenance team.

Figure 1. Dump Truck A (OPT Soluções, 2014)

2. MAINTENANCE TECHINIQUES

Maintenance activities aim at preventing extreme and unnecessary degeneration of equipment in general, caused by regular wear or inadequate operation. There are several indexes to describe degradation or, conversely, its absence or infrequency. One of this indicators is the availability, described as one item's capability of executing a specific function for a period of time, taking into account the combined aspects of its reliability, maintainability and maintenances support, considering presence of required external resources (ABNT NBR 5462, 1994).

Furthermore, Kardec and Nascif (1998) define the practical concept of Operational Availability as given by Eq. (1), where MTBF stands for Mean Time between Failures, corresponding to the period of time dedicated to maintenance checks and repairs, and MDT stands for Mean Downtime, which includes not only the MTBF, but also any other delays in getting needed personnel or parts necessary for repairs.

$$\text{Operational Availabilty} = \frac{\text{MTBF}}{\text{MTBF+MDT}} \tag{1}$$

Another important concept necessary is Predictive Maintenance. According to the Brazilian National Standards Organization (ABNT NBR 5462, 1994), it is the type of maintenance that assures quality of service, based on the application of systematic techniques, with centralized or sampled supervised methods, aiming to reduce to the minimum level preventive and corrective maintenances.

Mobley (2008) points out that the main predictive techniques are vibration analysis, thermography, and lubricant oil analysis. The latter one has become an important tool recently, with strong recommendations from laboratories and fleet specialists that lubricant oils should be collected and analyzed in periodic intervals in order to keep the fleet subsystems operating properly. This should happen because usually all parts of an equipment show a particular life cycle, and identifying wear symptoms without disassembling the systems is highly cost-effective.

The oil analysis can be made in the laboratory or online, that is, during operation. When sent to the laboratory, the oil is assessed regarding the amount of particles found in its bulk, its size, form and composition. These particles originate from dynamic friction between moving parts in the system. Some key parameters analysed besides contamination are additivation, viscosity, density and testes such as Total Acid Number (TAN) and Total Base Number (TBN). With respect to the online system, it makes us of a particle counter fixed in one of the hydraulic oil hoses, which displays the contamination level according to International Organization for Standardization in the document ISO 4406:1999.

3. METHODOLOGY

Many are the parameters analysed in lubrication oil, whose main objectives are decrease wear rates between moving parts, cooling and cleaning of active surfaces, removal of wear particles, aid sealing and prevent leakages. It is important to highlight some of this parameters, such as viscosity, defined by Brunetti (2013) as the force per unit area necessary to impose a unit velocity gradient, or qualitatively, the easiness the oil has to flow. He also defines the dropping point as the lowest temperature at which an oil can flow by gravity effect only. Other characteristics are also important, and when necessary will be detailed on the text.

High importance should be given to oil collection, in order to achieve reliable analysis conditions. SOS^{SM} program, devised by Caterpillar (2014), provides clear instructions for oil collection, for further monitoring. Both pressurized and non-pressurized systems should have the lubricant sample extracted with minimum contamination potential, and information such as date, machine hours readings and oil previous specification. Both types are constantly used by OPT Soluções.

The tests performed in the oil samples are divided into five categories: wear, contamination, additivation, physical tests and particle counting. Wear is related to solid surface damage, usually associated to progressive loss of material, due to contact of moving components, solid, liquid and gases (POSSAMAI, 2011). For wear tests, the levels of Silver, Chromium, Copper, Iron, Molybdenum, Nickel, Plumb, Tin and Titanium are measured. Oil contamination occurs when external substances infiltrate the fluid system, by wear or chemical reactions within the lubricant. In this case, Aluminum, Potassium, Sodium and Silicon compounds are examined. Additivation tests verify the presence of Boron, Barium, Calcium, Magnesium, Phosphorus and Zinc related substances. The physical test measured viscosity and the presence of water in the oil, being both parameters crucial for fluid quality.

4. RESULTS

4.1 Reportable and critical samples

The oil samples collected for this study by OPT Soluções were divided into three groups: Reportable, Critical and Regular. For the first and second group, Reportable and critical, oil was collected from the Dump Truck A, from rear axis, (samples AD 33720, AD 27740 and AD08271). The user`s manual specifies oil SAE 80W for use in the differential system. Tables 1 to 4 show the rear axis oil analysis results for this system.

As for the third sample (AD 8271), it is considered Critical, since high Iron, Aluminum and Silicon concentrations were measured. The first two elements indicate atypical wear of component surfaces, and the last element points to external contamination in the oil.

Table 1. Oil sample from Dump Truck A rear axle (OPT Soluções, 2014).

Sample						
Sample	Status	Collect date	Processing date	Hour meter	Fluid hour meter	Changed?
AD 33720	Reportable	05/20/2014	05/23/2014	4000	506	No
AD 27740	Reportable	05/08/2014	05/08/2014	3809	315	No
AD 08271	Critical	03/14/2014	03/20/2014	3494	490	Yes

Table 2. Wear result from Dump Truck A rear axle oil sample (OPT Soluções, 2014).

Wear (Parts per million)								
Ag	Cr	Cu	Fe	Mo	Ni	Pb	Sn	Ti
Silver	Chromium	Copper	Iron	Molybdenum	Nickel	Plumb	Tin	Titanium
0	3	6	495	10	1	0	0	0
1	3	7	451	11	1	0	1	0
0	8	6	982	27	2	2	2	1

Table 3. Contamination result from Dump Truck A rear axle oil sample (OPT Soluções, 2014).

Contamination (Parts per million)			
Al	K	Na	Si
Aluminum	Potassium	Sodium	Silicon
12	0	0	28
13	0	10	25
25	0	0	56

Table 4. Additivation and physical tests result from Dump Truck A rear axle oil sample (OPT Soluções, 2014).

Additivation (Parts per million)					
B	Ba	Ca	Mg	P	Zn
Boron	Barium	Calcium	Magnesium	Phosphorus	Zinc
3	2	221	9	816	41
3	2	169	9	774	20
5	5	345	16	457	23

Physical tests		
V (100º C)	Water	Visual
Cst	%	Visual
16,9	0	N
16,9	0	N
17,1	0	N

This equipment should be put aside for maintenance in the next expected stop, when sealing conditions, eventual leakages, filter situation and any abnormal instances should be monitored and fixed.

After the oil change recommended by OPT Soluções, and 315 run hours, another oil analysis was performed in Dump Truck A, indicating now a Reportable condition, because all contaminants were reduced drastically, except for Iron levels. Thus, another measurement was requested due 150 run hours. When reaching 506 run hours, a new oil analysis was performed, in which Iron levels were low, validating the predictive work executed by mechanical staff.

Oil was also collected from Dump Truck A hydraulic system, (samples AD 33624 and AD08248), for which the user`s manual specifies oil ISO 68. Tables 5 to 9 to show the hydraulic system oil analysis results.

Table 5. Oil sample from Dump Truck A hydraulic system (OPT Soluções, 2014).

Sample						
Sample	Status	Collect date	Processing date	Hour meter	Fluid hour meter	Changed?
AD 33634	Reportable	05/20/2014	05/23/2014	4000	4000	No
AD 08248	Reportable	03/15/2014	03/20/2014	3494	3494	No

Table 6. Wear result from Dump Truck A hydraulic system oil sample (OPT Soluções, 2014).

Wear (Parts per million)								
Ag	Cr	Cu	Fe	Mo	Ni	Pb	Sn	Ti
Silver	Chromium	Copper	Iron	Molybdenum	Nickel	Plumb	Tin	Titanium
3	0	6	16	1	0	1	0	1
1	0	10	26	0	1	3	1	0

Table 7. Contamination result from Dump Truck A hydraulic system oil sample (OPT Soluções, 2014).

Contamination (Parts per million)			
Al	K	Na	Si
Aluminum	Potassium	Sodium	Silicon
10	0	0	41
10	0	0	70

Table 8. Additivation and physical tests result from Dump Truck A hydraulic system oil sample (OPT Soluções, 2014).

Additivation (Parts per million)					
B	Ba	Ca	Mg	P	Zn
Boron	Barium	Calcium	Magnesium	Phosphorus	Zinc
4	0	58	3	308	406
1	0	47	3	344	406

Physical tests		
V (100º C)	Water	Visual
Cst	%	Visual
8,640	0	N
8,360	0	N

Table 9. Particle counting and Total Acid Number (TAN) result from Dump Truck A hydraulic system oil sample (OPT Soluções, 2014)

Particle counting (Particles per mililiter)			
> 4 µm	> 6 µm	> 14 µm	ISO
Micron	Micron	Micron	4406
64588	24238	1848	23/22/18
59129	5426	28	23/20/12

TAN
TAN
Mg KOH/G
< 2
< 2

This analysis shows a high particle contamination, for all sizes displayed. This yields the classification 23/22/18 according to ISO4406 standards, while the lab recommended values are 21/19/16. Thus, this equipment should be put aside for maintenance in the next expected stop, when sealing conditions, eventual leakages, hydraulic filter situation and any abnormal instances should be monitored and fixed. Oil refilling or sealing damage, such as the one shown in Fig. 2, can be responsible for the high contaminants level measured.Thus, oil microfiltration is highly recommended in this case, in order to decrease impurities levels and increase equipment life span.

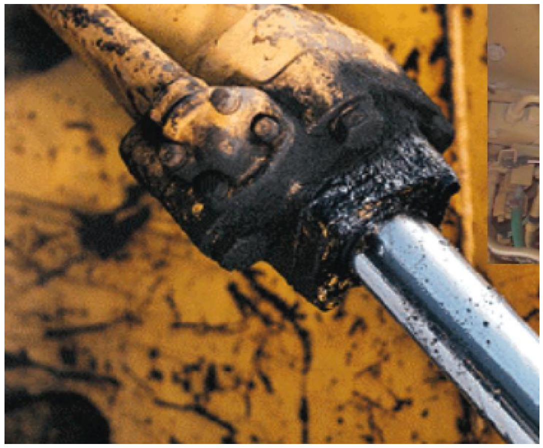

Figure 2. Oil leakage in hydraulic system (OPT Soluções, 2014)

Table 10 below shows particles per mililiter from ISO4406 standards.

Table 10. Particles per mililiter from ISO4406 standards (Parker Filtration, 2014).

Scale Number	Particles per mililiter	
	More than	Less of equal
>28	2.500.000	-
28	1.300.000	2.500.000
27	640.000	1.300.000
26	320.000	640.000
25	160.000	320.000
24	80.000	160.000
23	40.000	80.000
22	20.000	40.000
21	10.000	20.000
20	5.000	10.000
19	2.500	5.000
18	1.300	2.500
17	340	1.300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2,50	5
8	1,30	2,50
7	0,64	1,30
6	0,32	0,64
5	0,16	0,32
4	0,08	0,16
3	0,04	0,08
2	0,02	0,04
1	0,01	0,02
0	0	0,01

4.2 Normal samples

Collected oil classified as normal does not require any immediate action plan. Nevertheless, preventive maintenance should be executed as usual. Dump Truck A had its transmission system oil collected in 315 and 191 hours intervals. The oil is SAE80W. The analysis shows low contaminants level, and can be seen in Tab. 11 to 14.

Table 11. Oil sample from Dump Truck A transmission system (OPT Soluções, 2014).

Samples						
Sample	Status	Collect date	Processing date	Hour meter	Fluid hour meter	Changed?
AD 33640	Normal	05/20/2014	05/23/2014	4000	996	Yes
AD 27510	Normal	05/08/2014	05/08/2014	3809	805	No
AD 08249	Normal	03/15/2014	03/20/2014	3494	490	No

Table 12. Wear result from Dump Truck A transmission system oil sample (OPT Soluções, 2014).

Wear (Parts per million)								
Ag	Cr	Cu	Fe	Mo	Ni	Pb	Sn	Ti
Silver	Chromium	Copper	Iron	Molybdenum	Nickel	Plumb	Tin	Titanium
3	1	3	97	17	0	0	0	0
0	1	2	90	15	0	1	1	0
0	1	2	82	12	1	0	2	0

Table 13. Contamination result Dump Truck A transmission system sample (OPT Soluções, 2014).

Contamination (Parts per million)			
Al	K	Na	Si
Aluminum	Potassium	Sodium	Silicon
11	0	0	12
10	0	8	12
7	0	0	10

Table 14. Additivation and physical tests result from Dump Truck A transmission system sample (OPT Soluções, 2014).

Additivation (Parts per million)					
B	Ba	Ca	Mg	P	Zn
Boron	Barium	Calcium	Magnesium	Phosphorus	Zinc
4	1	40	1	152	6
1	1	54	1	78	10
0	1	56	1	80	9

Physical tests		
V (100º C)	Water	Visual
Cst	%	Visual
9,270	0	N
9,380	0	N
9,600	0	N

An important tool in oil analysis and predictive maintenance in general is the investigation of trend lines. For Dump Truck A samples shown above there is no significant variation between the three trials, indicating a stable behavior of contaminants, without substantial risk for the system.

An important task is to define the source of each element in the oil analysis, in order to focus on the contamination root cause. According to OPT Soluções, the origin of some elements can be seen in Tab. 15 below.

Table 15. Origin of contaminants (OPT Soluções, 2014).

Element		Origin of contaminant
Fe	Iron	Gears, bearings, axes, sleeves
Cu	Copper	Bushings, bronze valves, bearing housing, heat exchangers
Si	Silicon	Dust, seal materials, water coolant additives
Mo	Molybdenum	Rings, water coolant additives, solid additives

5. CONCLUSION

Oil analysis tool for terrestrial fleet is becoming essential in regard to prevent unexpected equipment failures. Standardizing of oil collect intervals allows the maintenance manager to use trend lines to predict equipment behavior during equipment life. This technique should be disseminated further for terrestrial logistics, earthwork and heavy duty vehicles in general, in order to increase equipment reliability. Both financial and safety aspects are involved when failure prevention is in focus.

This work illustrates the detailed use of predictive maintenance procedures for oil analysis, together with equipment operations condition monitoring, saving mechanics time and resources, and finally preventing avoidable failures. Dump Truck A had its rear axle and transmission system oil analysed, with wear and contamination parameters discussed. It was clear that the implementation of an effective predictive maintenance plan reached nof results for the equipment operation quality. This included reduction of potential corrective maintenance costs, workforce and supply resources.

Thank Fapemig (Fundação de Amparo a Pesquisa do Estado de Minas Gerais, companies and persons mentioned in this article.

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