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RESEARCH

The Initial Estimate of the Useful Lifetime of the Oil in Diesel Engines Using Oil Analysis

S.A. Adnani[a], S.J. Hashemi[b], A. Shooshtari[c], M.M. Attar[d]

[a]*Department of Engineering, Hamedan Branch, Islamic Azad University, Science and Research Campus, Hamedan, Iran.*
[b]*Petroleum University of Technology, Department of Engineering, Iran.*
[c]*Bu-Ali Sina University, Department of Engineering, Iran.*
[d]*Department of Mechanics, Hamedan Branch, Islamic Azad University, Hamedan, Iran.*

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Corresponding author:

S.A. Adnani
Department of Engineering, Hamedan branch, Islamic Azad University, Science and Research Campus, Hamedan, Iran
E-mail: ah_adnani@yahoo.com

A B S T R A C T

In this paper the Initial lifetime of the lubricating oil in 70 Diesel engines model E6-350 ECONODYNE 4VH has been estimated using oil analysis. The engines have been installed on the super heavy vehicles. This method is used to change the used oil based on oil operating hours, odometer and taking samples before that. Next, the samples are sent to the laboratory for analysis and obtaining the results. In order to be able to determine the overall condition of the engine, we have to study various parameters, such as wear elements, pollutants, elements correlation coefficients, viscosity, base number, acid number, type and the amount of engine wear in the same condition of the engine model, oil consumption and operating condition and therefore, the useful oil life is determined (100 hours). At last, a formula for silicon and aluminum elements is found. If the number of samples increases then the error rate will be reduced. So, the results are only based on the number of taken samples.

1. INTRODUCTION

Today, machines and equipment condition monitoring through oil analysis as a method of effective maintenance program is known. Nevertheless, the application of this technology to the various types of industry and user equipment is still very broad to a certain extent [1].

The best performance engine oil is important in two aspects: 1) the economy 2) in terms of its effect on engine life. The economic aspects should be emphasized the probability that the engine oil should be changed sooner is very high and it is not economically. On the other hand, it may be late to oil change because this is the probable cause engine damage and wear. So, the use of oil analysis is the best method for achieving this goal. Among the important factors that could affect the oil life reduction as follows:

- Improper storage and contamination before use,
- Incorrect oil selection and mixed oils that are not compatible with each other (for example, when overflow),

- Lack of adequate consumer appliances (air filter, oil filter and etc.),
- Fuel, water and dust contaminations,
- Not regulated engine,
- Existence of excessive metal particles in oil,
- Oil clean reduction in sensitive mechanical systems (turbines, compressors and hydraulic) [2].

2. ENGINES SPECIFICATIONS

- Model: E6-350 ECONODYNE 4VH
- Horsepower maximum BHP@1800 rpm: 350 (261 Kw)
- Compression Ratio (pressure@1000 rpm): 15:1(31.72 bar)
- Bore & Stroke: 123.8 mm × 152.4 mm
- Cylinder: 6
- Year: 1990
- Manufactured by Mack Co. in U.S.A [3].

3. EXPERIMENTAL WORK

Sampling procedure has been done when changing the engine oil and after laboratory tests, test results have been evaluated (see Table 1).

Table 1. The number of engines and samples.

Tested engines	Oil samples number
70	160

Table 2. The new oil properties [4].

Manufacturer	Sepahan
Oil name	Generator speedy
Performance grade(API)	CD/SF
Grade (SAE)	40
T.B.N (mgKOH/g)	14.5
T.A.N (mgKOH/g)	1.1
Viscosity index(Min)	99
Viscosity at 40 ° C (cSt)	163.91
Viscosity at 100 ° C (cSt)	15.84
Open flash point (° C)	241

Sampling has been done so that each engine has been sampled in two or three times. Since all engines have the same oil, model and work conditions, so variables are low. If oil samples increases, errors in results will be less. In addition to the regular test and verification of new oil, specifications in terms of quality and standards of the new oil have been tested in accordance with Table 2. The results are based on the number of oil samples in accordance with Table 1.

4. OIL USEFUL LIFE ESTIMATION

For engine oil life estimation, items should include physical and chemical properties of oil, such as acid number, base number, viscosity, oil pollution, and wear parameters can be analyzed at various functions. Then we should compare the figures obtained from physical and chemical properties of oil. As we know, the new oil properties go away from its ideal operating conditions and incurred loss. So in first step, we evaluate the wear and pollutants elements that play important role in oil life reduction.

4.1 Wear elements

Metallic particles in engine oil are mainly due to wear. If wear rate arises then the rate of metal in the oil will be higher. The most wear elements and their origins are according to Table 3 [5]:

Table 3. Wear elements and origins [2,6].

Wear elements	Origins
Fe	Cylinder bush – Piston rings –Pins – Cylinder block – Nuts
Cr	Rings – Liners – Valves – Cooling system
Al	Cylinder – Piston – Blowers
Cu	Piston pin bushes – Crank case – Oil cooler
Pb	Bearings

4.2 Determination of maximum concentration limit for wear elements

To determine the limit of wear, pollution and silicon boundary between normal and abnormal wear on engine components, the formula for the standard deviation formula (1) can be used:

$$\sigma = S.D. = \sqrt{\frac{\sum (X_i - \mu)^2}{N}} \tag{1}$$

Where σ, the standard deviation values, Xi, wear and pollutant elements, μ, wear and pollutant element values, N, the number of values [1]. According to oil analysis results, we can have the data on Table 4.

Table 4. Maximum concentration limits for different elements of wear in engines (ppm) [7].

Elements	Si	Pb	Cu	Cr	Al	Fe
Average	8.1	2.8	2.7	2.8	3.2	26
Standard deviation	5.6	2	2.4	2.4	1.8	16
Maximum concentration limits	14	5	5	5.5	5	42

4.3 Correlation coefficient

One of the basic definitions of statistics is correlation between two variables. Dependence between two variables is defining correlation. The correlation coefficient changes between -1 and 1. Relationship between two variables can be positive or negative. However, a closer correlation between the two variables, then the dependency rate is higher [8]. Here, by using Pearson's correlation and statistical analysis software (s.p.s.s), we can calculate correlation coefficients between wear and pollutant elements. The results can be seen in Table 5.

Table 5. Correlation coefficient between wear elements.

	Fe	Al	Cr	Cu	Pb	Si
Fe	1	0.626	0.474	0.369	0.541	0.526
Al	0.626	1	0.632	0.334	0.439	0.869
Cr	0.474	0.632	1	0.217	0.442	0.544
Cu	0.369	0.334	0.217	1	0.274	0.208
Pb	0.541	0.439	0.442	0.274	1	0.367
Si	0.526	0.869	0.544	0.208	0.367	1

According to Table 5, aluminum and silicon have the most correlation, while silicon and copper have the lowest correlation. In fact, with the arrival of silicon in oil, erosion effects occur in parts which are made of aluminum, such as pistons. According to the correlation rate, effects of erosion vary in different parts of the engine. Next, a higher correlation is between aluminum and chromium. In fact, wear in each of these two elements has a direct effect on other wear. For example, if silicon entrance causes erosion on the pistons then the rings that made of chrome and the piston grooves will wear. Other elements that are correlated influence on erosion of engine components. Since the aluminum and silicon have the most correlation between each other, therefore, according to Fig. 1 and equation (2) the exact relationship between them is found.

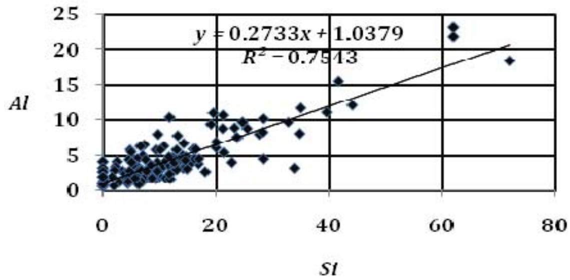

Fig. 1. Silicon and aluminum profile (ppm).

$$Y = 0.2733X + 1.0379 \quad (2)$$

Here, X and Y are amount of silicon and aluminum in ppm, respectively. So if x = 14 ppm then y = 4.86 ppm. So the results in Table 4 are correct.

4.4 Engine wear process

According to (Fig. 2) and plotted points, operating hours by increasing iron concentration was increased. Points that have gone beyond the maximum concentration limit for iron element (42 ppm) will appear up to 100 hours. So this time is the warning border for iron.

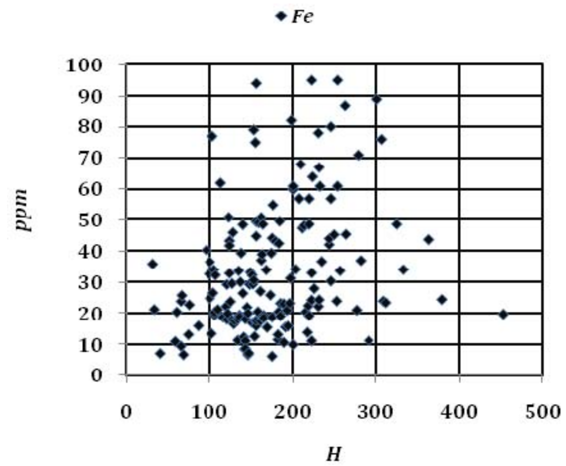

Fig. 2. Operating hours and iron wear debris concentration.

Figure 3 shows that up to 100 hours, the copper has exceeded its maximum limit (5 ppm). So, 100 hours is determined as a warning border for it. According to scatter of points in Fig. 4, with increasing operating hours, chromium concentration has also increased. Since up to 100 hours points that have gone beyond the limit 5.5 ppm are strongly, so, 100 hours is determined as a warning border for chromium.

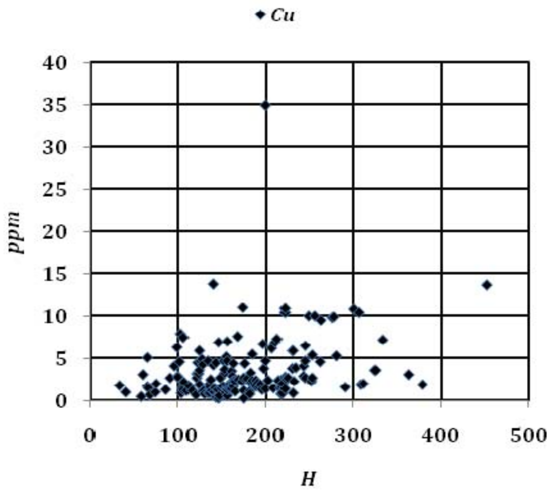

Fig. 3. Operating hours and copper wear debris concentration.

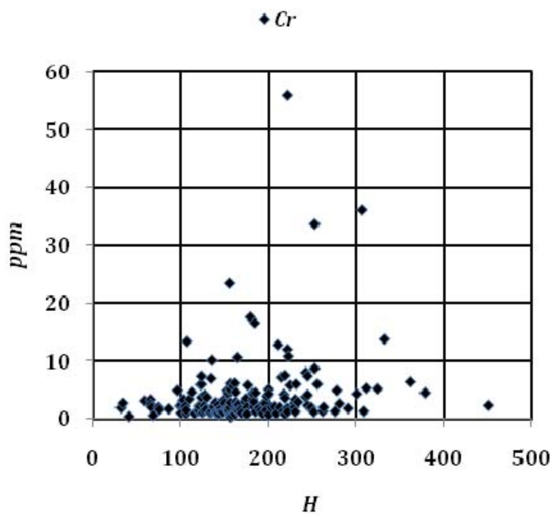

Fig. 4. Operating hours and chromium wear debris concentration.

Figure 5 is related to the aluminum element. With increasing operating hours, aluminum concentration has also increased. Thus, according to the plotted points, up to 100 hours, the limit points of these elements have exceeded from 5 ppm. So, for this element, 100 hours is a warning border too. Figure 6 is related to lead element. With increasing operating hours, lead concentration has also increased. According to the plotted points, up to 100 hours, the limit points of these elements have exceeded from 5 ppm. So, for this element, 100 hours is a warning border. But beside the wear elements, pollutants also play a main role in loss of life and oil properties. Based on oil analysis, the only pollutant in oil samples is silicon that is in the form of dust into the oil. Therefore, according to (Fig. 7) we investigate this pollutant.

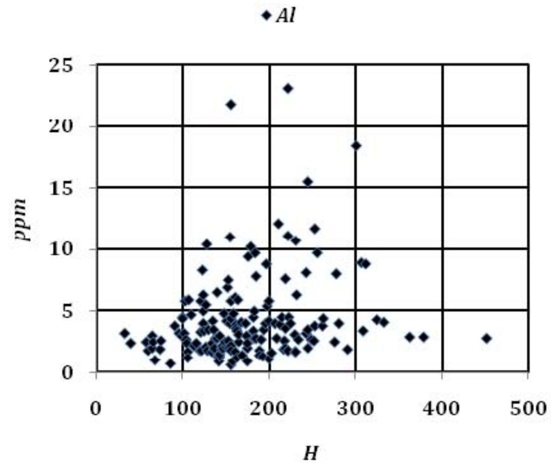

Fig. 5. Operating hours and aluminum wear debris concentration.

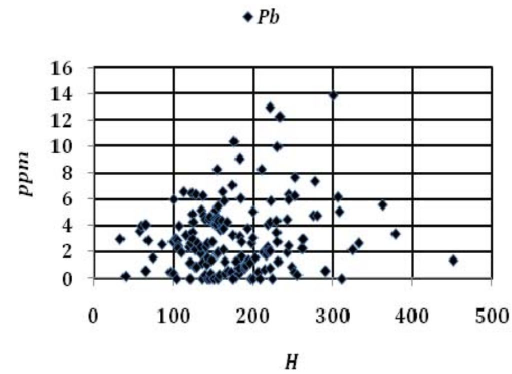

Fig. 6. Operating hours and lead wear debris concentration.

Figure 7 shows the limit points of these elements have exceeded from 14 ppm. So, for this pollutant, 100 hours is a warning border. Oil quality and its life are affected by silicon.

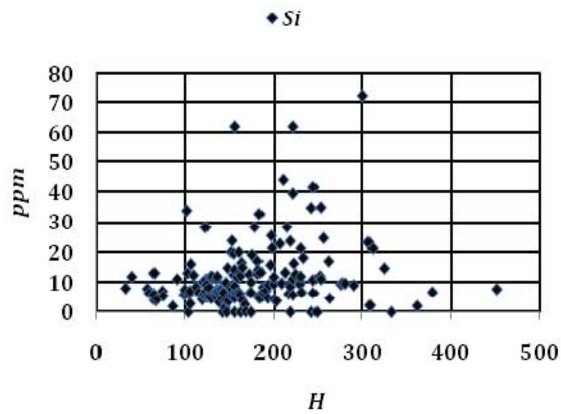

Fig. 7. Operating hours and silicon wear debris concentration.

The analysis conducted can be summarized bordered warned on wear elements as presented in Table 6.

Table 6. Warning border for wear elements.

Elements and pollutants	Warning border
Fe	100
Al	100
Cr	100
Cu	100
Pb	100
Si	100

Here, wear elements of oil were studied. But in addition to these cases, the properties of the oil play main role in oil life. That is why in this step, we will study the physical and chemical properties of the oil.

4.5 Wear index

One of the most important factors in engine wear is wear index of iron particles in oil so called P.Q. [2]. According to (Fig. 8), with increasing operating hours, iron particles have also increased. According to focal points, up to 150 hours, points are separated from each other and even we see points that reached to 250 ppm. This matter indicates sudden increase in the number of iron particles. So, 150 hours is determined as an warning border for P.Q, So at this step, we investigate other oil properties.

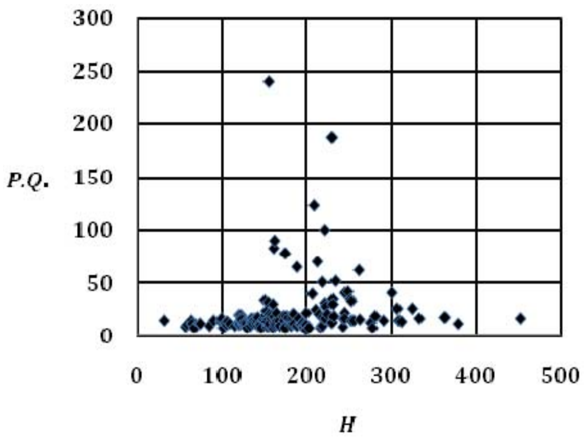

Fig. 8. The variation of wear rate on engines.

4.6 Viscosity

Viscosity as a one of oil properties, affect on reduction of bearings friction and oil film thickness. Therefore, evaluation of viscosity in oil analysis program is sensitive. Any change in the viscosity of the lubricant indicates oil degradation, the presence of thermal stresses in the oil and oxidation [1,9]. So after analyzing the wear index, we desire to investigate the viscosity of the oil in different hours and conditions. According to (Fig. 9), the viscosity of oil declined from 164 cSt. In normal conditions, i.e. without pollutants, due to the increase in oil hour, viscosity trend has become decreased and approximately remains at 150 cSt. But the greatest loss of viscosity is after 120 hours. In (Fig. 10), the viscosity of the oil due to the presence of the contaminant is 150 cSt. Up to 200 hours, maximum viscosity loss is seen. So, 120 hours is determined as warning border for viscosity.

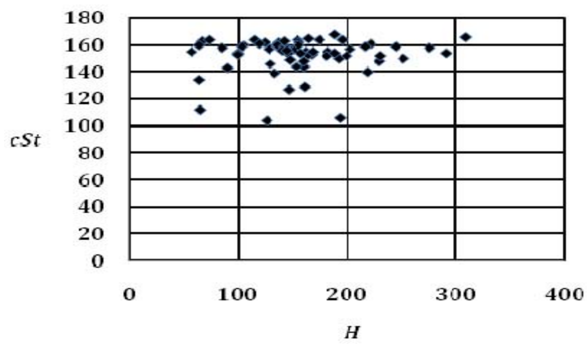

Fig. 9. Operating hours and viscosity without pollution.

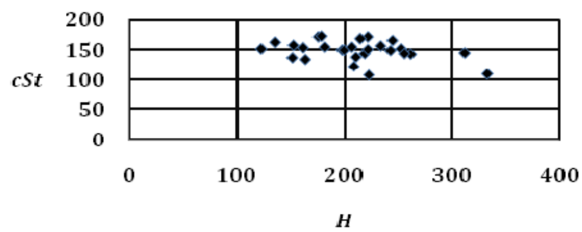

Fig. 10. Operating hours and viscosity with pollution.

4.7 Base number

Base number is a kind of oil properties. By reducing the oil base number, oil ability in the face of acid entering from combustion get weak. It indicates the need to replace or add new oil [1,2,10,11]. On the base of tested samples, oil base numbers in different status were evaluated and the results are in accordance with Fig. 11.

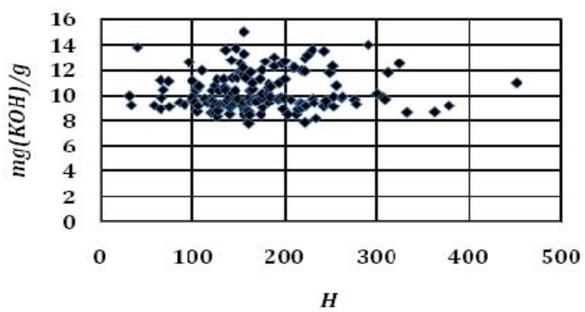

Fig. 11. Operating hours and base number.

According to the (Fig. 11), standard limit of base number is 14.5 mg (KOH) but maximum loss is 7.5 mg (KOH) and it is happened on 160 hours. It is very natural because with increasing operating hours, oil properties and its life losses. So by increasing operating hours, the oil life decreased as a result of oil properties. So, 120 hours is determined as a warning border for base number.

4.8 Acid number

Acid number is a kind of oil properties that is used for industrial oil. Acid number is used for measuring of oil acidity. Increasing acid value indicates the end of the useful life of oil and its replacement is necessary. Acid value higher than 4 mg (KOH) is highly corrosive and bearings and other metal substances can be invaded [1,2,11]. According to (Fig. 12), with increasing operating hours, the amount of acid number has also increased. According to focal points, up to 180 hours, the acid number has exceeded its limit (4 mg (KOH)). So, 180 hours is determined as a warning border for acid number.

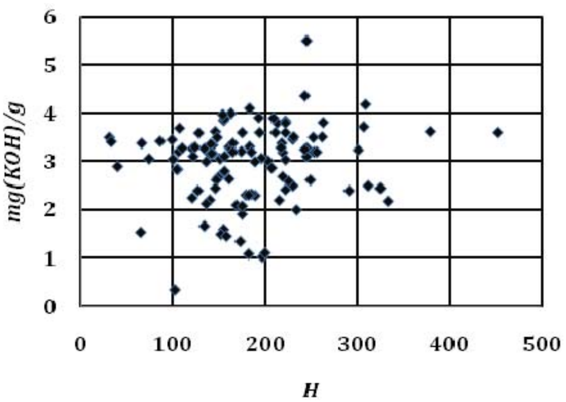

Fig. 12. Operating hours and acid number.

So, the properties of the oil and its corresponding warning limits can be summarized as described in Table 7.

At this stage of the investigation carried out on erosion, pollution, and finally the physical and chemical properties of oil and according to the results in Table 6 and 7, and based on the number of samples, look carefully and errors, initial engine oil life is estimated 100 hours. Based on figures obtained after 100 hours, we can see the presence of contaminants, the sudden drop in oil properties and wear on engine parts and it is necessary to oil change.

Table 7. Warning border for oil properties.

Oil properties	Warning boundary
Base number	120 hours
Acid number	180 hours
Viscosity	120 hours
P.Q	150 hours

4.9 The engine oil life in kilometer

Now we intend to equivalency the oil by other factors such as the amount of kilometer unit, kilometers were recorded at each sampling. According to the Figs. 13 to 15, we can also estimate oil life in hour and kilometer. Since the operation of heavy vehicles in terms of work-place is different, so we classify vehicles into three categories respectively, "Tandem", "Keshande" and "Jean Paul".

4.10 "Tandem" engine

Figure 13 shows the correlation between operating hours and the distance traveled by the vehicle "Tandem". This vehicles move in a limited area. As in previous discussions of the oil life was 100 hours, now, with respect to (Fig. 13), we want to get the maximum distance traveled by vehicle after 100 hours. So 100 hours is equal to 3000 km.

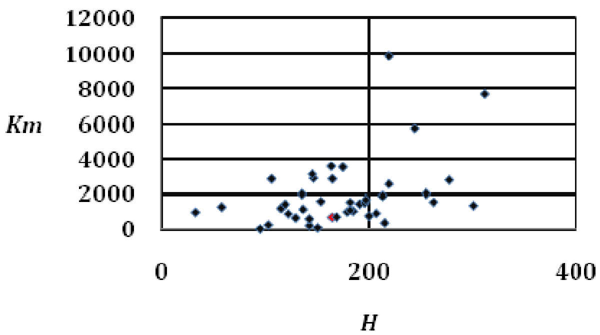

Fig. 13. Operating hours and distance.

4.11 "Keshande" engine

According to data from oil analysis, Fig. 14 shows the relationship between distance traveled by these vehicles and operating hours. It is worth mentioning that these vehicles are more mobile and have road traffic. Therefore, according to the 100 hours, the maximum distance traveled by these vehicles is 5,900 km.

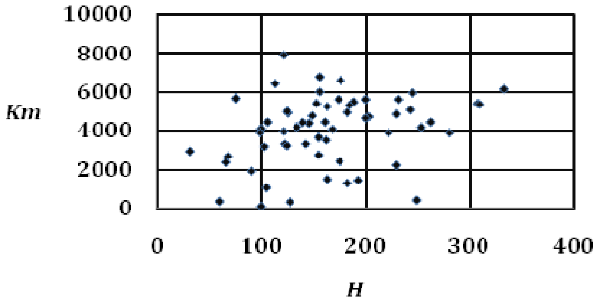

Fig. 14. Operating hours and distance.

4.12 "Jean paul" engine

Based on data from oil analysis, Fig. 15 is obtained. This vehicles move in a limited area. Based on points in (Fig. 15), for 100 hours, maximum distance traveled by these vehicles is 900 km.

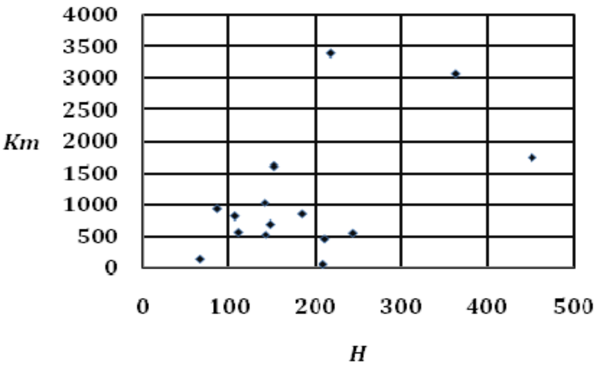

Fig. 15. Operating hours and distance.

Correspond to the useful life of oil per hour with maximum distance traveled by all vehicles; we can summarize the results presented in Table 8.

Table 8. Primary and useful life of the oil in all vehicles.

Vehicle	Operating hours	Km
Jean paul	100	900
Tandem	100	3000
Keshande	100	5900

5. CONCLUSION

As was mentioned to achieve the oil life should be a lot of things are considered, including the following:

- Wear elements
- Pollutants
- Physical and chemical properties of oil
- Sampling error
- Reading operating hours indicator error
- Oil laboratory equipment error
- Error in the type of oil used in an engine oil (two types)

Based on the above, we investigated wear elements, pollutants, their allowable limitations and correlation coefficients. The highest correlation was between silicon and aluminum element. We introduced a relation between them and we got a formula about it. According to the resulting curves, we noticed that in what time abnormal abrasion of engine parts occurs. Therefore, we chose warning boundary that will have minimal wear on engine parts. The physical and chemical properties of the oil studied and according to the figures the warning boundary (100 hours) is determined in order to prevent sudden and sharp changes in oil properties. Finally, considering the results of wear elements, silicon and physical and chemical oil properties, the useful life of oil in hour and kilometer is determined. It is important that the results are only based on oil samples taken from the vehicles. So if we increase the number of oil samples, surely, better results can be obtained. That is why a title as "Early Life" for the oil life is selected. If, we provide the ideal conditions for engines, oil life of 100 hours goes beyond. These conditions are as follows:

- Replace air filters (every 4 months),
- Choosing the right oil,
- Choosing the right fuel,
- Proper using in accordance with the recommendations of vehicle manufacturers
- Check to make sure no oil pollutants including aerosols, fuel, water and silicon into engine,
- To ensure the quality and authenticity of replacement parts for engines.

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