LUBRICATING OIL CHARACTERISTICS OF VEGETABLE AND MINERAL OIL BASED LUBRICANTS AND THEIR BLENDS IN A TWO STROKE SI ENGINE

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Abstract Lubricating oil properties of vegetable and mineral oil based lubricants have been investigated in a two stroke SI engine. Three more blended lubricants prepared from varying proportion of vegetable and mineral oil based lubricants were also tested. The wear in piston ring was found to increase with running hours but the rate of wear in all of the piston rings was the minimum when the engine was tested with the blended lubricating oil which was prepared from vegetable oil (50%,) and petroleum based commercial oil (50%). The pure vegetable oil based lubricant (oil 100%) also showed better anti-wear characteristics than 100% commercially used mineral lubricating oil in a two stroke SI engine. The oil properties including viscosity, total base number (TBN), total acid number (TAN) and ash contents of vegetable oil based lubricants are found favorable and competitive to those of the mineral oil based lubricant. The flash point of vegetable oil was found lower than the commercial lubricant by 10^{o}C. But viscosity degration of commercially based mineral oil was nearly 4 times higher than vegetable oil when their temperature was raised from 40^{o}C to 100^{o}C

Key words: Vegetable oil, Lubricants, Wear, Viscosity.

INTRODUCTION

Vegetable oil has got extensive use in domestic areas but its application is limited in the industrial fields. Vegetable oil is used as a brake fluid in automotive industries specially for its anti-corrosive and lubricating properties but its application in the fields of lubrication is limited for reasons not known. The research investigations of the past six decades on mineral oil based lubricants have improved the oil properties like viscosity, total base number (TBN), total acid number (TAN), dispersing and detergent qualities etc. and diversified their uses in all fields of lubrication specially for all sorts of rotating and sliding parts of machinery, equipment, vehicles and transports. Naturally available mineral oil can not be used directly as a lubricating oil rather a series of processes have removed the undesirable substances from the commercial lubricants. Usually thermal distillation process separates and removes the low volatile substances (fuels) from the mineral oils (petroleum) products in the first phase. Later on vacuum evaporation and condensation process separate the lubricating oil from highly viscous tar like residuals from the remaining mineral oil. Apart from these additives packages are added to improve properties of lubricant including viscosity index, dispersing, and detergent quality specially to increase anti-wear characteristics and durability of service life. Additive like Zinc Dialkaldithiophosphate (ZnDTP) have improved anti-wear property of the commercial lubricants of the vehicle using unleaded gasoline [Kawamura, M. et al., 1991]. The investigation on the deterioration of engine.

oil shows that the engine oil additive (ZnDTP) reacts with lead (Pb) of blow-by gases and forms PbDTP, which reduces anti-wear characteristics of the engine oil. But the same additive (ZnDTP) remains unchanged with unleaded gasoline and improves anti-wear characteristics. Kawamura et al. further found that the additive (ZnDTP) decomposed during running hours and formed lubricative complex with detergent additive (Succinimide). In the experimental investigation it was found that the anti-wear characteristic was improved in presence of detergent additive. It was further noticed that the additives had the effects on the formation of the soot aggregates in the diesel engine oil. Most of the soot dispersed in diesel engine oil as small aggregates. But after prolonged running large aggregates were formed which might cause abrasive as well as corrosive wear.

Richard et al. [Demmin, R.A., et al., 1989] conducted a field test on the engine oil viscosity and bearing wear. Wear appeared to be acceptably low for the three highest viscosity oils. Bearing wear was much higher for lowest viscosity oil. It is further suggested that the minimum HTHS viscosity needed (limits of oil rheology) for adequate protection is somewhere

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between 2.6 and 2.8mPaδs .The effect of adpack quality on bearing wear was investigated by comparison of Newtoniam oils: API SF (C and B) to API SG (E and F). The more important comparison of oil C to oil E is in the low viscosity range where less protection is provided by rheology of oil and formulation chemistry will play a larger role. In all three categories of bearing wear, oil E was marginally better than oil C, however, the difference was not extreme. The benefits of higher quality package were not evident in comparison between high viscosity oils B and oil F. In that viscosity range, the difference in additive package have no apparent effect on wear. The test result [Demmin, R.A., et al., 1989] suggested that the adpacks used in the test did have a small effect on bearing wear, but it was secondary to that of viscosity. A number of investigators have cited that additive treatment as an important factor, sometimes more important than rheology .

During the operation period of the engine, piston ring and cylinder wall experiences severe thermal and mechanical stresses where the wear is predominant. S.B. Saville et al. [Saville, S.B., et al.,1989] studied lubricating condition in the piston ring zone of single cylinder diesel engines under typical operating conditions. The thin film layer of oil in this region is exposed to high temperatures and pressures; hot reactive gases from combustion (e.g. O_2, NO_x, radical, H_2O, mineral and organic acids); high shear stresses, and freshly worn metal surfaces could have catalytic effects. The combination of these effects can result in higher wear of rings, liners and in the formation of piston deposits. Furthermore, precursors and reactive species (such as free radicals) can be formed in the piston ring zone and transported to the sump where they can initiate new reactions.

Some additives are added to engine oil to retain its quality from degradation. The difference between the quality levels API SF and SG was driven by the need for better sludge and oxidization control. Many research investigations are found on the sludge test. Thermogravimetric analysis [Graf, R.T., et al.,1989] of drain and sludge shows that drain oil and sludge have the same contaminants but in varying proportions. Sludge mainly contains carbon (resin), ash and volatile organic. Ash content is found constant (1.3%) in VE new oil and drain oils but it increases in rocker sludge (3.9%). Carbon content increased to 8.2% in VE drain oil and 16.2% in VE rocker sludge though new engine oil contains only 0.1% carbon. The remaining volatile organic reduces with running hour. Sludge formation is undesirable in lubricating oil since it reduce detergent quality of oil which helps re-circulation of contaminants and wear scars. The re-circulation of hard solid contaminants is very harmful as it enhances wear. Thus impetus for API SG quality lubricants is due, in part, to insufficient slug control with API SF oils in field found services. But in the present research investigation it is the presence of soot (carbon) in the oil seems to reduce wear by varnishing effects and formation of lubricative complex.

The effects of oxides of nitrogen (NOx) on engine varnish and sludge formation have been investigated by R.S. Spindt et al. [Spindt, R.S., et al.,1951] and it is well known . Work of R.S. Spindt et al. had shown that varnish and lacquer deposits were high in nitrogen content . Chemical analysis of exhaust and blow-by gases had shown high level of NOx and nitric acid [Q. Payne, et al.1951]. Engine test [Spindt, R. S., et al,1965] with nitrogen free atmosphere (in which air was replaced by oxygen and carbon dioxide) produced little or no varnishes. When NOx was added to the crankcase atmosphere, the level of engine deposits increased dramatically [Spindt, R. S., et al.,1952]. The effect of fuel composition on the deposit formation is well known [Spindt, R. S., et al.,1952, Dimitroff, E., et al. 1969, Spilner, I. J., et al.:1981]. Fuels with a high level of heavy (>C9) aromatics give increased varnish formation [Dimitroff, E., et al. 1969]. Dimitroff et al reported that heavier olefins (> C7) or light aromatics such as benzene, toluene, and xylenes do not lead to varnish formation. Other authors have indicated that light olefin lead to varnish formation [Spilner, I. J., et al.:1981, PORIM,1983]. They indicated that olefins such as ethylene and propylene are from alkyl aromatics in the combustion chamber. R.S. Spilners [Spilner, I. J., et al.:1981] has measured higher olefin content in the blow-by than it was present in the original fuel [Spilner, I. J., et al.:1981].

However in the present investigation piston ring wear is found to be reduced with the blended lubricating oil C (50% vegetable oil and 50% commercial oil). But the piston ring wear increased with the blended oil D (30% vegetable and 70% commercial oil) when the exhaust gas produced large soot agglomerates with water.

Further research investigations to the improvement of vegetable oil may totally substitute the petroleum based lubricating oil in near future. The presence of common lubricating agent like aliphatic fatty acid ($C_nH_{2n+1}COOH$), specially stearic [$CH_3(CH2)_{14}CO_2H$] in vegetable oil [PORIM,1983, Masjuki, H. H., et al.,1994] has increased the concern of research investigation to use and improve the vegetable oil to engine oil and other lubricants. The present research work has the objectives to study the oil properties, piston rings wear and performance of a two-stroke SI engine running with vegetable and mineral oil based lubricating oils and their different blends.

EXPERIMENTAL SET-UP AND PROCEDURE

In this research investigation, a two stroke gasoline fueled generator engine was tested using its conventional lubricating oil E (100% commercial oil). Later on the same engine was tested using a vegetable oil based lubricating oil A (100% vegetable oil) and blends of vegetable and mineral oils. Three samples of lubricating oil were prepared from the blends of vegetable oil and mineral oil in different proportions. The blended oil B, oil C and oil D contained 70%, 50%, 30% vegetable oil respectively and corresponding admixture with mineral oil based commercial engine oil. The generator engine was tested at a constant speed with 220V and constant load of 0.3 kW.

The blended lubricating oil samples prepared from vegetable and mineral oil based lubricants are shown in table 1.

Table 1 Samples of lubricants.

Oil samples	vegetable oil (%v/v)	Commercial lubricant (%v/v)
Oil A	100	0
Oil B	70	30
Oil C	50	50
Oil D	30	70
Oil E	0	100

During the test of the engine with one sample of lubricant, the oil sample and piston rings (upper and lower) were taken out at every 5 hours interval in the cumulative 20 hours operation. The weight loss from individual the piston ring was taken as the measure of wear in the respective piston ring. After necessary cleaning and drying of the rings, they were weighed in an electronic balance. Degradation of viscosity with the rise of temperature of all the lubricating oils and blends were measured between the temperature 40^{o}C and 100^{o}C. Total base number (TBN) of a lubricant is the measure of alkalinity. The unit of TBN is measured by the number of milligram potassium hydroxide requires to neutralize one gram sample of lubricant. The properties of oil like flash point, total base number, total acid number and ash content were tested and measured in the core laboratory.

RESULT AND DISCUSSION

Piston rings wear

The figure 1 and figure 2 depicts the weight loss in upper and lower piston rings respectively with the five different lubricants and blends as shown in the figure. It is apparent from the both figures 1 and 2 that the oil A (100% vegetable oil) exhibits the best anti-wear characteristics to both upper and lower piston rings during the first five hours of operation. But after the first 5 hours of operation, the same oil A provides different anti-wear characteristics to upper and lower piston rings. It is further noticed that during the second 15 hours of operation the wear rate or the gradient of weight loss increased in the top of the piston ring. But the same decreased in lower piston ring when the engine was tested with the same lubricant A. The oil C which was a blend of 50% vegetable oil and 50% mineral oil based lubricant exhibited the best anti-wear performance to lower piston ring during last 15 hours of operation as shown in figure 2. The same oil C also showed similar performances to upper piston ring at the last 8 hours (12th to 20th hour) of operation. The pure vegetable oil based lubricant (oil A) also depicts similar anti-wear characteristic to bottom piston ring like the blend oil C (50% vegetable oil) and it is ranked second for lower piston ring though it is ranked third to upper

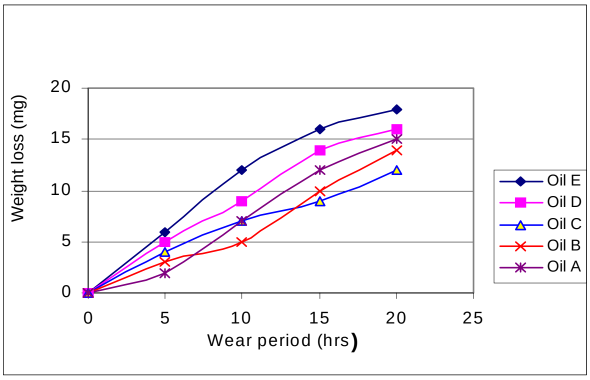

Fig. 1: Piston ring (top) wear Vs. Time

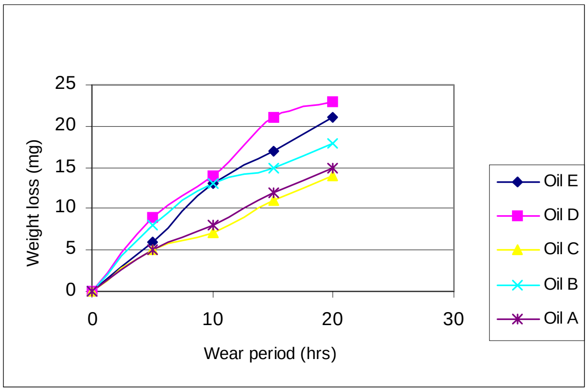

Fig. 2: Piston ring (bottom) wear Vs.Wear period

piston ring. The test conducted with commercially used mineral oils also showed less anti-wear characteristics and ranked 4th. The blended oil D (30% vegetable oil) showed the minimum anti-wear performance specially in the bottom piston and it is ranked 5th among the five samples of lubricants. The upper piston ring was also subjected to similar anti-wear characteristics but the wear rate enhanced in mineral oil based lubricant. The conventional mineral oil based lubricant ranked fifth for anti-wear characteristics of upper piston ring (Fig.1) though it is ranked 4 th for lower piston ring (Fig. 2). Thus the upper and lower piston rings are not subjected to similar wear-stresses as they depict two different anti-wear characteristics. It can be concluded that though the blended lubricating oil C (50% vegetable oil) offers the best anti-wear performance in operating condition probably from the varnishing effect of the lubricative complex generating smooth soot of the exhaust of vegetable oil. The vegetable oil based lubricating oil A (100% vegetable oil) also found competitive and even better than commercially used mineral lubricating oil in all operating condition. The additives present in the commercially used lubricants may be a cause of enhanced piston ring wear with mineral oil than vegetable oil based lubricant. Though the additives in the commercial lubricant may be a factor of enhancing piston ring wear but it reduces the volatility as well as flash point of the lubricant by elevating the properties. The additives in the commercial lubricants improve the oil properties specially to raise flash point, TBN, anti-oxidization and anti-foaming quality. The vegetable oil has low flash point. But the additives present in the mineral oil based lubricant have played a significant role to improve the flash point and lubricating property of the blended oil C having 50% vegetable and 50% mineral oil which showed the best anti-wear performance.

Viscosity of lubricant

The viscosity of single graded lubricant varies with temperature but the viscosity of multi-graded lubricant remains constant or may vary within the acceptable limits. The viscosity of the vegetable oil, mineral oil and their blends (oil A to oil E) was measured between 40^{o}C and 100^{o}C. The figure 3 shows the degradation of viscosity of the different lubricating oil samples. It is found that the viscosity of commercial lubricant of the two stroke SI engine degraded more acutely from 80 cSt to 35 cSt when the temperature of the lubricant was raised from 40^{o}C to 100^{o}C. On the other hand the degradation of viscosity in the vegetable oil based lubricating oil A (100% vegetable oil) is found the minimum where the viscosity reduced from 35 cSt to 25 cSt within the same temperature range. It is apparent that the viscosity degradation is nearly 4 times higher in commercial lubricant than vegetable oil based lubricant. Thus the vegetable oil based lubricant behaves as a multi-graded lubricants which favors anti-wear characteristics may be used in extreme operating conditions of summer and winter seasons like multi-graded oil.

Flash point

Flash point of a lubricating oil is the indication of phase changing temperature from liquid phase to gaseous state. The figure 4 depicts the variation of flash points of vegetable and mineral oil based lubricants and their different blends. The mineral oil based lubricant has the higher flash point (126.5^{o}C), than the vegetable oil based lubricant (110^{o}C). The addition of vegetable oil in mineral oil based lubricants reduces the flash point of the blend to a value closer to the flash point of the vegetable oil. It appears that the vegetable oil based lubricant contains some low volatile organic substances deplete it flash point. The flash point of any lubricant may be improved to a higher value by mechanical and chemical processes. The distillation and removal of low volatile substances from any lubricant may elevate the flash point. Moreover the addition of chemical some additives can also elevate the flash point of vegetable oil from 110^{o}C. to upper values. All lubricants vaporize more or less in the combustion chamber. But the vaporization of lubricant in the combustion chamber produces lubricating complex, which reduces wear in the cylinder and piston rings.

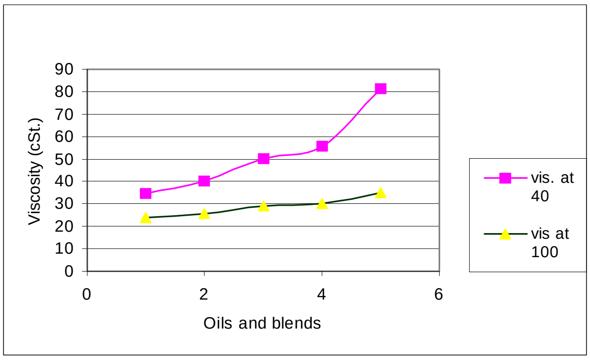

Fig. 3: Variation of viscosity of oils and blends

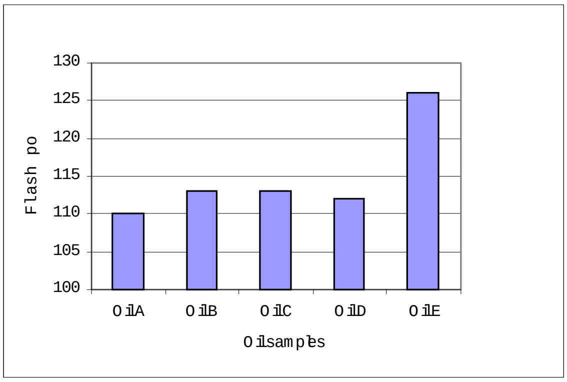

Fig. 4: Flash point Vs. Oil samples and blends.

Total base number (TBN)

Total base number of a lubricant is the measure of alkalinity. The unit of TBN is measured by the number of milligram potassium hydroxide requires to neutralize one gram sample of lubricant. From the figure 5, it is seen that the oil A (100% vegetable) has the highest TBN (3.90) while the oil D (30% vegetable) has the lowest TBN (3.25). The mineral oil based commercial lubricant has TBN (3.75) very closer but lower value to that of vegetable oil based lubricant. The addition of alkaline-based chemical additives in any lubricating oil can improve the TBN. Thus it is seen that the natural vegetable oil based lubricant has the TBN favorable to minimize wear rate but TBN value of commercial lubricant is increased by additive package which may have adverse effects in the wear rate when engine oil vaporizes inside the combustion chamber.

Total acid number (TAN)

Total acid number of any lubricant is the measure of total amount of both weak and strong acidity present in the lubricant. The figure 6 shows that total acid number (TAN) of commercial lubricant is higher (0.70) than the total acid number of vegetable oil (0.44). All lubricants should have lower TAN value for improving it anti-oxidation properties. Higher TAN value of lubricant is more favorable to oxidation as well as to enhance wear rate. TAN value of the blended lubricant decrease with

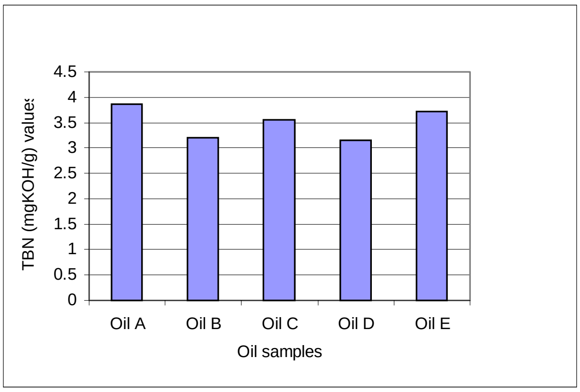

Fig. 5: TBN (mgKOH/g) Vs. Oil samples

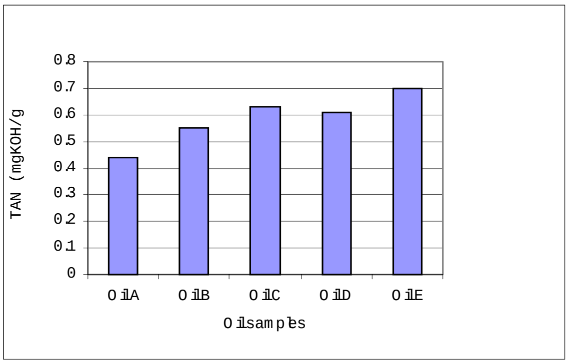

Fig. 6: TAN (mgKOH) Vs . Oil (g) samples

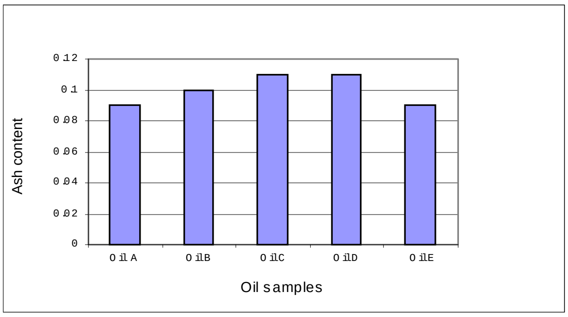

Fig. 7: Ash content Vs. Oil samples

of the percentage of vegetable oil. Total acid number of any lubricant may be artificially decreased with the addition of alkaline substance.

Ash content

Ash particulate is generally formed from the oxidation of dissolved inorganic substances and additives present in mineral fuel and oils. Ash particulate may also be formed from the unburned inorganic substances. The figure 7 shows the ash content of the different lubricants and their blended lubricants. It is found that the oil D (30% vegetable oil) has the highest ash percentage (0.11% w/w). The presence of more ash content in lubricating oil is the cause of more wear rate with the lubricant. The pure vegetable oil and the commercial oil have the lowest ash content (0.09% w/w). Thus the lowest ash content in vegetable oil plays an important role of better anti- wear characteristics.

CONCLUSIONS

1. The vegetable oil based lubricant and their blends (oil A, B, C) have better anti-wear quality to both piston rings (upper and lower) than mineral oil based commercial lubricant E.

2. Vegetable oil based lubricant shows very small change of viscosity (10.54 cST) within the temperature interval of 60^{o}C (i.e. 40^{o}C to 100^{o}C). But the viscosity of mineral oil based commercial lubricant changes very sharply (46.19 cSt) within the same temperature interval. Thus vegetable oil based lubricant behaves like multigraded viscosity oil where the response of viscosity gradient with temperature is negligible and favorable to minimize wear rate at high temperature.

3. Flash point of vegetable oil based lubricant is 110^{o}C but that of commercial lubricant is higher (126^{o}C). Thus commercial lubricant has a higher flash point which favor less oil evaporation from combustion chamber during combustion period.

4. Research investigation of vegetable oil based lubricants should also be extended to further uses where the oil operating temperature is low and in the equipment using lower viscosity lubricant.

5. `Further research investigations and improvement of some properties of vegetable oil based lubricant may diversify its uses in many areas and may substitute mineral oil based lubricants from broad areas in near future.

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