ENGINE PROBLEMS DUE TO POOR QUALITY OF DIESEL FUEL

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The writer has found that about 30% of engine failures inspected by him were caused by combustion related problems.

In most cases the fuel was of poor quality and this resulted in the damage to the injection pump or the injectors themselves.

The damage to the injectors resulted in poor spray patterns, which in turn either caused piston damage, or dilution of the lubricating oil in the sump of the engine. The result of such injector failures is often a hole in the block. This is caused either by a connecting rod breaking away from the piston due to seizure, or a connecting rod bearing failing and then also causing a hole in the block.

The quality the fuel used in the modern diesel engine is therefore of the utmost importance.

1. The Fuel Situation in South Africa

The South African industry is supplied with liquid fuel from two refineries in Durban, one in Cape Town and one in Sasolburg. These refineries refine liquid fuels from crude petroleum.

There are furthermore a gas to liquid fuel plant at Mossel Bay and the coal to liquid plants of Sasol at Secunda.

Due to the high demand of certain grades of liquid fuel, importing of refined products is also taking place from time to time.

Apart from the local distribution of fuel around the refineries, refined petroleum products are transported to the Reef area by means of an underground pipeline as well as rail tankers and road tankers.

The pipeline, road tankers as well as rail tankers, supply the main depots of the big fuel companies. From these depots fuel is again transported to distributors, namely to forecourts of filling stations, or the bulk tanks of large commercial users. On some occasions smaller wholesalers also form part of the supply chain.

South African Diesel is often accused of being of poor quality. The truth is that fuel leaving the refineries, is of a top quality and conforms to the European EN 590 as well as the SANS 342 (2006) specifications.

During the transportation and handling of the fuel, problems sometimes do crop up, due to poor house keeping, carelessness or even criminality.

It is therefore possible that the final consumer can end up with a poor quality of fuel due to problems in the supply chain. A lot of these problems can be avoided simply by good house keeping.

2. Physical properties of fuel required by diesel engines. (apart from combustion and heat properties)

1. Lubricity: The fuel must have sufficient lubricity to lubricate all the parts in the fuel system. Lubricity is the property of the fuel to allow components to slide over each other without wear and damage.

2. Freedom from particle contamination

3. Freedom from water contamination

4. Diesel fuel must not be used at excessively high temperatures.

3. Lubricity

3.1 It must be kept in mind that the injection system of a diesel engine can only be lubricated by the fuel it is injecting. The fuel therefore must have a certain minimum amount of lubricity.

A few years ago, diesel sold in South Africa had a sulphur content of 0,5% which was later reduced to 0,3% sulphur.

Together with the sulphur, lubricating compounds existed in the fuel, which provided sufficient lubricity or "oiliness". It is for this reason that years ago, diesel fuel was also known as "diesel oil".

The amount of inherent lubricity in the diesel fuel, was of such a nature that the fuel in fact had a reserve capacity of lubricity. For this reason it was considered for a long period that it was not necessary to include a specification on "lubricity" in the diesel fuel specification.

Due to environmental issues, it was decided to reduce the sulphur content of diesel fuel. It was firstly lowered to 0,3% sulphur and later to 0,05% sulphur. Ultra low sulphur fuel with 0,005% sulphur was also made available recently.

The process of removing the sulphur from the diesel fuel, however had a side effect. The compounds which provided lubricity were also removed and broken up in the fuel refining process. The result of this process is that the fuel which is produced with a low sulphur content, does not have inherent lubricity.

In order to function properly, an additive package is therefore nowadays added to refined diesel fuel to provide amongst other, detergent and lubricity properties to the fuel. Due to the fact that this additive package cost money, only the required amount of additives is added to the diesel fuel to provide a good quality diesel fuel for engines. The fuel therefore has no reserve capacity of lubricity compounds.

As mentioned before, lubricity in the diesel fuel is the property of the fuel to lubricate the surfaces which slide over each other and to prevent damage and wear. This provides a long and smooth operation of the fuel system.

Fuels with a higher volatile content than diesel, such as illuminating paraffin etc, does not have any inherent lubricity. No lubricity additives are added to this type of fuel, because there is no need for this property in the normal application.

There is however a substantial price difference between illuminating paraffin and diesel fuel. This is due to the fact that illuminating paraffin does not carry the same amount of taxes that diesel has. There is therefore an incentive for operators to illegally blend paraffin with diesel fuel, in order to save money.

3.2 The paraffin on its own has virtually no lubricity and therefore when it is blended into the diesel, the resultant lubricity of the mixture is usually below the required minimum. The result of fuel with a poor lubricity is that the needles of the injectors start getting sticky and scuffing occurs between the needle and the passage in the injector tip. This means that the needle of the injector is not operating as it should.

Under normal circumstances, the high pressure of the fuel to be injected into the cylinder, lifts the needle against the preset spring force.

The spring force is however limited in its capacity and therefore whenever the needle gets sticky and jams, the needle can not close fast enough and properly under the available spring force.

As a result of the poor sealing of the needle on its seat, hot gasses burn back into the needle tip chamber and overheating and discolouration of the needle tip occurs. During this process the seat between the sharp end of the needle and the injector tip body deteriorates. This leads to poor sealing of the needle on its seat.

The above situation results in a poor spray pattern which normally causes poor combustion. White exhaust smoke is emitted and washing away of the lubricant film on the cylinder liners occur. The engine would also suffer a loss of power.

If the degree of washing away of the lubricant on the cylinder liner is above a certain limit, this action leads to piston seizure. The seizure starts on the piston crown section above the top piston ring and then progresses downwards towards the skirt of the piston. If left long enough, total seizure of the piston occurs. This normally results in the breaking up of the piston and the connecting rod coming loose. The final result is often a hole in the block.

Another problem which often occurs when unburned fuel washes away the oil film on the cylinder liner, is that dry rubbing between the piston ring and the liner takes place. When the degree of liner wash is such that piston seizure does not yet take place, dry rubbing of the rings can take place. The result of the dry rubbing is a wear pattern of grooves in the ring material and sharp corners of the ring, which often gets mistaken for dust inhalation of the engine. Several cases have been investigated where oil analysis proved that virtually no dust entered the engine, yet the rings were sharp and the rubbing surface of the rings were scored, with grooves in the direction of piston travel. In these cases the injector needles showed definite damage on the shanks.

There is also a further consequence of a poor spray pattern. If the poor spray pattern is of such a degree that it does not cause the abovementioned problems, then the droplets of unburned fuel reach the cylinder liner and dilute the oil film on the cylinder liner. If this process is allowed to exist for a period of time, the

lubricating oil of the engine experiences a drop in viscosity. Due to the lower viscosity of the lubricating oil, the bearings can then no longer carry the load imposed on them and very often bearing failure occurs. The failure is often of a catastrophic nature.

When the needle does not close properly on the seat, dripping of fuel from the nozzle tip occurs and this means that combustion is now taking place on the piston crown material. The result of this combustion on the piston material, is that cracking of the piston crown often occurs. If the dripping is of a more serious nature, melting of the piston material occurs. It is therefore not uncommon to find cracks or a hole melted through the piston crown. This happens when the fuel is not atomized into a fine spray, but rather in the form of a jet of fuel, or drops of fuel dripping onto the piston crown.

During this process of poor combustion, the engine would emit white smoke and would be running unevenly, especially during idling and acceleration. The engine would also experience a loss of power.

3.3 Another aspect that must be kept in mind is that the modern diesel engine is a highly developed race horse with extremely high injection pressures. In order to achieve these high pressures, the clearances between pump elements and injector needles had substantially reduced from years gone by. In old diesel engines the clearance between the needle and the tip body was in the order of 5 or more micron. In the later common rail engines this clearance had dropped to about 1,5 to 2 micron. This means that the needle is fitting much tighter in the nozzle passage. This aspect places a further requirement on the lubricity and cleanliness of the fuel.

Several cases had been inspected by the undersigned where a good diesel engine failed within a matter of a few kilometres, when supplied with fuel with poor lubricity.

3.4 It is considered necessary to explain the difference between the conventional diesel engine and the new common rail type of diesel engine.

In the conventional diesel engine, an exactly measured quantity of fuel is pumped by the element of the injector pump and it is delivered to a single injector. Whenever the stroke of the delivery of the pump stops, the delivery of the fuel to the injector stops. No further fuel can then enter the combustion chamber.

In the case of the common rail system, pressure is always available to the injectors. The pressure is supplied by a multi plunger pump. The pump delivers the fuel into a high pressure chamber, which is the so-called "Common Rail". From this chamber, fuel is supplied to the different injectors and is constantly available. The fuel to be injected is controlled electronically by small valves in the injector which open and closes under electronic instructions.

This means that in the case of the common rail system, fuel will always be available to the injector when the needle becomes sticky in its movement. This means that fuel can continuously spray into the combustion chamber, if the needle does not close properly or in time.

This action causes excessive smoke to develop and being blown out of the exhaust. The engine would not fire on this particular cylinder in the normal way and this would cause uneven running of the engine.

During this process excessive fuel will dilute the oil film on the cylinder liner and eventually dilute the lubricating oil in the sump of the engine. This diluted oil can then cause damage to the turbo charger bearings, the cam shaft bearings as well as the crankshaft bearings.

3.5 The aspect of bio diesel is becoming more important lately. Good quality bio diesel has a very good lubricity value and can be blended with diesel without any serious side effect.

The quality control of Bio Diesel is however costly and difficult. Very often bio diesel is produced with the quality of one batch being good and the next batch poor.

The use of poor quality bio diesel can however cause exactly the same type of damage and problems explained above.

The problems encountered with poor quality bio diesel is usually poor lubricity as well as the fact that this fuel often contains droplets of free water which provide similar problems but will be discussed in the next paragraph.

4. Tests for Lubricity

During the years, several tests were developed and tried, to determine the lubricity value of diesel fuel.
The American Specifications favour the "SBOCLE". This test determines the scuffing damage done to a steel ball when rubbed on a rotating cylinder.

4.1 A test which was developed in Brittan and which was later incorporated in the EN 590 specification is the "HFRR" (High Frequency Reciprocating Rig). During the rewriting of the South African fuel specification SANS 342 (2006), the HFRR test was also included as a required test determining the lubricity of the diesel fuel.

4.2 This test consists of a steel ball which is oscillated on a polished steel plate under a light load and a temperature of 60°C. After 75 minutes, the contact surface on the ball is observed under a microscope. A small flat surface is normally rubbed on the ball, which is called a "Wear Scar". The average diameter of this wear scar is then measured under the microscope. The specification requires that the wear scar on the ball should not exceed 460micron.

One of the problems associated with the HFRR machine, is the repeatability of the results. After numerous tests it was found that there are often deviations in the results from the same fuel.

To overcome this problem, a University in Germany in association with a major oil company developed a so called "Complementary Rating". This method entails that the appearance of the wear scar damage on the ball should be observed under the microscope. A rating from 1 to 5 is then assigned to the wear scar. A rating of 1 is a smooth wear scar, indicating good lubricity. A rating above 3, indicates that the wear scar is of such a nature, that grooves are clearly visible on the damaged surface. This means that although the wear diameter might be within the specification, the fuel is in fact not good enough for a diesel engine.

It is the experience of the writer that this rating provides a greater degree of repeatability and that it correlates very well with engine results from the industry

The Tribology Laboratory at the University of Pretoria applies the "Complementary Rating' to the HFRR tests that they do.

4.3 Another machine which is used with success in the testing of diesel fuel, is the "Optimol SRV Machine". The Tribology Laboratory at the University of Pretoria is in possession of both the HFRR as well as the SRV machines.

Although the SRV machine is not the official recognized test method in the SANS 342 specification, it provides a fast and repeatable result in the testing of diesel fuels for lubricity.

The mechanism of operation of the SRV, is in essence exactly the same as that of the HFRR. The difference is that the temperature of the SRV machine is normally kept at 110°C. The load is not kept constant, but is increased by 50 N every one minute of running. The friction coefficient is measured continuously in real time.

Whenever the friction coefficient rises and exceeds the value of 0,3, the machine switches off and the applied load on the ball is noted.

A great number of tests were done on fuel which came from engines that failed due to fuel problems. It was determined that a minimum load of 700N is required from the fuel to ensure that injector problems due to lubricity would not occur.

It must be noted that very few independent laboratories who conduct tests on diesel, can in fact do lubricity tests. This is because of the high cost of the test and the testing equipment. This test is however essential when injector damage occurs. Another aspect which must be kept in mind is that the present fuel in the tank might be of good quality, while the damage was in fact caused by the previous tank of fuel. The method of sampling is also important.

5. Particle contamination

Fuel that leaves the refineries is normally filtered to a high level of cleanliness.

During transportation and handling, fuel often gets contaminated. The most common type of contamination is that of dust. In South Africa the dust contains a high level of Silica which is a very hard substance. On the Mohr Hardness scale, Silica is rated with a figure 7 where Diamond is rated with a figure of 10. Silica particles can easily cause wear damage on hard steel.

As mentioned earlier, the modern diesel engine relies on much smaller clearances than its predecessors. The components in the injection system and the clearance between the needle of the injector and the injector tip body is nowadays in the order of 1,5 to 2 micron.

5.1 Whenever these dust particles enter the space between the needle and the injector tip body, or between the plunger and the pump body, the particles cause wear and stickiness. This is due to the extreme hardness of the material of the dust. The damage caused by these particles is wear and the result is excessive leakage along the needle and poor sealing on the injector tip seat. The stickiness and poor sealing

of the needle, causes the poor spray patterns referred to earlier in this report. The wear caused by the dust particles can also cause a lack of pressure build up from the supply pump due to internal leakage.

In order to prevent damage due to particle contamination, common rail engines are now filtering their fuel through a 2 micron filter. Experience has however shown that this is not always good enough. It is therefore better to prevent the ingress of dust into the fuel rather than to filter it out afterwards.

The mining company "Kumba Iron Ore" at their Sishen mine is doing extensive filtration on bulk supplies of fuel and lubricating oil. They have also fitted additional filtration on vehicles and have achieved tremendous results in the life of injectors and engines. The high cleanliness levels which are being maintained in their lubricating oils as well as in their diesel fuels have extended the life of components substantially.

6. Water

It must be noted that diesel is hygroscopic and therefore always absorbs a small amount of water from atmospheric moisture.

This absorbed water is not a problem and the diesel that is generally used, has always a small amount of water absorbed. However, when free water droplets are present in the fuel, serious consequences normally develop.

6.1 The substance we know as water, does not have any lubricity or lubricating properties, which oil etc normally has.

Whenever micro droplets of water enter the injection system, scuffing of the needle or the injector pump plunger usually occur almost immediately. The scuffing and seizure of the needle or injection pump plunger is very similar to that of diesel fuel without enough lubricity. The damage done by micro droplets of water can normally be distinguished by localized damage, rather than damage spread over a wide area.

6.2 The water often enters the fuel system by condensation in fuel tanks, due to the breathing of the tanks when exposed to sunlight and heat and cooling down at night. The normal exchanging of air due to the fuel consumption, also causes moist air to be sucked into the tank. The condensed water then normally accumulates at the bottom of the tank and can then enter the suction line of the injection system.

Whenever fuel is added to the tank, the turbulence due to the filling of the tank mixes the water lying at the bottom into micro droplets of water. These droplets then float in the diesel for a period of time before settling under gravity. If during this period, fuel is taken from a tank to the engine, then the fuel will be contaminated with droplets of free water.

6.3 Another source of water contamination is bulk supply tanks which also breathe and where water can accumulate at the bottom of the tank.

6.4 Finally water can also enter the fuel system by criminality where water is sometimes used to compensate for fuel stolen from the tanker.

6.5 Another aspect apart from the lack of lubricity of water, is the fact that algy can grow on the interface between water and the diesel fuel. This algy will then plug filters and will cause fuel starvation to the engine.

6.6 Another serious consequence of water in the diesel fuel, is that when the droplets of fuel enter the high pressure area on the needle tip, the water can flash off. Very often the injector tip explodes under the influence of the expanding water.

6.7 Apart from the exploding of the injector tip, it is very often found that small cavities appear on the sealing surface of the needle due to an action similar to cavitation in centrifugal pumps and on cylinder liners.

6.8 It is therefore of the utmost importance that diesel fuel should be kept free from free water and that proper water traps and water removal systems be installed on diesel engines.

7. High Temperatures of Injected Diesel Fuel.

7.1 The effect of low temperatures of diesel is generally known to most operators. At low temperatures the diesel starts freezing and the wax in the diesel blocks the flow of fuel through the filters. The CFPP (Cold Filter Plugging Point) of diesel fuel is something that is normally considered in winter time when temperatures are low.

The effect of low temperatures is normally not mechanically serious, as the engine would normally come to a standstill or would not start. The damage is therefore usually small, if any.

7.2 The effect of high temperatures of diesel fuel on the injection system, is however not known to everybody and is of a more serious nature.

The aspect of lubricity was already discussed in more detail earlier in this paper and attention is again drawn to the importance of lubricity.

7.3 Laboratory tests have revealed that even a very good fuel looses its lubricity properties as the temperatures rises.

Tests done by the writer have revealed that a fuel with a SRV value of 800N at 110°C drops down to an SRV value of 500N at 140°C.

If it is kept in mind that 700N on the SRV, is normally considered as the threshold for good operation of a diesel engine, it shows that even a good fuel will become a poor fuel at the elevated temperatures.

Similar tests on the HFRR with a good fuel, also showed an increase of the wear scar at elevated temperatures

7.4 The effect of the low lubricity at a high temperature, is exactly the same as the low lubricity of a poor quality fuel at normal operating temperatures. This means that a good fuel will give the same injector damage at high temperatures that a poor fuel will give at normal operating temperatures.

7.5 The remedy for the high temperatures is typically the installation of fuel coolers on the return line from the injectors to the tank. Several Common Rail engines are

already equipped with such coolers. The cooler is normally a liquid to air heat exchanger and it must be of sufficient capacity to cool the return fuel down.

The fuel heats up in the injection system during the handling and the distribution of the fuel, but it heats up substantially in the injection system during combustion.

The undersigned has measured outlet temperature differences in excess of 15°C and higher between outlet from the injection system and the coolant temperature.

This means if that the fuel is not cooled, the hot fuel that returns to the tank will gradually heat up the fuel in the tank. This would cause the problems associated with high temperature fuels as discussed. The Common Rail engines make use of a bigger circulation of fuel to cool the injection components.

Another aspect which can be beneficial in the cooling of the fuel is to never let the tank fuel volume get below 25%. This means that enough fuel is available to cool down in the tank before it returns back to the injection system.

A diesel engine should never be allowed to run the tank empty, because injector damage usually results from such an action.

8. Taking all the above into account, it is very important to supply a diesel engine with good quality clean fuel at a reasonable temperature.

This means that good house keeping is of the utmost importance and special care must be taken to prevent any contamination of the fuel with either water or substances such as paraffin etc.

If the engine is not supplied with a good quality clean fuel, costly repairs can result.