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A METHOD TO EVALUATE METALLIC CONTENTS IN USED OIL SAMPLES

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Summary. *Used oil from engines can be a source to diagnose their wear since it is how all internal generated impurities are evacuated. It requires the evaluation of many engine used oil samples. In this work, metallic concentrations detected by spectrometric analysis from used lubricant are evaluated. A method to correct the measured concentrations is presented. Thus the reference concentrations are defined, obtained and reestablished. Besides. the limit concentrations are defined together with the characterization scales***.**

Key words: *Maintenance, Predictive maintenance, Fault diagnosis, Used oil analysis, Fault monitoring*

1. INTRODUCTION

Wear in engine main parts is a problem that needs special care, therefore this work will study the lubricant degradation and contamination only when is related to wear. Besides, wear is more complicated and it can make more damage to the engine than the other two

In Fig. 1 is shown the general procedure to diagnose engine wear. Initially, using an analytic technique allows to get the values of the measured metallic concentrations. Next this values follow a modification process to obtain the corrected metallic particles concentrations.

Information from results with previous samples is stored in a stable database, and by means of statistical treatment, allows to get the values of the metallic concentrations that will be considered as standard. Using these values as reference, the corrected concentrations of each wear metal is evaluated.

Depending on these values and using experts experience, diagnose of wear in engine parts is possible using a group of simple sentences. Saving the information in a stable database and working with an appropriated computational tool, make an expert system of diagnosis.

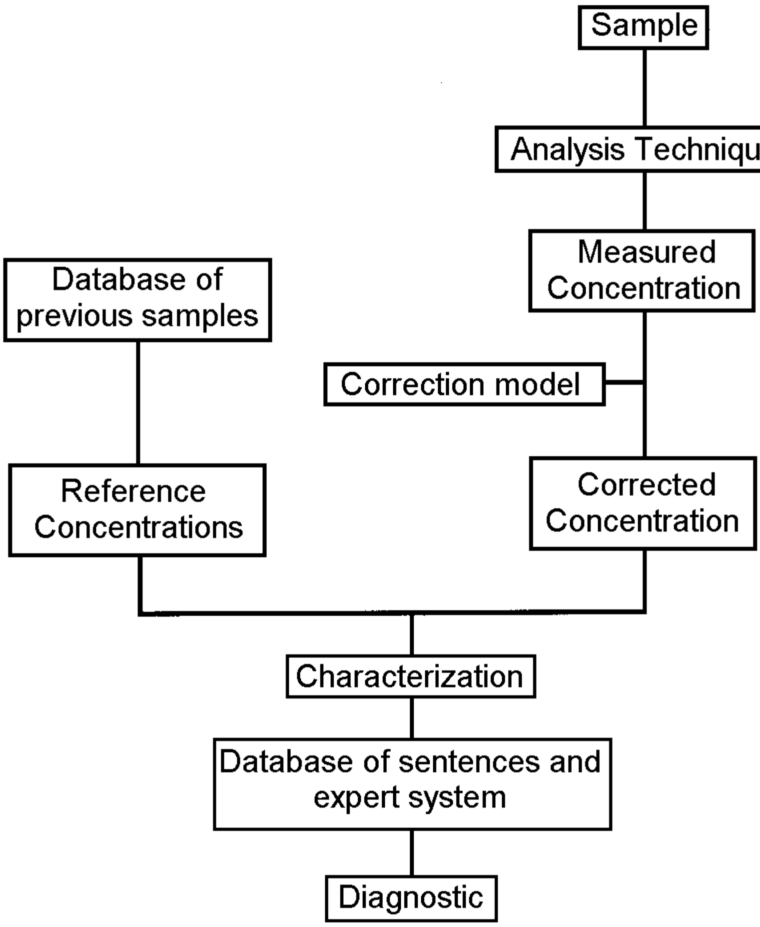

Figure 1- General procedure to diagnose engine wear

2. CORRECTION OF MEASURED METALLIC CONCENTRATIONS

Many factors affect the oil concentration, therefore, independently of what method was used to quantify wear, the results generally are deviated from the desired values and shown un information about oil contamination. A previous treatment to these results is necessary to calculate the corrected concentrations; without considering aspects as oil leakage, oil refill and oil filtering.

These corrected concentrations values are very important to the diagnosis, because they will show the real contribution of metallic particles to the oil. They carry out a more exact evaluation of the engine wear rate to better quantify the severity and risk of the involved mechanical problems. The factors that affect the laboratory metallic measured concentrations are:

2.1 Measurement technique

To correct the errors due to the measurement equipment it is necessary to know the oil particles distribution (depending on fault type), the wear mechanism, etc. This information is unknown and no correction technique can be applied previous to the measurement. However, same equipment is used, it supposes a systematic error introduced by the utilized technique. This case considers no influence on the oil contamination rate (occurrence speed).

2.2 Refill and oil consumption

The added oil, necessary to counteract the internal consumption or external loses. attenuate the pollutants concentrations. The laboratory results should consider a correction since consumed oil transports the pollutants leaving the lubricant concentration constant but less total volume. Therefore, when the engine does not have any oil reposition, the contribution of particles will be bigger than the standard case. Otherwise, a dilution effect due to a new amount of oil will reduce the concentration.

2.3 Oil filtering

The filter retains an important quantity of particles depending on its use, its retention efficiency and the oil particle distribution. According to Staley (1988) the filter retention efficiency is greater than 90% when particles size is greater than 10 mm. Studies made by the author (Fygueroa, 1994a) have demonstrated that oil filtering effect is negligible when concentrations are measured with a spectrometer, since it only detects particles size lesser than 5 mm

2.4 Oil composition

Clean oil only modifies concentrations due to wear. To correct measured concentrations, considering added oil and its composition, the following expression (Fygueroa, 1994b) is used:

$$C_c = C_0 + \frac{A}{V_0}\left[\frac{(C_m - C_0 e^{-\frac{A}{V_0}}}{1 - e^{-\frac{A}{V_0}}} - C_a\right] \qquad (1)$$

where Cc = corrected metallic concentration
C_0 = initial metallic concentration of the bath oil
Cm = metallic concentration measured with the spectrometer
Ca = new oil metallic concentration
A = total added oil quantity
V_0 = total oil volume in the crankcase

2.5 Oil durability during service

During engine service with standard wear, the metallic concentration of the oil will increase with time, this increasing of metallic elements is exponential since it accelerates the engine wear due to their own presence; it originates more wear and so forth. This effect becomes worse with the increasing of service. This behavior is counteracted by the new oil added, oil dilution reduce particles concentration, so the final resulting tendency turns lineal, specially when oil service periods are not excessively prolonged; it means that:

$$\frac{C_{c1}}{C_{c2}} = \frac{K_1}{K_2} \qquad (2)$$

where C_{c1} and C_{c2} are the corrected metallic concentrations for one element in the oil at K_1 and K_2 kilometers respectively.

2.6 External silicon.

The silicon mainly comes from outside with a small contribution from the engine wear; then, the quantity originated from both causes should be known. Fygueroa and Macián, (1994), show results from oil analyses of urban buses engines without admission problems due to non filtered air, where the relationship between the external silicon content and the total silicon content is in the range of 85% to 95%. This range lightly decreases during engine work, when filter gets dirty due to particle accumulation. Besides, the increasing of the oil silicon content accelerates the rate of engine wear.

3 REFERENCE CONCENTRATIONS

No absolute scale (Schilling, 1965, Benlloch, 1985 and Shepherd and Espinoza, 1988) exists to characterize the contamination of the oil, therefore, according to Collacot (1982) the corrected results from the spectrometric analysis can be qualified with phrases like high, medium or low concentration. These expressions are related to those values considered as standard and they will be named the reference concentrations. Metallic particles concentrations low means a typical engine wear condition, mean values require to make a preventive action of maintenance to avoid a latent mechanical defect, high values should be considered as a serious problem and a corrective action of maintenance is imminent.

3.1 Obtainment

A big sample of statistical data that represents all motor types and models should be used to obtain the reference concentration values. The procedure to obtain the concentrations reference values (Fygueroa et al., 1997) has three stages: A preliminary investigation stage, using box and whiskers diagrams, to find until what values for an specific metal concentration the data samples follow a normal distribution. A complementary investigation stage, using population probabilistic diagrams to notice what distribution type fit the tendency of the samples bulk. A verification stage to check, by means of frequency histograms, the adjustment fixing of the data samples to the supposed distribution. This database allows to know the type of distribution the engine metallic wear is adjusted. The mean of this distribution is recommended as reference concentration.

3.2 Types

According to the population on statistical study we have the following reference concentrations: total (R_t), of mark (R_M), of model (R_m) and of motor (Rv). The first one conforms the whole population of oil samples, it takes in account the simultaneous influence of all the marks, models and engines on study. The mark reference concentration is less generic than the previous one and it characterizes oil samples from engines made by one engine maker. The model reference concentration accounts for oil samples of same engine model. The engine reference concentration applies to a specific engine and it is obtained from their own samples.

3.3 Use

The reference concentrations give us idea about typical behavior of an engine, model, mark or total group, they are used to compare and qualify their own corrected concentrations.

The first time a sample is analyzed, it receives a reference concentration value known from its model, mark or total reference concentration. This justifies the existence of series of reference concentrations, more general as less information about the engine oil is known.

3.4 Reestablishment

These four reference concentrations should not remain static, they have to progress as the number of analyzed samples grows; when the generation rate of wear particles reaches a dynamic equilibrium they are stabilized to a certain value. Engine reference concentration should be reestablished every time one of its samples is analyzed; the others depends on the amount of analyzed samples. This reestablishment action allows to see how the engine samples belonging to one model or mark behave. Use of a convergent lineal expression (Fygueroa et al., 1997), Eq. (2), is recommended to allow for a damped development of the reference concentration:

$$R' = \frac{AR + \sum_{i=1}^{n} C_i}{A + n} \tag{3}$$

where A = Weight coefficient of the last reference concentration; it represents the population size until the last reestablishment.

R = Last reference concentration.

R' = Reestablished reference concentration.

n = Samples used for reestablishment. A+n is the population size at the reestablishment time.

C_i = Reestablishment value (corrected concentration or engine, model or mark reference concentration)

4. LIMIT CONCENTRATIONS

To characterize the particles concentration in oil samples an standard, medium and high category is defined. The particles contents in these groups are demarcated by two limits: Alert limit, to separate the standard from the medium concentrations and alarm limit to separate the medium from the high concentrations.

According to Monchy (1987) common wear phenomenon follow a normal distribution; therefore, the alert limit (L_1) will be the concentration value from which the sample population gets away from the normal case. The approach to establish the alarm limit (L_2), considers that critical cases appear on the 40% of the samples that get over the alert level.

A study of the metallic sample concentrations based on their frequency histograms, shows that only 10% of the samples exceed the alert limit and 4% the alarm limit. Thus the alert limit is the concentration for samples below 90% and alarm limit is that below 96%.

5. EVALUATING SAMPLES CONCENTRATIONS

Knowing the reference and limit concentrations, the following step resides in evaluating the samples metallic concentrations. It assigns to each metallic content an attribute to classify it, based on an evaluation scale.

The evaluation can be quantitative or qualitative. The quantitative assignment type is a simple comparison between the absolute value of the corrected metallic concentrations and the with limit concentrations. It has the disadvantage of requiring different characterization scales depending on the engine metallurgy although, works very well as appreciation human tool, but it is not easy to systematize.

Using the quantitative characterization, in this report a parameter is defined to generalize, aspects related to the predictive maintenance by means of oil analysis.

5.1 Relative difference

The characterization of metallic concentrations in engine oil samples should consider the data deviation respect to the standard wear. To allow for this comparison a characteristic parameter Z, named relative difference, is defined:

$$Z = \frac{Y - R_v}{R_m} \tag{4}$$

It uses the reference concentration value from different engines belonging to a same model; thus, by adimensionalizing using this model reference concentration, the engine wear is compared with its own engine wear model.

The relative difference sign, point out the importance of the engine wear respect to its specific service conditions:

If $Z<0 \rightarrow Y<R_v \rightarrow$ low wear

If $Z=0 \rightarrow Y=R_v \rightarrow$ standard wear

If $Z>0 \rightarrow Y>R_v \rightarrow$ high wear

5.2 Characterization scale

The relative difference and limit concentrations as will be explaining allow the establishment of a quantitative characterization scale. As first approach, to find the critical relative differences, it is supposed that $R_v=R_m=R_M={}_{Rt}=R$, then:

Alert relative difference $Z_1 = \frac{L_1}{R} - 1$

Alarm relative difference $Z_2 = \frac{L_2}{R} - 1$

Studies carried out (Macián et al. 1992) have shown that L_1/R and L_2/R values are non material dependent, being their values 1,8 and 3,2 respectively. Therefor, the alert relative difference Z_1 is 0.8 and the alarm relative difference Z_2 is 2.2, which origins the characterizations scale shown in Table.1.

Table 1. Characterization scale for metallic wear concentrations.

STANDARD	MEDIUM	HIGH
$Z < \frac{L_1}{R} - 1$	$\frac{L_1}{R} - 1 < Z < \frac{L_2}{R} - 1$	$\frac{L_2}{R} - 1 < Z$
$Z<0.8$	$0.8<Z<2.2$	$Z>2.2$

5.3 Qualitative characterization types

Qualitative characterization in metallic wear concentrations oil samples can be made in many ways, the main ones are:

- With words: low, medium and high; low, half-low, half-high, high and ultrahigh; etc.
- With indexes: 1, 2 and 3; 1, 2, 3, 4, and 5; etc.
- With colors: red, yellow and green; rainbow; etc.
- With indicators: lines, bars, stars, etc.

Table 2 shows some examples of the different presentation types for qualitative characterization, they are compared with the quantitative characterization scale of metallic wear contents.

Table 2. Ways to show qualitative characterization

COLORS	Green	Orange		Red	
INDEXES	1	2	3	4	5
WORDS	Standard	Moderate	Medium	High	Ultrahigh
$Z = \frac{Y - R_v}{R_m}$	0.8	1.5	2.2	4	

5.4 Indexes

On diagnostic analysis they are the best way for the special treatment of the qualitative characterization of the results.

It can be used as combination of three as 1-2-3; 1 stands for standard level, 2 medium level and 3 high level. The more indexes are using, the more levels should be accounted for. The example in Table 2 shows five levels: one standard, two medium and two high levels. The two medium levels are: 2 that stands for moderate and 3 for medium. The two high levels are: 4 that stands for high and 5 for ultrahigh.

Increasing the indexes improves the characterization accuracy; however, if the level range is unclear, the obtained accuracy is opaqued by the levels complexity. Thus, depending on the application, a less possible index should be used.

6. CONCLUSIONS

It is presented a correction method of the metallic concentrations obtained from spectrometric analysis.

The method allows to obtain and actualize the reference concentrations.

The method allows to find the limit concentrations.

The quantitative and qualitative characterization scales of metallic concentrations in oil samples were defined

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