Fresh, Clean, and Clear: Potable-Water Systems

Part 1

In the first of a two-part series, we detail materials, design, and installation for plumbing, pumps, and filters.

Text and photographs by Steve D'Antonio

Above—*Clean fresh water for drinking, cooking, and cleaning is as essential to the operations of any recreational or commercial vessel as propulsion and electrical systems.*

While potable-water systems are typically simple when compared to onboard fuel or electrical systems, it's no less important that they work correctly and safely. Components for water systems must be sound and sanitary. After all, contaminated water or an unexpected shortage due to leaky plumbing can be just as harmful to a vessel's crew as leaking fuel or electrical faults.

System materials, design, and ongoing maintenance all play important roles in assuring the quality of fresh water available on any boat. Mostly gone are the days of clear-vinyl red-trace hose and pipe-to-hose adapters. Most new-boat builders and refit yards have wisely switched to proprietary polyethylene plumbing, while larger vessels often include sophisticated whole-boat filtration and UV sterilization systems. Despite these advances and the relative ease with which systems can be assembled today, many standard requirements are neglected, and many errors continue to be made in design, installation, and maintenance.

It is essential that a potable-water

system be leak-free. Clean drinking water is a precious commodity aboard most vessels, and even when more water is readily available, a leaking pressure system causes the pump to cycle needlessly, shortening its life, waking those aboard at night, and dampening areas of the boat where water doesn't belong. Leaks allow contaminants, germs, bacteria, and other organisms to enter.

Potable-water systems should be easy to service and repair. Usually boat designers and builders will determine access, but when you have the choice, place potable-water equipment in accessible locations based on the frequency of required access. For example, pumps, filters, and accumulator tanks are high on the access list, while water heaters and distribution manifolds may fall somewhere in the middle, and individual plumbing runs and fittings toward the bottom. Avoid "burying" critical components such as pressure water pumps, filters, and water heaters where bulkhead or other major disassembly is required for their repair, routine service, and winterizing, not to mention replacement. I've encountered more than one vessel that had been built around a water heater. This can be a rude awakening for an owner faced with a replacement bill that includes significant deck or bulkhead surgery. Nothing can sour an owner's experience of a boat more than poor access to essential components, along with the associated fees for a skinny mechanic to wriggle through to malfunctioning equipment (at 5′7″ and 140 lbs, I've been there and done that!).

Selecting Materials

Materials selection is perhaps the most important decision when designing potable-water systems. The American Boat & Yacht Council—through its Standards and Technical Information Reports standard H-23, "Installation of Potable-Water Systems for Use on Boats"—provides a list of accepted materials. In general, those that meet applicable ABYC and National Sanitation Foundation (NSF) guidelines are safe for use in a vessel's potable-water system. (Note that not all conventional copper-alloy plumbing components—brass, bronze, and copper—are suitable for potable water.)

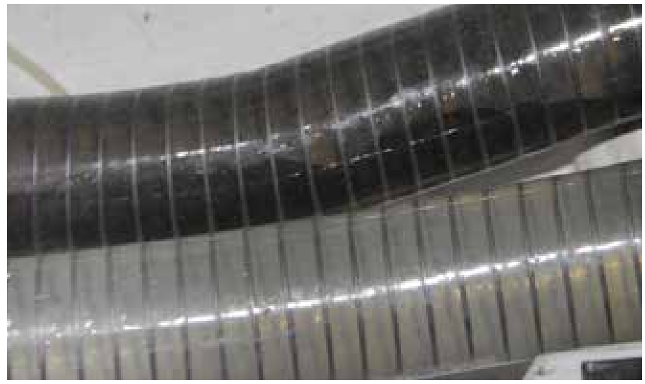
Selected materials must be properly rated to carry potable water. They must be corrosion resistant; must not impart any taste, color, or odor to the water; and must be galvanically compatible with each other. Approved materials include "lead-free" copper alloys, which comply with the U.S. federal Safe Drinking Water Act of 1974, amended in 1986, 1996, and most recently in January of 2014. This legislation (more stringent with each amendment) mandates that, among other components, pipe, fittings, solder, and flux for pipe connections must not contain more than 0.25% lead (0.20% for solder and flux) for wetted surfaces. This guideline is established by National Sanitation Foundation (NSF) Standard 61. Additionally, 300 series stainless steel, nickel-copper alloy, glass-lined metal (many water tanks are manufactured using this technique), and NSF-conforming plastic and rubber are all acceptable materials.

Hose or tubing, regardless of its material makeup, must be designed for potable water. To make this determination, check if "NSF 61" or "Potable Water" is printed on the component. If it's not there, contact the manufacturer to determine if the plumbing is approved for potable water. Such approval must come directly from the manufacturer, rather than a dealer, and it must be in writing.

Just because a material such as clear polyvinyl chloride (PVC) hose is common in potable-water applications, this doesn't mean it's suitable. Cross-linked polyethylene tubing that carries the NSF 61 designation is frequently employed for potable-water applications and is well suited for the role. However, polyethylene-clad-aluminum tubing, sometimes referred to as PAP or PEX-AL-PEX, which is designed for radiant heating systems, is not specifically approved for potable water; it carries no NSF 61 identification.

American Boat & Yacht Council (ABYC) and National Sanitation Foundation (NSF) standards for onboard potable-water systems require that all plumbing be approved to carry drinking water. The two examples of cross-linked polyethylene (PEX) tubing, ***left,*** *carry either the "potable" or "NSF-61" designation, while the reinforced polyvinyl chloride (PVC),* ***below,*** *is labeled for potable water.*

Plumbing, Manifolds, and Valves



Potable-water systems, especially those with clear hose, are prone to contamination. The black accumulation inside the top hose doesn't bode well for the quality of the water that passes through it.

Traditionally, onboard potable-water-plumbing systems are custom-made in either copper tubing, similar to that used for household water applications, or clear PVC hose. The inside diameter of the plumbing is typically a minimum of ½″ (13mm), but should comply with requirements established by pump manufacturers. Since most pumps deliver pressure in the 35-60-psi range, plumbing must be capable of operating at this pressure and preferably more, to handle the occasional surge or malfunctioning pump pressure switch. Of course, hot-water plumbing must be capable of working properly at higher temperatures.

Copper and PVC tubing work well but have limitations. While copper tubing is durable and acts as a natural biocide (copper chemically prevents biological growth, and because it's opaque it excludes the light necessary for algae to thrive), it is expensive and time-consuming to install. Copper is also an excellent electrical conductor, which means that if it touches a vessel's uninsulated electrical wiring (through chafing or crushing), a short circuit may occur. Additionally, because of its galvanic incompatibility, copper plumbing should not be installed aboard aluminum vessels. Copper is susceptible to leaching (copper particles shedding into the water) and structural degradation if the water is acidic (ph lower than about 6.5).

On the positive side, copper is extremely durable and, with just a few exceptions, probably the last plumbing system ever needing to be installed aboard any boat. It simply doesn't fail or leak, provided the materials are chosen correctly and installed properly. It's not unusual to encounter 40-year-old marine copper-plumbing systems that work as well as the day they were installed; only their fixtures have been replaced and upgraded on multiple occasions throughout the vessel's life.

Copper plumbing for potable water should be seamless type K or L tubing (K has a slightly thicker wall), which is annealed and thus capable of being flared for connection. Flaring is an excellent method of plumbing termination; it requires no heat or solder, only a flaring tool. Copper pipe, on the other hand, installed extensively in homes and businesses, is drawn tempered and thus designed to be soldered. Because it cannot be formed or bent during installation and is usually soldered (compression fittings will also work), it's not common on boats, although I've occasionally seen it.

Clear-PVC hose is widely used and with good reason. It's exceptionally easy to install and relatively inexpensive. Connection or termination is by simple barbed pipe-to-hose adapters and common hose clamps, which make it easy to repair. However, there's not much else that's desirable about this material. Clear PVC is prone to kinking, crushing, splitting, and flattening under vacuum. Most clear-PVC tubing is designed to operate at either no or low pressure of up to 150 psi (1.03 N/mm^2) depending upon the reinforcement. Additionally, when it's exposed to hot water it tends to distort or soften, which can cause it to release from its clamped fittings. The maximum permissible temperature for PVC tubing is rarely above 150°F (65.5°C). There are heavy-walled, filament-reinforced varieties of clear PVC less prone to these failures, but they tend to be quite stiff and difficult to work with, and they're more costly. Worst of all, any clear tubing for potable water will support algae growth. It's not unusual to find clear PVC installations infested with black or green bio-colonies, clearly visible on the inside of the hose walls.

More rigid PVC and chlorinated polyvinyl chloride (CPVC) pipe popular in residential and commercial buildings is also viable for marine applications (because it's impermeable

Left—*While it's commonly installed in onboard water systems, especially by do-it-yourselfers, clear PVC hose is prone to kinking and crushing and should be avoided.* ***Right***—*The exception is kink- and crush-resistant wire-reinforced PVC hose, which is appropriate for pressure and suction applications.*

*Reliable, easy-to-install proprietary plumbing systems commonly employ PVC tubing, **1,** and PEX tubing, **2.** Those that rely on O-rings for watertight seals are prone to leakage when stressed or if tubing and receivers don't remain parallel. **3**—To eliminate the stresses that could cause leaks, accessory fittings hold the tubing in a gentle 90° curve as they enter the manifold.*

it's also ideal for sanitation systems). It's strong, relatively inexpensive, and easy to install with primer and glue. However, its rigidity makes it difficult to work with for the short, less-than-straight runs often found on small- and medium-sized craft.

An alternative, the first-generation tubing "kit" for potable-water systems, is a gray, flexible PVC-like tubing initially made from polybutylene (PB). Polybutylene-based systems gained wide popularity in production boats in the 1970s and '80s but tend to become brittle and fracture over time. As a result, PB hasn't been installed in new builds in the marine industry for several years, although many systems are still in service. While working as a mechanic, when I boarded a vessel to winterize it, the last thing I wanted to see was yards of gray, flexible PB tubing for the water system. Disassembling it was difficult and nearly always resulted in leaks or broken components. Eventually I, and other mechanics tasked with winterizing these systems, amassed sizable collections of adapters, T fittings, and unions as well as replacement parts to complete the job.

The successor to polybutylene tubing, the second generation of kit tubing, gets it right. Cross-linked polyethylene tubing, or PEX, is ideal for potable water. Made from high-density polyethylene, or HDPE (the same material used for some dripless stuffing boxes), it's strong, relatively lightweight, extremely flexible regardless of temperature, and does not become brittle over time.

Cross-linked polyethylene tubing designed for potable water is available from several manufacturers; one advantage of a proprietary system made from PEX is that it's essentially an off-the-shelf kit. Manufacturers offer a wide array of tubing diameters, colors (such as red and blue for hot and cold water, respectively), connectors, valves, manifolds, and other fittings that enable the installer to plumb virtually any type of fitting, fixture, or vessel. Other than a tubing cutter, no special tools are required for the proprietary marine systems; professionals and do-it-yourselfers alike can easily install them with minimal practice. Systems designed for the domestic, shore-based market often found aboard 50′ (15.2m) and larger vessels—require special expansion tools that allow fittings to be inserted into tubing; however, these tools are readily available and easy to use.

As desirable as the PEX systems may be, they have two potential faults: First, versions that rely on O-ring seals are often made up of a body, O-ring, and collet; side loading of tubing where it enters this body termination assembly will often leak. The O-ring makes an effective watertight seal, but if the tubing does not pass through the O-ring at a right angle or nearly so, the seal is compromised. Minimizing side loading in these installations may take some practice; it's often achieved by including either a 90° fitting or an accessory fixture that induces a gentle 90° "sweep" into the tubing. Proper support also helps prevent poor angle entry and the resultant leaks. Second, because the watertight pressure seal is formed between the O-ring and the outer surface of the PEX tubing, the O-ring may not effectively seal if this surface is marred, nicked, or scratched. Therefore, before the tubing is inserted into the termination fitting, it should be closely inspected for damage.

A final note on PEX systems: Most manufacturers caution against sealants or pipe "dope" that may adversely affect the plastic connection material. Sealant must not be applied to the O-ring connections. If required on threaded connections, choose a paste or compound that is not harmful to plastic and carries an NSF or Food and Drug Administration (FDA) rating. One safe product with potable water and most plastics is Leak Lock, manufactured by Highside Chemicals (Gulfport, Mississippi); Teflon tape also works well. Beyond pipe dope problems, there's little else that can cause a PEX system to go wrong.

Pumps

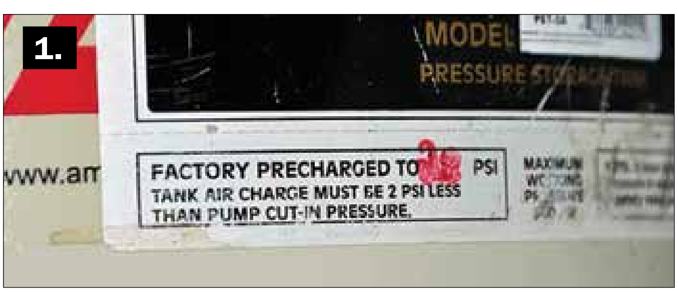
The most common pressure pumps for onboard water systems are the traditional diaphragm style and the newer multi-chamber diaphragm, or wobble plate. The former utilizes the familiar exposed cogged-belt or direct-drive motor whose rotation is converted to reciprocal movement via a crankshaft and connecting rod. Multi-chamber diaphragm pumps (typically incorporating four or five chambers) employ a series of small diaphragms activated by an offset or eccentric plate, sometimes called a wobble plate, housed within the pump head. These pumps are compact; their design eliminates the need for a belt or connecting rod, as all moving parts are contained within the pump. Their output pressure is noticeably more consistent than the traditional single-diaphragm pump, whose jerky motion produces pulsation at faucets and showerheads. Traditionally, these pumps are 12V or 24V DC.

Larger systems that require greater capacity and longevity typically call for centrifugal pumps, which should be installed to be easily accessible. Because they aren't self-priming, these pumps must be primed when dry, but they typically require little or no additional attention. Owners or operators should be briefed on the priming procedure. Of the 12VDC, 24VDC, 120VAC, and 240VAC sizes, the latter two are more common aboard larger vessels and are especially long-lived. Many users report the water pressure is as good or better than that found in shoreside domestic water systems

Most potable-water systems benefit from an accumulator tank, which utilizes a canister, either plastic or metal, and air pressure to minimize pulsation. Accumulator tanks are plumbed in parallel; that is, they are teed into the cold-water side of the system. As water enters the tank under pressure, it encounters the "charge" of air pressure maintained within the tank via a diaphragm or bladder. In some cases, the "head" of air can be renewed or adjusted via a tire-type Schrader valve and monitored with an attached pressure gauge. Most tanks come precharged with between 10 psi and 20 psi (0.07 N/mm^2 and 0.14 N/mm^2). The charge supplies the necessary pressure for water until it's expended. Therefore, brief demands such as washing one's hands don't actuate the pump's pressure switch.

With few exceptions, an accumulator tank provides smoother, more consistent water flow and lengthens the life of the pump, as it prevents rapid on–off fluctuations. If the head of air within the tank escapes or if the diaphragm fails, changes in the water pressure and pump run time are noticeable.

A variation on the multi-chamber diaphragm pump introduces speed control to manage water pressure based on demand. As demand



1—*Accumulator tanks are typically pre-charged with a head of air (this one rated at 28 psi), which reduces the "water hammer" effect and pump short-cycling.* **2**—*Reliable self-priming DC diaphragm pumps can eliminate the need for an accumulator tank in smaller systems.* **3**—*Larger vessels rely on 120 or 240VAC non-self-priming pumps. This model is equipped with a proprietary pre-filter to prevent debris from damaging the pump.*

increases, so does the speed of the pump's motor. The result is smoother, more consistent flow without the need for an accumulator tank.

For any system or pump style, a few rules of thumb apply. Most small, self-priming potable-water-system pumps utilize some type of diaphragm and check-valve arrangement, and in some cases several. Diaphragms and check valves are typically long-lived and reliable; however, check valves can be damaged by debris. Even the smallest piece of plastic, rubber, or other material lodged within a pump's check valve will prevent it from operating properly. Most pumps benefit from the installation of a screen or pre-filter before the pump (these are often wire mesh of the size specified by the pump manufacturer). It's important to note that some pump manufacturers specifically prohibit installing conventional particulate filters before the pump, as they can cause cavitation, poor performance, and, in some cases, damage to the pump. Follow the manufacturer's instructions for the specific pump.

Water pumps should be selected based on the number of fixtures that may be in use aboard a vessel. A water pump's capacity is typically determined by the number of gallons of water it can provide in one minute, or gpm. A small boat with two fixtures running simultaneously—a galley sink and shower, for instance—would require approximately 3 gpm (11 lpm), while a larger vessel may require between 4 gpm and 10 gpm (15 lpm and 38 lpm) and in some cases more, depending upon the number of fixtures and types of appliances used simultaneously.

Water pumps in potable-water systems should be self-priming or easily primed and capable of running dry without sustaining damage. Most diaphragm pumps are able to do this. Depending on the pumping mechanism, it may suffer if allowed to run dry; flexible impeller pumps are typically not capable of running dry for more than a few seconds without incurring damage. Higher-quality pumps that will suffer from damage when run dry often incorporate a fault indicator and an automatic shutdown.

Many potable-water pumps are plagued by flaws in electrical connections. These pressure pumps are commonly driven by electric motors, which means they are inductive loads and particularly sensitive to voltage drops. Excessive voltage drop—lower voltage reaching the pump than is available at the battery—results in slower-turning, hotter-running motors that tend to be short-lived.

In this instance, voltage drop is most commonly a result of undersized wires supplying electricity to the pump. Ideally, all DC motors should be wired for a 3% voltage drop, and certainly no more than a 10% voltage drop (because maintaining capacity is so critical, bilge pump wiring, for instance, should not exceed 3% drop). This may mean choosing wire one or two sizes larger than what you may be accustomed to, and often larger than that installed by the pump manufacturer. When replacing or repairing pumps, don't assume the existing wire size is correct; consult the voltage-drop tables to confirm the appropriate drop.

Filters and Cleaning

Whole-vessel filtration is gaining popularity as filters that can remove particulates as well as chlorine and heavy metals become readily available, inexpensive, and easy to replace.

With the relatively low initial cost of filter housings and replacement elements, it's tough to justify *not* installing at least a whole-boat sediment filter. The price of the materials is often less than $100. Most water is less than sterile, and the water supplied by most boats' water systems often needs some form of filtration. Water filters can, under some circumstances, capture microorganisms such as cryptosporidium, toxoplasma, giardia, and entamoeba (collectively known as cysts), which can be harmful if consumed. Additionally, many water filters can remove rust, sediment, foul odors, and taste, as well as chlorine, lead, copper, chromium, and other harmful metals.

Potable-water filters are either whole-vessel or point-of-use. Whole-vessel filters are essentially the same as whole-house filters, many of which are available from marine and home improvement retailers. They filter all the water as it's supplied aboard the vessel. This all-encompassing approach improves overall water quality, and there's no concern about swallowing a little water from the head sink while brushing your teeth.

Whole-vessel-filter systems must be large enough to not restrict flow, meaning capable of handling a minimum of 5 gpm (19 lpm), or more depending on the pump capacity. The filter media area must also be large enough to accommodate a reasonable amount of debris without the water system suffering from a noticeable reduction in pressure or volume.

Typically, the choice for this type of filter will be one that either just captures sediment or has a combination filter to capture sediment and incorporates carbon filtration to remove odor, taste, and chlorine. These filters require space, usually in the engine compartment, lazarette, or a storage locker, roughly equivalent to the size of a large-city telephone book, as well as enough room to access and replace filter elements. Some plumb these systems to work with garden hose fittings to allow for filtering of incoming water before it enters the tank. While this is a good idea, it will not address contaminants that enter or develop within the vessel's tank, water heater, and plumbing system. Additionally, activated-charcoal or carbon filters must never filter water as it enters a vessel's tanks. Doing so removes the chlorine and thereby virtually ensures biological growth within the tank.

Point-of-use filters are typically designed for drinking water alone. Although they may be plumbed to an existing faucet, most utilize a dedicated spigot that's installed at the galley or head sink. The filters are smaller; however, because they are called upon to convey considerably less volume than a whole-boat filter, they tend to last a full season or more. Many point-of-use filters offer one-stop shopping: they capture rust and sediment, and they incorporate a carbon component that deals with all the other nasty items like metals, cysts, and chlorine.

To safely and effectively remove cysts, any water filter must be capable of absolute 1-micron filtration. If the filter doesn't provide its efficiency rating as either "absolute" or 100%, then it most likely has a nominal rating, which could be considerably less efficient—something like 50% or 75%—at removing 1-micron and larger objects.

Another variety of filters eradicates biological growth with ultraviolet (UV) light. Water passes through a

Point-of-use filters located at specified faucets add another layer of protection for water intended specifically for drinking and cooking.

Water-treatment systems that rely on ultraviolet light are effective at eradicating biological contamination. Most include a sight glass to confirm operation of the bulb. When installing these filters, ensure access for bulb replacement.

chamber illuminated with a UV light, which kills most biological life-forms. Provided it's sized properly and maintained (the bulbs require periodic replacement, often annually), this is yet another effective step to ensure that water is clean and contaminant-free as it exits a tap. Most units operate on 120VAC or 240VAC.

Note that many microorganisms, bacteria, fungi, and mold spores enter through the potable-water-tank vent and blossom into an active bio-colony once inside the warm, wet confines of a marine water tank. To reduce the entry of these contaminants, locate the vent for the potable-water tank inside the boat—in the galley sink, for instance. Although counterintuitive—fuel and holding-tank vents exist outside the cabin for obvious reasons—

it's a desirable approach for potable water. An ideal location for a water-tank vent is the galley or head sink, so if the tank overfills, water will drain harmlessly into the sink. The vent should include a riser above the sink so water from an overfilled sink can't drain back into the tank.

Related to filtration is overall system cleanliness. Any time a system is significantly disassembled for maintenance, repair, or additions, or after a new system is completed, it should be sanitized by flushing with a solution of filtered water and 5.25% hypochlorite chlorine bleach (unscented liquid laundry bleach). Many municipalities recommend sanitizing wells and cisterns with a 200-ppm solution, which is the approach I favor. (For sanitizing a new system, a concentration of 50–100 ppm is usually sufficient.) Allow the solution to stand within the system for a minimum of one hour, then flush thoroughly with clean 1-micron pre-filtered water until no odor remains.

If the tank and plumbing system become heavily fouled with biological life, begin removal by scrubbing with dishwashing soap and filtered water. (This is a good reason to include inspection ports that allow access into every baffled chamber.) Once that's completed, the system can be shocked with the appropriate bleach solution. Treating with bleach alone will often kill only the upper layers of the contamination, particularly of it's heavy, and may lead to a chlorine-resistant colony.

How do you know if a tank is supporting a bio-film? Inspect the inside at least seasonally and, with very clean, dry hands (washed with soap or liquid hand sanitizer) feel the inside of the tank. If it's slimy, then it's likely supporting a bio-film. Also check the plumbing. If it is heavily fouled and can't be practically cleaned, you may need to replace it. Alternatively, draw a sample from the tank and send it to a water-testing lab for analysis.

To keep the system pure and free of unwanted life-forms, adding just enough—and no more—bleach to enable a sensitive nose to detect it (usually about 1 ppm) at the faucet is considered safe maintenance for plumbing and tanks. However, this level of chlorination is only effective at keeping an already clean system clean; it will do little or nothing for a contaminated tank and plumbing. Chlorine will dissipate, so these levels need to be maintained with periodic re-treatment. If the water is run through a whole-boat or point-of-use carbon filter (remove the filter for the nose test or tap the water before the filter), the slight chlorine odor will be easily removed.

In *Professional BoatBuilder* No. 153, Part 2 of our potable-water series will focus on water tanks and onboard water heaters. PBB

About the Author: *For many years a full-service yard manager, Steve now works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting." He is the technical editor of* Professional BoatBuilder*, and is writing a book on marine systems, to be published by McGraw-Hill/International Marine.*