My Ultimate Custom Trawler Diesel Fuel Management System

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Abstract: Solve ninety percent of your diesel problems with a deluxe custom fuel management system. I spent two thousand dollars, but you could spend as little as three hundred. You might want to leverage my twenty lessons learned from this project, & possibly to explore the references included below for kits, why we'd want to polish fuel in the first place, & explore a few other topics of interest to every diesel boat owner. But beware: this is fundamentally a detailed "how to" article with some new twists, not a "why" article. So if you're interested in a very clean & reliable fuel supply, & how achieve that, read on!

Photos of M/S Sojourn, the host of my new fuel management system:

   

The popular literature claims the predominant cause of diesel engine shut downs is contaminated fuel, especially in warmer climates. I have two diesel engines aboard the M/S Sojourn – a 1982 120 HP Ford Lehman & a 1994 5.5 KW Northern Lights Lugger generator. A contaminated fuel issue was one thing I never wanted to deal with. So I started with a set of objectives, did my research & built a design that I took almost a year to finish. Much of that period was think time. So if you are able leverage my effort, I would be delighted. Here's what I came up with.

<u>The General Principle</u>

The simplest fuel management system employs a filter, some plumbing & a pump to move fuel from one source to one destination. Add more than one source of fuel, more than one destination, more than one filter, one or more fuel-water separators, some valves to direct the flow of fuel down different paths with the capability to filter the fuel while your engines are running or not & you have a more sophisticated fuel management system. Add some water sensors in the fuel path, some gauges to tell you exactly when it is time to change filter elements, a higher volume pump to not only move the fuel, but to actually stir it up in the fuel tanks to put contaminants into suspension to be filtered out, & you now understand the fundamentals of the fuel management system I have built, being used successfully aboard my vessel, & am about to describe to you in nauseating detail.

The basic premise behind this system is that whatever contaminants exist in the fuel (dirt, water, bugs, i.e., algae – dead or alive), the only way to sustain reliable engine performance over time is to remove all these contaminants from your fuel & from your tanks with high quality filters. Fuel additives are another interesting but somewhat controversial topic not included in this article.

Please note that this is primarily a "how to" article, & does not attempt to duplicate the substantial body of literature that describes why fuel polishing is a good thing to do. There are references below to a few of the more definitive articles on that topic, however.

<u>Twenty Lessons Learned</u>

Lesson One: Perform your own research on the internet & with fellow boaters to see what others are doing in the area of fuel management. Focus on those sources that give thorough treatment to long term fuel storage since that's what most recreational boaters do—<u>we store fuel more than we burn it</u> (winter lay-ups, relatively long periods in marinas or at anchor between cruises). In other words, our fuel often spends much more time sitting in tanks than flowing through engines. Focus on the issues that fuel <u>storage</u> creates, & how best to resolve those issues as well as issues created by taking on contaminated fuel at the fuel dock.

Lesson Two: Document <u>everything</u>. There are many very good reasons for doing this. You may remember what you were intending a week or a month from now, but what about a year from now? What about five years from now? What about the next owner of your boat? Documentation adds low cost value to the boat. All it costs is some time & thought. Use that documentation for the next article you will contribute to your favorite owner's association bulletin. It can be fun. Think of it as a detailed entry in your ship's log. Take lots of photos of the entire system. It helps in your documentation, you can show off your handiwork without forcing your audience into your engine room, & it's something to look at & admire in the off season.

Lesson Three: Plan to use one larger size of valves, pipe & connectors than in your existing fuel system. For example, if you have 5/16" fuel hose between your tanks & engines, use 3/8" valves, connecting pipes & fuel hose. Adapt to the larger size with adapters (e.g., hose barb adapters on your new fuel system). Using this principle, you should not suffer from any fuel starvation issues at high loads (e.g., with high RPM underway).

Lesson Four: Take plenty of time to think about what you want this project to accomplish. Your think time up front will pay off handsome dividends later.

Lesson Five: Integrate your new fuel management system into your existing installation as seamlessly as possible. Use existing tank monitors, find a breaker that matches & fits into an existing breaker panel, etc. This not only makes good sense operationally, but is a more professional installation & saves cost while creating higher value.

Lesson Six: Obviously cost will constrain function, so prioritize your needs carefully. I had the luxury of defining what function I wanted with less focus on cost constraints (I am not yet throttled by fixed income!). So while I spent over two thousand dollars on this project, a good basic fuel polisher comprising a good filter & pump can be built for less than $300. You have a wide range of choices for cost & function.

Lesson Seven: Design your physical layout so that your fuel path & operations are visually intuitive. For example, it should be clear that a bypass path goes around the filter just by looking at the pipe & valve pattern on the bulkhead of your engine room.

Lesson Eight: Buy more materials than you think you will need such as fuel hose, valves, hose barbs, elbows, pipe lengths, etc., & you'll probably use most of them & still need more of something else. Remember, every design & installation truly is unique, & you always need something that you don't have.

Lesson Nine: Do as much construction off the boat, or at least outside the engine room where you are likely to have better light, better access to tools & be more comfortable. Build your design around this principle[1]. When you do start assembling parts, do a "try-for-fit" on as much of the system as possible. In other words, assemble everything "loosely" with no thread sealer or anything else that precludes easily disassembling & trying something else. This will save lots of time, frustration, & will result in a better physical layout. Consequently, things are more likely to work the first time you start "tightly" assembling.

Lesson Ten: I guarantee that even if you do a "try-for-fit", you will still discover a few surprises & will need to do some disassembly of a "tight" assembly. Take it in stride & "git 'er done!"

Lesson Eleven: The very last step you should take after designing, assembling & testing components of your new system as much as you can before putting into the boat is to take apart your current fuel system. Don't disable your boat before it is absolutely necessary. Then when you're ready, do it.

Lesson Twelve: Test as much of your installation before you put fuel through the system. You are less likely to have leaks once messy fuel starts flowing & I found several flaws in my design as I was thinking about how to test it.

Lesson Thirteen: I worried less about leaks between hoses & hose barbs secured with hose clamps. I worried most about brass to brass connections & tested logical groups of those connections most thoroughly with compressed air outside of the engine room.

Lesson Fourteen: Power consumption constraints should also be part of your functional prioritization. While I would have loved to have had a 120 GPH pump, I couldn't justify the consumption, costly wiring, etc., to support a 40 amp pump, not to mention the much larger physical size of this "super pump"!

Lesson Fifteen: Your entire system should be readily accessible for ease of operation & maintenance. I wanted to put my array of valves & gauges in the pilot house, but that's where the Admiral put her foot down! So even though flipping valves & checking gauges requires a trip to "the Holy Place", all functions can be easily performed. Don't forget to think about clearance to change filter elements above enclosures, & room to drain water from fuel-water separators below enclosures.

Lesson Sixteen: You must ensure that all components of the system are diesel fuel tolerant. Pay special attention to pumps & valves.

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[1] **Jurrens' Law**: "the older you are & the more constrained your engine room is, the more important this design principle becomes."

Lesson Seventeen: Ensure that all electrical components are marine rated (e.g., wiring that's stranded & tinned), in-line fuse holders (I prefer the waterproof kind) & breakers (no household breakers please!)
Lesson Eighteen: Ensure that your installation will pass a marine survey, so know the rules. Ask! Pay special attention to using appropriate (the best!) fuel hose (must pass the 2 minute fire test & will be labeled USCG Type A1/A2). Also, ensure your hose is secured to bulkheads & other hoses such that there is virtually no movement of the hoses possible—give them the wiggle test (again, check the code before you design & certainly before you install).
Lesson Nineteen: Stick to what you know works in your boat. This is one of the reasons I chose not to use a magnetic debugger, for example & stuck to good old fashioned filters.
Lesson Twenty: Perhaps most important of all, do not set a close-in deadline by which the project must be done just before you go on a cruise. Give yourself plenty of time to thoroughly test the system, if for no other reason, to give yourself confidence that you're not going to lose power at a crucial moment (the whole point of the system) because of a "bug" you haven't worked out, but also to get you very comfortable that you know what different gauge readings mean in the context of all possible operating conditions. Give it time. Test the heck out of this new system before you depend on it!

The Design Objectives

Quality & Reliability: I wanted clean fuel, so I needed to reliably remove all contamination (dirt, water, bugs) with sub-micron filtration capability & at the same time, perform high volume circulation in order to suspend contaminants to be removed by filtration). This would increase overall reliability.
Flexibility: I wanted to be able to transfer fuel from one tank to another, be able to isolate or connect fuel tanks as needed to enable quarantine or equalization. I wanted to be able to operate this fuel system with or without the engine running in order to pump, polish, transfer, bleed & drain.
Information: I wanted to know what was happening in terms of location & volume of fuel, whether there was water in the fuel or not, including visible & audible indications as well as the status of filter elements so I'd know when they need to be changed.
Survivability: I wanted lots of redundancy – back ups for everything possible, including water monitors, filters, gauges, pumps & valves. I also wanted real time recovery capability. If one filter element became fouled, I wanted to keep running on another while it was being changed. This requires back ups, bypasses & shut offs. If a gauge broke, I wanted to isolate it from the system. If a pump died, I wanted backup & bypass capability for both fuel & electrically. My fuel polishing pump needed to be a backup to my engine & generator lift pumps. If any of my diesels ever got into a runaway situation, I wanted to be able to starve either or both of fuel to regain control. I also wanted high volume filtration capacity so I could process a significant volume of contamination without constant filter element changes. Additionally, I wanted to achieve sub-micron filtration capability, but also wanted access to ubiquitous filter elements so I could find them anywhere.
Installation: I wanted this system to be modular so I could build & test most of it outside the engine room & before it was charged with fuel. I also wanted it neatly organized & able to fit onto existing spaces on the engine room bulkhead as much as possible.
Operation: I wanted visually intuitive & well documented operations, including automatically timed or continuous operations. It had to be very easy to bleed, or purge air from the system & changing filter elements had to be as easy as possible, either while underway or polishing in port or at anchor. I wanted low current draw but moderately high volume circulation capability. I wanted filters whose elements were cheap & easy to acquire. Once installed, I wanted a very low maintenance system with ease of operation safety as priorities, both electrically & for spill-avoidance
Integration: I wanted to incorporate all this new function into my existing fuel system, but I chose to keep my diesel furnace & its own in-line filter separate. I use this furnace only rarely, it has low tolerances & it will still benefit from using the clean fuel once it has been polished.

The Parts & Approximate Cost

You will notice that I have not included a precise list of parts used in this design as each installation will be significantly different based on functional design, implementation & how you integrate such a system into your existing fuel system or not. In Table 1, I have included a high level list of parts & approximate cost for my installation. The pictures & diagrams in this article will give you a fair estimation of the number of valves, connecting pipes & fuel hose. Beyond that, it should be fairly easy to make up your own list for your own requirements & installation.

Table 1: Approximate parts inventory & cost.

Parts	Approximate Cost (2004-2005)
Walbro continuous duty diesel pump	$120
GCF F-1 filter enclosure (incl. one element)	$460
Racor 500FG-P filter enclosure (incl. one element)	$130
Ball valves (<u>not</u> gate valves)	$250
¼" USCG approved type A1/A2 fuel hose (20 feet for connecting manifolds & pump)	$75
5/16"USCG approved type A1/A2 fuel hose (35 feet for connecting manifolds to existing fuel system, return lines, etc.)	$75
Water sensors & controllers	$170
Brass (assorted pre-threaded pipe lengths, hose barbs, elbows, adapters, etc.)	$150
SS hardware (cushioned hose clamps, regular hose clamps, etc.)	$100
Electrical (12 hour mechanical timer, 5A breaker, 100 feet of 16 gauge wire, terminal block for ground buss, fuse holders, crimp wire connectors, etc.)	$150
2 vacuum gauges	$75
Check valve	$25
King Starboard	$100
Piano hinge for F-1 tilt mechanism	$25
Other miscellaneous on hand items	$100
SUBTOTAL	**$2005**
Not including integrated existing fuel system elements (2 tanks, pneumatic tank tender (gauges G1 & G2), generator fuel-water separator (F-3 - Racor R120MAM), engine & generator secondary filters F-4 & F-5, furnace fuel filter F-6 & pump P3 as well as two 3-way valves (V13 & V19) stolen from existing fuel system installation.	?

Additionally, there are references on the internet that can be of use in this regard[2]. I used a total of about sixty feet of fuel hose, twenty new brass valves with stainless balls & Teflon sleeves (diesel fuel tolerant), a two by four foot sheet of ½" King Starboard, approximately seventy-five ½" stainless hose clamps, fifteen rubber insulated stainless cushion hose/pipe clamps with screw mounts (for mounting hose or pipe to a bulkhead or mounting boards that I call manifolds), assorted stainless screws & a wide assortment of brass pipe, elbows, cable ties, etc. For your installation, I suggest you spend some time at Home Depot looking at the various brass valves & pipes available, pick up a wide selection (far more than you think you'll need) & return that which you don't use. Obviously, two filters, a pump, two water sensors, approximately 100 feet of 16 gauge marine electrical wire, a 5 amp breaker & two inline fuse holders were part of my installation.

<u>The Implementation</u>

From my "wish list", I began to do some internet research for the best filters, the best pumps, the best fuel management system design & in general the state of the art fuel management for trawlers. This is at best a matter of opinion & at worst a matter of rather wild "religious" speculation. I finally gravitated toward that which is used by commercial vessels with diesel power plants such as ferries, fishing fleets & the boats that must reliably service offshore oil rigs in the Gulf of Mexico.

The heart of my new system is two high quality filters that could either be used in series or independently, with or without the engine and/or generator running that comprise two stages of filtration & a degree of redundancy. The primary polishing filter is Model F-1 manufactured by Gulf Coast Filters, Inc.(GCF)[3].

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[2] **"Fuel polishing":** search on the internet for this exact phrase (e.g., with http://www.metacrawler.com). This will reveal a significant number of informative articles on how & why fuel polishing.

[3] **Additional fuel polishing information & kits available:** see http://gulfcoastfilters.com/fuel_polishing.htm which also describes the importance of fuel polishing & different ways of achieving it efficiently. There is also a description of kits for sale. Another very famous article on fuel polishing by the infamous Capt'n Wil using the GCF filters can be read in its entirety at http://www.trawlerworld.com/features_06.htm. This article also describes why simple "pour-in solutions"

This filter is the only one I know that claims to provide sub-micron depth filtration[4] capability. This filter achieved some acclaim a few years ago as you can use a roll of Bounty brand paper towels as its filter element. You can also purchase their commercial element, which is what I've chosen to do, but it is intuitively appealing to be able to use a roll of paper towels in a pinch or as a sacrificial element until an extremely dirty fuel situation is cleaned up & then switch to the commercial element. The primary drawback is that this filter enclosure is very large. It requires at least 33 inches of total vertical clearance for the enclosure & sufficient headroom to remove & replace filter elements. This requirement can be reduced to "only" 24 inches or so if installed with a tilt mechanism to allow the top of the enclosure to be tilted toward an open overhead space (e.g., a hatch that can be opened in the overhead of the engine room). This is what I opted to do.

This filter enclosure is also a fuel-water separator; some think one of the best & has a mammoth sixty ounce water reservoir. In my installation, the F-1 is accompanied by the optional microprocessor-controlled water sensor which fires a strobe light (Seco-larm SL-126) in the pilot house when water needs to be drained from the reservoir at the bottom of the filter enclosure. The other advantage of using a much larger filter is that it lengthens the interval between necessary element changes (large capacity).

Note that while most of the pipe fittings in this installation will be ¼", 3/8" or 5/16", the F-1 has huge ½" female fittings in, out & drain. I adapted the in & out fittings to ¼" which I used to connect the filter enclosure to the F-1 manifold, but chose to terminate the drain in the full size ½". This assembly included a 90 degree elbow (male on one end, female on the other) to a short ½" pipe (male to male) to a ½" valve (female in, female out) to a short pipe (male to male) to clear the bottom of the filter, even when tilted (see below), then to a 90 degree ½" elbow (female to female) ending in a plug (male) with a square head for use with a wrench. This plug is a recommended safety feature & is only removed when actually draining water from the F-1 reservoir (remove the plug, then open valve 7 to drain into a small bucket). Be sure to allow for enough clearance below this filter enclosure to allow room for at least a shallow container into which fuel-contaminated water can be drained.

GCF also makes a smaller filter enclosure called the O-1 Jr. Where the F-1 element is the size of a roll of (Bounty) paper towels, the O-1 Jr. element is the size of a roll of toilet paper. This is still a fine filter with a good reputation & useful in a space-constrained lower cost application. Note that this filter is not a fuel-water separator, so it is still recommended that another filter with fuel-water separation capability be included as water is a major source of contamination ("bugs" grow when water is present in fuel) & can quickly kill an expensive injection pump on your engine(s).

The second filter in the system is the ubiquitous Racor 500FG-P[5] which is an edge filter[6]. Filter elements for this unit are widely accessible & small for convenient storage aboard (unlike the GCF). I use a two micron element to ensure the fuel that reaches the secondary fuel filters on the engine & generator is as clean as possible. Be aware, however, that while the GCF filter has standard "iron pipe" size (1/2") & NPT

(why simply pouring an additive of some sort into the fuel tanks) do not address the entire problem of fuel contamination caused by prolonged storage in warm climates.

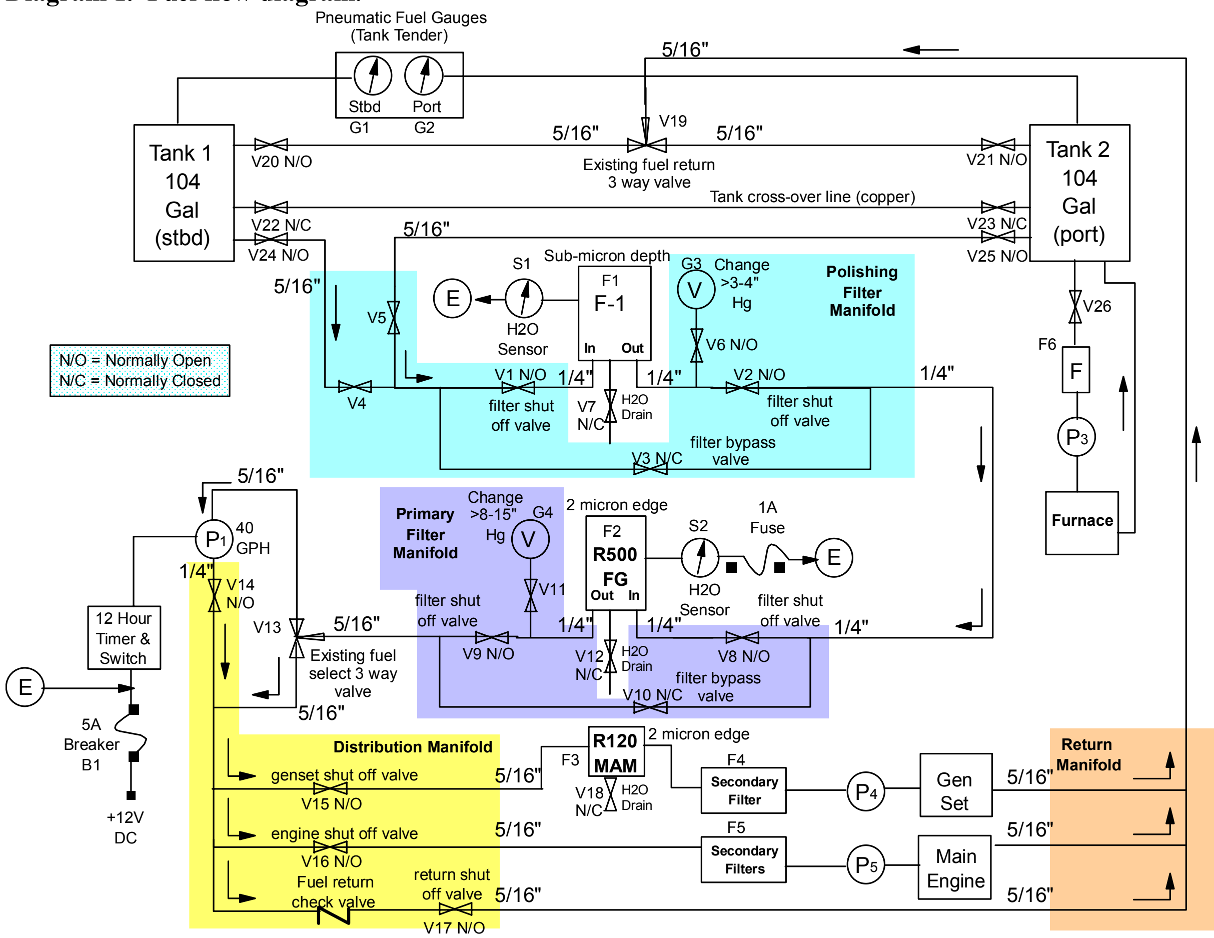
[4] **Depth filtration** versus edge filtration means that fuel (or oil) passes through the entire length (depth) of a three dimensional element. The advantage of this type of filtration is that sub-micron filtration can be achieved, at least theoretically & the depth filtration elements from Gulf Coast Filters, for example, can handle a significantly greater volume of contamination before the element must be changed.

[5] **Racor part number terminology explained**: FG suffix on the part number means it is the basic model. Add a "–P" for a water probe. Accompanying the probe in the transparent bowl of the filter enclosure, I also added the intermediate priced water detection kit (Racor #RK20726), which I purchased from MAESCO.COM for $82) & installed it in the pilot house. This kit displays a red light & sounds a buzzer in the presence of water in the R500's bowl.

[6] **Edge filtration** is by far the most common type of filtration. Fuel passes through the edge of a usually circular accordion element, from inside to out or vice versa. The advantage of this type of filtration is that a large volume of fuel can be filtered normally to approximately two microns.

tapered threads[7], the Racor has the more sophisticated fuel-specific SAEJ1926 fittings into & out of the filter, including O-rings. While these fittings are very specialized, they are commonly available & adapt to various size pipes & hoses. I purchased mine at Mid-Atlantic Engine Supply Company—part number 9040-6-4 since I was using ¼" hose (inside diameter, or ID) & then since I was connecting the filter to fuel hose, I added a hose barb fitting There is also an excellent article at the following web address explaining these SAE fittings (http://www.maesco.com/products/racor/r_access_fit/r_fits/r_fits.html)

Diagram 1. Fuel flow diagram.



I chose not to employ a magnetic debugging device, preferring to use the simplest methodology that I can easily & intuitively understand – the best filters I can lay my hands on. Also notice that at the advice of Gulf Coast Filters, I used a check valve in the fuel flow return manifold to prevent an inadvertent siphon effect when the system is not running & to prevent unintended introduction of air into the system. Also pivotal to any effective diesel fuel polishing (scrubbing) system is a relatively high volume pump designed

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[7] **Pipe & thread terminology** is important in purchasing pipe fittings. I chose to use the most common type already threaded fittings called "iron pipe". For example, MIP or MIPT is called male iron pipe threads & FIP or FIPT is a female iron pipe thread (this does <u>not</u> mean the pipe is made of iron – it just means the pipe (in our case) is brass but uses the MIP or FIP pipe thread pattern. These are important labels on piece meal brass fittings you need to purchase for this project. Another important standard is NPT, or National Pipe Thread. This is the U.S. standard for tapered threads, which means you have flexibility in connecting these fittings. Since they're tapered & you're using a sealing compound such as Lok-Tite, this is useful when aligning fittings for assembly. So, for example, when purchasing valves, I looked for valve bodies & elbows that terminated on both sides with FIP patterns. When looking for connecting pipe, I looked for MIP with NPT tapered threads.

to pump diesel fuel. This is one area where I felt a slight compromise was called for – not primarily because of cost or space, but because of a reasonable balance between volume of fuel pumped per unit of time (important to "stir up" the sludge in the bottom of a tank so it can be filtered out) & the "volume" of electrical consumption.

I initially had ordered & received the best diesel fuel pump I could find from GCF[8], which was a magnificent Oberdorfer bronze gear pump with a powerful Lesson motor. While its size was a bit daunting (almost two feet long & almost a foot in diameter, after purchasing it & returning it (after much soul searching—it truly was an engineering marvel that pumped 120 GPH), I opted for the popular and much less exciting Walbro[9] 40 GPH continuous duty pump, which I also purchased from GCF. Not only was the Walbro a fraction of the size, it consumed only 5 amps of electrical current instead of close to 40 amps & was about one fourth the cost! Yet it still pumped a respectable 40 GPH. Whatever pump you choose to use, ensure that it is designed for diesel fuel & that it is a continuous duty pump rated for marine use. See the two diagrams below for a representation of the complete system. Diagram 1 depicts the flow of fuel & Diagram 2 illustrates the associated electrical flow.

I built the bulk of the system on four separate manifolds, or assembly boards (see shaded areas in Diagram 1): the F1 filter manifold (polishing filter), the F2 filter manifold (primary filter), the distribution manifold (distributes fuel from & to pump, to engine, generator, return line) & finally, the return manifold (after fuel comes back from engine or generator or return line above, returns excess fuel to the fuel tanks).

Advantages of this manifold construction technique are significant. First, the manifolds, each of which serve an intuitively obvious & discreet function, can be assembled & tested in a setting more comfortable & efficient versus assembling such a system component by component in the engine room. I built these in my comfortable basement shop or boat cockpit. I was able to adjust the size & design of each manifold with various brass fittings I acquired. I bought many more valves, connecting pipes, hose barbs & other needed components than I ever conceived of needing, with the intent of returning those I didn't use. I did this because I found it difficult to anticipate everything I was going to need.

I had two goals with respect to the design of each manifold. First, I wanted the fuel path to be visually intuitive (e.g., easy to see, based on valve position & the way the pipes connected the valves how the fuel would flow through the filter or bypass the filter). Second, I wished to minimize the size of each manifold. As this design & installation took the better part of a year of thinking, refining & implementing, this manifold approach worked well for me. I could then place each manifold (and filters) where space permitted on the bulkheads of the engine room. Connecting them as necessary with an appropriate length of fuel hose was then required. Using manifolds in this manner made for a handsome installation as a dividend. A side benefit of taking a good deal of time for the project is that it spread the cost out over time.

There were also a couple of disadvantages of this manifold approach. Mounting each valve individually onto the engine room bulkheads would have taken less total space. If bulkhead space is at an absolute premium, you should consider this approach. Additionally, if a leak were to develop in one valve joint, you would need to remove an entire manifold to fix the leak outside the engine room. There would still be only two hoses to disconnect, but a manifold full of fuel to contain.

The first step in building the manifolds was to assemble the desired valve configuration loosely without Loc-Tite as a try-for-fit with different lengths of brass pipe of the same size as valve fittings. You can buy lengths of brass pipe pre-cut to different lengths ranging from "close length", which is the shortest to 6" or more & you want the kind that is already threaded to fit into the female threads of the valve bodies), in my case, they were either ¼" or 3/8", adjusting the length of the connecting pipes to get the desired physical configuration. I made sure that as I did this, there was plenty of clearance to swing all valves through their

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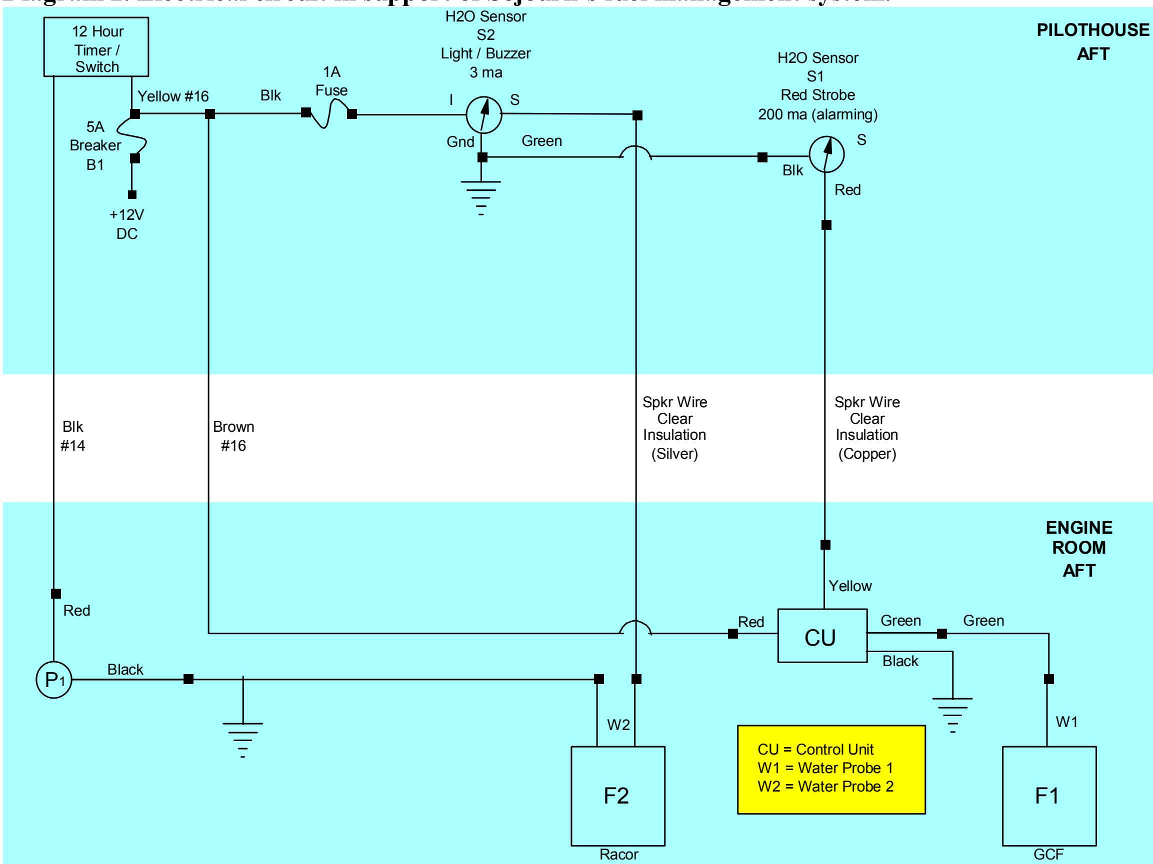
[8] **Gulf Coast Filters**, P.O. Box 2787, Gulfport, MS 39503 (228) 832-1663, http:/www.gulfcoastfilters.com
[9] **Walbro Engine Management Corporation**, After-Market Division, 6242 Garfield Street, Cass City, MI 48726-1397. Walbro part number 14-527U includes a U.L. listed oil pressure safety switch.

normal range of operation. Where valves were necessarily in close proximity (e.g., the Distribution Manifold), I bent the handle away from the backing board & out of the swing path of the adjacent valve.

Diagram 2. Electrical circuit in support of Sojourn's fuel management system.



All required inputs & outputs of each manifold were terminated with brass hose barbs that would match their counterparts on either other manifolds or existing fittings within the current fuel system (in my case, I had assembled these manifolds over the winter assuming ¼" fittings on the fuel tanks. It turns out these existing fuel system fittings were in fact 5/16" & it is difficult in the distant recesses of a dimly lit engine room to tell the difference. So please avoid the mistake I made & ensure you know the actual size of your fittings. In some cases, older fuel hoses are not labeled, so I went to a marine store & bought some labeled 5/16" fuel hose & ¼" hose. If one was a tight fit over an existing fitting, that clearly identified its size.

Once this configuration was done, I measured what the required size of backing board would be for each manifold. These manifolds were constructed on a backing of ½" King Starboard rectangles[10] onto which either ¼" or 5/16" bronze ball valves with Teflon sleeves were assembled, connected by either ¼" or 5/16" brass tubing (red brass is preferred but not essential). The two filter manifolds included capabilities to flow fuel through the filters, bypass the filters, monitor when filter elements needed to be changed with vacuum gauges, hose barb inputs & outputs to connect each manifold to other components in the system.

[10] **King Starboard** is amazing material, although not inexpensive. Normal woodworking tools can be used to shape this high density polyethylene plastic which is completely impervious to weather & fuel. It is available from any of the major marine stores. I rough cut the manifold pieces with a circular saw & then routed a small curve on all front-facing edges. All holes drilled to mount the manifolds were countersunk so all mounting screws were flush with the surface (usually four mounting screws per manifold).

Photo 1. F1 (GCF) filter, F1 manifold & 40 GPH pump P1.

Once I had my try-for-fit configuration & the appropriate size backing board cut, then & only then did I start the final assembly of the valves & pipes with fuel tolerant (this is important!) thread sealer (see below). After these assemblies were complete, I secured them to the backing boards with rubber lined stainless cushion clamps over the pipe lengths with stainless screws into pre-drilled holes into the backing board. Be careful not to over tighten as you risk breaking the seal to valves on either side of the clamps. Within each manifold, I assembled each brass to brass joint with Blue ThreadLocker (blue in color & medium strength that can be unassembled, but only with a wrench). I do not recommend using the "strong" (red in color) as it can only be disassembled by heating (burning) it until it becomes ash. This seemed counter-intuitive with a fuel system & the blue works just fine. The Lok-Tite or PermaTex brands seemed to work equally well. I used a good quality label gun that I own to clearly label the number & purpose on each valve, gauge & manifold consistent with the designations on Diagrams 1 & 2.

I felt it was critical to carefully assemble & test each joint using this fuel-tolerant "Threadlocker" material to eliminate leaks before charging the system with fuel as leaks after installation are messier to rectify. I then pressure-tested each manifold with compressed air using an adapter commonly available to connect the brass fuel pipe to the air gauge with a tire-filling adapter and pressurizing it overnight as extra anti-leak insurance. I used compressed air from a portable compressor & tested each manifold to 15 PSI, which I figured should be significantly greater pressure than would be encountered during fuel operations. All this up-front effort paid off since as of today, my installation has had ZERO leaks! I'm told this is unusual for a fuel system this complex.

I mounted the manifolds to the engine room bulkheads using cheap & readily available, but high quality stainless household deck screws countersunk into the surface of the plastic boards. They come in various lengths, are driven by a #2 square drive (requires a special bit for your cordless drill to drive these screws) & they are very “sticky”, that is, they stay where you screw them.

Photo 2. F2 (Racor) filter, F2 manifold & 40 GPH pump P1.

After the manifolds were screwed to the engine room bulkheads, connections between them, to & from the pump, tanks to the engines & return lines were made using ¼” or 5/16” USCG Type A1/A2 marine diesel fuel hose & a single stainless hose clamp of appropriate size per connection.

Notice in Photo 1 the tilt mechanism for the GFC (F1) filter. This allows the entire F1 filter enclosure to tilt forward at the top approximately 40 degrees. This was necessary because there was insufficient headroom in the engine to allow easy insertion & removal of the F1 filter element. During normal operation, two stainless wing nuts, one on either side of F1 toward the top, along with a stainless “piano hinge” at the bottom, hold the 36 pound filter enclosure (sans fuel) firmly in place. This tilt mechanism was also built of King Starboard fastened to the F1 brackets outside the engine room & later the entire assembly was then fastened to the aft engine room bulkhead. Note also visible in Photo 1 is a brass chain. This stops the forward tilt of the F1 enclosure at the desired angle which allows the filter element to be removed through the hatch in the ceiling of the engine room to the pilot house. The operation of this tilt mechanism was also tested with the filter enclosure empty & full since the entire assembly, including two gallons of fuel, is in excess of fifty pounds so it has to be very sturdy.

You may observe that the ball valves (Apollo brand[11]) in the photos are open when they are in line with their axis & closed when perpendicular to their axis. In this way, the selected fuel flow path is visually

[11] **Apollo valves** were inexpensive & purchased at Home Depot. They are not specifically rated for diesel applications, but if the body is brass & the ball is stainless with a Teflon sleeve, the only thing you’re not

intuitive. For example, in Photo 1, you'll notice that on manifold F1, the valve to gauge G3 is open. The bypass valve (V3) is also open & the two valves that lead fuel through filter F1 (V1 & V2) are currently closed. Similarly, of the two valves on the left side (V4 & V5), you can see that V4 (fuel from starboard tank) is open & V5 (fuel from the port fuel tank) is closed. So a quick visual inspection of manifold F1 will tell you that filter F1 is currently bypassed & isolated (e.g., for changing the element) & fuel is currently sourced from the starboard fuel tank. Likewise, a quick inspection of Photo 2 will illustrate that the bypass valve is closed & the two valves that allow fuel to & from filter F2 are open; therefore, F2 is online, as is gauge G4

Testing It All

After installing the system, it was necessary to thoroughly test it. What follows is a summary of functions & specific test cases exercised in my two tank, two engine & multiple filter application. First, it was necessary to charge the system with fuel & purge air from the fuel path. Next, dockside tests were run to ensure reliable fuel delivery to the engine & generator in a no-load situation. And finally, Admiral & Captain got underway to run sea trials in order to exercise the system as thoroughly as possible under a variety of operating conditions, with the Admiral at the helm & the Captain in the engine room recording gauge readings during a variety of scenarios.

Charging the System with Fuel

I carefully poured 1.5 gallons of clean diesel into the GCF filter F1 (this enclosure is large), following the instructions in my documented operations manual, which is operation 15 (changing F1 filter element)[12]. When almost full, I slowly inserted the filter element & topped off the filter enclosure with fuel. I waited five minutes for air to settle out with the enclosure lid screwed on loosely to prevent spills due to wave motion), then topped off with an additional 0.5 gallons (approximately) & secured the lid securely. I then did the same for the Racor filter (F2) but with only 0.5 gallons of fuel. As there was obviously air in the fuel flow path from the initial installation process, I then purged all air in the fuel path between tanks & engines.

The primary purpose of testing from this point on, of course, first at the dock & later with sea trials was to establish base line operating procedures as well as to determine what vacuum gauge readings were normal under a variety of operating conditions. I also needed to know whether the existing lift pumps on the engine & generator were up to the task of pulling fuel through this new longer fuel path in excess of sixty feet & through both of my new filters concurrently as well as individually. Thankfully, there were no apparent fuel starvation issues or leaks whatsoever & I quickly became familiar with what the gauges should read.

Part of the tests at the dock included ensuring all electrical wiring & instrumentation worked as intended. On F1, I purchased & installed GFC's microprocessor controller & red xenon strobe light (water sensor S1), which is rather large at almost 4" in diameter & 3" deep, so I mounted it behind a set of louvered doors in the pilot house of our motorsailer – it is thus out of the way, but still very visible through the louvers when lit (alarming). Water sensor S2 for the F-2 Racor filter uses a much smaller & more discreet gauge that has both a visible red LED when water is present as well as an audible buzzer when water is present in F2. I simply flush mounted this indicator on the pilot house bulkhead near where the strobe is for the S1 sensor which is also near the breaker & twelve hour mechanical timer for pump P1 for ease of operation. Both sensors & indicators make it obvious when water is present in the reservoir of either or both fuel-water separators & when it is time to drain water from F1 & F2. Both S1 & S2, along with their indicators, tested functional with their own power-on test when the breaker & timer were activated.

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paying for, but getting is the diesel testing rating. Judge for yourself – pay $5 to $10 each at a home improvement center, or three or four times as much from a marine center.

[12] **Sojourn's Fuel System Operations Manual:** If you would like a soft copy of my ten page operations manual for this project, please email me at gjurrens@aol.com. I would be glad to send it to you by return email (no hard copy requests via snail mail please).

Table 2: Summary of Tests

Test Location	Test Conditions	Test Results
At the dock (9 scenarios)	Fuel polishing with one of the filters & with, with & without generator running under load, with & without engine running at different RPMs (no load)	Record vacuum gauges (G3 & G4) in each of these nine scenarios for the operations manual.
Underway (5 scenarios, each run at 7 different RPMs)	Each of five scenarios (engine only, engine & generator, one or two filters, with & without concurrent polishing, i.e., pump P1 on or off) running at various RPMs from 1000 to 2200 RPM	Record vacuum gauges (G3 & G4) at each RPM in each of these five scenarios for the operations manual.

My conclusions from this testing are that for day to day operation of the engine & generator, this fuel system is largely self-tending, has more than adequate capability to provide more fuel than is needed, with or without the fuel polishing pump running, at all engine & generator loads. The tests verified the validity of the design. Perhaps more importantly, they gave me the confidence that this system met my reliability & capability objectives & is simple to operate.

Operations Summary:

This system was designed to perform any of twenty-two discrete operations at will. These include polishing port fuel or starboard fuel, transferring fuel from one tank to another & vice versa, isolating fuel tanks or interconnecting them, emergency shutdown, burn fuel from one tank or the other, bypass the fuel polishing pump or not, bypass either filter or not, isolate & drain water from each filter enclosure, change each filter element, either while running & polishing on the other filter or not, bleed air from all lines to & from the engine, generator, pumps & filters, bypassing gauges individually & finally Winter storage & Spring commissioning. Each operation is documented so as to perform them simply & safely.

Under normal operation, the only changes I need to make is to select which tank to draw fuel from & to which tank to return fuel. Beyond that, no visit to the engine room is necessary at all until it is time to check or change the elements. I only need to turn on a breaker in the pilot house & turn the twelve hour timer to the desired number of hours. Beyond that, it is a simple matter to monitor the gauges, also in the pilot house, to ensure that nothing unintentional is happening (e.g., polishing starboard fuel, returning it to the port tank & possibly causing a spill). The basic rule is return fuel to the same tank it is drawn from unless you are intentionally transferring fuel from one tank to another, in which case you must carefully monitor this operation to prevent an unintentional spill.

In Conclusion

Building this fuel management system took some spare time that I chose to spend on a very thoughtful approach to an age-old set of problems – dirt, bugs & water in diesel fuel, as well as moving fuel around & monitoring its status. I believe the leisurely time spent in design, assembly & testing paid off handsomely in a leak-free & highly functional system that should provide many years of relatively simple & trouble-free operation. It is arguably complex, but as long as it’s reliable & does what it is supposed to do, criticize away. If you haven’t guessed by now, I am an engineer & the bottom line is that this was a lot of fun for me! This was a sizeable project, but I believe the peace of mind that it offers & the entertainment it yielded me was well worth it

At the Dock Test Results – Set 0

Test #	Generator	Engine	P1	F1	F2	G3 (F1)	G4 (F2)	Comments
1	Off	Off	On	On	Off			Starboard
2	Off	Off	On	Off	On	2	0	Starboard
3	Off	Off	On	On	On	4	7	Starboard
4	On	Off	Off	Off	On	0	1.25	load
5	On	Off	Off	On	On	1.25	1.5	load
6	Off	On	Off	Off	On	0	1.4	No load
7	Off	On	Off	On	On	1.5 2	1.9 2.3	700 RPM 1000 RPM (no load)
8	On	On	Off	On	On	2.5	2.9	700 RPM (no load)
9	On	On	On	On	On	6	9	Loaded gen Eng no load

Sea Trial Test Results – Set 1: Engine only, Racor (F2) only, polishing pump P1 off (generator & F1 offline, no concurrent fuel polishing).

Test #	Generator	Engine	P1	F1	F2	G3 (F1)	G4 (F2)	Comments
10	Off	On	Off	Off	On	0	<1	1000 RPM
11	Off	On	Off	Off	On	0	<1	1200 RPM
12	Off	On	Off	Off	On	0	1	1400 RPM
13	Off	On	Off	Off	On	0	1.1	1600 RPM
14	Off	On	Off	Off	On	0	1.4	1800 RPM
15	Off	On	Off	Off	On	0	1.5	2000 RPM
16	Off	On	Off	Off	On	0	1.5	2100 RPM
17	Off	On	Off	Off	On	0	<2	2200 RPM

Sea Trial Test Results – Set 2: Engine only, both primary filters, polishing pump P1 off (maximum engine fuel filtration, no concurrent fuel polishing).

Test #	Generator	Engine	P1	F1	F2	G3 (F1)	G4 (F2)	Comments
18	Off	On	Off	On	On	0	1	1000 RPM
19	Off	On	Off	On	On	0	1	1200 RPM
20	Off	On	Off	On	On	0	1.5	1400 RPM
21	Off	On	Off	On	On	1	1.5	1600 RPM
22	Off	On	Off	On	On	1	2	1800 RPM
23	Off	On	Off	On	On	1	2	2000 RPM
24	Off	On	Off	On	On	1	2	2100 RPM
25	Off	On	Off	On	On	1	>2	2200 RPM

Sea Trial Test Results – Set 3: Engine & generator, Racor (F2) only, P1 off (F1 offline, burning fuel in both engines, but no concurrent fuel polishing).

Test #	Generator	Engine	P1	F1	F2	G3 (F1)	G4 (F2)	Comments
	On	On	Off	Off	On			1000 RPM
	On	On	Off	Off	On			1200 RPM
	On	On	Off	Off	On			1400 RPM
	On	On	Off	Off	On			1600 RPM
	On	On	Off	Off	On			1800 RPM
	On	On	Off	Off	On			2000 RPM
	On	On	Off	Off	On			2100 RPM
	On	On	Off	Off	On			2200 RPM

Sea Trial Test Results – Set 4: Engine & generator, both primaries on (F1 & F2), P1 off (burning fuel through both filters to both engines without concurrent fuel polishing).

Test #	Generator	Engine	P1	F1	F2	G3 (F1)	G4 (F2)	Comments
	On	On	Off	On	On			1000 RPM
35	On	On	Off	On	On			1200 RPM
36	On	On	Off	On	On			1400 RPM
37	On	On	Off	On	On			1600 RPM
38	On	On	Off	On	On			1800 RPM
39	On	On	Off	On	On			2000 RPM
40	On	On	Off	On	On			2100 RPM
41	On	On	Off	On	On			2200 RPM

Sea Trial Test Results – Set 5: Engine & generator, both primaries (F1 & F2), P1 on (burning fuel through both filters to both engines & polishing fuel while running).

Test #	Generator	Engine	P1	F1	F2	G3 (F1)	G4 (F2)	Comments
42	On	On	On	On	On			1000 RPM
43	On	On	On	On	On			1200 RPM
44	On	On	On	On	On			1400 RPM
45	On	On	On	On	On			1600 RPM
46	On	On	On	On	On			1800 RPM
47	On	On	On	On	On			2000 RPM
48	On	On	On	On	On			2100 RPM
49	On	On	On	On	On			2200 RPM

Detailed Operations Manual

Set Up: Normal Fuel Flow (Operation 0)

1. **Valves that are normally open:**
   a. 1, 2, 6 – flow through F1 fuel polishing manifold
   b. 8, 9, 11 – flow through F2 primary fuel filter manifold
   c. 14 – flow through pump P1
   d. 15 – flow to generator
   e. 16 – flow to engine
   f. 17 – flow to return manifold
   g. 20, 21 – flow into tanks 1 & 2
   h. 24, 25 – flow from tanks 1 & 2

2. **Valves that are normally closed:**
   a. 3 – F1 bypass
   b. 7 – F1 water drain
   c. 10 – F2 bypass
   d. 12 – F2 water drain
   e. 18 – F3 water drain

3. **Valves that need to be selected:**
   a. 4 or 5 – source fuel from tank 1 (starboard) or tank 2 (port) respectively
   b. 13 – three way valve to route fuel through pump P1 or bypass P1
   c. 19 – three way valve to return fuel to tank 1 or tank 2
   d. 22, 23 – connect or isolate tank 1 & tank 2
   e. 26 – fuel flow to furnace on or off

Operation 1: Polish (clean) port fuel
<u>Why</u>: Circulate fuel through filtration to prevent fuel contamination problems or to correct an existing fuel contamination issue.
<u>When</u>: 1 time per week north of the tropics, 3 times per week in the tropics, circulate the entire fuel supply through the filters 5 times after a lengthy period of non-use (storage)
<u>Caution</u>: Ensure fuel is coming from, and going back to, the same tank. Otherwise, there is a risk of a spill by overfilling a tank.

a. Ensure normal fuel flow in Set Up
b. Open valve 5 – fuel from port tank
c. Close valve 4 – prevent fuel from starboard tank
d. Select 19 to port tank (3-way valve) – returns fuel to port tank
e. Turn on breaker B1
f. Turn timer clockwise to desired number of polishing hours
g. Monitor gauges G1 & G2 <u>very</u> carefully until you are sure the desired operation is proceeding as planned <u>and</u> no undesired operation is taking place (i.e., unintentional transfer of fuel from one tank to another, potentially causing a spill from unintentionally over filling a tank)
h. When operation is complete or is to be aborted, turn off breaker B1

Operation 2: Polish (clean) starboard fuel
Why: Circulate fuel through filtration to prevent fuel contamination problems or to correct an existing fuel contamination issue.
When: 1 time per week north of the tropics, 3 times per week in the tropics, circulate the entire fuel supply through the filters 5 times after a lengthy period of non-use (storage)
Caution: Ensure fuel is coming from, and going back to, the same tank. Otherwise, there is a risk of a spill by overfilling a tank.

a. Ensure normal fuel flow in Set Up
b. Open valve 4 - fuel from starboard tank
c. Close valve 5 - prevent fuel from port tank
d. Select 19 to starboard tank (3-way valve) – returns fuel to starboard tank
e. Turn on breaker B1
f. Turn timer clockwise to desired number of polishing hours
g. Monitor gauges G1 & G2 very carefully until you are sure the desired operation is proceeding as planned and no undesired operation is taking place (i.e., unintentional transfer of fuel from one tank to another, potentially causing a spill from unintentionally over filling a tank)
h. When operation is complete or is to be aborted, turn off breaker B1

Operation 3: Transfer fuel from starboard tank to port tank
Why: Balance the ship while keeping the two fuel tanks isolated (quarantined) as a guard against future potential contamination
When: One tank is very full and the other is very empty, and it affects the trim of the ship
Cautions: If starboard fuel is contaminated, transferring some or all to the port tank will contaminate that fuel as well. Additionally, there is a risk of a spill by overfilling a tank, so *be sure to monitor this operation very closely from start to finish,* particularly on gauge G2.
Advice: polish fuel in starboard tank before transferring to port tank

a. Ensure normal fuel flow in Set Up
b. Open valve 4 – fuel from starboard tank
c. Close valve 5 – prevent fuel from port tank
d. Select 19 to port tank – return fuel to port tank
e. Turn on breaker B1 & turn timer counterclockwise to "hold"
f. Monitor gauges G1 & especially G2 very carefully throughout the entire operation
g. When desired fuel has been transferred, or if the operation is to be aborted, turn off breaker B1 first and then return timer dial clockwise to "off"

Operation 4: Transfer fuel from port tank to starboard tank
Why: Balance the ship while keeping the two fuel tanks isolated (quarantined) as a guard against future potential contamination
When: One tank is very full and the other is very empty, and it affects the trim of the ship
Cautions: If port fuel is contaminated, transferring some or all to the starboard tank will contaminate that fuel as well. Additionally, there is a risk of a spill by overfilling a tank, so *be sure to monitor this operation very closely from start to finish,* particularly on gauge G2.
Advice: polish fuel in port tank before transferring to starboard tank

a. Ensure normal fuel flow in Set Up
b. Open valve 5 – fuel from port tank
c. Close valve 4 – prevent fuel from starboard tank
d. Select 19 to starboard tank – returns fuel to starboard tank
e. Turn on breaker B1 & turn timer counterclockwise to "hold"
f. Monitor gauges G2 & especially G1 very carefully throughout the entire operation
g. When desired fuel has been transferred, or if the operation is to be aborted, turn off breaker B1 first and then return timer dial clockwise to "off"

Operation 5: Isolate starboard & port fuel tanks from one another
Why: Keep two independent sources of fuel separate from each other
When: Taking on fuel of dubious quality, prevent contamination taken into one tank from contaminating the fuel in the other tank. Also, if letting the boat (and fuel) sit for more than a week, or it has been sitting for some time without polishing the fuel, it is good practice to keep the tanks isolated to prevent potential contamination in one tank from spreading to the other tank.
Caution: *Always* isolate the tanks when taking on fuel of uncertain quality. *Always* isolate the tanks any time a regular polishing routine of complete circulation of all fuel three times a week in the tropics is not possible or practical.
Advice: Polish fuel before opening cross-over between tanks. It is good practice to keep the tanks isolated as a normal practice, and open cross-over as a no power fuel transfer capability only when you want equal fuel in both tanks. *Exercise this with caution.*

a. Close valve 22 – fuel from/to starboard tank
b. Close valve 23 – fuel from/to port tank

Operation 6: Connect starboard & port tanks to one another
Why: Equalize fuel in the two tanks without needing to resort to using the pump to transfer fuel
When: When you want to treat the two fuel tanks as a single source of fuel
Caution: *Never* connect the tanks when taking on fuel of uncertain quality into either tank. *Only* exercise this operation if fuel in both tanks is known to be of excellent quality
Advice: It is good practice to keep the tanks isolated as a normal practice & view cross-over as no power fuel transfer capability when you want equal volume of fuel in both tanks. This could take significant time for the volume of fuel in the two tanks to equalize. *Exercise this operation with caution.* You may be contaminating good fuel.. It is also a good practice to connect the tanks only after fuel in both tanks has been polished (operations 1 & 2)

a. Open valve 22 – fuel from/to starboard tank
b. Open valve 23 – fuel from/to port tank

Operation 7: Emergency shutdown
Why: A spill is imminent (i.e., too much fuel transferred from one tank to another), or you are experiencing electrical problems with fuel management system (e.g., pump P1)
When: Any time quick termination of fuel management operations is required
Advice: Always be prepared to execute this operation during any fuel transfer operation

a. Turn off breaker B1
b. Turn off timer T1
c. Secure any valves that should be normally closed (see fuel management system diagram – N/C) or appropriate valves to isolate a leak that has developed.

Operation 8: Burn fuel from starboard tank
Why: More fuel in starboard tank than port, or fuel in port tank is known or suspected to be contaminated
When: Any time you do not wish to burn fuel from port tank
Caution: unless explicitly transferring fuel from one tank to another (see operations 3 & 4), always return excess fuel to the same tank from which it was sourced

a. Ensure normal fuel flow in Set Up
b. Open valve 4 – fuel from starboard tank
c. Close valve 5 – prevent fuel from port tank
d. Select 19 to starboard tank – returns fuel to starboard tank
e. Turn on breaker B1, turn timer counter-clockwise to "hold" (this is optional IF engine or generator lift pump are able to generate adequate vacuum to operate without pump P1)

Operation 9: Burn fuel from port tank
Why: More fuel in port tank than port, or fuel in starboard tank is known to be contaminated
When: Any time you do not wish to burn fuel from starboard tank
Caution: Unless explicitly transferring fuel from one tank to another (see operations 3 & 4), always return excess fuel to the same tank from which it was sourced

a. Ensure normal fuel flow in Set Up
b. Open valve 5 – fuel from port tank
c. Close valve 4 – prevent fuel from starboard tank
d. Select 19 to port tank – returns fuel to port tank
e. Turn on breaker B1, turn timer counter-clockwise to "hold" (this is optional IF engine or generator lift pump are able to generate adequate vacuum to operate without pump P1)

Operation 10: Bypass pump P1
Why: Pump fails or no polishing required beyond normal filtration
When: Just normal filtration while underway
Question: Are engine and generator lift pumps powerful enough to draw fuel through F1-F5 without P1? May be necessary to bypass F1 if not (installation-specific)

a. Ensure normal fuel flow in Set Up
b. Turn off breaker B1 and timer T1
c. Close valve 14
d. Select 13 to bypass pump

Operation 11: Bypass filter F1
Why: Element needs to be changed
When: vacuum gauge reads >3-4 (above little white arrow on face of gauge)
Caution: *Never* bypass both F1 & F2 at the same time as this will allow any contaminants in the fuel to be passed directly to secondary filters on engine or generator and they may get clogged quickly, shutting down the engine (gradual loss of RPMs until dead – could damage the *very* expensive injector pump if secondaries pass contaminants through). Also, never close both the F1 filter path (valves 1, 2) and F1 bypass path (valve 3) at the same time, as this will prevent *any* fuel from flowing, may damage pump P1, may create a fuel leak from building up excess fuel system pressure, and *will* shut down engine and/or generator.
Advice: As a normal practice, it really makes sense to leave both F1 & F2 filters on line, and only take one or the other off line to change an element (safety in redundancy) or to isolate a leak:

a. Ensure normal fuel flow in Set Up
b. To bypass:
    a. Close valves 1, 2
    b. Open valve 3
    c. Perform operation (e.g., operation 13 or 15)
c. To reverse bypass to put filter back on line:
    a. Open valves 1, 2
    b. Close valve 3

Operation 12: Bypass filter F2
Why: Element needs to be changed
When: vacuum gauge reads >8-15 (above little white arrow on face of gauge)
Caution: *Never* bypass both F1 & F2 at the same time as this will allow any contaminants in the fuel to be passed directly to secondary filters on engine or generator and they may get clogged quickly, shutting down the engine (gradual loss of RPMs until dead – could damage the *very* expensive injector pump if secondaries pass contaminants through). Also, *never* close both the F2 filter path (valves 8, 9) *and* F2 bypass path (valve 10) at the same time, as this will prevent *any* fuel from flowing, may damage pump P1, may create a fuel leak from building up excess fuel system pressure, and *will* shut down engine and/or generator.
Advice: As a normal practice, it really makes sense to leave both F1 & F2 filters on line, and only take one or the other off line to change an element (safety in redundancy) or to isolate a leak:

a. Ensure normal fuel flow in Set Up
b. To bypass:
    a. Close valves 8, 9
    b. Open valve 10
    c. Perform operation (e.g., operation 14 or 16)
c. To reverse bypass to put filter back on line:
    a. Open valves 8, 9
    b. Close valve 10

Operation 13: Drain water from F1
Why: To ensure water that has been "filtered out" does not reach the engine (injector pump) and cause potentially costly damage
When: Red strobe (water sensor S1) flashes when water needs to be emptied from the reservoir in the bottom of filter F1
Question: should polishing operation 1 or 2 be underway before beginning this procedure to keep the lines and filter full of fuel and consequently displace any air that might be introduced during draining?

a. Ensure breaker B1 is off
b. Close valves 1, 2
c. Ensure drain valve 7 is closed
d. Remove plug from end of drain valve 7
e. Place container under valve 7 to catch water/fuel drained
f. Remove filter housing top cover with T handle on top and set aside
g. Crack open valve 7 until clear fuel comes out
h. Carefully dispose of water/fuel mixture as if it were all fuel
i. Close valve 7 and replace plug
j. Slowly fill housing with clean fuel until near full.
k. Moisten rubber gasket around housing lid assembly with clean fuel
l. Reinstall lid assembly as tight as possible using both hands. *Do not use any tools or cheater pipes.*
m. Ensure red strobe (S1) no longer indicates water is present in filter F1. If it doesn't, repeat this operation
n. Open valves 1, 2

Operation 14: Drain water from F2
Why: To ensure water that has been "filtered out" does not reach the engine (injector pump) and cause potentially costly damage
When: Racor fuel/water indicator (water sensor S2) flashes and buzzes intermittently, indicating water needs to be emptied from the reservoir in the bottom of filter F2

a. Ensure breaker B1 is off
b. Close valves 8, 9
c. Place container under valve 12 (normally closed) to catch water/fuel drained
d. Remove filter housing top cover with T handle on top and set aside
e. Crack open valve 12 only as much as needed to begin draining & until only clear fuel comes out
f. Close valve 12
g. Slowly fill housing with clean fuel until near full.
h. Moisten rubber gasket around housing lid assembly with clean fuel
i. Reinstall lid assembly as tight as possible using both hands. *Do not use any tools or cheater pipes.*
j. Carefully dispose of water/fuel mixture as if it were all fuel
k. Ensure fuel/water indicator (S2) no longer indicates water is present in filter F2. If it doesn't, repeat this operation
l. Open valves 8, 9

Operation 15: Change F1 filter element
Why: The element is getting clogged after removing significant contaminants from the fuel, which means it is getting harder for the pump (P1) to draw additional fuel through the now less porous filter.
When: vacuum gauge reads >3-4 inches (above little white arrow on face of gauge)
Caution: Ensure you have isolated the filter from the flow of fuel before you open the housing to replace element

a. Close valves 1, 2
b. Place container under drain valve 7
c. Remove filter housing top cover with T handle on top and set aside
d. Remove plug & slowly open (crack) valve 7 to begin draining fuel from filter housing. Drain as much fuel as possible from the housing before proceeding.
e. Loosen wing nuts at the top of both sides of the housing mounting bracket. This will allow the filter housing to tip forward. Tilt slowly until it is stopped by the chain.
f. Place bucket under filter casing and carefully pull filter element out of the top of housing by grasping the washer (handle)
g. Hold guide positioning plate at center bottom of element with two middle fingers inserted into center tube
h. Unscrew and remove the element hold down assembly nut. No tools. Nut is hand-tightened only
i. Remove the used element from the center tube assembly, lower the element into the bucket, and set aside for proper disposal
j. Replace with a new E-1 filter element, OR a Bounty paper towel roll for addressing initial cycles of very dirty fuel and/or tanks. Once fuel is coming out clean, then insert the E-1 element for ongoing filtering operations.
k. Tighten element hold down assembly nut
l. Slide element assembly back into filter housing
m. Return filter housing to vertical position, install & tighten snugly wing nuts with lock washers
n. Close drain valve 7 and replace plug
o. Slowly fill housing with clean fuel. It will take 1 ½ to 2 gallons of clean fuel and about three to five minutes for air bubbles to escape new element
p. Moisten rubber gasket around housing lid assembly with clean fuel
q. Reinstall lid assembly as tight as possible using both hands. Do not use any tools or cheater pipes.
r. Open valves 1, 2
s. Start engine and ensure operation. It may be necessary to bleed the fuel lines (see operations 17 & 18), but it may take several minutes of operation before any air in the line causes engine operation problems (rough running, loss of RPM, quits running, etc)

Operation 16: Change F2 filter element

Why: The element is getting clogged after removing significant contaminants from the fuel, which means it is getting harder for the pump (P1) to draw additional fuel through the now less porous filter(s).
When: Vacuum gauge reads >8-15 (above little white arrow on face of gauge)
Caution: Ensure you have isolated the filter from the flow of fuel *before* you open the housing to replace element

a. Close valves 8, 9
b. Place container under drain valve 12 to catch fuel to be drained from housing.
c. Remove filter housing top cover with T handle on top and set aside
d. Drain 2 inches of fuel from filter housing by slowly opening (cracking) valve 12
e. Place bucket under filter casing and carefully pull filter element out of the top of housing by grasping the plastic handle on the element
f. Remove the used element, lower it into bucket, and set aside for proper disposal
g. Replace with a new 500 series 2 micron filter element (Racor part number 10500)
h. Close drain valve 12 by firmly finger tightening only against O-ring. *Do not over tighten.*
i. Slowly fill housing with clean fuel & wait about a minute or so for air bubbles to escape new element
j. Moisten rubber gasket around housing lid assembly with clean fuel
k. Reinstall lid assembly as tight as possible using one hand. *Do not use any tools or cheater pipes.*
l. Open valves 8, 9
m. Start engine and ensure operation. It may be necessary to bleed the fuel lines (see operations 17 & 18), but it may take several minutes of operation before any air in the line causes engine operation problems (rough running, loss of RPM, quits running, etc)

Operation 17: Bleed fuel lines on engine

Why: If air gets into the fuel line between tank and engine, it will run rough or not at all, and that air must be "bled" (purged) from the fuel path. This is done by venting air by loosening 4 bleed bolts in succession, starting with the lowest pressure (bolt farthest from the engine), and ending with the highest pressure (bolt closest to the engine).
When: the most likely time for this to happen is after changing filter elements, or possibly while draining fuel/water separator reservoir.
Advice: Use the polishing pump P1 to assist in removing air from the fuel lines (versus the manual lift pump on the engine (a hand operated lever on the lower aft starboard side of engine). Only use the manual pump if P1 is not operational.
Caution: Ensure valves are set up for returning fuel to same tank (operation 1 or 2), and *not* set up to transfer fuel from one tank to the other (operation 3 or 4) so as to avoid an unintentional spill)
Question: Is air in the fuel lines likely after draining water from filter reservoir?

a. Ensure normal flow for polishing fuel from either tank (i.e., operation 1 or 2) and engine is not running
b. Begin polishing by turning on breaker B1 and timer T1, ensuring fuel is being returned to the same tank from which it was drawn
c. Locate bleed bolt 1 on center top of aft secondary filter toward aft end starboard side of engine. It is painted neon green, as is the wrench on the engine room bulkhead that fits it. Loosen bleed bolt 1 just enough to allow air bubbles to escape. Once no bubbles and only fuel emerges, carefully tighten bleed bolt 1 (not too tight!)
d. Repeat the process for bleed bolt 2 located on center top of forward secondary filter (approx 8 inches forward of bleed bolt 1).
e. Repeat the process for bleed screw 3 aft on side of injector pump, which is located forward on starboard side of engine, this screw is also painted neon green.
f. Repeat the process for bleed screw 4 forward on side of injector pump, also painted neon green.
g. Start engine to ensure proper operation. If there is air remaining in the line, it may take a few minutes for it to reach the engine resulting in partial or total loss of RPM.

Operation 18: Bleed fuel lines on generator
Why: If air gets into the fuel line between tank and generator, it will run rough or not at all, and that air must be "bled" (purged) from the fuel path. This is done by venting air by loosening 2 bleed bolts in succession, starting with the lowest pressure (bolt farthest from the generator cylinders), and ending with the highest pressure (bolt closest to the generator cylinders).
When: the most likely time for this to happen is after changing filter elements or possibly while draining fuel/water separator reservoir.
Advice: Use the electric polishing pump P1 to assist in removing air from the fuel lines (versus the manual lift pump on the engine (a hand operated lever on the lower front of generator). Only use the manual pump if P1 is not operational.
Caution: Ensure valves are set up for returning fuel to same tank (operation 1 or 2), and *not* set up to transfer fuel from one tank to the other (operation 3 or 4) so as to avoid an unintentional spill)
Question: Is air in the fuel lines likely after draining water from filter reservoir?

a. Ensure normal flow for polishing fuel from either tank (i.e., operation 1 or 2)
b. Begin polishing by turning on breaker B1 & timer T1, ensuring fuel is being returned to the same tank from which it was drawn
c. Locate bleed bolt 1 (19mm) located at the top of the secondary filter element enclosure. Loosen bleed bolt 1 just enough to allow air bubbles to escape. Once no bubbles and only fuel emerges, carefully tighten bleed bolt 1 (not too tight!)
d. Repeat the process for bleed bolt 2 (10mm) located to the right of bleed bolt 1 where the metal fuel feed lines branch off to the injectors.
e. Start generator to ensure proper operation. If there is air remaining in the line, it may take a few minutes for it to reach the generator resulting in partial or total loss of RPM.

Operation 19: Bypass vacuum gauge G3
Why: Gauge is damaged
When: While underway, if gauge is in fact damaged, unless it can be isolated from the fuel flow, air will be injected into the fuel system, potentially causing engine shut down
Advice: As a normal practice, leave gauge on line so it can monitor filter element status

d. To bypass:
    a. Close valve 6
    b. Repair or replace gauge
e. To reverse bypass to put gauge back on line:
    a. Open valve 6

Operation 20: Bypass vacuum gauge G4
Why: Gauge is damaged
When: While underway, if gauge is in fact damaged, unless it can be isolated from the fuel flow, air will be injected into the fuel system, potentially causing engine shut down
Advice: As a normal practice, leave gauge on line so it can monitor filter element status

f. To bypass:
    a. Close valve 11
    b. Repair or replace gauge
g. To reverse bypass to put gauge back on line, open valve 11

Operation 21: Prepare for winter storage in a freezing climate
Why: Liquid in vacuum gauges (glycerin) may freeze and crack the housing if the temperature drops below 10 degrees below zero (Fahrenheit)
When: As the boat is being laid up for the winter (in Minnesota, that is early October of each year).
Advice: if there is any question about the temperature dropping below zero, take the gauges out of the boat and store in a heated facility.

a. Add stabilizer ("Sta-bil") to each fuel tank via the deck fills per instructions on the can
b. Add Marvel Mystery Oil to each fuel tank via instructions
c. Run engine and generator for at least one hour
d. Perform operation 1
e. Perform operation 2
f. Close valve 6, remove gauge G3 and store in a heated facility winter if the temperature is expected to approach ten degrees below zero Fahrenheit (in Minnesota that's until late April to be safe)
g. Close valve 11, remove gauge G4 and store in a heated facility over the winter if the temperature is expected to approach ten degrees below zero.

Operation 22: Spring Commissioning

a. Re-install gauge G3 (if it was removed), open valve 6, and check for leaks under normal operation
b. Re-install gauge G4 (if removed), open valve 11, and check for leaks under normal operation