OIL CONDITION MONITORING OF USED LUBRICATING OIL OF HEAVY EARTH MOVING MACHINERY USED IN OPEN CAST MINES

DISSERTATION-II

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By

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "**To Study the Oil Condition Monitoring of Used Lubricating Oil of Heavy Earth Moving Machinery Used in Open Cast Mines**" in partial fulfilment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **Dr. Mayuk Sarkar** Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

The mater presented in this dissertation-II has not been submitted by me anywhere for the award of any other degree or to any institution.

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Signature of Examiner

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NAGARJUNA G.

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ABBREVIATIONS AND DEFINITIONS

XRF	X-Ray fluorescence
AAS	Atomic absorption
AES	Atomic emission spectroscopy
APC	Automatic particle counter
CFD	Computational fluid dynamics
ETV	Electrothermal vaporization
FESEM	Field emission scanning electron microscope
HEMM	Heavy earth moving machine
ISO	International standard organization
IPCA	Index particle coverage
K	Potassium
LSCM	Laser scanning confocal microscope
LNF	Laser net finder
LPQ	Liquid particle quantity
Li	Lithium
MS	Mass spectroscope
Na	Sodium
OES	Optical emission spectroscope
OLVF	Online visual ferrography
PIFS	Partition Iterated Function System
PIFS	Partition iterated Function System
SCM	Support vector machine
Si	Silicon
TAN	Total acid number
TBN	Total base number
UCCE	Ultimate corrosion and condition expansion
3D	Three dimensions
µ	Micron

ABSTRACT

The lubricating oil used in Heavy Earth Moving Machinery operated in open cast mines will be collected at different time interval for experimentation. The experimental results will be further analyzed to understand the remaining life of the lubricating oil and the pattern of the deterioration. The analysis includes, Ferrography analysis, Viscosity analysis, TAN/TBN analysis.

Chapter 1

INTRODUCTION

1.1. Introduction to wear debris analysis

Originally designed and manufactured mining equipment's to meet customers' demands, but these can change dramatically over. However, high value products such as Haul trucks, Mining crushers, Cranes, Conveyer belts drivers undergo very harsh environments like 'Neyveli Lignite' and 'hutti' are rich particle present in the air. These particles mixed with lubrication oil and then start producing high wear debris and leads to break down of the machinery. Condition monitoring is very comprehensive method to monitor the machine through lubrication oil because it gives better results and defective components than vibration analysis [1].

Every lubrication oil contains the main contaminants are [SAE 881827, 881825, 95255]

1. Solid particles: Wear debris and soot, which are high damage mechanical components and catalyse lubricant breakdown.
2. Liquid contaminates: corrode metals, water, fuel and has the contamination functioning of lubricants.
3. Gaseous contaminants: Acidic combustion products, which corrode component of surfaces and degrade the oil.

Type of particles	Morphology	Generation mechanism	Machine condition
Rubbing	smooth surface; Random outlines of the boundary shapes	The broken parts of the shear mixed layer	Normal wear particles, dramatically increased quantity of the particles in a machine may be forecast impending trouble
Cutting	Long, curved particles	Generated as a result of one surface penetrating	The presence of independent cutting particles is not significant, but frequent presence of several hundred particles of cutting wear

		another (two body and three body abrasive wear)	particles indicates a sever wear process being under a way
Spherical	Like small balls	Generated in the bearing fatigue cracks from rolling bearing fatigue, or cavitation erosion, welding or grinding process associated with high temperature.	The very frequent presence of this wear particle given the warning of impending trouble
Laminar	Thin particles with random outlines of the boundary shapes; smooth surfaces with frequent occurrence of holes.	Formed by the passage of a wear particles through a rolling contact, probably as a result of wear particle through rolling contact, probably as a result of the second martensite layer and tempered martensite layer	Generated throughout the life of a bearing. The increased presence of laminar wear debris with severe wear of uncertain origin, indicates a problem with a rolling contact bearing

Chunk	Chunk particles with one flat or worked surface, while the other three parapedicular dimensions are uneven and irregular with a jagged boundary profile.	Generated from the rolling fatigue and combined rolling and sliding	The presence of chunk particles indicates a high load and or speed of gears
Sever sliding	A surface with scratches in parallel grooved sets.	Generated by sever sliding wear	Presence of these particles indicates a breakdown of lubricating films. When these particles appear frequently, it indicates an abnormal machine condition

Table.1. Wear particles and their relevant information for machine condition monitoring [2].

The above shown six basics wear particle types generated generates while mining machinery in mechanical action and include non-metallic, sand and dirt particles images of few wear particles responsible to generate wear particles in the machinery.

1.2. Methods to analyse wear debris

Wright and Neale show (1987) wear particles monitor by three ways, those are: [3]

1. Direct debris detection:
   It includes inductive and capacitive techniques, optical oil turbidity monitors and electrically conducting filters.

2. Debris collection and inspection:

   Specially designed oil filters, Magnetic plugs, Centrifuge filtration system are part of this group.

3. Lubrication sampling and analysis:

Process like X-Ray fluorescence (XRF), Spectroscope analyse. Atomic absorption (AAS) and metal analysis like electric particle counting, direct reading ferrography, electron microprobe, and some other methods like neutron activation analysis, microbiological analysis and some general physical or chemical tests are comes under this group

In this thesis work we are using lubrication sampling method using for heavy machinery, those are ferrography, chemical and physical test will do. Spectroscopic, microscopic and by another test are also will conduct if there any necessary to find by these.

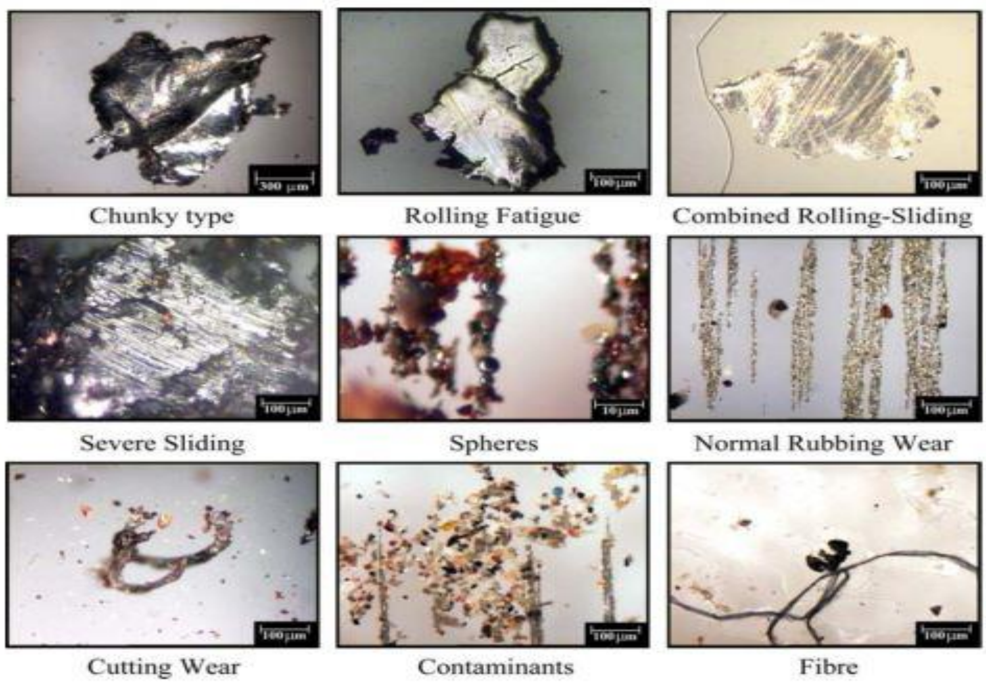

Figure. 1. Gallery of wear material [4].

1.3. Wear debris analysis procedure

Most of the open cast mining areas are having high density particles in the air, these particles mixed with lubrication oil and increase the wear rate. Analysis of these wear particles gives the state of the machine health, the following elements are determined to know the condition of machinery: [5]

1. Quantity of wear debris being generated (debris concentration)
2. Size distribution
3. Wear metal analysis
4. Morphology
5. Colour of wear debris
6. Chemical form of wear debris (Elemental composition of wear debris)

1.3.1 Quantity

Wear debris inside the lubricating oil directly related to the contamination. The sudden increase in wear debris quantity means severity in wear. In running process debris, chemical additive and soot increase the wear rate this cause by the failure of machinery components [6][7][8].

1.3.2 Size

The particle size distribution is very important to know because there are microscopic and macroscopic wear debris are formed during operation. Not every metallic or non-metallic debris has same size. The debris generation while sliding is exponential function of size [9]. Size of the wear debris also gives the severity of the wear [4]. Automatic particle analysis and ferrography gives very much familiar results in size distribution.

1.3.3 Wear metal analysis

Wear metals gives the wear generation components and condition of the machinery. Although only concentration of metallic particles does not give the accurate results. Some of the metal analyse techniques are: [5]

- Ferrography
- Atomic absorption spectroscopy (AAS)
- Atomic/optical emission spectroscopy (AES/OES)
- Mass spectrometry (MS)
- X-ray fluorescence spectroscopy (XRF), and
- Magnetic chip detectors.

1.3.4 Morphology:

Morphology of debris consist of shape, boundary texture and surface characteristics. These characteristics gives the mechanism and mode of wear debris generated [10].

1.3.5 Colour:

Colour of the debris gives the loading condition acting while generating wear debris. The colour extraction from debris is a teddies process, for the we need high resolution microscopy [11].

1.3.6 Chemical form:

What type debris material is exacted by elemental analysis. This chemical form of debris gives what machinery components are getting wear.

1.4 Lubrication analysis

After running of engine, the engine lubrication oil properties will be change. According to the SAE specifications oil lose its lubrication property after some time. To maintain the heavy-duty engine uses in mine truck we need to maintain proper lubricant properties. For this reason, there are some standard lubrication oil test are Ph value test, Flash point, TNAB (Total Number of Acid and Base). These test on engine lubrication oil given the oxidation in gasoline engines are more compare to other fuels [12].

Chapter 2

SCOPE OF THE STUDY

There stay broad difficulties for those inspired by the tribological outline of engine cylinder congregations, valve trains and motor orientation. The accompanying are essential angles justifying itemized innovative work in quest for enhanced execution and solidness [13].

Most of the mine machinery maintenance department is not using the wear debris analysis because of equipment cost is more costlier and technicians are less reliable to do analysis. I found some key points why to apply the wear debris analysis used in heavy duty engines lubrication oil, they are listed below:

1. Improved condition monitoring and mechanism of wear debris generation in different environment conditions.
2. Development of a linkage between lubrication mechanics and synthetic mechanics, with a superior comprehension of the wear and debris particles.
3. Consolidation of the improvements in the comprehension of lubrication oil rheology to make more viable outline guesses.

Chapter 3

OBJECTIVE OF THE STUDY

This research proceeding to:

- Analyse the lubrication changes in machinery those are using in very harsh environment.
- Find wear debris generation and their effect on the condition of the machinery.
- Understand the remaining life of the lubrication oil and the pattern of the deterioration.

Chapter 4

LITERATURE REVIEW

This chapter reviews the previously done work regarding condition monitoring methods, process, advancements relevant to this research. This chapter provides an overview on how the wear debris related to condition of machine, methods used, what type of wear debris will produce by machinery, how to find them, how they affect the machinery components.

Xiaoliang Zhu et. al [14] shown the parallel sensing method into the 3×3 series sensing methods, because of previous (traditional) Parallel circuit multiple sensing method generates higher data. This data was larger to analyse, then they modify sensory method without losing sensitivity we can measure debris particles of 50 µm. It's great achievement for online wear debris analysis.

Yeping Peng et. al [15] classified wear particles in online mode. They developed a new hybrid search-tree discrimination model using a multi-SVDD, K-means clustering algorithm and a SVM. The method was evaluated using more than 200 wear debris samples. Different colour of debris was achieved but in less efficiency due to fuzzy colour information and discrete distribution.

Felix Nga et. al [16] studied the hydraulic system of excavator. In this experimentation they installed the sensors after pump, before pump and also fixed a filter after motor. All the sensors were online because of the long process. The diagnosed and prognosed the total hydraulic system, for the same they proposed two ways, one was simple but gave less information while other was complex circuit but gave more data (uses the more sensors). The excavator filter was changed after every 500 machine engine hours. Electronic oil sampling system was designed and installed to allow oil samples that were taken from areas that were not suitable for particle counters. They collected data from every sensor, particles quantity by online and size by electronic microscope. At the end of the experimentation they effectively found Na, K, Si and Li.

J. Kattelus et. al [17] investigated the relation of pitting and vibration generation in gear (18CrNiMo7-6) which was case hardened (60–62 HRC). Experimentation was carried on gears using pinion rotating speed of 2250 rpm and loading of 405 Nm. They added ferrous particles (larger than the 70 µm diameter) and ferromagnetic metallic particles (larger than the effective diameter of 200 µm) in lubricant (ISO 4406) which was used as gear box oil. They found wear debris of 4 µm. Online visual inspection (because pitting is large progress mechanism) and particle monitoring using ferrography, pitting effect in macro level did by visual inspection. Particles generation up to 800 load cycles is normal and pitting effect also, but slightly variation increased. At higher cycles (12*10^6) particles are increased very rapidly and pitting is also very high. The statistical vibration acceleration descriptors indicating random peaks in vibration signal are more suitable indicating tooth wear than spectrum methods. Vibration acceleration descriptors indicating peaked signal correlate with the wear of gear contact, but the correlation is not as strong as in wear particle on-line monitoring.

Bin Fan et. al [18] theoretically and experimentally derived a formula for debris concentration in lubricant at lower rate. They gave the debris concentration based on time laps, size and debris loss factor. They assumed wear rate is equal to the wear debris produced, in general it is quiet less. The results after the experimentation for two different wear conditions were then compared to theoretical values. Finally, simplified formula for PCL was derived.

Víctor H. Jaramilloa et. al [19] gave the details about the right now and future condition monitoring of machinery parts in industries. Two stages in condition monitoring, in experiment he used specific sensors to get the running behaviour data. This data he divided in to local and global data this data is validated by Bayesian two stage method. Faulty, different parts of the experimental rig consisted of an electric motor connected to a brake via two gearboxes. Three case studies on the resulted data on Motor–Gearbox misalignment, Gearbox Soft-Foot and Gearbox–Worm-gear misalignment, Worm-gear–Gearbox misalignment, finally he found the difference in faulty level in each case.

Yeping Peng et. al [20] gave a review on recent advancements in technology of online sensors used in condition monitoring. These sensors were used to measure chemical properties of lubricant, quantity of wear debris and type of particles. They used the four-ball test rig and particle imaging system. The LPQ was the input of wear severity identification modelling with a mean-shift algorithm. Finally, they evaluated this research for to build the algorithm of small and larger particle online condition monitoring in lubricants. Large debris (>20µm) has the good information than small debris (>5µm). This algorithm gives the better results on quantity, size, morphology than existing one for online monitoring. Debris colour was extracted by using oxidation wear.

H.L. Costa et. al [21] tested the effect of wear particle size on the wear rate of the base material. In this experiment they used different aluminium alloys at different sliding wear condition and evaluated them. They observed that larger debris undergoes different forms and also, they are the main reason for wear like fatigue, scars, digging, cold-welding.

Jia-wei Zhou et. al [22] investigated erosion and other type of wears occurring inside the pipe of pneumatic conveyor. They used the CFD to analysis and then verified it by calculations (Eulers Legrangian method). They modelled the different shapes of particles. Elbow middle plane in the V-H and H-V shapes had medium and H-H had high erosion rate. The mean erosion rate is decreased with increased swirling of the particles.

Xiaoliang Zhu et. al [23] used sensors for to condition monitoring of lubrication oil, those types of debris are physical and chemical properties of debris concentration. All sensors used for live monitoring machine health at approximately 10µm for high complex to take repeated samples from the machines like marine engines, wind turbine gear boxes, aeroplane, space equipment.

Hongkun Wu et. al [24] found a new process by which a video footage was used to analyse the wear particles in lubricant oil for this, a Gaussian mixture modelling has been proved to be an efficient and robust technique for recognising object from real-time surveillance videos, it is used to expose wear particle from the captured video. Next, the particles in the video are tracked to collect their profiles in multiple views. To ensure the tracking reliability, the particle motion is estimated with Kalman filter, which is extensively employed in object tracking area such as traffic management and robot navigation. After this the particle was successfully identified and tracked in multiple views, 3-D representation of the particle is reconstructed. Based on the contour information, shape-from silhouette (SFS) is an effective technique to reconstruct 3-D object without detailed information about every pixel. As a result, SFS is applied to construct 3-D particle and compared with other particle imaging approaches. And this method can provide the thickness information as well as particle volume which can be used to estimate the material loss and wear rate.

Morten Henneberg et. al [25] used a dual filter system and calculated the wear particles effect on filters at quasi-static mode. For this they had used the ship thruster and gear box lubricant oil. When system changes from online to offline filtration found that increase in similar particle burst, which is observed sometimes.

Song Feng et. al [26] monitor the wear of the spur gears using ferrography technic and continuous wear particles are modelled using kragelsky's fraction method. Newly added the friction values at different stages so, then wear depth can be more accurately calculated**.** These stages are run-in on stage, study state and sever state. Online ferro-gram have low resolution and many interferences such as bubbles, extracting visual features is more challenging than using offline ferrograph. During running stage wear rate is more due to more asperities contact and then stabilized. During sever ware rate is again increased due to high wear particles presented.

Yeping Peng et. al [11] used four-ball rig to calculate the wear particles in lubricant and then directed to the high frame video sensor and these sensors are extracting the images and these images are not proper for evaluating every particle. Image pre-processing methods were adopted to separate wear particles from the background and to improve the image quality through a motion-blurred restoration process before the colours of the wear debris were extracted. This method is used for online oxidation monitoring for industrial purpose. For this experiment Fe_2O_4, Fe_2O_3 used to dark colour means high temperature wear.

Gwidon P et. al [27] classified wear particles into three types, fatigue, abrasive and adhesive. The fatigue wear particles were generated using an FZG back-to-back gear test rig. A pin-on-disk tribometer was used to generate the abrasive and adhesive wear particles. Scanning electron microscope (SEM) images of wear particles were acquired, forming a database for further analysis. The particle images were divided into three groups or classes, each class represents a different wear mechanism.

Each particle class was first examined visually and then, area, perimeter, convexity and elongation parameters were determined for each class using image analysis software and the parameters were statistically analysed. Each particle class was then assessed using the automated classification system, based on particle surface texture. The results of the automated particle classification were compared to both the visual assessment of particle morphology and the numerical parameter values. Texture-based classification system was a more efficient and accurate way of distinguishing between various wear particles than classification based on size and shape of wear particles.

Li Du1, Jiang Zhe [28] inductive sensors used for monitoring only conductive particles those are ferrous, copper and aluminium. In previous sensors direct induction solenoids used, now authors developed a high throughput based on planar inductive coil. The high throughput was achieved by using a two- layer planar coil with a micro scale fluidic pipe crossing the coil's centre, because of the small volume of the sensing zone. The sensor has a high sensitivity and disable to measure metal particles as small as 50 mm. Compared to a counterpart micro fluidic inductive Coulter counter, the throughput had been improved 6 times without sacrificing the sensitivity.

Valis D et. al [29] proposed new methodology to diagnosis the engine using wear particles. In this paper authors collected the oil samples and did the oil quality test, particle present using Atomic Emission Spectrometry (AES) for chemical particles in lubricant. Fourier Transformation Infrared (FTIR) and Laser Net Finder (LNF) for particles morphology and additives´ concentration. These instrument data accuracies considered as 5-10% and are divided in two types one moto hours and date wise. An approach of failure modelling based on operational data, non-trivial oil variables which are recorded in two dimensions, suggest promising input to maintenance and cost optimisation. Approach is based on non-traditional classes of Levy processes, outcomes are supported by two relevant case studies. This entire analysis done based on First Hitting Time (change of particle size or concentration). All the analysed done by regression analysis and FIS approach.

Hongkun Wu et. al [30] studied on separation algorithm of chain type wear particles, due to chain type wear particle they will break at any moment (bottle neck). In this paper the debris info by ferrography (online) and then analysed by two methods. One is distance based transformation and another integrating ultimate corrosion and condition expansion (UCCE). A distance transformation method by removing edge pixels consider as corrosive. In corrosive expansion method he took uniform scale it gives the less accuracy and then he improved multi scale method (Considering different scales). An improved multi-scale corrosion expansion method has been therefore proposed for on-line purposes. Compared with ultimate corrosion-conditional expansion, the proposed method has higher separation accuracy and efficiency by applying a flexible corrosion strategy.

Surapol Raadnui [4] gave an overview on analysing of wear particles by computer image scanning equipment, for this he did analysis on sample that is already available and compared with results. The scanning image method gives the good results but he found some morphological errors, so finally he concluded naked eye can gives higher results but it takes more time. He mentions the quantitative image analysis (size, shape, Fourier transformation, fractal dimensions), surface analysis (Hight to width aspect ratio), colour extraction using stereo microscope, ppm by filtration technic, inline wear particle morphological analysis using Laser-Net Fines' gives the high resolution of particle size 5-100 micro meters.

P. Podsiadlo, G.W. Stachowiak [31] checked the analytically and mathematically (No mathematical equations mentioned) whether the surface particle morphology helps to give the accurate result in wear particle analyses. For this authors used Partition Iterated Function System (PIFS) by self-particle characterization. They found that surface morphology gave more accurate results than scale invariant method. PIFS (Algorithm for characterize the particle size).

K. Velten a et. al [32] tested the Neural network which gives much more statistical data than previous multi linear regression model. They conduct the fretting test on material block and monitored the friction force and normal load, fretting behaviour. Based on particle size and shape, mechanical properties of material substituted in neural network with their modified neural network that is previously used by JONES. Accurate results were obtained which is higher than previous results. Compared to any other regression model this model gives the accurate and robust results.

T. H. Wu et. al [33] an online visual ferrograph sensor characterized by image analysis and miniaturization was developed. A new design of the oil flow channel with the flow direction parallel to the magnetic flux. It is in between two electromagnet poles reduces the electromagnet size greatly. Wear debris images under transmitted, reflected, and full light conditions were deposited via a CMOS image sensor. The OLVF shows good deposition effects for both large and small wear debris with suitable.

M.A. Khan et. al [34] developed new method for online wear debris analysis, for that they made custom video sensor (optical microscope) with test ring. This data analysed by the custom MATLAB online coding and then they evaluated the shape, size and colour of each particle. This entire method tested on the Back to Back gear failure test ring. This new methodology gives the 80% accuracy, rest is gone by some miss match.

William R. Jones Jr. & Stuart H. Loewenthal [35] used the ferrography to characterize wear debris from full-scale bearing fatigue tests. Authors experimented on deep groove ball bearing in test ring and then particle size, ppm and shape was determined by the ferrograph result. Elemental analysis is done by the energy dispersive X-ray Spectro meter. Four fatigue failures were detected by accelerometers at 443, 526, 1013, and 1096 hours.

In three of the four failures, there were increases in the number of spheres, the wear severity index and the composite Ferro-gram density prior to failure detection by accelerometers. Conclusion is there was no correlation between the fatigue failures and iron concentrations in the lubricant as measured by ordinary emission spectrometer techniques. Four types of wear particles were observed normal rubbing wear particles, spheres, nonferrous particles, and severe wear (spall) fragments. Fatigue micro spall and laminar particles were not observed.

Shashikant S. et. al [36] developed a test setup that could predict the failure of seals under various rotational speeds, lubrication mechanisms, and spring loads. Misalignment is the root cause of failure of face seals used in Y-assemblies. (Not date in X-axis).

Yali Zhang et. al [37] had given quantitative index of particle coverage area (IPCA) and wear debris ferro-images were obtained via OLVF to characterize wear degrees. OLVF tested the four-cylinders HM2.0T with visual ferrograph sensor, oil level indicator, oil filter, collector. Samples collected were nearly 300 and substituted it into the reaeration analysis index particle coverage analysis (IPCA) divided.

Adler, J. and Hancock, D [38] corrected the equipment that was previously available to measure the fractal dimensions of the wear particles by dilation method. This method in fractal dimensions increases the measuring accuracy of wear debris particles. It is an easy process and gives more accurate results than previous one, direct measurement. This method gives the fast results and they used dilation method for off line analysis.

Ahn H.S et. al [39] did direct lubricant debris analysis on several parts like Turbine gearbox, support bearings, generator gear trine and coolant. Wear particles monitored by filter blockage technic and counted by microscope, the shape of debris detected by manual optical microscopes. Ferrous and non-ferrous particles, chemical compounds particles of 10 to 15 micro meters with this data can also give statistical analysis of wear debris by using Weibull distribution function.

Anderson, D.P. [40] used the ferrographic technic, Optical microscope, scanning electron microscope for analysing the wear particles in lubrication oil. Wear particles occurring in fields are different types of wear particles like ferrous and non-ferrous alloys, chemical compounds and Friction polymers. Properties of wear particles, shapes of particles and effects of wear particles present in lubricant oil are based on contaminants on lubricant like coal dust and asbestos.

Beerbower A. [41]**.** did distribution analysis on wear particles to measure wear rate. Wear particles in the lubricant oil are measured by Automatic particle counter(APC). The size distribution done is by manual microscope and analysed by ferrography.

Bings. N et. al [42] analysed the metal wear particles in the lubricant by using the inductively coupled plasma atomic emission spectroscopy, it detects the metal wear particles, most with high ppm. Modified emission collector to new carbon collector, experimentally concluded this is simplest and fast method than previous one.

S. Ebersbach et. al [43] used condition monitoring of spur gears on centrifugal pump for wear particles by laser scanning confocal microscope (LSCM) in different loading condition by sliding method and filtration. By this test it is found that less of laminar and fatigue particle were formed at normal load, but at constant over load fatigue pitting particles are formed and increase in severity due to increased localized stress. In cyclic loading fatigue particle are increasing towards severity.

Monica P. Escobar et. al [44] used Electrothermal vaporization (ETV) for determination of debris particles in lubrication oil and this modified equipment gave more accurate result. Al, Mg, Fe, and Y metal-organic compounds were found in the lubrication oil. As per the results the modified equipment gave good result than the one before.

Jain. A et. al [45] used Spectre laser particle counter to count the wear particles in the oil sample and before doing that, Jain. A counted dilute particle in oil and heated it for removing sticky nature in oil, making it easier to do experiment and for better results.

Kirk. T.B et. al [46] used optical and laser scanning confocal microscopy (SCM) to count the wear particles, determine the different shapes of the wear particles in lubrication oil. Different types of wear particle, micro structure and their participation in the contamination of lubricant oil are also analysed.

Liu. Y.W et. al [47] used the Optical microscope with high speed to determine the wear particles on lubrication oil, predetermined data for each colour of material by using special computer and hardware is also available. In this experiment wear particles size and surface roughness in the lubrication oil was evaluated by using light reflection technique. Such classification can be based on multidimensional scaling of shape, texture and colour features of wear debris.

Myshkin. N.K et. al [48] analysed the wear particles in the lubricant oil by laser computer scanning. However neural network scanning method was used to efficiently analyse the size, shape, texture of the wear particles. Initially wear particles shape and orientation is described by the fourier law in the software. However, the analysis of a single response does not permit the correct conclusion. The major reason was that there was an insufficient number of particle images used to describe the wear process problem, it should be noted that during the test the oil used for stage 'a' was not removed but used at stage 'b' as well. Every oil sample contained debris general during the previous stages therefore, one can expect that a small volume of sample can cause statistical unbalancing of the result. The neural-net response depends considerably on small changes of object ratios in the sample.

Myshkin, N.K et. al [49] developed a new technic to analyse wear debris particles in lubricant based on 'Optical effect on Magnetic field' and described the principle of operation of optical-ferro analyser. Myshkin compared the sensitivity of equipment in the laboratory and the results with previously available devises and found that OF had higher particles sensitivity to low concentrations ($5\times10^{-}4$ of mass%) and finally concluded this instrument could be useful to measure wear particles in time analysis.

Peleg. S et. al [50] classified texture based on the change in their properties with changing resolution. The area of the grey level surface is measured at several resolutions. This area decreases at coarser resolution since fine details that contribute to that area disappear.

Fractal properties of the picture are computed from the rate of this decrease in area, and are used for texture comparison and classification. The relation of a texture picture to its negative and directional properties, are also discussed.

Peng. Z [51] used an intelligent system to analyse the wear debris particles in lubrication oil for monitoring the condition of engine. This inelegant system has particle analyser, particle counter and the expert system these are connected with computer, this computer gives the results as condition of engine based on wear particles on lubricant compare with ASME standards.

Peng, Z. and Goodwin, S [52] used an intelligent system to analyse the wear debris particles in lubrication oil for monitoring the condition of engine. This intelligent system had particle analyser, particle counter and the expert system, these three are connected with a computer. They developed a new expert system, this expert system is divided into four parts Databases, Rules, Interface engine and Interface design these are connected to a computer and it gives the results as condition of engine based on wear particles on lubricant compared with ASME standards.

Peng, Z. and Kirk, T.B [53] studied two-dimensional fast Fourier transform, power spectrum and angular spectrum analyse, which are applied to describe wear particle surface textures in three dimensions. The Laminar, fatigue chunk and severe sliding wear particles which have previously proven difficult to identify by statistical characterization. The spectral analysis effectively identifies the surface texture pattern of isotropic or anisotropic.

Peng, Z. and Kirk, T.B [54] investigated six common types of metallic wear particles by studying three-dimensional images obtained from laser scanning confocal microscopy, using selected numerical parameters, which can characterise boundary morphology and surface topology of the wear particles. Two neural network systems, i.e. a fuzzy Kohonen neural network and a multi-layer perceptron with back propagation learning rule have been trained to classify the wear particles. Finally, they shown that neural network gives almost equal results to the conventional process.

Peng, Z. and Kirk, T.B [55] trained the computer to analyse the wear particles in lubricant, for this they used LSCM to 3D scan of wear debris and divided these debris into six different types, same like neural network.

Peng, Z. and Kirk, T.B [2] investigated laser scanning confocal microscope and characterized it into six different types by using neural network "fuzzy kohenen". Based on the results an expert system trained that grey systems gave the suggestion to machinery condition.

Podsiadlo, P. and Stachowiak, G.W [56] combined two surface measurement equipment's, field emission scanning electron microscope (FESEM) and stereoscopy to measure morphology values at very small micro level into three dimensionally content. They also characterised the shapes and size of wear particles with different colour patterns.

Podsiadlo, P. and Stachowiak, G.W [31] check the analytically and mathematically (No mathematical equations mentioned) weather the surface particle morphology helps to give the accurate result. Wear particle analysing using partition iterated Function System (PIFS) to self-particle characterization, with surface morphology gives the more accurate results than without.

Prabhakaran, A. and Jagga C.R. [57] monitored the stem turbo generator of turbine and it's bearings components in scheduled time. Samples were taken in scheduled time and analyzed with different methods like ferro-grapy, ICPAES, SEM, SEM/EDMAX for analyzing the different wear particles like Fe, Al, Si, Ca, Zn, S, Cl, Mn, Cr, Cu. After collecting and comparing all data they proclaimed that the results were near about same.

Raadnui, S. [4] gave an overview on analyzing wear particles by computer image scanning equipment. Authors compared the result of this sample with the earlier available results. The scanning image method gave good results but authors comforted some morphological errors. Finally, authors declared that naked eye gave good results but it took more time..

Scott, D. and Westcott, V.C [58] explained that how ferrography works and how it can be used to analyse the wear particle differentiation. Before this technique authors had used the techniques of ferromagnetic and microscope. They also represented how easy it was in the time of its invention.

Stachowiak, G.W. and Podsiadlo, P. [59] **s**howing analytical way of three-dimensional wear characterization by combine both scanning electron microscope and stereoscope to get better surface tropology values. They fallowed the procedure same as previous paper in experimental way.

Umeda, A. [60] used both multi-layer neural network and self-organizing neural network for characterizing wear particles according to the sliding condition. Author experimentally concluded that self-organizing neural network gave classification data without any inputs while multi-layer neural network needs input and output data for classification.

Vahaoja, P et. al [61] determined the presence of wear particles in lubricant from different samples. For this, authors used flame atomic absorption spectroscopy and inductively coupled plasma-optical spectroscopy. They diluted the oil sample in kerosene and compared the results with both equipment and found that ICPOS gave good result in dirty conditions.

Yang, Z., Hou, X. and Jones, B.T. [62] developed a new method of determining multi metal components by the use of X- ray Fluorescence spectrometry. Authors had taken sample from engine oil diluted by organic components mostly kerosene, to study even distribution of wear particles by making a thin film with diluted oil on disc. The disc containing wear particles which were evenly distributed were processed through solid paper extraction and further digested by micro woven digestion method. Authors simply analyzed the wear particles seen on the surface of disc which were same as direct sample oil analysis. They carried the experiment again with increasing the time to digest the X-ray radiation on sample for determining the best oil sample load on the disc plate by trails and error methods. They also plotted the graph for optimum point.

M.C. Isaa et.al [63] explained the analysis of ferromagnetic wear particles used in lubricating oil samples that were collected from the engines, generators and gearboxes of commercial marine ships. Authors studied in detail about the flash point, viscosity measurement, ferrography analysis and energy dispersive X- ray analysis (EXD) and they applied these concepts to extract the relevant information about the physical aspects of using lubricating oil and wear condition of the part of generators, gearbox and main engine.

Chapter 5

RESEARCH METHODOLOGY

Research methodology consist of thermotical and experimental analysis of the pooches and it involves the concept of qualitative and quantitative analysis. In this research going to condition monitoring of HEMM based on lubrication analysis.

The lubricating oil used in Heavy Earth Moving Machinery operated in open cast mines will be collected at different time interval for experimentation. The experimental results will be further analysed to understand the remaining life of the lubricating oil and the pattern of the deterioration.

- In oil analysis physical and chemical properties, the analysis includes Viscosity analysis, TAN/TBN analysis test will be conducted.
- In wear debris analysis quantity, size (quantitative analysis) will be conducted using automatic particle counter.
- For morphological features of the wear debris in lubrication ferrography analysis will conduct, if any necessary spectroscopic or other analysis also conduct.

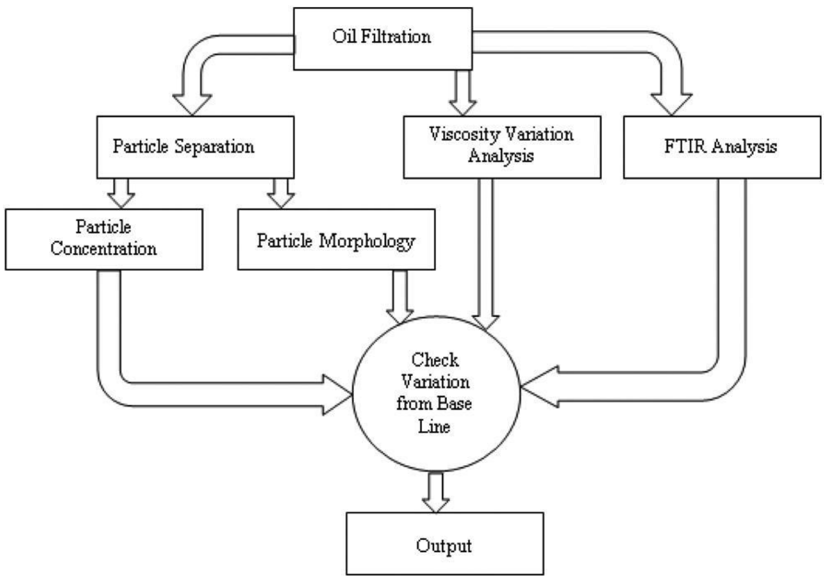

Figure.2. Steps in the lubrication oil analysis [64].

5.1. Viscosity

Viscosity changes in the lubrication cause the miss-heat dispassion and then machinery freeing. Every lubrication oil has the specific kinematic viscosity index which represents.

$$Viscosity\ index\ (VI) = \frac{L - U}{L - H}$$

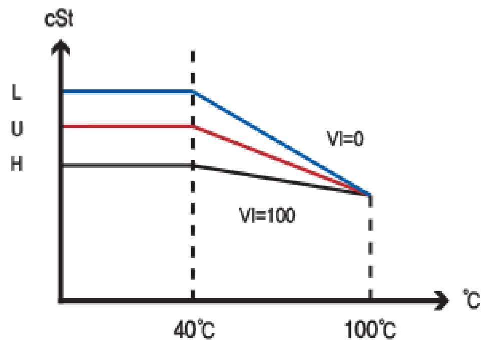

Fig.3 Change of viscosity with variation in temperature

5.2. Ferrography analysis

Ferrography is most used method since 1972, this method gives the robust results for the ferromagnetic wear debris in lubricants [65]. Ferrography is two types direct and analytical ferrography. In this research dual analytical ferrograph is discussed for analysis.

Procedure:

The sample lubrication oil flows over glass designed especially for sliding. Magnetic field will apply on the sliding sample with varying magnetic field. large size particles attract to strong magnetic force and small particle attracts to the low magnetic force. A cleaning agent used to remove the lubrication oil and a ferroscope collect the particles data by using video footage or microscopic method [66].

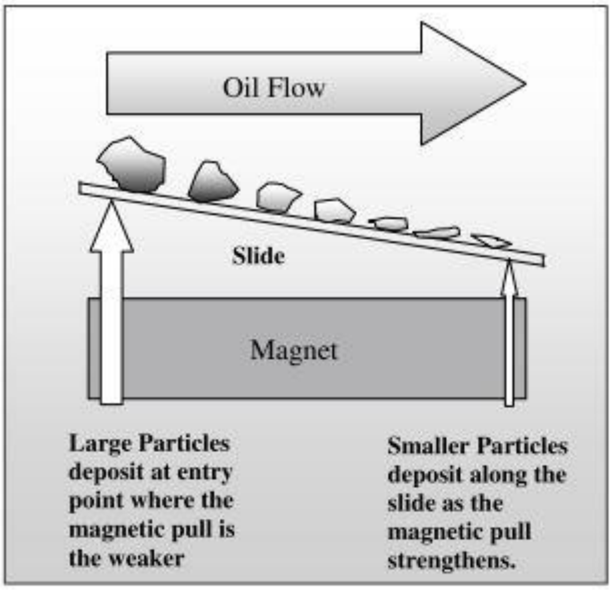

Fig. 3 Ferrogram maker[66]

Chapter 6

EXPECTED OUTCOMES

In open cast mines generation of wear debris high compared to normal conditions due high concentration of particles in environment. This leads quickly contamination of machinery components. While this research work will find a better condition machine and do remedy with continuation of this research.

Chapter 7

SUMMARY

Wear mechanism and wear generation in lubrication oil has been studied. Identified what are the advancements in online and offline mode wear debris analysis. Studied what are the equipment's uses for extract different characteristics of wear debris.

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