

Estimation of Oil Drain Life of Engine Oils in New Generation Diesel Engines in Tropical Conditions

M.V. Ganesh Prasad
Engine RD Ashok Leyland, Ltd.

P A Lakshminarayanan

ABSTRACT

Field trials are carried out on diesel engines operating in tropical conditions at higher dust levels, temperature, humidity and load factor than the European and North American conditions. Passenger buses and trucks with engines of sump capacity 0.061-0.110 litre/hp and SAE15W40 viscosity oil meeting API CG-4+, API CH-4, API CI-4 from Group-I and Group-II base stocks are considered. Results show that the CH-4 oil is best suited for the subject engines. Oil drain interval is found proportional to the sump volume for the same stress on oil. Group-II base oil performed better than Group-I in limiting TAN and controlling oil consumption. Cost effective oil with a TBN of eight is sufficient with low-sulphur fuels without affecting oil drain interval. Iron concentration and kinematic viscosity decide useful oil life with respect to the limits fixed by the engine manufacturer. Oil life is found to be higher for passenger buses than trucks. The engine wear is more a function of silica concentration, load factor and age than the API category of oil.

KEY WORDS: oil life, Engine life, Wear, Oil stress

CITATION: Prasad, M. and Lakshminarayanan, P., "Estimation of Oil Drain Life of Engine Oils in New Generation Diesel Engines in Tropical Conditions," *SAE Int. J. Fuels Lubr.* 5(2):2012, doi:10.4271/2011-01-2405.

INTRODUCTION

Lubricating oil as a part of the engine build performs critical functions necessary to transmit the forces from moving parts to stationary parts or to other moving parts, and maximizes useful service life of engine. It is replaced like other serviceable parts, e.g., piston, rings and bearings after a life period when its physical and chemical properties, wear metals and other contaminant concentrations are high. One of the critical measures for engine oil performance is the drain interval, that is, how long oil should remain in an engine before it is changed. Oil service intervals are designed by engine manufacturers to provide maximum engine protection under a wide variety of operating conditions. The intervals depend on engine design, severity of the operating conditions, environment factors such as dust, ambient temperature, operating altitude and fuel quality, in addition to the load hauled by the vehicle. Improving diesel fuel quality, engine design, combustion and reducing oil consumption increases longevity of oil. There are significant developments in lubricating oil technology to meet growing demands for longer oil service intervals considering the conservation of natural resources, environmental pollution, reducing

operating costs and downtime and meet stringent exhaust emission standards

EFFECT OF FUEL QUALITY

Sulphur concentration in fuel is one of the critical parameters in determining fuel quality as it leads to the formation of sulphuric acid during combustion which corrode the engine components. Engine oil, due to the addition of bases in it, prevents corrosion by neutralization of the above acids. Basicity of engine oil indicated by Total Base Number (TBN) is the ability of the oil to neutralize acids. [Figure-1](#) shows the impact of sulphur concentration in fuel on TBN. It can be observed that the depletion in TBN is 7.5 mg KOH/g with a sulphur concentration of 1.5% and 2.5 mg KOH/g with 0.5% sulphur concentration [1].

EFFECT OF EMISSION STANDARDS

For reducing nitric oxides emissions, new diesel engines use exhaust gas recirculation (EGR) and are designed to operate at retarded injection timings. Consequently, engine oils are subjected to higher soot loading causing increased oil viscosity that could lead to poor oil-pumping ability, oil filter

plugging, lower engine cleanliness levels and more importantly higher engine wear.

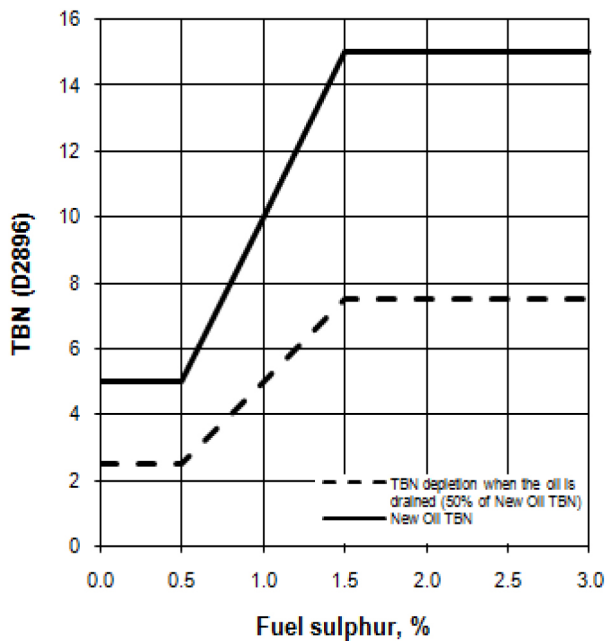


Figure 1. Effect of sulphur concentration on TBN (mg KOH/g of oil) depletion [1]

EFFECT OF OPERATING CONDITIONS

Operating conditions of the engine, like dust concentration in intake air, air intake system filtration efficiency, ambient temperatures, altitude and the load greatly influence the oil performance. Suspended silica (quartz) in the dusty environment enters the oil circuit through the inducted air. This causes abnormal wear of components and reduces engine life and therefore an upper limit is set on the concentration of the silicon in oil.

An experiment conducted on a 5.7 litre engine at no load and 2000 rpm with fine silica (quartz or sand) dust of size about 10 micron (ISO fine dust) indicated that every one gram of dust entering the engine wears out 0.01 gram of the piston ring. After 40 g of silica ingress, the blowby increases abruptly, signifying the end of life of piston-ring-liner assembly. The blowby and silica addition are normalised with the swept volume of the engine and plotted in Figure-2 [2]. It can be seen that for a diesel engine, the limiting dosage of sub-ten micron sand is seven gram per litre of swept volume. This important parameter can be used for calculating the life of an engine operating in dusty areas like mines or deserts or using a given air intake system with a certain filtration efficiency. Figure-3 shows a cross plot of normalised wear rate against filtration efficiency of the air intake system [3].

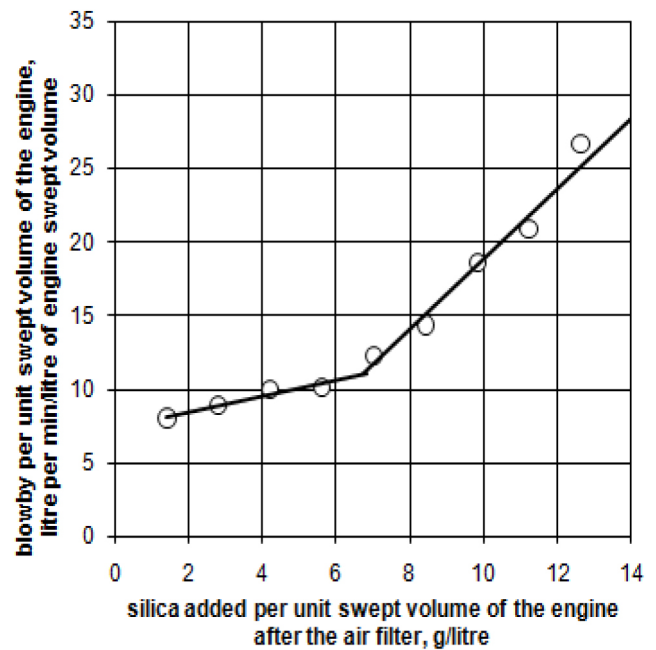


Figure 2. Effect of silica addition on blowby [2]

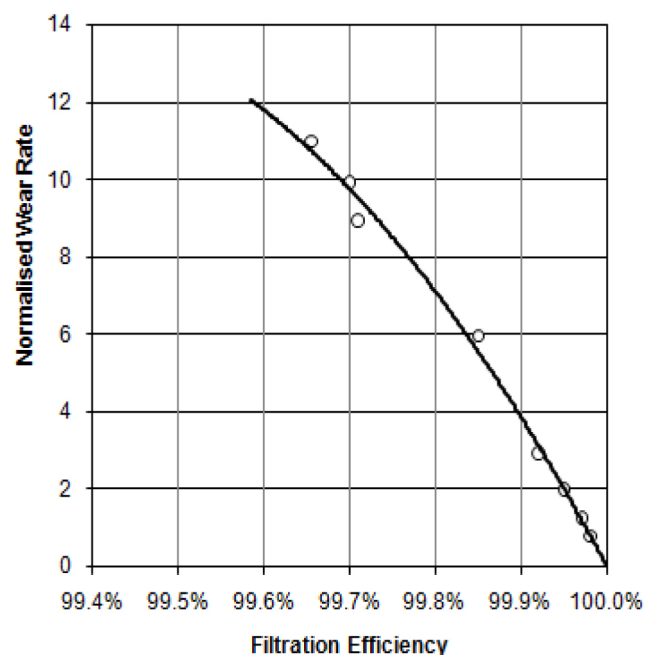


Figure 3. Normalized wear rate versus air filtration efficiency [3]

From Figures-2 and 3, the engine life could be estimated as 1200 h when the filtration efficiency is 99.90% (of the main filter with a cyclonic separator of efficiency of 70-75% at a particle size of 15 μm) as given in the example below for a 5.7 litre engine (turbocharged after cooled) drawing 600 kg/h of air containing 99 g of dust/kg of air on a typical Indian road (Table-1). Engine wear rates have been calculated to decrease by a factor of 10 when high efficiency

air filters are used in place of standard efficiency filters. When filtration reaches 100%, the wear of all critical parts has been shown negligible [3].

Table 1. Calculation of Engine life

quantity of dust required to destroy the engine	30	g
dust concentration at a height of 2m from ground on the road	99.2	mg/kg of air
air drawn in on the average by a vehicle	600	kg/h
efficiency of cyclone in the duct	72%	
dust entering the main filter assembly	16 666	mg/h
efficiency of the cyclone in the main filter assembly	85%	
dust entering the filter element in the main filter assembly	2,500	mg/h
efficiency of the main filter element	99.000%	
dust entering the safety element	25	mg/h
life of the engine	1,200	h

Figure-4 indicates that the engine life decreases exponentially with the decrease in the filtration efficiency below 99.9% and a cyclonic separator efficiency of 70-75% at a particle size of 15 μm . This also shows that the engine life improves significantly if the filtration efficiency is improved, e.g., the life doubles when the filtration efficiency is increased from 99.9% to 99.95%.

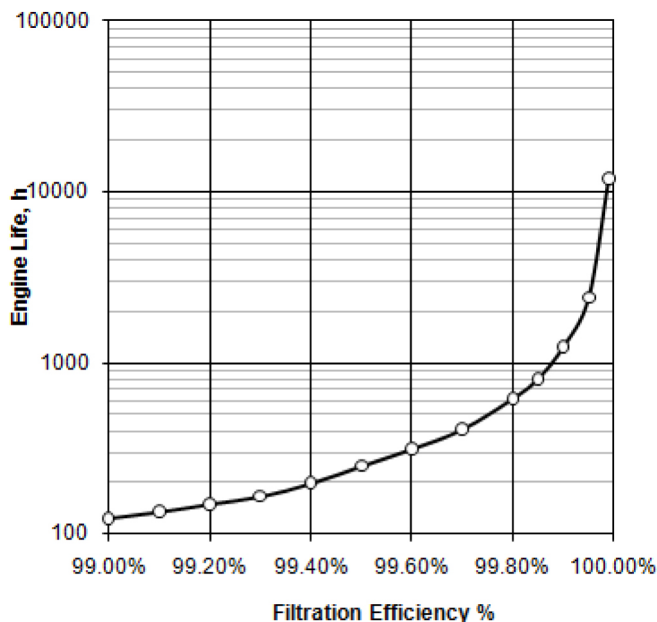


Figure 4. EFFECT OF FILTRATION EFFICIENCY ON ENGINE LIFE

For a given engine, temperature of oil depends on the duty cycle and ambient temperature. Higher operating temperature results in oxidation of oil molecules and affects oil properties. It also results in less than proper oil film thickness (due to lower viscosities at higher temperatures) leading to boundary lubrication regime and hence metal to metal contact. Therefore, higher the ambient temperature, the lower is the life of both the oil and the engine.

Operating at higher altitude and lower air availability results in higher soot levels and temperature and causes increased wear.

As the roads are slower at 60 km h⁻¹ on the average and the customer prefers fuel economy to speed, Indian vehicles operate at a relatively higher vehicle weight (GVW) to power ratio of 0.25 ton/hp. Consequently, engines operate at a 70% duty cycle, unlike 30% (GVW to power ratio = 0.06 ton/hp) in European and North American countries where vehicle speed is more valued than fuel economy. Therefore, higher dust levels in intake air, higher ambient temperatures, higher operating altitude and lower power to vehicle weight ratio affect useful oil life and thereby challenge extension of the oil drain interval and engine life.

ENGINE DETAILS

A 6-cylinder inline direct injection turbocharged and inter-cooled diesel engine with a bore of 104 mm and a stroke of 113 mm and optimised at different ratings was used for the study. The engines with eleven litre sump capacity are rated at 132 kW and are BS-I, BS-II and BS-III compliant (Indian emission standards equivalent to Euro-I, Euro-II and Euro-III respectively- Appendix-1) while the engines with 16 litre sump capacity are rated at 135 kW, 165 kW and 2500 rpm and are BS-III compliant. The pistons are tin coated with turbulent combustion bowl. The top ring is chrome ceramic coated and the oil ring is nitrided. The liners are plateau honed. While the BS-II compliant engines are with rotary fuel injection pump, the BS-III compliant engines are with Bosch electronically controlled injection system with a rotary pump, or common rail. The 165 kW at 2500 rpm engine operates at a maximum peak firing pressure of 140 bar while other engines operate at a maximum of 122 bar.

TEST PROCEDURE

Even though laboratory tests and theoretical predictions can simulate different conditions that affect the oil performance, field tests allow evaluation of performance under actual conditions of weather, duty cycle and maintenance practice. Vehicles that have completed 20 000 km and with known history of oil consumption and fuel consumption were selected for trial so that trivial problems are avoided during the field trials. Air filter, fuel filter and lube oil filter were replaced with new filters at the start of experiment. The first-filled oil was drained in warm condition. The engine was charged with test oil and flushed for ten minutes at low idling speed. Finally, the flushed oil

was drained and fresh test oil was charged again to the maximum capacity of sump.

Oil samples of 250 ml were collected using a tube and syringe in airtight aluminium containers at the beginning of trial and at every 10 000 km of vehicle run. An equivalent amount of fresh oil was added back to the sump. Thanks to Indian Additives Ltd. (IAL), Chennai, the samples were analyzed for physical and chemical properties, total base number (TBN), total acid number (TAN), kinematic viscosity, soot and wear metals using the standard test methods indicated in [Appendix-2](#). Based on the concern limits that can harm the engine as given in references [4, 5, 6, 7, 8], rejection limits were initially set for wear metals concentration and oil properties as shown in [Table-2](#) and were used in deciding the oil change interval for the tests. When any of these parameters is at its limit then the trials were restarted for the next cycle as per the above mentioned procedure.

TEST BACKGROUND

During the years 2003 to 2005, to increase the drain interval from 10 000 km for both long haul and stop-go operation, field trials were conducted by the authors on engines satisfying BS-I, BS-II, and BS-III emission standards and oil with viscosity grade SAE 15W40 meeting API CG-4+, MB 228.3, VDS2; API CH-4, MB 228.3, VDS2 and API CI-4, MB 228.3, VDS3 oil specifications with Group-I and Group-II base stocks on intra city buses (short haul) and intercity buses (long haul). API CG-4 is strengthened to CG-4 PLUS with additives to avoid abnormal wear of valve train components experienced in the U.S.A. and Japan (MB 228.3). An eleven litre capacity oil sump was used for the above trials. Oil was found in good condition even at 45 000 km in the experimental vehicles. At the end of the experiments, the CH-4 oil was released for production vehicles and oil drain intervals were specified as 24 000 km for stop-go and 36 000 km for long haul applications, to take into consideration unknown conditions in the field. [Figure-5](#) and [Figure-6](#) show that there is good repeatability of the data of long haul trial in three vehicles with CH-4 oil for properties such as kinematic viscosity, TBN and TAN over four oil drains, 45 000 km each (a cumulative distance of 200 000 km). It can be observed that the kinematic viscosity was increasing for the first three drain periods while for the fourth drain, viscosity is dropping which can be attributed to fuel dilution into oil associated with a sudden drop in TBN. In vehicle-2 there were problems of fuel dilution and consequently the kinematic viscosity drops initially, and then starts increasing due to soot accumulation.

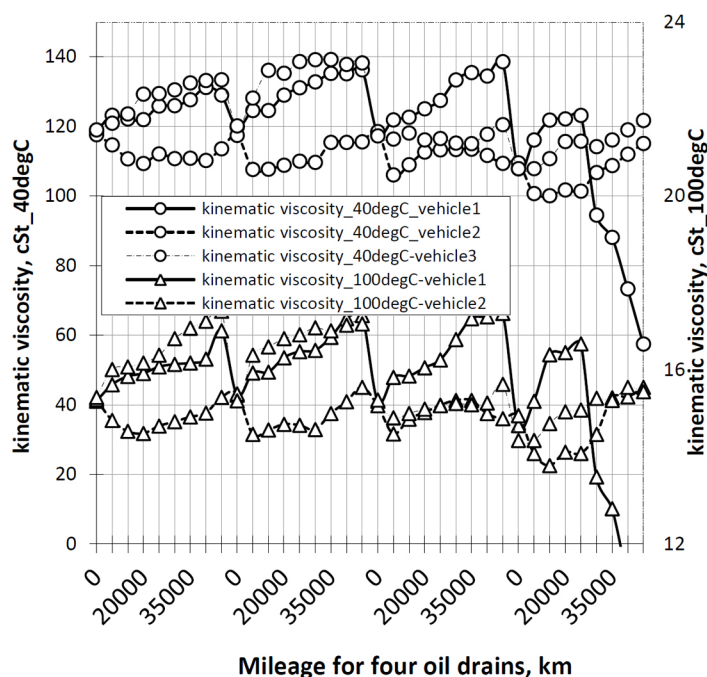


Figure 5. REPEATABILITY IN KINEMATIC VISCOSITY AT 40 AND 100 °C

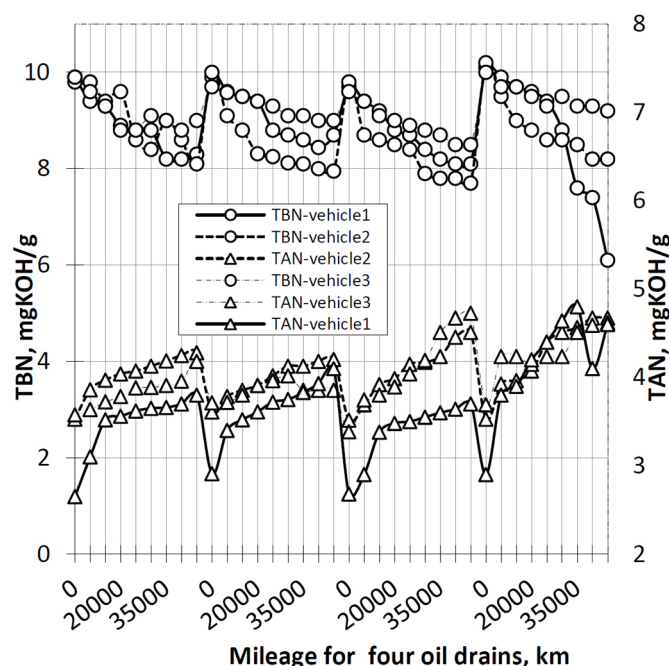


Figure 6. REPEATABILITY IN TBN AND TAN

To triple the oil drain intervals further, BS-III compliant engines (city bus and truck applications) with oil sump of 16 litre capacity and SAE 15W40 grade oil meeting API CH-4 were subjected to field trials. Spin-on type oil filter of higher capacity for long life is used for the trials to eliminate effects of filter change. Fuel with 0.05 % sulphur was used. The air filter and the fuel filter were changed at 75 000 km and 16 000 km respectively or when the pressure drop across filters reached the limits. Any intermediate servicing or maintenance of vehicle did not include engine oil, oil filter and air filter. It was ensured that the engine did not have any oil leakage problem. Oil in the sump was maintained within two litres below the maximum level throughout the trials by frequent oil level check and top up when required.

RESULTS AND DISCUSSION

Oil analysis reveals the condition of the oil for necessary action avoiding any damage to the engine. Also, it helps in arriving at the oil drain period with higher confidence level for many applications where analysis is not possible in field. During the current trials with 16 litre oil sump, a trend of the parameters is established for deciding the oil drain interval. Two buses operating between the two Indian cities, namely Chennai and Hosur covering around 700 km per day (long haul) with a top speed of 90 km h⁻¹, and two trucks operating under long haul application with a top speed of 60 km h⁻¹ and two buses operating within Chennai city (stop-go) with an average speed of 15 km h⁻¹ were the experimental vehicles. The stop-go bus in some stretches of the city drop to an average speed of nine km h⁻¹. More than 70 oil samples were collected from six test vehicles over a cumulative mileage of 0.8 million km. The physical and chemical properties, wear metals and their change with age of oil are discussed in the following sections. In this paper, the results for 16-litre sump are deliberated and where necessary, the data of eleven litre sump are presented for comparison.

PHYSICAL AND CHEMICAL PROPERTIES

TBN and TAN

TBN is a measure of alkaline reserve capacity of engine oil for neutralizing strong acids obtained from the combustion of sulphurous fuel. It is given by the quantity of perchloric acid, expressed as an equivalent amount of potassium hydroxide (mg), required for neutralizing one gram of oil sample in the solvent comprising of glacial acetic acid and chlorobenzene. Low TBN results in insufficient neutralization of acids leading to corrosion of engine components, particularly around the piston ring pack, piston ring lands and bearings at the small end of the connecting rod.

TAN is the amount of potassium hydroxide in mg to neutralize the acids in one gram of oil dissolved in a mixture

of toluene, propan-2-ol and a small amount of water. It indicates the acidity due to both strong and weak acids.

Figure-7 shows TBN depletion rate is slightly higher for trucks application than for city bus application. This is clearly because of higher duty cycle on truck application. For trucks, TBN has decreased from 10.3 to 8.9, while for passenger bus application it has decreased from 10.0 to 8.8 over a distance of 100 000 km.

Table 2. OIL REJECTION LIMITS FOR TEST TRIALS

PARAMETERS	Caution limit used in this paper	Rejection limit
Kinematic Viscosity @ 100degC,cSt	-15% to +25%	-15% to +25%
TBN, mg KOH/g (D2896)	50% of fresh oil	50% of fresh oil
Flash point COC, deg C	Min 180	Min 180
Insoluble, Wt%		
Pentane	Max 5.0	Max 5.0
Toluene	Max 4.0	Max 4.0
Oxidation resins	Max 1.0	Max 1.0
Soot, Wt%	Max 5.0	Max 5.0
Fuel dilution Volume, %	Max 2.5	3%
Water volume, % Max	0.5	0.5
Iron, ppm	200-250	350
Aluminium, ppm	35	40
Chromium, ppm	20-30	60
Lead, ppm	30	60
Copper, ppm	20-30	60
Silicon, ppm	20-30	40

A trend similar to TBN can be observed for TAN in Figure-7. The rate of increase of TAN is higher for truck application than for passenger bus application. TAN increased from 3.2 to 4.1 for trucks while it increased from 3.0 to 3.8 for passenger buses over a distance of 100 000 km.

Conventionally, oil is rejected either if the deterioration in TBN is 50% (Figure-1, Table-2) or when TBN is equal to TAN. The current data shows a maximum deterioration in TBN by 13.6% while the maximum increase in TAN is 28.1 % in the drain period. The fact that both are within the allowed limits is attributed to the advent of new generation fuels containing very low sulphur content of 0.05%. Therefore, TBN or TAN limit may not be a useful yardstick to judge oil life in modern engines. On the other hand, the cost of oil can be brought down by reducing the initial TBN from about 11.0 to 8.0 for the same drain interval. Lesser the TBN additives lesser the sulphated ash formed. Hence, reduction in TBN helps additionally in enhancing the life of diesel particulate filter.

Soot Accumulation

The soot contamination in the oil is a major cause for oil deterioration. Engines emitting low nitric oxides to meet

higher emission standards and operating at increased oil drain intervals allow higher soot deposits in the oil, to meet customer demand [9]. Combustion chamber deposits increase with the soot content [10]. Carbon (soot) contamination in oil was measured by the absorption spectrum of soot in oil using Fourier Transform Infrared Spectroscopy, FTIR. The deposits on the rings and ring grooves cause bore polishing and ring groove wear respectively as studied in references [11 and 12]. An engine is to be protected from soot related wear and lubrication problems caused by soot accumulation resulting in increased viscosity [13]. Extensive studies showed five types of soot-induced wear mechanisms out of which abrasion by primary soot particles is predominant [14]. Under such conditions, oil film thickness was determined to be the crucial factor to prevent engine wear. Certain additives help in maintaining the thickness of oil film by dispersing the soot and preventing agglomeration and hence in avoiding large soot particles contacting the metal parts.

Soot level trend in oil is shown in [Figure-8](#). The initial soot for fresh oil was not zero because the fresh oil was inevitably mixed with some used oil remaining in the circuit. It can be observed that the rate of accumulation of soot is higher for truck operation than passenger bus operation owing to the higher load hauled. However, the soot accumulation over 100 000 km for truck application was at a maximum of 2.5% which is below the rejection limit of 5.0%. Hence, soot limit also does not help in estimating the oil life in the modern engine under investigation.

Insoluble Contamination

The engine oil is continuously exposed to high temperatures and combustion products resulting in oxidation of the oil molecules and the formation of compounds not soluble in oil (sludge or oxidation resin). Pentane and toluene are solvents used in estimating the amount of insoluble sludge (percentage of oil) when tested as per ASTM-D893. The insolubles increase the deposit formation on the piston [15, 16] and increase kinematic viscosity of the oil resulting in lubrication related problems. Antioxidants are added to limit formation of oxidation resin.

[Figure-9](#) shows the rate of contamination of insolubles (oxidation resins), calculated as difference between pentane and toluene. It is higher for engines in truck application than passenger bus application owing to the higher operating temperatures under severe load conditions. Nevertheless, the insolubles are 0.4% in 100 000 km for truck application which is below the rejection limit of 1.0%. Therefore, insolubles in oil apparently do not determine the oil life.

Kinematic Viscosity

The ability of fluid molecules to cling together to resist flow (viscosity) is indicated by the SAE number and is defined at 40° C and 100° C. Viscometers measure viscosity by the time taken by a known amount of oil to flow under gravity. Viscosity is a strong function of temperature. Therefore, multi-grade oils with viscosity index improvers

are used in almost all the diesel engines. Higher the viscosity index more is the consistency of viscosity over a temperature range.

The required viscosity of an engine oil is a part of the engine design. A minimum oil film thickness (a function of viscosity at maximum operating temperature) is to be maintained to prevent metal to metal contact and hence avoid undesirable wear. Kinematic viscosity degrades (usually increases, [Figure-5](#)) with the age of oil due to the accumulation of soot, insolubles, and sediments, which are produced by incomplete combustion and constant exposure to high temperatures inside the combustion chamber.

It can be observed from [Figure-10](#) and [Figure-11](#) that the trend of kinematic viscosity at 100° C and 40° C is similar to that of soot and other insolubles. Also, it can be inferred from [Figure-12](#) that the change in kinematic viscosity over 100 000 km is slightly less than the rejection limit of 25%. As expected, the rate of increase of viscosity is higher for truck application similar to the trends of soot and insolubles. A good correlation between kinematic viscosity and soot ([Figure-13](#)) demonstrates the strong influence of soot on kinematic viscosity. It can be surmised that kinematic viscosity of oil aging in an engine influences the life of oil.

Oil Consumption

Oil consumption is the rate at which oil is consumed and is indicated either in km/litre or as a percentage of fuel consumption. Oil consumption is due to its exposure to products of combustion at high temperature and it is governed by engine design, operating speed and oil quality. Increase in viscosity increases oil consumption [17].

Cumulative oil consumption is the cumulative top-up volume, which includes the volume of sample taken for analysis, over the entire drain period. The average oil mileage is given by the slope of the trend line, as indicated in [Figure-14](#), which is 9.69×10^{-5} litre/km (13 330 km/litre) for passenger bus application while for truck application it is 7.5×10^{-5} litre/km (10 320 km/litre). This means that the oil consumption for passenger bus application is 30% less than for truck application, which can be attributed to higher operating temperatures and engine speed as a result of higher operating loads. Oil consumption and thereby oil sweetening with fresh oil has a great influence on its physical properties. The current data includes the effects of oil consumption and sweetening.

WEAR METALS AND SILICA

Friction between moving parts and corrosion cause microfine particles to shear off the surface and form wear metals and become suspended in oil. Proper oil film thickness and additives can reduce frictional wear and sufficient TBN reduces wear due to corrosion. Despite the above precautions, wear does take place affecting the life of the engine. Monitoring the concentration of wear metals is, therefore, important for proper maintenance of the engine. Wear metals