

Two complementary oil analysis systems for thermal engine development

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A complete solution to approach the problem of oil measurement on a thermal engine is described :

- Aeration with the SMAC from D2T and developed under French Petrol Institute (IFP) License,
- Composition with the Oil Sample Analysis OSA2,

The SMAC is a measurement system of aeration based on the difference of gas compressibility and oil compressibility. The system is connected in serial or in parallel with the engine and an oil small sample is isolated to be analysed in the compression area.

The SMAC offers the possibility to measure aeration level in each part of the oil thermal engine circuit in few minutes, quantify oil effect on hydraulic push rod and variable valve actuation ...

The OSA is actually two instruments in one : optical emission spectrometer and an infrared spectrometer.

The optical emission spectrometers burns a portion of the oil sample and measures sub-microscopic metals. These metals are present due to component wear inside the engine that is being sampled.

The infrared spectrometer scans a portion of the oil sample measures physical properties and contaminants. The onboard computer controls both spectrometers, combines the results from each and gives a report with wear metals, contaminants and other physical data like fuel dilution, oxidation, nitration, viscosity and TBN.

With the OSA, engineers have the ability to decide, based on scientific data, whether potential engine problems would exist.

The OSA offers a solution to this problem by providing an evaluation for the probability of a potential failure within few minutes, in comparison to the traditional commercial laboratory.

Keywords: Tribology, Oil Analysis, Oil Aeration, Valve train development

INTRODUCTION

D2T Group has worked on the development of 2 new tools to analyze the oil properties.

The first one called SMAC measures the oil aeration rate on a running engine.

The second one called OSA done the oil composition of a sample taken on an engine or an other mechanical component like a gear box.

This paper describes the physical principles of these tools and presents the results obtained during development engine testing phases.

THE SMAC System

Oil aeration can be a real problem in modern engine oil circuit. The oil aeration level has an effect on the lubricating properties, the thermal stability and the compressibility of the oil.

Different measurement methods have been used to understand these phenomena and prevent engine problems. Some are "lab tests" (ASTM methods) performed on oil samples, others are performed on engines

Nevertheless, there doesn't exist satisfactory method and tool to determine the aeration ratio on a running engine. For this reason IFP ("Institut Français du Pétrole") has developed a specific method named SMAC ("Système de Mesure d'Aération par Compressibilité" ; Compressibility based on aeration measurement). The measurement principle based on compressibility, has been demonstrated and validated by IFP. IFP then decided to license D2T Group in order to develop and to set up an industrial measurement system.

Measurement principle

The SMAC measures the volumetric gas ratio (bubbles volume/total volume) at a chosen location in an oil circuit.

The basic principle is to take an oil sample on a running engine *whilst maintaining pressure and temperature* and to compress it up to 200 bars in order to analyze the compression curve and so to determine the aeration ratio.

Presentation of the system

The whole SMAC system (figure 1) consists in a hardware system controlled by a PC.

The hardware part is packaged within a metallic box (780 x 600 x 780 mm) equipped with rollers. It contains :

- a measuring part including all the components used to sample the oil and to compress it to determine its physical characteristics,
- a power part including all the components used to produce the energy to compress the sample of the analyzed fluid,
- an electric and electronic box.



Figure 1: SMAC

The measuring part (figure 2) is composed of :

- a compression chamber in which the temperature is maintained at the same level than the engine oil temperature,
- two solenoid valves to sample the fluid to be analyzed,
- a piston to compress the oil sample,
- sensors to measure the pressure, the temperature and the piston displacement (oil sample volume).

The linear increase of pressure up to 200 bars is done by a digital regulator and a servo hydraulic valve, which are controlling the piston stroke.

The PC is equipped with a specific software allowing it:

- to be controlled by a test bench PC,
- to start and stop automatically a measurement,
- to control the whole components and the regulation of the pressure increase through the digital regulator,

- to do the real time acquisition of the piston displacement, the pressure and the temperature in the chamber,
- to store the data and send it if necessary to the test bench PC.

The software performs the data analysis and calculation of the volumetric aeration rate.

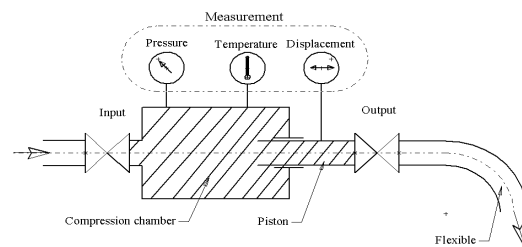


Figure 2: measurement body

SMAC capability

This system is able to measure an absolute oil aeration ratio under the pressure and at the temperature of the chosen measuring location in the engine oil circuit. The SMAC is able to analyze oil up to 160°C with an aeration rate under pressure from 0.5 % to 15 % with an accuracy of +/- 0.1%.

The SMAC system can be connected in serial or in parallel with the circuit studied (engine, test loop,...).

How use the SMAC on a running engine ?

Different engine tests have been conducted to demonstrate the real aeration induced in running engines.

The typical experimental apparatus is described below.

Hydraulic circuit.

An hydraulic circuit is established between the SMAC and the engine (figure 3). The oil comes from the engine sampling point to the SMAC and goes back to the sump. Pipes are designed to induce the minimum pressure drop. Care must be taken about the connecting lines from the engine to the SMAC. It is recommended to avoid sharp bends, fittings restrictions, at least on the SMAC inlet side.

After the measurement cell a restriction is placed to allow a sufficient oil flow through the SMAC with a minimum loss of oil pressure in the engine.

Just before the measurement cell, a partial oil derivation is made through a heating chamber around the cell to maintain its temperature as close as possible to the engine oil temperature.

On the engine, we have used typically two sampling points. One in the main oil gallery, and a second in the cylinder head.

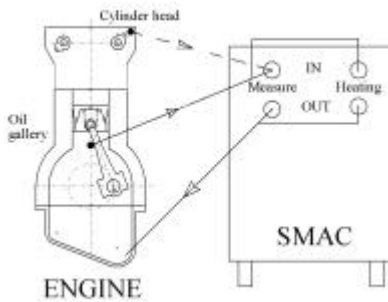


Figure 3: SMAC oil circuit

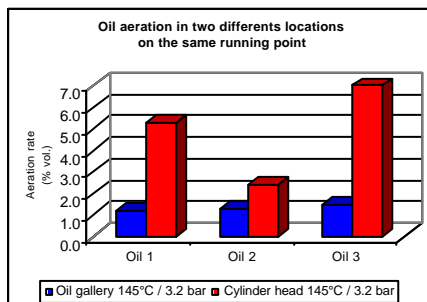
The both locations are interesting to evaluate the oil capability to insure a good lubrication. The aeration in the cylinder head is a very pertinent indication of the compressibility of the oil used by the valve trains equipped with hydraulic lash adjusters. These kinds of effect has been explained in the paper [1].

Example of SMAC tests results

We show hereafter a presentation of results obtained on a four stroke, four cylinder, gasoline engine. These results have been obtained in steady state condition measurements.

Influence of the running point

All the running point parameters could have an effect on the aeration ratio. One of them is the engine oil temperature. In the figure below, we can observe the evolution of the oil aeration in the cylinder head for two different temperatures and for three oils on the same running point.



In each case, the aeration ratio increase for these running conditions when the temperature increases.

Nevertheless, the oil formulation has an influence on the increase step.

The SMAC is in this way useful to develop an oil formulation or to choose it.

Influence of the location.

The aeration ratio is linked to the location in the lubrication circuit. In this way, for the same running point, we can observe different aeration ratio in the oil circuit.

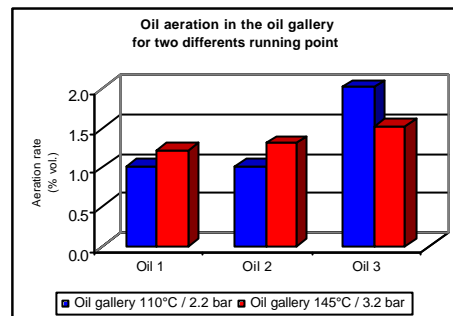


Figure 5: Location influence

Test results conclusion

The SMAC is an useful tool to determine the aeration ratio on a running engine.

The SMAC measurements are complementary to tests lab one because they permit to accede to the aeration ratio on a pressured oil circuit. This is so easy to compare in real conditions several circuit and oil formulation.

On this engine and this running point, the aeration ratio in the cylinder head is greater than the aeration ratio in the oil gallery. Nevertheless, the oil 2 is less sensible to the location than the others.

THE OSA System

It is more and more necessary to reduce the duration of the development phase of new engines and gear boxes. In order to follow the evolution of these components during the test phase, it is very interesting to be able to analyze the oil composition. Indeed, the oil composition is a very pertinent indicator of the state of the component.

Oil analysis is a non invasive, preliminary means of assessing the mechanical condition of an engine, where as detailed wear analysis, crack testing and component evaluations must wait until a test is completed and the engine disassembled.

Oil analysis permits to detect excessive wear rates or other kinds of damage concerning the cooling or injection circuits.

Instrument description

This tool is called OSA2 (second generation of On Site Analyzer). The OSA2 system is packaged in a box (965 x 559 x 432 mm) with an integrated computer. It features an integrated infra red spectrometer, an optical emission spectrometer and a viscometer. The OSA is equipped with an automated system for sample transporting and draining. The system is completed by a computer in order to manage the whole system including the analyzer, and to analyze the measurements.

The instrument is able to produce the analyze results in about less of five minutes and to purpose remedial recommendations. The OSA is able to print out the report or to send it to a remote computer.



Figure 6: OSA2

Measurement principle

The OSA is based on two spectrometers and a viscometer.

The Infra Red spectrometer

The oil sample (about 30ml) is pumped into a vertical infrared sample cell positioned in the IR spectrometer's optical path. A carefully manufactured spacer sandwiched of 100 micrometers between the IR transparent cell windows creates a repeatable oil thickness from sample to sample.

The sample cell places the oil 90° vertically in the IR beam. Controlled variable IR light frequencies come from the IR light source, pass through the oil sample and the

frequency absorption is measured on the light exit side of the cell with a photo detector. The oil absorbs the infrared frequencies selectively depending upon the structure of the oil molecules and thereby creates an absorption spectrum that is the fingerprint for that particular oil. The infrared spectrum for each sample is qualitatively and quantitatively reproducible, repeatable and precise.

The base oil has its own distinctive spectrum. The additive package, blended into the oil, improves the oil's operating characteristics but changes areas of the IR spectrum. During the oil's service life, contaminants like fuel, water, soot, blow by products of combustion, mix and dissolve in the blended oil creating more spectral components.

In order to evaluate the properties of the used oil, the properties must be compared to known values of a virgin sample. The virgin oil as well as typical contaminants have known valued spectra and are statistically modeled by the OSA computer into a "Quant" file. There are numerous "Quant" file in the OSA's software, e.g. gasoline engine lube oil, diesel lube oil, transmission oil, gearbox oil ... The OSA operator selects unknowingly the appropriate "Quant" file when he selects on the OSA screen the type of equipment and oil being tested.

With the appropriate Quant file in the OSA's computer and the sample spectrum available, the spectral ranges per the characteristics being tested are selected and quantified by the use of the "Quant" file.

The values for fuel, antifreeze, TBN are Quants. Certain tests can be done without a Quant file by measuring a one frequency absorption value. Such a measurement is referred to as a "calculated value". calculated values are for soot, water, oxidation and nitration.

The sample emitting light

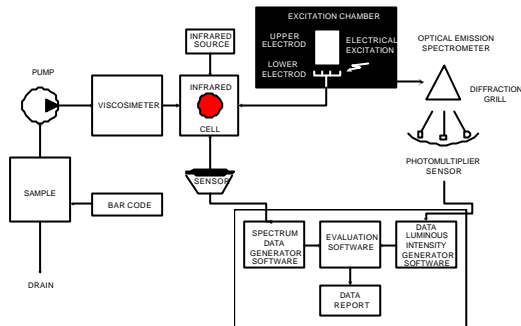
In contrast to the light absorption technology of the infrared spectrometer, the second analysis technique creates its data through the sample emitting light. The metal constituents of the alloys in engines and gearboxes, the inorganic compounds in an additive, the contaminants and antifreeze emit characteristics wavelengths of light whose intensity is a function of the quantity present.

After completing the 45 seconds infrared test, the oil pump moves the sample up to through a highly electrically charged electrode into a DC arc energy plasma that instantly flashes off the oil and excites the metals so they emit light. The emitted light beam is focused on a grating that separates the wavelengths into the selected for each test metal. The selected, representative wavelengths are impacted onto a line of photomultiplier sensor cells that measures, very sensitively and precisely, the amount of light emitted by each metal in the original oil sample. To eliminate the possibility of others metals light wavelengths

impinging in the photomultiplier sensor (that would create data inaccuracies), a narrow slit mask is positioned directly in front of the photomultiplier sensor.

The third part of the OSA : the viscometer

The new generation of OSA system is equipped with a miniature spectrometer in order to provide with a good accuracy the viscosity measurement.



OSA capability and limitations

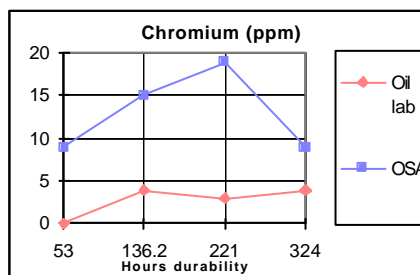
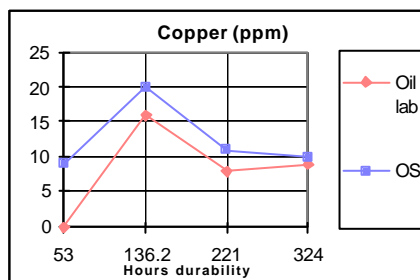
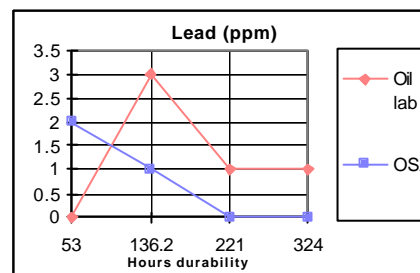
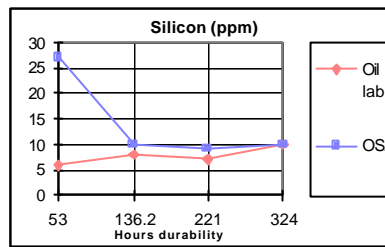
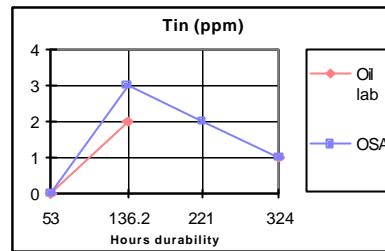
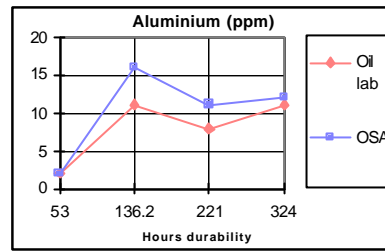
The OSA system has the capability of measuring seven wear metals, two metallic additives, five contaminants and five physical-chemical characteristics

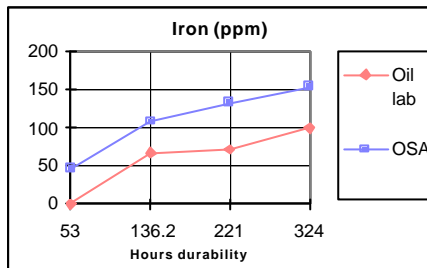
TEST	DETECTION LIMIT	ACCURACY
	ppm	ppm ± %
Aluminium	2.5	15
Chromium	2.5	15
Copper	1.5	10
Iron	55	10
Lead	5	10
Potassium	10	15
Silicon	2.5	15
Sodium	1.5	10
Tin	2.5	15
Zinc	1.5	10
Water	0.1	15
Glycol	< 0.5%	20%
Fuel	2%	15%
Oxidation	Absorbency	5%
Nitration	Absorbency	5%
Soot	0.10%	2%
TBN	5%	1.5%

Tests results

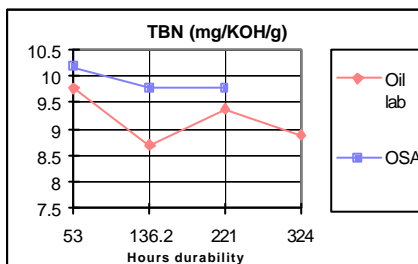
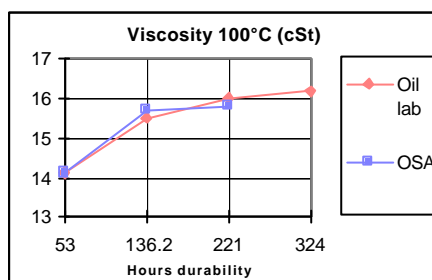
All the tests we have done in D2T Group using the OSA demonstrate that :

- the OSA gives with a very good accuracy the level of metal contained in an oil as it shown here below :





- the comparison between OSA and tests lab results concerning TBN, dilution, soot, fuel, glycol, water, oxidation and nitration have always the same trend but not the same absolute values. It is due to the method used. The OSA doesn't use the ASTM method and so the calculated values by the OSA software on the basis of the spectrometric analyze are quite different.



- the repeatability of the OSA is good and sufficient to detect the evolution of a component as an engine or a gear box.
- the OSA has a good capability to follow the evolution of the oil composition all along a duration test of a component. In this way, it is a good tool to prevent a damage. Early detection triggers an investigative process whereby a specific durability issue may be identified and corrected.

OSA limitations

Although a lot of technology has been included into the OSA, it was not designed to be an all inclusive laboratory. Its limitations are the following ones :

- The OSA is unable to test new lube oils. Indeed, it is not possible to secure enough out of specification oil to create Quant files.

- The OSA is unable to realize test for oxidation in a synthetic oil. The infrared spectrum of a synthetic oil has spectral features that prohibit modeling and making Quant file for oxidation.

The OSA is unable to analyze Diesel oils that have soot greater than 1.8%.

- Indeed, they are too opaque for infrared transmission, thereby eliminating the availability of an IR spectrum applicable to the Quant file.
- The OSA does not measure particle size.
- The OSA is sensible to a too high level of fuel. A concentration of 7% or less of unburned fuel in a lube oil will not damage the OSA or be dangerous. Higher concentrations of fuel will explode when ignited in the excitation chamber.
- Coolant and antifreezes contain water which will damage the infrared cell. Any data would be totally erroneous.

Furthermore, the OSA will not handle the following fluids :

- SAE5weight < Lube < SAE60weight
- Gears and transmissions oil greater than SAE140 weight
- Brake/Power steering fluids
- Cutting oil
- Fire Resistance Fluid
- Grease
- Heat Transfer Oil
- Metal working Oil
- Refrigerator Compressor oil

OSA method against test lab ones

After several years of high tech effort, the OSA is a major step towards the goal to follow the evolution of a component as an engine or a gear box. It gives the possibility to predict a failure and so to reduce the costs of developments. Validation testing which uses lower cost pre-production engines will benefit by saving large numbers of hours of cell time and by identifying component manufacturing defects quickly.

Nevertheless, the OSA is not yet capable of being an ASTM laboratory in a box.

Although relatively fast and convenient, it lacks the very low detection limits and the precision of laboratory instrumentation. Even with its present limitations, it can adequately handle the needs of 80% of the manufacturers need.

The instrument is designed to work in a high volume, quick turn around environment where accuracy featured by central labs is not as vital as consistent trend monitoring.

GENERAL CONCLUSION

The both tools SMAC and OSA are now available to support the engineers all along their developments of new engine.

The SMAC is an useful tool to compare and characterize several engine architectures and lubricant characteristics.

The OSA permits to improve the quality of the products and to reduce the costs of the development phase by reducing the number of engine failures, minimizing time spent running unproductive tests and improving the ability to determine root cases of component failures.

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