J. Civil Eng. Mater.App. 2022 (December); 6(4): 221-228

Journal of Civil Engineering and Materials Application
Journal home page: http://jcema.com

Received: 06 September 2022 • Accepted: 29 November 2022

Research

doi: 10.22034/jcema.2023.168596

Reducing the Costs of Using Construction Machinery by Using the Oil Condition Monitoring Technique

Tavakol Rajabi

Department of Civil Engineering, Payame Noor University, Tehran, Iran,

*Correspondence should be addressed to Tavakol Rajabi, Department of Civil Engineering, Payame Noor University, Tehran, Iran. Email: amir.rajabi.1486@gmail.com.

ABSTRACT

In this research, with the aim of reducing the costs of maintenance and use of construction machinery in the road construction sector, the methods of increasing the time intervals for changing the engine oil of these machines have been discussed. Accordingly, as a case study, this goal was achieved in an excavator of the Komatsu PC220-7 model using SAA6D102E-2-C engine oil by means of an engine oil condition monitoring system that was used at intervals of 55, 110, and 165 hours of operation. Machines have been investigated in construction and road construction projects. The main parameters of this research include viscosity at 40 degrees Celsius, alkaline number, erosive elements (iron, chromium, aluminum, copper, lead), oil additives (zinc, phosphorus, calcium), oil contaminants (calcium, sodium, and Boron) and Particle Quantifier for each of which a standard index has been considered and the change of these parameters in three periods of 55, 110 and 165 hours of vehicle engine operation has been investigated. Also, as an economic discussion, the cost parameters in Iran for these conditions have been investigated. The results of this research showed the good performance of the oil during 165 hours of engine operation.

Keywords: construction machinery, condition monitoring, productivity increase, engine oil

1. INTRODUCTION

Every year, a lot of expenses are incurred for the construction of roads and construction projects in the countries of the world, and part of these expenses are related to the equipment and maintenance of machinery related to construction projects. A very large percentage of these machines are used in the construction of projects, but some of these machines are also used in the maintenance stages of construction projects, which is why their proper operation can reduce costs. Construction and maintenance of construction projects, especially road construction projects where the use of machinery is very high [1-4]. Various machines are used in several construction and road construction projects, and one of the most used types of these machines is excavators, which are widely used. Excavators available in Iran are not very diverse in terms of manufacturing plants and their types, and the reason for this is so diverse that it is not in the scope of this article. But one of the most common types of these excavators is the Komatsu excavator. Machines used in construction projects and especially road construction should be checked at appropriate intervals, and their consumables should be replaced and repaired at appropriate times [5]. One of these consumables in construction machinery is the oil of these machines, which must be replaced at appropriate times, and due to the continuous operation of the machines and their engines, this replacement and the costs associated with it for many Construction companies and project builders and contractors are very important [6-8]. Various methods are used to improve the service life of machines and their maintenance, and among them, condition monitoring is one of the appropriate maintenance and repair techniques in creating a balance between the cost and the efficiency of the devices [9-11]. There are several methods for monitoring the condition of devices, such as analyzing vibrations, heat, sound, etc. However, practical experience shows that the oil condition monitoring technique is a suitable method, especially in the field of construction machinery. Because most of the main systems of construction machinery (engine, hydraulic, gearbox and differential) are done in a more frictional way. Therefore, the oil that is continuously circulating and in contact with various internal parts of the system contains general information about the action and internal reactions of the system. The device makes it possible to choose the best oil and determine the maximum working time [12-15]. Lubricating oil of internal combustion engines is exposed to many changes that are affected by working conditions, fuel quality, environmental conditions, and operational parameters. These factors also affect the intensity of decomposition and corruption of lubricating oil. In this sense, it is necessary to replace the engine oil before the oil loses its protective properties. On the other hand, unnecessary or premature replacement of lubricating oil, especially from an economic and environmental point of view, will leave adverse effects in the field of network management. The approximate demand of 38 million tons per year in the world market for oil lubricants such as motor oil, gear oil, etc., shows the importance of research on determining the optimal working life of oil and evaluating its economic effects [16-19]. Ahmadi and Salami research determining the best time to change the engine oil D9408 Liebahr crane by monitoring the condition of the oil by analyzing the percentage changes of each of the parameters PQ, TBN, oil additives, erosion particles, and oil contaminants at time intervals of 150, 140, 130 120, 110 and 160 working hours of the engine, the time to change the engine oil of this device increased from 125 hours to 150 working hours of the device. The importance of determining the appropriate time for engine oil replacement from the point of view of the return of capital and time in net management depends on accurate, continuous planning and along with the analysis of this process while taking into consideration its operational parameters, ignoring these conditions will lead to ineffectiveness. Because of the reduction of the useful life of the engine, the increase in the stoppages caused by the repair, and the increase in the repair costs [20]. From this point of view, the goal of future research is to increase the time intervals for replacing the oil of the Bill Komatsu PC220-7 engine with the help of monitoring the condition and evaluating its direct economic effects on the net cost.

2. MATERIALS AND METHODS

The test and monitoring analysis condition was done through oil analysis on a Bill Komatsu PC220-7 machine with a SAA6D102E-2-C engine. The important parameters of this engine are given in Table 1. This plan was implemented during the period of 625 hours of operation of the engine with the regular execution of the sampling program from the engine part for precise analysis, on the mentioned device and by preparing three types of oil samples as described below: New oil sample (before use): The engine oil used in this machine is Behran Turbo Diesel 20W50. This type of sample is considered an indicator for evaluating the quality of working oil. Engine oil sample in 125 operating hours of the device at the same time as a replacement: this type of sample is in the initial stages of project implementation and with three repetitions in order to ensure that the oil and engine conditions are satisfactory in order to increase the working hours of the oil, as well as information about the normal values (in the condition The health of the device) is the parameters analyzed for the oil. Engine oil sample at continuous time intervals of 55 hours, 110 hours, and 165 hours of device operation: This type of sample is for the purpose of analyzing the process of the analyzed parameters and evaluating the percentage of their changes in order to make an accurate decision in diagnosing the service life of the engine oil. During the implementation period of the project, two periods of 165 hours were achieved.

Table 1. Important parameters of the evaluated engine

Evaluated engine parameters	Description
Engine model	**ASS6D102E-2-C**
Number of cylinders	**6**
maximum power (kw)	**125(KW) In 2000(RPM)**
cooling system	**Water**
Engine oil chamber volume with filter	**24 (LI)**

2.1. WATER COOLING SYSTEM

2.1.1. THE VOLUME OF ENGINE OIL COMPARTMENT WITH FILTER

The analyzed parameters of the oil sample include viscosity at 40 degrees Celsius, TBN, oil additives, erosive elements, PQ index, and oil contaminants. In examining the condition of the oil in each time period, the method of determining fixed limits, trend analysis, and the recommendations of the manufacturer (OEM2) of the equipment was used. Finally, in order to evaluate the economic effects of the implementation of this project (increasing oil performance), the parameters that affect the service cost of engine oil for 625 operating hours of the Komatsu excavator, 220 cases of treatment with another Komatsu 220 excavator active in the same project. It has been compared that the oil change was done every 125 hours of engine operation according to the previous routine. During this period, the conditions affecting the oil (type of oil filter used, oil filter replacement time, temperature, and working load) and working time (total service and maintenance conditions) were similar for both devices.

3. RESULTS AND DISCUSSION

3.1. VISCOSITY ANALYSIS

The viscosity of the samples was evaluated by ASTM D-445 standard method. The viscosity of the oil used in construction machinery is generally measured at 40 degrees Celsius [6]. Viscosity can decrease or increase due to contamination with fuel or excessive mixing with water. As a general rule, it is safe to increase engine oil service intervals as long as the viscosity is within ±10% of the viscosity of new oil.

Table 2. Amount, abnormal level and excessive level of oil viscosity in 165 working hours

temperature viscosity of 40 degrees Celsius in 165 hours of engine operation (CSt)	Abnormal threshold	Threshold exceeded	Percentage change
	New oil viscosity+- 10%	New oil viscosity+- 20%	
	New oil viscosity (CSt)	New oil viscosity (CSt)	
185	164.7≤ ≤201.3	146.4≤ ≤219.6	2.64

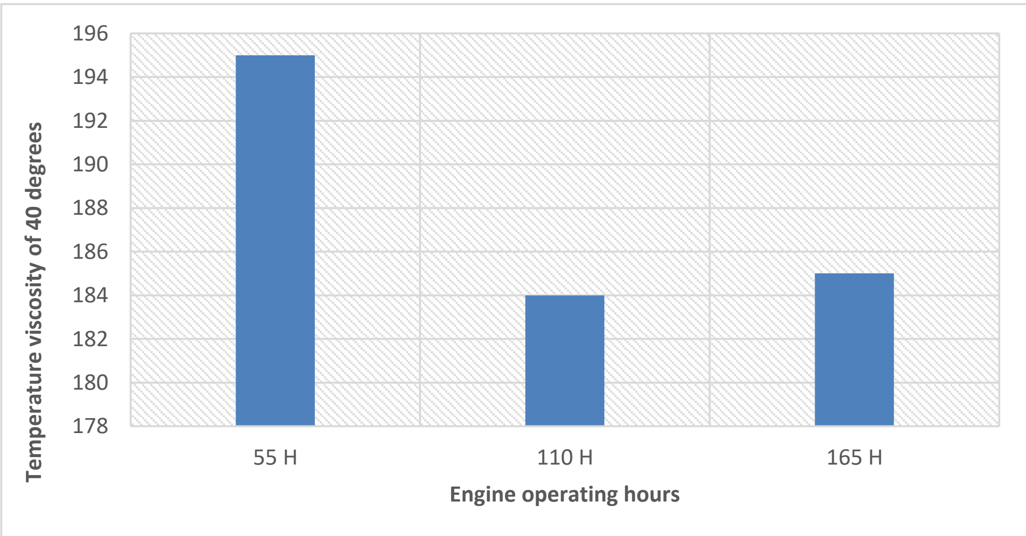

Figure 1. Viscosity analysis results in different time intervals of engine work

As can be seen from Figure 1, after 165 hours of engine oil operation, the viscosity changes have not yet reached the upper limit of the abnormal range, while the percentage change of this parameter is less than 50%.

3.2. OIL ALKALINITY NUMBER TBN3

In this research, TBN was evaluated by ASTM D-2896 standard method. The oil is constantly exposed to the acidic environment caused by combustion products (oxidation of oil, mixing of oil with fuel with a high percentage of sulfur, contamination of oil with water, etc.), which must cause corrosion of various parts of the engine. TBN actually measures the remaining alkalinity of the oil additives used to neutralize the acidic environment. In this sense, the reduction of TBN means the gradual loss of the oil's cleaning properties. The minimum recommended amount of TBN for Iranian fuel is 6 mgKOH/g. Considering the value of this parameter as 68.8 mgKOH/g in the 165-hour oil sample, it shows that the quality of the oil is maintained in the neutralization of the acidic environment after this number of hours.

3.3. ANALYSIS OF EROSION PARTICLES

According to the ASTM D-6595 standard and using atomic spectroscopic spectrometry (AES), the amount of each erosive element in the oil samples was evaluated. The most important metal particles were rubbed three times: 55 hours, 110 hours, and 16 hours at engine speed. Its values are shown in Figure 2. As can be seen, there is no significant difference between the values of each element three times. The percentage of changes in the most important elements of erosion during 165 hours of operation is less than 50%.

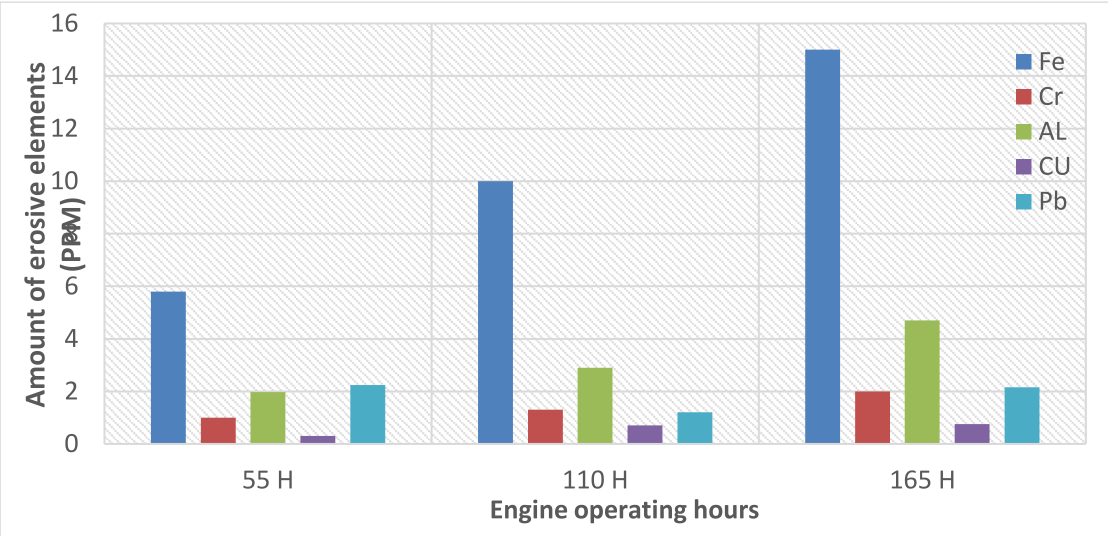

Figure 2. The results of the analysis of the elements caused by erosion in different time intervals of engine work

According to the results of their research, Ahmadi and Molazadeh explained that if the concentration of abrasive metal particles is between 50 and 100 PPm, a 50% change in these elements can be the reason for possible damage in the engine.

Table 3. Amount, abnormal surface, excessive surface and percentage change of metal material, wear in 165 working hours

Abrasive metal element	The amount of PPm in the 165-hour sample	Abnormal threshold Mean value + standard deviation (PPm)	Threshold exceeded Mean value + twice the standard deviation (PPm)	Percentage change
Fe	8.81	12.73	16.61	38.79
Cr	1.6	2.45	3.3	32.06
AL	3.54	5.63	7.72	37.53
CU	0.55	0.99	1.43	26.18
Pb	2.42	3.45	4.48	22.37

3.4. REDUCTION OF ADDITIVES

Because the base oil is obtained from the refining of crude oil, it still does not have the necessary properties for use in machines, substances such as cleaners, viscosity index improvers, etc. A lot, it decreases over time. The amounts of the most important elements added to the oil in the period of 165 working hours of the device are shown in Figure 3. The results indicate the acceptable performance of the oil after 165 hours of engine operation. Also, according to Table 4, the change percentage of each substance is not more than 50% after 165 hours. It should be mentioned that the levels of additives are measured in comparison with the levels of the same materials in new oil (before use). Most of the equipment manufacturing factories consider a reduction of up to -10% as an abnormal reduction threshold and up to -20% as an excessive reduction threshold.

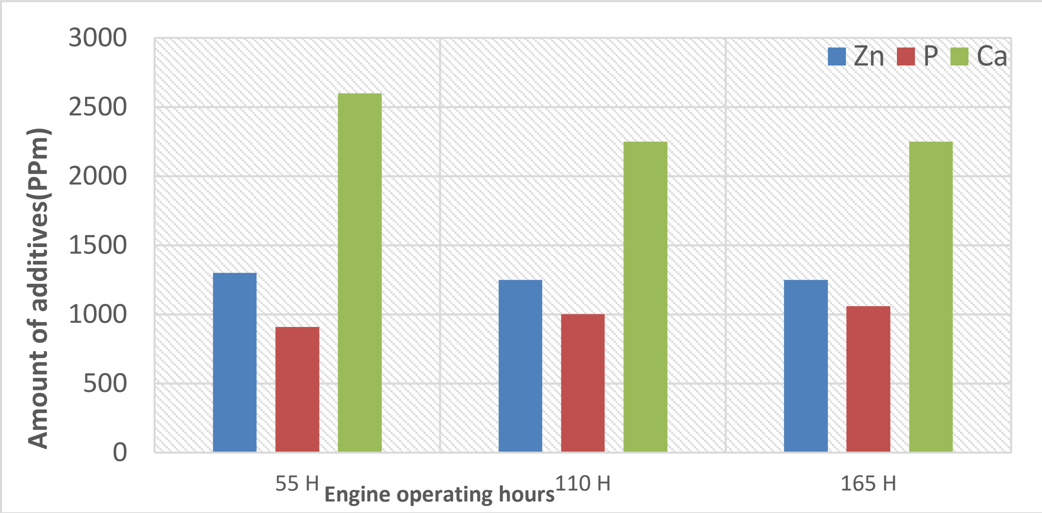

Figure 3. The results of the analysis of additives in different time intervals of engine work

Table 4. Amount, abnormal surface, excessive surface and percentage change of additives in 165 working hours

Abrasive metal element	The amount of PPm in the 165-hour sample	Abnormal threshold Its amount in new oil-10% Its amount in new oil (PPm)	Threshold exceeded Its amount in new oil-20% Its amount in new oil (PPm)	Percentage change
Zn	1259	1163.7	1034.4	1.35
P	1051	945.9	840.8	5.14
Ca	2296	2986.2	2654.4	6.22

3.5. ABRASION INDEX

There are different indicators of the wear condition, such as the PQ1 particle quantity meter and TDPQ2 erosion intensity coefficient. In the experiments conducted by the laboratory, PQ values were reported, which actually indicate wear particles larger than 10 micrometers. Figure 4 shows the values of PQ in three sampling intervals of 55 hours, 110 hours, and 165 hours.

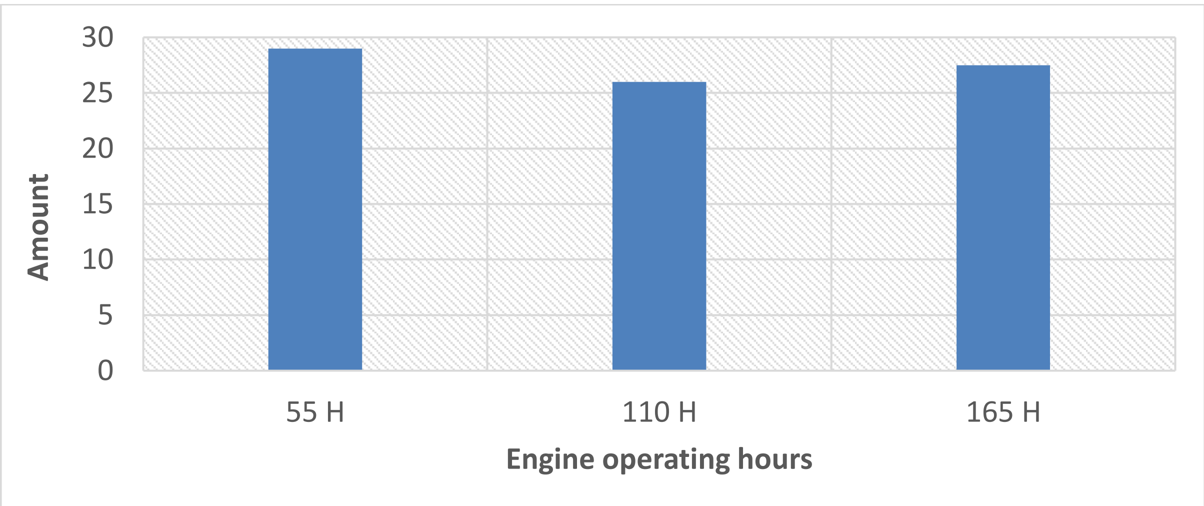

Figure 4. The results of analysis of the Particle Quantifier in different time intervals of engine work

As can be seen from Table 5, the PQ value after 165 hours is between the abnormal level and the excessive level. Also, this table's results show that this parameter's change percentage after 165 working hours is less than 50%.

Table 5. Amount, abnormal surface, excessive surface and percentage change of additives in 165 working hours

Abrasive metal element	The amount of PPm in the 165-hour sample	Abnormal threshold Mean value + standard deviation (PPm)	Threshold exceeded Mean value + twice the standard deviation (PPm)	Percentage change
PQ	28	28.91	30.57	4.5

3.6. CONTAMINATING SUBSTANCES

Silicon and sodium usually enter the engine oil environment and are known as pollutants. Boron can also be a sign of oil contamination with engine coolant because this substance is the basis of the antidote. Figure 5 shows the number of polluting substances (silicon, sodium, and boron) during different working hours of the engine..

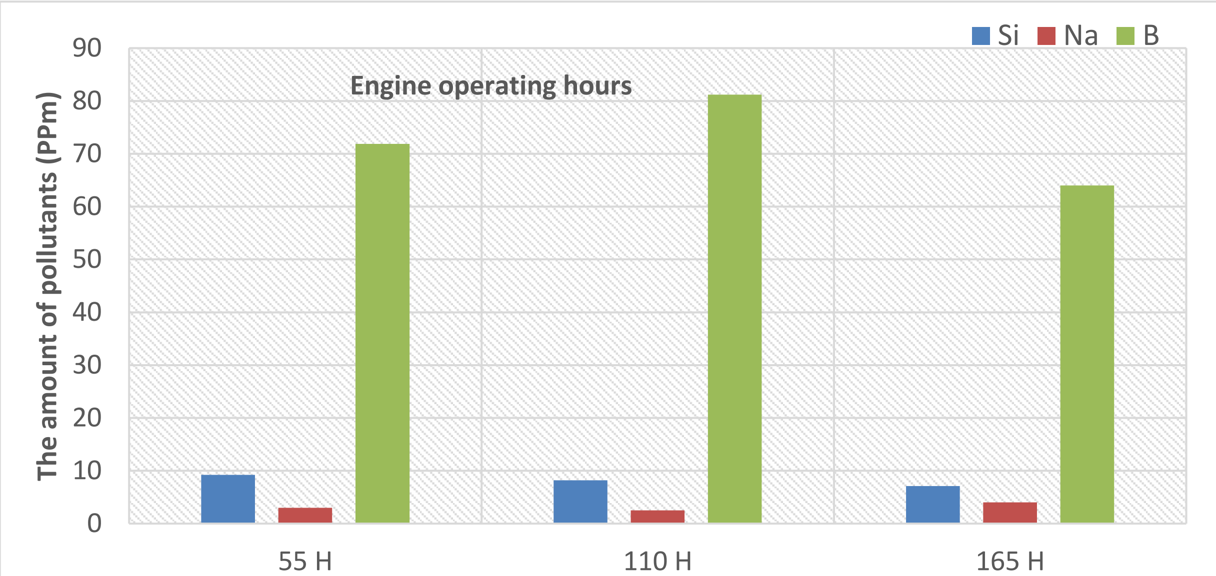

Figure 5. The results of the analysis of polluting substances at different working intervals of the engine

Table 6 shows that the amount of each pollutant after 165 working hours is less than the abnormal threshold. Also, the results of this table show that the percentage of changes of each pollutant after 165 hours was at most 50%.

Table 6. Amount, abnormal level, excessive level and percentage change of oil polluting substances

Abrasive metal element	The amount of PPm in the 165-hour sample	Abnormal threshold Mean value + standard deviation (PPm)	Threshold exceeded Mean value + twice the standard deviation (PPm)	Polluting substances
Si	7.23	11.08	14.79	11.93
Na	1.96	2.09	3.31	30.92
B	81.31	104.28	124.04	10.6

3.7. ECONOMIC EVALUATION

In order to evaluate the economic effects of increasing the hours of oil operation, the cost of the parameters that are directly affected by the engine oil service during 625 hours of engine operation for the Komatsu 220 mechanical excavator tested with another active Komatsu 220 excavator in the same project where the oil is replaced every 125 hours of engine operation has been compared (Figure 6). During this period (the same operating hours of two Komatsu 220 machines), the conditions affecting the oil performance (type of oil filter used, oil filter replacement time, temperature, and workload) total operating hours (service and maintenance conditions) for every Two devices were similar. For this purpose, the parameters studied in the engine oil service are listed in Table 7. It should be mentioned that now the service and maintenance is such that after every 2 times, the engine oil is replaced, the engine oil filter and fuel are replaced (primary filter every 250 hours and secondary filter every 500 hours), and for every oil change with Engine filters require a service person for an average of 40 minutes. As it is clear from Figure 6, economic savings have been achieved in each of the costs related to engine oil replacement, except the cost of performing tests, by increasing the engine oil replacement time to 165 hours.

Table 7. The compared parameters of engine oil service cost during 625 hours of operation of two Komatsu excavators

	Amount of oil used (liters)	The number of used oil filters	The number of fuel filters used	Number of oil analysis tests	total service work (working minutes)
Komatsu excavator 165 hours oil change	75	2	3	9	120
Komatsu excavator 125 hours oil change	125	3	4	5	160

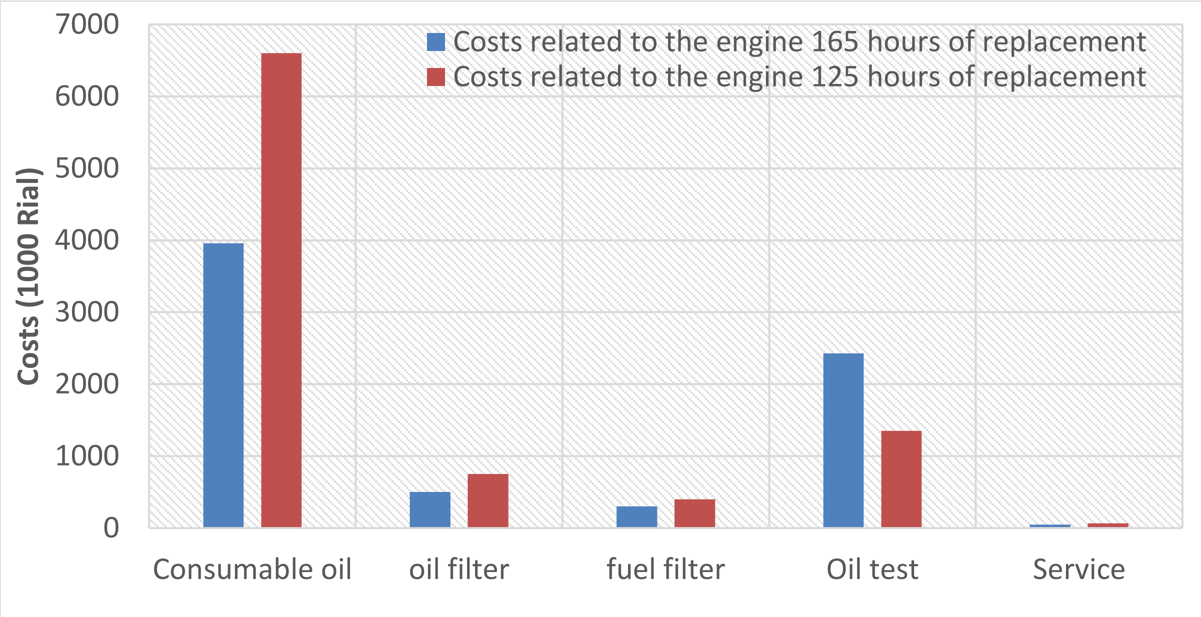

Figure 6. Comparison of the oil service parameters costs of two engines, 125 and 165 hours, oil change during 420 hours

4. CONCLUSION

This research aims to increase the oil change intervals of SAA6D102E-2-C Bill Komatsu PC220-7 engine oil, which is currently done in 125-hour intervals. In this sense, using the condition monitoring technique on oil samples taken at intervals of 110, 55, and 165 hours, it was determined that the oil has an acceptable performance in 165 hours of engine operation. This means that during this period, the percentage change of each parameter of viscosity at 40 degrees Celsius, oil additives, oil pollutants, erosion elements, and Particle Quantifier (PQ) was less than 50%. At the same time, their values were less than the maximum level. Finally, by observing the same conditions that affect the performance of the engine oil on the Komatsu 220, the replacement intervals have been upgraded to 165 hours, compared to other Komatsu models with 125-hour engine oil change intervals, at 6 working hours. A total of 462,670 Tomans (not counting the cost of oil tests) was achieved, which will be more significant by generalizing the results of this research on the set of active heavy equipment of each company.

FUNDING/SUPPORT

Not mentioned any Funding/Support by authors.

ACKNOWLEDGMENT

Not mentioned by authors.

AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

5. REFRENCES

[1] Zhu X, Zhong C, Zhe J. Lubricating oil conditioning sensors for online machine health monitoring–A review. Tribology International. 2017 May 1;109:473-84. [View at Google Scholar]; [View at Publisher].

[2] Agoston A, Ötsch C, Jakoby B. Viscosity sensors for engine oil condition monitoring—Application and interpretation of results. Sensors and Actuators A: Physical. 2005 Jun 30;121(2):327-32. [View at Google Scholar]; [View at Publisher].

[3] Duan C, Deng C, Gharaei A, Wu J, Wang B. Selective maintenance scheduling under stochastic maintenance quality with multiple maintenance actions. International Journal of Production Research. 2018 Dec 2;56(23):7160-78. [View at Google Scholar]; [View at Publisher].

[4] Schexnayder Jr CJ. Heavy construction equipment replacement economics (Doctoral dissertation, Purdue University). [View at Google Scholar]; [View at Publisher].

[5] Rao X, Sheng C, Guo Z, Yuan C. A review of online condition monitoring and maintenance strategy for cylinder liner-piston rings of diesel engines. Mechanical Systems and Signal Processing. 2022 Feb 15;165:108385. [View at Google Scholar]; [View at Publisher].

[6] Han Y, Song YH. Condition monitoring techniques for electrical equipment-a literature survey. IEEE Transactions on Power delivery. 2003 Jan 14;18(1):4-13. [View at Google Scholar]; [View at Publisher].

[7] Zhou W, Habetler TG, Harley RG. Bearing condition monitoring methods for electric machines: A general review. In2007 IEEE international symposium on diagnostics for electric machines, power electronics and drives 2007 Sep 6 (pp. 3-6). IEEE. [View at Google Scholar]; [View at Publisher].

[8] Tavner PJ. Review of condition monitoring of rotating electrical machines. IET electric power applications. 2008 Jul 1;2(4):215-47. [View at Google Scholar]; [View at Publisher].

[9] Karballaeezadeh N, Mohammadzadeh S D, Shamshirband S, Hajikhodaverdikhan P, Mosavi A, Chau KW. Prediction of remaining service life of pavement using an optimized support vector machine (case study of Semnan–Firuzkuh road). Engineering Applications of Computational Fluid Mechanics. 2019 Jan 1;13(1):188-98. [View at Google Scholar]; [View at Publisher].

[10] Ji B, Zhang X, Mumtaz S, Han C, Li C, Wen H, Wang D. Survey on the internet of vehicles: Network architectures and applications. IEEE Communications Standards Magazine. 2020 Mar;4(1):34-41. [View at Google Scholar]; [View at Publisher].

[11] Cheng JC, Chen W, Chen K, Wang Q. Data-driven predictive maintenance planning framework for MEP components based on BIM and IoT using machine learning algorithms. Automation in Construction. 2020 Apr 1;112:103087. [View at Google Scholar]; [View at Publisher].

[12] Yang W, Tavner PJ, Crabtree CJ, Feng Y, Qiu Y. Wind turbine condition monitoring: technical and commercial challenges. Wind Energy. 2014 May;17(5):673-93. [View at Google Scholar]; [View at Publisher].

[13] Prajapati A, Bechtel J, Ganesan S. Condition based maintenance: a survey. Journal of Quality in Maintenance Engineering. 2012 Oct 19;18(4):384-400. [View at Google Scholar]; [View at Publisher].

[14] Newell GE. Oil analysis cost-effective machine condition monitoring technique. Industrial Lubrication and tribology. 1999 Jun 1;51(3):119-24. [View at Google Scholar]; [View at Publisher].

[15] Poley J. Reciprocating Engine Oil Analysis (EOA)‖. InCTC Analytical Services, Papers From Practicing Oil Analysis 2000 Conference 2000 (pp. 93-100). [View at Google Scholar]; [View at Publisher].

[16] Raposo H, Farinha JT, Fonseca I, Ferreira LA. Condition monitoring with prediction based on diesel engine oil analysis: A case study for urban buses. InActuators 2019 Feb 16 (Vol. 8, No. 1, p. 14). MDPI. [View at Google Scholar]; [View at Publisher].

[17] Zhao J, Wang D, Zhang F, Liu Y, Chen B, Wang ZL, Pan J, Larsson R, Shi Y. Real-time and online lubricating oil condition monitoring enabled by triboelectric nanogenerator. ACS nano. 2021 Jun 25;15(7):11869-79. [View at Google Scholar]; [View at Publisher].

[18] AlShorman O, Irfan M, Saad N, Zhen D, Haider N, Glowacz A, AlShorman A. A review of artificial intelligence methods for condition monitoring and fault diagnosis of rolling element bearings for induction motor. Shock and vibration. 2020 Nov 4;2020:1-20. [View at Google Scholar]; [View at Publisher].

[19] Wakiru JM, Pintelon L, Muchiri PN, Chemweno PK. A review on lubricant condition monitoring information analysis for maintenance decision support. Mechanical systems and signal processing. 2019 Mar 1;118:108-32. [View at Google Scholar]; [View at Publisher].

[20] Ahmadi, H., & Salami, P. Determination of oil life for crane Liebherr Model D9408 diesel engine by Oil Condition Monitoring. [View at Google Scholar]; [View at Publisher].