The skies are crystal clear and the view of the coastline is gorgeous. But an offshore high pressure system has been grinding against a deepening inshore low pressure cell for the last two days. The resulting pressure gradient has generated 25 knot winds and whipped up steep chop off the port bow. The motion is uncomfortable but not extreme so there's no thought of retreating. The diesel drones rhythmically as progress to windward is slowly made. Rhythmically…until the RPM's drop for a moment.

The RPM's return to their pre-set level so quickly the captain can't be sure they actually dropped at all. Did rough seas dislodge debris in the fuel tank and is now clogging the fuel filters? A few moments later, all uncertainty is extinguished when the RPM's dip again. The scenic coastline will be a lee shore should the diesel die.

Most boats have very simple fuel systems that would benefit from a few upgrades. Many engine rooms are littered with valves in tedious, unknown locations requiring detective work to understand how to make changes. Filters may be impossible to reach or obsolete models without water separation capabilities. Fuel lines are often cheap, deteriorating rubber with hose clamps slicing through their jackets. If you plan to venture far from home, a robust fuel system will keep you from being vulnerable.

Unraveling the mess in an engine room can be fairly simple: there are three great do-it-yourself projects that will greatly improve your fuel system:

1. Install a fuel polishing system that cleans and circulates fuel on demand. This is especially important to boats like sailboats because diesel has a short shelf life and doesn't store well (more on that later).
2. Install a dual-element secondary filter on the main engine. With the turn of a valve handle, an operator can instantly shift to a clean filter, even change-out the dirty one while the engine continues to run. This is especially important for single-engine boats.
3. Simplify the system by centralizing valves into a manifold "valve-farm" location.

Know thy enemy

There are four primary culprits in fuel: dirt, water, algae, and fuel decay. Dirt is self explanatory, but the other three deserve a closer look.

Water. Water will destroy injectors very quickly and because it's heavier than diesel it sinks to the bottom, precisely where fuel is drawn. Water will invariable occur in fuel tanks: small amounts commonly accumulate from condensation. But other culprits include deck-fill fittings (check o-rings regularly) and ill-planned fuel vents that are vulnerable to rough weather. Finally, the original fuel source may be contaminated, an especially difficult problem in third world countries. Most modern fuel filters include water separators but they will become overwhelmed

with more than a few ounces of water. Transparent bowls let you keep an eye on progress.

Bugs. An anaerobic strain of algae can prosper in the boundary layer of diesel and water present in almost all tanks. As the algae decays, the dead cells sink to the bottom and form sludge on the tank bottom. Rough seas agitate the fuel, dislodge this goo and clog filters. Biocide will kill the algae and may temporarily exacerbate the problem. You will need lots of filters to get you through the transition period.

Degradation. As fuel ages, it decays. Tar-like globules of asphaltenes precipitate and sink to the floor of the tank. Sailors and long-range trawlers are especially vulnerable because fuel starts to degrade within 90 days and these miserly boats may keep fuel aboard for months or years. The best solution is to use your boat. But fuel stabilizers and regular circulation can help though you'll need a good supply of filters until the globules are re-suspended.

The Offshore Diesel Supply System

The further a boat ventures from home – whether power or sail, the more robust the system has to be. For many cruisers venturing into remote areas where fuel may be questionable and supplies non-existent, a robust fuel system is especially important. The following is a list of "best practices" for fuel system initial design – not all elements can be retrofitted into an existing system but it's a good list to consider:

- Drain-off at the lowest point of the tank to remove water.
- All valves clearly marked and mapped for easy access (SEE PHOTO 1). Best is really a centrally located and well designed valve farm (manifold). Often, valves are scattered throughout an engine room in inaccessible places. Sometimes, adjunct equipment has been installed (home-spun transfer systems for example) and have so many scattered, non-marked valves that even a certified ship's engineer couldn't retrace the owner's thinking. Fuel supply/return manifolds should have spare outlets so future equipment (generator, diesel heater) can be easily added.

- Secondary filtration. Typically Racor, Fram, or Dahl filters remotely mounted. Ideally, there should be dual-mounted filters (SEE PHOTO 2): side-by-side filters that can be instantly switched so a clean filter can be brought online quickly and the clogged filter changed without disruption.

- Fuel transfer. If the boat has two tanks, it's handy to be able to transfer fuel between tanks and trim the boat. If it has more than two tanks, its mandatory.

- Fuel polishing. Fuel polishing is nothing more than filtering and circulating onboard fuel and is part of a full-feature fuel transfer system (see diagrams).
- Calibrated sight tubes. Fuel gauges are notoriously inaccurate and other after-market monitoring systems require significant interpretation. Sight tubes are bulletproof (SEE PHOTO 3)

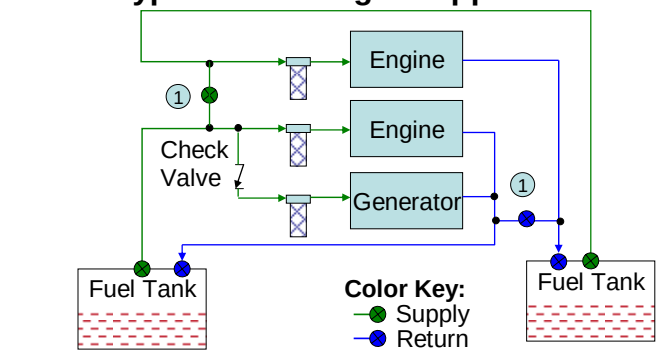
- Fuel lines should be heavy and well protected from chafe. The best solution is to use high pressure hose and hydraulic fittings instead of barbed nipples and hose clamps.
- Vacuum gauge on engine side of secondary filter. As the filter clogs, the engine will have to suck more to get fuel which creates a vacuum. Once the vacuum starts to crest 5" hg, you will need to start planning when to change it. At 7" hg, its time to change.
- Boost pump. Having a low-flow pump installed in the supply side allows the engine to be bled. If your fuel valves are arranged in manifolds, pressurizing the entire supply manifold will let you bleed any engine (generator, etc). Also, if the filters start to clog, the pump will push fuel through the filters thus extending their range in a pinch
- Day tank. A tank that holds enough fuel for 5 - 24 hours of running at cruising speed (SEE PHOTO 4). Obviously, this is only practical for slower, long range cruising boats that have modest fuel requirements. The main tanks act as a reservoir where fuel is stored until it is filtered and pumped into the day tank. If a fuel problem develops, the day tank gives several hours of running time for the operator to solve the problem.

Do-it-yourself fuel system upgrades.

1. Clean-up your engine room by organizing the valves into accessible locations. Install a vacuum gauge. If you have a Racor filter housing, replace the tee-handle on the top with a vacuum gauge. Otherwise, tee into the supply line between the engine and the filter and install a gauge (see Vacuum Gauge in Figure 2).
2. Install a dual filter elements. If you only have a single fuel filter for your main engine, you are vulnerable. If your filters clog – as in the opening example – you will have to change filters in a rocking, pitching boat. A better solution is installing a hot standby filter (see picture). You can make your own with two single filter housings a bevy of valves befitting a nuclear reactor (and hope you know what valves to turn when the time comes) or get a purpose-built unit from Racor. With the Racor unit, you just turn a single handle, and it's much more compact. Convenience comes at a price: this unit starts at about $750, plus fittings.

3. Install a polishing system. The further you venture from home, the higher on your list of fix-it priorities this should be. Or if you have just bought a used boat with suspicious fuel and are considering hiring a service to polish your fuel, why not have a mechanic install this system and do it yourself?(Fuel polishing services are very expensive, and sometimes need repeat service).

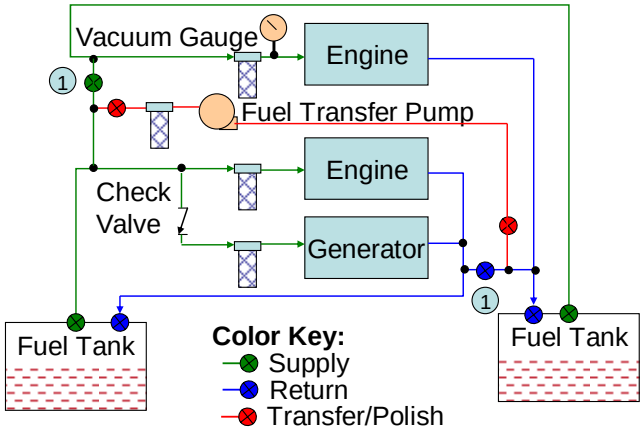
Figure 1
Typical Twin Engine Application



1 Cross-over valves closed under normal operation. Starboard engine draws and returns from/to starboard tank; port engine draws and returns from/to port tank.

Figure 1 is a standard, twin engine installation with two tanks. Figure 2 has added a simple polishing system that works fine, but cannot be run while the engine is running due to contention issues. But still, this is a great retrofit as long as you do not need to transfer fuel while underway.

Figure 2
Simple Transfer/Polish System



1 Cross-over valves closed under normal operation. Starboard engine draws and returns from/to starboard tank; port engine draws and returns from/to port tank.

An even better system can be built if you organize all the valves into an easily accessible, logical valve manifold system (SEE PHOTO 5). Look at Figure 2 again and imagine an actual engine room and where the valves are. Figure 2 looks simple on paper but can be very confusing in an engine room – especially with more than two fuel tanks. Figure 3, while there is more equipment, is vastly more flexible, intuitive and easily managed. When you need to make a fast decision, you have a greater likelihood of getting it right the first time with Figure 3 (twin engine) or Figure 4 (single engine). This configuration also lets the operator bleed any engine by using the boost pump to pressurize the supply manifold.

Figure 3
Organizing valves into manifolds

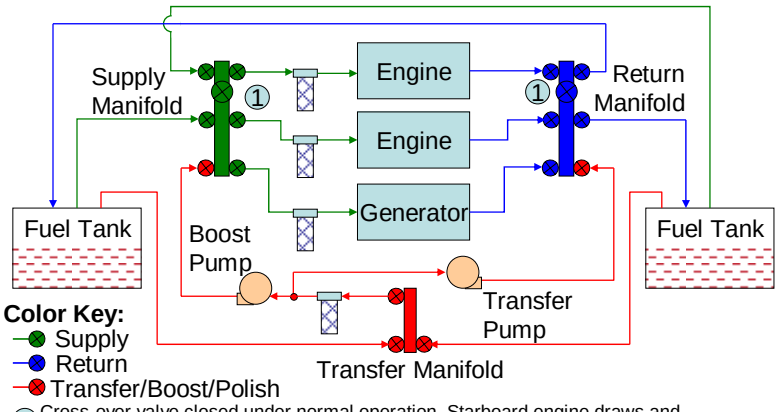
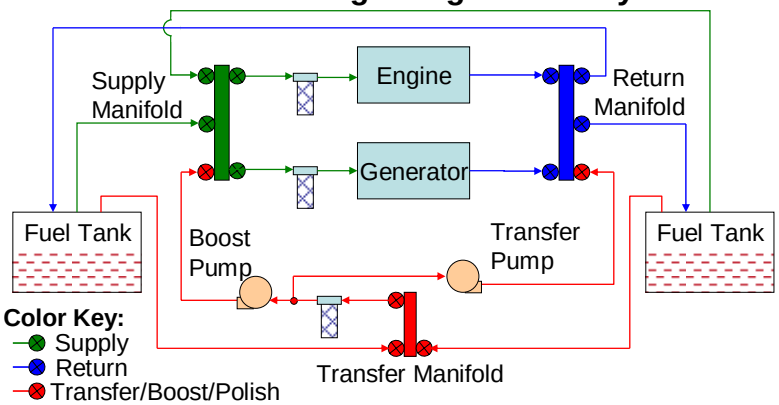


Figure 4
Full Feature Single Engine Fuel System



4. Upgrade your skills. The final and perhaps easiest do-it-yourself project is to upgrade yourself. Take a diesel education course or hire your mechanic for a few hours. Talk to your engine manufacturer and see if they have courses. Some of the larger boat shows also have courses. Education is always a great investment.

Most boaters take their fuel system for granted. It's easy to do and unfortunately, many boat builders respond to market indifference by only installing basic fuel systems. But think about the captain in the opening sequence: what would happen if this were you on your boat? Do you have a vacuum gauge and can you tell if your filters are clogging? If they are, what would you do? With just a few of the above upgrades, you would be able to avoid this situation altogether. And if you did find yourself in trouble, you would merely to switch a valve and press a new filter into service without missing a beat.

Case Study: Nordhavn

Very few recreational powerboats are capable of crossing oceans. But one builder specifically designs their boats to do just that. In fact, several of their boats have circumnavigated the globe, including a 40-footer that, in 2001, sprinted around the world in just 170 days. Although a factory sponsored event, this boat was essentially a production boat with the exact same 965 gallon capacity that all Nordhavn 40's carry.

Fuel range was tight on the 2300 nautical mile California to Hawaii leg so PAE developed a cleaver idea to monitor consumption. In addition to flow meters, a one gallon fuel tank calibrated to the 1/10 gallon was installed. At least once a day, the actual consumption was measured over time. The boat arrived with over 100 gallons of fuel in reserve. The idea was integrated into the design of the Nordhavn 47 supply tank (SEE PHOTO 6).

Fuel management is critical. The engineers at Pacific Asian Enterprises (parent to Nordhavn and Mason Yachts) developed several novel ideas that have been incorporated into modern designs. "Fuel management systems need to be as simple as possible" according to PAE president Dan Streech. "Long distance voyaging can be tiring and stressful so it's easy to make a mistake. Switching the wrong valves could over-fill a tank and dump hundreds of gallons of fuel overboard. In addition to the environmental issues, it could easily mean falling short of the destination."

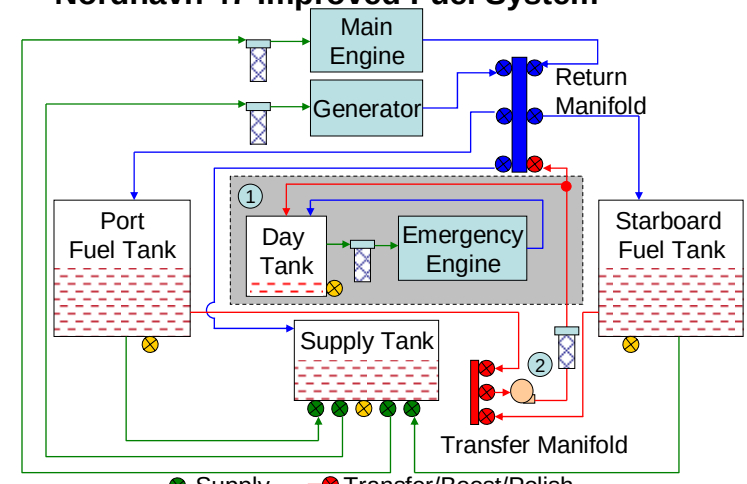
After 100's of thousands of ocean miles of research and development, PAE introduced a simplified fuel system on their Nordhavn 47. Two main "saddle" tanks are outboard of the main engine (1425 gallons total). A third "Supply" tank (70 gallons) is centered just forward of the engine and sits relatively low, though

well clear of bilge water. This configuration enables several novel design elements:

1. The supply tank can either be gravity fed from the main tanks or filtered through a transfer/polishing system
2. By using a central supply tank, the main tanks can be sucked completely dry without risk of introducing air into the engine feed fuel. No reserve fuel need remain in the tanks.
3. All valves are accessible and clearly marked.

Virtually all Nordhavns come equipped with a wing engine, a complete spare propulsion unit including shaft and prop that can be used as a back-up should the main engine or shaft fail. To isolate the wing engine from potential fuel contamination problems, it draws its fuel from a small day tank that can only be replenished from a filtered source.

Figure 5
Nordhavn 47 Improved Fuel System



NOTE: All connections to fuel tanks have valves (not shown). Always in ON position

(1) Emergency Engine is dedicated propulsion unit (including shaft and prop). Configuration assures fuel cleanliness – must be filtered from onboard supply

(2) Walbro 6802 Fuel Pump on 1-hour timer

While this robust fuel system adds substantially to the price of the boat, owners appreciate the well-thought out systems. These are truly wonderful little ships.