



MAURITIUS RESEARCH COUNCIL

OIL BASED CONDITION MONITORING MAINTENANCE

Final Report

Year 2001

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This report is based on work supported by the Mauritius Research Council under award number MRC/RUN-9805. Any opinions, findings, recommendations and conclusions expressed herein are the author's and do not necessarily reflect those of the Council.

OIL BASED CONDITION MONITORING MAINTENANCE

by

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July 2001

Acknowledgements

I wish to thank the Mauritius Research Council for having sponsored this study. My thanks also go to the National Transport Corporation for having so diligently supplied much needed oil samples more particularly the Principal Mechanical Engineer and his staff for their precious collaboration.

I wish equally to place on record my thanks to the Vice Chancellor of the University of Mauritius granting necessary authorisation to proceed with this piece of work.

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Abstract

The oil analysis is an important maintenance tool for vehicle owners. It is based on the monitoring of the physical and chemical properties together with the contamination level of the lubricant. Thus, through these properties, the condition of the engines can be assessed and recommendations can be taken on the future maintenance actions.

The main part of the project work consists in collecting used oil samples for analysis purposes. The oil properties are monitored over a time scale and linked with the maintenance history of the particular vehicle in order to determine the variation trends of these properties and the factors affecting them.

The wear metals contents of the oil have been trended as well as the physical properties. Cumulative values have been plotted for the wear metals. Statistical analyses of the test data especially for the standard deviations have been carried out; these have been used to determine the reportable and the alert limits and the moderate and the rapid trends.

This study started in June 1998 and rolled on through to 2001. The collection and submission of oil samples for analysis purposes was solely the responsibility of the firms and companies participating in the project. In fact three companies were chosen at random and some 280 oil samples were expected to be obtained. However some way through, two of the companies showed sign of slackness and pulled out for reasons of staff earlier committed to the project leaving the company or otherwise. Ultimately only one company supplied the bulk of the oil samples. The advantage so derived is that a more thorough analysis was made possible with a substantial number of samples for the vehicles of that particular company.

CHAPTER 1

Predictive Maintenance

1.1 Introduction and Brief overview

Predictive maintenance is a management technique that uses regular evaluation of the actual operating condition of plant machinery, production systems and plant maintenance functions to optimize total plant operation.

Predictive technology can be used for much more than just measuring the operating conditions of critical plant machinery. The technology permits accurate evaluation of all functional groups, such as maintenance, within the company. Properly used predictive maintenance can identify most, if not all, factors that limit effectiveness of the total plant. Predictive maintenance uses direct monitoring of the operating condition, system efficiency and other indicators to determine the actual mean-time-to-failure or loss of efficiency for each machine train and system within the plant. A predictive maintenance program can minimize unscheduled breakdowns of all mechanical equipment in the plant and ensure that repaired equipment is in acceptable mechanical condition. Normal mechanical failure modes degrade at a speed directly proportional to their severity. If the problem is detected early, major repairs in most instances can be prevented.. Unless proper repairs or corrective actions are made, the data provided by the predictive maintenance program cannot be effective.. Predictive maintenance can provide the data needed to achieve optimum, consistent reliability, capacity and efficiency from critical production systems.

There is a variety of technologies that can and should be used as part of a comprehensive predictive maintenance program.

A number of methods have been developed in the recent years to help the maintenance personnel for prediction of the health of equipment or system and the required actions to be undertaken. These methods include:

Vibration monitoring and analysis,

Temperature monitoring (Thermography),

Corrosion monitoring,

Crack and stress monitoring,

Leakage monitoring,

Performance monitoring, etc. and of course

Oil monitoring (Oil/wear particle analysis),

Since mechanical systems or machines account for the majority of plant equipment, vibration monitoring is generally the key component of most predictive maintenance programs. However, vibration monitoring alone cannot provide all the information that will be required for a successful predictive maintenance program. Oil analysis has become an important aid to preventive maintenance.

Lubricating oil analysis is an analysis technique that determines the condition of lubricating oils used in mechanical and electrical equipment.

Of all these methods, oil/lubricant monitoring is an important and useful technique for predictive maintenance on engines.

The fundamentals of the oil analysis method rely on the function of carrying wear debris and the chemical changes occurring with mileage.

Some 10 tests are conducted on used oils. They are as follows:

Viscosity

Flash Point

Total acid number

Total base number

Wear metals – iron, aluminium, copper, lead, chromium

Silicon

Water content

Fuel dilution

Pentane Insolubles

CHAPTER 2

2.0 Definitions of Useful Parameters

2.1 Viscosity

This is one of the most important properties of a lubricating oil. The primary function of a lubricant is to reduce friction and minimize wear by separating lubricated surfaces with an oil film without imposing unnecessary viscous drag. An increase in viscosity usually indicates that the oil has deteriorated perhaps through oxidation. A decrease usually indicates that the oil has been diluted, the degree to which a lubricant resists a viscosity change due to temperature is expressed by/as the viscosity index. The higher the VI the less the viscosity will change as a result of a temperature change. Excessively low viscosity will reduce the oil film strength weakening its ability to prevent metal to metal contact. Excessively high viscosity may impede the flow of oil to vital locations like the bearing support, reducing its ability to lubricate.

2.2 Oxidation:

Lubricating oil oxidation can result in lacquer deposits, metal corrosion, or thickening of the oil. Most lubricants contain oxidation inhibitors. When additives are used up, oxidation of the oil itself begins.

Oxidation tends to raise the viscosity of an oil. It is a form of deterioration to which all petroleum oils are subject. It is accelerated by high temperatures, catalysts and the presence of water, acids or solid contaminants. Oil oxidation forms two general classes of degradation products.

Oil insoluble materials-insoluble resins, varnish or sludge

Oil soluble products-soluble resins, organic acids and peroxides.

Paraffinic oils tend to have greater oxidation resistance than naphthenic oils, though the latter are less likely to form hard deposits.

The oxidation stability is an important factor in the prediction of an oil's performance. Acids formed are corrosive to metals. Sludges may deposit on sliding surfaces, causing them to wear or stick or may plug oil screens or passages. It is a prime requisite of oils in use in closed systems, where the oil is circulated for extended periods. The higher the

operating temperature, the greater the need for oxidation stability, the more so in the presence of water, dirt or catalytic metals.

Anti-oxidants in engine oils help to prevent formation of combustion by-products. They act as radical scavengers - by combining with and rendering harmless the precursors to oxidation by-products and metallic catalysts.

Most lubricating oils contain specialized additive packages which increase useful life and provide additional performance characteristics. Detergents and dispersants are added to lubricants to:

- Remove particulates from machine parts

- Improve particulate stability

- Suspend and disperse particles

- Neutralise acidity

Surface protection is maintained by anti wear agents. These are the inorganic compounds (zinc phosphides, iron phosphides) which are very stable at high temperatures. Other common agents include zinc diaryl (diakyl) dithiophosphates (ZDDP), tri-cresyl (TCP) phosphate and other phosphorus compounds.

2.3 Contamination:

Oil contamination by water or coolant can cause major problems.

Water contamination is detrimental to any lubricant. Low levels of water (<2%) are typically the result of condensation. Higher levels would indicate a source of water ingress. Water can enter a system through seals, breathers, hatches, and fill caps. Internal leaks from heat exchangers and water jackets are other potential sources. When water is present in an oil , it poses serious threat to the equipment. Water is a poor lubricant, and promotes rust and corrosion to the components. Dissolved water in an oil will cause oil oxidation and reduce the load handling ability of the oil. Water contamination can also cause the oil's additive package to precipitate. Water in any form will cause accelerated wear, increased friction , and high operating temperatures. If left unchecked, water will lead to premature component failure. In most stems water should not exceed 500 ppm.

In addition to abrasive wear, particulate contamination can also cause degradation and failures due to mechanisms of erosion, contaminant lock (silting and jamming), fatigue wear and oxidation. Three body abrasive wear occurs when hard particles such as sand,

metal and metal oxides are trapped within the lubricant film between two moving surfaces. The hard particles can bridge the gap across the dynamic clearance of the component and cut away material from the component surfaces. This wear generated debris must then be filtered out from the system or it becomes contaminant and will cause additional wear. Particles smaller than 5 m or in many cases less than 1 m, are the particle sizes that can enter the clearance and then cause abrasive wear, jamming and surface fatigue.

2.4 Fuel dilution

Fuel dilution in an engine can cause severe problems. If the fuel system of the engine is faulty it can allow unburnt fuel into the oil. The problems caused by this are two-fold: firstly the fuel will lower the viscosity of the oil dramatically to the point that it will not function correctly at operating temperatures with a subsequent loss of hydrodynamic lubrication to the bearings and the possible torching of piston crowns. The second and less obvious problem, is the depletion of the oil additive package. Because fuels do not contain the additives that oils do, a fuel dilution problem will physically dilute the additives in that oil.

Oil dilution by fuel can weaken the film strength, sealing ability, and detergency. It may be caused by improper operation, fuel system leaks, ignition problems, improper timings,

2.5 Total Acid Number (TAN)

This is a measure of the amount of acid or acid like material in the oil sample.]It is an indicator of oil serviceability. Oil oxidation causes acidic by-products to form. High acid levels can indicate excessive oil oxidation or depletion of the oil additives, and can lead to corrosion of the internal components. Acid is also produced in the combustion chamber of engines. By monitoring the acid level, the oil can be changed before any damage occurs.

The TAN is lowest when an oil is new, and increases with use. Condemning limits are heavily dependent on the application. In general, a sharp increase in TAN indicates accelerated oil oxidation. The TAN of a new oil will vary based on the oil additive package. An R & O oil will usually have a very low TAN, around 0.03. An AW or EP

oil will have a slightly higher value, around 0.5. Engine oils commonly have a higher TAN, in the neighbourhood of 1.5.

2.6 Total Base Number (TBN)

The TBN indicates the ability of the oil to neutralise acidity. The higher the TBN the greater its ability to neutralise acidity. Causes of low values may be the use of improper oil for an application, waiting too long between oil changes, overheating, and using high sulphur fuel.

Many oils (especially motor oils) are fortified with alkaline additives to neutralise acids that are formed as a result of oil oxidation. In diesel engine applications, acid is formed in the combustion chamber when moisture combines with sulphur under pressure. Monitoring the TBN ensures that the oil is able to protect the component from corrosion due to acid. The TBN of an oil is highest when the oil is new, and decreases with use. Condemning limits are based on the application.. As a rule the TBN should not drop below half of its original value. TBN values for new engine oils can run from 4 to 30 depending on the application.

2.7 Wear Metals

Wear particles in the oil of a machine can provide significant information about the condition of the machine. This information is derived from the study of particle shape, composition, size, and quantity. One method of wear particle analysis is routine monitoring and trending of the solids content of machine lubricant. The quantity, composition, and size of particulate matter in the lubricating oil are indicative of the mechanical condition of the machine. A normal machine will contain low levels of solids with a size less than 10 microns. As the machine's condition degrades, the number and size of the particulate matter will increase. All solid materials in the oil are measured as a percentage of the sample weight or volume. Any unexpected rise in reported solids is cause for concern. Typical wear metals are; iron, chromium, nickel, aluminium, copper, tin , lead, molybdenum. The source of the various metals from the engine system is shown in table 1.

IRON	liners, rings, crankshaft, gears, roller bearings
CHROMIUM	Rings, Roller bearings
NICKEL	Roller bearings, Valve Stems, Valve Guides
ALUMINIUM	Pistons, Bearings, Roller Bearing Cages
COPPER	Bronze Bushes, Bearings Cages, Synchro Rings, End Plates
TIN	Bearings, Pistons
LEAD	Bearings, Mild EP Additive
MOLYBDENUM	Rings, Synchro Rings, Solid EP additives.

Table 1: Wear Metals Sources

CHAPTER 3

3.1 API RATING

What ENGINE TYPE is covered by the rating.

DESCRIPTION of what the product does.

3.1.1 SJ

Gasoline engines in passenger cars and light duty trucks beginning with 1997 models.

Oil designed for this service level provides greater fuel economy, lower volatility and lower phosphorous limits over the previous SH category.

3.1.2 SB

Minimum Duty Gasoline Service.

For engines operating under conditions mild enough to require only minimum protection. Non detergent oil. Should not be used in any engine unless specifically recommended by the equipment manufacturer.

3.1.3 CF, CF-2

Off-Road indirect injected diesel engines and two-stroke diesel engines.

Provides effective control of piston deposits, wear and bearing corrosion in a broad range of fuel types often found in off-road applications. Provides effective control over cylinder and ring-face scuffing and deposits in

two-stroke cycle engines.

3.2 SAE Viscosity

Grade

Cold Starting

Temperature

Conditions

Descriptions

3.2.1 5W-30

-13° F

Provides excellent fuel economy and low temperature performance in most late model automobiles. Especially recommended for new cars.

3.2.2 10W-30

0° F

Most frequently recommended viscosity grade for most automobile engines, including high performance multi-valve engines and turbo-charged engines.

3.2.3 10W-40

0° F

The first multigrade introduced. A good choice for controlling engine wear and preventing oil breakdown from oxidation. Note: Always check your owner's manual or warranty requirements before using this grade.

3.2.4 20W-50

15° F

Provides maximum protection for high performance, high RPM racing engines.

Excellent choice for high temperature and heavy loads such as driving in the desert or towing a trailer at high speeds for long periods of time.

3.2.5 SAE 30

SAE 40

15° F

32° F

For cars and light trucks, where recommended by manufacturers. Not recommended when cold temperature starting is required.

SJ was adopted in 1996 and covers oils used in gasoline engines in current and earlier passenger cars, sport utility vehicles, vans and light truck under vehicle manufacturers' recommended maintenance procedures. SJ oils may be used where SH and earlier categories have been recommended.

SH applies to gasoline engines in cars, vans and light trucks and indicates that the oil provides improved control of engine deposits, oil oxidization, and engine wear compared to earlier oils. It also provides protection against rust and corrosion.

CF was adopted in 1994 for use in indirect injected off-road diesel engines that use a broad range of fuels, including those with a high sulfur content. It offers effective control of piston deposits, wear and corrosion of the copper-coated bearings used in this type of engine.

CF-2 is formulated for use in two-stroke diesel engines requiring highly effective control over cylinder and ring-face scuffing and deposits.

CF-4 covers oils for use in high-speed, four-stroke diesel engines. They are designed for use in on-highway, heavy-duty truck applications.

CG-4 describes oils for use in high-speed, four-stroke diesel engines, and is suitable for both highway and off-road applications. They provide effective control of high temperature piston deposits, wear, corrosion, foaming, oxidation stability and soot

accumulation. These oils are especially effective in engines required to meet 1994 emission standards.

CHAPTER 4

4.0 Oil Analysis (Lubricant Testing) and Equipment Maintenance

The term “oil analysis” connotes different things, depending upon one’s background and objectives. To some it means determination of new oil specifications to see if an oil is fit for a particular use. To others it means the condition of a used oil, a means of determining drain intervals. To still others it means spectrometric analysis for wear metals, a means of determining if parts are abnormally wearing. Actually, it is mixture of all or part of these definitions because all these objectives can be worked out through oil analysis.

Oil analysis is viewed as a dynamic entity of vehicle maintenance. When regularly used, oil analysis can be a routine maintenance function and a tool which will allow the user to know his vehicle engine condition, its operation parameters, and its lubrication condition. It is not meant simply to diagnose problems just before or after failure, but to help prevent the engine from attaining near-failure or failure condition.

The optimal performance of the oil analysis relies on the oil sampling. A valid sample is one which represents the oil circulating through the system at or near operating temperature. Taking samples from a pan or sump bottom may include metallic particles or contamination having no relationship to the engine’s current condition. Cold samples may be stratified from settling of dense material in the oil. It is also important to protect the oil sampling process from sources of external contamination. There are two preferred methods of obtaining a sample.

One is to install a valve in the main circulating system. This is excellent in theory, but it is constrained by practical problems like the reluctance to make this installation due to the cost incurred and the difficulties in having access to the lubrication line. Some systems have in-built sampling points. Examples include most heavy marine equipment (piping to purifiers), large stationary engines and compressors (piping), large air conditioning units (charging valves), and diesel truck tractors (petcocks in lube bypass filter housings).

The other preferred sampling method, utilization of a suction device through dipstick or fill holes, enables most lube systems to be conveniently sampled. Typical devices involve the use of a suction gun having a head with a female thread adaptor for the container

used. A tube inserted in the lube system allows the sample to be drawn into the container. The disadvantage of such a procedure is that, though the tube can be replaced for each new sampling, the head must be wiped clean to prevent cross-contamination from one sampling to another. To overcome the contamination inherent in sampling guns, a device was developed that is completely disposable and which also serves as the sample container.

4.2 Oil sampling

Optimal performance in oil sampling depends directly on the following areas:

Selecting Optimum Sampling Point.

In circulating oil systems such as shown in figure 1, the best location is a live zone of the system upstream of filters where particles from ingress and wear debris are the most concentrated. Usually, it means sampling on the fluid return or drain lines. In most cases where oil drains back to sumps without being directed through a line (e.g, diesel engine), the pressure line downstream of the pump (before filter) must be used. Sampling should be avoided from dead zones such as static tanks and reservoirs.

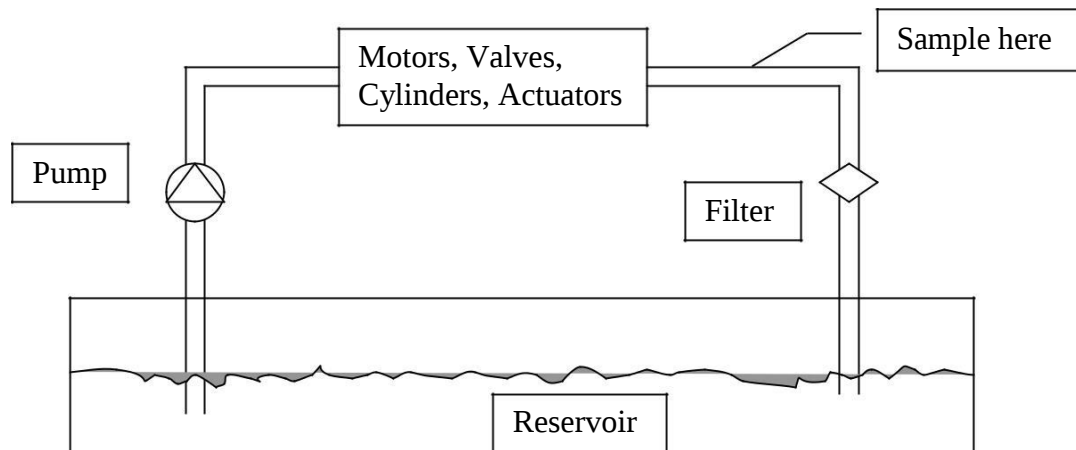


Figure 1

4.3 Collecting Representative Samples

Once a sampling point is properly selected and validated, a sample must be extracted without disturbing the integrity of the data. When a sample is pulled from turbulent zones such as at an elbow, particles, moisture, and other contaminants enter the bottle at representative concentrations. Moreover, machines should always be sampled at their typical work environment., ideally while they are running with the lubricant at normal

operating temperature. Likewise, during (or just prior to) sampling, machines should be run at normal loads, speeds and work cycles. Sampling valves should be flushed well prior to sampling.

Minimizing Data contamination

Since an important objective in oil analysis is the routine monitoring of oil contamination, considerable care must be taken to avoid “contaminating the contaminant.” Once atmospheric contamination is allowed to contact the oil sample, it cannot be distinguished from the original contamination.

Three levels of bottle cleanliness are identified by bottle suppliers: clean (fewer than 100 particles > 10 μ m/ml), super-clean (fewer than 10), and ultra-clean (fewer than 1). Selecting the correct bottle cleanliness to match the type of sampling is important to oil analysis results.

For the purpose of this project the samples submitted to the lab are taken by the companies involved in the project in pre-cleaned sample bottles provided. The bottles have been cleaned by the lab. There is, however, no direct control over the method of sampling. Improper sampling can create errors in the data generated by the analysis of the sample. Because of the relatively large number of samples analysed, the statistical effect of such errors are believed to be minimum.

CHAPTER 5

5.0 Methodology

Phase 1

5.1 Used oil samples of widely used IC engines were collected as per the recommended preventive maintenance schedule.

5.1.1 The samples were then analysed. The parameters monitored through the tests include:

Viscosity

Flash Point

Total Acid Number

Total Base Number

Wear Metal Contents viz

Fe

Al

Cu

Pb

Cr

Silicon

Fuel Dilution

% Water Content

Pentane Insolubles

Viscometer

TAN gage

Water content measurement apparatus

Atomic Absorption Spectrometer

Data collected over two/ three years

5.1.3 Statistical Interpretation and analysis of results

5.1.4 Setting up of alarm levels of selected parameters

Phase II (proposed)

5.2 Continue next phase of project by extending oil renewal period as per results obtained above

5.2.1 Repeat same series of tests

5.2.2 Increase oil change period as long as selected parameters are within alarm limits

CHAPTER 6

6.0 Results Interpretation

The interpretation of the test results is a very important aspect of the project. Using these results, trends can be established for each of the parameters tested and also for each vehicle. Sudden changes in trends might indicate excessive wear of an engine part or any other problem. Further, the condition of the oil can be known. The results might show that the oil is fit for further use.

Proper interpretation will also help in predicting failures and hence taking appropriate action at the right time.

The goal, of course, is to make decisions that not only optimise the use of equipment components but that are economically justified as well.

The origins of the problems could also be deduced. For example: excessive fuel dilution would cause the viscosity of the oil to be reduced by a considerable amount (depending on the rate of dilution) and thus reducing its lubricating properties. Therefore, excessive dilution together with reduced viscosity might indicate that there has been a fuel leakage into the engine. This could be attributed to faulty injectors (diesel engines). Similarly, excessive presence of a wear metal in the oil might indicate that a particular engine part is wearing out and need to be replaced.

Thus, oil based condition monitoring maintenance has its advantages. It represents the leading edge of maintenance decision making, and its application will mean very substantial savings.

The recommendations should include suggestions as to whether the oil is satisfactory for continued service and workable and if possible economical drain interval should be established.

Severe service factors include:

- Hot, dusty working environments
- Short trips
- Heavy loads; full throttle operations
- Extended duty cycles

Excessive idle time

CHAPTER 7

7.1 Test Procedures

ASTM test procedures have been complied with for the analysis of the oil samples. A description of some of the test methods follow; those not described and more information about the procedures can be obtained at the **Mauritius Standards Bureau** the MSB, which was responsible for doing the testing.

Standard test method for acid and base number by color-indicator titration

(ASTM designation: D 974-95; IP designation: 139/93)

7.1.1 Introduction

This test method covers the determination of acidic or basic constituents in lubricants soluble or nearly soluble in mixtures of toluene and isopropyl alcohol. It is applicable for the determination of acids or bases whose dissociation constants in water are larger than 10^{-9} ; extremely weak acids or bases whose dissociation constants are smaller than 10^{-9} do not interfere. Salts react if their hydrolysis constants are larger than 10^{-9} .

In new and used oils, the constituents considered to have acidic characteristics include organic and inorganic acids, esters, phenolic compounds, lactones, resins, salts of heavy metals, and additives such as inhibitors and detergents. Constituents considered to possess basic properties include organic and inorganic bases, amino compounds, salts or weak acids (soaps), basic salts of polyacidic bases, salts of heavy metals and additives such as inhibitors and detergents.

This test method can be used to indicate relative changes that occur in an oil during use under oxidizing conditions

7.1.2 Terminology

Acid number, n-the quantity of base, expressed in milligrams of potassium hydroxide per gram of sample that is required to titrate a sample to a specified end point.

Base number, n- the quantity of acid, expressed in milligrams of potassium hydroxide per gram of sample that is required to titrate a sample to a specified end point.

Strong acid number, n- the quantity of base, expressed in milligrams of potassium hydroxide per gram of sample that is required to titrate a hot water extract of the sample to a golden-brown end point using methyl orange solution.

7.1.3 Summary of Test Method

To determine the acid of base number, the sample is dissolved in a mixture of toluene and isopropyl alcohol containing a small amount of water, and the resulting single-phase solution is titrated at room temperature with standard alcoholic base or alcoholic acid solution, respectively, to the end point indicated by the colour change of the added p-naphtholbenzein solution (orange in acid and green-brown in base).

7.1.4 Apparatus

Burette: A 50-mL burette graduated in 0.1-mL subdivisions, or a 10-mL burette graduated in 0.05-mL subdivisions.

7.1.4.1 Water: It is being referred to mean distilled water

7.1.4.2 Hydrochloric acid solution, Standard alcoholic (0.1M): This reagent constitutes of 1000 parts of anhydrous isopropyl alcohol (2-propanol) for 9 parts of concentrated hydrochloric acid.

7.1.4.3 Methyl orange indicator solution: This solution constitutes of 0.1 g of methyl orange dissolved in 100 mL of water.

7.1.4.4 Potassium Hydroxide solution (0.1 M): This reagent is prepared by first adding 6 g of solid KOH to approximately 1 L of anhydrous of isopropyl alcohol (containing less than 0.9 % of water). The mixture is boiled gently for 10 to 15 minutes with stirring to prevent the solid from forming cake at the bottom of the container. Then, a minimum of 2 g of barium hydroxide is added and the mixture is again boiled gently for 5 to 10 minutes. The mixture is afterwards cooled to room temperature, allowed to stand for several hours and the supernatant liquid is finally filtered.

7.1.4.5 Titration solvent: The solvent consists of 500 parts of toluene and 5 parts of water for 495 parts of anhydrous isopropyl alcohol.

7.2 Preparation of used oil samples

The sampling procedure should be observed strictly, since the sediment itself is acidic or basic or has absorbed acidic or basic material from the sample.

The sample of used oil is heated to 60 $^{\circ}\text{C}$ and the container is agitated until all sediment is homogeneously suspended in the oil. If the original container is of opaque material, or if it is more than $\frac{3}{4}$ full, the entire sample and is transferred to a clear glass bottle having a capacity at least one third greater than the volume of the sample. All

traces of sediment are also transferred by violent agitation of portions of the sample. After complete suspension of all sediment, the sample is strained for removal of large contaminating particles.

7.2 Test for acid and base

2.0 0.2 g of the prepared used oil sample is placed into a 250-mL Erlenmeyer flask. 100 mL of the titration solvent and 0.5 ml of the indicator solution are added to the sample and the whole mixture is continuously swirled until the sample is entirely dissolved by the solvent. If the mixture turns to a:

yellow-orange colour, then the following step is the acid number procedure

green or green-black colour, then the following step is the base number procedure.

7.3 Blank

A blank titration is made on 100 ml of the titration solvent and 0.5 ml of the indicator solution, adding 0.1 M KOH solution in 0.05 or 0.1-mL increments. The quantity of 0.1 M KOH solution required to reach the end point (orange to green) is recorded. This blank titration is important because the titration solvent usually contains weak acid impurities which react with the strongly basic components of the sample. To correct the base number for the sample, an acid number blank is determined for the solvent.

7.4 Procedure for acid number

The solution resulting from step 7 is titrated immediately at a temperature below 30⁰C. 0.1 M KOH solution is added in increments and the mixture is swirled to disperse the KOH. The mixture must be shaken vigorously near the end point, but care must be taken to avoid dissolving carbon dioxide in the solvent. As the end point is approached the yellow orange colour changes to green or green-brown. The end point is definite if the colour persists for 15 s or if it reverses with two drops of 0.1 M HCL.

Calculation

Acid number, mg of KOH/g = [(A-
B)M*56.1]/W Where:

A= KOH solution required for titration of the sample, mL

B= KOH solution required for titration of the blank, mL

M= molarity of the KOH solution

W= sample used, g

7.4.1 Procedure for base number

If the titration solvent containing the dissolved sample assumes a green or green-brown colour after the indicator is added, the titration is carried as in 7.3, but with 0.1 M HCL solution instead of 0.1 M KOH. As the end point is approached, the green-brown colour changes to orange

Calculation

Base number, mg of KOH/g = $[(E_m + F_m) * 56.1]/W$

Where

E=HCL solution required for titration of the sample

M= molarity of the HCL solution

F=KOH required for titration of the acid number blank,mL

M= molarity of the KOH solution

W= sample used, g

Standard test method for kinematic viscosity of transparent and opaque liquids

(ASTM designation: D 445 – 96; IP designation: 71/95)

7.5 Introduction

This test method specifies a procedure for the determination of the kinematic viscosity, , of liquid petroleum products, both transparent and opaque, by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer.

The method is intended for application to liquids for which primarily the shear stress and shear rates are proportional (Newtonian flow behaviour).

The range of kinematic viscosities covered by this test method is from 0.2 to 300000 mm²/s at all temperatures.

7.5.1 Terminology

Density- the mass per unit volume of a substance at a given temperature.

Dynamic viscosity - the ratio between the apparent shear stress and rate of shear of liquid.

Kinematic viscosity - the resistance to flow of a fluid under gravity.

For gravity flow under a given hydrostatic head, the pressure head of a liquid is proportional to its density, . For any particular viscometer, the time of flow of a fixed

volume of fluid is directly proportional to its kinematic viscosity, ν . Where $\eta = \nu \rho$ and η is the dynamic viscosity coefficient.

7.5.2 Apparatus

Viscometer

Viscometer holders

Temperature-controlled bath: A transparent liquid bath is used. The depth must be sufficient such that at no time during the measurement of flow time, any portion of the sample in the viscometer is less than 20 mm below the surface of the bath liquid or less than 20 mm above the bottom of the tank. For each series of flow time measurements, the temperature control of the bath liquid shall be such that within the range from 15⁰C to 100⁰C, the temperature of the bath medium does not vary by more than 0.02⁰C of the selected temperature over the length of the viscometer, or between the position of each viscometer, or at the location of the thermometer.

Temperature measuring device in the range from 0⁰C to 100⁰C
Timing device

7.5.3 Reagents

Chromic acid cleaning solution, or a nonchromium-containing, strongly oxidizing acid cleaning solution.

Sample solvent, completely miscible with the sample- A volatile petroleum spirit of naphtha is suitable.

Drying solvent: A volatile solvent miscible with the sample solvent and water.

Acetone is suitable.

Water: It stands for deionized or distilled water.

7.5.4 Calibration and verification

Viscometers

7.5.5 Test procedure

The viscometer bath is adjusted and maintained at the required test temperature-between 15⁰C to 100⁰C. Thermometers are held in an upright position under the same conditions of immersion as when calibrated. They should be viewed with a lens assembly giving approximately five times magnification and be arranged to eliminate parallax errors. Two

viscometers are charged in the manner dictated by the design of the instrument. After 10 minutes, the volume of the sample is adjusted to coincide the filling marks as in the viscometer specifications. The charged viscometers are allowed enough time to reach the test temperature. With the sample flowing freely, the time required for the advancing ring of contact to pass the first timing mark to the second is recorded. For the measured flow time, t , and the viscometer constant, C , the kinematic viscosity is calculated as follows:

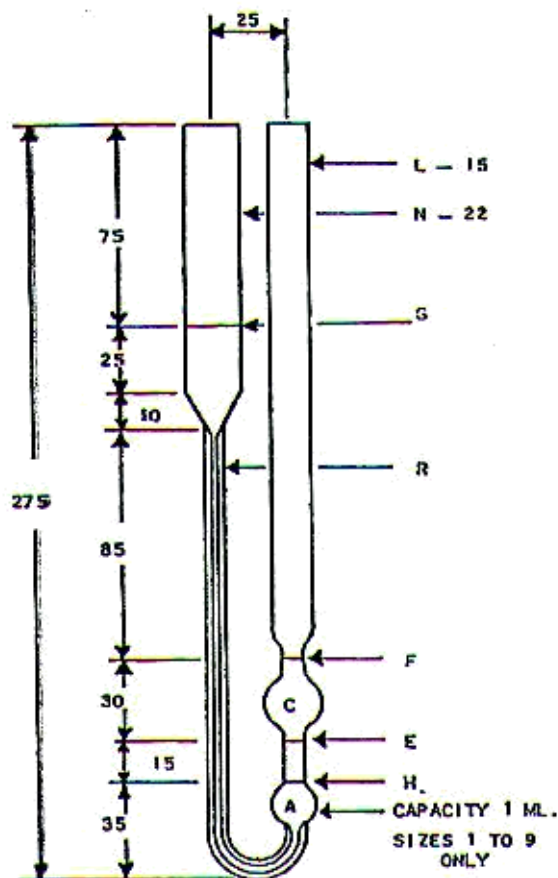
$$\nu = C \cdot t$$

where:

ν = kinematic viscosity, mm^2/s ,

C = calibration constant of the viscometer,

$(\text{mm}^2/\text{s})/\text{s}$, t = mean flow time, s .



7.6 Standard test method for insolubles in used lubricating oils (ASTM designation: D 893 – 92)

7.6.1 Introduction

This test method covers the determination of pentane and toluene insolubles in used lubrication oils. Procedure A of the standard test method (ASTM designation: D 893 – 92) provides the method for the determination of insolubles without the use of coagulant in pentane. It provides an indication of the materials that can be readily be separated from the oil solvent mixtures by centrifuging.

Pentane insolubles include oil-insoluble materials and some oil-insoluble resinous matter originating from oil degradation or additive degradation, or both.

7.6.2 Terminology

Pentane insolubles in used oil analysis is separated matter resulting when a used oil is mixed with pentane.

7.6.3 Apparatus

7.6.3.1 Centrifuge tube, cone-shaped, conforming to the dimensions given in fig. 1, and made of thoroughly annealed glass. The graduations, numbered as shown fig. 1, shall be clear and distinct and the mouth constricted in shape for closure with a cork. Scale error tolerances and smallest graduations between various calibration marks are given in table 2.

Range, mL	Smallest Scale Division, mL	Maximum Scale Error, mL
0 to 0.1	0.05	0.02
Over 0.1 to 0.3	0.05	0.03
Over 0.3 to 0.5	0.05	0.05
Over 0.5 to 1.0	0.1	0.05
Over 1.0 to 2.0	0.1	0.10
Over 2.0 to 3.0	0.2	0.10
Over 3.0 to 5.0	0.5	0.20
Over 5.0 to 10.0	1.0	0.50
Over 10 to 25	5.0	1.0
Over 25 to 100	25.0	1.0

Table 2: Calibration Tolerances of Cone-Shaped Centrifuge

7.6.3.2 Centrifuge, meeting all safety requirements for normal use and capable of whirling two or more filled centrifuge tubes at a speed that can be controlled to give a relative centrifugal force (rcf) between 600 and 700 at the tips of the tubes. The revolving head, trunnion rings, and trunnion cups, including the rubber cushion shall be soundly constructed to withstand the maximum centrifugal for capable of being delivered by the power source. The trunnion cups and cushions shall firmly support the tubes when the centrifuge is in motion. The centrifuge shall be enclosed by a metal shield or case strong enough to eliminate danger if any breakage occurs. The speed of the rotating head is given by:

$$\text{Speed, rpm} = 1337 \text{ (rcf/d)}$$

where:

rcf = relative centrifugal force

d = diameter swing, mm, measured between tips of opposite tubes when in rotating position.

7.6.3.3 Oven, explosion-proof, capable of maintaining a temperature of $105 \pm 3^{\circ}\text{C}$.

7.6.4 Reagents and solvents

Pentane-Commercial-grade normal pentane, conforming to the following requirements:

Initial boiling point, min	33.3°C
Dry point, max	40.5°C
Olefins	None
Isopentane, max, %	20
n-pentane, min, %	80
Reid vapour pressure (ASTM Test Method D 323) max	117 KPa

7.6.5 Sampling

The sample of used oil is heated to $60 \pm 5^{\circ}\text{C}$ and the container is agitated until all sediment is homogeneously suspended in the oil. If the original container is of opaque material, or if it is more than $\frac{3}{4}$ full. The entire sample is then transferred to a clear glass bottle having a capacity at least one third greater than the volume of the sample, and all traces of sediment is transferred from the original container to the bottle by violent agitation of portions of the sample in the original container. After complete suspension of all sediment, strain the sample or a convenient aliquot through a 150- μm sieve to remove large contaminating particles.

7.6.6 Test procedure

7.6.6.1 A clean centrifuge is dried for 30 minutes at $105 \pm 3^{\circ}\text{C}$, cooled in a desiccator and weighed to the nearest 1 mg. 10.0 $\pm$ 0.1 g of the prepared sample of used oil is transferred into the tube and pentane is filled to the 100-mL mark. With the tube closed with a stopper, the mixture is shaken until homogeneity. The mixture should not be allowed to stand for more than 3 hours.

7.6.6.2 All the insolubles from the removed stopper is washed with a minimum of pentane using a wash bottle having a fine jet. The weights of each pair of filled centrifuge

tubes should be balanced. The centrifuge tubes are placed in the centrifuge on opposite sides of the head and centrifuged for 20 minutes at a rate sufficient to produce a relative centrifugal force (rcf) between 600 and 700 at the tips of the whirling tubes. The supernatant liquid is carefully decanted without disturbing the precipitate and leaving not more than 3 mL of liquid in the centrifuge tube.

7.6.6.3 10 mL of pentane is added to the tube. All the insolubles are dislodged and broken from the bottom of the tube by means of a clean stiff wire. All the insolubles adhered to the wire is washed back into the tube with pentane, thereby filling the tube to the 50-mL mark. With the stopper on, the tube is shaken for homogeneity of the solution. With the stopper removed, the tubes are centrifuged for 20 minutes. The supernatant liquid is poured from the centrifuge tube, with much care in order to avoid disturbing the cake of insolubles.

7.7 The entire operation, described in 6.3, is repeated.

7.7.1 The centrifuge tube containing the washed precipitate is dried for 30 minutes at 105 °C, cooled in a desiccator and weighed to the nearest 1 mg.

7.7.2 The percentage of insolubles in the used oil is calculated as follows:

$$\text{Insolubles, \%} = 10 (B - A)$$

where:

A = mass of clean, dried, centrifuge tube, g, and

B = mass of dried insolubles and centrifuge tube, g.

7.8 Standard Test Method for Gasoline Diluent in Used Engine Oils by Distillation (ASTM Designation: D 322 – 92; IP Designation: 23/83 (92))

7.8.1 Introduction

This test method covers determination of the amount of dilution in crankcase oils of engines when gasoline has been used as the fuel.

7.8.1 Terminology

Fuel diluent, n-in used oil analysis, unburnt fuel components that enter the engine crankcase causing dilution of the oil.

7.8.2 Summary of test method

The sample, mixed with water, is placed in a glass still provided with a reflux condenser discharging into a graduated trap connected to the still. Heat is applied, and the contents

of the still are brought to boiling. The diluent in the sample is vaporized with the water and the liquefied in the condenser. The diluent collects at the top of the trap, and the excess water runs back to the still where it is again vaporized, carrying over an additional quantity of diluent. The boiling is continued until all the diluent has been boiled out and recovered in the trap. The volume is recorded.

7.8.3 Apparatus

7.8.3.1 Flask, round-bottom type

7.8.3.2 Condenser, liebig straight-tube type

7.8.3.3 Trap, 5 mL, graduated in 0.1-mL increments

7.8.3.4 Heater-Any suitable gas burner or electric heater may be used with the glass flask.

7.9 Test procedure

7.9.1 The sample is mixed thoroughly. 25 mL of the sample is transferred to the flask by means of a 25-mL graduated cylinder. Approximately 500 mL of water is added to the flask. The trap is filled with cold water and 1 mL of denatured ethanol is added to the water in the trap.

7.9.2 The apparatus is assembled as in Fig 1 , so that the tip of the condenser is directly over the indentation of the trap.

7.9.3 The flask is heated such that refluxing starts within 7 to 10 minutes after heat is applied, with the water and sample being at 21⁰C to 38⁰C prior to application of heat. After boiling and condensation has begun, the rate of boiling is adjusted so that condensed distillate is discharged from the condenser at a rate of 1 to 3 drops per second.

7.9.4 From the time refluxing starts, readings of the amount of diluent are taken at the following times: 5 minutes, 15 minutes and 30 minutes and each 15 minutes following until the test is complete. Completion of the test shall be determined on the basis of either or both of the following criteria:

The test is complete when the volume of diluent increases by not more than 0.1 mL in any 15-minutes period during the course of the test

The test is complete when the volume of diluent obtained in a given time indicates completion, as follows:

Time from start of refluxing	Test is complete if apparent volume of diluent collected is equal to or less than:
---------------------------------	---

5 min	No visible diluent
30 min	2.0 mL
60 min	4.0 mL
90 min	5.0 mL

7.9.5 When the test continues without reaching the limit defined in the criterion, to a point at which any of the conditions described in the second criterion are encountered, the latter shall define the completion of the test.

7.9.6 When the test is complete by either of the criteria, the heat is turned off. The equipment is allowed to stand for at least 30 minutes to allow the distillate to separate completely and to cool to approximately room temperature. The volume of diluent collected is read in the trap. If the volume of diluent exceeds the calibrated capacity of the trap, discontinue the test and the results are reported as 20% plus.

7.9.7 The diluent content of the sample, expressed as volume percent, is equal to the volume of diluent in millilitres multiplied by 4.

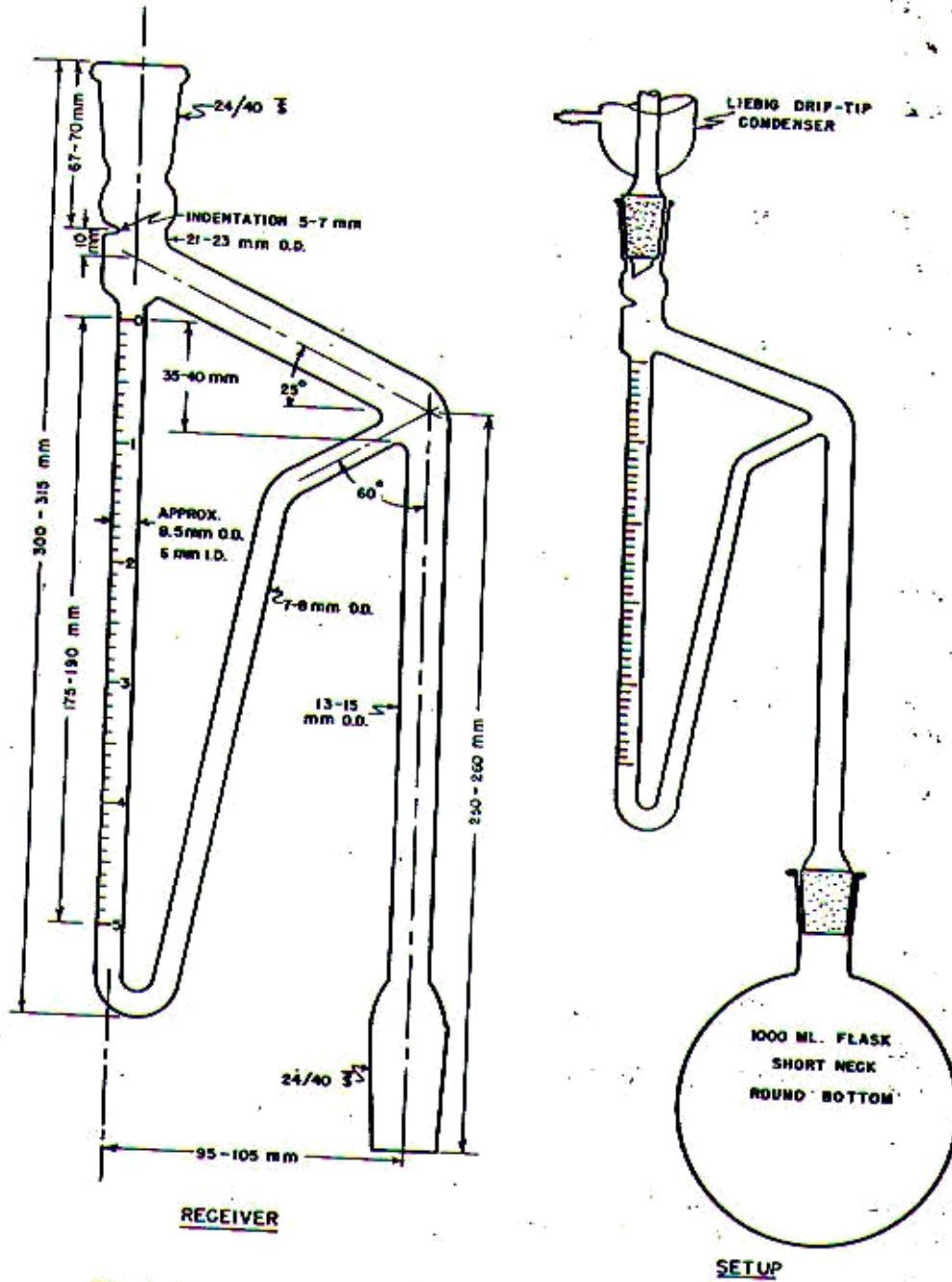


FIG. 1 Apparatus for Determining Diluent in Gasoline Engine Crankcase Oil

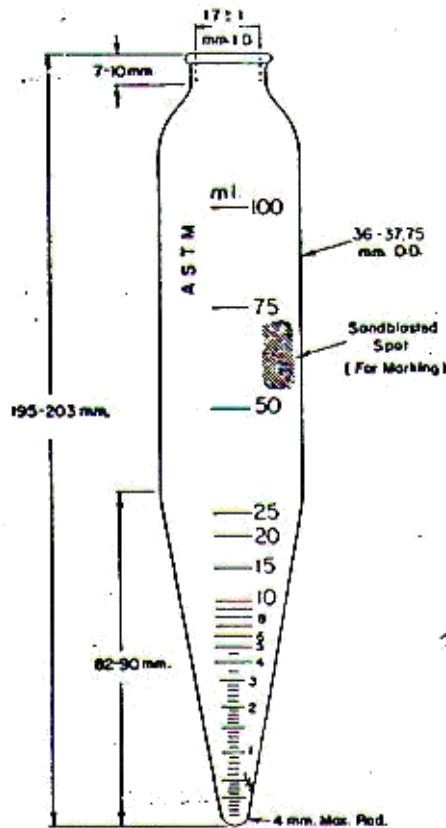


FIG. 1 ASTM Cone-Shaped Centrifuge Tube

7.10 Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

ASTM Designation: D 5185 – 95

7.10.1 Introduction

This test method covers the determination of additive elements, wear metals, and contaminants in used lubricating oils by inductively coupled plasma atomic emission spectrometry (ICP-AES). The specific elements are listed in Table 3.

Elements	Wavelength. Nm
Aluminium	308.22, 396.15, 309.27
Chromium	205.55, 267.72
Copper	324.75
Iron	259.94, 238.20
Lead	220.35
Silicon	288.16, 251.61

Table 3: Elements determined and suggested wavelength

7.10.2 Terminology

Additive element: a constituent of a chemical compound that improves the performance of a lubricating oil.

Analyte: an element whose concentration is being determined.

Babington-type nebulizer: a device that generates aerosol by flowing a liquid over a surface that contains an orifice from which gas flows at a high velocity.

Contaminant: a foreign substance introduced in the oil.

Detection limit: the concentration of an analyte that results in a signal intensity that is some multiple (typically two) times the standard deviation of the background intensity at the measurement wavelength.

Inductively-coupled plasma (ICP): a high temperature discharge generated by flowing an ionizable gas through a magnetic field induced by a load coil that surrounds the tubes carrying the gas.

Linear response range: the elemental concentration range over which the calibration curve is a straight line.

Profiling: a technique that determines the wavelength for which the signal intensity measured for a particular analyte is a maximum.

Radio frequency (RF): the range of frequencies between the audio and infrared ranges (3 kHz to 300 GkHz).

Wear metal: an element introduced into the oil by wear of oil-wetted parts.

7.10.3 Summary of test method

A weighed portion of a thoroughly homogenized used oil is diluted ten-fold by weight with mixed xylenes or other suitable solvent. Standards are prepared in the same manner. An optional internal standard can be added to the solution to compensate for variations in test specimen introduction efficiency. The solutions are introduced to the ICP instrument by free aspiration or an optional peristaltic pump. By comparing emission intensities of elements, in the test specimen with emission intensities measured with the standards, the concentrations of elements in the test specimen is calculable.

7.10.4 Interferences

Spectral interferences can usually be avoided by judicious choice of analytical wavelengths. When spectral interferences cannot be avoided, the necessary correction should be made using the computer software.

7.10.5 Apparatus

Inductively-coupled plasma atomic emission spectrometer: a sequential or simultaneous spectrometer, equipped with a quartz ICP torch and RF generator to form and sustain the plasma

Nebulizer: Babington-type high –solids nebulizer. This type of nebulizer reduces the possibility of clogging and minimizes aerosol particle effects.

Peristaltic pump: It provides a constant flow of solution. The pumping speed is in the range 0.5 to 3 ml/min. The pump tubing must be able to withstand at least 6 h of exposure to the dilution solvent and is made from viton.

Solvent dispenser:

Ultrasonic homogenizer: bath-type or probe-type to homogenize the sample.

7.10.6 Reagents and materials

Base oil: lubricating base oil that is free of analytes, and having a viscosity at room temperature as close as possible to that of the samples to be analyzed.

Dilution solvent: white spirit.

7.10.7 Sample handling

It is extremely important to homogenize the used oil in the sample container in order obtain a representative test specimen.

7.10.8 Preparation of test specimens and standards

Blank: A blank is prepared by diluting the base white oil ten-fold by mass with the diluting solvent.

Working standard, 10 g/mL: 2g of 0.0500 mass % multi-element standard and 8 g of base oil are diluted by 90 g of dilution solvent.

Check standards: The instrument is prepared and the standards are checked in the same manner as the working standards such that the concentrations of elements in the check standards are similar to the concentrations of elements in the specimen.

Test specimen: The test specimen is diluted in the solvent until the test specimen concentration is 10 mass %.

7.10.9 Preparation of apparatus

Instrument: The instrument is set up for the particular solvent chosen.

Peristaltic pump

ICP Excitation Source: The plasma source is initiated at least 30 minutes before performing the analysis. During the warm-up period, the dilution solvent is nebulized. A carbon check is performed on the torch for carbon build-up. Wavelength profiling:

Operating parameters: The appropriate operating parameters are assigned to the instrument task file so that the desired elements can be determined. These parameters include the element, wavelength, background correction points (optional), interelement correction factors (optional), integration time and internal standard correction (optional). Multiple integrations are required for each measurement, and the integration time is typically 10s.

Calibration

The linear range must be established once for the particular instrument being used. This is accomplished by running standards between the blank and the working standard. Analyses of test specimen solutions must be performed within the linear range of response.

At the beginning of the analysis of each batch of specimens, a two-point calibration consisting of the blank and the working standard is performed. The check standard is used to determine whether each element is in calibration.

7.10.10 Procedure and calculation

Analysis: The test specimens solutions are analyzed in the same manner as the calibration standards (i.e same integration time, background correction points, plasma conditions, etc). Between test specimens, dilution solvent is nebulized for 60 s. Elemental concentrations are calculated by multiplying the determined concentration in the diluted test specimen solution by the dilution factor.

Quality control with check standard: The check standard is analyzed after every fifth sample, and if any result is not within 5 % of the expected concentration, the instrument needs to be recalibrated and the test specimens are re-analyzed back to the previous acceptable check standard analysis.

CHAPTER 8

8.0 Testing Program

Altogether some 280 samples of used oil were initially earmarked for testing. These samples were to be obtained from three companies chosen at random:

The National Transport Corporation (CNT)

The Mechanical Transport Limited (MTL)

The Police Mechanical workshop (PMW)

The NTC is the only state owned/ financed public transport company with a fleet of some 200 diesel propelled buses.

The MTL is a private going concern/truck/lorries company. The vehicles are used to transport sugar from the sugar mills to the bulk sugar terminal. The lorries are also diesel propelled.

The PMW is the workshop of the Mauritius Police Department at Line Barracks. A mix of motor-cycles and jeeps was obtainable; the motor cycles were petrol propelled and the jeeps were diesel propelled.

It was our firm conviction that their full collaboration would be obtained ; however the number of samples obtained from the MTL and the PWM were rather small to enable proper and reliable conclusions to be drawn. Their samples nevertheless were tested and the results recorded in Appendix .

On the other hand the NTC was highly consistent in its supply of oil samples. Fairly interesting analysis had been performed.

Six buses of the NTC were sampled of make ISUZU, NISSAN, ASHOK LEYLAND (2) and TATA (2).

The ISUZU, NISSAN and TATA are natural aspirated engines while the A/LEYLAND is turbocharged.

Lubricating oil used for the ISUZU, NISSAN and TATA was the shell Rotella TX - a 2104 monograde oil and that for the A/LEYLAND the shell Rimulla - a 2104 monograde oil.

The number of vehicles from the MTL was 10 as follows:

MITSUBISHI L300, FP 415 – 4 off

LEYLAND DAF - 3 off

NISSAN CWB - 3 off

Lubricating oils used shell Rotella/Rimulla

As for the PMW the number of vehicles was 8 as follows:

MITSUBISHI L200 (diesel)	- 1 off
TOYOTA PRADO (diesel)	- 1 off
MAZDA 323 (petrol)	- 1 off
HONDA 750 motor cycle (petrol)	- 1 off
SUZUKI VITARA motor cycle (petrol)	- 1 off
LEYLAND COMET motor cycle (petrol)	- 1 off
YAMAHA 750 motor cycle (petrol)	- 1 off
TOYOTA HILUX Motor cycle (petrol)	- 1 off

The analysis would be more pertinent the NTC vehicles on account of the substantially larger number of samples analysed ; nonetheless when considered together all vehicles combined, NTC, MTL and PMW, they constitute a relatively large data-base.

CHAPTER 9

Results

9.1 Data Sheets for the NTC vehicles are shown in tables 4 to10 for

NISSAN 574 FB 95
ISUZU 1382 AP 95
A/LEYLAND 3448 NV 96
A/LEYLAND 2766 SP 96
A/LEYLANDDDF 862
A/LEYLAND DA 538
TATA CX 587

9.2 Data obtained for the MTL vehicles are presented in Appendix I for

MITSUBISHI 3557 JL98
LEYLAND DAF 438 ZG 96
NISSAN 1766 JU 96
NISSAN 1816 JU 96
LEYLAND DAF 2394 ZF 91
MITSUBISHI FD 533
LEYLAND DAF 1098 ZG 92
MITSUBISHI 842 JU 92
NISSAN 2987 AG 97
MITSUBISHI 963 JU 92

9.3 Data sheets for the PMW are presented in Appendix II for

LEYLAND COMET GM 7434
HONDA GM 7585
YAMAHA 750 GM 7697
SUZUKI VITARA GM 7281
MAZDA 323 GM 7304
MITSUBISHI 200 GM 7031
TOYOTA HILUX GM 7254

However, on account of the relatively small number of samples received and analysed for NTC vehicle CX587 and those of MTL and PMW these will not be further considered.

574
Table 4

574

Table 4 (ctd)

1382
table5

1382
Table 5 (ctd)

3448
table 6

2766
table 7

862
table 8

538
table 9

587

table 10

For each of the wear metals iron, aluminium, copper, lead, chromium, the cumulative sums have been calculated. They have been plotted and are shown in graphs 1 to 6.

9.4 General Observations (NTC vehicles):

The graphs show small increase in the Cu content and rather substantial increases in the Fe, Pb and Cr contents for the NTC vehicles.

The results obtained for the parameters tested have been plotted; they are shown in graphs 7 to 14.

9.5 Detailed Observations (Graphs 7 – 14)

9.5.1 Vehicle 574 FB 95 (NISSAN)

Wear Metals: Except for Si , the other metals Cu, Pb, Al and Cr show wide variation.

An increase in the flash point is accompanied by a corresponding decrease in the viscosity and the fuel dilution. A further drop in the fuel dilution is accompanied by a corresponding drop in the viscosity and

The Fe content peaks at 178156 kms and falls to a minimum at 195159 kms and remains fairly constant subsequently. This peak could be attributed to an error in, the collection of the oil sample, the testing method etc

The Al content is practically zero except that it peaks at 195159 and 216425 kms
Si content remains near to zero except that it shows a peak at 195159 kms. Again this peak may result from an error in sampling, testing etc. There is practically no increase in the Cr content.

9.5.2 Vehicle 1382 AP 95 (ISUZU)

Fuel dilution peaks at about 497530 kms due to dripping of fuel from injectors.

The injectors were changed, the fuel dilution dropped reaching a low of 0 at 515976 kms. It then rose again at 609479 kms; stayed constant. This is followed by a decrease from between 614310 and 641930 kms.

The viscosity of the oil shows a minimum at the point where the injectors were changed I e 497530 kms and a rather sharp increase between 614310 and 641930 kms. Evidently a decrease in the fuel dilution will cause an increase of viscosity.

An increase in the fuel dilution is accompanied with a fall in the flash point as shown at 497442 kms, 614310 kms.

574

graph1(cum

1382

graph2cum

3448

graph3cum

2766

graph4cum

862

graph5cum

538

graph6

Trend lines for Fe and Cu contents indicate relatively small increases. However that for the Cr content shows a rapid increase. Wear of liner, crankshaft and bearing possible.

Otherwise engine has not been subject to major maintenance.

9.6 Vehicles 2766 SP 96 and 3448 NV 96

The situation as presented by these two vehicles is very much different to that of the NISSAN and ISUZU discussed above.

The wear metals contents trendlines for Al and Pb increase slowly whereas that of Cu increase relatively more rapidly and that of Cr increases much more rapidly. Both show a problem associated with main and connecting rod bearings. They are definitely not as robust as the NISSAN and the ISUZU.

2766 SP 96 shows a decrease in the flash point and the TAN but an increase in viscosity

Pb, Cr, Al trend lines show increase in their contents indicating possible main and connecting rod bearing problems.

9.7 Vehicles DF 862 and DA 538

For DF 862 the Fe, Cr, Pb and Cu trend lines all show increase contents due possibly to bearing , liner and ring problems. TAN is fairly constant with slight increase in viscosity and quite large increase in fuel dilution.

For DA 538 TAN and fuel dilution show slight increase whereas viscosity increased sharply; flash point is practically constant. Cr and Fe contents show increases.

Both vehicles have been subjected to quite a lot of maintenance:

DF 862 had a new engine fitted at about 95000 kms. DF 538 had its engine reconditioned on 24672 kms. They show remarkable change in the wear metals content subsequent to the maintenance.

DF 862 shows sharp increase in Cr followed by sharp drop. There is also a rise and fall in the Al content. Pb, Fe, Cu, Al are all on the rise. Possible bearing problem.

As a result it has been found appropriate to lump together for further analysis purposes

574

graph7para

574

graph8

1382

graph9para

1382

graph10

2766

graph11

862

graph12

538

graph13

538

graph14

DA 538 and DF 862

3448 NV 96 and 2766 SP 96

9.8 Limits

9.8.1 For oil analysis purposes the following alarm levels and trends are of relevance:

Alert level : First warning of developing problem

Reportable level : Problem has progressed to quasi serious stage

Moderate trend : Problem is progressing, action may be required

Rapid trend : Problem is progressing rapidly, action is required.

9.6.2 Limit calculation equations

The alarm levels and trends are calculated as follows:

Alert level : Average + 2 x Standard deviation

Reportable level : Average + 4 x Standard deviation

Moderate trend : 60% of Alert limit

Rapid trend : 90% of Alert limit

Statistical analyses of the test data have been done and the standard deviation for the parameters tested for the NTC vehicles has been determined using which the limits and trends as defined above have then been calculated. These are shown in tables 11 to 14.

Tab11

Stats574 table 11

stats 574 able 11ctd

Stats table12

Stats table12

stats2766table13

stats2766 table13

stats2766ta13

For a much better visual appreciation of the limits these have been inserted on the graph of the respective parameter plotted against mileage; they are shown in graphs 15 to 43.

574LimitCr
graph15

574limitcu
graph16

574limitFe
graph17

574limitAl
graph18

574limitPb
graph19

574limitvis
graph20

574limitTAN
graph21

574limitFlashPoint
graph22

574limitFudilution
graph23

1382Culimits
graph24

1382Felimits
graph25

1382Pblimits
graph26

1382Crlimits
graph27

1382vislimits
graph28

1382TANlimits

graph29

1382FlashPointlimit
graph30

^{1382}Fu Dilutionlimit
graph31

27663448Felimits
graph32

27663448Culimits
graph33

27663448Pblimits

graph34

27663448Allimits
graph35

27663448Crlimits

graph36

27663448FuDillimit
graph37

27663448Vislimits
graph38

862vistanFlPFuDilimis
graph39

862FeAlCuPbCr limits
graph40

538wmlimits&trends
graph41

538TANVisFuDilFlshPointlimits
graph42

538FeFuDilPentInslimits
graph43

9.9 Observations

9.9.1 Vehicles 574 FB 95& 1382 AP 95

Wear Metals: Except for Pb they are all within the reportable limits, graphs 15 to 31.

Viscosity, TAN ,Flash Point,and Fuel dilution are below the reportable limits.

9.9.2 Vehicles 2766 SP 96 & 3448 NV 96

It is observed from graphs 32 to 36 for the wear metals Al, Cu, Cr and Fe their contents are all above their alert limits but below their reportable limits

The % fuel dilution for 2766 SP 96 is above its reportable limit of 3. 39 on 197106 kms.

This vehicle had an injector problem.

The wear metals are below their respective reportable limits except for Pb content for vehicle 3448 NV 96, graph 34.

The viscosities are below their respective reportable limits noting however that for 2766 SP 96 approaching the reportable limit value of 262 at about 190000 kms , graph 40.

9.9.3 Vehicle DF 862

Viscosity, TAN, flash point and % fuel dilution are within their respective reportable limits, graph 39.

The Fe and Al contents are well below the alert and reportable limits. However the Cu, Pb and Cr are above their limits both alert and reportable. This vehicle had main and connecting rod problems, graph 40.

Vehicle DA 538

The Al content shows a tendency to increase as from 71772 kms but it's still below the reportable value of 206 mg/g. The Cr also shows the same tendency, graph 41.

This vehicle was beset with piston ring liner connecting rod bearing problems with high oil consumption.

The flash point, TAN and % fuel dilution very often jump above their respective alert limits showing the tendency to move into the reportable limits as from 71772 kms, graphs 42 & 43.

9.10 General Discussion

It is observed that the wear metals contents for the NTC vehicles shoot above the alert limits but tend to stay below the reportable limits which is a good thing when one bears in mind the definition of those two types of limits.

The ISUZU and NISSAN demonstrate good resistance to wear and tear as opposed to the ASHOK LEYLANDS. The A/Leyland are prone to main and connecting rod problems as well as piston and piston ring problems. The copper, chromium and lead contents tend to increase with mileage more particularly for vehicle 3448 NV 96. The % fuel dilution for vehicle 2766 SP 96 goes well above the reportable limit, graph 37 clearly indicating the occurrence of a problem; in fact the fuel injector was the cause. The viscosity went down, graph 38.

It very often happens that a particular wear metal content for one of the vehicles climbs above the alert limit and just after it goes down as for example the iron content for vehicle 2766 SP 96, graph 32. Such an occurrence should not be judged alarming. However if the wear metal content is above the alert limit and shows a tendency to approach the reportable limit subsequently for each and every sample tested then there would be cause for alarm. Such a state of affairs can be observed for vehicle 574 FB 95. Graph 15 for the chromium contents and graph 18 for the aluminium contents illustrate this tendency; same was observed for vehicle 3448 NV 96 for chromium contents, graph 36.

One important aspect to be considered is lowering of the limits, both alert and reportable for the case when the vehicle shows increase in maintenance frequency as evidenced with vehicles DF 862 and DA 538; mileage run may have started to take its toll on the engine. Monitoring of the engine's condition or health must be done with the interpretation of more than one parameter; it would be desirable for each parameter to be plotted on a separate individual graph as for example the chromium and aluminium contents for vehicle 574 FB 95 referred to above; those two graphs would indicate an incoming bearing problem, possibly connecting rod bearing.

This study brings out the need for proper recording of data, both maintenance and oil test results, if oil condition monitoring is to be utilised as a tool for vehicle maintenance. Computerised data entry and recording of test results is to be strongly recommended.

Needless to say that for this kind of maintenance tool to be effective the test results must be made speedily available.

The sampling of the engine oil is a very important aspect. The way the sample is collected, the frequency, the accessories used and the procedures adopted will to a very large extent determine how informative the results will be and how much reliable shall be the diagnostic of the inherent problems of the engine. The best location to draw an oil sample must be envisaged and the best tools/equipment for drawing the sample must be used.

Ports for oil sampling are classified into two categories, primary and secondary. The Primary port is the location where routine oil samples are taken for monitoring oil contamination, wear debris and the chemical and physical properties of the oil. Secondary sampling ports can be placed anywhere on the system to isolate upstream components. This is the location where contamination and wear debris contributed by individual components will be found. For circulating systems the preferred location is on the return line, not the reservoir. It is advisable to sample at 50% of the oil level. Sumps normally hold a large volume of oil to dissipate heat, to allow air to rise and contaminants to settle. Therefore the most concentrated contamination is on the bottom of the sump and the cleanest oil towards the top. The drop tube vacuum sampling method is a simple way to draw an oil sample.

The cleanliness of the bottle for collecting the oil sample is a very important factor. Glass bottles were used for this work; they are durable, lend themselves easily to visual inspection; the cost may be prohibitive. However as glass contains silica erroneous result with respect to silicon content in the oil may be obtained. The Si content in the oil samples tested had not been elaborated upon in this report; the silicon content reported will have been derived not from the engine components but from the environment. Dust particles on the road ways account for its presence in the oil. Air filters therefore must be changed as often as possible.

Pentane insoluble as well as water contents in the oil samples were found to be negligible or nil. No ingress of coolant water was detected.

A survey was carried out to find the type of maintenance normally resorted to in the local context; the result is shown in Chart 1. Most (78%) adopt preventive maintenance, 8%

adopt preventive and run to failure and 14% make use of a combined preventive/predictive approach to maintenance.

Piechart
Chart1

Conclusion

The objectives of this study have been attained; a relatively large data base has been created in the form of tables. Graphical representation of test results has been done and trends to show the evolution of the parameters have been indicated. Statistical analysis with respect to standard deviations has enabled the alert and reportable limits to be calculated and subsequently these have been inserted on the graphs. The progress of the parameter within those limits need careful interpretation.

Predictive maintenance is much more than a maintenance scheduling tool. It is one of the means to improve the overall effectiveness of plants and machinery. Implementation of an oil condition monitoring program can significantly reduce maintenance costs and improve plant and machinery reliability and safety. Lubricant analysis for machinery condition monitoring is to be recommended and is at its best provided a significant amount of historical data. It is essential to establish a base line for each item of equipment. Major changes in the analytical results will occur due to machinery wear and contamination. Companies having relatively large fleets should adopt this approach for the maintenance of their vehicles; increased availability, prevention of unforeseen failures and above all unanticipated or unwanted downtime will be added benefits. Predictive maintenance is still at the embryonic stage in Mauritius. There is a great need to create the awareness amongst all the stakeholders especially with respect to equipment of a critical nature as for example in the power generation plants.

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Appendix I
MTL Data Sheets

ZF91

MIT842

MIT963

3557

ley1098

Nisan2987

1766

MITFD533

Nissan1816

2394ZF91

Appendix II
PMW data sheets

GM7585

GM7697

GM7281

GM7304

GTM7434

7031

7254

8003

Appendix III
Rimulla specs

Rotella specs

oil submission form

Survey form