BELL PERFORMANCE FUEL ISSUES SERIES: MOST COMMON DIESEL FUEL PROBLEMS

EXECUTIVE SUMMARY

Diesel fuel, the fuel of choice for most of this country’s transportation and boating industries, is more prone than gasoline to problems with incomplete combustion, deposits and poor emissions. Deposits on injectors, valve and in combustion chambers can all have negative effects on vehicle/& boat performance. Diesel fuel of the ultra-low sulfur variety has far less natural lubricity than before, and all #2 diesel fuels have the potential for cold weather gelling problems. The tendency to store diesel fuel leads to potential for oxidative break down, build up of harmful water in the storage tank, and microbial infestation of the fuel supply, which necessitates use of a biocide to eliminate the infection.

INTRODUCTION

Diesel fuel powers most of this country’s over-the-road transportation, rail and large marine fleets (as well as many pleasure boats). In Europe, diesel cars are more common than here in the States. To be sure, diesel does offer advantages over gasoline as a vehicle fuel. Diesel engines tend to be more efficient, relying on compression ignition than spark ignition. They last longer as well, which is part of the reason they are universally preferred for large industrial applications.

As a diesel fuel user, whether truck or boat, you may aware of certain problems that come with the territory. The common issues fuel users experience with diesel are:

COMBUSTION CHAMBER DEPOSITS

Diesel fuel does not burn as cleanly as gasoline does. This is due in part to diesel being composed of larger, heavier hydrocarbon chain molecules. Larger molecules contain more energy than shorter molecules (because they contain more carbon bonds to break and release heat energy) but they also have a greater chance of not combusting completely. When they don't combust completely, they can form deposits in the combustion chamber. When deposits build up in the combustion chamber, it changes the volume of the chamber and subsequently increases the minimum cetane rating of the fuel needed by the engine to maintain perfect top-dead-center combustion and maximum fuel burn at the proper time. The same effect also happens in gasoline engines, where combustion chamber deposits increase the minimum octane rating by several points early in the engine’s life.

Combustion chamber deposits can also act as both insulators and fuel sponges. Excessive deposits will change the rate at which heat can escape the cylinder, trapping the heat inside and raising temperatures. When this happens, nitrogen oxide emissions (NOx) increase, which are terrible for air quality.

Excessive chamber deposits disrupt ideal combustion and performance by absorbing fuel and by disrupting proper air flow within the cylinder. Typically these deposits can build up in the piston bowl area. This changes the air flow within the chamber away from the ideal flow designed when the engine was engineered, and this leads the engine away from idea combustion. Absorbing fuel happens because chamber deposits are porous with a network of cracks and crevices that can act as sponges.

This being said, combustion chambers deposits tend to have a greater effect on engine performance and power than they do on mileage. Vehicular studies do not show combustion chamber deposits to significantly lower fuel economy; injector and valve deposits have a much greater effect on fuel economy.
INJECTOR DEPOSITS

All diesel engines use some form of fuel injection. Most small diesel engines used to use a system called indirect injection (IDI) while larger engines use direct injection (DI). Today, most modern passenger car diesels have switched to DI for fuel economy reasons. IDI tends to be smoother and quieter, while DI is more fuel efficient. The fuel injector sprays the diesel fuel into hot, compressed air, and the mixture auto-ignites. Efficient metering, atomization and fuel-air mixing are key requirements for good combustion and especially important for low levels of exhaust emissions.

Spray Patterns of Clogged vs Clear Injectors

Modern diesel injectors are designed to exacting standards and form an integral part of the process for optimizing fuel combustion. Their flow characteristics are set to allow a small pilot injection of fuel to initiate combustion, and then inject progressively more fuel into the burning mixture. Such an approach provides a low rate of pressure rise and smoother combustion.

Mechanism of Formation of Injector Deposits in Diesel Engines

- Appearance: a uniform varnish type layer with a black brittle nodular layer on top
- Thickness: 6 μm
- Mass: tons of micrograms
- Flow restriction: 26%

Both gasoline and diesel fuels consist of components that boil over a wide temperature range (the diesel range is higher than the gasoline range). When the engine is switched off, fuel remaining in or near the pintle tips mixes together with any remnants of un-burnt engine oil and is subjected to high heat soak temperatures. Such high temperatures lead to the formation of free radical species, and then to a
combination of auto-oxidation, chemical rearrangement and degradation of the remaining fuel – and deposits form within the injector.

Diesel fuel does not have the same injector deposit control specifications that gasoline does. Therefore it may be useful for the consumer to use an aftermarket fuel treatment to remove these deposits and prevent their formation.

Effect of Deposits on Diesel Injectors

Clean fuel injectors are critical for efficient diesel engine operation. A well dispersed spray pattern maximizes fuel-air mixing, while good atomization ensures rapid, efficient combustion. All diesel fuels, but especially those containing products from refinery conversion processes, have a tendency form a small amount of coke in the annulus of the injector. This coke is believed to be caused by the thermal decomposition of unstable compounds in the fuel. It is such a common problem that injectors are designed to tolerate a certain level of coke. However, many of today's diesel fuels give excessive levels of injector coking, disrupting the fuel spray pattern and degrading atomization.

Higher emissions, noisier engines and a decrease in fuel economy are the result, as shown by controlled vehicle studies. These studies show up to a 15% decrease in city economy and 5% decrease in highway (according to EPA test protocols). For the FTP driving protocol, the results are a 2-11% reduction in fuel economy over the FTP driving protocol, depending on the level of plugging (8-30%).

Another definitive study used fouled injectors collected from two different types of vehicles in the field to show the changes in performance based on sets of injectors with varied average levels of fouling and ranges of fouling. Under the worst conditions of 30% average flow restriction, with a corresponding range of 30% between the best and worst injectors, the author showed: a 700% increase in hydrocarbon (HC) emissions

In high-fouling injectors, research shows the engine compensates and can cause some cylinders to receive too much fuel and some to receive too little (rich and lean). Once cleaned, a 10.5% improvement results in 40-100 kph acceleration times and a 15.8% improvement in 80-100 kph times. This is confirmed in other parallel vehicle studies, where clogged injectors show a reduction in engine power up to 22% and a 1.3 – 2.8 second penalty in acceleration tests.

INTAKE AND PORT VALVE DEPOSITS

Example showing the effect of detergent additives on inlet valve deposits compared to unadditized fuel.
Poor fuel combustion and stratified diesel fuel which has broken down in storage (because of water buildup, age or microbial contamination) can lead to the deposit formations building up on the valves in the engine. Problems with power loss, decreased fuel economy, startability, driveability demerits, decreased power (increased acceleration times) and increased emissions can all result from this.

Valve deposits can also be a result from a mixture of environmental contaminants and also from mechanical issues in older engines, where engine blow-by (from a worn PCV valve), cylinder blowback (from insufficient ring seal and wear), exhaust gas recirculation (in large transportation truck engines) and lubricating oil, all of those can combine to build up on the valve stems and underside of the valve, forming deposits.

Typically the biggest effect from these deposits comes when they get large enough to physically block the manifold passage and restrict air and fuel flow into the cylinder. This used to be quite common when carburetors were widespread, and would result in poor acceleration, power, fuel economy and raised emissions. But even low levels of deposit accumulation can affect mileage and emissions, since the deposit can act as a sponge, absorbing fuel into the pores of the deposit, then releasing the fuel through evaporation or desorption (release of absorbed fuel). This disrupts the flow of fuel at the proper timing interval into the cylinder and reduces droplet evaporation efficiency, thus creating an imbalance in the fuel/air mixture into the cylinder. And this means the engine isn’t functioning or combusting fuel optimally.

So the typical issues in modern, port fuel-injected engines that have valve deposits are poor driveability (particularly upon cold start-up and during warm-up conditions) and poor emissions performance. Vehicular studies using standard driving procedures like the CRC show a linear correlation between the level of valve deposits and “driveability demerits”, which are an index related to how well or poorly the vehicles performance on “driveability”. It can be clearly show that valve deposit buildup affects the vehicle’s driving performance and it gets worse the more deposits that build up.

**LUBRICITY**

The term “lubricity” means the lubricating power of the fuel as it flows through the engine. Most consumers only think of engine oil (their typical 10W30 blend) when considering engine lubrication. But diesel engine technologies have long relied on the lubricity of the diesel fuel to keep some types of engine parts from wearing out too quickly. Fuel pumps and injectors both rely on the lubricating compounds naturally found in diesel fuel after distillation at the refinery.

In recent times, the federal government has used amendments to the Clean Air Act to force reductions in the maximum level of sulfur to be found in on-road diesel fuel. Reducing sulfur in the fuel is good for the environment because it means less sulfur leaving the vehicle as SO2 or SO3 emissions (which can lead to acid rain). But the chemical processes used to strip the sulfur from the fuel – hydro-treating – drastically reduce the low-sulfur fuel’s ability to lubricate the engine parts that used to depend on such lubrication (because it chemically destroys the complex organic molecules that perform the function). And with that comes injectors and fuel pumps that wear out faster, leading to higher maintenance costs.

This issue is most pronounced in the long-haul trucking industry where vehicles log many hundreds of thousands of miles per year.

**COLD WEATHER PERFORMANCE**

Cold weather performance is a big issue for diesel truckers who live and work in cold northern climates. Diesel fuel, being a mixture of carbon-based molecules, contain complex “paraffin wax” molecules as part of its composition. These waxes serve to contribute to the energy value of the fuel. But when the fuel
gets cold, these waxes will come out of solution, making the fuel cloudy. Once out of solution, they stick together to form larger and larger crystals of wax. This effect increases the colder the weather. Eventually enough wax floats around in the fuel that the fuel gels up and the wax plugs the fuel filter, shutting off fuel flow and sidelining the vehicle.

This is why diesel operators in cold weather will use a “cold flow improver” product. These kind of products keep the fuel from gelling by keeping the wax crystals in suspension from sticking together. They stay small enough that they can pass through the fuel filter without a problem, where they get burned off in the combustion chamber with the rest of the fuel. If you live up in cold northern weather, it would be wise to consider this kind of treatment if you have not already.

Cold weather can also make larger diesel engines hard to start. Diesel engines rely on compression to heat the air in the cylinder (compressed gas, all other things being equal, gets hotter than the same amount of gas in a larger volume of space). Gasoline engines don’t have the same cold starting issues because they have the aid of a spark plug to force the fuel to combust. But in a diesel engine there is no spark, and the engine must turn over many times in order for enough heat to build up and permeate the walls of the cylinder such that auto-ignition of the fuel will happen. This is why large trucks are hard to start in the winter.

Diesel fuels with higher cetane ratings are easier to start in cold weather because more of the different-size molecule combust at the proper time. Some drivers may have a cetane-raising fuel treatment in order to gain these effects without the extra expense of higher-cetane diesel fuel.

**DIESEL FUEL STABILIZATION AND BREAK DOWN OVER TIME**

Any petroleum product – gasoline, diesel, fuel oil, natural gas – will react with things in the environment they are exposed to, like water, metals and light. Light really just acts as a catalyst to accelerate oxidation reactions – where oxygen reacts with the fuel molecules and causes them to react with other molecules – fuel or not - leading to the formation of polymers that react with other polymers in chain reactions. Over time, the fuel starts to separate and break apart, with these “heavy end” molecules agglomerating together and sinking to the bottom of the mixture (because they are the heavier molecules).

Fuel which has oxidized and stratified like this loses some or most of its ability to combust at an optimal level. And this means poor fuel combustion in the engine, incomplete combustion, formation of deposits, more unburned or partially burned fuel leaving the combustion chamber (poor emissions), and less-than-optimal fuel economy (because stratified fuel doesn’t give the maximum energy value upon combustion that fresh fuel does). All in all, this is not the best situation for the vehicle or boat operator that is stuck with this kind of fuel problem.

What most commonly causes or contributes to fuel instability and breakdown? As mentioned before, exposure to water or air can start or speed up fuel oxidation. Both water and air are excellent oxygen donators, and oxygen is the primary culprit in oxidation. Exposure to certain kind of metals (like copper) as the fuel passes through a fuel storage and delivery system – this can also start and speed up oxidation, although these kind of metals merely act like catalysts and oxygen would still need to come from another source (not usually an issue in the typical fuel storage system or tank). Exposure to light, like exposure to metals, is a catalytic contributor, because sunlight (and also heat contributes energy needed to jumpstart the oxidation chain reactions. This is why diesel fuel poured into a glass jar and left exposed to sunlight will still darken over time – the oxidation reactions cause the color change. Lastly, if the tank has a microbial contamination (more on that later), these acids given off by the microbial biological processes attack fuel and hasten its breakdown.
The whole issue of stabilization and storage is a bigger issue for diesel than for gasoline because it is much more common to store diesel fuel for longer periods of time. Fuel suppliers and industrial customers who store fuel and need to keep it fresh will use an oxidation inhibitor – a fuel stabilizer – to interfere with these harmful reactions and keep the fuel fresh. Consumers who store fuel (such as the boat owner who leaves fuel in his tank over the boat's winterization period) are advised to do the same.

**WATER BUILD-UP**

Water build-up in diesel fuel tanks is a universal problem across the nation. Almost any stored diesel fuel left for any amount of time will end up with water in the bottom of the tank; it’s an even bigger issue for boats and marine storage tanks. Water sinks to the bottom of the tank because water is heavier than diesel fuel is. What’s more, you don’t even have to have a storage tank for this to happen – water even builds up in the fuel tanks of long haul trucks. The culprit in all of these situations is the venting of the tank to the outside air. Outside air packed with water vapor travels in and out of the tank. In storage tanks, the water from the air condenses and rolls down the side of the tank when the air cools down in the evening. In diesel vehicles, the temperature change comes from hot diesel fuel returning to the tank after being used to cool the injectors. Injectors get hot due to their tremendous pressures. The engine uses diesel fuel circulated from the tank to dissipate some of this heat. The now-hot fuel is then circulated back to the fuel tank. This temperature difference causes water condensation in this environment, even when the fuel isn’t technically being "stored" for a long time.

So what’s the problem with water build-up? Why does it matter? It matters, for the following reasons:

- As noted below, water allowed to accumulate in a tank increases the chance of a microbial infestation – bacteria and fungi which can play havoc with the fuel system.
- Water in a vehicle or boat fuel tank can be sucked up and circulated into the hot injector. When it reaches the hot tip, the water expands in volume by 40x, blowing the injector apart and sideling the vehicle. Not a good thing when you are stranded and face a repair job.
- Water in fuel accelerates the oxidation and break down of the fuel.
- Water contributes to tank corrosion

All of these are good enough reasons to control the build-up of water in the tank; this is typically done by using some kind of concentrated fuel treatment.

**MICROBIAL CONTAMINATION**

Storage of diesel fuel for long periods of time also makes them more susceptible to contamination by microorganisms like bacteria and fungus. This happens when the stored fuel becomes contaminated with water; this happens in storage tanks that are vented to the outside. Humid air flows in and out of the storage tank, and when the air cools at night, the temperature change causes the moisture in the air to condense into the tank. Since water is heavier than diesel, the water collects at the bottom of the tank. This provides the necessary environment for microbes to grow and flourish in fuel – they lived at the interface with the water and fuel, and draw their necessary elements and nutrients from both the fuel and water phases. Pretty soon you’ve got a microbial infestation that produces slimy “mats” which float on top of the fuel. The microbes multiply, excreting acids from their biological processes which both corrode the fuel tank and accelerate the breakdown of the diesel fuel, leaving you with a tank of nasty, poor quality fuel.

As you can guess, microbial contaminations are most common in situations where the fuel is stored for long periods of time, and also more common in marine situations where the fuel tank is around water. How do you know if you’ve got an infested tank? You’ll probably notice rough running and poor...
performance with your vehicle or boat. Fuel filters will clog more often and (if you have a storage tank you can see the fuel in), you should be able to see slime floating on top of the fuel (along with foul sulfurous odors). All of these are strong indicators that the diesel fuel tank has a microbial problem.

There are a number of fuel additive products that will claim to eliminate microbial infestations from fuel simply by controlling water. This is where the devil is in the details. Once a tank has an active infestation, simply removing the water alone will not disinfect the tank. You could put fresh fuel in the tank, and over time the microbes would come back in full force. To kill an active infestation, you need to use a Biocide product, which acts such like a pesticide or disinfectant to actively kill and destroy the bacteria and fungi. However, this is not to say that products which control water build-up are useless in this context. Controlling the water buildup is a preventative measure; by keeping water from building up in the tank, you make it much less likely that you will have an infestation. So using an additive which controls water is a good idea when used as part of a preventative maintenance regiment for the fuel. But removing water along will not kill an infestation if it does take root in your fuel.

CONCLUSION

Rudolph Diesel's conception of an engine which combusted fuel based on compression (instead of a spark ignition) is the dominant engine used in heavy industry, long-haul transportation and boating. Consumers who own diesel cars love the outstanding fuel economy. Using a little care and good housekeeping in taking care of your diesel fuel will not leave you disappointed with the results.