

## CLEAN FUEL – KEEP RUNNING

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### Abstract

This paper is an opportunity to learn more about how evolving diesel engine technology is driving the need for cleaner fuel. While that may seem to be fairly straightforward, delivering clean and dry fuel consistently to your engine's fuel injection system can be a great challenge. We'll explore these challenges and how they can be overcome, with a large focus on handling fuel prior to being pumped into your vehicle. Written from the angle of a global filtration company, the focus will be on the role of filtration in achieving the necessary OEM specifications, but also included is important info on other topics like storage tanks, pumps, and engines. We will explore the challenges of keeping fuel clean and dry from the refinery all the way up to the point of injection on your engine, all with the end goal of keeping fleets running. Clean Fuel – Keep Running!

### 1. New Engine Technology and the Need for Clean Fuel

Today's engines use what is called "high pressure common rail" (HPCR) fuel injection systems that operate upwards of 40,000 psi (2800 bar). These systems require *very clean* fuel to operate as-designed for their entire service interval. Unfortunately in most cases, new fuel does not mean clean fuel.

#### 1.1 Fuel Contamination

Fuel contamination can be separated into two broad categories: inorganic and organic. Inorganic contaminant is typically hard particulate (dirt) picked up throughout distribution. From the refinery fuel is typically very clean, but as it gets transported throughout distribution (which can include pipelines, terminals, and delivery trucks) it gets more and more dirty. Once onsite, as it's stored in bulk tanks and moved for distribution and use, it picks up contaminant from the infrastructure as well as ambient conditions.

Organic contaminant represents anything carbon-based, typically longer hydrocarbons with various chemicals attached. These organic contaminants can also come from a variety of sources at or downstream of the refinery: lubricity improvers, cold flow improvers, biodiesel, corrosion inhibitors, etc. It is very important for fuel additives to be dosed at the right levels

and under the right conditions to ensure the best overall fuel stability, otherwise these additives can become insoluble and therefore “filterable”.

Generally speaking hard particulate (inorganic contaminant) will cause permanent damage to the injector system, while softer particulate (organic contaminant) will cause fouling, i.e. deposits build up on the injectors. In both cases the engine does not run as-designed and can result in a decrease in fuel economy, a decrease in power, and an increase in emissions.

## **1.2 Fuel Cleanliness**

Most fuel is delivered to storage tanks 500-1000 times dirtier than what is allowed in these injection systems. Traditionally only on-engine filters would be used to remove the contamination in the fuel to meet injection system fuel cleanliness specifications, but the requirements for HPCR fuel are so clean that a two-step approach is needed to achieve consistent cleanliness: first filter fuel in the bulk storage tank prior to use in the equipment and then with the on-engine filters. Bulk filters should remove contamination in the fuel down to a cleanliness level of ISO 14/13/11, whether the contaminant present is hard or soft. It should be noted, however, that all fuel filters are designed with the goal being to remove the hard inorganic particles, so while they will also filter the soft organic materials, life may be greatly reduced in comparison.

Besides meeting HPCR fuel cleanliness requirements, the use of bulk filtration also provides the necessary protection against any highly contaminated fuel that may be delivered (ongoing or as a one-time occurrence). By filtering prior to use in the equipment, the bulk filtration system will stop excess organic and inorganic particulate from being delivered into your equipment’s tanks, ensuring the onboard filters can meet the expected service intervals. If a fuel problem should exist, it may plug up the bulk filters but not the on-engine filters. This eliminates costly unscheduled downtime and makes operation and maintenance much more predictable.

Today’s engines are more sophisticated than ever and require cleaner fuel than ever before. Investing in a bulk fuel filtration system will protect your equipment against dirty fuel, eliminate unplanned downtime, and keep you running.

## **2. Emissions Driving Changes and We Say Goodbye to Sulfur**

As we discussed last month, many new engines employ high pressure common rail (HPCR) technology, injecting diesel fuel upwards of 2700 bar. These engines are being challenged to meet stricter (cleaner) emissions requirements from governments around the world. To meet that challenge, engine OEMs are employing both on-engine and exhaust after-treatment solutions. HPCR is an example of an on-engine technology, carefully controlling the amount and timing of diesel that is injected into the cylinder. This, along with other on-engine technologies such as exhaust gas recirculation (EGR), does what is needed to minimize emissions while limiting the compromise of power and fuel efficiency.

### **2.1 Aftertreatment Technologies**

The other technologies used to limit emissions are in the exhaust stream, called aftertreatment solutions. These devices include, but are not limited to, diesel particulate filters (DPFs) and selective catalytic reducers (SCR). Both of these technologies serve to reduce both particulate matter (PM) and oxides of nitrogen (NOx) coming out of the engine to meet whatever emissions standard is in place where the engine is operated. In all cases, the on-engine technology is working in harmony with aftertreatment devices, which depends on the specific

strategy employed by the engine OEM. Some engine OEMs have met emissions requirements using just on-engine technology with no aftertreatment, but most have both to some extent.

So why is this important in a column about fuel and the delivery of clean and dry fuel to your injection system? First, because the aforementioned aftertreatment devices used to meet emissions standards around the world use precious metals as a catalyst (chemical “stimulant”) for the beneficial reaction that aids in reducing PM and NOx. These precious metals can be poisoned and cease to work as designed in the presence of sulfur, which is (or was) present in high numbers in diesel fuel around the world. Second, sulfur in the diesel is linked to the creation of sulfuric acid (acid rain) when burned in an engine, so its removal can have immediate benefits to the environment. This brings us to our barrel of oil and the beginning journey it takes to your engine’s injector.

All diesel fuel starts as a barrel of oil brought out of the ground somewhere around the world. It can be light crude or heavy crude depending on the density or it can be sweet crude or sour crude depending on the sulfur content (the more sulfur present, the more sour it is considered). For every barrel of oil that is produced, only about 15% of it goes to the production of diesel fuel. Jet fuel takes up about 10% and the majority goes to petrol fuel. The remainder is made into other hydrocarbon products like plastics. Interestingly, only about 1% of a barrel of oil is used for the production of what we might traditionally consider “oil”.

## **2.2 Oil Refining**

When oil enters the refinery it goes into a crude distillation unit, where it is heated under pressure to split up the “heavy stuff” from the “light stuff” and everything in between. This is done multiple times under different pressure and temperature conditions. Various catalysts are also used here, which allow refineries to manipulate the chemistries of the fuel as needed. For example, as mentioned previously there is a large demand for (lighter) petrol fuels. To meet this demand, refineries will treat some of the heavier streams to turn them into lighter fuels for this market. These petrol streams are then stripped of the unwanted sulfur and nitrogen compounds. To raise the octane number of these fuels, they are sent to a reformer where large amounts of hydrogen are produced as a by-product.

Meanwhile, back in the diesel process, that same hydrogen is used in a hydrotreater along with heat and catalysts to remove sulfur from the diesel stream (current acceptable levels for new emissions engines reside around 10-15 ppm). The really cool part happens after the hydrotreater, where the hydrogen sulfide is reacted with oxygen to give solid sulfur and water vapor. There are of course very limited waste streams in refining, so the sulfur is sold to other industries where it is put to good use (in fertilizer, for example).

This is about as simple as it can be made in just a few paragraphs, but the important point is that sulfur can no longer exist (<15 PPM) and refineries are upgrading their equipment to meet this requirement. The final products from crude oil refineries are petrol, diesel, bitumen and LPG gas which is either sold, stored in a controlled environment or distributed using pipe lines, rail carts or road tankers.

## **3. Additives in Diesel Fuel**

Raw ultralow sulfur diesel fuels coming out of today’s modern refineries require various additives to bring them into specification. Although the details of each fuel spec vary in

different parts of the world, the function of an additive is generally the same: to give the fuel a characteristic that it otherwise wouldn't have right out of the refinery. Specific additive functions vary, from corrosion inhibitors to lubricity, cold flow, and cetane improvers, just to name a few. There are also a lot of choices in the marketplace for additives that are dosed into diesel at the end-user level.

### **3.1 Additive Dosing**

Just like everything else, there are right ways and wrong ways to dose additives. Best practices typically include blending at similar temperatures using the right type of dosing system (i.e. injection of the additive while the fuel is flowing through a pipe to promote good blending). But what does this have to do with fuel filtration? As the filtration industry works to design fuel filters to meet the cleanliness specifications of the new injection system, filtration efficiencies are getting tighter and tighter. To guarantee the cleanliness in the harsh operating environments in which onboard fuel filters live, manufacturers are designing to beta ratios (filter efficiencies) previously never required nor achieved. Unfortunately, this highly efficient filtration has some adverse effects and has caught a lot of the industry by surprise.

### **3.2 Additives and Filter Plugging**

While aiming to achieve "clean enough" fuel in bulk and onboard filtration, filters sometimes start plugging with soft organic material, not hard particulate. While filters are designed in the laboratory to capture hard particulate, they aren't particularly good at the soft stuff. Capacities are decreased significantly, in some instances filters plug more than 1000 times faster.

So what now that these soft organics are showing up on filter media? Numerous papers have been published since sulfur was removed from fuel about 6 years ago highlighting injector deposit problems. It's quite possible that these deposits are caused by exactly the same substance that is now plugging the filter. Why didn't it plug before? Quite simply fuel filters may not have been efficient enough to catch the problem. Injection systems could tolerate 6 micron and smaller particles, so filters weren't designed to catch particulate much smaller. Now with the sensitivity of HPCR around 2-3 microns, the potential to filter out more "stuff" is there.

Of course this leaves us with many more questions than it answers, which may be a bit frustrating. There are too many stakeholders in this discussion for one point of view to come in and solve it. Are the additives unstable? Under what conditions are they unstable? Have they always been that way or is this a new phenomenon caused by something else? Does the high efficiency of the filter media act as a catalyst for this to happen? What about the filter media itself? Do the properties of the fuel change downstream of the filter once these organics are captured? If they are all captured, will injector deposits appear?

At this point we can only say that if you have issues with plugged bulk or onboard filters work closely with your fuel, additive, and filter suppliers and identify and solve the problem. As an industry we're publishing as much information as possible about these incidents and learning more about their cause and what might prevent them. Most importantly, remember that in all cases a plugged filter did its job by preventing unwanted material from passing downstream.

#### 4. Delivery and Storage:

Now that you understand how fuels are produced, the final product is ready to be delivered to customers that are spread across a wide geographical area. Fuels can be transported via pipe lines, rail carts, road tankers and sea [bulk cargo carriers]. The customer can be a bulk fuel depot that distributes the fuel to end users in a specific region, transporters, mining / quarrying operations or retail outlets.

##### 4.1 Pipeline Transport

When using pipelines, one has to understand that the infrastructure may be aging, the pipeline can be used for various fuels and fuel contamination is going to be a challenge that many will face. Similarly if road tankers aren't dedicated for specific fluids, contamination once again becomes an issue.

##### 4.2 Storage Vessels

Transportation and storage vessels have various different sizes and shapes, and they range from the 750 000L concrete tank with a floating roof to the 1000L tank that's mounted to a trailer. When addressing filtration in the distribution chain one has to take the following into consideration:

- Position of storage tank [above / below surface]
- Size of storage tank
- Seasonal conditions [high rainfall/maximum temperature difference/dust and wind factor]
- Site layout

In general, storage tanks are installed and no maintenance procedure is followed. With time particulate builds up in the tanks and this has to be removed by the on board filters. Apart from particulate, water is another challenge that most end users face. Water can enter via the following ways:

- **Condensation**, this is a natural phenomenon that occurs with temperature and ambient humidity conditions
- **Breathers** that are poorly installed or the lack of tank breathers
- For underground tanks, **seepage** via poor installation or ground water that has eroded the tank and hasn't been detected

Excessive water in fuel will result in corrosion, microbial growth and reduced fuel injector/pump life.

##### 4.3 Filtration on Storage Tanks

Filtering fuel in the distribution chain is critical bearing in mind the ultimate objective is to achieve an ISO Cleanliness of 14/13/11 before the fuel enters the vehicle's diesel tank. Filtering fuel on the inlet to the storage tanks, is called the "Clean" process. This is the first stage of filtration for bulk storage whereby the contamination from the distribution chain is removed.

Apart from the pump flow rate for decanting, one must also determine the monthly consumption of fuel used so that the filtration system is correctly sized. To reduce costs, most filter assemblies [particulate and coalescing assemblies] are sized slightly higher than the decanting flow rate but this is just a short term solution. As the volume of fuel increases, the number of element change outs increase and eventually the end user discards the filtration system due to the high frequency of element change outs.

Most storage tanks should be fitted with a good quality breather. A breather prevents contaminant and water [moisture in the air] from entering the storage tank when fluid is being dispensed. When the tank is being filled, the air from the storage tank releases the water particles that have been trapped on the outer edge of the filter media. The micron rating for the filter media used on breathers should range between 3 $\mu$ m - 6 $\mu$ m [absolute], standard air elements should be avoided as some of these elements does not trap the water particles.

To comply with environmental impact, the filtration system on the inlet should be installed within the self banded wall and the installation should be fitted with indicators so that the end user is aware that the filter elements need to be replaced with a new set of elements.

### **5. Clear & bright - ISO Cleanliness levels**

When people talk about clear and bright, they could be chitchatting about the weather. However, in the domain of fuels and lubricants this expression has been used since the 80s. The oil industry calls it the Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual). In all fairness, using the above ASTM D4176-04(2009) may sound clear but it is not the brightest thing to do.

The test provides a field test to evaluate visually a fuel sample for particulate matter and free water similar to Test Method D4176, plus a numerical rating for free water. The color of the sample is supposed to indicate if the sample is FFP, meaning Fit For Purpose. Two major concerns with this 30 year old, but still commonly used, visual test method: “What can we, as humans, see?” and “What is FFP and what is it worth in the real world?” Both questions are a reality check and I believe most of you will confirm that in three decades a lot can change.

Thirty years ago some of you were in college, or just married; some of you were not even born yet which applies for a multitude of fuels and fuel additives too. There are around 1100 different hydrocarbon chains used in today’s world to drive engines. A high percentage of these hydrocarbons weren’t there back in the 80s and for sure we are not comparing any modern engines with robust but polluting old timers.

#### **5.1 How to See the Dirt**

The lower limit of human visibility is about 40 $\mu$ m (1 $\mu$ m = a millionth of a meter). This means that smaller particles are just blurry to us, or just plain invisible. The fact is that modern High Pressure Common rail injectors are not very fond of particles greater than 2  $\mu$ m and a visual test is no longer good enough to determine “FFP”. A common patch test using a microscope with suitable magnification is more appropriate. Alternatively, in addition to visual patch testing, which visually shows the contamination, automatic particle counting can give you a better understanding of the number of particles and their size that are in a set of sample fluid. There are various standards of measuring the results but the most common are ISO 4406, NAS 1638 and SAE AS 4059.

#### **5.2 ISO 4406 Cleanliness**

Most component manufacturers publish filtration level recommendations using the three scale ISO code (ISO 4406), which permits the differentiation of the dimension and distribution of the particles that are allowed in the fluid. This level is identified by measuring the number of particles 4 $\mu$  and greater, 6  $\mu$  and greater, and 14  $\mu$  and greater in one milliliter of the system

sample. The range between the upper and lower limits for each scale number is a factor of two. This also means that for each increase of one ISO code number, the number of particles can double. For bulk fuel filtration, the target cleanliness as per ISO 4406 is ISO 14/13/11.

The oil world estimates that there are 700,000 samples taken per day, but most of them are done upstream, before the fluids are transported towards you. And in most cases even before the final blend stage. The first step is to assure yourself or company that your investment in fuel and lubricants is safe; therefore sampling and cleanliness control the moment you receive the goods is critical. You cannot control that which you do not measure.

## **6. Clean Fuel to Keep Running**

During the course of this paper we've attempted to bring you up to speed on the changes taking place in the world of diesel fuel and engine technology and why it should be of concern to anyone owning or operating diesel-driven equipment. Generally these changes are being forced by emissions control legislation globally, with advancements in injector technology and changes in fuel specifications [10ppm sulfur content] being a byproduct. With some parts of the world being further along in the implementation than others, the results in the long run will be the same: cleaner air coming out of diesel engines, injection technology more sensitive to dirt and water, and new fuel and additive chemistries to make everything run.

### **6.1 Global Markets**

Some OEMs have announced that they will be using their latest low-emission engine technology for export into markets where emissions regulations may not yet be fully enacted. In countries where higher sulfur diesel is still in use (much of the developing world), this would poison low-emissions aftertreatment catalysts, so there will be plans put in place to remove the emissions devices before being sold into these markets. This will be acceptable if that market does not regulate total particulate or NOx being emitted. However, the sensitive nature of these latest-and-greatest engines (using high pressure common rail) to any dirt in the fuel will surely create challenges for end-users of this equipment, making the use of clean diesel fuel more critical than ever.

### **6.2 Get it Clean, Keep it Clean**

Fuel being delivered from the refinery through distribution picks up contaminant along the way. To protect against taking delivery of this dirt, we advocate high efficiency filtration at the inlet of the tank infrastructure used to fuel equipment. It provides a very effective place to filter due to the high volumes of steady-state flow (filters perform their best at steady-state vs. cyclical flow), and will insure against any future fuel supply issues. When sizing the inlet filtration system, one must take into consideration the monthly consumption and the level of cleanliness of the fuel supplied. Once problematic fuel is delivered into your revenue-generating assets, the cost to deal with it goes up exponentially. To combat the entrance of ambient dirt and moisture, we advocate for an effective breather filter on the tank. This will keep your liquid "investment" protected against the elements and put you in a position to deliver the cleanest fuel into your equipment.

### **6.3 Deliver it Clean**

The most critical step in delivering clean fuel is also the most obvious. You must utilize a high efficiency filter on the downstream side of the tank, filtering the fuel as it's being dispensed into the equipment. This will be the last chance against any contamination that

may exist. Even though you filtered on the inlet, tank scaling, contamination from piping, or general fuel/additive stability problems can exist downstream.

#### **6.4 Fuel Cleanliness Target**

It is important you target a fuel cleanliness level that will allow you to meet your desired equipment service intervals, and be sure that anything that might plug the onboard filter during operation will instead plug the dispenser filter. This will allow you to contain and deal with a problem without passing it downstream. For this reason we advocate a cleanliness level of delivered fuel to be ISO 14/13/11. This level of cleanliness is high enough so that it can still be measured with a simple patch test but low enough that it will generally plug up with the same “stuff” that will plug the onboard filter.

#### **6.5 Clean Fuel – Keep Running**

The end user is responsible for ensuring that clean fuel is supplied to the equipment and juggling all of the diesel-engine related topics can be daunting: H<sub>2</sub>O, NO<sub>x</sub>, PM, sulfur, hydrocracking, catalysts, ULSD, additives, ISO Cleanliness, microns, high pressure common rail, Tier 4, etc. Use the experts that exist in the market to help you understand; ask questions and seek answers on all-things diesel. When it comes to fuel cleanliness, apply the principles outlined in this paper (clean fuel at the tank inlet, protect it in storage, and polish it as it is dispensed into your equipment), and you will gain the confidence that no matter what challenges or problems your incoming fuel may present, none of them will ever reach your equipment. **Simply put, clean fuel will keep you running!**