

Oil Properties Analysis and Ferrography Analysis to Monitor the Condition of Single Speed Worm Gearbox

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Abstract

Condition monitoring of the system is important, historical data is available for the system but we cannot always depend on it for near-net prediction of system failure. In this paper, oil properties analysis and ferrography analysis is used to maintain and extend the life of the system. Due to sliding motion in the case of a single-speed worm gearbox temperature increases and it leads to a decrease in the performance of oil properties. As result, the overall performance of the gearbox gets affected. In oil property analysis, response parameters like viscosity index, and TAN are analyzed, whereas Direct reading ferrography offers parameters like large particle count and small particle count, Wear Severity Index, and Wear Particle Concentration. Analytical ferrography gives us morphology related to wear particles. Microscopic examination of wear particles helps to find out the type of wear and source of wear. As per industrial application, the speed of the gearbox, the geometry of gear pairs, the material of gears, and oil level, the type of lubricating oil and load on the gearbox determines the process input parameters. On the basis of the required process parameters, an experimental setup using a single-speed worm gearbox is developed. Oil examination is carried out at fixed time intervals for recording response parameters. The oil samples obtained by experimentation can be examined through oil properties analysis and ferrography analysis. The current study includes formulating relation of oil properties to the wear of gear pairs to make a condition-based maintenance policy to maintain and extend the life of the gearbox.

Keywords

Ferrography, oil properties analysis, worm gearbox, Bio chromatic microscope and condition monitoring.

1. Introduction

study of wear, friction, and lubrication of surfaces that are in relative motion comes under the concept of tribology. Maintenance of the tribomechanical system depends on friction, wear, and lubrication. About 90 % of savings can be achieved through maintenance is possible with the help of the tribological approach. Wear of any system is unavoidable but keeping track is possible. There are various techniques used for condition monitoring of the system such as vibration analysis, spectroscopic analysis, etc. but this technique cannot tell about the actual type of wear, source of wear and change in oil properties. In this paper, ferrography and oil properties analysis is used to check the condition of the gearbox. To avoid sudden failure of the system it is requisite to monitor a viscosity index of oil, TAN, increasing WPC, and wear trend to prevent the sudden breakdown of the system.

Condition monitoring helps to find out how a change in oil properties impact the life of worm gearbox and overall performance of worm gearbox. Also it is useful to establish the relation of oil properties analysis with ferrography analysis to make a better condition based maintenance policy.

From an industrial application point of view, e.g., small machinery, escalators, conveyors, packaging equipment, etc. normally a worm and worm gearbox is used. It normally works in all three shifts per day. When there is power transmission from the input shaft to the output shaft in the gearbox, there is a sliding motion between the gear pair

and it leads to friction loss which creates heat energy and it is blown away into the oil. As a result, temperature increases which causes a decrease in oil viscosity and degradation of lubrication oil. But degradation is decided on oil properties like tribological, physical, and chemical properties. Such changes lead to the wear of the gearbox. In such a case trend analysis is much more important. The viscosity of lubricating oil relies on various factors. The viscosity of oil decrement is due to the increase in temperature of oil, the consolidation of nanoparticles, and nano particle type.

Parameters like oil viscosity, type of oil, and additives in it, also have a great impact on the failure of gear because, after degradation of oil, abnormal wear particles are generated. It leads to reduce the performance of oil. Oil is necessary to lubricate the gearbox so that it keeps up the gearbox in operating condition. If oil fails to do its task of lubrication because of sudden changes in its properties, then there are more chances of failure of the gearbox. After degradation of oil, it loses its properties which causes abnormal wear having small as well as large particles of wear-out material. Here ferrography plays an important role to detect the wear-out material, type of wear that took place and source of wear. Condition monitoring of lubricating oil provides data about the working of the worm gearbox. Further, this data is used to find out and point out faults of the system and is useful to make decisions regarding preventive maintenance policy.

Various analysis techniques like acoustic emission, temperature, vibration, and ferrography of oil are used to find out problems in the worm gearbox. Then it comes to knowing operating parameters and surrounding condition of the gearbox is directing to degradation of the oil used in the industrial gearbox. A study of oil with a set process parameter tells degradation of oil and estimates remaining useful life. Condition monitoring of oil used in gearbox and study of oil properties are effective techniques to find out the root cause. Attributes for the failure of oil are contamination present in the oil, viscosity of oil, the content of moisture, presence of foreign material, and temperature of oil .

Many researchers work on different condition monitoring techniques, but they didn't put a combination of these techniques together to find out the optimal solution. Present work will help to find out how changes in oil properties impact the life, wear rate and performance of a single-speed worm gearbox. After studying the combination of these two analyses together we come to know the exact action needed to avoid the sudden breakdown of the system

2. Literature Review

Kumaret al. (2016) worked on the comparison of lubricants and the development of an optimization model of the rolling mill. Lubrication for any machine plays an important role and its performance is directly associated with the speed, reliability and life of the machine. The explanation of used oil sample is quite difficult because factors are interdependent on each other. Therefore data from number of oil samples are taken for study. In this case trend of results is more important so trend analysis plays an important role and decisions are taken on the trend of lubricant performance.

Gorla et al. (2013) explained the hydraulic losses of the gearbox. Efficiency of a system becomes a concern in power transmission. During the design phase of gearbox to predict the power losses CFD simulation were performed. He explained that factors affecting the viscosity are an increase in temperature of oil, the consolidation of nanoparticles, and nanoparticle type.

Narwariya et al. (2018) designed an axle performance test system. Test lubricant is evaluated over each of temperature range, for each of five load speed conditions. Three synthetic gear oils were evaluated, based on various combinations of synthetic hydrocarbons, esters, and viscosity improvers, and were compared to conventional SAE 80W-90 lubricants. As a result it is seen that there are some parameters like oil viscosity, type of oil, and additives in it, that also has a great impact on the failure of gear because after degradation of oil abnormal wear particles are generated which leads to reduce the performance of oil.

Bhat and Sonawane (2019) researcher look at the impact of oil degradation on the overall performance gearbox for evaluation of performance deterioration of oil used in sliding pair. The experimental setup driven by an A.C motor (1HP) is used for this evaluation the gearbox runs under normal loading conditions according to industrial application it consists of HP 140 Lubrication oil for the performance evaluation of oil. He claimed that viscosity and TAN are the crucial parameters to knowing the condition of lubricant. It is possible to judge the deterioration of lubricant on the basis of viscosity and TAN. For this experiment, an unheated viscometer is used to calculate

viscosity and TAN for the used oil. As a result, this paper indicates that viscosity of oil is get reduced over the application due to wear while there is an increase in TAN over the period of application because of oxidation. Thus the impact of change in oil properties is on gearbox failure. On the basis of oil properties analysis it is possible to judge the condition of gearbox.

Dalley (2015) illustrates the use of ferrography to find out wear, type of wear, and source of wear. More and Jaybhaye, (2019) designed the test rig to carry out an experiment on spur gearbox they illustrate the use of wear debris analysis to solve the problem of wear. Author uses direct reading ferrography and analytical ferrography as a technique for study the wear. With the help of direct reading ferrography they find out large particle concentration and small particle concentration. Further it is utilize to calculate WPC and WSI. Analytical ferrography gives Morphology related wear particle i.e size shape and source of wear. It was observed that abnormal noise was coming from the system. The sample oil is checked it is come to know that after performing ferrography wear severity index is quit high normal rubbing wear was increased.

Mishra et al. (2016) works on a review paper on fault detection of worm gearbox. He explains the combination of vibration analysis and wears debris analysis are very useful techniques for fault detection.gives an important view on operating parameters and surrounding conditions directing the degradation of oil.

Dube and Jaybhaye (2021) works on the Effects of different vegetable oils and additives in gearbox operation and its Condition monitoring. Author uses ferrography technique to evaluate the performance. He found that combination of oil blend 25% natural oil blend and 75% EP-90 shows a better result as compared to EP 90 oil.

Karajagikar et al. (2016) design the test rig to carry out the condition monitoring of the worm gearbox by using vibration analysis and ferrography analysis. A 1HP A.C motor is used to drive the input of the worm gearbox having a 1:20 ratio.EP 90 Castrol oil is used to test the performance of the gearbox.As a result,he concludes that a combination of ferrography analysis, condition monitoring, and vibration analysis plays a vital role in taking decisions regarding preventive maintenance.

Rathore et al. (2019) discussed an overview of diagnostics and prognostics of rotating machines for timely maintenance intervention. He takes the case of the turbine for condition monitoring he finds out that Condition-based monitoring is most reliable technique for accurately estimating the condition of a critical part. As a result, he tells condition monitoring is useful to take up decisions on preventive maintenance.

Zhu et al. (2013) tell detail about the importance of condition monitoring and oil properties are effective techniques to find out the root cause of the type of wear and source of wear.

3. Method

3.1 Experimental setup:

To study the impact of change in oil properties on wear, of a single-speed Worm gearbox and for taking the decision regarding maintenance of a gearbox, the test rig is developed as shown in Figure 1 to carry out the experiment with set input parameters.

A single-phase A.C motor with 1.0 HP capacity which runs at 1440 rpm is used to drive the input shaft of the worm gearbox, motor shaft and input shaft of the gearbox are coupled by using jaw coupling. Industrial gear oil 68 is used in a single-speed worm gearbox, it has specifications like a gear ratio of 1:20, type reduction having 50mm in size, with a transmission capacity of 0.5 HP.

A special arrangement of a flat belt with a flat pulley type of load mechanism is used to apply load on an output shaft of the gearbox. The test rig is running daily in 2 shifts as per industrial application. Auto on/off is achieved by using an electronic timer unit.

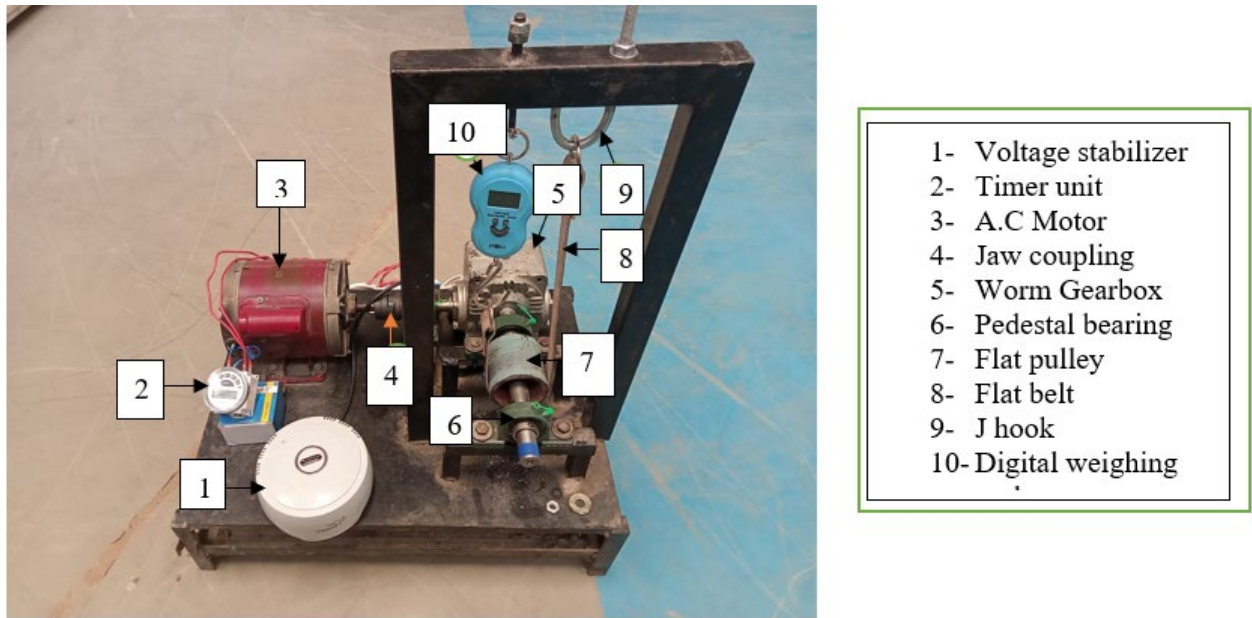


Figure 1. Experimental setup

3.2 Experimental analysis

In oil properties analysis, viscosity and TAN are the most important parameters which actually hamper the oil properties and have a greater impact on the wear rate of a gearbox. To check the viscosity a kittiwake unheated viscometer is used to find out the kinematic viscosity of oil at 40°C, 100°C and with TAN arrangement to main unit TAN also calculated which is shown in Figure 2 and Figure 3 respectively. As per the AGMA standard lubricating oil has to be changed after a certain time interval.



Figure 2. Unheated viscometer device



Figure 3. TAN device

Ferrography analysis is carried out to find out wear particle count, types of wear and source of wear. There are two types of ferrography, In direct reading ferrography Initially, the sample oil was heated on a hot plate at 60°C for homogeneous suspension of particles in the oil. After that 1 ml of sample oil was diluted with 1 ml of Carbon tetrachloride (used as solvent) to reduce the viscosity of oil flows directly through a precipitation tube under which there is a strong permanent magnet, which affects metal particles so that it deposits them close to it. Large particles are removed more quickly compared to smaller ones, because the force exerted upon a particle within the magnetic field is proportional to its volume, whereas the moment resistance through a medium is in portion to the cross-section area in a diagonal way to a moment of direction. After all the particles have been deposited, the light intensity is registered and the percentage of the areas covered by both large and small particles is determined. The ratio of large and small particles remains constant up to the point when higher rates of wear occur. DR ferrography is shown in Figure 4. which gives large particle quantum (DL), small particle quantum (DS). which helps to calculate the cumulative value of (DL) WPC and WSI.



Figure 4. DR ferrography

Whereas analytical ferrography is based on ferrogram analysis. It is done in the way that 3 ml of sample oil with 2 ml of solvent (fixer oil) was pumped across the glass substrate which was supported at a 3-degree incline under which there is a strong magnet. The particles then deposit on the glass slide selectively, according to their size and in the same way as in the case of a direct reading ferrograph. The more magnetic the material is, the stronger the effect of selective extraction. Even large, but least magnetic particles will be extracted along the whole length of the ferrogram, which is due to gravity. After the particles have been extracted, the rest is washed out by a solvent, and then the remaining particles get attached to the glass slide. The sample made in this way is known as a ferrogram as shown in Figure 5, which is heated to 330°C for 90 seconds as per ASTM standard.



Figure 5. Dual slide ferrogram maker

With the help of a bio-chromatic microscope Olympus BX-51, microscopic examination is carried out of wear particles as shown in Figure 6.



Figure 6. biochromatic microscope Olympus BX-51

4. Data collection:

At every 43 hours, oil samples are taken from the gearbox to carry out oil properties analysis and ferrography analysis. All oil samples should be taken while the system is in operation. Oil samples are collected from the same location i.e from the fill cap with the help of a dispo van attached with a flexible pipe. For every sample, oil properties analysis and ferrography analysis are carried out and data will be collected in standard form as shown in Table 1.

In direct reading ferrography wear severity index which gives the severity of system wear. It is calculated by using the formula, $DL * [(DL-DS)/DS]$. Whereas wear particle concentration (WPC) is calculated by the formula $(DL+DS)$.

Table 1. Data Collection

Sr No.	Oil running hours	Viscosity at 40°C (Cst)	Viscosity at 100°C (Cst)	Total Acid Number (TAN) (mgKOH/g)	Observed reading		Σ DI	WPC (DI + Ds)	WSI $DL * [(DL - DS) / DS]$.
					DI	Ds			
0	00	157.7	15.5	0.2	0	0	0	0	0
1	43	154.9	15.3	0.4	161	136	161	297	29.59
2	86	154.1	15.2	0.4	178	131	339	309	63.56
3	129	153.6	15.2	0.5	203	142	542	345	87.20
4	172	153.3	15.2	0.5	257	189	799	446	92.46
5	215	152.6	15.1	0.5	311	233	1110	544	104.11
6	258	152.2	15.1	0.6	322	207	1432	529	178.89
7	301	148.4	14.8	0.7	334	146	1766	480	430

Types of wear particle generated in oil samples of 1 to 6 is shown in Figure 7 to 12.

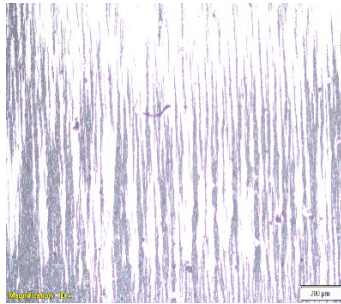


Figure 7. normal rubbing wear
Sample 01



Figure 8. Cutting wear
Sample 02

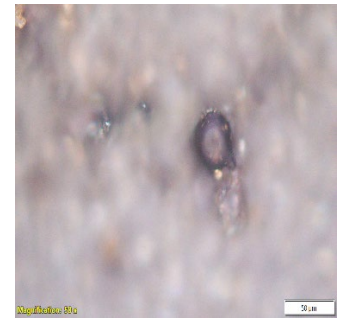


Figure 9. Black oxide
Sample 03

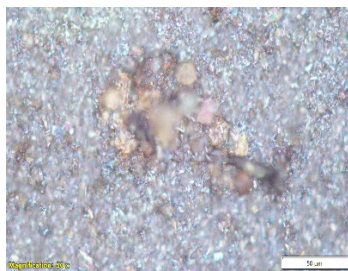


Figure 10. rolling and sliding wear
Sample 04



Figure 11. rolling fatigue wear
sample 05

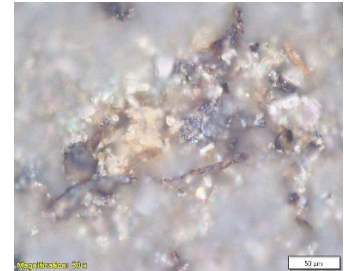


Figure 12. cutting wear
sample 06

5. Results and Discussion

In Oil properties analysis kitiwake unheated viscometer is used to find out kinematic viscosity at 40°C, 100°C and TAN. Whereas Direct reading ferrography was utilized to obtain information about the wear situation in the gearbox. In which two readings of DL and DS is obtained for each oil sample. These readings are used to calculate the wear severity index which gives the severity of system wear. It is calculated by using the formula, $DL * [(DL - DS) / DS]$. Whereas wear particle concentration (WPC) is calculated by the formula $(DL + DS)$ which indicates existing wear in the system. Analytical ferrography is used to develop a ferrogram slide of all ten samples and analysis is done by using a biochromatic optical microscope (Olympus BX51). Wear particles deposited to a glass substrate, and it is used for microscopic examination fig. to fig. shows different types of wear occur.

5.1 Numerical result

Oil properties analysis

Viscosity of lubricating oil at 40°C, 100°C are checked and average readings are taken for more accurate result. The experimental outcome suggests that the physical properties of oil under different running condition. The kinematic viscosity at 40°C of fresh or unused oil (HP 80W90) is 157.7 cSt. The kinematic viscosity at 40°C of used oil (HP 80W90) are 154.9, 154.1, 153.6, 153.3, 152.6, 152.2, and 148.4 cSt for different running condition 43, 86, 129, 172, 215, 258, and 301 Hr. running of gearbox and the kinematic viscosity at 100°C of fresh or unused oil is 15.5 cSt. The kinematic viscosity at 100°C of used oil are 15.3, 15.2, 15.2, 15.2, 15.1, 15.1, and 14.8 cSt for different running condition 43, 86, 129, 172, 215, 258, and 301 Hr. working of gearbox. It is clearly seen that viscosity is showing decreasing trend due to friction. It indicates that increased wear because of friction which lead to decrease in viscosity.

Total Acid number (TAN) is very important parameter for conditioning and monitoring of oils. The results of total acid numbers will help us to decide residual life of lubricant. The sum of acidic compounds within the lubricants is called (TAN) that's described as number of milligrams of potassium hydroxide similar to the acidic compounds. TAN is a direct indication of oil oxidation considering the fact that acids generated during oil oxidation are directly predicted by titrating with base. TAN of fresh or unused oil (HP 80W90) is 0.2 mg KOH/g. TAN of used oil (HP 80W90) are 0.4, 0.4, 0.5, 0.5, 0.5, 0.6, 0.7 mg KOH/g for different running condition 43, 86, 129, 172, 215, 258, and 301 Hr. running of gearbox. TAN is displaying increasing fashion due to oxidation.

It is seen that from oil properties analysis degradation of lubricating oil is happen with respect to running hours of gearbox. Viscosity of oil is continuously decreased due to friction whereas TAN is continuously increased because of oxidation. it will result information of wear.

Ferrography analysis

All oil samples are checked with direct reading ferrography to know the count of wear particle. Large particles are seems to be increasing with running hours of gearbox. It means occurrence of large particle in wear formation is more whereas fluctuation is seen in small particles count. At some cases it is more and in some case it is less. As shown in Table 1. it is seen that value of $\sum DL$ are 161, 339, 542, 799, 1110, 1432, and 1766 for different running condition 43, 86, 129, 172, 215, 258, and 301 of gearbox. The values are continuously increase which shows that wear is also increase with running hours of gearbox. Wear particle concentration (WPC) is calculated by using formula and they are 297, 309, 345, 446, 544, 529, 480 for different running condition 43, 86, 129, 172, 215, 258, and 301 of gearbox. Up to 215 hours it is continuously increase which means there is increase in WPC. And in the last wear severity index is calculated and they are ranges from 29.59, 63.56, 87.20, 92.46, 104.11, 178.89, and 430 for different running condition 43, 86, 129, 172, 215, 258, and 301 of gearbox. For the last 301 hours WSI is quite high as compared to previous readings at the 301 hour wear is at the top.

Analytical ferrography analysis is carried out for all samples. Ferrogram 01 shows variety of particles like small cutting wear, sliding wear particles which indicate gearbox running-in. Debris particles deposited are smaller in quantity and smaller in size also. Figure 7 to 12 (for sample 1 to 6) shows different forms of wear debris generated during subsequent usage of gearbox. Thus, it indicates normal wear situation and worm and worm gear is the major source of wear with bearing least source of wear.

Ferrography analysis plays very important role after oil properties analysis it shows that there is continuous increase in large size wear particle, WPC, WSI. It means that wear is continuously increased because of oil degradation.

5.2 Graphical Results

In oil properties analysis to check the trend of decrease in lubricating properties graphs are plot against oil running hours.

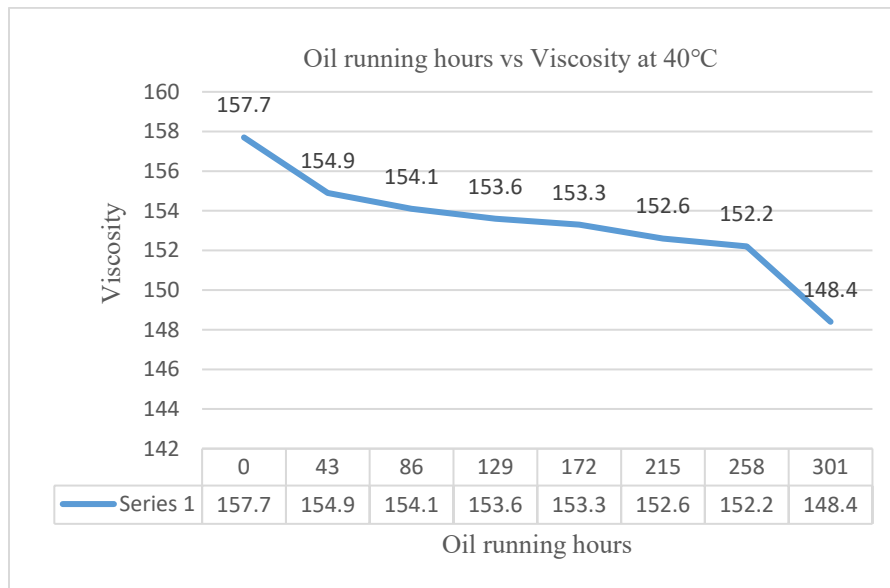


Figure 13. Plot of Oil running hours vs viscosity at 40°C

In the Figure 13 plot of oil running hours vs viscosity at 40°C is shown. It is clearly seen that viscosity of oil is decreasing. After 258 hours it is drastically changed to 148.4 cst. It means friction is more in gearbox.

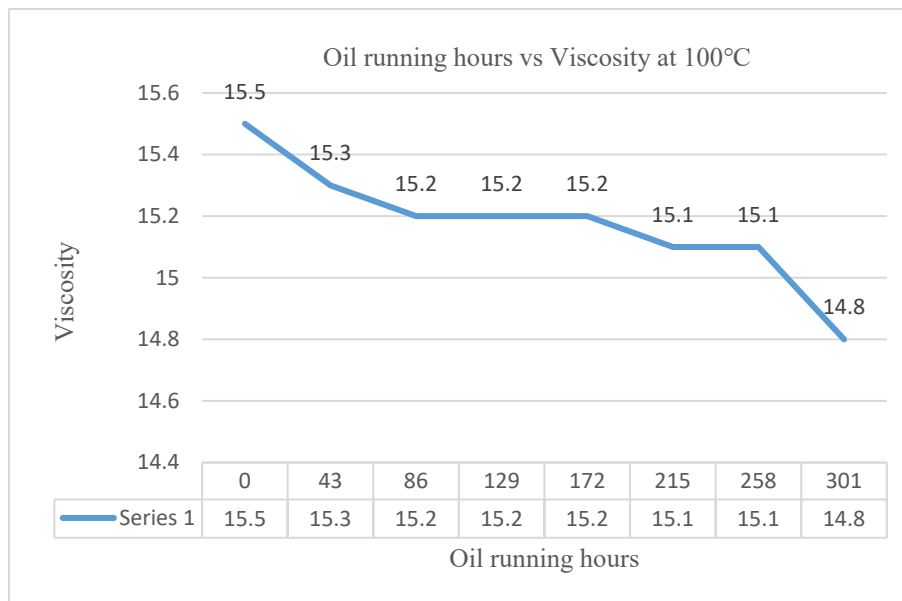


Figure 14. Plot of oil running hours vs Viscosity at 100°C

In the Figure 14 plot of oil running hours vs viscosity at 100°C is shown. It is clearly seen that viscosity of oil is decreasing. After 258 hours it is drastically changed to 14.8 cst. It means friction is more in gearbox.

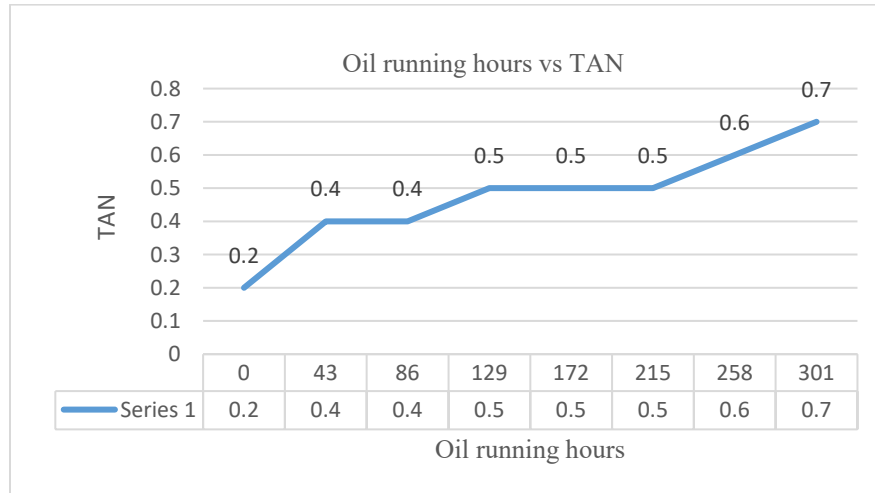


Figure 15. Plot of oil running hours vs TAN

In the Figure 15 plot of oil running hours vs TAN is shown. It is clearly seen that TAN of oil is continuously increased. It means oxidation is happen. After 215 hours it is increase in linear fashion to 0.7 est. It means oxidation is more in gearbox.

Overall, oil properties analysis shows there is degradation of oil with respect to running oil of gearbox.

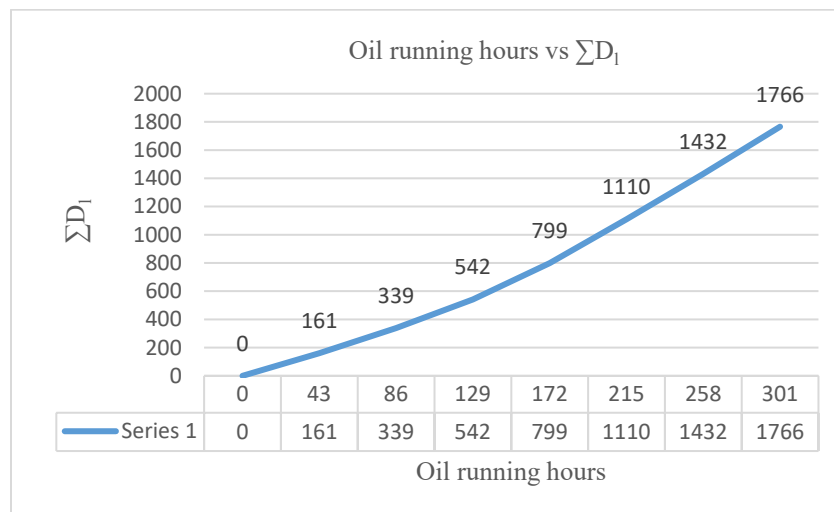


Figure 16. Plot of oil running hours vs ΣD₁

In the Figure 16 plot of oil running hours vs ΣD₁ is shown. It is clearly seen that ΣD₁ is continuously increased. It means continuous wear is happen. After 215 hours it increase much faster. That means there is more increase in wear after 215 hours.

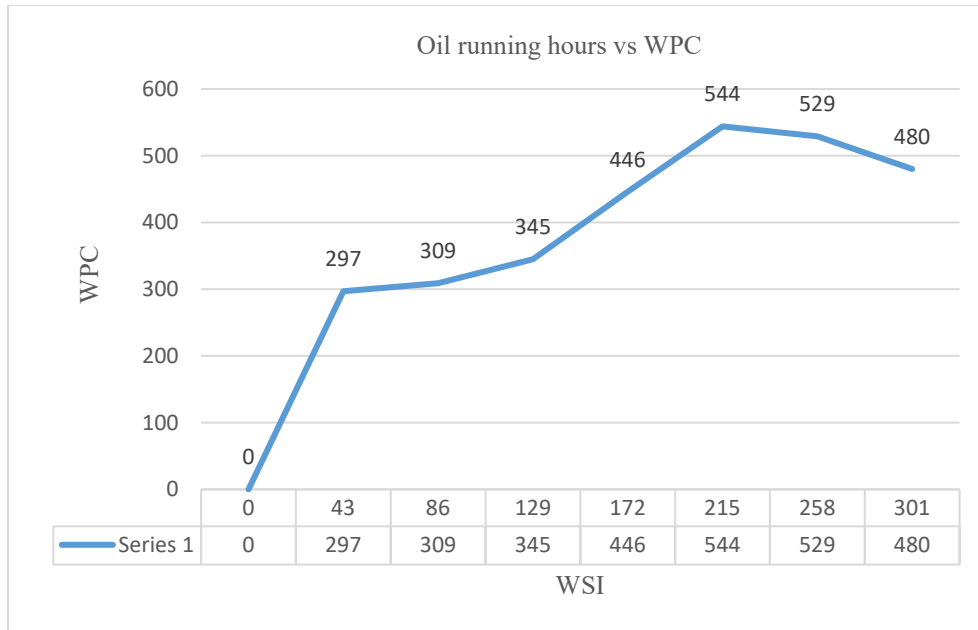


Figure 17. Plot of oil running hours vs WPC

In the Figure 17 plot of oil running hours vs WPC is shown. It is clearly seen that WPC is continuously increased from 0 to 215 hours It means wear rate is more on that span.

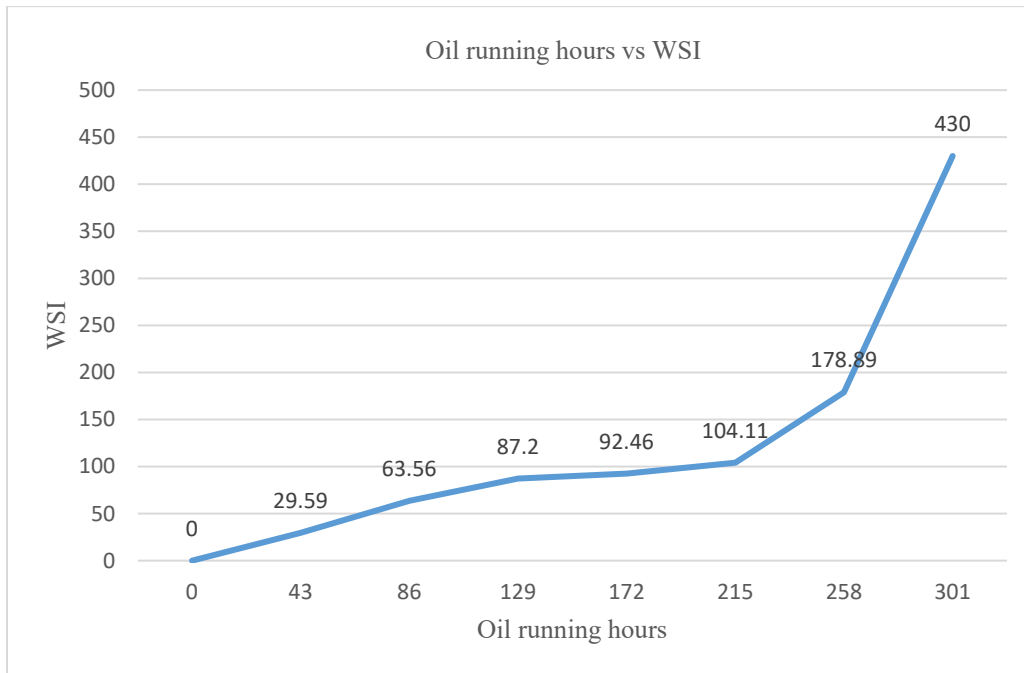


Figure 18. Plot of oil running hours vs WSI

In the Figure 18. plot of oil running hours vs WSI is shown. It is clearly seen that WSi is continuously increased from 0 to 215 hours but from 215 to 301 hours It means Since the value of WSI is very high. WSI trend inferred that the condition of gearbox might be critical or because of very bad condition of oil due to oil degradation and absence

of oil filtration in the system wear rate is more on that span. Overall direct reading ferrography shows there is continuous increase in wear because of oil degradation.

6. Conclusion

In this study, constant speed and load are applied to the single-speed worm gearbox system. Oil properties analysis and ferrography analysis have been used to investigate the condition of a single-speed worm gearbox under the normal operating condition. Oil properties analysis provides viscosity index and TAN No. which shows the viscosity of oil decreases with degradation of oil, and an increase in TAN leads to corrosion. Ferrography analysis provided wear rate, oil condition, type of wear mechanism, and source of wear.

In the case of oil properties analysis, kinematic viscosity goes on decreasing with time and TAN No. increases with time. the wear rate is low initially and it goes on increasing with time. Correlating these two condition monitoring techniques resulted in the comprehensive diagnosis of the operating condition of the worm gearbox. Because they are dependent on each other. As no. of running hours are increasing degradation of oil also increases, change in oil properties depends on the number of running hours and wear rate depends on the change in oil properties. It is seen that process parameter with no. of running hour cause a change in oil properties and a change in oil properties causes an increase in wear. From this study, we can conclude that change in oil properties impacts on wear of the gearbox which shows that both are the function of gearbox running hours.

A combination of oil properties analysis and ferrography analysis is very useful to find out the source of the problem if arises and to take corrective action as well as to make the condition-based maintenance policy to maintain and extend the life of the system.

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