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- Risks of Hazardous Waste (Excerpt)
- OnSite Sewage Treatment Alternatives (Excerpt)
- Filtration Processes
- Solubility Rules Help Avoid Water Treatment Pitfalls

Articles

4151 Naperville Road
Lisle, Illinois 60532-3696 USA



Introduction

Dear WQA Members:

The water industry touches upon a variety of issues on a daily basis. Our goals for the WQA educational kits are to highlight these issues and provide the background information to address them.

This year's kit looks at how sampling schedules used by public water systems can miss the presence of pesticides, explains the operation of onsite wastewater treatment systems, reviews filtration basics, and demonstrates the utility of solubility rules for ionic compounds.

Pesticides in Drinking Water

As WQA's recent consumer survey indicates, only 45% of the consumers surveyed are confident that their water source doesn't pose a health risk. The infrastructure and regulatory framework that delivers centrally treated water to consumers in the United States is a fantastic achievement, but one that is constrained by fiscal and physical reality. As the atrazine article in this educational kit indicates, aging infrastructure is not the only contributor to water quality problems. Contaminant sampling schedules may be providing an incorrect picture of a central system's water quality, due to their dependence on the availability of funding.

Softeners and Septic Systems

The effect of water softeners on onsite systems has been a contested issue for a number of years. The Water Quality Research Foundation recently approved funding for a research study that will look at the problem from a new angle by examining the effects of the ratios of monovalent and divalent cations on the septic systems. The article included in this kit reviews the components and operation of residential onsite waste systems.

Surface and Media Filtration Introduction

Filtration is usually the least expensive of the treatment techniques and the one with the greatest impact on the performance of downstream treatment processes. The subject is well worth a review.

Solubility Rules

A number of treatment applications take advantage of the relatively low cost of filtration by finding methods to convert dissolved materials into solids (precipitates) that can then be filtered. Solubility rules can help determine whether or not a dissolved substance will form a precipitate from a given water sample.

Our past educational kits have received high marks for their convenient format of brief, informative articles and included

quizzes. WQA's monthly Webinars and synchronized recordings from the annual conference sessions are another source of bite-sized educational opportunities. These materials can be found online through wqa.org/education. The audio files from both the Webinars and the conference sessions can be downloaded to a CD or a MP3 player for listening on the go.

Bite-sized education will be a regular offering from WQA in the near future. The education department has begun a major restructuring project that will make finding answers among WQA's wealth of technical educational materials easier. In addition, all users, not just WQA-certified personnel, will be able to track their educational progress and choose educational materials that meet their individual needs.

Your feedback is always welcome. Drop me a note at tlubner@wqa.org, and let me know what educational topics or offerings you'd like to see.

Sincerely,



Tanya Lubner, PhD
Director of Education & Certification
Water Quality Association

Additional educational resources can be found, organized by topic, at wqa.org/education and are available in the WQA Store at wqa.org/store or by calling 630 505 0160.

Each year, WQA Aquatech USA offers over 30 consecutive hours of education on a wide variety of water treatment topics. See wqa-aquatech.com for the upcoming 2011 sessions. Recordings and speaker slides from past meetings are available through the WQA Store (wqa.org/store, 630 505 0160).

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Risks of Hazardous Waste (Excerpt)

11.4 PESTICIDES IN GROUNDWATER, SURFACE WATER, AND DRINKING WATER

Pesticide contamination in water has become a pervasive problem in the US. Surface water runoff carries pesticides from agricultural fields into rivers, lakes, and reservoirs. Rain or snow carries pesticides through the soil into groundwater that is the source of drinking water.

Under the Safe Drinking Water Act, originally passed in 1974 to regulate the nation's drinking water, the USEPA sets standards for allowable pesticide levels in drinking water and requires water utility companies to monitor these levels. Setting these standards is a two-part process. First, the EPA sets a nonenforceable Maximum Contaminant Level Goal (MCLG), which is a goal based solely on health considerations. These MCLGs are set at levels 'at which no known or anticipated adverse effects on the health of persons occur, and which allows an adequate margin of safety.' Second, the EPA sets enforceable Maximum Contaminant Levels (MCLs), which are based on MCLGs but adjusted to ensure technical and financial feasibility. Due to this adjustment, federally enforceable MCLs are not as stringent as the MCLGs, allowing pesticides to legally remain in public drinking water. Therefore, federal regulations for pesticides commonly found in drinking water fail to adequately protect the public's health (EWG, 2010).

The EPA has set enforceable MCLs for three pesticides called atrazine, alachlor, and simazine. However, it has not set enforceable MCLs for cyanazine, metolachlor, and acetochlor, which are three major pesticides used in the US. Instead, the EPA has issued nonenforceable Lifetime Health Advisories (LHAs) for these contaminants. Consequently, water utility companies are not required to test for these contaminants or inform their customers if these contaminants are found at levels that exceed federal health advisories (EWG, 2010).

11.4.1 ATRAZINE

Atrazine is a widely used herbicide utilized for the control of broadleaf and grassy weeds in corn, sorghum, rangeland, sugarcane, macadamia orchards, pineapple, turf grass sod, asparagus, forestry grasslands, grass crops, and roses. It is used most extensively on corn crop in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, Ohio, Texas, and Wisconsin. Total estimated agricultural use in the US is 76.4 million pounds annually, with 86% of that amount applied to corn alone (EPA, 2008a). Due to health concerns and persistent contamination of groundwater, atrazine was banned in the European Union in 2004.

Many factors contribute to atrazine runoff and drinking water contamination. First, atrazine does not bind well to soil particles, so it is easily carried off of fields with storm water. Second, many areas of heavy application (namely Northern Missouri and Southern Iowa) have high clay content in the soil. Clay soils have relatively low infiltration rates and thus promote runoff during storm or flood events. Third, many Midwest farms practice no-till farming, which increases runoff potential and loss of atrazine due to the restrictive layer of the claypan that limits infiltration. Finally, atrazine application periods typically occur during the months that receive the most rain. Heavy rainfall directly following application can greatly increase atrazine losses. Because of these factors and the sheer quantity and density of atrazine application, hundreds of water systems have atrazine detections in their finished drinking water, impacting millions of people across the country.

In 2004, Holiday Shores Sanitary District in Holiday Shores, Illinois, filed class action lawsuits against the manufacturers and primary distributors of atrazine. These lawsuits have expanded to include over 60 cities from across the Midwest looking to hold the corporations accountable for the contamination of their drinking water systems. A judgment in the case has not yet been issued.

Health Effects of Atrazine

The endocrine-disrupting properties of atrazine have been demonstrated in studies. Atrazine has been found to alter the brain's pituitary functions, resulting in the suppression of two hormones, luteinizing hormone and prolactin hormone. Changes in these hormones have concerning consequences. Research has shown that even brief atrazine exposure to a lactating mother alters the endocrine makeup of the mother's milk, raising concerns about the subsequent development of the child. Exposure to atrazine and atrazine metabolites have caused delayed puberty in both male and female rats (USEPA, 2009). Additional studies showed health effects such as increased risk of intrauterine growth retardation, reduced semen quality, and spontaneous abortions in humans, as well as demasculinization and hermaphroditism in frogs (Munger, 1997; Arbuckle, 2001; Hayes, 2002; Swan, 2003).

The effects of atrazine in frogs have received particular attention. Hayes et al. (2002) examined atrazine exposure on the development of the African clawed frog. During larval development, the larvae of the frogs were exposed via immersion to 0.01 to 200 ppb of atrazine. Study results demonstrated that greater than 0.01 ppb of atrazine exposure resulted in hermaphroditism and demasculinization in

Risks of Hazardous Waste (Excerpt)

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male frogs. Furthermore males had a ten-fold decrease in testosterone levels when exposed to 25 ppb atrazine. The study concluded that atrazine converts testosterone to estrogen.

A growing body of evidence also indicates that agricultural exposures may contribute to birth defects. Winchester (2009) investigated whether babies conceived during the months when surface water agriculturals are highest are at greater risk for birth defects. In the study, concentrations of nitrates, atrazine, and other pesticides were measured in water samples from 186 stream sites representing 51 hydrological systems, accounting for 50% of the US drinking water, from 1991 to 2002. The highest concentrations of pesticides were found in May and June, with annual peaks from April to July. Results from the study of approximately 30 million babies, showed that total birth defects, as well as 11 of the 22 birth defect subcategories, were more likely to occur in babies that were conceived between April and July.

3

Ochoa-Acuna (2009) investigated atrazine exposure from drinking water and the prevalence of small-for-gestational-age (SGA) and preterm delivery. The study found that atrazine, and perhaps other co-occurring herbicides in drinking water, was associated with an increased prevalence of SGA. Alarmingly, SGA resulted from exposure to atrazine in drinking water at levels just above 0.1 µg/L, well below the current MCL of 3.0 µg/L.

Cancer has also been associated with exposure to atrazine. MacLennan (2002) evaluated cancer incidence among approximately 2,000 workers at a Louisiana plant that manufactured atrazine and other triazine herbicides. Incidences of prostate cancer among active company employees were statistically increased.

Syngenta and the Atrazine Monitoring Program

After the use of atrazine was banned in Europe in 2004, the EPA expressed concern over the presence of atrazine in some water systems in the US. Subsequently, the Atrazine Monitoring Program (AMP) was created. With assistance from the EPA, Syngenta, the primary manufacturer of atrazine, tested 134 public water systems weekly or biweekly for atrazine and three chlorotriazine breakdown products: DIA, DEA, and DAC.

The AMP data revealed that levels of atrazine and its chlorotriazine breakdown products during some periods of the year were much higher than levels reported by water systems. Many water systems tested as part of the AMP showed levels exceeding the MCL at some point during the year. In other words, values reported by water systems and values shown by the AMP did not match up.

The AMP data showed that atrazine 'spikes' likely occurred during weeks of atrazine application or heavy rainfall. These spikes of atrazine levels in post treatment water exceeded the 3 ppb MCL for short periods of time, but averaging and infrequent testing allowed these levels to be overlooked by water systems. Figure 11.1 presents AMP data of several water systems with an atrazine 'spike.' State data from the same period do not indicate a spike.

Inconsistencies between data reported to the state by water systems and data from the AMP sparked much political and media interest. In August 2009, the *New York Times* published an article titled, 'Debating How Much Weed Killer is Safe in Your Water Glass,' detailing inconsistencies between the two data sets and the overall danger of atrazine contamination in the US. Increased media coverage placed more pressure on Congress to address these issues, which in turn placed pressure on the EPA. The EPA responded with a press release stating it would begin a re-evaluation of atrazine. EPA's re-evaluation plan includes the review of atrazine effects to inform safety measures and plans for incorporating new epidemiologic and experimental studies into the atrazine risk assessment.

11.4.6 REMOVAL TECHNOLOGIES

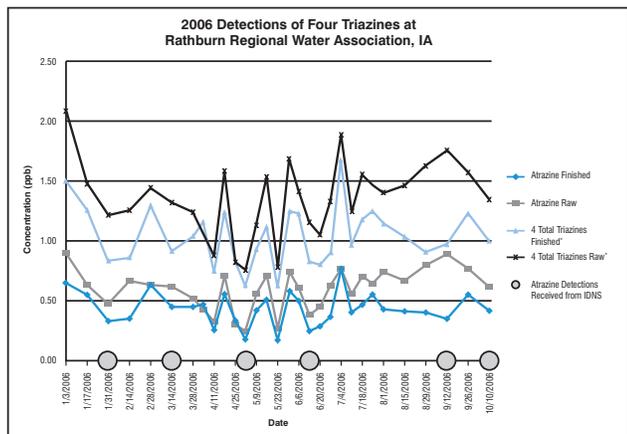
Investment in removal technologies has obvious benefits. Many pesticides can be removed from water using a technology called granular activated carbon (GAC). GAC has a random porous structure, containing a broad range of pore sizes ranging from visible cracks and crevices down to molecular dimensions. GAC uses this porous structure to remove dissolved contaminants from water in a process known as adsorption. This porous structure results in a large adsorption surface area (USBR, 2009).

Risks of Hazardous Waste (Excerpt)

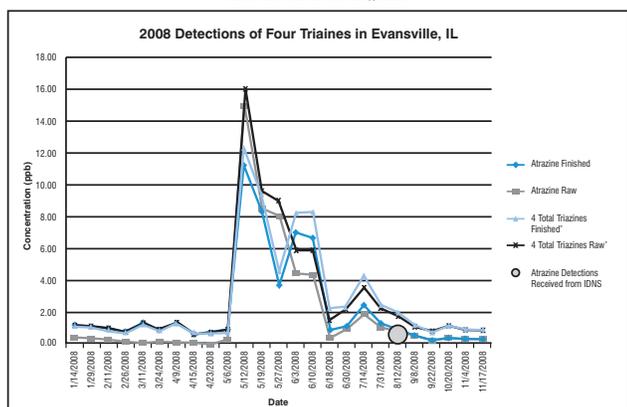
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GAC is found in many applications ranging from personal in-home use to industrial, commercial, and municipal treatment systems. GAC treatment technologies include:

- Pour-through devices for treating small volumes, such as a hand-held... filter [pitcher].



*Total triazines includes atrazine and 3 daughter products, although many other breakdown products may be present. Dates of IDNS Atrazine Detections are approximate.



*Total triazines includes atrazine and 3 daughter products, although many other breakdown products may be present. Dates of EPA Atrazine Detections are approximate.

Figure 11.1 Comparison of Syngenta AMP data and state data (source: Syngenta AMP, Illinois EPS (IEPA) Bureau of Water, Iowa Department of Natural Resources Water Supply Program (IDNSWP)). Lines represent concentrations of atrazine or atrazine plus three degradate triazines detected under the Atrazine Monitoring Program. Dots represent atrazine concentrations reported to the state by water systems.

- Faucet-mounted (with or without bypass) for treating water at a single faucet
- In-line filter (with or without bypass) for treating large volumes for several faucets
- High-volume commercial units for treating community water supply systems. Typically they are gravity-fed (larger volumes) or pressure-driven (smaller volumes) contactors. These high-volume units can be sequenced in parallel or in series. GAC filters can be used alone or can also be combined with media filters (USBR, 2009).

Installation and operation of granular activated carbon systems [for central treatment systems], however, are expensive. Capital costs to install GAC systems are in the order of millions of dollars. Purchase of land (if necessary), and operation and maintenance costs, including reactivation or the purchasing of new carbon columns, can add to the overall cost.

Many public water providers cannot afford to install this type of advanced treatment system. In order to recover costs for the installation of new treatment systems, water systems have filed lawsuits against the manufacturers of chemicals found in drinking water. For example, Holiday Shores Sanitary District (in Holiday Shores, Illinois) has filed class action lawsuits against the manufacturers and primary distributors of atrazine, to recover costs of treatment.

11.5 CONCLUSION

Pesticides will continue to be part of human life and the environment in order to increase crop production. It is imperative for public health authorities to educate the public, farmers, and farm workers on the use of and risks from pesticides. Improvement of human quality of life by means of more efficient and environmentally-friendly food production will clearly be a challenge for years to come. Reduction in the annoyance produced by pests is also part of the equation and poses major challenges to balance the well-being of the ecosystem. Rigorous testing and more stringent rules need to be adopted to address the harms posed by pesticides. Scientists, legislators, public health officials, and other stakeholders should familiarize themselves with the different pesticides that are used in their environment and invest in research and development for safer alternatives.

Acknowledgments

Jasmin Abou-Diwan, Alvaro Camacho, and Marlene Gomez contributed to this chapter.

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Risks of Hazardous Waste (Excerpt)

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Reprinted from *Risks of Hazardous Wastes*, Paul E. Rosenfeld, Lydia G.H. Feng, Pesticides, p135-139, Copyright 2011, with permission from Elsevier.

QUIZ 1: "The Risks of Hazardous Wastes Excerpt" (0.25 CPD)

- What does the USEPA take into consideration when setting the MCLG for a contaminant?
 - Instrumentation detection limits and feasibility of enforcement
 - The financial feasibility of reducing a contaminant to a specific limit
 - The likelihood of seasonal contaminants
 - The levels at which no adverse health effects can take place
- What does the USEPA take into consideration when setting the MCL for a contaminant?
 - Instrumentation detection limits and feasibility of enforcement
 - Contribution from other contaminants
 - The likelihood of seasonal contaminants
 - The levels at which no adverse health effects can take place
- In the absence of enforceable MCLs for certain pesticides, the EPA has issued nonenforceable LHAs (Lifetime Health Advisories). What type of actions are water systems required to take for contaminants under LHAs?
 - No actions and no reporting is required
 - Bi-annual testing and reporting is required
 - Quarterly testing and reporting is required
 - Annual testing and reporting is required
- What are the pathways by which pesticides can get into drinking water?
 - Runoff
 - Evaporation
 - Taken up by vegetation
 - Evapotranspiration
- What is the effect of the high clay content and the no-till farming practice in the US Midwest on the loss of atrazine from the area to which it was applied?
 - Reduces the need for reapplication
 - Helps prevent runoff
 - Improves soil infiltration rates
 - Promotes runoff
- Atrazine is classified as what type of health hazard?
 - Endocrine disruptor
 - Lysosome
 - Mutagen
 - Pathogen
- Why doesn't the AMP and reported data from the public systems match?
 - Poor sampling technique by public systems
 - Bias in the AMP program
 - Testing frequency insufficient
 - Outdated analytical equipment
- Which treatment technology is recommended by the authors for atrazine?
 - Ion Exchange
 - Reverse osmosis
 - Granular activated carbon
 - Ozonation
- What is the drawback to centralized water treatment for atrazine?
 - Expensive
 - Inefficient
 - Not regulated
 - Ineffective

Onsite Sewage Treatment Alternatives (Excerpt)

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WHY IS SEWAGE TREATMENT IMPORTANT?

Effective sewage treatment prevents a variety of ailments that can be spread by exposure to pathogens that can be present in untreated sewage, and thus helps prevent disease. Discharges of untreated sewage can contaminate groundwaters and surface waters used for drinking, recreation, and fish and shellfish fisheries (Figure 1).

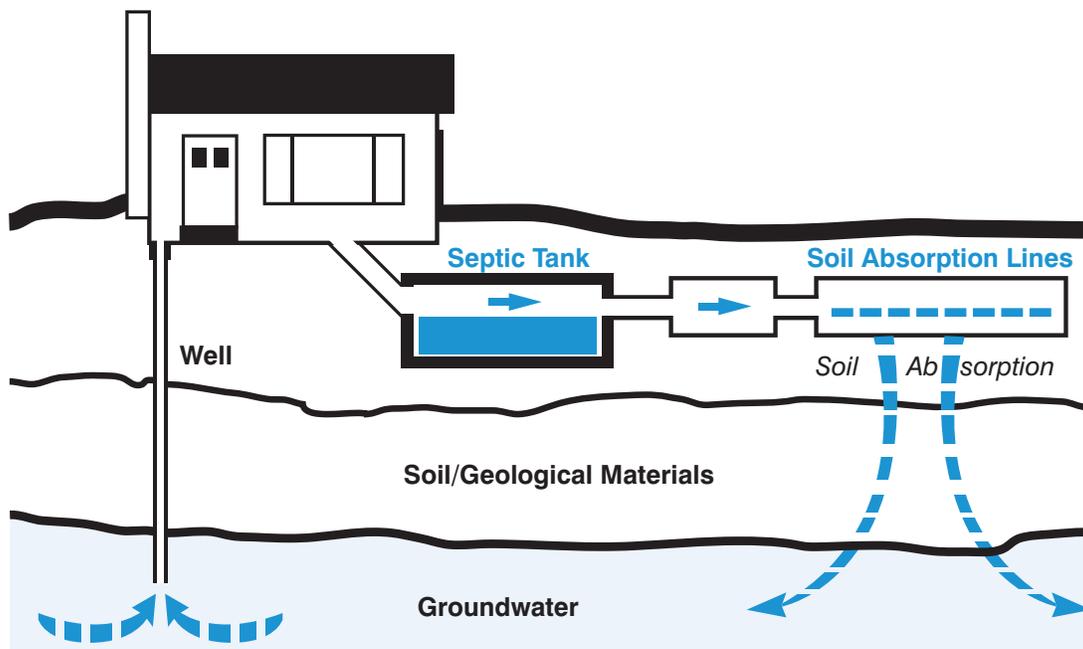


Figure 1. Many rural residences use groundwater wells as water sources, and rely upon onsite treatment systems for sewage disposal. Onsite treatment systems, such as the system represented above, disperse partially treated wastewaters in soils. When such systems are correctly sited, designed, installed, and operated, passage of wastewaters through the soil removes contaminants, which protects the groundwater from contamination. The above figure represents a conventional onsite system, similar to systems used by many rural households. Environmental factors, such as soil type and depth to groundwater, will determine the site suitability for conventional onsite systems.

Untreated sewage from failed conventional septic systems or sewage discharged directly into the environment can percolate into groundwater, contaminating drinking water wells with pathogens. The discharge of untreated sewage to streams can spread disease through direct contact, making such streams unfit for forms of recreation that involve skin contact with the water such as swimming and boating. Disease can also spread by indirect (secondary) contact such as through contact with rodents or insects that received primary exposure and, in turn, harbor the pathogens. Discharged, untreated sewage also can damage the receiving streams' ability to support healthy, living communities of aquatic organisms and can contaminate fisheries.

GENERAL PRINCIPLES OF SEWAGE TREATMENT

Raw sewage and septic wastewaters contain a variety of contaminants (Table 1). Many technologies are available to render the sewage suitable for safe discharge to the environment. These include those used in the municipal treatment

works that receive sewage discharged to public sewers in the nation's developed areas; conventional onsite sewage treatment that uses a septic tank and soil absorption field commonly used in rural areas; and the alternative onsite technologies that form the focus of this publication. Most sewage treatment technologies operate by combining basic physical, chemical, and biological processes (Figure 2).

1. Primary treatment removes solid chunks and particles from raw sewage through gravity separation and/or screening. A septic tank is the most common primary treatment device in onsite systems. In alternative systems, the septic tank is commonly outfitted with an outlet filter, to capture solid particles that are too small or too light to settle. When used with conventional septic systems, an outlet filter will extend system longevity and improve performance. The partially-treated liquid discharged from primary treatment is called *primary effluent*.

Onsite Sewage Treatment Alternatives (Excerpt)

continued from page 6

Table 1. Sewage contaminants and modes of treatment

Component	Description	Mode of Treatment
Solids (includes particulates)	Primarily carbon-based, slowly biodegradable organic compounds	Most are removed by primary treatment (settle by gravity and/or separated by screening or outlet filter). ^a
“BOD” (biochemical oxygen demand)	Biodegradable organic carbon compounds, in particulate and soluble forms	Particulate BOD is removed by primary treatment. Soluble BOD is consumed by native bacteria in the soil absorption field ^b and/or secondary treatment process that transform carbon-chain organic compounds to CO ₂ via metabolic processes. Advanced treatment (if present) removes additional BOD.
Bacterial, viral, and protozoan pathogens	Disease-causing agents, contaminants of fecal matter	These organisms, well adapted to the oxygen-poor environment of the human gut, are not well adapted to well-aerated environments. When pathogens are present, some perish in secondary treatment, but some remain in secondary effluent. Pathogens perish in the soil absorption field ^b and/or disinfection processes.
Nitrogen (N)	N as organic and ammonium (NH ₄ ⁺) forms	N associated with solids is removed via primary treatment Some N is volatilized and lost to the atmosphere. Secondary treatment converts much of the remaining N to the nitrate (NO ₃ ⁻) form. Advanced treatment can be installed to remove additional N prior to discharge.
Phosphorous (P)	P as organic and inorganic phosphate chemical forms	P associated with solids is removed via primary treatment and in secondary clarifier, if present. P binds to soil particles, and is not highly mobile in most soil environments. Advanced treatment can be installed to remove additional P prior to discharge.
Household chemicals	Cleansers, detergents, etc.	Minimal treatment: disposal with septic wastewater should be minimized.

^a Primary treatment tanks (septic tanks) must be cleaned out periodically to maintain system function.

^b Absorption field soils must be well aerated to function effectively.

Onsite Sewage Treatment Alternatives (Excerpt)

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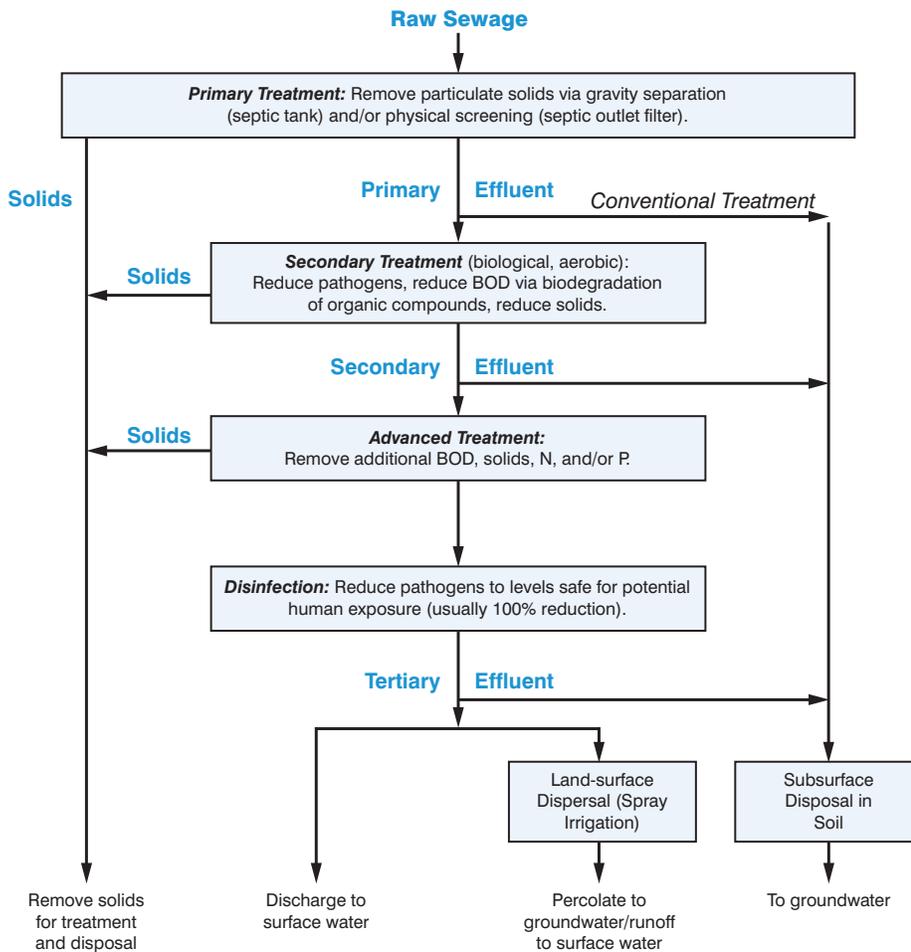


Figure 2. The figure is a generalized flow chart of the sewage renovation process used in onsite treatment. In addition to the processes shown, some removal of nitrogen, phosphorous, other nutrients, and other contaminants occurs due to primary and secondary treatment.

2. Secondary treatment processes (also called *microbial digestion*) receive primary effluent. Most secondary treatment processes move the effluent through an aeration process environment that is favorable to aerobic microorganisms, those that thrive in atmospheric oxygen (O₂) environments. The following wastewater renovation processes occur during this treatment:

- Pathogenic microorganism populations are reduced. The vast majority of microorganisms found in sewage thrive within the human digestive system, an environment where oxygen does not occur as O₂. Consequently, these organisms are not well adapted to aerated environments. Within secondary

treatment devices, some microorganisms (including most pathogens) perish as a result of exposure to O₂.

Other organisms, including predators that consume pathogens, do thrive in an aerobic environment, sustained by the rich mix of O₂ with H₂O, biodegradable organic compounds, and essential nutrients that comprises sewage. Where the effluent passes through secondary treatment media with small pores (such as a sand filter, or natural soils), pathogen numbers are also reduced via physical straining.

- Biodegradable organic contaminants, such as dissolved organic substances and organic particles remaining in the effluent after primary treatment, are removed.

The microorganisms in the aerated secondary treatment medium consume and metabolize biodegradable organic compounds, deriving energy by breaking the carbon-carbon bonds and converting the organic carbon to carbon dioxide (CO₂).

- Small particulate contaminants are removed. Where the filtration media are comprised of mineral particles with small pores (such as a natural soil or a sand filter), particulate contaminants are removed via physical screening; biodegradable components of the particles captured in the fine pores are consumed by the resident aerobic bacteria.

The partially-treated liquid discharged from secondary treatment is called *secondary effluent*.

3. Advanced treatments are optional processes that may be applied to remove additional contaminants from secondary effluent prior to dispersal. Advanced treatment is usually included only in systems intended to discharge directly to the land surface or to surface water streams.

Advanced treatment processes designed to remove additional nitrogen and phosphorous from the effluent are sometimes necessary to protect water quality in streams receiving treated effluent discharges.

4. Disinfection systems often rely on chlorination, ozonation, or ultraviolet light. Systems that discharge treated effluent where there is a potential for direct human exposure (i.e., discharge to surface waters or the soil surface) are often required to disinfect the effluent so as to eliminate potential hazards due to human exposure.

Effluent that has been disinfected, and has received advanced treatment is called *tertiary effluent*.

Onsite Sewage Treatment Alternatives (Excerpt)

continued from page 8

Treated effluent must be discharged to (or dispersed in) the environment. Secondary effluent is commonly dispersed in soils below the surface, while tertiary effluent may be discharged to flowing waters (such as a surface water stream) or on the soil surface. Surface discharge or dispersal typically requires a permit from an agency responsible for protecting surface water quality as well as an onsite septic system permit.

CONVENTIONAL ONSITE TREATMENT OF DOMESTIC SEWAGE

The conventional means of treating sewage with onsite systems is with a septic tank and soil absorption field (Figure 3).

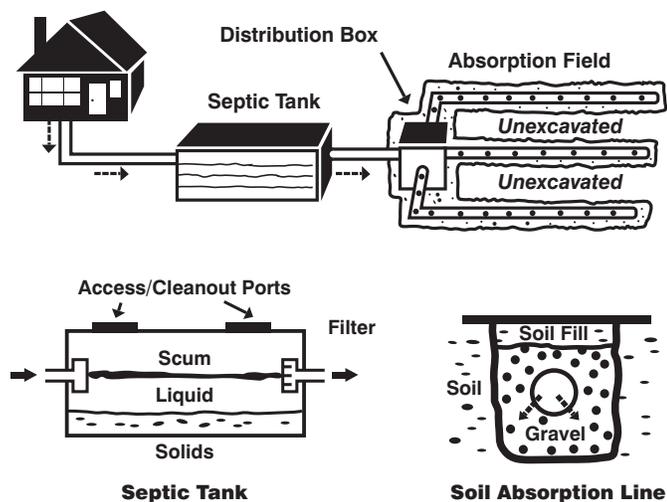


Figure 3. Conventional onsite wastewater treatment systems (above) include a septic tank (lower left) to perform primary treatment and an absorption field. Effluent from the septic tank is directed by gravity through a distribution box to an absorption field which contains multiple soil absorption lines (lower right) to disperse effluent to the soil where additional treatment occurs. Soil absorption lines are commonly constructed in gravel-lined trenches, but other methods of construction are also possible.

Primary treatment (the removal of solids from the sewage) occurs in the septic tank. If the septic tank fails to perform, solids will enter the distribution box and soil absorption field in large quantities. The accumulated solids will render these components ineffective. When a soil absorption field or a distribution box begins to “clog” with solids, a typical result is unequal distribution of the effluent and the overloading of nonlogged absorption areas, which then tend to clog at an accelerated rate. Untreated or partially treated effluent may emerge on the surface in such situations. A septic tank outlet filter, essentially a screen that captures small particles, can help to ensure against this result.

Some removal of organic contaminants occurs in the septic tank. Its oxygen-poor environment promotes some decomposition by anaerobic microorganisms, but this process has only a minor effect.

The distribution box allocates the effluent equally among several soil absorption lines. The distribution box is usually situated below the septic tank outlet, so effluent can move to the distribution box via gravity flow. Because flow through the distribution box also occurs via gravity, the box is leveled during installation to achieve equal distribution of effluent among the soil absorption lines.

The soil absorption lines distribute the effluent to the soil where biological treatment can occur. Effluent moves through soil pores and encounters resident microorganisms. Each absorption line is laid out with a low pitch (generally 1/8 to 1/4 vertical inch per horizontal foot). The low pitch helps distribute effluent evenly along each absorption line’s entire length. Most soil absorption lines are perforated 4-inch PVC pipe laid in gravel-lined trenches, although soil infiltration chambers . . . may also be used.

Effluent emerges from each pipe and percolates through the gravel to the bottom of the trench. Although less common, other absorption-line configurations, including soil infiltration chambers, may be used. State regulations require consideration of soil type and other environmental conditions when an onsite system is designed and includes the amount of trench bottom required for each 100-gallons-per-day of wastewater system design capacity.

Although the distribution boxes and soil absorption lines are intended to distribute effluent evenly throughout the soil absorption field, it rarely occurs in practice because of the lack of precision in building field systems that depend on gravity for effluent distribution. Therefore, soil absorption fields are commonly larger than would be necessary if precise and even effluent distribution were assured.

The most common cause of conventional septic system failure is inadequate cleaning of the septic tank, which leads to movement of solids into the absorption lines where they accumulate and impair drainfield function—a condition known as *clogging*. A qualified septic system contractor should be employed by the homeowner periodically to remove solids from the septic tank, which will minimize this problem.

Other causes of septic system failure can include:

- Improper installation, leading to excessive effluent accumulation in one area of the soil absorption field
- Installation of a system that is too small to handle the household’s wastewater production
- Installation in soils with inadequate capacity, or
- Home usage patterns that produce wastewaters in excess of the absorption system’s treatment capacity.

Onsite Sewage Treatment Alternatives (Excerpt)

continued from page 9

SUSPENDED GROWTH SYSTEMS

Aerobic Treatment Units

A number of stand-alone treatment systems are available for purchase on the open market. Aerobic treatment units (ATUs), or package plants, are modular sewage treatment units that can be purchased through and installed by a commercial contractor (Figure 7).

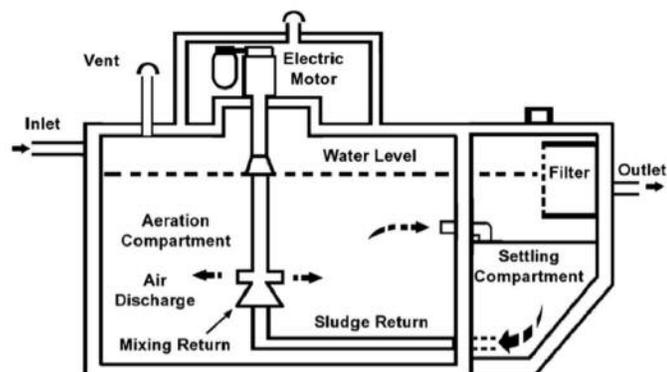


Figure 7. An aerobic treatment unit is a mechanical system that treats effluent using natural processes that require oxygen. The system consists of an aeration chamber, a mechanical agitator, and a sludge settling compartment. Secondary treatment takes place in the aeration chamber. Some units also include a disinfection device (not shown).

Household scale ATUs are commonly purchased, delivered, and installed as self-contained modules containing some level of primary treatment (in some cases, only a screen), secondary treatment (generally, a suspended media biological treatment process), a procedure (called *polishing*) to remove additional contaminants, such as small particles or nutrients, as required to meet water quality standards, and disinfection.

Many ATUs are designed for discharge to a surface water stream and are rated by the quality of effluent they will produce if operated correctly. If direct access to a surface water stream is not available, surface water discharge is not an option. High quality effluent from an ATU can also be discharged to a soil dispersal system, either above or below ground.

Although the term “package plant” implies ease of operation, some user care is required. Filters and screens must be cleaned periodically, and pumps must be maintained and replaced. The suspended growth treatment process requires a pump, mechanical agitator, or similar device that cycles on and off several times during each operating day. These devices can require maintenance as can the disinfection mechanism (if present). Depending on location, it may be possible to purchase maintenance services from a commer-

10

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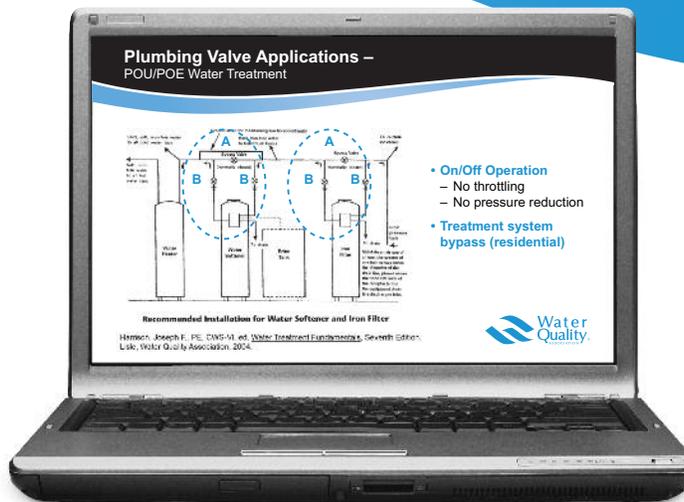
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Onsite Sewage Treatment Alternatives (Excerpt)

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cial contractor. Because experience has shown that self-maintenance by homeowners often results in system failure, the state agency may require a maintenance contract as a condition of permit approval. Like most other onsite treatment alternatives, operation of a package plant requires electric power.

Where effluent is discharged to the surface, a surface discharge permit must be obtained. Generally, such a permit will include *effluent limitations*, or numerical limits on the amount and/or concentration of contaminants that can be released in the effluent to the stream. An ATU's ability to meet water quality standards should be considered by homeowners making purchase decisions.

Editor's Note:

As demonstrated by the University of Wisconsin-Madison and National Sanitation Foundation (NSF) research on the effects of water softeners on septic tanks, the volume of discharge from a softener's regeneration cycle is roughly 50 gallons[†]. While this amount is often less than the volume of wastewater generated by a residential clothes washing machine, homeowners with onsite wastewater treatment systems are cautioned against washing numerous loads of laundry in a single day to avoid exceeding the system's capacity. Specifiers of any point-of-use and point-of-entry water treatment equipment that generates a waste stream must take into account both the capacity of the waste drain and the onsite treatment system, along with water usage patterns.

[†] "Onsite Wastewater Treatment Systems Special Issues Fact Sheet 3: Water Softeners", USEPA Risk Management Research, August 13, 2010.

QUIZ 2: "Onsite Sewage Treatment Alternatives Excerpt" (0.25 CPD)

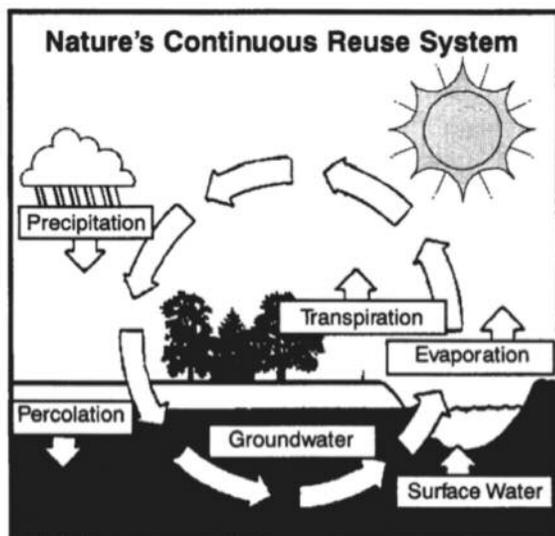
1. Why does sewage need to be treated?
 - a. To reduce space in landfills
 - b. To extract reusable minerals
 - c. To provide black water for reuse
 - d. To prevent disease
2. Which technique is used at the primary treatment stage to remove solids?
 - a. Septic tank
 - b. Gravity separation
 - c. Effluent discharge
 - d. Centripetal force
3. In addition to destruction by oxygen, what other methods can be used to remove pathogens in secondary treatment?
 - a. Digestion by acid
 - b. Physical straining
 - c. Ultraviolet disinfection
 - d. Chlorination
4. Which contaminants are removed in the advanced treatment process?
 - a. Nitrogen compounds
 - b. Dissolved gasses
 - c. Pathogens
 - d. Hardness ions
5. Which stage of treatment must be completed before effluent may be dispersed below the surface?
 - a. Primary
 - b. Secondary
 - c. Tertiary
 - d. Advanced Treatment
6. What are the two components of a conventional onsite sewage system?
 - a. Advanced treatment unit and pump chamber
 - b. Aerobic digestion and filtration
 - c. Anaerobic digestion and filtration
 - d. Septic tank and solid absorption field
7. What's the most common cause of septic tank failure?
 - a. Inadequate cleaning of the tank to remove solids
 - b. Presence of microorganisms in the soil absorption field
 - c. Presence of wastewater from a water softener
 - d. Use of a too large soil absorption field
8. Since onsite sewage treatment systems are sized based on usage patterns, how could peak use volumes that exceed capacity impact operation?
 - a. If average monthly use within design capacity, no impact
 - b. Peak use over capacity leads to clogging and system failure
 - c. If the composition of waste is within design parameters, no impact
 - d. Peak use over capacity only impacts efficacy of secondary treatment
9. What discharge options do aerobic treatment units offer that conventional units do not?
 - a. Direct discharge to sanitary sewer
 - b. Below ground soil dispersal
 - c. Direct to black water collection tank
 - d. Direct to surface water stream
10. Which level of treatment is not included with conventional units, but is standard with aerobic treatment units?
 - a. Primary
 - b. Secondary
 - c. Tertiary
 - d. Quaternary

Filtration Processes

Excerpted from *Water Processing: Residential, Commercial, Light Industrial, 3rd Ed.*

The filtration process is perhaps the most readily understood technique in water treatment, and its results can actually be observed. The basic principles of filtration/separation have been working for eons in our environment. As part of the hydrologic cycle (Figure 1-1), some filtration takes place as water seeps and percolates down through layers of earth. By the time the water has reached the underground aquifer, it is free of any particulate and some of its adsorbed gasses...

Figure 1-1
The Hydrologic Cycle



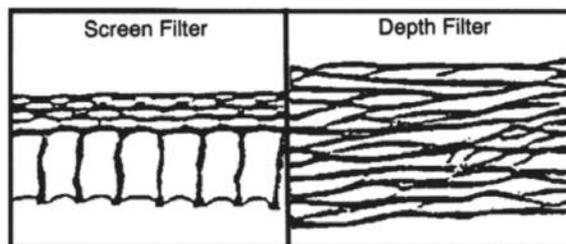
Courtesy: Fresh Water Foundation

Filtration, as such, involves the process or processes of separating suspended matter from a liquid. One of the most common methods of filtration consists of passing water through a bed (column) of granular medium or through various porous media, such as coated paper, membranes, and other special fabrics, to remove undissolved suspended particulates. When these particles result in cloudiness and discoloration, this condition is referred to as "turbidity." Such particulate may be finely divided silt, sand, solid organic matter, precipitated iron, bacteria, or algae, which may be present in both surface or well water sources. Well designed tank-type media filters are capable of removing these suspended solids from water down to about 10.0 micron size.

Particles smaller than 10 microns can be destabilized and then agglomerated together into larger and filterable flocs with the aid of coagulants such as aluminum sulfate (alum). Effective coagulation, mixing, and flocculation prior to media filtration can remove particles down to one micron in size.

In more refined filtration/separation techniques that are used to remove particles not visible to the naked eye (less than 20 microns), special membrane-type media in cartridge-style filters are employed. Two processes are used to remove these extremely fine nonionized species in a sort of "screening out" technique, as shown in Figure 1-2. The first microfiltration involves the removal of species in the 0.06 to 2.00 micron range. The second process is the ultrafiltration membrane method, which is capable of removing particulate matter in the 0.025 to 0.200 micron range and also rejects dissolved macromolecules above the 1,000 molecular weight (MW) cutoff. (This chapter does not cover micro- or ultrafiltration. See *Water Filtration for Point-of-Use Application*, by the Water Quality Association, Lisle, Illinois, 1989.)

Figure 1-2
Examples of Surface (screen) and Depth Filter Media Elements



In its larger technical sense, filtration processes do involve a wide variety of equipment, mechanics, chemicals, devices, and an array of media products in order to "separate" particulates or molecules from fluids. At large industrial, municipal, and specialized commercial water treatment facilities, one or more of the following water rectification modes may be used.

- Simple strainers and sieves
- Granular media-type gravity, pressure, or vacuum filters
- Centrifugation
- Cartridge-type filters
- Precoat filters
- Chemical—coagulation/precipitation
- Filter presses
- Membrane technology...

Filtration Processes

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THE MECHANICS OF FILTRATION

Home and business filters, for the most part, follow the basic principles of large commercial filtration systems and fall into two broad categories: surface filters and depth filters. Essentially, filtration is accomplished by either surface and depth filters or by electrostatic attraction of undissolved particles in water to certain types of filter media.

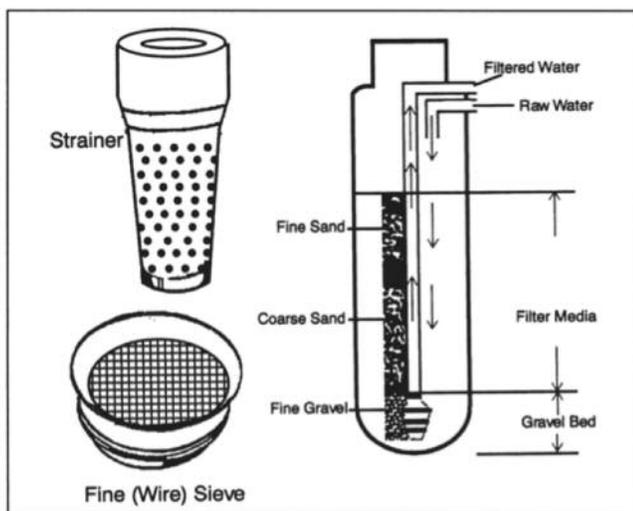
Surface (screen) filtration can be described as a “straining” technique, somewhat akin to the sifting of flour in baking, where a series of holes or perforations (all the same size) in a flat metal or plastic sheeting can remove particulate from a liquid. This series of surface holes holds back solid particles on the basis of size, allowing those of smaller diameter to pass through.³

In this “screening out” process, however, a layer usually will build up on the surface filter and become a secondary filter surface. This surface layer then does the actual filtering—and in so doing, establishes a type of “depth filter” element upon the surface filter itself. The problem with surface filtering in home and business situations is that such filters clog easily, much like the debris often observed at the grating of a storm water catch basin.

Surface filters can be either strainers with uniform holes or perforations in a rigid material, or certain membranes with very uniform, tiny openings.

Examples of surface filters (Figure 1-3) include Y-strainers, faucet aerator screens, sump strainers, and basket hair catchers in swimming pool filter systems.

Figure 1-3
Basic Filtration Techniques



Depth filters (or deep-bed filters), on the other hand, are the most common design for domestic purposes. The tank-type filters contain loose media, which form irregular pathways for the water or liquid to pass through. In addition, some media, such as granulated activated carbon, are highly porous particles, offering microfiltration of some microorganic molecules. With the use of more than one layer of medium in filters, the void spaces can be varied even further. Depth filtration is described as “water [liquid] flowing through a mass filter medium or series of media, following a torturous pathway, with many entrapments”⁴ – usually of successively decreasing void spaces through the depth of the filtering bed. In deep-bed depth filters, particulate matter is first deposited in the upper inch or two of the bed. Once the layer of particulate is deposited, additional particles can flow through the irregular maze of channels or paths to be entrapped in locations deeper in the media bed.⁵ Examples of deep-bed depth filters include anthracite, sand, and garnet mixed media systems.

Depth filtration also includes those string-wound and special fabrics (Figure 1-2) used as part of cartridge-style filter units.

Some undissolved particulates in water carry a very slight charge; thus in certain cases, these particles are separated by electrostatic attraction to the filter medium itself.

TURBIDITY

Turbidity, or cloudiness, in water is caused by very small particles that remain suspended and tend to “float” because of their very low density. The standard analysis measurement for turbidity is reported in Nephelometric Turbidity Units (NTU), which have superseded the Jackson Turbidity Units (JTU) of measurement formerly used in water analysis. Turbidity in potable water cannot exceed 0.5 NTU, according to current US Environmental Protection Agency (EPA) Primary Drinking Water Standards. A reading of 5.0 NTU triggers a mandatory “boil water” alert in public water systems.

Temporary cloudiness in water, such as may be noticed in a freshly drawn glass, is often caused by excess air. This cloudiness disappears rapidly upon standing. Another cause of cloudiness in a glass of drawn hot water can be extremely fine precipitants created during the heating; this condition generally clears itself quickly. Still another form of cloudiness in water may be the rare case of methane gas (CH₄), common in marsh water sources.⁶

Some turbidity (both organic and inorganic in nature) in surface water will settle out when the water is allowed to stand. On the other hand, a portion of this material may be present as finely divided, colloidal matter that cannot be removed by settling. In general, most turbidity in residential water treatment can be removed by passing the water through a bed (tank) of granular-type media in a sediment filter.

Filtration Processes

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The finer the particle size of a given filter medium, the greater the filter's ability to remove the particulate. Some turbidity and color in water are composed of such small particles that they slip right through the conventional filter medium.

In commercial applications, removal of these extra-fine species usually requires the help of a chemical feed application. Often, a chemical such as alum (aluminum sulfate) is added in low dosages to the stream of water to neutralize the electrical charge or to destabilize the particles, thereby causing them to adhere to one another and, in turn, form larger particles. These particles are then removed first by settling, then filtration.⁷

In the home and on the farm where turbidity and sediment are encountered, a more easily maintained and automatic system is needed. The operation of chemical feed devices is generally more than the average homeowner or businessperson wants to be bothered with. Very often, a small automatic filter can do the task. Most domestic filters are either porous

media-type whole-house units or disposable cartridge filters at one or two faucets for drinking water, depending on the amount and type of particulate to be removed. Where softening, demineralization, or reverse osmosis is involved, filtering would be the first (or pretreatment) step so a clear stream of water would be feeding these subsequent treatment modes.

References

3. *Water Filtration for P.O.U.*, Water Quality Association, Lisle, IL, 1989.
4. *Basics of Filtration & Separation*, Nuclepore Corp., Pleasantown, CA, 1978.
5. Ibid.
6. W. McGowan, *Water Processing for Home, Farm and Business*, Water Quality Association, Lisle, IL, 1988.
7. E. Nordell, *Water Treatment for Industry*, 2d ed., Reinhold Press, New York, 1962.

QUIZ 3: "Filtration Processes" (0.25 CPD)

1. What is the definition of filtration?
 - a. Conversion of dissolved solids into suspended particles
 - b. Separation of suspended solids from liquids
 - c. Evaporation of liquid to create solid particles
 - d. Exchanging of undesirable particles for desirable particles in a liquid
2. What is the minimum size particle that can be removed by media filters?
 - a. 0.200 microns
 - b. 2.00 microns
 - c. 10.0 microns
 - d. 1,000 atomic mass units
3. Surface filtration is often described as what type of process?
 - a. Electrostatic attraction
 - b. Adsorption
 - c. Loose media
 - d. Straining
4. What is a disadvantage of surface filtration?
 - a. Poor attraction between the particles and the surface
 - b. Surface clogs easily
 - c. High capital costs
 - d. Difficult to operate
5. What is the basic design of depth filtration that is responsible for accomplishing separation?
 - a. Incorporation of a strainer to trap larger particles
 - b. Creation of irregular pathways for water with entrapment for particles
 - c. Initial deposition of large particles
 - d. The ability of small particles to pass through the media bed
6. What causes turbidity?
 - a. Cloudiness
 - b. Color
 - c. Large suspended particles
 - d. Small suspended particles
7. What level of turbidity triggers a mandatory "boil water" alert in public water systems?
 - a. 0.05 NTU
 - b. 0.5 NTU
 - c. 5.0 NTU
 - d. 50 NTU
8. Other than membranes, what can be used to remove turbidity-causing particles too small for separation by conventional filter media?
 - a. Coagulation
 - b. Chlorination
 - c. Ion Exchange
 - d. Settling

Solubility Rules Help Avoid Water Treatment Pitfalls

Tanya Lubner, PhD, Water Quality Association

Knowledge of solubility behavior of water contaminants can help predict proper treatment system application and avoid pitfalls in operation and maintenance of treatment equipment.

Water treatment techniques can be separated into two broad categories; those that address suspended substances, and those that address dissolved substances. Suspended substances in water form heterogeneous mixtures, with visible particles. The resulting mixture is called a suspension.

Dissolved substances in water are evenly dispersed in a given volume. They form solutions, which are homogeneous mixtures that contain particles not visible to the naked eye. Ionic substances may undergo a chemical reaction with water, resulting in a separation of these substances into their component ions. This process is known as ionization.

Suspended substances are typically treated with physical techniques such as filtration. When particles are too small to be removed by physical treatment, techniques that cause agglomeration of these particles are used.

Removal of dissolved substances requires technologies capable of chemical interaction, and some examples include lime softening, oxidation, ion exchange, adsorption, and the treatment of chlorine with activated carbon. By this definition, reverse osmosis may be considered a physical technique that can effect separation on an atomic level.

A number of water contaminants can move between the two categories of suspended and dissolved substances. For some applications, this can be beneficial as it allows the use of less expensive treatment technologies. A good example is the removal of dissolved iron by the combination of aeration and filtration. In other applications, the formation of solids from dissolved substances can be detrimental to both water-using devices and water treatment equipment. Examples include the formation of scale in a water heater or the unintended precipitation of iron compounds in an ion exchange resin tank.

At the chemical level, substances may be classified as either ionic or covalent, although some will demonstrate both types of behavior. Ionic compounds consist of positively-charged cations and negatively-charged anions. The valence electrons are localized on the ions and the electrostatic attraction of the opposite charges holds the compound together. Purely covalent substances share valence electrons over the molecule and do not separate into ions.

Solubility of any substance is dependent both on the nature of that substance, also known as the solute, and on the nature of the substance in which it is being dissolved, or the solvent. Water is considered a strongly polar solvent, meaning that the electrons in each H₂O molecule are arranged such that the overall molecule has a slightly positively-charged end, or pole, and a slightly-negatively charged end, as illustrated in Figure 1.

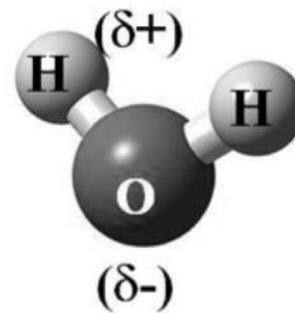


Figure 1: Polarization behavior of a water molecule

Since like dissolves like, ionic compounds are more likely to be separated into their ionic components in water than covalent substances. Figure 2 depicts the interaction between the polar molecules of water and the ions of a sodium chloride crystal that lead to the crystal dissolving into sodium cations and chloride anions.

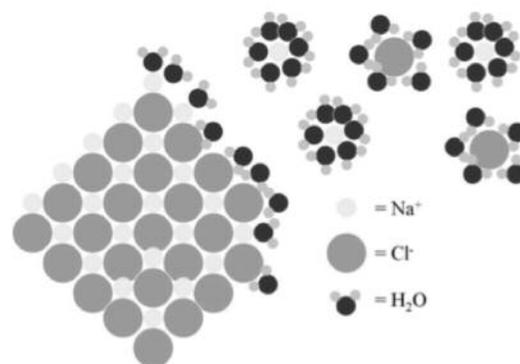


Figure 2: Sodium chloride crystal dissolving

Solubility Rules Help Avoid Water Treatment Pitfalls

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Most mineral salts and inorganic acids and bases are in the category of ionic compounds. Nonpolar organic molecules, made up mainly of carbon/hydrogen chains, are in the category of covalent compounds. Some organic molecules - such as acetic acid - have ionizable portions and will dissolve in water by ionizing. Polar organic molecules, short-chain alcohols like ethanol, are also very comfortable in the polar environment of water. Hydrogen bonding is another interaction by which water can stabilize the dissolution of a solute. Hydrogen bonds are attraction between atoms of hydrogen and oxygen, hydrogen and nitrogen, and hydrogen and fluorine.

Each ionic substance has a maximum solubility - a maximum amount that can be dissolved - at a specific water temperature. This amount is typically reported in grams (g) per 100 milliliters (mL) of water. Substances with solubilities greater than 1 g per 100 mL of water are considered very soluble, substances with solubilities between 1 g and 0.1 g in 100 mL of water are slightly soluble, and substances with less than 0.1 g solubility per 100 mL of water are insoluble.

Maximum solubilities for a number of ionic compounds have been measured and can be found in reference books, such as the *CRC Handbook of Chemistry and Physics*. For example, sodium chloride, which is readily recognized by anyone working with ion exchange technology to be very soluble, has a maximum solubility of 36.0 g/100 mL H₂O at 25°C. Calcium sulfate is considered as having the potential to form scale, and indeed, its maximum solubility is reported as 0.2 g/100 mL H₂O at 25°C.

Solutions that contain the maximum amount of a particular solute are said to be saturated. Solutions that contain more than the maximum amount of a particular solute are said to be supersaturated and are unstable. These are typically formed when the temperature of an already saturated solution is slowly lowered. Any slight change in condition, such as an additional decrease in temperature, the addition of a seed crystal, evaporation of solvent, or turbulence, quickly leads to the precipitation of the excess solute.

Another useful tool in determining solubility of a substance is its solubility product, K_{sp} . The smaller the number, the less likely a substance will dissolve, or, conversely, the faster it will precipitate from solution if any of its component ions happen to get added to the same solution. For example, the solubility product of calcium carbonate (CaCO₃) is 8.7×10^{-9} , while the solubility product of iron(II) hydroxide [Fe(OH)₂] is 1.6×10^{-14} , a considerably smaller number. If sodium hydroxide (NaOH, caustic) is added to water containing ions of ferrous (Fe^{II}) iron, calcium, and bicarbonate alkalinity in order to raise the pH, based on the solubility product, the first substance to precipitate will be iron(II) hydroxide followed by calcium carbonate (Figure 3).

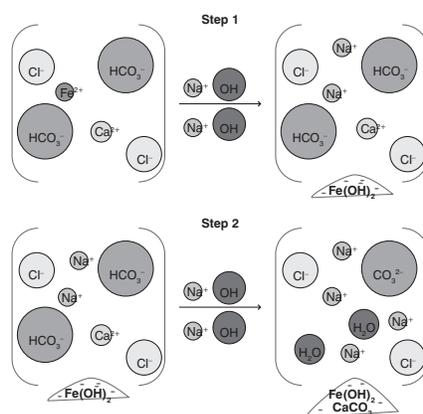


Figure 3: Solubility product and order of precipitate formation

The idea that ferrous iron could precipitate is not commonly discussed in water treatment, the focus usually being on the precipitation of ferric (Fe^{III}) iron. What the study of solubility reveals is that whether or not a substance will precipitate depends not only on the cation present, but on the anion as well.

Cations and anions do not exist separately from each other, even though they're dissociated and physically separated in water. The distance by which they're separated is relatively small, resulting in a net neutral charge on a solution. This is an important point that often gets overlooked, as in the case of iron discussed above. The balance of positive and negative charges is also illustrated in ion exchange when

removal of calcium from the raw water with the ion exchange process results in the addition of an equivalent charge of sodium ions. Likewise, on a water analysis, anytime the alkalinity concentration as calcium carbonate is greater than the hardness concentration as calcium carbonate, the difference is due to the presence of monovalent cations from the first column of the periodic table [sodium (Na⁺), potassium (K⁺), etc.].

Accounting for the monovalent cations is typically of greater importance in deionization processes. Excessive concentrations of monovalent cations can also be a problem for softening applications with resin in the sodium or potassium form. A low ratio of hardness and other polyvalent cations to total anions on a water analysis would indicate this type of situation. Because the opposite charges must be in balance, such a water analysis result could also indicate an error in the analysis itself and is worth investigating.

Common situations in water treatment explained by the solubility rules:

1. The high solubility of sodium chloride and potassium chloride in water (rules 2 and 4) precludes the possibility of these substances being removed from water with inexpensive means such as precipitation followed by filtration. Separation of water from dissolved sodium, potassium, and chloride ions requires the application of distillation, reverse osmosis, deionization, or electrodeionization technologies.
2. The addition of a base such as sodium hydroxide (NaOH) to raise the pH of slightly acidic, moderately hard water with alkalinity in proportion to or slightly higher than the concentration of hardness, causes scaling. At acidic pH the alkalinity is due to the presence of bicarbonate. The addition of a base strips a hydrogen ion off the bicarbonate, converting it to carbonate. In the presence of dissolved hardness ions, carbonate scale quickly forms.

Solubility Rules Help Avoid Water Treatment Pitfalls

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Keeping track of the various cations and anions in solution is also important because once dissociated, the ions from different compounds have the possibility of exchanging to form new compounds. If the new compounds are less soluble than the parent compounds, the reactions are particularly favorable, i.e. they'll happen fast, and can cause problems, as was demonstrated in the ferrous iron precipitation example in Figure 3.

Another example, illustrating the importance of considering both the cations and the anions, is a water sample that's been isolated from ambient air and contains calcium only from calcium chloride (CaCl_2). This compound will separate into its component ions, upon contact with soap anions it will form soap curd, but will not form scale if heated. Add in a little sodium carbonate (Na_2CO_3), which is also soluble, and calcium carbonate (CaCO_3) and scale will quickly form.

Forgetting to account for both the type of cation and the type of anion dissolved in a given water supply had led to the erroneous conclusion that water softening by ion exchange, with resin in the sodium form, causes a reduction in pH which then results in corrosion of metal piping. This proclamation often follows a discussion of chemical-based softening procedures, which remove both the hardness ions and the bicarbonate anions from water. As a weak base, bicarbonate can help maintain a higher pH. The removal of it from water can, indeed, result in more acidic water, which would be more corrosive to

metals. However, softening by ion exchange removes only the hardness cations, replacing them with sodium ions. The procedure does not affect the concentration of bicarbonate, carbonate, or any other anion, and, therefore, does not affect pH of the water.

Below are some rulesⁱⁱⁱ for predicting solubilities of ionic compounds in water. Temperature is assumed to be 25°C (77°F).

1. All common inorganic acids are soluble [e.g. hydrochloric (HCl), nitric (HNO_3), etc.].

Note: Only the first hydrogen of polyprotic acids will easily dissociate [e.g. carbonic (H_2CO_3), sulfuric (H_2SO_4), phosphoric (H_3PO_4)].

2. All compounds of alkali metals are soluble [sodium (Na^+), potassium (K^+), rubidium (Rb^+), cesium (Cs^+)]. Alkali metals are all located in the first column from the left on the periodic table.
3. All ammonium (NH_4^+) compounds are soluble.
4. All compounds of chloride (Cl^-) and bromide (Br^-) are soluble, except those with lead (Pb^{2+}), silver (Ag^+), and mercury (Hg^{2+}).

DEFINITIONS:

Anion = Negatively-charged ion or molecule.

Atom = The smallest part of an element that maintains the properties of an element. Atoms consist of a nucleus in the center that contains protons and neutrons and is orbited by negatively-charged electrons.

Cation = Positively-charged ion or molecule.

Compound = A substance formed from a combination of elements.

Covalent bond = A type of attraction between atoms in which valence electrons are delocalized and shared between the atoms involved in the bond.

Electron = A negatively-charged subatomic particle that orbits the nucleus in an atom.

Element = The simplest form of a substance which cannot be broken down any further by chemical means.

Ionic bond = Electrostatic attraction between ions of opposite charge in a compound.

Ionization = Separation of a compound into component ions.

Molecule = The smallest form of a compound that still maintains the properties of that compound.

Monovalent = An ion with either a negative or a positive charge of one.

Neutron = A subatomic particle without a charge that is found in the nucleus of an atom.

Nucleus = The center of an atom. The nucleus contains protons and neutrons.

Polar = A covalently-bonded compound of different elements in which the atom(s) of one element more strongly attract the delocalized valence electrons to create a slightly negative area on one end of the molecule, resulting in a slightly positive end on the opposite side of the molecule.

Polyprotic = An acid that can donate more than one positively-charged hydrogen ion (H^+). E.g. sulfuric acid, H_2SO_4 . Because a positively-charged hydrogen ion has no electrons and consists only of its single proton in the nucleus, H^+ in the terminology of acid-base reactions is often referred to as a proton. Likewise, when a base binds H^+ , it is said to be "protonated".

Polyvalent = An ion with a positive or negative charge greater than one.

Precipitate, precipitation (↓) = Precipitate is the solid formed when oppositely-charged dissolved ions combine to form an insoluble substance. Precipitation is the act of formation of the solid. In chemical reactions, the formation of a precipitate is indicated by a downward arrow, written after its molecular formula.

Proton = A positively-charged subatomic particle found in the nucleus of an atom. In acid-base terminology, a positively-charged hydrogen ion (H^+). (See Polyprotic)

Solute = The substance being dissolved to form a solution. Solutes may be gases, solids, or liquids.

Solution = Homogenous mixture of two or more substancesⁱⁱⁱ. Solutions where water is the solvent are called aqueous.

Solvent = The substance performing the dissolving of the solute to form a solution.

Valence electrons = The electrons in the outermost electron shell of an atom. These are the electrons furthest from the nucleus. When an atom becomes an ion, the number of valence electrons either increases or decreases. An increase in valence electrons results in a negatively-charged ion – anion – and a decrease in valence electrons results in a positively-charged ion – cation.

Solubility Rules Help Avoid Water Treatment Pitfalls

continued from page 17

- All compounds containing nitrate (NO_3^-), chlorate (ClO_3^-), perchlorate (ClO_4^-), and acetate (CH_3COO^-) are soluble.
- Most sulfates (SO_4^{2-}) are soluble. Compounds with calcium (Ca^{2+}) and silver (Ag^{2+}) are slightly soluble. Compounds with barium (Ba^{2+}), mercury (Hg^{2+}), and lead (Pb^{2+}) are insoluble.
- All compounds of **carbonate** (CO_3^{2-}), phosphate (PO_4^{3-}), sulfide (S^{2-}), and sulfite (SO_3^{2-}) are insoluble, except those of ammonium (NH_4^+) and alkali metals.
- All alkali metal hydroxides (MOH, where M=metal) are soluble. Barium hydroxide [$\text{Ba}(\text{OH})_2$] is soluble. Calcium hydroxide [$\text{Ca}(\text{OH})_2$] is slightly soluble. All other hydroxide compounds are insoluble.
- All compounds of bicarbonate (HCO_3^-) are soluble.**

Solubility can be affected by both the temperature of the water and the pH. Higher temperature generally increases the solubility of ionic substances in water, however the reverse is true for the formation of calcium carbonate scale. Conversely, colder temperature will decrease solubility.

Acidic pH also, typically, enhances solubility of substances, because it reacts with the anion portion of the ionic compound and converts it to the more soluble form. An example is the reaction of acid with calcium carbonate. The carbonate binds the free hydrogen ion in the acidic water to become bicarbonate, and the resulting calcium bicarbonate compound dissolves (rule 9).

The ions already present in solution will affect the extent to which additional such ions are dissolved, especially if the second source of these ions is only slightly soluble. A solution containing sodium carbonate will severely limit how much calcium carbonate will dissolve into it. This is known as the common ion effect and is a function of equilibrium and Le Chatelier's principle, both of which are beyond the scope of this article.

A water analysis for dissolved substances is the best place to start when approaching a water treatment problem. Knowledge of the solubility rules will help in determining how to best apply and troubleshoot water treatment technologies to either take advantage of the possibility for solid formation or to avoid formation of solids.

ⁱ D. Lide, ed, *CRC Handbook of Chemistry and Physics*, 77 ed, CRC Press, Inc.: Boca Raton, 1996.

ⁱⁱ Ibid.

ⁱⁱⁱ R. Chang, *General Chemistry*, Random House: New York, 1986.

QUIZ 4: "Solubility Rules Help Avoid Water Treatment Pitfalls" (0.25 CPD)

- What type of behavior is required for a compound to be considered dissolved in water?
 - Formation of large, visible particles
 - Separation into cations and anions
 - Precipitation of a solid
 - Surface tension
- What is meant by maximum solubility?
 - The point at which a solute is fully hydrogen-bonded with water
 - The point beyond which a precipitate forms
 - The point at which a solution contains the maximum amount of solute
 - The relative solubility of all ionic compounds to that of sodium chloride
- An excess of sodium sulfate and sodium carbonate are added to water containing calcium chloride, magnesium chloride, and iron(II) chloride. Use the solubility products, K_{sp} , listed below to determine what substance will precipitate first.

$\text{CaCO}_3 K_{sp} = 3.36 \times 10^{-9}$	$\text{CaSO}_4 K_{sp} = 4.93 \times 10^{-5}$
$\text{FeCO}_3 K_{sp} = 3.13 \times 10^{-11}$	$\text{MgCO}_3 K_{sp} = 6.82 \times 10^{-6}$

 - CaCO_3
 - CaSO_4
 - FeCO_3
 - MgCO_3
- Based on the solubility rules, which of the following substances is insoluble?
 - Calcium acetate [$\text{Ca}(\text{CH}_3\text{COO})_2$]
 - Iron(III) bicarbonate [$\text{Fe}(\text{HCO}_3)_3$]
 - Copper chloride (CuCl_2)
 - Iron(II) hydroxide [$\text{Fe}(\text{OH})_2$]
- Which of the following calcium compounds is insoluble?
 - Calcium sulfite (CaSO_3)
 - Calcium chloride (CaCl_2)
 - Calcium bromide (CaBr_2)
 - Calcium perchlorate [$\text{Ca}(\text{ClO}_4)_2$]
- Which of the following does NOT/do NOT influence solubility of a substance?
 - Concentration units
 - Presence of component ions
 - Temperature changes
 - Turbulence of flow
- Which water treatment process must account for interference from potential precipitation of even the highly soluble compound of sodium chloride?
 - Oxidizing filter
 - Chemical softening
 - Reverse osmosis
 - Ozone disinfection

Instructions

Please use the answer sheet below to record the correct answers. When you have completed the quizzes you'd like graded, detach the answer sheet from the booklet and mail to the address below or fax. The answers must be 70% correct to earn credit. [These quizzes may also be taken online at http://training.wqa.org/2011edkitqz/index.htm](http://training.wqa.org/2011edkitqz/index.htm)

WQA 2011 Educational Newsletter Quiz Answer Form



FIRST NAME _____ LAST NAME _____

COMPANY NAME _____

COMPANY ADDRESS _____

CERTIFICATION ID# _____

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Please use blue or black ink. Shade Circles Like This → ● Not Like This → ⊗ ⊕

QUIZ 1: "Risks of Hazardous Waste Excerpt"					QUIZ 2: "OnSite Sewage Treatment Alternatives Excerpt"					QUIZ 3: "Filtration Processes"					QUIZ 4: "Solubility Rules Help Avoid Water Treatment Pitfalls"				
	A	B	C	D		A	B	C	D		A	B	C	D		A	B	C	D
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When you have completed the quiz, detach the answer sheet from the booklet and mail it to:

Water Quality Association • Attn: Education Dept.
 4151 Naperville Road • Lisle, Illinois 60532-3696
OR Fax to 630 505 9637