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A selection of technical articles to pique the plumbing engineer's curiosity

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Welcome to the New ASPE Journal

by William Hughes Jr., CPD, LEED AP, FASPE, 2012–2014 ASPE President

Fellow ASPE Members, I am pleased to introduce the first volume of ASPE's newest quarterly publication for members only: the *ASPE Journal*.

This newest member benefit was created to provide ASPE members with a platform to provide and share technical information and ideas that you as a member use in your daily system designs.

ASPE Journal is for each ASPE member. This is your opportunity to provide technical information to your fellow members of ASPE. You can use this publication to share your experiences and technical expertise on topics that you feel are important and relevant to the issues facing plumbing engineers.

Our goal in publishing *ASPE Journal* is to provide small selections of timely technical information in a convenient format that you can read at your leisure and file for future reference. Hopefully some of the articles will spark a conversation or two among you and your colleges. The ultimate goal is that you will take part and help contribute your expertise.

ASPE Journal is for everyone—from beginners to experienced designers—so please be part of this newest member benefit and share your ideas, experiences, and expertise with your fellow ASPE members.

Remember: this is your publication, a member benefit, and it is provided to you to assist you in advancing your professional career.

If you would like to contribute an article or have ideas for topics that you feel should be included, please feel free to contact ASPE Director of Publications, Gretchen Pienta, at gpienta@aspe.org.

I hope you enjoy this inaugural issue of *ASPE Journal*.

Reclaimed Water Treatment Methods

Part 1: UV and Ozone Treatment

by Brian Soderholm

Taken at face value, building an on-site commercial reclaimed water system can seem quite simple: divert various non-septic wastewater streams into a tank (via a pre-filter), drop in a submersible pump, and voila! You have a viable alternate water supply. Unfortunately, this approach neglects to address the great potential for aesthetic and hygienic issues that can come back to haunt the consulting engineer or designer in the form of dissatisfied customers or even legal entanglements.

Very simply, when water from any source without a residual disinfectant is put into a tank and stored for extended periods at ambient temperatures, an incubation process inevitably occurs. Musty and rotten odors begin to develop, discoloration can occur, and a whole host of microorganisms can flourish (including aerobic and anaerobic bacteria, viruses, parasites, cysts, algae, and more). If the water is used for irrigation, fixture flushing, evaporative cooling processes, or any other application that could lead to human contact (via consumption, aspiration, etc.), the risk of causing illness (or, at minimum, a "gross-out" effect) can be considerable.

Studies performed by institutions such as the University of Pittsburgh Special Pathogens Lab (specialpathogenslab.com) and the Roof Water Research Center at Massey University in Wellington, New Zealand (massey.ac.nz) have identified significant risks for microorganisms such as fecal coliforms (most notably E. coli), Legionella, Pseudomonas, mycobacterium, and Cryptosporidium in harvested rainwater. Reclaimed condensate, graywater, groundwater, and process water can present their own microbiological challenges (many the same as rainwater). A certain proportion of these risks can be mitigated via proper system installation and maintenance; however, the reality is that equipment is seldom properly maintained, and once commissioned, the fate of a reclaimed water system is entirely in the hands of its owner, while the legal liabilities remain for everyone involved in the project.

WATER QUALITY ISSUES

The following are the most common water quality problems or complaints in reclaimed water systems.

ALGAE

Algae are small (single or multi-cell) green plant organisms often found in water storage tanks, particularly those exposed to sunlight. Algae can create a layer of floating scum on water and can occasionally lead to green slime infestations in tanks and piping. Water discoloration and turbidity combine with organic fouling of mechanical equipment to create real headaches for end-users. Algae themselves tend to create a musty odor. Moreover, anaerobic bacteria feed on dead algae, which can lead to significant putrid odor issues.

DISCOLORATION

Reclaimed water can become discolored for a multitude of reasons, though the primary cause is organic staining (typically in harvested rainwater). As organic debris such as leaves and grasses decay in a storage tank, they produce natural tannins, which can cause musty odors as well as brownish-yellow staining. Other things such as algae and soil minerals (e.g., iron and manganese, which can be present in reclaimed groundwater) may also lead to discoloration. Regardless of the cause, discoloration can render ultraviolet (UV) disinfection ineffective and can also contribute to the “yuck” factor in such applications as toilet flushing.

HARDNESS

Hardness minerals such as calcium, magnesium, and potassium are really only an issue in groundwater recovery systems. As water passes through layers of soil, it picks up these minerals, which can lead to scaling of UV lamps, piping, and other equipment.

IRON

Together with manganese, iron causes staining and fouling of mechanical equipment and fixtures including membranes, filters, UV lamps, pumps, piping, and water closets. Like hardness, it typically is only found in groundwater reclamation applications.

MICROORGANISMS

A very broad category, microorganisms include bacterium, viruses, cysts, and other parasites. Fecal coliforms (e.g., E. coli), Cryptosporidium, and a handful of other potentially harmful bacteria are often transported into water storage tanks via bird droppings, rodents, amphibians, or insects. Other bacteria such as Legionella are found virtually everywhere, but they are particularly common to mechanical equipment such as evaporator coils, making condensate recovery systems particularly at risk for infestation.

The warm, stagnant environments of many reclaimed water storage tanks provide ideal incubation conditions for many of these potentially harmful pathogens, with some studies showing multiplication rates of more than 10 times between freshly collected reclaimed water and water discharged from the system (with the bulk of the multiplication occurring in the storage vessel).[1] The risk of a flushing toilet, an irrigation sprayhead, or an evaporative cooling system allowing someone to ingest or aspirate any of these harmful agents should not be ignored.

ODOR

If left stagnant and untreated, a reclaimed water system has a high probability of smelling foul. Organic debris and algae provide ample food supply for bacteria, particularly of the anaerobic type. The wastes secreted by these bacteria can lead to a general putrefaction of the stored water, causing smelly restrooms (when supplying toilets or urinals) and foul-smelling campuses (when used for irrigation). Other less noxious, yet no more desirable, odors stem from dirt, algae, and tiny fungi (typically attributed with a musty smell). Indeed, the best method to combat odors is to prevent them from forming in the first place.

ORGANIC FOULING

The accumulation of organic matter, whether it washes into storage tanks (e.g., grass or leaves) or physically grows in storage tanks (e.g., bioslime), can do more than simply render reclaimed water aesthetically unpleasing. It can also lead to mechanical problems within a system. Excessive organic fouling can lead to failures with pumps, piping, motorized valves, UV lamps, and various system sensors. Once established in a system, it can be very difficult to remove.

TURBIDITY

Turbidity is cloudiness in water caused by suspended solids.[2] It is often measured in nephelometric turbidity units (NTUs), which is really just a measurement of light refraction rates from suspended particles in a beaker of water. In reclaimed water, the suspended solids referenced may stem from algae and other organic debris, soil-based substances, or a multitude of other non-dissolving contaminants. The best way to contend with turbidity is to filter the water. Filtration to ≤25 microns (μ) is typically sufficient to reduce or eliminate turbidity issues.

VOLATILE ORGANIC COMPOUNDS

Volatile organic compounds (VOCs) is a general term for a multitude of natural and man-made chemical substances (e.g., paints and solvents), some of which have been linked to long-term cancer risk (e.g., benzene). Often a byproduct of industrial pollution, they are sometimes found in reclaimed groundwater sources. In systems for nonpotable applications, VOCs are rarely an issue. However, it may be necessary to reduce VOCs in reclaimed groundwater being used for irrigation purposes, and in other cases, local officials may mandate the removal of VOCs prior to sending reclaimed water to sanitary sewer systems (e.g., in toilet flushing applications).

TREATMENT TECHNOLOGIES

Table 1 shows the most common available water treatment technologies. In general, most systems that incorporate disinfection (which is recommended) utilize a UV, ozone injection, or chemical injection (typically chlorine) platform. Disinfection is almost always combined with some form of pre- and/or post-filtration. The job of the engineer or designer is to work with the system manufacturer to identify a filtration and disinfection package uniquely tailored to the demands of the project being designed.

This series of articles will look at each of the treatment methods outlined in Table 1 in greater detail, exploring how each method works, the best applications for each method, sizing and selection criteria for equipment, and potential pitfalls of the technology. Keep in mind that it is critical to work with an experienced manufacturer when incorporating the various treatment technologies into a project.

ULTRAVIOLET LIGHT TREATMENT[3]

Ultraviolet energy is found in the electromagnetic spectrum between visible light and x-rays and can best be described as invisible radiation. To kill microorganisms, the UV rays must actually strike the cell. Therefore, the water to be treated must be relatively clear to allow UV radiation to penetrate the entire water stream. The typical recommendation is filtration ≤5 μ prior to any UV treatment to prevent light refraction off of suspended particles and to prevent microorganisms from “hiding” behind these particles.

UV energy penetrates the outer cell membrane, passes through the cell body, and disrupts DNA, preventing reproduction. UV treatment does not alter water chemically; nothing is being added except energy.

UV disinfection does not remove dissolved organics, inorganics, or particles in the water. The degree of inactivation by ultraviolet radiation is directly related to the UV dose applied to the water. The dosage, a product of UV light intensity and exposure time, is measured in milliwatt seconds per square centimeter (mW-s/cm^2) or in millijoules per square centimeter (mJ/cm^2). (The two units are equal.) Water treated with proper levels of UV may be considered nearly bacteria-free.

Table 2 lists the UV dosage requirements to destroy common microorganisms. Most UV units are designed to provide a dosage greater than 30 mJ/cm^2 after one year of continuous operation. Note that UV requires a higher dosage to effectively disinfect some organisms (most molds and protozoa, plus cysts of Giardia lamblia and Cryptosporidium).

For water treatment, special low-pressure mercury vapor lamps produce ultraviolet radiation at 254 nanometers (nm), the optimal wavelength for disinfection. The UV lamp never contacts the water; it is either housed in a quartz glass sleeve inside a stainless steel water chamber with an inlet on one side and an outlet on the other (see Figure 1) or it is mounted external to the water, which flows through UV-transparent Teflon tubes inside the assembly.

BEST APPLICATIONS FOR UV TREATMENT

Although 100 percent destruction of microorganisms cannot be guaranteed, it is possible to achieve a 3-log kill, or about 99.9 percent reduction in certain applications and with proper maintenance. For a UV unit to successfully disinfect water, certain water-quality variables must be considered. Many contaminants in water can reduce the transmission of UV light through the water, which reduces the UV dose that reaches the bacteria. These UV-absorbing contaminants include turbidity, iron, and tannins (humic and fulvic acid), which are common to surface water supplies. Suspended particles are a problem because microorganisms buried within particles are shielded from the UV light and pass through the unit unaffected.

UV disinfection is actually most effective for treating high-clarity purified reverse osmosis (RO) or distilled water. In the case of reclaimed water systems, the best applications would therefore likely be condensate recovery or rainwater harvesting. If UV treatment is to be used in applications such as graywater or groundwater reclamation, great care should be taken to ensure that the water is of adequate clarity (and also not likely to scale UV

TABLE 1 EFFECTIVENESS OF TREATMENT METHODS ON COMMON RECLAIMED WATER QUALITY ISSUES

Treatment Method	Turbidity Reduction	Discoloration Reduction	Odor Removal	Odor Prevention	Micro-organism Removal	Micro-organism Deactivation	Micro-organism Prevention	Iron Removal	Hardness Removal	VOC Removal	Algae Prevention	Prevention of Organic Equipment Fouling
UV	N	N	N	P[1]	N	E	E[1]	N	N	N	P	P
Ozone	N	E	E	E	N	E	E	E[2]	N	P	E	E
Chlorine	N	P	E	E	N	E	E	E[2]	N	N	N	P
Chlorine Dioxide	N	P	E	E	N	E	E	E[2]	N	N	E	E
Pre-tank Gross Filtration (≤ 400μ)	P	P	P	P	N	N	N	N	N	N	P	P
Filtration ≤ 115μ	P	N	N	N	N	N	N	E[3]	N	N	P	E
Filtration ≤ 25μ	E	P	N	N	N	N	N	E[3]	N	N	P	E
Sub-Micron Filtration (≤0.2μ)	E	P	N	P	E[4]	N	P[5]	N	N	N	E[4]	E[4]
Mem-brane Filtration	E	E	E	N	E[6]	N	N	N	N	E	E	E
Ion Exchange	N	P[7]	P[7]	N	N	N	N	P[8]	E	N	N	N
Aeration	N	P	P	E	N	P	E	E[2]	N	E[9]	E	N
Carbon Filtration	P	P	E	N	N	N	N	N	N	E[9]	P	N
Copper/ Silver Ionization	N	N	N	E	N	E	E	N	N	N	E	N

E = Effective; P = Partially Effective; N = Not Effective
1 Requires adequate tank recirculation through 5μ pre-filtration and UV reactors.
2 Requires post filtration to capture iron precipitates. Recommended ≤ 25 μ.
3 Requires oxidation of dissolved iron prior to filtration. Filter dP monitoring required for non-backwashing systems.
4 Failure to maintain filters may cause microorganism/organic bleed through.
5 Requires adequate tank/system recirculation through filtration.
6 Failure to clean/change membranes may allow microorganism bleed through.
7 Reduction of organic tannins via anion exchange media can (in certain cases) be used for odor/discoloration control.
8 Ion exchange is not recommended for iron removal when iron content ≥ 2 ppm
9 Aeration and carbon filtration to be used in tandem. VOC removal capabilities vary by specific contaminant.

sleeves), according to the following general guidelines:

- Maximum turbidity: 5 NTU
- Maximum suspended solids: 10 milligrams per liter (mg/L)
- Maximum prefilter porosity: 5 µ
- Color: None
- Maximum iron: 0.3 mg/L
- Maximum manganese 0.05 mg/L
- pH: 6.5–9.5
- Maximum hardness: <6 grains per gallon (gpg)
- Minimum UV transmittance: 80 percent

SIZING AND SELECTION OF UV TREATMENT SYSTEMS

UV lamp sizing for water treatment is based almost entirely on maximum flow rates, which are a calculation of internal lamp surface area, bulb output, and required contact time. In the end, it is all about exposing the water to the right amount of UV light for the correct amount of time. Most UV lamps carry multiple ratings, often based on meeting various NSF International classifications. For example, a lamp might have a 20-gallons-per-minute (gpm) maximum flow requirement if an NSF Class A rating is to be achieved (corresponding to 40 mJ/cm^2 of UV exposure). At the same time, it may have a 40-gpm maximum flow to achieve an NSF Class B rating (i.e., 16 mJ/cm^2 of UV exposure). For reference, Class A is a potable water standard, and Class B is typically used as a reclaimed water standard.

Often, flexible orifice flow restrictors or other flow-restriction devices are used to regulate proper flow through UV lamps to achieve adequate rates of disinfection. Note that while UV lamps themselves typically cause no real pressure loss, these flow regulators can often cause high pressure differentials, particularly when the system is operating at full design flow. Upsizing the flow restrictors can be equally problematic, as this may allow for excessive flow (and a subsequent reduction of UV dosage).

Another accessory that is highly recommended is a UV intensity monitoring system. This basically consists of a UV light monitor that mounts on the side of the lamp housing. The sensor is exposed to the UV light after it has passed through the stream of moving water, therefore providing a worst-case measurement of UV intensity (measured in mW/cm^2). Typically, this intensity is transmitted to a UV light meter in the form of a 4-20 milliamp (mA) signal. The signal is translated by the meter into an approximate

TABLE 2 REQUIRED UV DOSAGE TO DEACTIVATE COMMON MICROORGANISMS

Bacteria	Dose (mJ/cm^2)
Agrobacterium tumefaciens	8.5
Bacillus anthracis	8.7
Bacillus megaterium (vegetative)	2.5
Bacillus megaterium (spores)	52
Bacillus subtilis (vegetative)	11
Bacillus subtilis (spores)	58
Clostridium tetani	22
Corynebacterium diphteriae	6.5
Escherichia coli (E. coli)	7.0
Legionella bozemanii	3.5
Legionella dumoffii	5.5
Legionella gormanii	4.9
Legionella micdadei	3.1
Legionella pneumophilia	3.8
Leptospira interrogans (infectious jaundice)	6.0
Mycobacterium tuberculosis	10
Proteus vulgaris	6.6
Pseudomonas aeruginosa (laboratory strain)	3.9
Pseudomonas aeruginosa	10.5
Rhodospirillium rubrum	6.2
Salmonella enteritidis	7.6
Salmonella paratyphi (enteric fever)	6.1
Salmonella typhimurium	15.2
Salmonella typhosa (typhoid fever)	6.0
Shigella dysenteriae (dysentery)	4.2
Shigella flexneri (dysentery)	3.4
Staphylococcus epidermidis	5.8
Staphylococcus aureus	7.0
Streptococcus faecalis	10
Virus	Dose (mJ/cm^2)
Bacteriophage (E. coli)	6.6
Hepatitus virus	8.0
Influenza virus	6.6
Poliovirus (Poliomyelitis)	21
Rotavirus	24
Cyst	Dose (mJ/cm^2)
Giardia Lamblia	20–100 (under debate)
Cryptosporidium	19

Source: RW-UV-240 Owners Manual; Water Control Corporation. Adopted from text by Howard Taylor, Head of Engineering.

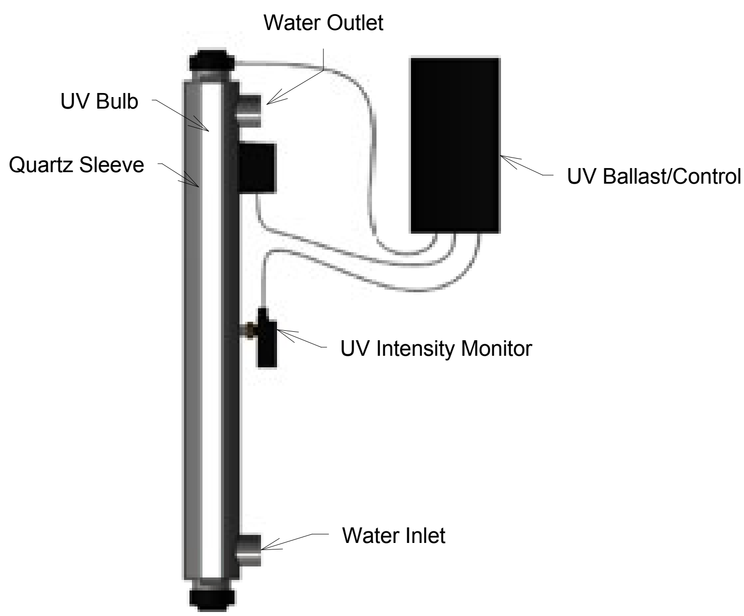

FIGURE 1 TYPICAL UV REACTOR

microjoule per square centimeter (µJ/cm²) light intensity reading (based on maximum lamp flow rates), which can then be displayed for the end-user to see. If the bulb life begins to wane, the quartz sleeve becomes dirty, or the water quality is too poor for good light transmittance, then the end-user will know that the water is not being properly sanitized. (Note: mJ/cm² is equivalent to 1,000 µJ/cm².)

Typically, a low UV level setpoint can be programmed and tied into an alarm system or even to a solenoid shutoff system that stops the flow of reclaimed water and may open up an alternate source, such as potable water or municipally reclaimed water.

POTENTIAL PITFALLS OF UV TREATMENT SYSTEMS

Point Disinfection

UV units kill bacteria at only one point in a water treatment system and do not provide any residual germicidal effect downstream. If just one bacterium passes through unharmed (100 percent destruction of bacteria cannot be guaranteed), nothing prevents it from attaching to downstream piping surfaces and proliferating. Recirculating the volume of a storage tank and piping system through a UV treatment system a few times every 24 hours can drastically reduce downstream growth, but will not eliminate it 100 percent.

Cell Removal

Bacteria cells are not removed in a UV unit; rather, they are converted into pyrogens (toxins). The killed microorganisms and any other contaminants in the water are a food source for any bacteria that survive downstream of the UV unit. Due to these limitations, the piping in a water system treated by UV disinfection may need to be periodically sanitized with a chemical disinfectant. Another option is to apply a small dose of disinfectant (e.g., 0.5 parts per million [ppm] of sodium hypochlorite) prior to delivering reclaimed water out to a system.

Maintenance Requirements

UV lamps do not burn out as normal florescent lamps do. Instead, the UV lamps will solarize, reducing their intensity to about 60 percent of a new lamp after about one year of continuous use. When lamps are new, they will generate a dosage level near 60,000 µW-s/cm². When the dosage drops to 30,000 µW-s/cm² (the minimum dosage needed to effectively kill bacteria in potable systems), lamps should be replaced. (Note: 30,000 µW-s/cm² = 30,000 µJ/cm².)

Flow Rate

All UV units have a maximum flow rate capacity, and some have a minimum flow rate as well. If the flow is too high, water will pass through without enough UV exposure. If the flow is too low, heat may build up, which can damage the UV lamp (depending on the type of bulb used). The water flow in a reclaimed water system may be intermittent, so a UV unit with stringent minimum flow requirements should not be placed on the water line supplying fixtures or equipment in a nonrecirculating system. UV units are most effective in constant (or frequently) flowing recirculating systems

OZONE TREATMENT[4]

Ozone was first discovered in the Netherlands around 1900 and was subsequently used to purify drinking water as early as 1906. Ozone is now used to help purify water for many cities, beverage manufacturing, bottled water manufacturing, and fish farms.

Ozone is produced naturally by the ultraviolet rays of the sun and by the high-voltage discharge of lightning. Ozone may be generated on demand in much the same way. A high-intensity ultraviolet light will produce small amounts of ozone, and a high-voltage corona in the presence of air or oxygen will also produce ozone.

Ozone is basically oxygen (O_2) atoms that have been activated (energized) to the point of accepting an extra oxygen atom to form a molecule known as ozone (O_3). It is inherently an unstable molecule and will react with a great variety of materials to return to its more stable oxygen state. In fact, if the ozone molecule cannot find a material to react with, it will naturally decay back into oxygen within 20 to 40 minutes after generation. This reaction with other materials (called oxidation) makes ozone very attractive to help purify water.

An ozone generator (see Figure 2) typically consists of an oxygen concentrator, an air dryer, and one or more ozone pods (hollow cylinders). Under normal operation, an electronic circuit provides approximately 10 kilovolts (kV) to the inner electrode of the pod. The outer shell of the pod forms the other electrode and is at earth-ground potential (0 volts). Small amounts of room air are passed through the 0_2 concentrator and drier. Purified, dried oxygen is then passed through the generator pods and exposed to the high-voltage corona field produced within. This field causes some percent of the oxygen to convert to ozone, which can then be mixed with the water to be purified.

The mixing can be accomplished via an inefficient process called sparging, in which an ozone bubbler is installed at the bottom of a storage tank. However, a much more efficient way to ozonate a water supply is via a recirculation/injection loop, whereby water is pulled from a storage tank and pumped through a venturi ozone injector assembly. The differential pressure created in the venturi causes fresh ozone gas to be pulled (via a supply tube) from the generator and into the circulating stream of water. Provided enough return piping exists, or an ozone contact tank is installed, a significant amount of ozone can be forced under pressure to dissolve in the recirculating water (limiting the amount of ozone off-gassing that will occur from the tank).

In car wash water reclaim systems, where ozone is often employed, these recirculation/injection systems work continuously throughout the day. In the case of commercial water reclaim applications, however, it is more advantageous to cycle these systems on and off based on dissolved ozone levels in the water, thereby saving energy yet at the same time ensuring adequate tank sanitation levels. Dissolved ozone sensors exist and can be inserted into storage tanks, but they are quite expensive and cumbersome. For this reason, the best option is usually to employ an oxidation-reduction potential (ORP) feedback system (see Figure 3).

ORP is a term used frequently in the water treatment and food processing industries. The system employs a probe, ideally mounted in a moving stream of the water being analyzed, with a sacrificial chemical that, when

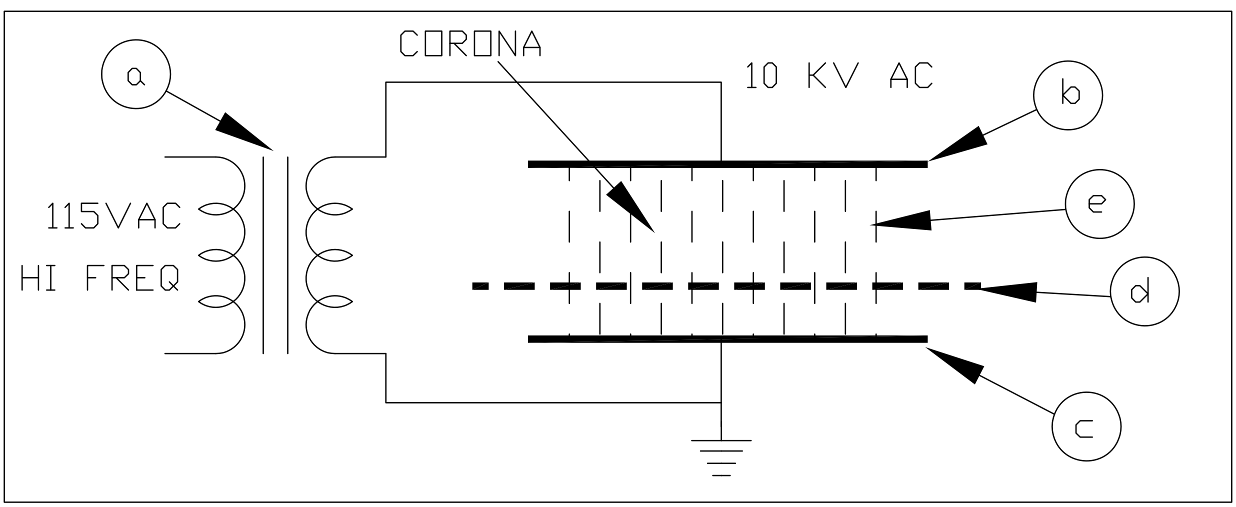

FIGURE 2 TYPICAL CORONA OZONE GENERATOR

a = High-voltage, high-frequency power
b = High-voltage electrode
c = Low-voltage electrode
d = Glass or ceramic dielectric
e = Ionized electric field

attacked by ozone, dissolved oxygen, chlorine, or other oxidizers, generates a millivoltage signal (the higher the oxidizer level, the higher the millivoltage). In layman's terms, ORP is a measure of the cleanliness of water and its ability to break down contaminants.

ORP has a range of –2,000 to +2,000, and units are in millivolts (mV). Since ozone is an oxidizer, we are only concerned with positive ORP levels (i.e., more than 0 mV). Negative ORP levels would be associated with very dirty water. Scientifically speaking, ORP sensors work by measuring dissolved oxygen levels.

More contaminants in the water result in less dissolved oxygen because organics are consuming the excess oxygen, therefore resulting in lower ORP levels. Water with a higher ORP level has a greater ability to destroy foreign contaminants such as microbes or carbon-based contaminants. ORP levels of 200–350 mV are generally accepted for toilet flushing, irrigation, and cooling systems. Complete sterilization occurs at levels of 600 mV and above.[5]

Ozone will attack and destroy viruses, bacteria, and other pollutants up to 3,000 times faster than chlorine. It works more effectively and efficiently because it attacks the bacterial cell walls, creating instant cell destruction. In addition, it will react with mineral ions such as iron and manganese, which helps eliminate problems such as rust color and white deposits on sinks, tubs, and swimming pools and reduce scale buildup in pipes. It can also prove effective at emulsifying shampoos, soaps, and detergents in graywater and even small amounts of hydrocarbons in water from vehicle washes or parking lots. Because it is so effective at oxidizing contaminants out of solution, it is always advisable to provide filtration (recommended ≤25 μ) prior to delivering ozone-treated water to fixtures and equipment.

Ozone will also react with hydrogen sulfide and other bacterial waste products that can result in the putrefaction of water and alleviate many odor issues. The reaction of ozone with some of these materials will also result in a very noticeable clarification of cloudy water.

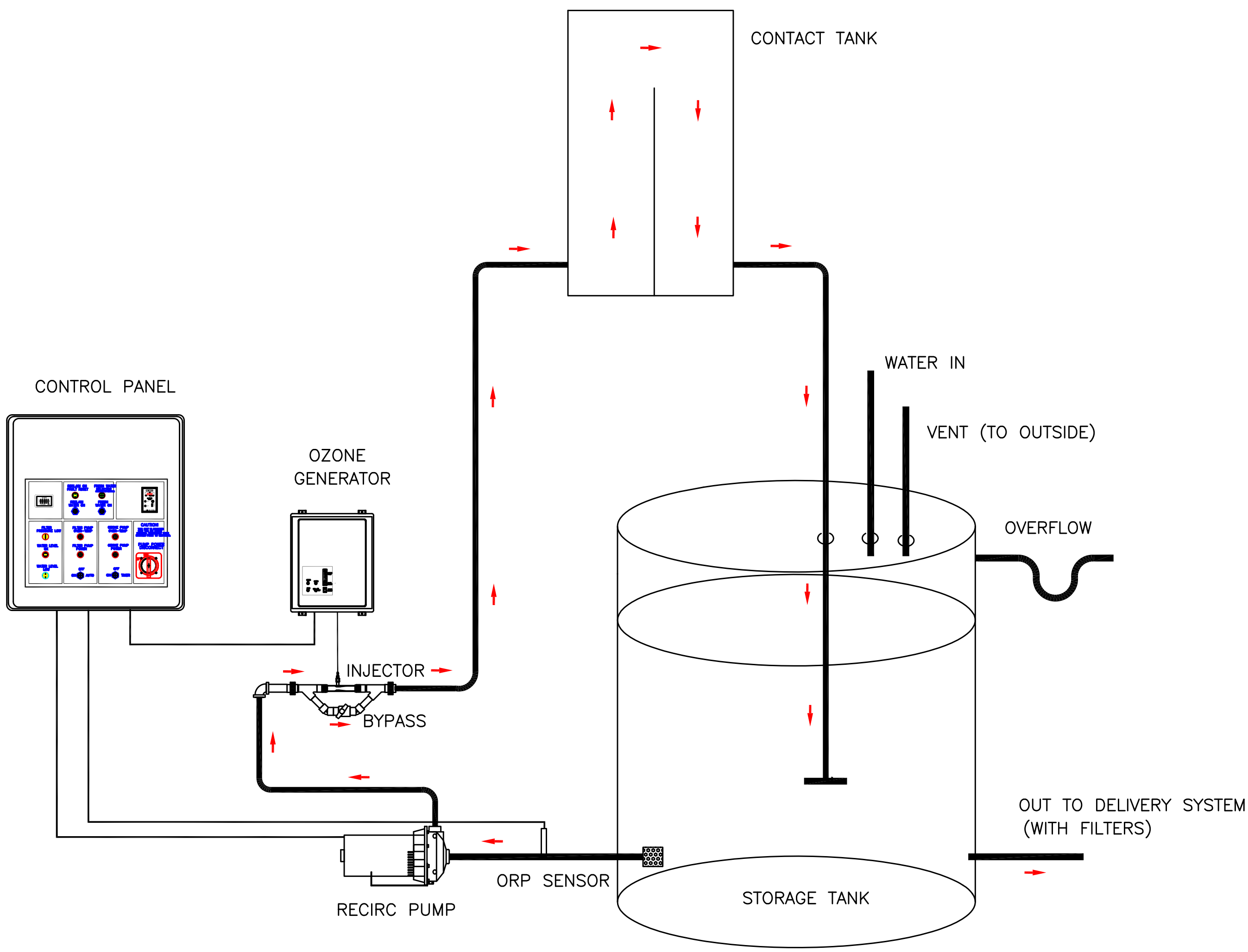

FIGURE 3 OXIDATION-REDUCTION POTENTIAL FEEDBACK SYSTEM

Unlike chlorine, ozone does not remain as a long-term residual in water, though it does leave a higher oxygen residual, which can significantly reduce the incidence of anaerobic bacterial infestation (and the bad smells that come with it). The half-life of dissolved ozone in relatively clear rainwater is around 17 minutes, with most ozone gone after about 40 minutes. If a longer-term residual disinfectant is desired, a small dose of 0.5 ppm sodium hypochlorite (chlorine) prior to the delivery of reclaimed water to a system will usually be sufficient.

BEST APPLICATIONS FOR OZONE TREATMENT

A complete ozone injection system with ORP feedback control can be expensive vis-à-vis other, more basic disinfection technologies (such as UV treatment and chemical injection). This cost premium is most acute in smaller reclaim applications (i.e., those less than 100 gpm or 10,000 gallons storage). Where ozone treatment has a very good niche is in larger applications (more than 100 gpm and in storage vessels from 10,000–200,000 gallons). In these larger applications ozone enjoys an economy of scale, which can make it a very attractive option.

This being said, ozone treatment systems are widely used in reclaimed water applications including toilet flushing, cooling tower feed, irrigation, and more. Unlike chlorine, ozone-treated water will not harm grass or plants. Whenever possible, it is best to use plastic (such as PVC, CPVC, or ABS) or 316 stainless steel piping materials to convey ozone-treated water. In reality though, the concentrations of dissolved ozone are typically low enough to avoid corrosion of copper and brass. If feasible, though, plastic or stainless steel should be employed. However, any piping conveying high concentrations of ozone (such as pipes containing ozone injection points) must be made of PVC or 316 stainless steel. Steel tanks should also be avoided unless they are constructed of 316 stainless or protected by a PVC liner.

SIZING AND SELECTION OF OZONE TREATMENT SYSTEMS

Though no hard and fast rules are associated with sizing ozone treatment systems, common sense would dictate that a recirculation pump of sufficient size and an ozone generator of sufficient output to adequately treat the tank volume dictated by the project are needed—bearing in mind the level of contamination of the water being treated (i.e., dirtier water equals more ozone required).

Only a very experienced engineer or a qualified manufacturer can make this sizing determination for a specific application. However, Table 3 gives some examples of pump capacities, ozone generator outputs, and maximum tank volumes based on the treatment of relatively clean rainwater.

POTENTIAL PITFALLS OF OZONE TREATMENT SYSTEMS

Ozone Exposure

Ozone is a noxious gas, which, with overexposure, can cause headaches and irritate the eyes, nose, and throat. Though no documentation of anyone dying or being seriously injured by ozone exposure exists, according to the U.S. Occupational Safety and Health Administration (OSHA) and the U.S. Environmental Protection Agency (EPA), 0.05 ppm is considered a safe level of ozone, and the maximum safe limit of ozone in the workplace is 0.1 ppm. Due to its strong odor, the gas is detectable at much lower concentrations. Ozone is also capable of causing oxidation damage to metallic (and other) equipment in mechanical rooms if present in high concentrations.

For these reasons, it is important to incorporate an air-quality monitor into any ozone system installation. Higher-than-desired ozone concentrations in the air will then trigger a system alarm, notifying the end-user of a leak or backup in the system. It is also necessary to ensure that any tank vents are directed to the outside and are installed using proper, sealed bulkhead fittings (Viton rubber seals are preferred). Any tank overflows in the mechanical room should

TABLE 3 EXAMPLES OF MAXIMUM TANK VOLUME VS. OZONE GENERATOR OUTPUT AND RECIRCULATION FLOW RATE

Recirculation Flow Rate	Ozone Generator Output	Maximum Tank Volume
45 gpm	8 grams per hour (g/hr)	16,000 gallons
45 gpm	12 g/hr	25,000 gallons
45 gpm	24 g/hr	40,000 gallons
60 gpm	30 g/hr	75,000 gallons

Note: Assumes relatively clean rainwater is being treated. This table presents examples of ozone treatment system sizes and is not a substitute for analysis by a qualified manufacturer.

be properly trapped to maintain a liquid seal. If venting to the outside is not an option, ozone destructor modules are available, which will instantly transform ozone gas back into regular oxygen and allow for venting in the mechanical room.

Room Ventilation

Regardless of what measures are taken to protect against ozone off-gas, it is a good idea to provide proper ventilation of the mechanical room. Allowing the room to breathe is critical to both eliminate any ozone in the air and provide the small amounts of makeup air required for the ozone generator. National Fire Protection Association (NFPA) standards and the International Mechanical Code require six air changes per day in mechanical rooms housing an ozone generator if the ozone generator is capable of producing 0.5 pound or more of ozone in 24 hours. Local, state, and federal codes or guidelines for the project location should be investigated by the engineer.

Maintenance

Ozone generators will require periodic pod rebuilds (typically every two to eight years depending on conditions and usage), and these rebuilds can cost up to several thousand dollars. Periodic replacement of ozone supply tubing and check valves will also be required on an as-needed basis. Finally, ORP sensors contain a sacrificial substance that must be replaced (usually every 12–24 months depending on conditions), and these sensors typically run several hundred dollars. End-users should have properly trained maintenance staff and appropriate budgets to handle these requirements.

Energy Usage

Ozone generators (and the associated pumping equipment) use just slightly more energy to operate than their UV system counterparts (though the difference is often quite negligible). Both systems use more energy than their chemical (usually chlorine) system counterparts, although chemicals are produced in energy-intensive factories and must be shipped to the site.

CONCLUSION TO PART 1

What should be obvious so far is that many treatment-related issues need to be considered when designing a reclaimed water system. No two systems are alike. Each presents its own advantages and challenges, though the risks of foul odor and microbiological contamination are common to all systems.

The good news is that a whole host of treatment methods are available, which, when properly applied (and often combined), can ensure clean tanks, clean systems, and safe, happy customers. To properly apply the different technologies appropriately, it is absolutely critical to work closely with knowledgeable manufacturers and distributors.

Part 2 of this series will examine chlorine and chlorine dioxide treatment, filtration, and membrane filtration.

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Sizing Drain Piping with DFU and Continuous or Semi-Continuous Flow

By Anjian Lu, CPD, LEED AP

This article was written to start a discussion on sizing drain piping with both drainage fixture units (DFU) and continuous or semi-continuous flow in gallons per minute (gpm). By reviewing major plumbing codes in the United States and the Manning formula, the author raises some questions and suggests some conversion factors between DFU and gpm. The conversion factors calculated and suggested are solely based on the International Plumbing Code (IPC).

Sometimes we need to size a drain receiving both DFU from plumbing fixtures and continuous or semi-continuous flow in gpm from a pump or other piece of equipment. In such cases, we need to convert either DFU to gpm or gpm to DFU.

Though according to the major plumbing codes, 1 gpm (0.06 L/s) of continuous or semi-continuous flow is equivalent to two fixture units,[1, 2, 3, 4, 5, 7] you must take caution in applying this rule. Let's review the Manning formula, the definition of DFU, and the diversity factor (DF) first before looking at suggestions based on the IPC. (For the Uniform Plumbing Code, the analysis would apply likewise.)

MANNING FORMULA

Manning's formula is:

$$V = (1.486/n)R^{2/3}S^{1/2}$$

where:

V = Velocity, feet per second (fps)

n = Roughness coefficient

R = Hydraulic radius, feet

S = Slope

The discharge formula below can be used to manipulate Manning's formula by substituting for V. Solving for Q then allows you to estimate the volumetric flow rate without knowing the limiting or actual flow velocity.

$$Q = AV$$

where:

Q = Flow rate, gpm

A = Sectional area of flow, ft^2

R and A can be calculated from the pipe diameter (D) and water depth (h) or h/D ratio.

DEFINITION OF DFU

1 DFU is defined as 1 cubic foot per minute (cfm) or 7.5 gpm from the drain outlet of a plumbing fixture. The following formula can be used to calculate the outlet flow:

$$Q = 13.17\ d^2 h^{1/2}$$

where:

Q = Discharge flow rate, gpm

d = Diameter of outlet orifice, inches

h = Mean vertical height of the water surface above the point of the outlet orifice, feet

Therefore, 1 DFU is close to the flow rate from an outlet with a diameter of 1 inch and a mean vertical height of water surface of 0.33 feet, or 4 inches.

DIVERSITY FACTOR

A lavatory is assigned a DFU value of 1, and a 4-inch building drain can take a load as large as 180 DFU at 1/8-inch-per-foot slope. This does not mean that a 4-inch pipe flowing half-full can flow 180 x 7.5 = 1,350 gpm. Calculation with Manning's formula shows that this 4-inch pipe can flow only 43.6 gpm when n = 0.013, S = 0.0104, and h/D = 0.5. This means that only 43.6/1,350 = 3.2 percent of lavatories are discharging their wastewater at the same time, or a diversity factor of 0.032.

By examining the values in Table 710.1(1) in the IPC and applying the above method, we can make two tables as shown in Table 1 and Table 2.

Table 1 lists the DFU and DF for different building drain sizes and slopes. DF is calculated by multiplying the DFU by 7.48 gpm and dividing by the flow capacity of the drain using Manning's formula where n = 0.013, S = 0.0052 (1/16-inch-per-foot slope), 0.0104 (1/8-inch-per-foot slope), 0.0208 (1/4-inch-per-foot slope), or 0.0416 (1/2-inch-per-foot slope), and h/D = 0.5. As you can see, the DF is diameter and slope dependent. For drain sizes 4 inches and larger, it varies from 0.019 to 0.046, or roughly 2 to 5 percent.

The corresponding flow rate in gpm and DFU/gpm are listed in Table 2. Similar to DF, the DFU/gpm ratio is also pipe size and slope dependent. It is recommended that this ratio be used for converting gpm to DFU. This will be discussed further in the examples later in this article.

TABLE 1: CORRESPONDING DIVERSITY FACTORS BASED ON IPC TABLE 710.1(1)

Diameter, in.	Slope, in./ft							
	1/16		1/8		1/4		1/2	
	DFU	DF	DFU	DF	DFU	DF	DFU	DF
1.25	—	—	—	—	1	0.373	1	0.52
1.5	—	—	—	—	3	0.2	3	0.284
2	—	—	—	—	21	0.062	26	0.07
2.5	—	—	—	—	24	0.098	31	0.107
3	—	—	36	0.075	42	0.091	50	0.108
4	—	—	180	0.032	216	0.038	250	0.046
5	—	—	390	0.027	480	0.031	575	0.037
6	—	—	700	0.024	840	0.029	1,000	0.034
8	1,400	0.019	1,600	0.023	1,920	0.027	2,300	0.032
10	2,500	0.019	2,900	0.023	3,500	0.027	4,200	0.032
12	3,900	0.02	4,600	0.024	5,600	0.027	6,700	0.032
15	7,000	0.02	8,300	0.024	10,000	0.028	12,000	0.033

Note: DFU = Drainage fixture units; DF = Diversity factor

Figure 1 is drawn based on the data in Table 2 for pipe sizes 3 inches and larger for analysis and user convenience.

From this figure we know that the DFU/gpm ratio is rather independent of pipe size when the pipe diameter is 6 inches or larger, at which we may roughly use 7, 6, 5, and 4 for S = 0.0052, 0.0104, 0.0208, and 0.0416 respectively.

TABLE 2: CONVERTING FLOW TO DFU, BASED ON IPC TABLE 710.1(1)

Diameter, in.	Slope, in./ft							
	1/16		1/8		1/4		1/2	
	gpm	DFU/gpm	gpm	DFU/gpm	gpm	DFU/gpm	gpm	DFU/gpm
1.25	—	—	—	—	2.8	0.4	3.9	0.3
1.5	—	—	—	—	4.5	0.7	6.4	0.5
2	—	—	—	—	9.7	2.2	13.7	1.9
2.5	—	—	—	—	17.6	1.4	24.9	1.2
3	—	—	20.2	1.8	28.6	1.5	40.4	1.2
4	—	—	43.6	4.1	61.6	3.5	87.1	2.9
5	—	—	79	4.9	111.7	4.3	157.9	3.6
6	—	—	128.4	5.5	181.6	4.6	256.8	3.9
8	195.5	7.2	276.5	5.8	391.1	4.9	553.1	4.2
10	354.5	7.1	501.4	5.8	709.1	4.9	1,002.8	4.2
12	576.5	6.8	815.3	5.6	1,153.1	4.9	1,630.7	4.1
15	1045.3	6.7	1,478.3	5.6	2,090.7	4.8	2,956.7	4.1

Note: DFU = Drainage fixture units; gpm = Gallons per minute

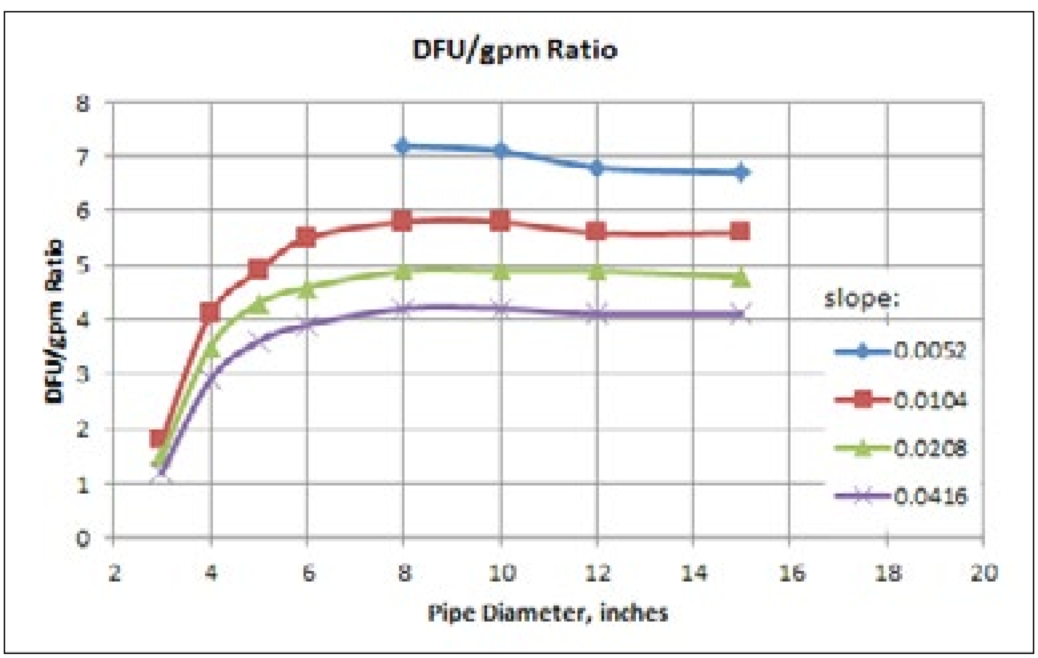

FIGURE 1: DFU TO GPM RATIO – BUILDING DRAINS

SIZING BUILDING DRAINS

EXAMPLE 1

A pump discharges 90 gpm to a building drain with 1/8-inch-per-foot (0.0104) slope. What size should the drain be?

Solution: Using Table 2, let's try a 4-inch pipe. Its capacity calculated with Manning's formula is only 43.6 gpm, well below 90 gpm. Thus, A 6-inch drain should be used (128.4 gpm > 90 gpm).

EXAMPLE 2

A pump with 50-gpm capacity discharges to a 4-inch building drain with 1/8-inch-per-foot (0.0104) slope, which already has 100 DFU. Is this drain big enough? If not, how big should the drain be?

Solution:

1. Convert to DFU: The DFU/gpm ratio for this drain is 4.1. DFU converted from gpm = 50 x 4.1 = 205. The total DFU for this drain is 205 + 100 = 305. Using Table 1, a 5-inch drain is needed (390 > 305). (Note: Most engineers would use a 6-inch drain because of the size availability.)
2. Convert to gpm: A 4-inch drain can only take 43.6 gpm (< 50 gpm). 100 DFU/4.9 = 20.4 gpm. Total gpm = 20.4 + 50 = 70.4 gpm (< 79 gpm, which a 5-inch drain can take). Using Table 2, a 5-inch drain is okay.

SIZING HORIZONTAL BRANCHES AND STACKS

Sizing horizontal branches is similar to sizing building drains, but there are a few differences.

Sizing stacks involves the number of branch intervals (BIs). We can calculate the flow rate for stacks with more than 3 BIs based on the following formula:

$$Q = 27.8r^{5/3}d^{8/3}$$

where:

Q = Stack capacity, gpm

r = 7/24

d = Stack diameter, inches

TABLE 3: CONVERTING GPM TO DFU FOR HORIZONTAL BRANCHES AND STACKS, BASED ON IPC TABLE 710.1(2)

Diameter, in.	Horizontal Branch			Stack				
				>3 BIs			2–3 BIs	1 BI
	DFU	gpm	DFU/gpm	DFU	gpm	DFU/gpm	DFU	DFU
1.5	3	3.18	0.94	8	10.5	0.76	4	2
2	6	6.85	0.88	24	22.6	1.06	10	6
2.5	12	12.41	0.97	42	41.1	1.02	20	9
3	20	20.2	0.99	72	66.8	1.08	48	20
4	160	43.6	3.67	500	143.8	3.48	240	90
5	360	79	4.56	1,100	260.7	4.22	540	200
6	620	128.4	4.83	1,900	423.9	4.48	960	350
8	1,400	276.5	5.06	3,600	912.9	3.94	2,200	600
10	2,500	501.4	4.99	5,600	1655.2	3.38	3,800	1,000
12	2,900	815.3	3.56	8,400	2691.6	3.12	6,000	1,500
15	7,000	1478.3	4.74	—	—	—	—	—

Note: DFU = Drainage fixture units; gpm = Gallons per minute; BI = Branch interval

Table 3 lists the capacity of horizontal branches and stacks based on IPC Table 710.1(2) and the corresponding gpm calculated using Manning's formula and the above-mentioned stack capacity formula for BI > 3.

From Table 3 we can see that the capacity for stacks with BI ≤ 3 is much less than that with BI > 3. This is because of the fact that the shorter terminal length limits the development of the terminal velocity and results in less flow (based on References 2 and 6). Since no formulas are available for BI ≤ 3, we may use the DFU for BI > 3, DFU for the subject BI, and DFU/gpm ratio for calculating the subject DFU or vice versa. For example, to convert 10 gpm to a corresponding DFU value for a 3-inch stack:

$$DFU = gpm \frac{DFU}{gpm} = 10 \times 1.08 = 10.8$$

Note: The flow in gpm is proportional to the DFU in this calculation. However, the diversity factor increases when DFU decreases. Therefore, this calculation for stacks with BI ≤ 3 may be conservative.

Figure 2 shows the DFU to gpm ratio for horizontal branches and stacks. For clarity, only the data for horizontal branches and stacks with D ≥ 4 inches and BI ≥ 4 are shown.

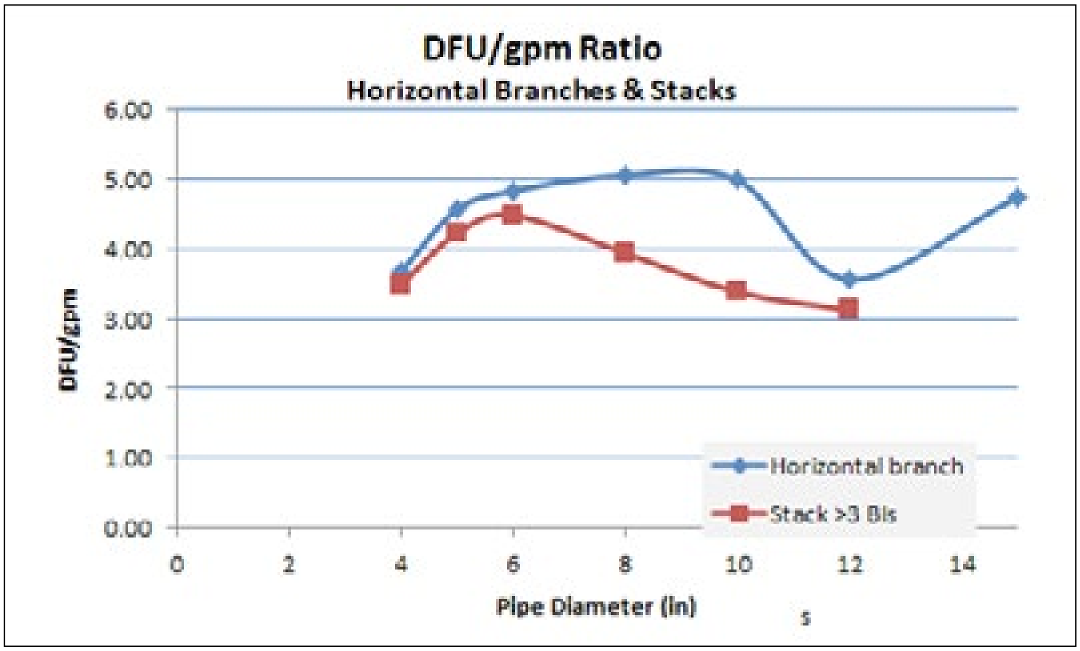

FIGURE 2: DFU TO GPM RATIO – HORIZONTAL BRANCHES AND STACKS

EXAMPLE 3

A pump with 50 gpm capacity discharges to a 4-inch horizontal branch drain, which already has 50 DFU. Is this drain big enough? If not, how big should the drain be?

Solution: From Table 3 we know that DFU/gpm is 3.67. The equivalent DFU = 50 x 3.67 = 184. The total DFU = 184 + 50 = 234 > 160. A 5-inch drain may be needed. For a 5-inch drain, DFU/gpm is 4.56. Therefore, the equivalent DFU = 50 x 4.56 = 228. The total DFU = 228 + 50 = 278 < 360. Thus, the drain should be 5 inches.

EXAMPLE 4

A 6-inch stack with 5 branch intervals has 200 DFU already. A pump with 50-gpm capacity is to connect to this stack. Is this stack big enough, or does it need to be enlarged? If this is a 1 branch interval stack, is 6 inches still okay?

Solution: From Table 3 we know that DFU/gpm is 4.48. The equivalent DFU = 50 x 4.48 = 224. The total DFU = 224 + 200 = 424 < 1,900. This stack is big enough.

From Table 3 we know that the capacity in DFU of this 6-inch pipe is only 350. 424 > 350. This stack is not big enough and has to be increased to 8 inches.

CONCLUSIONS

While a sanitary drainage system receives flow in both DFU from plumbing fixtures and gpm from pumps and/or other equipment with continuous or semi-continuous discharge, current practice with 1 gpm equivalent to 2 DFU may cause system overloading, especially when the latter composes a significant portion.

Analysis indicates that the above consumption is true.

By using Manning's formula, fixture drain outlet flow, and stack capacity formulas and based on the main plumbing codes in this country, plumbing fixture DFs and DFU/gpm ratios can be established as noted in this article for converting gpm to DFU and vice versa.

These figures can be used as shown in this article to calculate building drains, horizontal branch drains, and stacks with different BIs.

The proposed calculation for stacks with 3 BIs or less may be conservative owing to limited information available. Further discussions, even research, may necessary on this topic.

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5. Section 11.4.2, 2006 National Standard Plumbing Code
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7. Section 710.5, 2012 Uniform Plumbing Code

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Designing High-Purity Water Treatment Systems

Part 1: Needs Analysis

by Michael J. Schaefer, PE, CWS-VI

High-purity water is becoming more and more commonplace in many medical, industrial, pharmaceutical, and electronics production facilities. Whether high-purity water is used in a medical laboratory for glassware rinsing and blood analysis, in kidney hemodialysis, or as a final rinse of solvents from a metal anodizing process, the quality of the water that the end product sees is directly related to the final quality and durability of that product.

In medical applications, the accuracy of a patient's test results hinges on access to water virtually void of mineral content and free of bacteria. Manufacturers of brass castings for solenoid valves have come to know that unless they rinse off all machining solvents from the valve prior to shipment, their customer, probably an original equipment manufacturer with high-quality standards themselves, will reject the part, send it back, and not pay for it. A high-pressure boiler fed water of less-than-optimal quality will be required to run much less efficiently to prevent scale buildup or corrosion damage in its distribution system.

The production and distribution of high-purity water require special attention to proper sizing, the application of specific water purification technologies, and attention to the specific materials that are used in the components of the system to prevent latent contamination after the final water has been produced. These materials and technologies can be capital-intensive, so it is crucial for the installed system to meet the needs of the end-user regarding both the quantity and quality of the final water. During this series of articles, we will examine the different aspects of sizing and design of high-purity water systems, including conducting a needs analysis, sizing techniques and procedures, materials of construction, and understanding filtration techniques for problem water chemistry.

THE NEEDS ANALYSIS

The first step in designing a high-purity water treatment system is to determine the needs of the end-user's process. Knowing the quantity of water needed and the required quality of that water will determine how much treatment is needed and how important it is to maintain, or protect, the quality of the finished product water. Part of this process is also to determine the instantaneous need (maximum flow rate) of the end process. Knowing the quality and quantity available of the raw water source will also prove vital in determining how much treatment is needed and to what level the water needs to be refined.

Determining the required capacity (quantity) of product water and its minimum acceptable quality requires the engineer to gather detailed, reliable information from the end-user, equipment manufacturers' specification sheets, and the appropriate published water standards, if needed. Understanding the usage patterns for the high-purity water versus usage of other lower grade water consumed within the end-user's facility is a critical factor in keeping project costs and future operational costs in line.

High-purity water systems consist of a primary water treatment section, a pretreatment section, and a storage and distribution system that often includes polishing equipment to ensure final product water quality. Each of these sections use control systems that allow them to function together and deliver finished water of a quality and quantity that meet the end-user's needs. Part of any needs analysis requires the engineer to determine the level of sophistication of these controls. Some applications require tie-in and monitoring by the facility's central automation system, and in those scenarios control/programmable logic controller compatibility must be determined through coordinated effort with the facility's engineering group. In other applications, the level of sophistication must not exceed the ability of the end-user's staff to understand, monitor, and maintain the system. In many cases, simpler really is better.

QUALITATIVE NEEDS

One of the first steps the design engineer must perform is an analysis of the required quality characteristics of the final product water. These are determined by investigating a number of available resources:

- Internal controls and standards currently being practiced by the end-user and their line operators can provide accurate, real-world data. They also establishe a baseline level of the acceptable water quality as it relates to the user's final product quality standards. Caution must be used to verify that the quality acceptable years earlier when an existing system was installed is still acceptable in today's world of International Organization of Standardization (ISO) certification requirements.
- The manufacturer of the equipment being fed by the high-purity water will often have their own quality specifications. The equipment specification sheet or the machine's factory representative will provide valuable information on what has worked in the past for that machine. In some cases it may be determined that simple softening may be the only required form of water treatment.
- Industry guidelines are a common source for determining the final quality requirements of high-purity water. A number of industries, such as aerospace, electronics, and high-pressure boiler manufacturers, have established their own criteria for their respective needs. Laboratories use ASTM International or Clinical and Laboratory Standards Institute (CLSI) standards for Type I, II, or III reagent grade water. Kidney dialysis facilities use standards published by the Association for the Advancement of Medical Instrumentation (AAMI) and pharmaceutical manufacturing reference standards in the U.S. Pharmacopeia.

As each point of application for the finished water is being analyzed, its associated quality requirement should be recorded, and it should be determined, possibly at a later stage of the design process, whether a lower grade of water would suffice. In some cases, where one point of use has a higher quality requirement than the rest, a final polisher could be used for that one location, allowing the rest of the points of use to be treated to a lower, less expensive level. Alternatively, it may make sense to provide the higher quality of water to all points of use once all installation cost considerations are factored in. Table 1 shows established quality standards.

TABLE 1: TYPICAL WATER STANDARDS/GUIDELINES

	Microelecticonics, Electronics Grade, QR 1.2	Power	ASTM		Pharmaceutical, USP27
			Type I	Type II	
Conductivity	0.0546	<0.1	<0.056	<1	<1.3
Resistivity, MΩ-cm	18.2	>10	18	>1	>0.769
TOC, ppb	<50		50	50	<500
Silica, ppb	<5	<10	<3	<3	none
Bacteria, cfu/mL	<10	none			<100
Chloride, ppb	<0.1	<10	1	5	none
Sulfate, ppb	0.1	<10			none
Sodium, ppb	<0.5	<10	1	5	none

QUANTITATIVE NEEDS

The main criteria needed as part of a needs analysis are the locations of all high-purity water points of use and their daily usage patterns from both a total consumption and a high (peak) demand perspective. Whether the system design is for an existing facility expansion or an entirely new facility, meeting with the end-user and listing each of the points of use (POU), their individual usage patterns, and specific locations on a set of floor plans is the first step. A follow-up site survey/inspection of each POU during production time is the next step. This provides an opportunity to ask clarifying questions of the line operators. It also allows the designer to view the physical constraints associated with running the distribution loop to each POU.

The Needs Table

The quantitative characteristics associated with each POU must be described in writing in the form of a table showing specifically how water is dispensed during a typical high-use 24-hour period. Table 2 shows a fictitious needs table. The needs listed are the actual usage quantities for each hour. The total usage requirement for the 24-hour period is 1,950 gallons.

In this example, you can see that usage typically starts around 8:00 a.m. and ends at 10:00 p.m. We don't know from this table how the water is dispensed during each of the one-hour periods, but additional notes taken during the survey and customer interviews should provide those details. Membrane technology equipment produces high-quality water in a slow, continuous pattern. You can see where no/low periods of usage, during both the day and after hours, can be utilized to produce high-purity water at a slow rate, which can be stored to allow for quick, high-volume dispensing during periods of high demand. The data from this table will be used in the next article of this series to perform the actual sizing calculations of the primary production equipment, storage tanks, and distribution pumps.

In some cases, a specific POU will be inactive for a number of days between uses; if so, that must be described in detail. Points of use will have different usage patterns associated with their operation. Some will exhibit a continuous pattern (e.g., humidification, blood analyzers, hemodialysis machines). Others will be operated on a batch-type process/pattern.

In batch-type operations, a batch tank is filled with high-purity water; ingredients are added, mixed, heated, or cooled; and the water then is sent to another part of the plant to complete the process. This process may repeat three or four times per shift, or it may only happen twice a week; it may require 50 gallons per batch or 2,500 gallons per batch. Each time the batch tank is filled, the operator wants the product as fast as the system can deliver it. Many plants will stagger the batches or throttle the flow to make sure one filling operation doesn't starve another. Knowing how many gallons are needed (and how quickly) to refill the batch tank is a critical factor in sizing the finished product water storage tank, distribution loop piping, and distribution pumps. Rinse tanks used in metal finishing can be of all

TABLE 2: EXAMPLE NEEDS TABLE

Time Period	Water Use, gal
4 a.m. – 5 a.m.	Maintenance
5 a.m. – 6 a.m.	Maintenance
6 a.m. – 7 a.m.	
7 a.m. – 8 a.m.	
8 a.m. – 9 a.m.	200
9 a.m. – 10 a.m.	100
10 a.m. – 11 a.m.	200
11 a.m. – 12 p.m.	300
12 p.m. – 1 p.m.	
1 p.m. – 2 p.m.	200
2 p.m. – 3 p.m.	200
3 p.m. – 4 p.m.	250
4 p.m. – 5 p.m.	200
5 p.m. – 6 p.m.	
6 p.m. – 7 p.m.	
7 p.m. – 8 p.m.	
8 p.m. – 9 p.m.	200
9 p.m. – 10 p.m.	100
10 p.m. – 11 p.m.	
11 p.m. – 12 a.m.	
12 a.m. – 1 a.m.	
1 a.m. – 2 a.m.	
2 a.m. – 3 a.m.	
3 a.m. – 4 a.m.	

sizes, and while not dumped and filled multiple times a day, they may require a steady, constant overflow feed, or they may be subject to weekly dumps/refills.

Another common attribute of ingredient-mixing batch-type operations is the need to perform CIP (clean in place) operations after each batch. This may only require city water or soft water—not high-purity water—but that must be determined as part of the system design.

By designing and completing a needs table and then charting that data in conjunction with water treatment equipment sizing, you can accurately reflect the usage patterns of all points of use for the high-purity water system. The engineer can use this data as part of the process of verifying assumptions with the end-users and stakeholders. It uncovers areas where two or more batches should not be filled at the same time, requiring either staggered operation or a larger water storage/distribution system. The needs analysis, in written and chart form, is one of the most important components of the sizing process and should require sign-off/acceptance by all parties prior to specifying the treatment equipment and distribution system.

SUMMARY

Evaluating the quality of the water needed at each point of use, the volume of water required, and associated usage patterns using needs charts and determining the level of control sophistication are crucial factors that go into understanding and documenting the application needs of the end-user. This is accomplished through in-depth interviews with facility personnel, evaluating the process equipments' specification requirements, and careful review of the end-user's industry standards for their processes.

In recent years, high-purity water systems using membrane technology (reverse osmosis) have overtaken those using ion exchange as their primary treatment method. Typically reverse osmosis produces water at a slower rate, requiring storage of the finished product water during low demand periods, with distribution pumps that deliver the high-purity water to the point of use at a rate and in the amount needed. Because RO units have come down in cost in the past few years, it is common to see larger RO units specified, with storage tanks sized to deliver higher volumes in shorter periods of time. Instead of spending half the night refilling a large storage tank, the RO unit is sized large enough to refill its storage tanks between batches. More on that will be discussed in the next article in the series.

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