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Maintenance cost reduction of a hydraulic excavator through oil analysis

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ABSTRACT
The purpose of this article is to present the economic advantages that the Oil Analysis can offer to companies operating with hydraulic excavators. The financial advantages are the result of lower maintenance costs and increased productivity of the equipment. Real situations of an infrastructure construction company in which there were mechanical failures that could have been avoided if implemented with efficiency analysis of lubricants.
Keywords – Failure Analysis, Hydraulic Excavator, Maintenance Costs, Oil Analysis.

I. INTRODUCTION

The current economic context increasingly requires accurate and lower service costs to allow for greater profit margins and more efficient planning for companies. Large projects such as infrastructure construction are going through adjustments to adjust costs and productivity to levels once considered impossible. To reach the service cost targets, it is necessary to contain one of the main portion that compose it: the equipment maintenance cost. As the main players of these large projects in Brazil there are construction and mining companies. Fig. 1 below shows an example of Hydraulic Excavator.

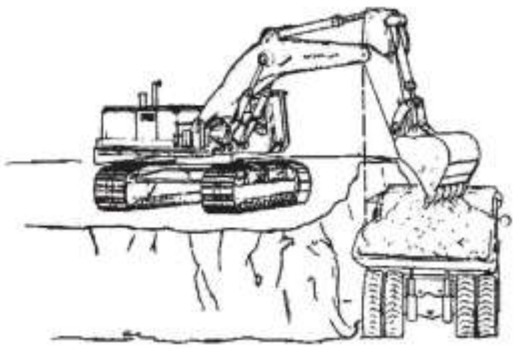


Figure 1: Hydraulic Excavator loading a truck. [1]

The hydraulic excavator is one of the main production equipment into a work of infrastructure once from that equipment is that the ground cuts are performed for earthworks, ore processing, foundation, etc. Stopping a bulldozer, however, should not be considered a single loss, since it implies consequent stop of as many planned to operate together as trucks, bulldozers, road rollers, tire tractors, water trucks, crushers and asphalt plants, increasing unproductive rates to these dependent equipment it. As a direct result of lack of productivity there is the increased cost of downtime machines and manpower lost.

As a tool to mitigate the mechanical failure of hydraulic excavators, there is the method called predictive maintenance Oil Analysis. The process of analyzing the condition of the lubricant in use is applied for decades and in recent years have been widely used as a tool for predictive maintenance and one of the most effective ways of assess the equipment.

The objective of this study is to demonstrate through empirical data of an infrastructure construction company that the use of lubricants analysis technique lowers maintenance costs by reducing failures, higher availability and reliability, longer life, higher efficiency to maintenance team, lower lubricant consumption, less downtime for corrective maintenance and less rework rate.

II. RELATED WORK

MAINTENANCE COSTS

The maintenance cost is the set of actions needed to maintain equipment in proper working order. The company which conducted out the present study, the cost of maintenance is considered includes the following items:

- Services performed, as a whole, including parts, accessories for replacement and labor costs in subcontractors and own workshops;
- Washing of equipment (just for maintenance), adjustments, painting and others;
- All undercarriages including tires, inner tubes, pin and bushing, shoes, belts, screws, tracks and other expenses;
- All preventive maintenance, including the applied lubricants, filters and also hand manpower used to perform.

According to DNER (in English, National Department of Highways), today DNIT (1996), cites a relevant paragraph regarding the maintenance costs over the lifetime of an equipment:

This cost can oscillate depending on the type of equipment from 50% to 100% of the cost of acquisition; these percentages include spending on preventive and corrective maintenance. (DNER, 1996).

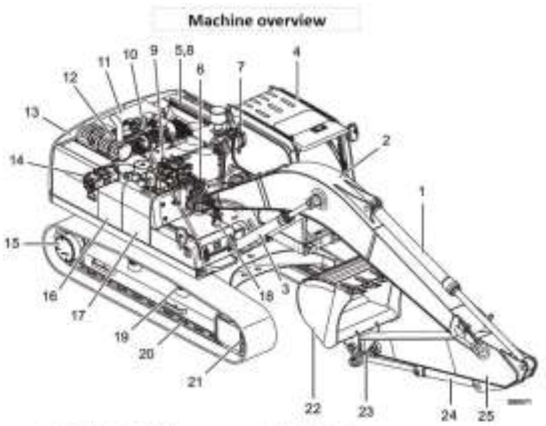
The maintenance cost is related to GDP (Gross Domestic Product) of Brazil because the indicator Maintenance Cost / Gross Revenue that on average between 1995 and 2011 is 4.11%. (Kardec & Nascif, 2009).

HYDRAULIC EXCAVATOR

The excavator is an equipment whose purpose is to stir or remove certain type of soil or material. Works parked and are usually mounted on undercarriage. It has mechanisms that allow it to spin 360 degrees and the digging system movement occurs through hydraulic cylinders. Fig. 2 shows the main components of this equipment, with their numbering.

The equipment has a set of components called "undercarriage" which is in the track area. This consists of rollers, pins, bushings, chain, shoes, sprocket and idler gear also called the idler. The sprocket is coupled to the belt gearbox and this set is commonly called "final drive".

In the bucket, teeth, also called spikes or nails adapters are fitted and these adapters are embedded. These teeth have various chemical compositions and different formats for different types of materials to be excavated.



1	Excavating arm cylinder	14	Main pump
2	Boom	15	Engine and gearbox tracks
3	Cylinder boom	16	Hydraulic oil tank
4	Operator's cab	17	Fuel tank
5	Oil radiator	18	Rotating gasket
6	Rotating engine and gearbox	19	Top track roller
7	Air purifier	20	Lower track roller
8	Radiator and air cooler	21	Driving wheel
9	Main control valve	22	Bucket
10	Engine	23	Joint
11	Rear hood	24	Bucket cylinder
12	Muffler exhaust	25	Excavating arm
13	Counterweight		

Figure 2: Hydraulic Excavator with details of some components. Adapted from [4]

The hydraulic excavator uses diesel engine as a power source for their other components, and there are two hydraulic pumps attached for braces system. Both are activated simultaneously when the engine speed is transmitted to the front drive shaft. The pump consists of rotating set, flow plate group, the block group valves and regulators. The displacement of the pump is controlled by the regulator and the motor output power is actually used by the proportional solenoid valve (Volvo, 2010).

The main control valve consists of two blocks of five reels and an intermediate block connected by screws. It contains six main spools for excavation units, three drums confluence and straight locomotion, a reel for the optional unit, a main relief valve, port relief valves and fastening and retention valves. These are controlled remotely by hydraulic servo system (Volvo, 2010).

The engine of the tracks is responsible for the displacement of the excavator. It is a hydraulic motor of variable piston axially, which consists of a housing, a rotating group and a door plate. The housing is equipped with a screw control for the flow angle. The rotating group consists of cylinders and pistons. The door plate consisting of compensation valve, check valves, exhaust valves and the switching valve displacement. The reducing tracks (or tracks gearbox) is a three stages planetary mechanism, three sets of sun gear, planetary gears and pinions, belt driven by the motor output shaft, mounted directly on the change box. The gearbox also houses the parking brake set, which is coupled by spring and released hydraulically (Volvo, 2010).

The rotating motor is responsible for spinning the machine. It is a hydraulic fixed piston motor. The group consists of a rotatable cylinder block and nine pistons positioned in the cylinder. The section of the cap has exhaust valves, and anti-cavitation valves and anti-recoil valves. The housing has a delay valve and a brake disc type. The reducer rotation (also called spinning Gearbox) is composed of sun gear, planetary gear, pinion gear and housing. The force applied to the rotating motor output shaft reduces engine speed through the solar and planetary gears, developing high torque is transmitted to the pinion gear (Volvo, 2010).

The hydraulic excavator has an important component called "H". It is responsible for the structural strength of the machine, as it is located below the operator's cab and the mats are engaged in it. Fig. 3 below shows this part.

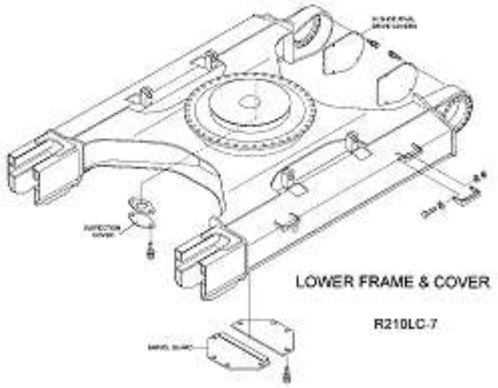


Figure 3: Structural part of the lower the excavator cabin, called "H". Adapted from [4]

FAILURES

As defined by Nepomuceno (1989), a failure is any problem in a system that remains until appropriate action is taken. A failure can cause interruption of the production, reduced efficiency and loss of a particular component in a catastrophic way. Thus, if the equipment is critical in a given process, is important provide some sort of monitoring to reduce its number of failures.

OIL ANALYSIS

The use of oil analysis as a maintenance technique began to be applied in the decade 50. The oil crisis has intensified the use of oil analysis, which started to fulfill a new role in maintaining allowing the monitor lube oil condition and identify the need for change or only partial replacement. During this period were introduced predictive techniques that allowed by oil analysis diagnose equipment problems. Currently environmental laws become even stricter the maintenance action related to using oil in industry, being necessary to the implementation of treatment plants and disposal methods and recycling of lubricants. The lube oil analysis is used with two main objectives: to identify potential equipment failures (SUPREME, 2012).

Nepomuceno at ALVES (2007) emphasizes the importance of analyzing the oil used in a preventative maintenance program, focusing on the monitoring of equipment and lubricant economy ceasing to replace the lubricating oil every operation period and starting to run the exchange only when necessary. He pointed out that an analysis program requires special investment and proper personnel's training and should be done with great accuracy, organization and rationalization, that the analysis results are well used. An analysis methodology is established, with physical-chemical tests such as the measurement of kinematic viscosity, determination of water in oil, metallographic analysis. He also pointed out the limitations of the process due to the high cost imposed to a permanent monitoring and to determine rapidly evolving faults (Alves, 2007).

According API2 apud at Alves (2007) the following services: oil trading, exchange the filter element of the oil and the maintenance and replacement of elements of the intake air filtering system when they are not monitored by analysis of lubricants, should be performed observing the recommendations of the engine manufacturers. Also according to the API, among the major sources of contamination of lubricating oils engines it was highlighted: dust, particles from wear of parts and combustion by-products such as water, acids, soot and dilution by fuel (Alves, 2007).

Through the oil analysis we can plan to stop the equipment, reducing downtime maintenance. Fig. 4 shows a predictive maintenance chart where near the warning level there is a reduction in the gap of acquisition and data analysis to define the exact time to intervene in the machine.

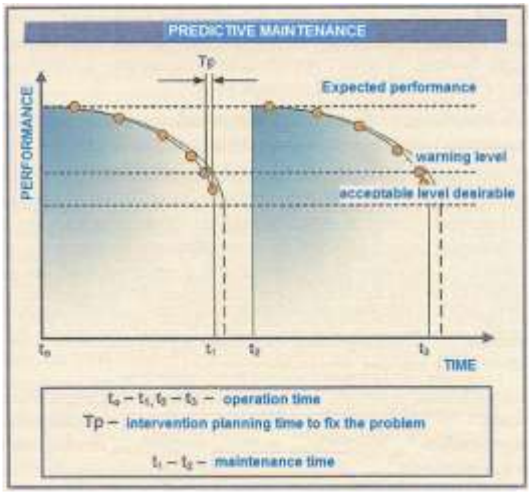


Figure 4: Predictive Maintenance Chart. Adapted from [3]

The lubricating oil analysis can be used for the assessment of equipment condition. Through evaluation of the chemical composition, amount, and form of the contaminants have been developed monitoring and analysis techniques which allow to define the machine component failure mechanisms. Analysis of lubricating can be divided into four groups: physical and chemical analysis; analysis of contamination; spectrometry; ferrography. (SUPREME, 2012).

The company which had undertaken the present study, reports of oil analysis laboratories feature all the groups, with a history of past results, indicating contamination levels are higher. All reports received by the oil analysis lab are transferred to the SAP software system, creating the results history for each equipment group, including hydraulic excavators. On SAP is allowed to make a report to demand feedback from test with negative reports, allowing advise on the criticality of wear or contamination. The laboratory responsible for analyzing the samples collected also indicates the mechanical interventions that must be performed on the equipment.

III. METHODOLOGY

GATHERING INFORMATION

The methodology proposes the gathering and organization of information of twenty-seven hydraulic excavators which provide services in different works of construction in distinct regions of the country. These machines perform earthworks to adjust the terrain.

Information was collected regarding the full year 2014, from January 1 to December 31.

Not to enter the construction sector particularities, the analyzed values do not distinguish the types of work and applications of the equipment, only the higher costs involved in repairs that could be avoided with the use of oil analysis.

Data and hours worked costs were obtained through SAP management software and two management reports (Machine Stop Daily Report - MSDP - and Report of the Work Measurement Monthly).

There was too much trouble to organize the data and put them in a practical way available and easy to access. This resulted from to the lack of SAP integration with other management reports (available in Excel sheets).

The absence of subsets of reform reports also interferes with the reliability of costs, making it difficult to determine which parts and labor workforce dedicated service were indeed due to component failure.

SAP

SAP is a software that assists in the integrated management system used by the company. On it are inserted various relevant information to the equipment through the program records.

Through SAP manufacturer data of each device were extracted. Information such as model, date of purchase, worked hours in the period, maintenance orders and cost of detailed parts. All reports obtained by the software were extracted in Excel .XLS format to make it possible the query and compilation of information without internet connection. Data were handled and rearranged properly.

MANAGEMENT REPORTS

The Machine Daily Report Stop (MDRS) reports which devices are in maintenance, detailing the parade causes. Specific and quick maintenance are not considered, as the report informs you only stopped equipment for longer than a day. Reports of 2014 were obtained to ensure that the costs reported in SAP were corrective maintenance, not accident or operating errors.

The reports were all inserted into the Excel PivotTable manually confronting dates reported in SAP to define the causes of failures, appropriating maintenance costs for each corrective maintenance performed. Costs were obtained through the maintenance orders relating to equipment in the given period of research.

IV. RESULTS AND DISCUSSION

The purpose of this study is to demonstrate through the collected data that it is feasible to obtain financial advantage through oil analysis in heavy construction companies. The construction company in question has the entire necessary infrastructure to reduce costs through predictive maintenance, but not to effectively practice by lack of investment in labor workforce and specialized training focused on predictive maintenance.

As it was not possible to collect enough information that prove the real cause of the subsets' failure, it was reported that the subsets with the negative oil analyses with consequent failure, could have the mechanical failure avoided, or minimized, through the subset maintenance after the negative conclusions of the oil analysis. This corrective maintenance is much less expensive than the part collapse, once the collapse do not allow the maintenance planning, increasing the dedicated time for the labor perform the maintenance, increasing the time for parts supplying, also causing worse quality of the service and, commonly, rework.

For the hydraulic excavators analyzed in this study, fails were detected at the following subsystems:

- Electrical: electrical system, lamps. Headlights, battery, horn, alternator and sensors.
- Structure: associated with the structural parts of the machine and general body shop.
- Motor and components: diesel motor, lubrication system, cooling system, admission system and the air conditioning system.
- Hydraulic: hydraulic cylinders, hydraulic hoses, valves, bombs and hydraulic motors.
- Driver's compartment: command knobs, windshields, windows, cleaner, rearview and general items inside the compartment.
- Excavation tools: digging shell and theirs fixers.

I.I. Collected data

The construction company in this study divides the excavators in two different equipment families, divided by their loading capacity

- EH 1 – Excavators with capability of 21 tons.
- EH 2 – Excavators with capability of 36 tons.

For each one of these excavators families, there are pre-defined values of their maintenance costs, in order to define the costs that the Equipment Central of the company will pay for the equipment rental. The estimated costs for the maintenance in each family in 2014 are:

- EH 1 – R$ 26,33 per hour.
- EH 2 – R$ 20,50 per hour.

These values were extracted using the SAP system of the company. These values were organized in Dynamic Tables, and are showed at the Tables 1 and below:

Table 1: Maintenance costs for EH 1 excavators

Prefix	Worked Hours (hours)	Maintenance cost (R$)	Equipment hour meter (hours)	Per hour cost of the maintenance (R$)
EH1	12.998	321.501,69	6.756	24,73
EH-0004	28	6.813,80	10.210	243,35
EH-0005	581	8.792,50	7.469	15,13
EH-0006	1.245	70.563,68	8.919	56,68
EH-0007	663	55.264,60	6.708	83,36
EH-0011	1.316	43.572,08	5.927	33,11
EH-0012	2.391	7.164,77	11.380	3,00
EH-0024	717	47.708,17	5.673	66,54
EH-0026	1	866,40	560	866,40
EH-0027	1.909	17.519,43	3.405	9,18
EH-0028	2.187	23.797,14	3.312	10,88
EH-0029	1.960	39.439,12	3.040	20,12

Table 2: Maintenance costs for EH 2 excavators

Prefix	Worked Hours (hours)	Maintenance cost (R$)	Equipment hour meter (hours)	Per hour cost of the maintenance (R$)
EH2	23.303	1.053.571,16	7.621	45,21
EH-0008	1.667	96.897,24	11.823	58,13
EH-0009	812	89.030,48	9.342	109,64
EH-0010	1.351	54.287,49	8.295	40,18
EH-0013	1.043	25.063,47	6.859	24,03
EH-0014	1.170	22.739,96	7.918	19,44
EH-0015	1.480	44.775,44	6.830	30,25
EH-0016	1.376	61.064,94	9.229	44,38
EH-0017	1.466	36.830,71	6.396	25,12
EH-0018	1.127	40.172,27	5.317	35,65
EH-0019	1.374	54.471,72	6.519	39,64
EH-0020	1.217	21.161,60	5.229	17,39
EH-0021	1.768	41.323,83	5.955	23,37
EH-0022	1.457	30.124,50	6.560	20,68
EH-0023	2.064	44.888,75	5.116	21,75
EH-0025	1.174	211.871,58	7.613	180,47
EH-0030	2.757	178.867,18	7.370	64,88

Through the distortion pointed by these tables, a research were performed in order to identify the equipments that could have their maintenance costs reduced, in case the oil analysis were effectively performed. These equipments are showed at Table 3 below.

Table 3: Equipment under study data

Prefix	Producer	Model	Year of manufacture
EH-0006	Volvo	EC210 BLC	2009
EH-0007	New Holland	E215B-ME	2009
EH-0009	Liebherr	R-944 C	2009
EH-0030	Komatsu	PC350 LC-8	2012

The estimated costs for each excavator are showed at Table 4 below.

Table 4: Estimated and real maintenance costs

Prefix	Model	Per hour cost for maintenance	
		Estimated	Real
EH-0006	EC210 BLC	R$ 26,33	R$ 56,68
EH-0007	E215B-ME	R$ 26,33	R$ 83,36
EH-0009	R-944 C	R$ 20,50	R$ 109,64
EH-0030	PC350 LC-8	R$ 20,50	R$ 64,88

It is possible to notice that the maintenance cost for the R-944 C model at Table 4 reached the order of 400% higher than estimated cost.

The selected equipment for this study has a negative historic reports to at least one subset. The analyzed reports pointed to contaminations and worn of equipment between the period of 2012 and 2013, failing in 2014.

The reports of equipment EH-0006 and EH-0030 pointed problems at the hydraulic system and, therefore, the cost reduction considered for this equipment would involve only the maintenances related to the hydraulic system of the equipment. The same criterion were applied to EH-0007 and EH-0009, with negative reports for the oil used at the engine crankcase.

I.II. Maintenance costs

For each equipment, the most relevant maintenance were determined and the costs that could have been avoided with the oil analysis.

- EH-0006 – Reconditioning of the hydraulic pump, services at the hydraulic cylinders, elevation cylinder inspection, valves commands inspection, hydraulic motor services. Costs: R$ 36.680,00.
- EH-007 – Services and repairs at the injector pump, injection pump inspection and valves and engine head inspection. Cost: R$ 15.170,00
- EH-009 – Repair and conditioning of the injector units, purchase of parts, technical service of inspection and inspection at the engine inlet. Cost: R$ 40.917,00.
- EH-0030 – Performed services at the hydraulic cylinders. Cost: R$ 21.593,77.

Table 5 shows the hypothetical maintenance costs in case all the aforementioned costs were avoided reducing the per houst cost of the hydraulic excavators.

Table 5: Maintenance costs with the oil analysis applied at the studied excavators

PREFIX	MODEL	WORKED HOURS	REVIEWED MAINTENANCE COST (R$)	PER HOUR MAINTENANCE COST REVIEWED (R$/HOUR)
EH-0006	EC210 BLC	1245	33.883,68	27,22
EH-0007	E215B-ME	663	40.094,60	60,47
EH-0009	R-944 C	812	48.113,48	59,25
EH-0030	PC350 LC-8	2757	157.273,41	57,05

The comparative Table 6 exposes the percentual cost reduction that would be obtained with the correct oil analysis for these equipment.

Table 6: Per hour reduction of maintenance cost, comparing with 2014 values

PREFIX	PER HOUR MAINTENANCE COST		
	REAL 2014	WITH OIL ANALYSIS	PERCENTUAL REDUCTION
EH-0006	R$ 56,68	R$ 27,22	51,98%
EH-0007	R$ 83,36	R$ 60,47	27,45%
EH-0009	R$ 109,64	R$ 59,25	45,96%
EH-0030	R$ 64,88	R$ 57,05	12,08%

For a more complex and comprehensive study, it is necessary to also analyze the time that these equipment remained stopped for maintenance and the value of these hours would be added to the maintenance cost. However, the lack of information from the studied company do not allow that these kind of calculation were performed, allowing us to analyze only the parts and the labor involved at maintenance.

The results are significantly positives, varying from 12% to 52% the positive impact at the excavators maintenance costs.

V. CONCLUSION

From the maintenance costs obtained through the oil analysis and remaining the same worked hours, it was possible to define the cost of R$ 114.360,77 that could have been reduced by the maintenance of the equipment studied.

Generally, it is possible to conclude that efficient application of the oil analysis for the excavators results in the cost reduction, increasing the infrastructure company's competitiveness.

It was verified that the necessity of computing with precision the equipment's stopped hours in order to obtain the relevant data as the mechanical disponibility and the average time of preparation of these equipment. Therefore, it is necessary to use the SAP system with more efficiency, integrating information of the time that the equipment remains operating and the repair time required, considering the time required to mobilize the equipment for the repair station, the repair time and the time required to give back the equipment for service.

It was found that maintenance cost calculation for the excavators is outdated, once the real values for maintenance are not similar with the estimated costs, justifying the company's difficulty to obtain the real information of these equipment. To obtain the real maintenance cost also allow to analyze the fleet renewal through the equipment production, involved costs, disponibility and the resale value.

In order to perform a more accuracy study about these maintenance costs, the operational costs of these equipment must be considered in order to obtain the economic viability of the equipment operation and to qualify these equipment in more productive or less productive. These values were not considered because the company in study did not published them.

Therefore, it is possible to conclude that the lubricating analysis is efficient in terms of the maintenance cost reduction although the lack of information and data compromise the real calculation of this benefit.

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