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ONLINE CONDITION MONITORING OF LUBRICATING OIL ON TEST BENCH DIESEL ENGINE & VEHICLE

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ABSTRACT

In present day practice, the engine oil change period is decided by offline laboratory investigations by the Original Equipment Manufacturers (OEM) and Oil companies. Generally the oil change period is fixed with reference to severe operating conditions. By following the generalized oil change period, the oil could have been discarded much before using until its full life. By investigating current practices in deciding the oil change period, it is established that the engine oil could provide additional service period before finishing its useful life. To ascertain that the oil is used until it reaches its discard limits real time monitoring of the oil degradation is suggested as potential solution, which could provide basis to extend the oil change period. By extended the oil change periods, the overall lubrication oil consumption shall be reduced, which impacts the economy positively, with reduction in petroleum imports requirement.

In the current work, engine oil samples (SAE 15W40 grade) collected from durability test engines in engine test rig. These samples tested for physical & chemical properties. Any changes in the properties of engine oil monitored, as it undergoes degradation due to usage. A prototype of capacitive type sensor was developed and validated with reference fluids. The dielectric values measured using proto type sensor in the used oil samples show a correlation with change in physical properties. This trend and thresholds of dielectric provides effective plat form to monitor the engine oil degradation.

Keywords: Engine oil, degradation, dielectric constant

INTRODUCTION

Fixing of oil change period (OCP) for automobiles has been time consuming exercise for all OEMs. To ascertain the right OCP, extensive collaborative environment exists between OEMs and Oil Marketing Companies (OMCs). Either OEMs setup their own laboratory or otherwise utilize the OMCs' labs to conduct the physiochemical property analysis, application specific tests like elastomer compatibility, tribology study to find wear and durability of the automobile parts. With this type extensive analysis, OEMs ascertain that when the lubricant will reach the throw- off limit for the given particular applications. Every OEMs keep separate throw off limits for each type & grade of the oils or they refer to standard guidelines provided by Oil companies like IOCL, HPCL, BPCL, Shell, etc. The throw off limits used to be arrived based on the changes in lubricant's physio-chemical properties or the loss of additive reserves that could potentially fail the lubricant from delivering its desired performances.

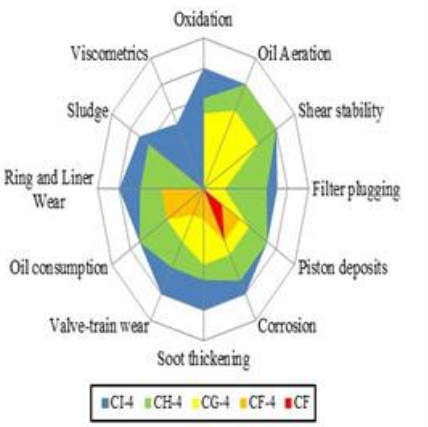
Based on the test results, standard oil change period (OCP) has been specified by OEMs in terms of kms and time period, whichever reached first, the oil needs to be replenished. Since the automobile e.g passenger car shall be utilized in different usage patterns, the worst case condition shall be considered to arrive at the ODI. This essentially limits the usage of oil up to its full life in other normal usage cases & underutilization situations. In this Phase-I work; conventional offline engine oil degradation monitoring methods for a heavy duty diesel engine is presented. Solution to extend the ODI by utilizing the oil to its entire potentials, with help of real time condition monitoring also discussed. Apart from above researched sensors, some commercially available sensors are also capable of online oil quality detection by way of interpreting lubricating oil dielectric property but they are costly. In this research work, an attempt is made to develop affordable dielectric sensor to monitor the engine oil condition.

Extensive Study of Engine Oil:

Degrading Properties: The American Petroleum Institute (API) has established service categories based on input from ASTM & SAE, under 2 major series, viz, a) "S" series (spark ignited) for oils in gasoline powered passenger cars & light trucks and b) "C" series (compression ignited) for oils used in diesel engine applications such as heavy duty trucks, construction and farm equipment. The evolution of diesel engine oil specification is based on various performance matrices. Recently added performance indices are compatibility with emission treatment systems and low amount of chemicals (Low SAPS – sulfated ash, phosphorus – sulfur).

Table.1.API Category Evolved As. API Classification of Oil Grades

API	Year	Service	Status
CJ-4	2006	For year 2007 and above emission standards, less than 500 ppm Diesel sulfur content and DPF compatible	Current
CI-4	2002	For year 2002 and above emission standards, less than 0.5% Diesel sulfur content	Current
CH-4	1998	For year 1998 and above emission standards, less than 0.5% Diesel sulfur content	Current
CG-4	1995	For year 1994 and above emission standards, less than 0.5% Diesel sulfur content	Current
CF	1994	For off-road, IDI and other diesel engines, using fuel with over 0.5% sulfur.	Current
CF-4	1990	For high-speed, four-stroke, naturally aspirated and turbocharged engines.	Obsolete
CE	1987	For high-speed, four-stroke, naturally aspirated and turbocharged engines.	Obsolete
CD	1955	For certain naturally aspirated and	Obsolete



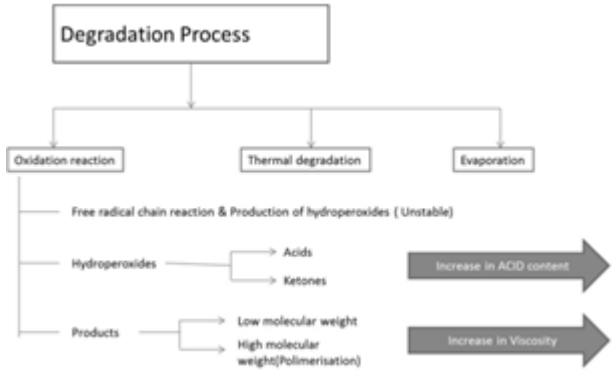


Fig.1. Relative Performance of API Categories **Fig.2: Degradation process of engine oil**

The selection of particular engine oil for given application is basically given by relative performance of each API category, as indicated in Fig. 1. Some of automobile manufacturers used to specify their own oil specifications like Mercedes-Benz had specified MB standards for all operating fluids used in their automobile products as lubricants ages, they become less capable of delivering expected performance largely due to the progressive dump of high amounts of sludge and insoluble compounds into the oil sump. The primary driver for this problem is oxidation. Oxidation is a general term used to describe a complex and series of chemical reactions, which disturbs the chemical stability of the liquid and encourages formation of new unwelcome molecular species within a lubricant sump. Initially, oxidation was characterized as a chemical reaction involving oxygen. The definition has been expanded to include any reactions involving electron transfer. The lubricant oxidation is a three-stage process. They are Initiation, Propagation and Termination. Initiation stage involved with the formation of a free radical, an atom or molecule fragment with one or more unpaired electrons. The biggest contributor of free radicals is the oxygen itself. Contaminants those are rich with oxygen (air, water) feeds oxygen to the system. Free radicals are highly reactive and un- stable, quickly combining with hydrocarbon components to form alkyl radicals and hydroperoxi- radicals.

The propagation stage occurs when hydroperoxi (peroxide) radicals react with the base oil or additives to regenerate an alkyl-radical (or generate an alcohol and water) and restart the cycle. When high temperatures exist, the peroxide radicals split and sustain the chemical reaction. When wear debris is present, peroxides may catalytically split to sustain the reaction, even at low temperatures. The propagation stage becomes autocatalytic, with the chemical reactions themselves providing the feedstock to start the next cycle. The termination stage occurs when the designated oxidation inhibitor (antioxidant) performs its function. All the three stages of engine oil degradation lead to formation of acidic components, which affect the dielectric constant of lubricating oil as shown in Fig. 1.

Fresh Oil Properties: Table 1, gives fresh oil properties of SAE 15W 40 grade lubricating oil. The typical value of Kinematic Viscosity at 100◦ C ranges from 14.5 to 15.7. The base number value is 9.6 initially and

decreases as degradation takes place. When the lower value of base number equals acid content, it shows end of oil life.

Validation of Engine Oil Properties:

On Test Bench Diesel Engine: Engine oil samples of a light commercial vehicle 4 cylinder, 4 Liters Test Bench Engine, which has 125 Kw @ 2500 rpm were collected at periodical intervals for laboratory analysis. In the investigation of the oil properties during target oil change period. The engine oil samples that were collected at specified intervals were analyzed in conventional offline laboratory investigations using standardized equipment as per prescribed ASTM standards. It is in practice to analyze this data to find out still available margin below the discard limits and at least three consequent set of such data has to be analyzed and only with a consistent trend will be used to establish the Oil Change Period of an automobile. In the current study, the oil samples collected from of similar Test bench engines over a period of 644 Kms & 2000 Kms were analyzed and the results were used to find out the useful life remaining in the oil.

Arrival of Threshold Values of the Major Affecting the Engine Oil Degradation: Oil change period used to be determined based on contamination in oil, degradation of oil and additives consumption rate. Poor quality of engine oil affects performance due to deposit built-up & piston ring sticking, valve deposits & pitting, soot & sludge deposits and could cause excessive wear of engine components.

Table.3.List of important oil properties

Property	Standards
Kinematic Viscosity [cST] At 40°C at 100°C	ASTM D 445
Total Base Number (TBN) [mg KOH/g]	ASTM D 2896 / ASTM D 4739
Total Acid Number (TAN) [mg KOH/g]	ASTM D 664
Density at 15°C [kg/L]	ASTM D 4052
Wear Elements by ICP	ASTM D 5185
Flash Point [°C]	ASTM D 92
Fire Point [°C]	ASTM D 92
Ethylene Glycol [% m/m]	ASTM E2412

In offline laboratory method changes in oil's physio-chemical properties were measured from the oil samples collected from engines with a standardized set of tools under prescribed conditions. Table 2 shows list of parameters tested and the reference standards for these tests. The measurement of viscosity provides indication of effective lubrication oil film available to provide adequate. The high shear rate viscosity [mPa.S)] at 150°C as per ASTM D4683 is measured during initial phase of a new oil development program; that is HTHS is an oil grade selection criterion. However the changes in engine oil viscosity during the engine operation used to be monitored with low-shear- rate Kinematic Viscosity (mm2/s) as per ASTM D 445 standard. Minimum and maximum limits have been specified for every grade of engine oils in SAE standard J300–2009. During the useful life of the engine the oil should stay within this grade limits. However due to dissolved / suspended soot, oxidation products and low temperature sludge in the oil, the viscosity may increase and the shear stability may be lost.

In practice when the viscosity deviates from the specifications for its grade, that point is the maximum period the oil could provide the design indented lubrication film characteristics. Total Base Number (TBN) is a measure of reserve alkalinity that is still available and could neutralize the acids formed during combustion and oxidation to protect engine parts from corrosion. In practice 50% reduction of the TBN value compared to fresh oil sample, is considered to be the discard limit. Total Acid Number (TAN) is a measure of increase in acidity level of engine oil due to the combustion and oxidation. It is an inverse trend to the TBN. As the TAN value increases TBN would be reducing. At the point of intersection, of both TAN & TBN trend lines, the oil is considered to be reached its end of life and any further continuation of service would eventually rendered higher level of damages to engine components. Measure of ethylene glycol would indicate as the oil contamination through engine coolant mix-up with engine oil. Such contamination is visible from any abnormal increase in sodium content. As a thumb rule, drop in flash point below 190°C could be an indication of possible contamination of engine oil due to diesel fuel mix-up. The measurement of wear elements indicates us some usual engine components wear. Table 3, provides guidelines to understand the origin of the wear metals that are usually found in engine oil analysis. The wear elements content used to be high at initial period as the engine undergoes bedding-in operation, but eventually reduces to minimum levels. If incase of any abnormal increase in any of the wear elements observed it is considered as the start of wear in the corresponding engine components.

Table.3.Origin of wear materials in engine oil

Wear Element	Potential Sources
Iron (Fe)	Cylinder bore/liner, crankshaft, camshaft, gear train & valve train
Lead (Pb)	Shell bearings and thrust washers
Copper (Cu)	Shell bearings, bushings, oil cooler tubes, fuel pump
Chromium (Cr)	Plating on piston rings, cylinder liners, cooling systems
Silicon (Si)	Dirt entry thro defective air intake system, silicon gaskets, also from anti-foam additive of the oil
Sodium (Na)	Coolant leakage
Aluminum (Al)	Piston damages, Aluminum bearings, Cylinder block surfaces.
Tin (Sn)	Camshaft bushings, bearings.

Sensor Development for Online:

Condition Monitoring: The Dielectric sensor has two co-axial cylinders, as electrodes, which separated by space or medium and works on the principle of capacitance. The medium has certain dielectric constant. The dielectric constant is the measure of a material's influence on the electric field. The net capacitance will increase or decrease depending on the type of dielectric material. Permittivity relates to a material's ability to transmit an electric field. In the capacitors, an increased permittivity allows the same charge to be stored with a smaller electric field, leading to an increased capacitance.

A coaxial type sensor with inner and outer electrode is developed as shown in Fig. 3.

Fig. 3. Proto type dielectric sensor

Fig. 4. Test set up for measuring dielectric constant

The Modification process work in progress to reduce the Percentage of Error.

RESULTS & DISCUSSIONS

The engine oil samples that were collected at specified intervals were analyzed in conventional offline laboratory investigations using standardized equipment as per prescribed ASTM standards. It is in practice to analyze this data to find out still available margin below the discard limits and at least three consequent set of such data has to be analyzed and only with a consistent trend will be used to establish the Oil Change Period of an automobile. In the current study, the 13oil samples collected for 644 Hours run test bench engine and 23 Oil samples collected from of similar Test bench engines over a period of 2000 Kms were analyzed and the results were used to find out the useful life remaining in the oil.

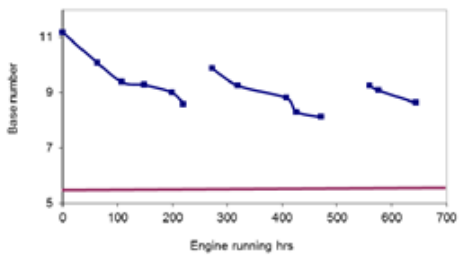


Fig. 5. Total Base Number Values for the Engine Test Bench @ 700 Kms

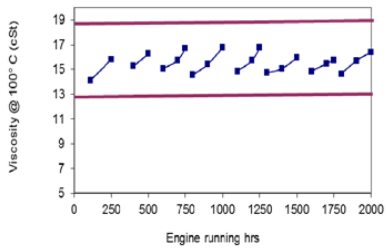


Fig. 6. Total Base Number Values for the Engine Test Bench @ 2000 Kms

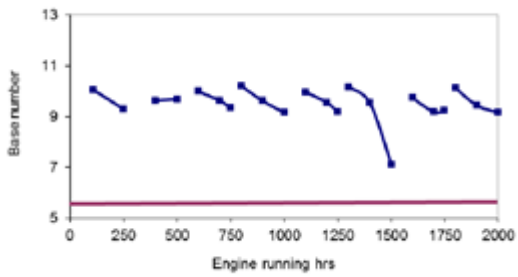


Fig. 7. Viscosity Values @ 100°C Values for the Engine Test Bench @ 700 Kms

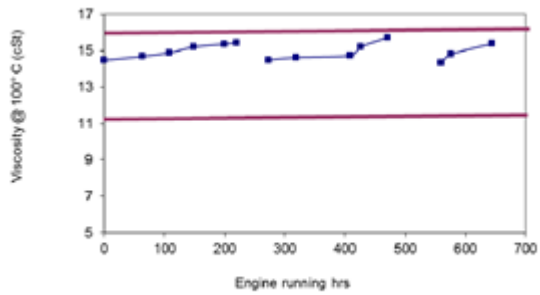


Fig. 8. Viscosity Values @ 100°C Values for the Engine Test Bench @ 2000 Kms

The acid content value has to be less than Total base Number at any given time. When acid value meets to that of TBN value, (Should not be less than 5) the lubricating oil is not to be used any more.

Viscosity: The Kinematic Viscosity value is within the limit value of 18.5, Hence this information says the oil can be used for some more extended hours.

Soot

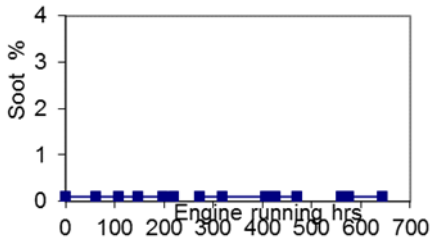


Fig. 9. Soot Content for the Engine Test Bench @ 700 Kms

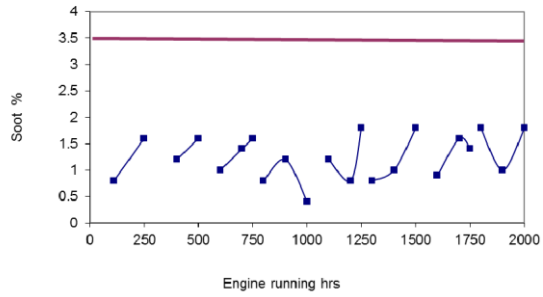


Fig. 10. Soot Content for the Engine Test Bench @ 2000 Kms

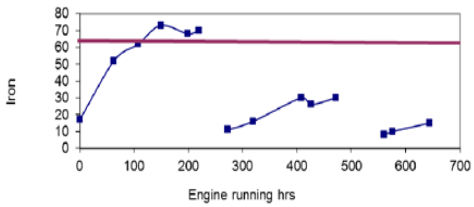


Fig. 11. Iron Content values for the Engine Test Bench @ 700 Kms

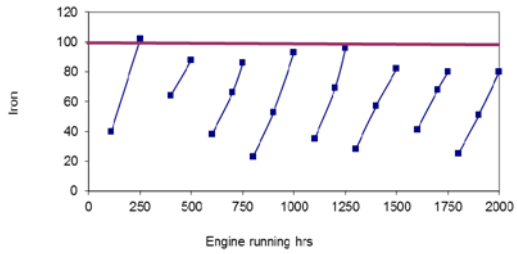


Fig. 12. Iron Content values for the Engine Test Bench @ 2000 Kms

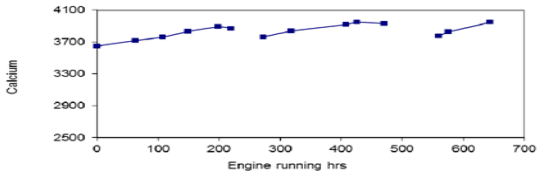


Fig. 13. Silicon Content values for the Engine Test Bench @ 700 Kms

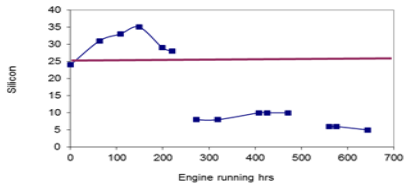


Fig. 14. Silicon Content values for the Engine Test Bench 2000 Kms

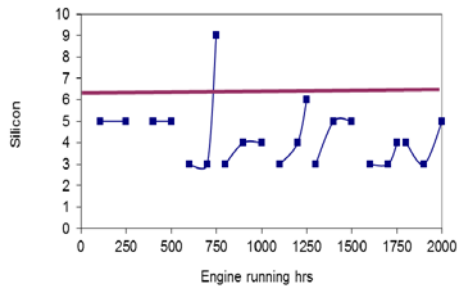


Fig. 15. Calcium Content values for the Engine Test Bench @ 700 Kms

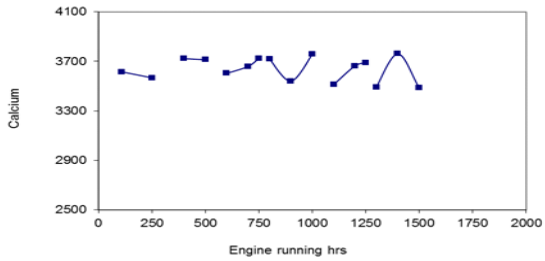


Fig. 16. Calcium Content values for the Engine Test Bench @ 2000 Kms

The soot content within limits and this parameter indicates Good Combustion. Soot percentage has gone beyond the 4% limit, it could be lead to the oil thickening on account of Viscosity raise

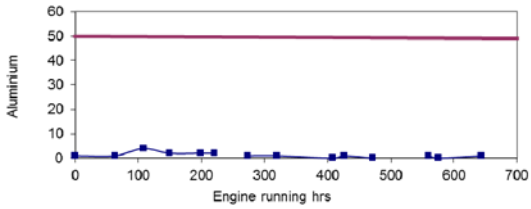


Fig. 17. Aluminum Content values for the Engine Test Bench @ 700 Kms

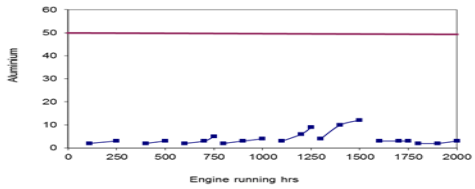


Fig. 18. Aluminum Content values for the Engine Test Bench @ 2000 Kms

The useful life of this lubricating oil is over at 250 Hours which is evident from Acid content equals the base number during this period. And this is the end of its useful life even though other properties such as viscosity, contents of Iron and oxides of silica are within limits.

CONCLUSION

Detailed experimental study is in progress to establish the relationship between various deterioration factors of lubrication oil, engine oil particularly in focus, with much recommended conductivity, permittivity principles. Objective of the study is to prove, on-line oil condition monitoring as a positive prognostic technique and also establish a platform for both individual vehicle owners and large fleet owners to save money by extending the oil change period up to the maximum useful life of the oil. By this way efforts were in place to show pathways to curb dependency of oil imports in long term by effectively utilizing the oils.

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