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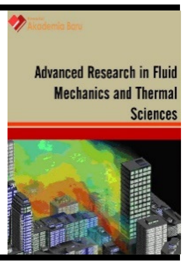

Oil analysis of used Perodua automatic transmission fluid (ATF-3) using spectrometric technique

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Syazuan Abdul Latip[1,*], Salmiah Kasolang[2], Zeno Michael[1], Ahmad Naufal Adnan[1]

[1] Fakulti Kejuruteraan Mekanikal, Universiti Teknologi MARA Johor, Kampus Pasir Gudang, Jalan Purnama, Bandar Seri Alam, 81750 Masai, Johor, Malaysia

[2] Fakulti Kejuruteraan Mekanikal, Universiti Teknologi MARA Shah Alam, 40450 Shah Alam, Selangor, Malaysia

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ABSTRACT

This paper investigates the severity level of wear metals occurred in Perodua MyVi 1300cc automatic transmission (AT) mechanism via multi-elemental spectrometric oil analysis. The work of analysis was performed merely on automatic transmission fluid (ATF) Perodua original equipment manufacturer (OEM) (ATF-3) series. The ATF was analyzed through actual operating distances. The operating mileage observed and analyzed was divided into three main categories. Category sample number (S1-S6) categorized as travelling distance (TD1) between 800km up to less than 20,000km travelling distance. Sample number (S7-S17) and (S18-S26) were each representing the operating travelling distance (TD2) and (TD3) encompassed of 20,000km up to less than 40,000km and 40,000km up to less than 60,000km, respectively. This analysis is primarily commenced based on limitations of the wear particle size that usually expressed as wear concentration in parts-per-million (ppm) unit. The typical concentration range for every element is between 1-100 ppm and the severity level of concentration for every element varies from one another. The element of Aluminum (Al), Chromium (Cr), Copper (Cu), (Ferum) Fe, Lead (Pb), Nickel (Ni), Tin (Sn), Titanium (Ti), Vanadium (V), Manganese (Mn), Argentum (Ag), Cadmium (Cd) are principally categorized as the wear elements. Barium (Ba), Boron (B), Calcium (Ca), Magnesium (Mg), Molybdenum (Mo), Phosphorus (P), Silicon (Si), Natrium (Na) and Zinc (Zn) are considered as additive elements which is subject to deplete and contaminate during used. From the analysis commenced, it was observed that the elements of Fe, Cu and Al were the most significant wear elements occurred throughout each operating categories and the occurrence of oxidation to be considered minimal as the element of phosphorus increases which indicates no sign of additive depletion to occur though the ATF had been used beyond its recommended period.

Keywords:
Automatic transmission (AT), Automatic transmission fluid (ATF), Operating mileage, Wear elements, Additive elements, Spectrometric

* *Corresponding author.*
E-mail address: syazuan6883@yahoo.com (Syazuan Abdul Latip)

1. Introduction

Considering the complexity of ATF production, function and properties; extending the use of it beyond the recommended period requires a better understanding of the physical and chemical properties of lubricants, how additives affect the interactions between lubricants and rubbing surfaces and understanding the correlation of wear and its severity level towards the automatic transmission (AT) mechanism. Traces of wear metals in used operating lubricant by principal vary in origin and its concentration value. These wear metals concentration obtained from the used lube provide vital information regarding the cause and level of the deterioration existed and progressed in operating mechanical component [1]. It has been affirmed that the occurrence of severe wear metals appeared to act as a catalyst that could speed up the degradation of a particular lubricant used during operation [2].

Apparently, a strong interaction between the content of metallic particles presence is very likely to contribute towards oxidation and degradation of the lube. In the case of automatic transmission fluid (ATF), qualitative analysis of wear metal concentration is very decisive to be evaluated. This evaluation outcome could eventually be a point of reference focusing on the level of severe wear metals and typical significant wear elements occur in AT mechanism analysed. Due to this concern, spectrometric analysis had been opt as reliable qualitative analysis basis that is highly practical to quantify the elements of additives, contaminants and wear metallic particles presence in the studied ATF samples. This work of analysis is performed based on elemental concentration which is expressed in parts-per-million (ppm) unit. Any increment or decrement value of concentration is a great indication in identifying difference characteristic of wear mode and severity occurred in an operating mechanism.

2. Automatic transmission (AT) system background

AT system has been well recognized for its ease of use for any level of drivers. Due to this reason, AT vehicle type is been widely used around the world and the demand keep on increasing throughout these years. Typical construction for an AT system consisted of a torque converter, a transmitting gear unit, multiple-disc clutches, band and a hydraulic control unit [3]. The function of torque converter is to ensure the system achieves required acceleration by smoothly transferring the engine power to the transmitting gear unit. The role of transmitting gear unit is to reduce, produce or reverse the rotation accordingly. The function of hydraulic control unit is to control automatic gear-shift changes by means of supplying hydraulic pressure to torque converter and transmitting gear unit, according to vehicle speed and throttle position. During operating conditions, the amount of clutch energy dissipated caused by clutch engagement causes high friction and could affect the life of components such as gear unit and band within the system.

The energy dissipated as heat eventually produces excessive temperature that contributes towards unnoticed deterioration of these components [4-6]. Apart from this, R. Martins [7] stated that, in dealing with transmission mechanism, the health monitoring of gearing system is essential to be diagnosed as it is highly subjected to tribological stress. Apart from the mechanical concern, Waldemar Tuszynski [6] and Yon-Sang Cho [8] stated that, lubricating oil used in any moving part of automotive system plays the most critical role to ensure not just the long lasting performance of the operating system but to provide continuous sufficient protection towards the components within the system. Previous studies had further emphasized on the importance of condition monitoring of any operating transmission system as the unnoticed occurrence of wear towards the mechanical components within the system could lead to catastrophic failure [9-11]. Hence, the health monitoring and assurance of peak performance of any transmission system, which in this case the AT system is highly significant to be studied in the focus of investigating the rheological aspects and reliability of extended ATF usage within the AT system.

2.1 Automatic transmission fluid (ATF) background

Principally, automatic transmission fluid (ATF) is applied to lubricate a vehicle's transmission, which can be composed of synthetic or mineral oil. Synthetic oils are the typical type used as it has lower operating temperatures and higher resistance to deterioration comparing to mineral oil. Most importantly, it contains valuable additives to sustain the desired friction properties, minimize wear occurrence and provide sufficient corrosion inhibition to the transmission components [4, 12].

ATF is basically categorized differently according to its intended purposes. The most commonly transmission fluids are categorized as; Dexron-III, Mercon, Mercon-V, Type F, ATF-3 and ATF-4. Selecting a proper and suitable quality transmission fluid is essentially important as today's transmissions are incredibly sophisticated and require own specific fluid formulations [15]. As transmission systems become more advanced, automobile manufacturers have introduced transmission fluids specifically designed for the intended purposes.

In order to meet and satisfy all of these demands, various kinds of required additives are applied to ATFs. These additives are blended with the base oil according to its grade and specific duty [3]. Additives are necessary to enhance the aspects of oil's performance and replace compounds which may have been lost during refining process of the oil [11]. The functions of additives are many such as dispersant, sludge and varnish control, antioxidants, anti-wear, friction modifier, planetary gear, bushing, thrust and washer protection, clutch plate modifier and band friction corrosion inhibitor, prevent corrosion and rust, seal swell agent, prevent loss of fluid via seals, viscosity improver, reduce rate of change of viscosity, pour point depressant, improve low temperature fluidity, foam inhibitor and foam control [15]. The degradation of the base oil and depletion of protective additives is considered as a complex process as it not only reduces the neutralization reserve and lifetime of the oil, but also causes severe wear within the system due to corrosion and rapid accumulation of wear elements [12-14].

2.2 Zinc Dialkyldithiophosphate (ZDDP) anti-wear additive

Used lubricant tends to differ in chemical and physical composition from unused lubricant. Unused lubricant has a relatively high anti wear concentration, a low free-acid value. During use meanwhile, the concentration of anti-wear decreases and the acid value rises [12, 13]. Though by using the highest-grade and keeping the ATF clean is definitely the best maintenance practice, but it will not provide the overall rheological condition of the lubricant [14]. ZDDP plays its role through absorption onto metal surfaces and hence provides various advantages: i) chemical-to-chemical contact rather than metal-to-metal contact, and ii) sufficient protection on rotating components from excessive wear [13-16]. Despite ZDDP is known for its anti-wear characteristic, it also plays the important role as antioxidant. The reaction of zinc and phosphorus elements within ZDDP are the most important additive elements required to minimize the occurrence of oxidation [17-18]. Thus, the efficient operation of AT system relies on the performance of ATF measured by its anti-wear additive properties. ZDDP is one of the important additives that act as an anti-wear agent in the ATF.

3. Methodology

In this study, the analysis was performed by means of SPECTROIL Q100 spectrometer instrument. Principally, both unused and used ATF samples were burned between a rotating carbon disc electrode and a carbon rod electrode. It was required that 3ml of the ATF sample was placed in a sample cap, then the disc was partially immersed in the ATF sample and the disc was then rotated as the burn proceeds. It is compulsory that a fresh disc and a newly sharpened rod to be used for each sample to eliminate sample carryover. In the beginning of the analysis, a large electric potential was set up between a disc and rod electrode with the ATF sample in the gap between them.

An electric charge stored by a capacitor was discharged across this gap creating a high temperature electric arc between 5000°C to 6000°C which vaporizes a portion of the sample forming plasma which emits intense light. These emissions were separated into individual wavelengths and measured using a properly designed optical system. The purpose of the optical system in a spectrometer is to separate the light coming from the plasma into the discrete wavelengths of which it is comprised. An optical device called a diffraction grafting which as shown was used to separate the discrete wavelengths. It is a concave mirror with very fine lines on its surface that causes incident polychromatic light to be separated into component wavelengths.

The purpose of the grating is to separate (diffract) the light into its component wavelengths. The spectrometric analysis was basically done based on ASTM D6595 standard of practice. This is the standard method used for determination of wear metals, contaminants and additives in any automotive lubricating fluid.

4. Results and discussion

4.1. Wear elements analysis

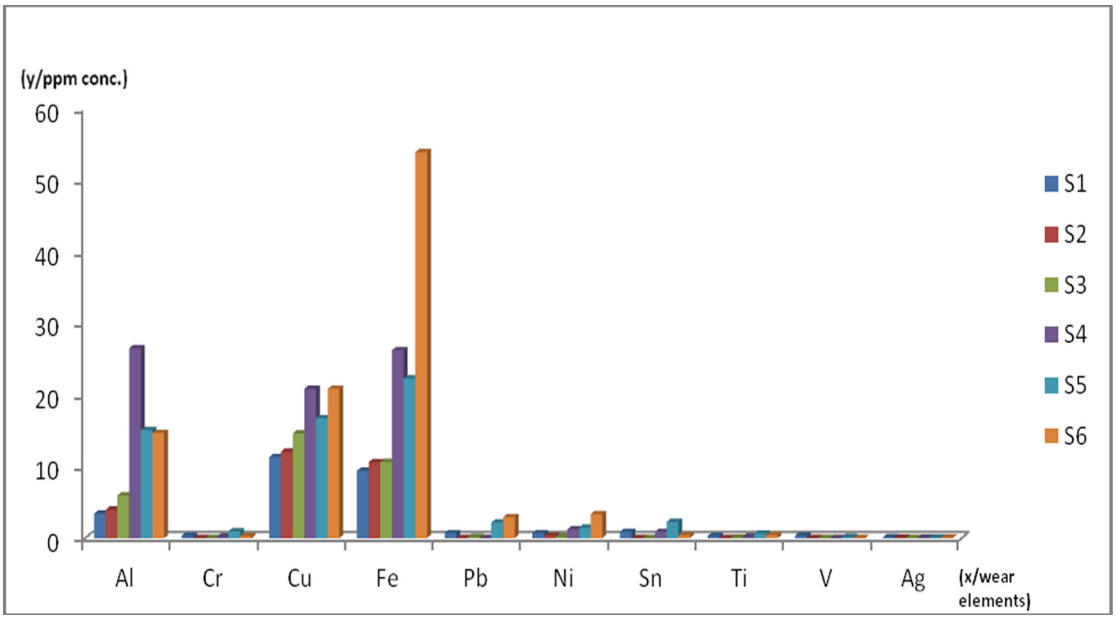

Fig. 1. Wear elements (ppm conc.) vs. (TD1) operating mileage

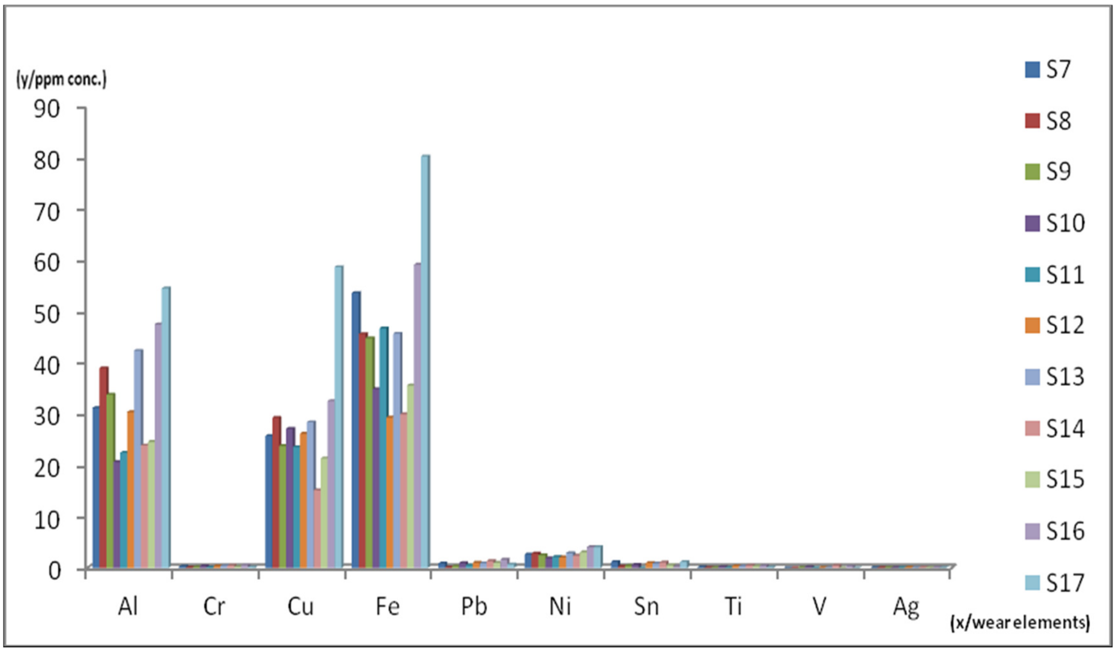

Fig. 2. Wear elements (ppm conc.) vs. (TD2) operating mileage

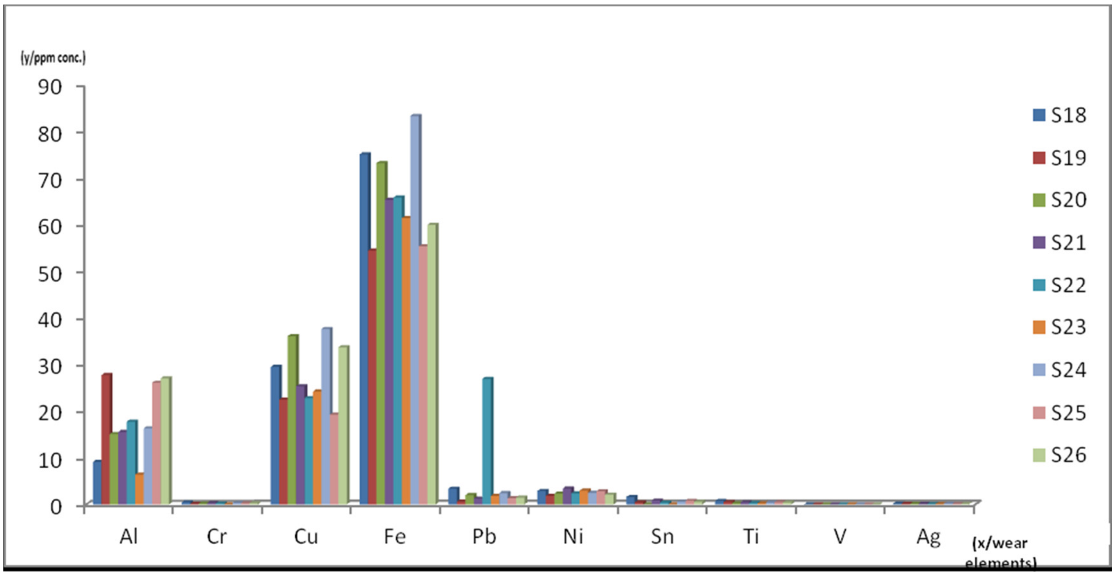

Fig. 3. Wear elements (ppm conc.) vs. (TD3) operating mileage

From the wear element analysis commenced, it was found that the elements of Fe, Cu and Al were the most significant wear elements occurred during the TD1 actual operating condition basis. The average wear concentration (ppm conc.) value obtained for each element was 22.161 ppm, 16.048 ppm and 11.577 ppm, respectively. Whilst, as observed for the TD2 sampling category, the wear elements of Fe, Cu, and Al showed the most significant value of wear concentration with the average value of 45.875 ppm, 28.29 ppm and 33.595 ppm, each.

TD3 sampling category showed the typical wear element result. It was noticed that the element of Fe, Cu and Al acquired the most momentous wear concentration value of 65.891 ppm, 27.8 ppm and 7.83 ppm, respectively. Thus, it can be clearly observed that similar wear elements tend to occur at high concentration value.

The elements were regarded as Fe, Cu and Al. The values of concentration of each wear element stated can be observed in the arrangement as follows;

Table 1
Wear element concentration

		TD1 [ppm]	TD2 [ppm]	TD3 [ppm]
i	**Fe**	22.161	16.048	11.577
ii	**Cu**	45.875	28.29	33.595
iii	**Al**	65.891	27.8	7.83

4.2 Additive elements analysis

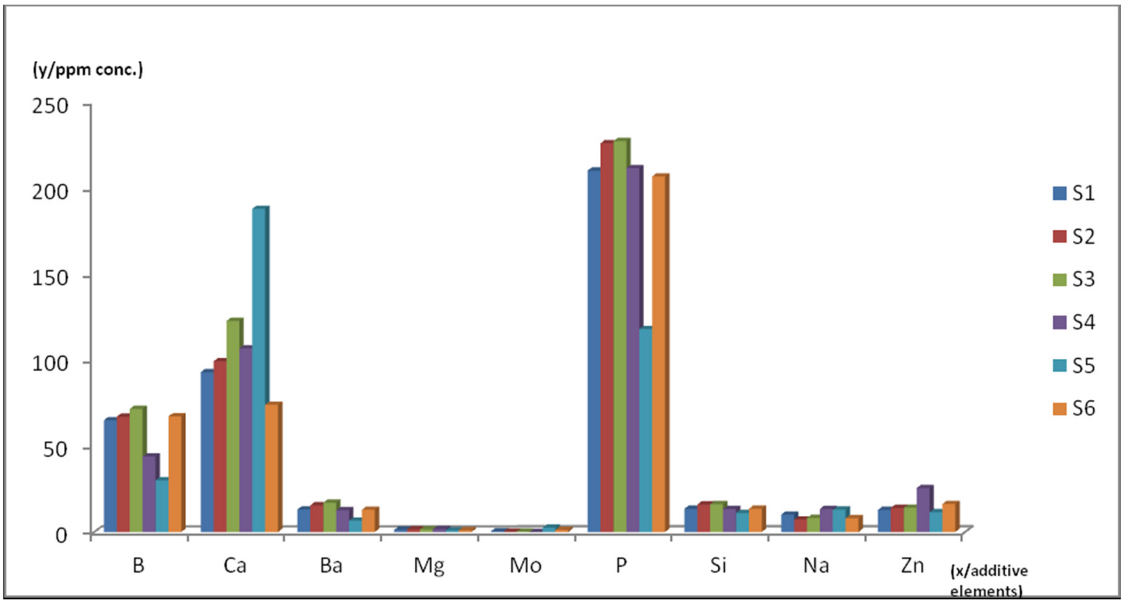

Fig. 4. Additive elements (ppm conc.) vs. (TD1) operating mileage

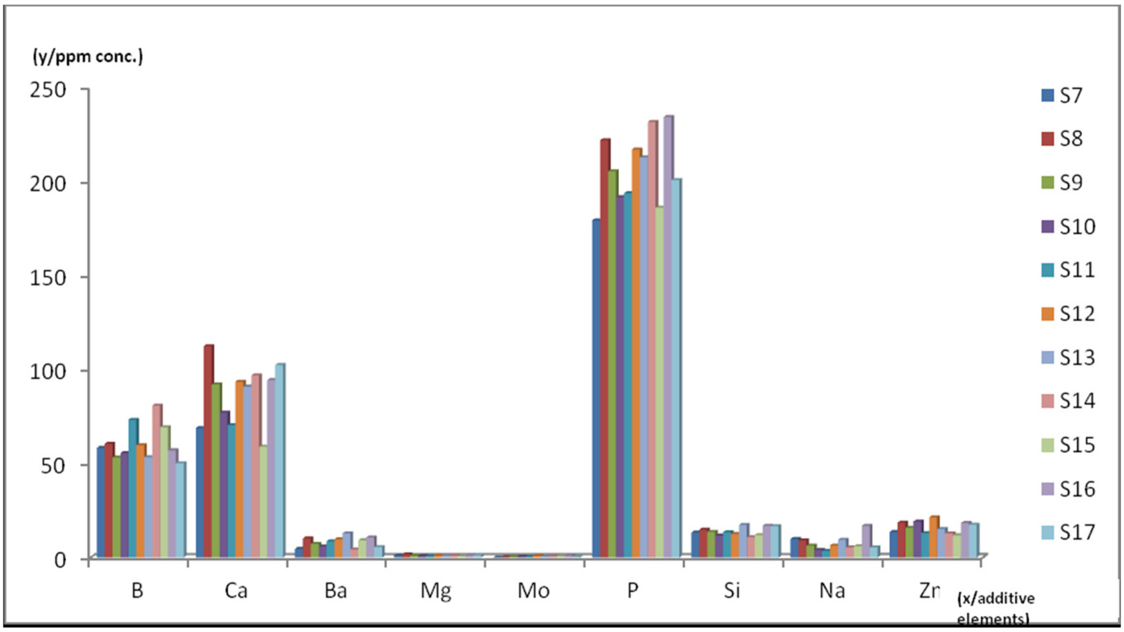

Fig. 5. Additive elements (ppm conc.) vs. (TD2) operating mileage

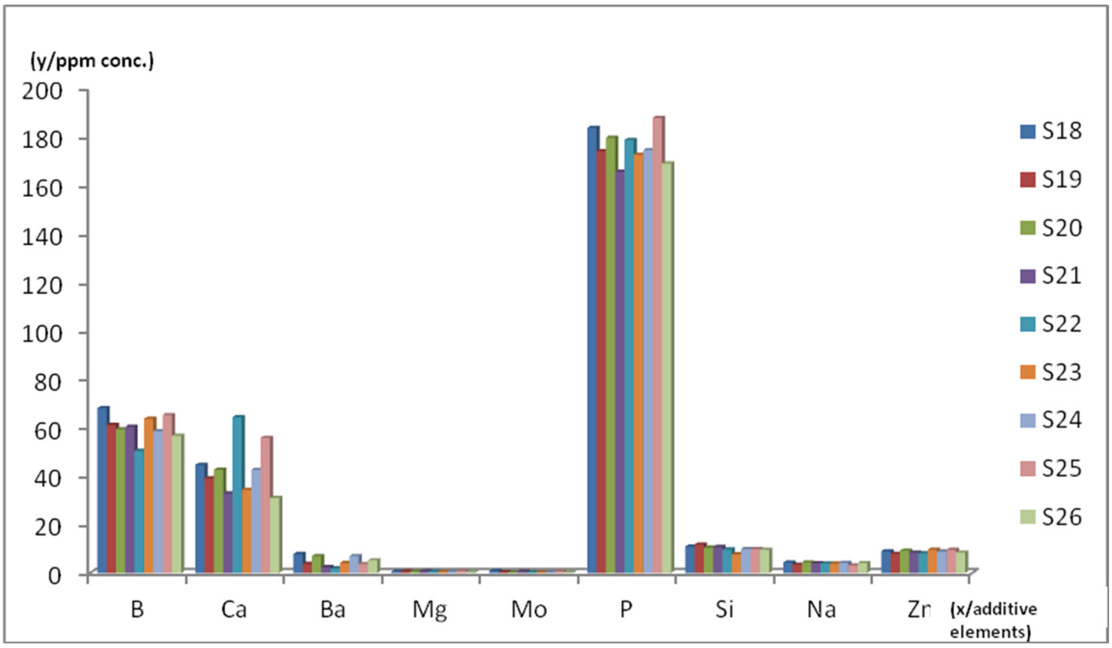

Fig. 6. Additive elements (ppm conc.) vs. (TD3) operating mileage

From the additive elements analysis carried out, it was observed that the element of P, B and Ca were the most significant elements presence in all three sampling categories followed by Zn, Mg and Si. The average values of concentration of each element are presented as follows:

Table 2
Additive element concentration

		TD1 [ppm]	**TD2** [ppm]	**TD3** [ppm]
i	**P:**	200.05	206.698	176.187
ii	**Ca:**	113.869	86.846	42.291
iii	**B:**	57.39	60.868	60.26
iv	**Zn:**	15.688	16.067	8.755
v	**Mg:**	1.318	1.084	0.603
vi	**Si:**	13.902	13.894	10.037

From the analysis, it was found that the elements of Fe, Cu and Al were the most significant wear elements occurred throughout both mission profiles. This outcome satisfied the claim made by Mohamad A. Al-Ghouti [19], Pavel Yaroshchyk [22] and A. Zararsiz [23] which affirmed that the elements of Fe and Cu were the wear metals that consistently present in relatively large amounts in the used lubricating oil. It can be observed that the element of Fe and Al showed a decreasing trend against the operating mileage. The average concentration value of Fe did not exceed the value of 100 ppm. It can be expected that the occurrence of severe wear is unlikely. This finding is in agreement with the result obtained with the study by Hakan Kaleli [24].

The concentration of Cu on the other hand was found to show the highest concentration value with regards to TD1 operating mileage. This may suggest the occurrence of high oxidation value. This scenario can be further observed during the TD2 operating mileage. It can be clearly seen than during this period, the occurrence of oxidation has been decreased and the element of phosphorus increases which indicates no sign of additive depletion to occur though the ATF had been used beyond its recommended period. This is in agreement with what has been observed by Mridul Gautam [21], John A. Williams [25] and Dairene Uy [26]. The same condition was observed with the element of Zn whereby sufficient protection towards the ZDDP had been given and it can be seen that Zn did not deplete during the period between TD1 and TD2.

5. Conclusion

It can be affirmed that the ATF degradation is unlikely and to be considered insignificant although the samples were used beyond the recommended period due to high neutralizing capacity of additives encountering the presence of wear elements, acidity effect and vital contaminants consisting of oxidation, sulphation, nitration and water. Prior to this, the depletion of vital anti-wear property recognized as ZDDP to be considered insignificant. This is due to the fact that the occurrence of critical elements of wear were effectively encountered and minimized by crucial additive elements which are categorized as phosphorus and zinc.

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