A METHOD TO EVALUATE METALLIC CONTENTS IN USED OIL SAMPLES

METODO PARA EVALUAR CONTENIDOS METALICOS EN MUESTRAS DE ACEITE USADO

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Abstract: Used oil from internal combustion engines is an important instrument to diagnose their wear since it is the internal generated impurities evacuation medium. To obtain this objective many engine used oil samples must be evaluated. In this work, a method to correct and evaluate the metallic concentrations detected by spectrometric analysis from used lubricant is presented and the reference concentrations are defined, obtained and re-established. Besides. the limit concentrations are defined together with the sample characterization scales.

Resumen: El aceite usado procedente de motores de combustión interna es una herramienta importante para diagnosticar su desgaste por ser el medio de evacuación de todas las impurezas que se producen en su interior. Para lograr esta finalidad es necesario evaluar un gran número de muestras de aceite usado. En el presente artículo se propone un método para corregir y evaluar las concentraciones metálicas obtenidas a partir del análisis espectrométrico del lubricante usado. Se definen, obtienen y actualizan las concentraciones de referencia. Finalmente se definen las concentraciones de referencia junto con las escalas de caracterización de las muestras de aceite usado.

Keywords: Predictive maintenance, used oil analysis, internal combustion engines, condition monitoring, wear metals.

1. INTRODUCCION

Wear in engine main parts is a problem that requires special attention, therefore this work will study lubricant degradation and contamination related to wear since the last is more complex and can make more damage to the engine than the former two.

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

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

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

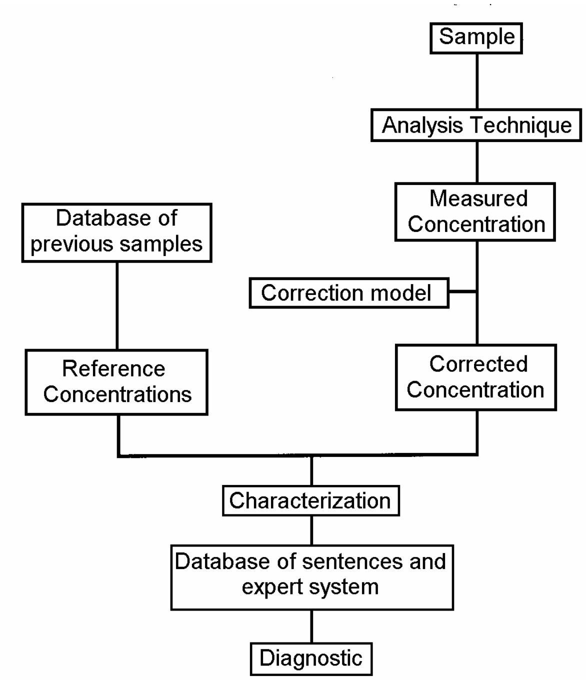

Fig. 1: General procedure to diagnose engine wear

2. CORRECTING MEASURED METALLIC CONCENTRATIONS

Many factors affect oil concentration, therefore, independently of the method used to quantify wear, results generally are deviated from desired values and shown inexact information about oil contamination. A previous treatment of these results is essential to calculate the corrected concentrations; considering aspects as oil leakage, oil refill and oil filtering.

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

2.1. Measurement technique

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

2.2. Refill and oil consumption

The added oil, necessary to counteract internal consumption or external loses. Attenuate pollutants concentrations. Laboratory results should consider a correction since consumed oil transports pollutants while lubricant concentration remains constant and total volume reduces. 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 particles quantity depending on its use, its retention efficiency and oil particle distribution. According to Staley (1988) the filter retention efficiency is greater than 90% when particles size is greater than 10 µm. 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 µm

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 = bath oil initial metallic concentration
Cm = spectrometer measured metallic concentration
Ca = new oil metallic concentration
A = total added oil quantity
V_0 = crankcase total oil volume

2.5. Oil durability during service

During engine service with standard wear, oil metallic concentrations will increase with time, this increase is exponential since engine wear accelerates 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 reduces particle concentrations, so the final resulting tendency turns lineal, especially 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 one element metallic corrected concentrations in oil at K_1 and K_2 kilometers respectively.

2.6 External silicon

Silicon mainly comes from outside with a small engine wear contribution; then, the quantity originated from both causes should be known. Fygueroa and Macián, (1994), show results from urban bus engines oil analyses without admission problems due to non filtered air, in this case 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 oil silicon content accelerates the rate of engine wear.

3. REFERENCE CONCENTRATIONS

No absolute scale (Schilling, 1965; Benlloch, 1985 and Pastor and Espinoza, 1988) exists to characterize the oil contamination, therefore, according to Collacot (1982) the corrected results from 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 reference concentrations. Metallic particle concentrations low means a typical engine wear condition mean values require to make a preventive maintenance action to avoid a latent mechanical defect, high values should be considered as a serious problem and a maintenance corrective action 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., 2006) has three stages: A preliminary investigation stage, using box and whiskers diagrams, to find until what values for a 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

Reference concentrations give us idea about typical engine, model, mark or total group behavior, 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 several 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 wear particles generation rate 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 population size until the last reestablishment.
R = Last reference concentration.
R' = Reestablished reference concentration.
n = Samples used for reestablishment. A+n is size population at the reestablishment time.
C_i = Reestablishment value (corrected concentration: engine, model or mark reference concentration)

4. LIMIT CONCENTRATIONS

To characterize particle concentration in oil samples an standard, medium and high category is defined. Particle content 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 SAMPLE CONCENTRATIONS

Knowing reference and limit concentrations, the following step resides in evaluating sample metallic concentrations. Based on an evaluation scale it assigns to each metallic content a categorizing attribute.

Evaluation can be quantitative or qualitative. Quantitative type is a simple comparison between corrected metallic concentration absolute value and 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 oil analysis predictive maintenance.

5.1. Relative difference

Characterization of metallic concentrations in engine oil samples should consider deviation data respect to 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 reference concentration value obtained 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.

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

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. Therefore, 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 of metallic wear concentrations oil samples can be made in many ways, the main ones are:

- Words: low, medium and high; low, half-low, half-high, high and ultrahigh; etc.
- Indexes: 1, 2 and 3; 1, 2, 3, 4, and 5; etc.
- Colors: red, yellow and green; rainbow; etc.
- Signs: lines, bars, stars, etc.

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

5.4. Indexes

On diagnostic analysis indexes are the best way for special results treatment from qualitative characterization.

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

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

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

6 CONCLUSIONS

- It is presented a correction method for metallic concentrations obtained from spectrometric analysis.
- The method allows to calculate and actualize reference concentrations.
- The method allows to find limit concentrations.
- Quantitative and qualitative characterization scales for metallic concentrations in oil samples were defined

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