EXHAUSTED

CONTROLLING ENGINE EXHAUST CONTINUES AS A MAJOR CHALLENGE IN THE QUEST FOR CLEAN AIR, WATER AND HULLS, BUT HOW HAS TECHNOLOGY HELPED IN THE TREATMENT PROCESS?

BY RICHARD BOGGS

A LOT OF FUEL HAS BEEN BURNED since *Dockwalk* published "Soot Solutions" in its October 2011 issue, and a lot of the generator soot problems we had three years ago are still with us. There aren't a great many more options now, but we have achieved better performance and cleaner boats thanks to a better understanding of exhaust treatment processes and more mature technology. However, some of the ideas many of us had just a few years ago have proven to be not quite as solid as we believed.


Courtesy of Jorge Lang

The Combustion Process

We generally think of combustion in a diesel engine as occurring in a lean environment as under normal conditions, there is more oxygen available than required to achieve complete combustion. When fuel is injected into the combustion chamber, it disperses and evaporates as it moves away from the fuel injector nozzle. Combustion does not begin until the fuel absorbs enough heat to reach ignition temperature. This short period of time is called the ignition delay and is determined by the fuel's cetane rating.

Fine droplets on the outside and leading edge of the column ignite first. This creates a situation where fuel in the rich central core can reach a very high temperature before it's exposed to enough oxygen to combust. As this fuel is heated, it breaks down into its constituent parts; the hydrogen component is driven off and burns easily. As the more volatile components are evaporated, the elemental carbon that remains may not have sufficient time to reach ignition temperature before the combustion stroke is complete. As the carbon core is transported with the other products of combustion leaving the cylinder, it forms a nucleus for other, lighter constituents to condense and form the sometimes-invisible matter responsible for soot staining and the foul odors associated with diesel exhaust fumes.

Just because the exhaust is invisible doesn't mean it's as clean and fresh as an alpine breeze. A 150kW Tier 4 diesel generator, an example of the latest and cleanest technology available, is permitted to discharge .02 grams per kWh of particulates. That might not sound like much, but it amounts to a pound of soot and unburned hydrocarbons every six days. Even the rudest looking exhaust stain takes only a few micrograms of soot to make a yacht hull look like a fender caught fire.

DPFs

The installation of passively regenerated diesel particulate filters (DPFs) as a stand-alone solution to soot and exhaust smell issues has proven elusive.

Regeneration is the process by which soot captured in the pores and on the surface of a DPF element is burned off. Regeneration reduces the carbon and hydrogen components of the soot to mostly carbon dioxide and water vapor. Regeneration also oxidizes the droplets of unburned fuel and lubricating oil before they can create the oil sheen so commonly seen in the water around a generator exhaust outlet. High temperatures produced during regeneration also burn off aromatic compounds that create the foul smell and eye-watering components of diesel engine exhaust.

Passive regeneration refers to the burning off process using only exhaust heat to initiate a reaction between exhaust-borne particulates and a metal-based catalyst coating on the filter substrate. Typically, a combination of the precious metals platinum, palladium and rhodium are used to reduce the temperature at which particulates transported in the oxygen-rich exhaust begin to oxidize. This process works very well when exhaust gas temperature can be maintained high enough for long enough to "light off" the layer of soot coating the filter surface. Despite published specifications, exhaust temperatures don't always match what DPF suppliers or buyers expect.

If exhaust temperature cannot be maintained at or above 350°C long enough to ignite accumulated


Richard Boggs

SeaClean diesel particulate filter installed on a 170kW generator

soot, the filter will quickly clog, and exhaust backpressure will rise rapidly to potentially destructive levels. Filter capacity determines how much unburned material can be trapped before backpressure begins to rise. Most DPF suppliers will specify the minimum size filter possible to keep the system price attractive to skeptical engineers who may still see DPFs as the high workload option. All too often, over the past three years, that view has been proven correct.

The failure of many DPF systems to perform as expected can be attributed to several reasons. Among the most common is high backpressure due to inadequate analysis of the entire exhaust system from turbocharger outlet to overboard discharge when the yacht was built. Extended operation of the generator at low loads and low exhaust temperature places just above under sizing of the filter element itself as the reason for too-frequent filter cleaning.

Diesel engines don't burn much fuel at low loads and the amount of heat created during combustion is far less than that created at higher loads. Because less heat is generated, cylinder pressure is lower, and exhaust gas cools more quickly as it expands in the power and exhaust strokes. Low pressure means less than ideal piston ring sealing and increased lube oil consumption. All these issues contribute to higher rates of engine wear and the addition of particulates to the exhaust flow.

Low T

When there isn't enough heat to burn the very small amount of fuel injected at low loads, there isn't enough heat left to raise exhaust temperatures high enough to initiate regeneration of a passive DPF. Turbocharged diesels use a technique called valve overlap whereby the exhaust and intake valves are open at the same time in order to achieve complete removal of exhaust gases and delivery of the greatest weight of cool, clean air to the cylinder before the compression stroke begins. The downside of this technique is that at low loads, a volume of cool air accompanies the already low temperature exhaust on its way to the turbocharger. As work (heat) is extracted from the exhaust to spin the compressor, it is cooled even further. This phenomenon is why the suppliers of passive DPF filters use very costly precious metal catalysts to initiate regeneration at temperatures claimed as low as 250°C.

Such low temperature performance comes with a potentially fatal flaw that has recently caused considerable expense and frustration for a growing number of owners and engineers. Precious metal catalysts are susceptible to "poisoning" by chemicals that are normally found in diesel exhaust. Despite progress in reducing sulfur content of diesel fuel used by on-road vehicles to only a few parts per million, sulfur and the exhaust particulates it creates is far from a dead issue for globe-trotting yacht crew. Sulfur is the Lucretia Borgia of the precious metal catalyst kingdom. Sulfur slowly and very effectively poisons platinum, palladium and rhodium catalysts until passive regeneration no longer occurs and trapped particles clog the filter.

Sulfur is not alone in this activity, however. Heavy metals, such as iron, copper, zinc and lead, can poison or deactivate a catalyst by "masking" or plating so that it becomes ineffective. Some cleaning chemicals containing chlorine, bromines and halogenated compounds used in refrigerants, along with silicon from atmospheric dust, will contribute to catalyst failure. The metallic and inorganic components of lubricating oil ash can mask catalysts as well as clog filter passages. If you have a precious metal catalyzed DPF, it is critical that only ultra-low sulfur diesel (ULSD) fuel is used, along with low ash lubricating oil.


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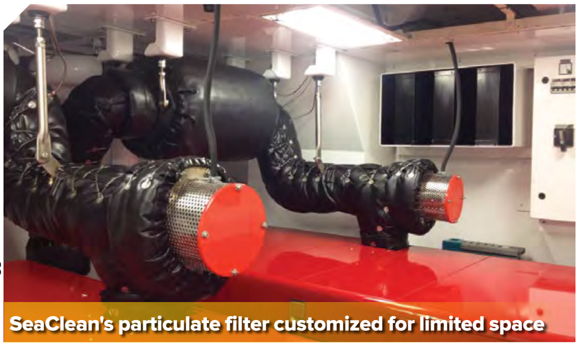

Richard Boggs

SeaClean's particulate filter customized for limited space

ULSD and Additives

If you use a fuel additive, know what's in it. Many additives actually raise sulfur content, and some fuel-borne catalyst additives use iron compounds that can quickly block a filter by masking or clogging it with inorganic ash. Ask for a laboratory analysis of additized fuel and pay careful attention to the ash content, which should not exceed a mass of 0.01 percent.

The best indicator of catalyst activity is the length of time a filter can be used before cleaning is required. Impending filter blockage will be indicated by a rapidly rising trend in exhaust backpressure.

Yachts that operate in regions where ULSD is not readily available should consider retrofitting electrical exhaust heaters if the filters are still functioning satisfactorily. If filter life has already decreased to unacceptable intervals, consider purchasing "drop in" replacements that utilize a "base metal" catalyst that can withstand marine diesel fuels with sulfur content up to 1,500 ppm or more in addition to electrical exhaust heaters. Base metal catalyzed filters require a higher temperature than precious metal catalysts to initiate regeneration. The minimum temperature for continuous operation is around 350°C, and most yacht generators require some form of exhaust heating before the filter.

Fortunately, several manufacturers of exhaust treatment systems have introduced actively regenerated DPFs for yachts with generators of around 65kW or larger. Several systems use electrical power to provide exhaust heating just upstream of, or even internal to, the DPF, and a few incorporate a diesel-fueled burner at the filter inlet.

Both techniques (fuel burners and electrical heaters) produce the same effect — higher exhaust temperature over a wider range of generator output — ensuring more consistent DPF regeneration and a cleaner exhaust. However, both techniques also produce side effects, which might benefit one yacht, but disadvantage another.

Fuel burners fitted to larger generators can be very large and impractical for retrofitting. The complexity inherent in fuel metering and delivery along with fans or blowers needed to supply combustion air make for high maintenance and less reliability than other systems. In addition, burning more fuel in the less-than-ideal conditions found in an exhaust pipe produces as much or more particulates than those exhausted by the diesel alone. This technique has proven effective as a solution when fitted to the main engine exhaust of small inland ferries or water taxis operating in urban areas as their use does not require a substantial electrical power supply.

It's Electric

Electrically regenerated DPFs offer two modes of regeneration, continuous or periodic. Continuously regenerated DPFs rely on electrical resistance heater to maintain exhaust temperature at a level high enough so that the filter substrate can reach the temperatures needed for the catalyst to react with organic compounds in the exhaust gas. Operational experience shows that better filter performance and longer periods between cleaning are obtained through continuous regeneration.

Periodic regeneration relies on a timer or a backpressure sensor to indicate the filter has trapped enough soot to impede exhaust flow. At that point, a controller will energize an electrical resistance heater to initiate regeneration for a set period of time. Large systems may use an array of filter elements, heaters and valves to direct exhaust gases through a previously regenerated element. While effective, periodic regeneration carries a risk of uncontrolled combustion of accumulated soot that can lead to local temperatures hot enough to melt and destroy the filter substrate.

Continuous electrical regeneration virtually eliminates the risk of uncontrolled combustion since soot is burned off before excessive amounts can accumulate. The technique also provides for finer control over the amount of heat delivered to the exhaust gas entering the filter. Better systems sense exhaust temperature and regulate the amount of power delivered to the heater in order to obtain a near constant filter temperature across the normal range of generator loading conditions. This has the additional benefit of reducing heater electrical consumption at high loads when generator power is required elsewhere on the yacht. It also allows the exhaust heaters to serve as exhaust-cooled load banks, eliminating the need for the complexity of water-cooled load banks.

The next three years most likely will see a proliferation of exhaust treatment systems for generators and main propulsion engines. Much of the development of those systems is driven by stricter emissions regulations that will apply to new builds, but will also find a place in the engine rooms of yachts undergoing major refits. The benefits of this technology go beyond the obvious environmental and health considerations. The savings in hull paint maintenance and the elimination of foul smells are already a pleasant reality for crew, owners and guests. DW