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SLUDGE

This article examines the causes and effects of sludging, particularly where it occurs in the small diesel bakkie.

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sludge *(noun)* : Thick greasy mud; sewage; muddy or slushy sediment or deposit; accumulation of dirty oil, esp. in sump of internal combustion engine.

This is how the Oxford English Dictionary defines sludge and it is a very accurate description of what is found in the sumps of internal combustion engines. In this case, sludge is a collection of resins, lacquers, combustion by-products, oil degradation by-products, water, dirt and wear metals. However, to the tribologist and the mechanical engineer there is a more specific definition for the word sludge: fuel soot, a combustion by-product. This can lead to some confusion as the two definitions are frequently used interchangeably. In this Technical Bulletin sludge will be taken to mean the accumulation of fuel soot (carbonaceous fuel combustion residues) in the oil and sump of a diesel engine. This article will examine the causes and effects of sludging, particularly where it occurs in the small diesel bakkie, and possible solutions to the problem.

Fuels and fuel soot

Diesel engines burn diesel as a fuel. This provides power by converting the chemical energy stored within the diesel into mechanical energy that the engine can use. Diesel is a fossil fuel and is derived from crude oil formed from the decay of plant and animal matter in the earth over millions of years. It is a potent store of chemical energy that can be easily converted into mechanical energy, which is why it has been used extensively for many years. Diesel and petrol used in internal combustion engines are the most familiar fossil fuels, but other examples include candle wax and cooking gas.

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Large quantities of soot are very damaging to the lubricating oil and, in turn, the engine.

In an ideal situation, if fossil fuels could be burnt with 100% efficiency, the only combustion by-products would be carbon dioxide and water vapour, which would have a minimal effect on the environment. Unfortunately, we do not live in an ideal world and it is not possible to burn fossil fuel with 100% efficiency. To make matters worse, these fuels are not pure chemical compounds but are a mixture of closely related but different chemicals, each with slightly different chemical properties. The petroleum chemists are capable of refining (purifying) crude oil to very high levels of purity but this would make fuels prohibitively expensive. Because of these two factors, burning fossil fuels is a very dirty business. Most of the combustion by-products of burning diesel in an engine are hazardous to the lubricating oil, the engine itself and the environment.

One of the major combustion by-products is soot. Soot is pure carbon (carbon black), the same as coal or the soot that forms on the wick of a candle or paraffin lamp. When formed in an engine the particles of soot are vanishingly small, of the order of 0.03µm or 1 000 times smaller than the width of a human hair. At this size the soot will do very little damage to either the engine or the oil. However a large truck may use as much as 7 500 litres of fuel in 10 000 km and a small bakkie 750 litres in 5 000 km, and this does amount to large quantities of soot which is very damaging to the lubricating oil and, in turn, the engine.

Soot and the functions of lubricants

The major functions of the lubricant in an engine are to reduce friction and thereby reduce wear, to act as a coolant, to act as a structural material and to control contaminants. All engine oils contain additives (chemicals) that are blended into the refined base oil by the oil companies in order to enhance the natural properties of the oil and to perform these tasks. Contaminants can either be external (such as dirt and water) or internal (such as combustion by-products - soot). They can be directly damaging to the engine or indirectly damaging by affecting the performance of the oil, and they can be removed passively (by settling out) or actively (by filtration).

Soot is an internal contaminant that is damaging to the oil and is actively removed by filtration. Engine oils contain two types of additives, amongst others, that are responsible for controlling soot. Firstly, detergents are used to clean up the engine and keep it clean. Secondly, dispersants are used to keep these contaminants in suspension so that they do not settle out on the inside of the engine. Unfortunately, as with all additives, these detergents and dispersants are sacrificial in nature and once they have done their job and have been used up, they cannot be regenerated and will no longer be able to protect the oil from degradation which can then result in engine damage or even failure.

Once the detergent and dispersant additives have been used up, the oil will sludge.

This is why oil and filters should be changed at the manufacturer's recommended intervals.

There are many reasons for an oil reaching the end of its useful service life and this can depend on a variety of factors such as:

- engine design
- driving cycle
- age and condition of engine
- environmental factors, e.g. dust, altitude
- type of engine oil used
- amount of fuel and oil consumed
- fuel quality
- operator's driving style

Often with a diesel engine the limiting factor for the useful life of the oil is the amount of soot being carried by the oil. This is particularly so in the case of small diesel bakkies and will be discussed later.

Once all the detergent and dispersant additives have been used up in the oil, the soot will continue to accumulate and the oil will sludge. The most dramatic effect that this will have on the oil is that its viscosity will increase rapidly. Viscosity is defined as a fluid's resistance to flow at a particular temperature. As the viscosity of the oil increases it becomes 'thicker' and flows more and more poorly until it reaches a point where it cannot flow at all. Viscosity is very sensitive to a change in temperature, i.e. the oil might still be supplying sufficient lubrication at an operating temperature of 90 – 130°C, but when it cools down to, for example 10°C during the night, the oil could be solid when you start the engine. Under these conditions the oil pump will not be able to pump this solid mass, leading to an engine failure due to oil starvation. High levels of soot can cause the following in your engine :

- Plugging of filters and oil galleries
- Sludge formation on the inside of the engine
- Excessive wear of camshafts and cam-followers
- Bearing failure

Factors influencing sludging

Many factors influence the rate at which an engine oil will sludge and it is important that regular oil samples are taken so that the level of sludging can be monitored (amongst many other things) and a safe oil drain interval determined. Perhaps the most important factor influencing sludging is overfuelling which is caused by an excess of fuel for the amount of air present in the combustion chamber. This can be caused by either a lack of air taken into the engine or excess fuel being injected into the combustion chamber. In either case, if there is too much fuel for the amount of air in the combustion chamber, sludging will occur.

If an oil sample indicates an unacceptably high level of soot then a few basic checks need to be made:

Application and / or environment can be the root of the problem.

A1 Was the sample representative of the engine? Was the sample taken cold or from the bottom of the sump or filter housing?

A2 Is the correct grade of oil being used for the engine (taking into consideration the vehicle's driving cycle and the conditions under which it operates)?

A3 Has the oil drain period been over-extended either due to a missed service or lack of maintenance?

A4 Is the application acceptable? Is the engine working excessively hard?

A5 Have environmental considerations such as altitude been taken into account?

A6 Have the oil filters been changed at the correct interval?

If none of these points explain why the engine is badly sludged then there is probably a mechanical reason for the problem. The following is a list of basic points to check:

Restricted air intake

B1 Blocked air filters

B2 Incorrect or unsuitable air filter for application or environment

B3 Collapsed or damaged induction hoses or pipes or a cracked air filter housing

B4 Blocked air intake system, foreign material inside hoses and pipes

B5 After sales modifications that may impair engine breathing

Turbocharger (if fitted)

C1 Boost pressures

Exhaust back pressure

D1 Excessive carbon build-up in exhaust manifold/ silencer/ muffler, etc.

D2 Exhaust brake (if fitted) linkages and adjustment

D3 Damaged, blocked or dented exhaust pipes

Fuel system

E1 Injector timing (spill timing)

E2 Injector condition (pressure and spray pattern)

E3 Injector pump calibration and settings

E4 Correct injectors fitted

E5 Quality of fuel used (make-up, purity, cleanliness and type)

E6 Altitude compensation device fitted, fuel pump calibrated to the environment

Mechanical efficiency

F1 Compression

F2 Blow-by

F3 Valve lift and clearance

F4 Breather operation and efficiency

If none of the mechanical points suggested here appears to be the cause of high soot content in the oil, then application and/ or environment may well be the root of the problem.

Wearcheck receives more calls on sludging in diesel bakkie engines than on any other subject.

South Africa's workhorse

Although sludging can occur in any diesel engine, it most commonly occurs in high speed, naturally aspirated, indirect injection engines with displacement less than 3 litres - in other words, in the small diesel bakkie, the South African workhorse. Sludging in these engines will now be discussed in detail as the technical department at Wearcheck receives more calls on this subject than any other.

The major effect that sludging has on the oil is an increase in viscosity which results in accelerated wear on start-up when the engine is cold, and an increase in frictional losses due to the drag caused by the increased viscosity. The rate of degradation and sludging of the oil is directly linked to the volume of fuel used.

When it comes to the operation of these vehicles in South Africa, this country has a unique set of operational, environmental and fuel factors that need to be considered. This also means that tests conducted in the countries of origin of these engines have limited relevance to South Africa.

Some of these factors - that are thought to be the main contributors to sludging - are detailed below:

Operation and environment

Although the legal loading limit for most of these vehicles is one tonne, overloading is a common practice in South Africa. Overloading leads to overfuelling, which results in excessive soot production and sludge formation.

South Africa is a large country, which means long journeys are made, frequently at high speed. This also causes overfuelling or, at least, maximum fuelling with the concomitant increase in soot production.

Long distance, high speed driving means that some fleet operators uprate fuel injection pumps to deliver more power. This leads to an excessive amount of fuel being injected into the combustion chamber, producing accelerated soot and sludge formation in the engine oil. High speed has two other effects that result in an increase in viscosity due to high temperature operation. Firstly, high temperature has the effect of causing an increase in the rate of oxidation of the base oil. For every ten degree increase in bulk oil operating temperature, this rate of oxidation doubles and causes an increase in viscosity, and secondly the more volatile fractions (light ends) of the base oil evaporate more quickly which also increases the viscosity of the oil.

High speed, long journeys, which produce elevated bulk oil operating temperatures also cause high 'under bonnet' temperatures. Since air density is sensitive to air temperature and, at higher temperatures, less air is drawn into the combustion chamber, overfuelling and sludging will be caused. The effect is the same as driving at high altitude without an altitude compensation device or without a derated fuel pump.

A large proportion of South Africa has areas where the altitude is greater than 1 300m, particularly in the major commercial regions, resulting in an air density approximately 13% lower than at sea level. If the fuel injection pump has not been rated accordingly or an altitude compensation device has not been fitted then, once again, overfuelling will occur, leading to excessive soot and sludging in the engine oil.

It is the blow-by that carries the soot into the sump.

The atmosphere in South Africa is dusty because of our relatively dry climate, proximity to deserts and dirt roads. Foreign air filtration systems are frequently not adequate for our driving conditions which results in the OEM's air filtration system becoming blocked with dirt over a period of time, and the volume of air being drawn into the engine is reduced. The outcome of this is overfuelling and increased sludging.

Although stop/start/idle driving conditions (urban cycle) are not healthy for any engine, neither is the variation between high speed/high load and high speed/low load which is what happens when driving up and down hills. By continuously going through this cycle of heating up and cooling down of the engine, an excessive amount of blow-by finds its way into the engine oil. Blow-by is the combustion gas that finds its way past the piston rings during combustion. It is the blow-by that carries the soot into the sump.

Under light load, diesel engines cool down rapidly. This results in contraction of the piston crown and distortion of the ring pack, and causes an increase in blow-by because of the increased clearance between piston, ring and liner. This increased blow-by will lead to more combustion by-products (soot) entering the oil until equilibrium has been restored between the pistons, rings and liners.

These are the major operational and environmental factors that can affect sludging in small diesel engines. There is, however, another factor that needs to be considered and that is the quality and specification of South African diesel fuel.

The fuel

Most diesel bakkie engines in this country come from Japan. Unlike

COUNTRY	DENSITY @ 15°C (kg/l)	90% BOILING POINT	END POINT
RSA	0.80 - 0.86	360°C (SPEC 362°C Max)	380°C
JAPAN	0.833	334°C (SPEC 350°C Max)	358°C

Typical densities and boiling points of diesel in South Africa and Japan.

South African coastal diesel has a very high sulphur content by world standards.

Japan, where the heavier fractions of crude oil are burned for power generation, in South Africa coal is used for this purpose. There is thus a limited demand for the heavier fractions of crude oil, resulting in a higher density and final boiling point for the locally refined diesel than, for example, for Japanese diesels. This trend is illustrated in the table below left.

However, most of the bakkies sold in South Africa originate from Japan. Usually these bakkies produce excessive smoke when operating with the locally produced fuel.

South African coastal diesel has a very high sulphur content by world standards (SABS maximum permissible 0.55% by mass). Sulphur is a natural constituent of crude oil and it is argued that it is not economically feasible to remove it from the crude oil. During the combustion process various chemical reactions take place and the result is the production of sulphur oxides and water vapour as normal by-products of combustion. However, when the engine cools down, the water condenses in the engine and reacts with the sulphur oxides to produce, amongst other chemicals, sulphuric acid. This is obviously not a very healthy state of affairs, but engine oils contain an additive to neutralise these acids. Unfortunately, like the dispersants and detergents, they are sacrificial and eventually get used up, and then the oil would need changing (oil analysis monitors this). TBN* depletion is often the reason for limiting an oil's life. However, this is not the case with small diesel bakkie engines where sludging and viscosity limits are usually reached first. There is some evidence that high sulphur content increases smoke production, which could affect sludge formation.

Is there a solution ?

Often, excessive sludging in these types of engines is due to a combination of the factors discussed here rather than a single one and this can mean that finding a solution, or even the cause, of a particular problem can be very difficult. The main reasons for purchasing a diesel bakkie as opposed to a petrol one (at increased initial capital outlay) are good fuel economy and an engine that lasts longer. These advantages can be offset by having to service the vehicle at shorter intervals, typically 5 000 km as opposed to 10 000 km for a petrol engine.

So, what can the owner of a diesel bakkie conclude from this discussion and what can be done to avoid sludging and increased viscosity with the potential for premature engine failure?

- Operational and environmental considerations must be taken into account such as overloading, high speed operation, elevated operating temperatures,

* *Total Base Number - a measure of the oil's ability to neutralise these acids.*

atmospheric conditions and air filtration. None of these should be abused.

- Overall, the most salient factor that shows up here is that the viscosity of the oil increases due to sludging, and sludging occurs as a direct result of overfuelling. Therefore, the conclusion is that oil drain intervals should be based on litres of fuel consumed rather than kilometres travelled. At the end of the day, this measures the total number of kilowatts put out by the engine and is a far more accurate way of measuring how hard the engine is working. It is also a good maintenance philosophy that should be adopted for any engine.

- Some Wearcheck customers have increased their sump volumes, either by using larger sumps or by fitting bypass filtration systems because the increased volume of oil allows it to carry a heavier load of soot. Bypass, centrifugal filters have also been fitted to aid in the removal of soot.

- Selection of the correct oil is also important. Recent research carried out at the University of Stellenbosch has shown that a good monograde oil tends to outperform a similar multigrade oil in these engines under South African conditions. The mechanisms for this are not clearly understood as yet but may have to do with the loss of light fractions from multigrade oils and the function of viscosity index improvers added to most mineral-based multigrade oils.

Oil drain intervals should be based on fuel consumed, not kilometres travelled.

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