PERFORMANCE EVALUATION OF A LUBRICANT DUE TO INCREASING THE WORK TIME IN TRUCKS OPERATING IN HEAVY DUTY SERVICE

Alencar Pedroso Filho, alencar@apep.com.br
Agronomist Engineer, studying MSc by Faculdade de Engenharia de Bauru UNESP / Mechanical Engineering, emphasis on Thermodynamics, Member of SAE (Brazil), AEA (Brazil) e STLE (USA); AP Engineering (Jau-SP).

Marco Antonio Lopes Garcia, marco.santal@canamaq.com.br
Agronomist Engineer, MSc by ESALQ USP – emphasis on Agricultural Mechanization, Piracicaba (SP); CANAMAQ (Assis-SP).

Renato Rodrigues Silva, renato.rrsilva@gmail.com.br
Agronomist Engineer, MSc by ESALQ USP – ênfase em Estatística e Experimentação – (Piracicaba-SP).

Vicente Luiz Scalon, scalon@feb.unesp.br
Mechanical Engineer, PhD, Professor at the FEB UNESP / Bauru (SP) – Mechanical Engineering; (Bauru-SP).

Alcides Padilha, padilha@feb.unesp.br
Mechanical Engineer, PhD, Professor at the FEB UNESP / Bauru (SP) – Mechanical Engineering; (Bauru-SP).

Abstract. *The life of a lubricating oil for diesel engines is conditioned by different variables. The viscosity, the TBN (Total Base Number) and fuel soot are important indicators attest to the conditions of an oil in use. It was proposed to increase the period of service charge of lubricating oil in a diesel truck fleet sugarcane. We evaluated the increase in service 33%, passing the exchanges that were performed at 15,000 km to 20,000 km. The work aimed at optimizing the use of lubricant and lubrication to reduce costs. Thus, 22 trucks participated in the test for two years, during which samples were collected periodically lubricating the engine every 5,000 km and analyzed in the laboratory to verify the performance of the lubricant in use. The results showed that the concentration of soot and viscosity were not affected by the additional service charge of oil. Since the alkalinity is their behavior conditioned by time of using the lubricant, that is, as it increases the length of service of oil charge, decreasing its alkalinity. In the proposed work, despite the increase of oil cargo service, the alkalinity has not reached its critical level, thus enabling its use for a longer period of time without compromising the engine.*

Keywords: *lubricant, physico-chemical properties, wear and lubricant life.*

1. INTRODUTION

By the multiple functions a lubricant has as friction reducer, wear reducer, cooling, cleaning and corrosion protection, the lubricating oil is an agent of the utmost importance in life and durability of equipment. Runge *at al.* (1994) emphasized that the useful life of lubricating oil is conditioned by different variables, being the viscosity, the alkalinity and the fuel soot are important indicators to demonstrate the quality and properties of lubricating oil in a diesel engine.

Recently, Toms and Toms (2008a), presented that the viscosity, in general, is the measure of the internal friction of a fluid or the resistance to flow, or yet the ratio of shear stress (shear strain rate). Due to its simplicity, the kinematic viscosity is the most popular measure used to determine the nominal viscosity of lubricating oils.

Still according to Toms and Toms (2008b), the determination of the kinematic viscosity of a fluid is the time it takes an oil sample to flow through a capillary tube under the influence of gravity. This capillary tube is immersed in a preheated bath providing stability and reproducibility of the test results. One of measurement unit for viscosity is the Stoke, which is equal to one square centimeter per second. But in the case of the kinematic viscosity measurement of lubricating oils a smaller unit is used, the centistokes (cSt), which is equal to one square millimeter per second. Kinematic viscosity is usually performed at a temperature of 40 °C or 100 ºC, thus standardizing the results and allowing the comparison between different users.

As cited by Trujillo (2004a), in his paper titled *"Resetting Oil Analysis Parameters for Changing Diesel Engines"*, viscosity is one of most important properties of the fluid and should be kept within preset limits for an optimum lubrication. These limits for viscosity, yet according to the same author, are set for two alert zones: one considered *"Warning"* and another *"Critical"*. In this *"Critical"* zone the conditions of the fluid will substantially favor the installation of catastrophic failures. In Table 1, it is specified limits for each of these alert zones:

Table 1: Parameters considered Limits for Oil Viscosity, according to Trujillo (2004):

Parameters for Viscosity at 100 ºC	
Warning Limits	- 5%
	+ 10%
Critical Limits	- 10%
	+ 20%

The Table 1 gives us the limits that indicate whether a lubricant shows a fall of 5% or a 10% increase in original viscosity, it will be telling us that this lubricant must be kept in an alert status and should be monitored with greater frequency. On the other hand, if the lubricant shows a fall of 10% or a 20% increase in its original viscosity, then this situation will be considered critical, and urgent measures must be taken to prevent catastrophic failures in this engine.

Another important property of lubricating oil for diesel engines is their alkalinity, called TBN - Total Base Number[1]. This alkalinity is designed to neutralize the acids formed during the process of fuel combustion , as cited by Carreteiro and Belmiro (2006). A fuel with significant sulfur content will contribute to acid formation during the combustion process. Then, these created acid formations in the engine, will be gradually neutralized by the alkalinity of the lubricant in use. According to Trujillo (2004b), the limiting indicator of the oil load life of the engine is when the TBN is as high as 50% of the original TBN of the lubricant, when new. He also parameterizes that if a diesel engine lubricating oil achieves a reduction of 75% of the initial value of the TBN, it will be in a critical area of work and damage will occur in the engine.

The Fuel Soot[2], also a residue of diesel engine combustion, is insoluble particles that are dispersed in the load of the engine lubricating oil and are highly abrasive, as reported by Evans and Hunt (2004).

As cited by Trujillo (2004c), the fuel soot is formed during the combustion process and enters the crankcase through the phenomenon called blow-by. This blow-by is the crossing of the engine lubricating oil gases from the combustion chamber to the crankcase. The carbonaceous fuel soot is of 98 percent in weight and has an original size from 0.01 to 0.05 micron, but tends to agglomerate to form larger particles in the crankcase. Fuel soot levels generally increase with the mileage and fuel consumption. Excess of fuel soot increases the viscosity of oil, leading to high temperatures, higher pumping costs, energy loss and the risk of boundary lubrication, especially in the *"cold start"*, a fact that increases engine wear. The lubricating oil ability to disperse the fuel soot is essential to the prevent polishing of the cylinder. It is also reported the fuel soot effects on the antiwear lubricant additives, with significant loss of this property.

The main objective of this experiment was to optimize the lubricating oil ability work time of the lubricant oil loads in diesel trucks operating in heavy duty service, in the transport of sugarcane. In the background, it also aimed to increase the operational efficiency of this the fleet. The analytical results of the oil samples were periodically monitored to not exhausting the lubricant and to not damage the engine in test.

It was mainly monitored three physic-chemical properties of the lubricant oil, which are: the Viscosity, the Total Number Number and the Fuel Soot. There was then an increase in service life of over 5000 km (increase of the lubricant oil load of 33%). Additional tests, such as Flash and Fire Point, presence of water and determination wear of the engine via atomic absorption spectroscopy with the determination of the concentrations of metallic elements present in oil samples collected periodically, that were crucial in this aforesaid paper.

---

[1] Total Base Number (TBN) – in this experiment we used the methodology ASTM D 2896.

[2] Fuel Soot – in this experiment we used the methodology Chevron/Texaco SP 24c.

2. RATIONALE OF THIS TECHNICAL PAPER

Several technical papers are produced in the United States and European Community countries , emphasizing the reduction of the generation of environmental liabilities, the reduction in consumption of oil products and the reduction of operating costs.

One of the successful programs and one of the best known in relation to the management of lubricant in use, is the "*Centinel Advanced Engine Oil Management System*", reported by Cummins USA (2011). This system provides increased durability of lubricant oil loads in engines of road transport trucks, with extended protection of internal combustion engine. The program itself is an advanced management system of engine oil, with oil load change intervals loads every 525,000 miles, or every 844,906 km run, and with oil filter element change every 75,000 miles or every 120,701 km for trucks in use in heavy duty service in motorways in the United States. As for trucks operating in industrial service, it is expected to change oil load every 4,000 hours of service, which equals 200,000 km run and change oil filters every 1,000 hours service, equivalent to 50,000 kilometers. The engines covered by this system, have ongoing management of engine operation observed by of Cummins technicians and by driver users, which enable immediate action in case of any observed abnormality.

Our goal was to show users that increasing safely the working time of the oil load will not cause problems to the engine as lubricants currently available and sold by Brazil's big oil companies, meet the most stringent specifications of SAE (Society of Automotive Engineers - USA), API (American Petroleum Institute - USA) and CMA (Chemical Manufacturers Association - USA).

It was also supposed to motivate automakers and manufacturers to research and develop similar programs to the Centinel, that cover the same success achieved by that automaker, and which are now north to users in the United States of America.

2. MATERIALS AND METHODS

For this experiment it was selected 22 Volvo Trucks, models FM 12-380 and FM 12-420, with similar mileage, equipped with internal combustion diesel engine. The trucks odometers were with an average mileage of 253,000 kilometers, and were used for transporting sugarcane, operating in the northern region of Parana State, in Brazil, in mixed "*latossol*" soils, at an altitude of 460 meters of the sea level. In these trucks it was adopted the system of 20,000 km for effecting oil load change of the engine instead of 15,000 km previously established.

The lubricant tested was a multigrade oil, that met the specifications of SAE 15W-40, CI-4/SL API, ACEA E7/A3/B3/B4-04, E5/E3/A3/B3-B4-02, Global Oil DHD -1, were with approvals DC-MB 228.3, Volvo VDS 3, Cummins CES 20/071-6, Mack Truck EO-M Plus , 271/M3276 MAN, MTU Type 2, Allison C-4, Caterpillar ECF-1.

After filling the engine with this lubricant, samples were taken periodically every 5,000 kilometers of service, taking into account comments made by Toms and Toms (2008c) cited in the text *"Establishing an Optimum Sample Interval"*. These samples were sent to two laboratories specialized in analysis of used lubricating oils in two Sugar and Alcohol Mills, one in São Paulo, which performed the tests for determining the Total Base Number and another Lab, in the State of Parana, which carried out the controls on Viscosity, Fuel Soot and other additional tests previously mentioned, in order to verify the typical characteristics of these lubricant loads, its contaminants, as well as wear levels on the engines involved in the program. The analytical methods used in this experiment are listed in Table 2 below. The test program included tests standardized by ASTM - American Society for Testing and Materials, and methodologies Chevron/Texaco for spectrometric tests and determination of the Fuel Soot.

Table 2. Methodologies Used for Used Oil Samples Analysis:

METHODOLOGIES USED FOR OIL SAMPLES ANALYSIS		
Description of Method	Number of Methodology	Goal
1. Appearance	-	abnormal visual aspects
2. Odor	-	abnormal olfactory aspects
3. Kinematic Viscosity cSt at 40 ºC	ASTM D 445	viscosity at 40 ºC ($mm^2.s^{-1}$)
4. Kinematic Viscosity cSt at 100 ºC	ASTM D 445	viscosity at 100 ºC ($mm^2.s^{-1}$)
5. Viscosity Index	ASTM D 2270	viscosity index
6. Fuel Soot	Texaco SP 24c / Chevron	fuel soot, percent
7. Flash Point	ASTM D 92	qualitative for fuel
8. Fire Point	ASTM D 92	qualitative for fuel
9. Presence of Water	-	qualitative for water
10. Distillation	ASTM D 95	qualitative for water
11. Total Base Number (TBN)	ASTM D 2896	alkalinity reserve of oil (mg $KOH.g^{-1}$)
12. Atomic Absorption Spectroscopy	Texaco / Chevron	wear of engine (ppm)

Additionally, using spectroscopy methods with one Atomic Absorption Spectroscopy (AAS), Varian model Spectra A 220, it was determined the concentrations of the wear elements of the engine parts, such as iron, copper, chromium, lead, aluminum, nickel, tin and molybdenum. It was also monitored the entry of dust in these engines, with analysis of the silicon concentrations in these engines, noting citations in work of Fitch (2000).

These additional tests with atomic absorption spectroscopy were only intended to monitor the wear of each of the engines involved in the test program, periodically, so there was no impairment in their service life, nor interfere with the real goal of the experiment, which was designed to evaluate the performance of lubricating oil loads working in one strict regime with oil load change expected for 20,000 km. These spectrometric analyzes were necessary to allow engine parts to keep their characteristics preserved and the experiment assured.

Of physical-chemical analysis of all trials performed as shown in Table 2, the main requirements evaluated were: Kinematic Viscosity according to ASTM D 445 Method, Alkalinity of the oil (TBN – Total Base Number) following the method ASTM D 2896, and Fuel Soot as determined by the CHEVRON/TEXACO SP 24c.

With these results, it was elaborated a correlation between their values the new suggested mileage. The values of TBN, Kinematics Viscosity and of the Fuel[3] Soot were confronted with the mileage data of the changes through statistical analysis, drawn from R Software , in order to evaluate the behavior of these variables due to the increase of the service life of the lubricant oil load by 33%.

3. RESULTS AND DISCUSSION

The results presented in the scatter plot (Figure 1) show there is no trend of decreasing viscosity with the increasing of the service life of the lubricant oil, and by increasing the suggested mileage for the oil load change to lubricant is not prone to the loss and neither to increase viscosity thus ensuring the lubrication characteristics decurrent of this variable.

In the Variance Analysis (F Test) for the variable viscosity, the Found F (0.173) was lower than the tabulated (0.8956), indicating that all averages of viscosity along the time are equal in terms of statistics ie with the increase of

---

[3] (R Software) - R Project for Statistical Computing: R provides a wide variety of statistical and graphical techniques, including linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering, and others.

5,000 km in the service life of the lubricant oil there is no significant viscosity loss and if it was observed it could lead to problems of wear on truck engines.

Some factors could have altered the viscosity of oil loads and they were carefully monitored . Trujillo (2004d) provided us with references about adverse factors for increasing or decreasing viscosity in lubricant oils and they are presented in Table 3 below:

Tabela 3. Causes of increase and decrease of Viscosity, by Trujillo (2004).

Increased Viscosity	Decreased Viscosity
1. High concentration of Fuel Soot	1. Dilution by fuel
2. Oxidation of oil lubricant	2. Presence of water not emulsified
3. Presence of emulsified water	3. Shear of polimers VI Improver
4. Glycol contamination	4. Adding oil with lower viscosity
5. Adding oil with higher viscosity	

We must also consider the aspects of the composition of diesel fuel used in Brazil. Let it be registered here, another factor that could contribute to the decreasing of viscosity: sometimes there can be a contamination of the lubricant oil of the engine by LCO[4] . This LCO is sometimes in the blend of the diesel, those with concentration of naphtha. It is added to correct the final viscosity of this fuel diesel. Then it can occur, according to system of the engine operation, poor fuel combustion of diesel fuel when injected into combustion chamber, promoting the crankcase oil contamination by this lubricant LCO present in the diesel and that was not *"burned"* in the chamber fuel combustion.

But with all these comments above controlled no significant increase or decrease of the viscosity was observed by these factors related by Trujillo (2004e) during tests in these two years.

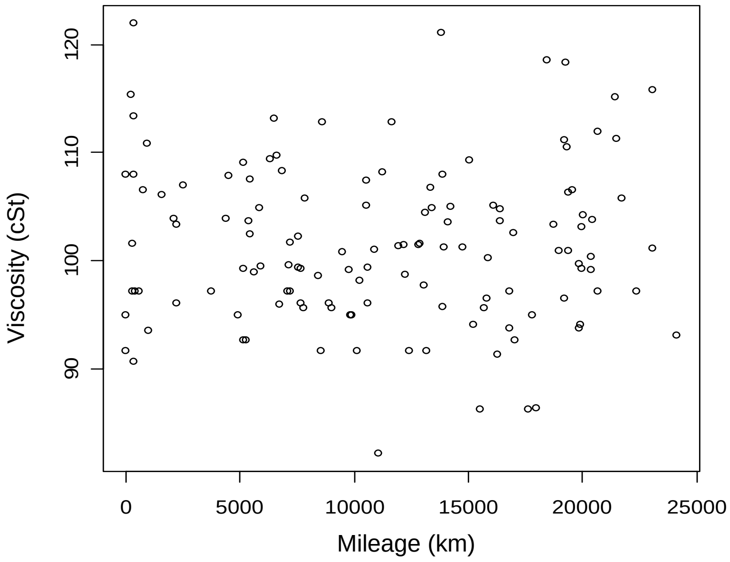

Figure 1: Scatter plot of viscosity measured in centistokes (cSt) according to usage load of lubricating oil, measured in kilometers.

---

[4] LCO - Light Cycle Oil

In relation to the variable of Fuel Soot, analyzing scatter graph (Figure 2), there is a concentration of data in the range of 0.5% although with the increasing of the mileage of the oil load change it has been an increase in the data in the range of 0.8%, which does not show one tendentious in the behavior graph that shows there is no correlation between the increasing in the percentage of soot in the lubricant oil with the increasing of its service life.

However through the variance analysis, it was observed was a significant difference in the percentages of Fuel Soot along the time, once the Found F (4.445) is greater than the Tabulated F (0.0367). Such percentages do not compromise the good performance service life of the lubricant oil and as a consequence of the engine of the trucks analyzed because they are below specified critical levels , according to reported by Drew and Fitch (1999). Still according to this author if there were contamination with high concentrations of fuel soot, it could occur dispersancy significant loss of the lubricant, performance loss of the anti-wear additives and significant increase in oil viscosity. These three factors were not observed as predominant trend in these two years of testing.

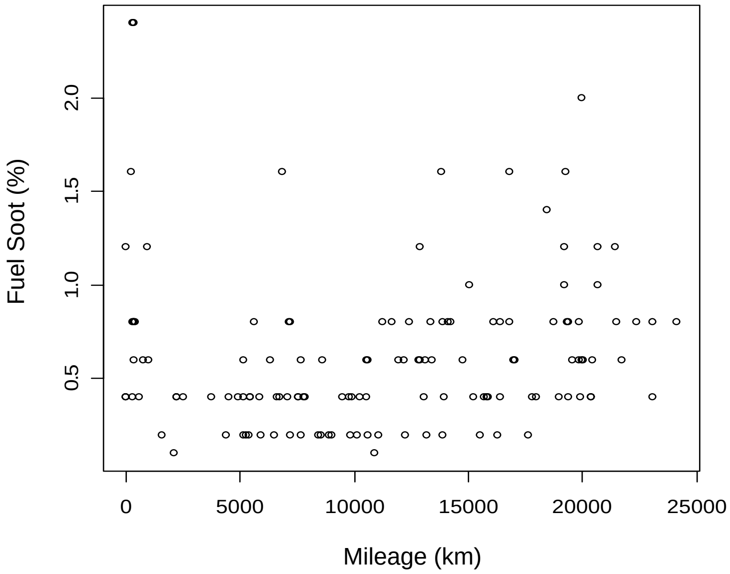

Figure 2. Scatter plot of soot (%), according to usage load of lubricating oil, measured in kilometers.

On the issue of the variable alkaline reserve (TBN), there is one decreasing linear tendentious in the behavior (Figure 3) along the mileage of lubricant oil change, ie, with the increase in oil service life there was reduction in the alkaline reserve of the lubricant, what could adversely affect in the maintenance of the engines of trucks if the loss of alkaline reserve was high, greater than 50% as cited by Trujillo (2004f).

By the analysis of variance such hypothesis was a confirmed, once the Found F (62.008) was much higher than the Tabulated ($1,185.10^{-12}$), ie, one can define a model where with increase in mileage occurs a decrease of the alkaline reserve, showing a difference of view between the statistical averages of along the mileage.

However, such decline does not reach the minimum acceptable levels which is 50% of the original TBN, as cited Trujillo (2004g) for a lubricant with original TBN greater than 10, allowing the load of oil to continue being used without any risk of acid corrosion in the engine.

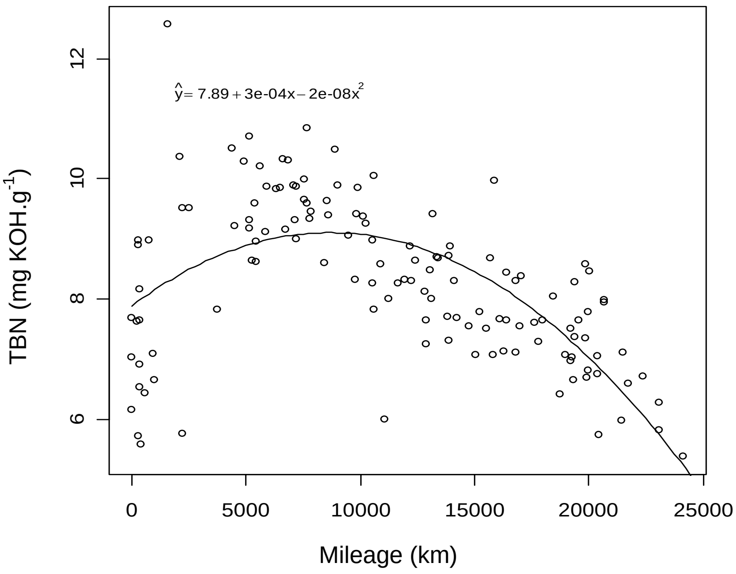

Figure 3. Scatter plot of alkalinity according to usage load of lubricating oil measured in kilometers. Note to the decrease in alkalinity, but to reach 20,000 km, the charges still had TBN average around 6.5 mg KOH.g^{-1} oil (greater than 50% of the original TBN).

There were no significant changes in levels of wear in any of the twenty diesel engines periodically monitored during two years of tests, or that were related to any of the three properties monitored in the experiment: Viscosity, TBN , and Fuel Soot.

4. CONCLUSIONS

It was proved that the increasing of 5,000 km (33% of the original) for a lubricant oil load change of these internal combustion engines, operating in this system of this region, did not affect its typical characteristics such as viscosity, and soot.

The variable alkalinity TBN decreased as expected as the load of oil was reaching 20,000 km but without reaching the critical limit, which was 5.5 mg KOH.g^{-1} for the lubricant in use. This made possible an increasing in the service life of lubricating oil loads as long as monitored by analysis attesting its quality, with the additional tests mentioned.

The results show a projection of reducing the consumption of 2,592 liters of lubricating oil, an economy with a total value of approximately R$ 35,000.00, with reductions in the oil load changes (72 oil load changes less) during the testing period. Thus the operational efficiency of the fleet of trucks was increased because there were fewer shutdowns for the lubricant preventive maintenance of the oil load changes, also contributing for the reduction of logistics costs.

It must be emphasized intangible benefits such as reduction of environmental pollution, less generation of environmental liabilities and the decreasing of the pressure on oil reserves.

It would be advisable that further studies were developed, combining high-performance lubricants, as the synthetic ones for example, in applications in heavy duty service, as in sugarcane industry, mining or road transport of cargo. Engine components should be investigated, such as new alloys for the lubricant coating of the piston heads and piston rings coatings, aiming to increasing of durability of these vehicle engines.

We suggest further studies and more detailed analysis for mileage increased beyond which was purpose of this paper, about the wear of components such as pistons, cylinder liners, piston rings, bearings, crankshaft and valve train, so there is not a severe wear on the engines.

5. BIBLIOGRAPHICAL REFERENCES

Runge, P.R.F., Duarte, G.N., and Gemperlé, R., 1994, "Lubrificação Automotiva", São Paulo, Brazil, Triboconcept Publishing.

Carreteiro, R. P. and Belmiro, P. N., 2006, "Lubrificantes e Lubrificação Industrial", Rio de Janeiro, Brazil, Interciência Publishing, IBP.

Toms, L. A. and Toms, A. M., 2008, "Machinery Oil Analysis – Methods, Automation & Benefits", Illinois, USA, STLE Publishing, Third Edition.

Evans, J. S. and Hunt, T. M., 2004, "Oil Analysis – Machine & Systems Condition Monitoring Series", Oxford, United Kingdon, Coxmoor Publishing.

Fitch, J. C., 2000, "Sorcebook for Used Oil Elements", Tulsa, USA, Noria Corporation Publishing.

Drew, T. and Fitch, J. C., 1999, "Oil Analysis Basic", Tulsa, USA, Noria Corporation Publishing.

Trujillo, G, 2004, "Resetting Oil Analysis Parameters for Changing Diesel Engines"; Practicing Oil Analysis Publishing, <http://www.machinerylubrication.com/Read/561/oil-analysis-diesel-engine> March,23, 2011.

Cummins USA, 2011, "Centinel Advanced Engine Oil Management System"; March, 23, 2011; Cummins USA; <https://quickserve.cummins.com/info/qsol/products/newparts/centinel.html>