EFFECT OF CONTINUOUS OPERATION ON WEAR CHARACTERISTICS OF SOME COMPONENTS OF A DIESEL ENGINE RUN BY ALTERNATIVE FUELS

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Abstract: Use of alternative fuels like vegetable oil or Biodiesel, purely or blended with diesel, are making use as substitute of mineral diesel which has harmful emission and limited store. One important aspect other that properties, performance, emission, combustion of alternative fuels is wear characteristics. Some important components of an engine are piston, piston rings, cylinder head, liner etc. where major wear takes place. In this present work, a four stroke single cylinder diesel engine is run by alternative fuel. The alternative fuel is used here Neem-Diesel blend. The same engine is run by this blend continuously and discontinuously with a view to investigates wear effect on the engine components due to continuous running. At the beginning of each experiment engine piston, cylinder head, liner, Gasket, Injector etc. have been changed and fitted newly. Wear characteristics, both quantitative and qualitative, have been studied by Ferrographic analysis (DR-V Dual Ferrograph) of collected lubricating oil samples from the oil sump. Images of the wear particles have also been taken using CCD camera. The comparative wear characteristics indicate critical damage of components occurred in case of continuous running of the engine and thus continuous mode of operation of the engine using Neem-Diesel blend should be taken care of.

KEYWORDS: WEAR, ENGINE, ALTERNATIVE FUEL, FERROGRAPHIC

1. Introduction

Vegetable oils or their blends with mineral diesel show various problems particularly for long term operation of compression ignition engine run by these new type of alternative fuels. Out of various problems wear plays an important role to select a particular alternative fuel or a suitable blend of any vegetable oil to be used in a compression ignition engine. Wear is an unavoidable phenomena of surface contact between engine parts like piston, cylinder, piston rings, cylinder head etc. Engine components life cycle, safety factors, performance ratings and maintenance schedule are predicted on normally occurring wear. The various techniques for wear characterization of internal combustion engines are Atomic absorption spectrometry (AAS) of lubricating oil samples from engine and Ferrography Technology of used lubricating oil drawn from lubricating oil sump. A.K. Agarwal et.al. [1,2] studied 20% vegetable oil mixed with diesel for long term operation of a compression ignition engine. They analyzed lubricating oil through atomic absorption spectroscopy and found lower wear and improved life cycle. In the same year they studied lubricating oils of a compression ignition engine run by biodiesel with a view to quantify wear through atomic absorption spectroscopy as well as Ferrographic technique. They found satisfactory results for long duration tests so far as wear is concerned. In the year of 2000, M.Priest and C.M. Taylor (3) performed their study on automobile engine tribology. They focused on tribological design and friction involved with the tribological components of the engine with special attention upon surface topography and surface interaction considerations. E.P. Becker and K.C. Ludema (4) , in the year of 2000, developed an empirical model of cylinder bore wear. In the year 2003, Boris Krzan et.al (5) experimentally evaluated universal tractor transmission oil which were vegetable oil based. They found significant satisfactory tribological results. N.H. Jayadas et.al.(6) in 2006 studied tribological properties of coconut oil. Their testing procedure were not by Ferrographly analysis, by four ball tester and test rig. In 2009, Surojit Ghosh et. Al (7) studied Ferrographic analysis of industrial machineries lubricating oil with a view to automated maintenance approach. In this year, K.N.V. Subrahmanyam (8) experimentally investigated various types of wear particles by Ferrographic analysis which can detect wear of various components well in advance. In 2003, Macian et.al (9) studies analytical approach to enable a more accurate wear determination from engine oil samples with a view to improved maintenance program for internal combustion engines. In 2010, P.R. Wander et. Al. (10) performed durability studies of compression ignition engine with diesel fuel as well as soy and castor oil methyl esters for long duration. They found satisfactory results with pure methyl esters so far wear and maintenance is concerned. However, in this present work a single cylinder, four stroke, water cooled Kirlosker made diesel engine is run by Neem-Diesel blend. At first, the engine is run by this blend (Neem and diesel proportion are 50:50 by volume) for 48 hours without any stoppage. After collection of lubricating oil from the oil sump, images of wear particles have been taken by ferrographic analysis. The same engine with replacement of its vital components is run again by this particular fuel blend for same duration but in discontinuous mode. Images of wear particles have been taken similarly. Results indicate that critical wear takes place in first case where as for the second case wear is marginal.

2. Wear Particle Analysis

Wear is basically the damage to any surface that generally involves sufficient loss of materials and it may occur as a result of relative motion between that surface and contacting substances. Wear particle investigations and fault diagnosis of different machineries or engines are not a new topic in maintenance engineering rather in the field of tribology. This technique has already been accepted as an effective and economic method to detect the actual condition of engine. Also, preventive maintenance strategy can be performed on machines if it applies properly [11]. Due to some shortcomings in traditional wear analysis, digitized image vision has become one of the solutions for the problems associated with conventional techniques, especially in case of offline condition monitoring. Wear mechanism has been classified in several ways by many researches or industry people. Wear mechanism depends mainly on the two surface in contact to each other. Basically, there are two types of wear occur in any machine interaction i.e.

- Mechanical wear ( Associated with friction, abrasion, impact and fatigue)
- Chemical wear ( it attacks the surface by reactive compounds and subsequent removal of products of reaction by mechanical action)

The maintenance strategy based on monitoring can be elucidated in various ways but the essential element has been indicated in figure1.

It is a quite well known phenomenon that lubrication is one of the best methods of detection of wear amongst other techniques, but wear particle distributions may be characterized based on the features such as:

- Material
- Size
- Shape
- Concentration

Wear particles can be simplified as normal particles, fatigue particles, sliding particles, characteristics particles a turning in
condition, red oxides, black oxides, cutting particles ball particles, wear polymerides, particles from corrosive wear, impurities, non-ferrous particles and etc [12]  

![Condition Monitoring](image1)

**Equipment repair** based on:
- Break down
- Scheduled Maintenance
- Parts reconditioning
- Service upgradation
- Reverse engineering
- Alignment / Balancing
- On/Off line monitoring

![Oil Analysis](image2)

**Oil Analysis** based on:
- In-service condition monitoring of lubricant of the operating equipments
  - Wear particles
  - Monitoring the mechanical condition of wearing parts
  - Monitoring the lubricant viscosity
  - Measurement of concentration of contaminants

![Vibration Analysis](image3)

**Vibration Analysis** based on:
- Online diagnostic assistance
- Phone support
- Preventive maintenance programme
- System design with calculation

![Trouble Shooting](image4)

**Trouble Shooting** based on:
- Engineering assistance in identification of the problem
  - Analysis of the problem (system, component, sound, vibration, failure)

![Failure Analysis](image5)

**Failure Analysis** based on:
- Determining the root cause of failure
- Evaluation of entire system
- Taking corrective action
- Component design

*Fig: 1 Strategic action of maintenance based on condition monitoring of engine.*

### 3. Types of wear particles

These are the basic wear particle types for ferrous and nonferrous particles that generates through the wear out progress. Normal rubbing wear particles (Fig 2) are generated as the result of normal rubbing wear in a machine. Rubbing wear particles consist of flat platelets, generally 1-15 microns or smaller. There should be little or no visible texturing of the surface and the thickness should be one micron or less. Cutting wear particles (Fig.3) are generated as a result of one surface penetrating another. There are two ways of generating this effect. A relatively hard component can become misaligned or ractured, resulting in hard sharp edge penetrating a softer surface (5-100 micron particles). Very fine wire-like particles can be generated with thickness as low as .25 microns due to the presence of abrasive contaminants. Cutting wear particles are abnormal. If a system shows increased quantities of large (50 micrometers long) cutting wear particles, a component failure is potentially imminent. Severe sliding wear particles (Fig.4) are identified by parallel striations on their surfaces. These are produced from surfaces undergoing high stress due to high speed/load and inadequate lubrication in the components. They are generally larger than 15 microns in size. Bearing Wear particles (Fig.5) generated as a result of fatigue in rolling element bearings and sleeves of journal bearings. These can be fatigue particles as well as laminar wear particles.

![Normal rubbing wear](image6)

*Fig.2: Normal rubbing wear*

![Cutting Wear](image7)

*Fig.3: Cutting Wear*

![Severe sliding wear](image8)

*Fig.4: Severe sliding wear*

![Bearing wear](image9)

*Fig.5: Bearing wear*

![Gear Wear particle](image10)

*Fig.6: Gear Wear particle (Pitch line fatigue)*

![Black Oxides](image11)

*Fig.7: Black Oxides*
Gear wear particles (Fig.6) generates in two ways, Pitch Line Fatigue Particles from a gear pitch line have much in common with rolling-element bearing fatigue particles. They generally have a smooth surface and are frequently irregularly shaped. The chunkier particle result from tensile stresses on the gear surface causing the fatigue cracks to propagate deeper into the gear tooth prior to spalling. Scuffing or Scoring Particles are caused by too high a load and/or speed. The particles tend to have a rough surface and jagged circumference. Black oxides (Fig.7) are associated with insufficient lubrication between metal surfaces. Particles are formed under high temperatures as result of metal to metal contact. Red oxides (Fig.8), commonly termed as rust associated with water contamination. Non ferrous metals (Fig.9) generally found in equipments and identified in ferrography may include aluminium, copper alloys and Babbitt metals. Sand/dirt, fibers and other contamination can be identified in ferrography. Sand/dirt can be from outside contamination of the lubricant. Sources can be from improperly cleaned systems, faulty seals and breathers etc. Fibers can be from ruptured filters etc. Evaluation of the health condition of the engine is purely subjective based on the following. Engine being monitored, morphology of particles that includes size of the particles, shape of the particles, surface structure, concentration and orientation of the particles and wear particles concentration.

4. Wear Measurement Techniques

Ferrography techniques have been found as one of the suitable measurement techniques of wear debris. It may provide the sufficient characteristics of particles, so that the operation wear modes within machines may be determined. It can allow the prediction of imminent behavior of engine. It can be used routinely to monitor the condition and wear of the vital components at higher risk. Generally to typical types of measuring techniques are quite popular like Direct Reading (DR) and Analytical Ferrography. But in the present work, direct reading has been utilized as the operational mode. With the help of DR instrument, the density of large particles (DL) and the density of small particles (Ds) can be measured very easily. On the basis of those parameters, the values of wear particle concentrations and percentages of large particles can be detected. By performing quantitative analysis of wear particles, the possible mode of wear generation can be detected. Based on the detection of wear, the further course of action for maintenance of equipments can take place [13].

The number of wear particles can be mathematically deducted by using the relationship,

\[
\text{Severity Index (S.I.)} = (D_L + D_S) (D_L - D_S) = (D_L^2 - D_S^2)
\]

Where \(D_L\) = Number of larger particles, \(D_S\) = Number of smaller particles, \(D_L + D_S\) = Concentration of solution, \(D_L - D_S\) = Size distribution.

5. Experimental Materials

The various physical, chemical and thermal properties of Neem-Diesel blends along with mineral diesel have been measured by standard apparatus like Bomb calorimeter, Red wood viscometer, Flash point and Fire point apparatus, Pour point and cloud point apparatus etc. A four stroke, single cylinder, water cooled, vertical diesel engine (compression ratio is 17.5) connected with an alternator have been taken with new fittings of its principal components and replacement of fresh lubricating oil. Now to characterize various types of wear particles, ferrography technique has been adopted in this study. Ferrography is the technique, which can determine the operating condition of wear by analyzing the amount, size, shape and colour of debris contained in lubricating oil of the engine. It can provide the microscopic examination and analysis of wear particles separated from all types of fluids by using magnetically precipitated wear particles from lubricating oil. It can also quantify wear particles on a glass substrate, which is called Ferrogram. Basically there are three types of equipments can be used in ferrography namely, Direct Reading (DR) Ferrograph, Analytical Ferrograph and Ferroscope. There are two approaches for ferrographic analysis, qualitative approach and quantitative approach. Qualitative approach means size distribution, detection of all wear debris categories, providing the useful information about debris characteristics, fault diagnosis of the engine and quantitative approach includes providing useful information about operating
condition of engine for debris characteristics, severity index determination. But mainly qualitative approach is taken into consideration for ferrography is this present study.

6. Properties of Neem-Diesel Blend

The various physical, chemical and thermal properties of N50 fuel have been experimentally measured by standard apparatus. Their values along with those values of pure mineral diesel are shown in Table I

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<tbody>
<tr>
<td>Diesel</td>
<td>0.854</td>
<td>2.87</td>
<td>45×10³</td>
<td>55</td>
<td>65</td>
<td>-13</td>
<td>-15</td>
</tr>
<tr>
<td>N50</td>
<td>0.77</td>
<td>27.06</td>
<td>54.13×10³</td>
<td>52</td>
<td>65</td>
<td>-1.2</td>
<td>-2.9</td>
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7. Result and Discussion

Lubricating oil has been collected from oil sump after considerable period running of the engine by N50 fuel in two different cases. The first case is continuous running of engine and second case is discontinuous operation. The collected lubricating oil samples have been analyzed by ferrographic technique and images of wear particles are shown in the following figures (fig12 to fig17), along with images of wear particles, their types and probable causes are also mentioned.

Case-I: Continuous Operation

Images of wear particle

For the first case, the wear particle concentration (WPC) is 1531.0. WPC limit considered as 100.0. Normal rubbing wear particles (ferrous particles of size less than 15 microns) are observed in large quantities. Low alloy steel severe sliding wear particles of size ranging up to 70 microns are observed in marginal quantities. Medium alloy steel severe wear particles of size ranging up to 34 microns are observed in small quantities. Presence of sliding wear particles is an indication of excessive sliding stress due to excessive load/speed on the sliding contacts (gears, cams, cam rollers, etc.). Fine cutting wear particles of size ranging up to 32 microns are observed in small quantities. Copper alloy particles of size ranging up to 24 microns are observed in negligible quantities. Babbitt bearing wear particles (could be from the connecting rod/crank shaft main bearings) of size ranging up to 44 microns are observed in small quantities. White non ferrous sliding wear particles (could be from power assembly area, piston, etc.) of size
ranging up to 80 microns are observed in large quantities. Sand/dirt particles are observed in marginal quantities. But for the second case Low alloy steel severe sliding wear particles of size ranging up to 40 microns are observed in small quantities. Cutting wear particles of size ranging up to 64 microns are observed in small quantities. Babbitt bearing wear particles of size ranging up to 30 microns are observed in small quantities. White non ferrous particles of size ranging up to 30 microns are observed in small quantities. Sand/dirt particles are observed in small quantities.

8. Conclusion
The first report is rated critical due to the presence of abnormal quantities of white non ferrous particles and high wear particle concentration. Abnormal wear out of white non ferrous components(piston, power assembly area, etc.) is indicated by the presence of abnormal white non ferrous particles. Presence of white non ferrous sliding wear particles could be due to severe sliding stress due to excessive load/speed conditions on the piston and related components which may lead to failure. Excessive sliding stress on the ferrous components(gears, cams, cam rollers etc.) is also indicated by the presence of marginal quantities of low alloy steel sliding wear particles. Inspection of internals can be planned at the earliest possible maintenance schedule for severe wear out of piston and related components. Resampling may also be considered before inspection. Large quantities of rubbing wear particles can create excess rubbing of internals and can lead to the generation of secondary wear in the equipment.

But the second report is rated marginal due to high wear particle concentration. Cleaning the lubricant (centrifuge to remove the existing wear particles and contaminants) is necessary to avoid the generation of secondary wear. Maintenance is also required on this equipment as the size and concentration of sliding wear particles, white non ferrous particles has decreased as compared to previous sample.

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Reference